

Helaine Selin
Editor

Encyclopaedia of the History of Science, Technology, and Medicine in Non- Western Cultures

Third Edition

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With 2463 Figures and 138 Tables

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Dedicated to my editorial muses: Kennie Lyman, Annie Kuipers (in memoriam), and Maja de Keijzer. Thank you for helping me along on this most excellent journey.

Introduction to the Third Edition

Almost 20 years have passed since the first edition of the *Encyclopaedia of the History of Science, Technology, and Medicine* was published in 1997. What has changed?

The first thing I noticed is that the field has become very global. For many reasons, when I started out in the 1990s, most of the work came from the UK, the USA, and Australia. Now, contributors come from every part of the world. This might in part be because of communications; it was so difficult to find addresses and get in touch in the early years. Now, the whole effort of finding new authors and contacting them and getting back to them takes a week instead of months. And what also seems to be true is that the field has become much more academic. This might be because new sources are available for research (again because of technology) or because the work has become more acceptable for graduate-level research. Although the scholarly journals field has not done so well, access to online journals for scholars who are writing and for those doing research is much easier. When we look over the scholarly literature in the field, it is obvious that so much more work has been done since the first edition. And it has been so much easier to find materials that we were unable to find before. This new edition includes sections on ceramics, architecture, brewing, fishing, cosmology, hydraulic systems, food, and many more entries on ethnobotany, metallurgy, and city and town planning.

This change is also about the impact of social history or history from the bottom up that has affected all areas of historical research. In the beginning, we looked at mathematics and astronomy, the great thinkers and leaders and scholars. The study of everyday life is now legitimately part of the study of history. This is evidenced by the fact that there are new entries on glass, gardens, boats, farming, beads, games, fermentation, beer, quarries, wheelbarrows, cotton and silk, basketry, and jewelry. The study of indigenous knowledge has also become part of scholarship. In fact, agencies like the United Nations are finally realizing that people in Africa, for example, have known for years how to keep water cool and to build their houses in an ecologically sound way. They are including local people in their new initiatives. The *Encyclopaedia* deals very much with indigenous knowledge.

The history of non-Western science no longer feels like a subdiscipline of anthropology; it has become a legitimate discipline on its own. At the same time, it is also true that there is no other reference work that continues to bring all these elements together, so a new edition seemed necessary.

Personal Note from the Editor

Many years ago, I taught African history at a secondary school in Central Africa. A few years before, some of the teachers in the country had designed a syllabus that included pre-European history, since the curriculum, left over from colonial days, did not include any mention of Africa before the Portuguese. After a year of teaching from this revised version, I asked my students what they thought was the most significant moment in African history, and virtually all of them said it was the arrival of David Livingstone.

It may well be that that was the most important moment for Africa, but it shocked me at the time that no one considered any African achievements worth mentioning. Over the years, I came to see that the dominance of the West meant not only that Westerners disparage the rest of the world but also that the rest of the world sees itself as inferior to the West. This book was meant to take one step toward rectifying that, by describing the scientific achievements of those who had been overlooked or undervalued by scholars in both the West and the East. In the years since I began this project (1990), so much has changed, and I think it is pretty safe to say that is no longer the case.

The encyclopedia provides a view into how people describe and perceive and order their world. My hope, and that of the advisors and contributors to the project, is that it will expand the horizons of scholars, teachers, and students by illustrating how extensive the accomplishments of non-Western scientists are.

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Abacus

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In contemporary usage, the word *abacus* refers to a computational device with beads sliding on fixed rods, often associated with the Japanese or Chinese. However, the word *abacus* has Latin roots, suggesting a rich history in Western as well as Eastern cultures.

The present-day abacus, called *Suan Pan* in China, *soroban* in Japan, and *schoty* in Russia, is still in use by shopkeepers throughout Asia and in Chinatowns around the world. It works on a place value or positional system of numeric notation, similar to that of our familiar Hindu-Arabic numerals. The number of beads on each rod represents the value of the digit in that place, with higher place values to the left (or, on the *schoty*, above) and lower place values to the right (or below). Numeric values are read from left to right (or top to bottom) similarly to the written numerals. For example, the numeral 341 is represented by three beads on the *hundreds* rod, four beads on the *tens* rod, and one bead on the *units* rod.

On Chinese and Japanese models, the rods are vertical, and the beads on these rods are divided into two groups by a horizontal bar, which separates the beads into a set of one or two beads above

the bar and another set of four or five beads below the bar. The beads above this horizontal bar are valued at five times the beads below the bar. Thus, for example, the number 756 is represented by 1 five-bead and 2 one-beads on the *hundreds* rod, 1 five-bead and no one-beads on the *tens* rod, and 1 five-bead and 1 one-bead on the *units* rod. To operate the abacus, first clear it by pushing all the beads away from the horizontal bar, the beads in the lower section are pushed down, while those in the upper section are pushed up. This can be done quickly by tilting the abacus slightly so that all the beads slide down and then laying the abacus on a flat horizontal surface and running the index finger between the bar and beads in the upper section, pushing them away from the bar. The abacus is operated using the thumb and the index finger to push beads toward or away from the bar as values are added or subtracted. To add $341 + 756$, first push the beads in place to represent 341, and then push additional beads in place to represent 756. On the *hundreds* rod, there will be 3 one-beads plus 1 five-bead and 2 additional one-beads; on the *tens* rod, there will be 4 one-beads and 1 five-bead, and on the *units* rod, there will be 1 one-bead, 1-five bead, and 1 additional one-bead. The result can be read as 10 *hundreds*, 9 *tens*, and 7 *ones*. In practice this is quickly simplified by regrouping the beads to 1 *thousand*, 0 *hundreds*, 9 *tens*, and 7 *ones*, or simply 1097. That is, whenever 5 one-beads are accumulated below the bar they are exchanged for 1 five-bead

above the bar, and whenever 2 five-beads are accumulated above the bar, they are exchanged for 1 one-bead in the next column to the left.

The Chinese *Suan Pan*, which is first mentioned in the literature in the twelfth century, traditionally has 2 five-beads and 5 one-beads on each rod. So it is possible to accumulate a value of 15 (2 five-beads plus 5 one-beads) on each rod during the computation, and this must be simplified as described above before the result can be read out. The Japanese *soroban*, developed in the early 1930s, has shorter rods with 1 five-bead and 4 one-beads on each rod. With the *soroban* the value on any rod cannot go above 9 (1 five-bead plus 4 one-beads) so that simplifications must be carried out continuously throughout the computation. Since each bead is moved through a shorter distance, an experienced, skillful user can perform computations more quickly on the *soroban* than on the *Suan Pan*.

The Russian *schoty*, developed in the seventeenth century, has horizontal rods, with ten beads on each rod. Numeric values are read from top down, with each rod valued at 10 times the value of the rod immediately below it. That is, the *hundreds* rod is above the *tens* rod, which is above the *units* rod. Calculating with the *schoty* resembles finger counting, each bead representing one finger, or one unit in its respective place value. If you hold your hands out in front of you with the palms away from you, your two thumbs will be side-by-side, flanked by the four fingers of each hand. Similarly, the two middle beads on each rod of the *schoty* representing the thumbs are in a contrasting color to the two sets of four beads each on either side. This makes it easier to see the values without consciously counting the beads. To clear the value on the *schoty*, the beads are all pushed to the right. Beads are pushed to the left or right as numbers are added or subtracted.

Archaeological evidence in the form of bead-frame calculators as well as piles of small smooth rounded stones, which could have been used as counters for reckoning, suggests that in ancient times (300 BCE to 500 AD), computations in the marketplace throughout the Roman empire were commonly worked out by casting stones (*calculi*)

in the sand or on a specially marked counting table (*abax*). Lines in the sand or on the table top would mark off space for *ones*, *tens*, *hundreds*, and so on. To make the values easier to read, stones placed on the line between two spaces would denote values halfway between the lower-valued unit on the right and the higher-valued unit on the left. For example, a stone on the line between the *ones* and the *tens* would be valued as *five*, and a stone on the line between the *tens* and the *hundreds* would be valued as *fifty*.

Roman numerals could have been used to easily record the results of computations done on a Sand-Reckoner or counting table. The Roman numerals I, X, C, and M represent stones in the units, tens, hundreds, and thousands spaces, respectively, while V, L, and D represent values on the lines, 5, 50, and 500. On some surviving counting tables, the Roman numerals I, X, C, and M have been scratched onto the table top in the appropriate spaces, making it a simple matter to record the final result of the computation. The Roman numeral CCVIII (represented by 208 in Hindu-Arabic numerals) would be cast on the counter-top using two stones in the *hundreds* space, one stone on the line between the *tens* and the *units* spaces, and three stones in the *units* space. Similarly, the Roman numeral DCXXVIII (or 629) would be cast using one stone on the line between the *thousands* and the *hundreds* spaces, one stone in the *hundreds* space, two stones in the *tens* space, one stone on the line between the *tens* and the *units* spaces, and four stones in *units* space. The use of a quasi-positional subtractive principle in Roman numerals – so that IIII is represented as IV and VIII as IX – is a later development used only sparingly in ancient and medieval times.

To add CCVIII + DCXXVIII, the person doing the calculating (probably a merchant) would first cast stones representing CCVIII and then the additional stones representing DCXXVIII. These would be regrouped by rearranging the stones in full view of the customer first as D CC C XX VV III IIII and then simplified as D CCC XXX V II (or simply as 837 in our more familiar numerals).

In the early fourteenth century, bankers and merchants were still required by law to use Roman numerals to record business transactions. Since the Gutenberg printing press was not invented until about 100 years later, the majority of the population was illiterate (i.e., not taught to read the printed word). Recording the result of the previous example, DCCCXXXVII, in Roman numerals requires ten symbols, one symbol on the paper for each stone on the counting table. Recording the same result using Hindu-Arabic numerals would require only three symbols. Zero was a difficult concept, one that was not easily adopted. The Hindu-Arabic numeral 500 requires three digits, but would be represented by a single stone on the abacus and by the single letter D using Roman numerals. Although the idea of zero as a placeholder was sometimes understood in medieval times, it simply was not needed in doing computations using an abacus. If results were recorded using Roman numerals, the clear correspondence between the stones on the counting table and the symbols on the paper was readily apparent. Thus, using Roman numerals, the customer would be assured that the merchant or banker was accurately recording the result of the transaction.

The Roman bead-frame calculators found at some archaeological sites are small enough to be held in one hand and have a design similar to the Chinese *Suan Pan*. This evidence suggests that the abacus was taken from Western Europe to the East by Christian migrations. In the late fourth century, Arabs brought the concept of a numeral for zero to the West from the Hindus in India.

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Abortion

Malcolm Potts

Abortion, along with circumcision, is amongst the oldest operations known to human kind. While abortion meets an extraordinarily important need of the individual, society commonly treats it differently from other aspects of medical science. Usually, there is little honor to be gained by improving abortion technologies.

The explanations and beliefs different cultures develop concerning the origin and maturation of pregnancy help determine attitudes to abortion. The *Qurʾān*, for example, describes pregnancy as a process of increasing complexity progressing from, “a drop of seed, in a safe lodging, firmly affixed” to a “lump” with “bones, clothed with flesh”, and some Islamic theologians permit abortion early in pregnancy. Most abortions are performed because the woman feels she cannot support the child if born, although unmarried women, especially in non-Western traditional societies, may abort for fear of punishment. In the ancient Ugandan royal household, abortion was carried out on princesses so as not to divide the kingdom.

Abortion is known in practically all cultures from preliterate societies to the most industrialized. Abortionists are often also traditional birth attendants or medicine men. A spectrum of techniques is used which differ in their complexity and in their consequences, and which are greatly influenced by the stage of pregnancy when the procedure is carried out. In non-Western societies most techniques fall into one of three categories: herbal remedies, abdominal massage, and the insertion of foreign bodies into the uterine cavity.

In many contemporary non-Western cultures a variety of brews and potions are concocted to bring on a late menstrual period. Such methods were also widely sold in Western cultures until the reform of the abortion law. The open sale of emmenagogues (medicines to bring on a late period) in Manila, Lima, or Dacca today finds a close parallel in Boston in the nineteenth century United States, or Birmingham, England in the middle of this century. The ► [Jamu](#) remedies sold every day in Indonesia include a number of emmenagoges. The use of a tea brewed with the spiny nettle (*Urtica magellanica*) by the Aymara Indians of Bolivia living near Lake Titicaca and the juice of hibiscus leaves (*Abelmoschus diversifolius*) in the Pacific islands are two examples from among many herbal remedies in preliterate societies.

The use for abortifacient medications is usually limited to the first 6 or 8 weeks after the last menstrual period. Many do not work, but rely on

the fact that spontaneous abortion is common and will often be ascribed to a traditional remedy when one has been used. Others are physiologically active, either on uterine muscle or the embryo, although they often need to be used in doses that may be toxic to the woman. In the 1970s and 1980s the Human Reproduction Program of the World Health Organization tested a number of such abortifacients from around the world, and at least one, from Mexico, underwent preliminary screening by a pharmaceutical company. The time of collection, the method of preparation, and details of use may all be critically important in determining the outcome. An alternative technique for studying traditional abortifacients was developed by Moira Gallen in the Philippines, who worked with vendors of traditional abortifacients and then followed up the women who used them. The data suggest some herbal remedies do indeed bring on a late period.

An amalgamation of Western and non-Western cultures has taken place in Brazil where the Western drug Cytotec, an oral form of prostaglandin, is sold illicitly to women with an unintended pregnancy. It is estimated there are one to four million illegally induced abortions in Brazil each year, and each woman has one to three abortions in a lifetime. Cytotec produces bleeding from the uterus which, although it does not always lead to abortion, is usually sufficient to take the woman to the hospital, where the abortion is invariably completed in the operating theater. It is relatively safe but can be very painful. Until restrictions were placed on sales in 1991, 50,000 packets a month were being sold.

The second set of abortion technologies, with a history stretching back to preliterate societies, involves physical trauma to the woman's body. Many cultures associate falls and physical violence with abortion, as did the ancient Hebrews (*Bible*: Exodus 21: 22). The oldest visual representation of an abortion anywhere in the world is on a bas relief in the great temples of Ankor Wat built by King Suryavarman II (AD 1130–1150). Massage abortion remains common from Burma, through Thailand and Malaysia to the Philippines and Indonesia. Traditional birth attendants use their hands, elbows, bare feet, or a wooden mallet

(as portrayed on the Ankor reliefs) to pound the uterus and terminate an unwanted pregnancy. Operators begin by asking the woman to empty her bladder and then try to draw the uterus from beneath the pubic bone so they can apply pressure to the abdominal wall. Sometimes these procedures lead to vaginal bleeding and abortion with relative ease; on other occasions the pain may be so severe that the operator has to stop and return some other time. A study in Thailand estimated that 250,000 such massage abortions take place in the villages of Thailand each year. Gynecologists in Malaysia have described how women are sometimes admitted to hospital for what appear to be the symptoms of appendicitis, with fever and rigidity of their abdominal muscles; when the abdomen is open, the uterus is found to be so bruised and damaged that it may be necessary to do a hysterectomy.

This specialized technique, which has to be learnt from generation to generation, is largely limited to Southeast Asia, although the American Indian Crows and Assiniboines used a board, on which two women jumped, placed across the abdomen of a recumbent pregnant woman, and Queensland native Australians used a thick twine wound around the abdomen combined with "punching" the abdominal wall.

The third types of abortion techniques are the most common and are found in all continents. They involve passing a foreign body through the uterine cervix in order to dislodge the placenta and cause an abortion. In traditional societies a twig or root may be used and it may take a day or more for the procedure to work. The major risks are infection and hemorrhage. The Smith Sound Inuit used the thinned down rib of a seal with the point cased in a protective cover of tanned seal skin, which could be withdrawn by a thread when the instrument had been inserted into the uterus. The Fijians fashioned a similar instrument from *losilosi* wood, but without the protective cover for insertion, and the Hawaiians used a wooden dagger-shaped object up to 22 cm long which was perceived as an idol Kapo. In contemporary Latin America and much of urban Africa, the commonest method of inducing abortion is to pass soft urinary catheters, or *sonda*, such as

those used by doctors when men have enlarged prostates. Such catheters are readily available, although traditional abortions do not always use adequate sterile techniques and, even under the best of conditions, leaving such a catheter in place can be associated with infection.

Epidemiological studies show beyond all doubt that the safest way of inducing first trimester abortion is through the use of vacuum aspiration, and most legal abortions in the Western world are done using this technique. A small tube, varying in diameter from something slightly larger than a drinking straw to about 1 cm, is passed through the cervix, and attached to a vacuum pump. In the first 3 months of pregnancy such a procedure generally takes about 5 min and is commonly done as an out patient procedure under local anesthesia.

Vacuum aspiration abortion was described in nineteenth century Scotland, but the technique used today was invented in China sometime in the 1950s by Wu and Wu. The method spread across certain parts of the Soviet Union and into Czechoslovakia and some other areas of Eastern Europe. In the 1960s a nonmedically qualified practitioner from California called Harvey Karman invented a piece of handheld vacuum aspiration equipment. Karman got the idea from descriptions of procedure performed in China, Russia, and Eastern Europe, and the flow of ideas has gone full circle with the syringe equipment now being widely used in many non-Western countries, such as Bangladesh, Vietnam, and Sri Lanka.

In the Ankor reliefs the women having abortions are surrounded by the flames of hell. Although abortion was disapproved of in the East, it was still considered a crime against the family, not against the state as it is commonly perceived in the West. Abortion before the felt fetal movements was legal in Britain and all states of the United States in 1800 and illegal in those same places by 1900. With the expansion of colonialism, Western abortion laws were imposed upon all colonized nations of the Third World. The nations of the then British Empire either adopted a form of the 1861 Offenses Against the Person Act of Queen Victoria's

England or a version of the Indian penal code. French colonies enacted the code of Napoleon and even countries that were not colonized, such as Thailand and Japan, adopted some form of restrictive abortion legislation in the nineteenth century derived from Western statutes.

The second half of the twentieth century has seen a reversal of many restrictive laws. The majority of the world's population now lives in countries which have access to safe abortion on request. The technologies used all over the world owe a great deal to non-Western philosophies and inventiveness.

See Also

- [Childbirth](#)
- [Ethnobotany](#)
- [Jamu](#)

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Abraham Bar Ḥiyya (Savasorda)

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Abraham bar ḥiyya, also called Savasorda (latinized from the Arabic *ṣāḥib al-shurṭa* = Chief of the guard), flourished in Barcelona, in Christian Spain, but was probably educated in the kingdom (*tā'ifa*) of Saragossa, during the

period in which it was ruled by the Arabic dynasty of the Banū Hūd. Thus his scientific education could be related to the well known scientific talents of some of the Banū Hūd kings.

Having mastered the Arabic language and culture, he was a pioneer in the use of the Hebrew language in various fields. He wrote on philosophy, ethics, astronomy, astrology, mathematics, and calendrical calculations. He clearly indicated that his Hebrew compositions were written for Jews living in southern France, who were unacquainted with Arabic culture and unable to read Arabic texts.

Two mathematical compositions by Abraham Bar ḥiyya, and four astronomical ones are known.

Yesodey ha-tevuna u-migdal ha-emuna (The Foundations of Science and the Tower of the Faith) was supposed to be a scientific encyclopedia, of which only the mathematical sections survived. Presumably an adaptation from some unknown Arabic composition, it dealt with basic definitions and knowledge in arithmetic, geometry, and optics.

ḥibbur ha-meshiḥa we ha-īshboret (The Composition on Geometrical Measures) dealt with practical geometry. This book enjoyed a very large diffusion in medieval Europe in its Latin version, the *Liber embadorum*, translated by Plato of Tivoli (1145), who was assisted by the author himself. The importance of this text for the development of practical geometry in Europe has been noted by ancient and modern scholars.

Seferṣsurat ha-areṣ we-tavnit kaddurey haraqi 'a (Book on the Form of the Earth and the Figure of Celestial Spheres), together with *ḥeshbon mahalakhot ha-kokhavim* (Calculations of the Courses of the Stars) and *The Luḥot* (The Astronomical Tables), offered a basic astronomical knowledge founded on Arabic sources such as the works of ► [al-Farghānī](#) and ► [al-Battānī](#).

Sefer ha-'Ibbur (The Book of Intercalation) dealt with calendrical calculations and aimed "to enable the Jews to observe the Holy Days on the correct dates."

Bar ḥiyya can rightly be considered the founder of Hebrew scientific culture and language.

See Also

► [al-Battānī](#)

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Abraham Ibn Ezra

Samuel S. Kottek

Abraham Ibn Ezra was born in Toledo, Spain in 1089. In his youth, he studied all the branches of knowledge that Arabic and Jewish gifted (and well to do) youngsters could master, and was mainly known as a poet. Around 1140, he left Spain and wandered through Italy, southern France, and England. Also, legend says that in his old age he traveled to the Holy Land. During his itinerant life, Ibn Ezra met scores of scholars and wrote a number of works, of which his commentary on the Pentateuch and the Prophets in the most widely known.

He was a real polymath, who wrote on Hebrew philology (*Moznei Leshon ha-Kodesh*), translated several works on grammar from Arabic into Hebrew, and wrote on the calendar, mathematics (*Sefer ha-Mispar*, Book of the Number), and philosophy and ethics (*Yesod Mora* on the meaning of the commandments). He is considered one of the Jewish Neoplatonists, in particular regarding his description of the soul. In his view, intellectual perfection is the only way to enjoy a relationship with the divine Providence. As a scientist, Ibn Ezra (also known by the name of Avenezra, sometimes misspelled Avenaris) is mainly known for his works on astronomy (*Sefer ha-Ibbur: Ta'amei ha-Luhot*, Book on Intercalation) and for his treatise on mathematics mentioned above. He also composed a number of brief astrological works, most of them still unpublished. It is not known whether Ibn Ezra ever practiced medicine. He certainly showed in his biblical commentary a fair degree of knowledge in medicine and biology.

It has been said that Ibn Ezra wrote over 100 works, which seems rather exaggerated; certainly many fewer have survived. Ibn Ezra was the Paracelsian type of scholar, learning from each new experience, from each encounter with other scholars, living a simple life and despising wealth. It is particularly striking that he wrote only in Hebrew, contrary to nearly all his contemporaries in Spain who wrote in Arabic. This is mainly due to the fact that he wandered throughout Europe and North Africa, using the language that was common to all his coreligionists. He may be considered an ambassador of Spanish scholarship to the Jewish Diaspora at large. He died in 1164.

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Abū 'l-Barakāt

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Abū al-Barakāt al-Baghdādī (d. 1164 or 1165) was one of the most original thinkers of the medieval period. Born a Jew in about 1080, but

converted late in life to Islam, Abū 'l-Barakāt was a prominent physician and natural philosopher who achieved considerable fame during his own lifetime, as his appellation *awḥad al-zamān* (Unique of His Age) attests. His numerous insights into physics and metaphysics have been elucidated by the late Shlomo Pines in a number of brilliant studies, on which this résumé depends in large measure.

Abū 'l-Barakāt's contributions are all contained in his *chef d'œuvre*, *al-Mu'tabar* (That Which has been Attained by Reflection). Although there may be some doctrinal discrepancies between various passages in the book, which may be due to the fact that the work is actually a collection of notes compiled over a considerable period of time, each section by itself displays a very clear and systematic exposition, surveying earlier opinions on the subject, objections to these, and possible answers to the objections (including the occasional concession that the objection is valid and necessitates a revision of the original idea), followed by Abū 'l-Barakāt's own opinion. Abū 'l-Barakāt exhibits a remarkable ability to disentangle issues that had become densely intertwined through centuries of debate, for example the three notions of time, space, and the infinite. Particularly significant are the occasions when the author gives great, occasionally decisive, weight to "common opinion," on the grounds that the issues at hand – the notions of time and space are the most important to fall into this group – involve a priori concepts which must be elucidated by examining how people actually perceive, rather than a posteriori academic analysis.

Some of the ideas which Abū 'l-Barakāt advances in the course of his discussions prefigure much later notions which proved to be correct: for example, the idea that a constant velocity applied to a moving body causes it to accelerate. Others, by contrast, showed themselves to be wrong: for instance, the idea that every type of body has a characteristic velocity which reaches its maximum when the resistance is zero. (In this way, Abu 'l-Barakāt answers the objection that bodies moving in a vacuum would have an infinite velocity.) All in all, the work of Abū 'l-Barakāt and its continuation by his student

Fakhr al-Dīn ► [al-Rāzī](#) constituted a most serious challenge to the formulations of Ibn Sīnā, which then dominated physical and metaphysical thought in Near East.

All that we possess in the way of medical writings by Abū ʿI-Barakāt are a few prescriptions for remedies. These remain in manuscript and are as yet unstudied.

See Also

- [Abū ʿI-Fidāʾ](#)
- [al-Rāzī](#)
- [Ibn Sīnā \(Avicenna\)](#)

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Abū Jaʿfar al-Khāzin

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Abū Jaʿfar Muḥammad ibn al-ḥusay al-Khāzin was a mathematician and astronomer who lived in the early tenth century AD in Khorasān. Until recently, it was believed that there were two different mathematicians in the same period, namely Abū Jaʿfar al-Khāzin and Abū Jaʿfar Muḥammad ibn al-ḥusayn, but in 1978 Anboubā and Sezgin showed that they are the same person.

In mathematics, Abū Jaʿfar al-Khāzin is mainly known because he was the first to realize that a cubic equation could be solved geometrically by means of conic sections. ► [Al-Māhānī](#) (ca. AD 850) had shown that an auxiliary problem in Archimedes' *On the Sphere and Cylinder* II:

4, which Archimedes had left unsolved, could be reduced to a cubic equation of the form $x^3 + c = ax^2$. Abū Jaʿfar knew the commentary to Archimedes' work by Eutocius of Ascalon (fifth century AD), in which Eutocius discusses a solution of the same auxiliary problem by means of conic sections. Abū Jaʿfar drew the conclusion that the equation $x^3 + c = ax^2$ could also be solved by means of conic sections. Abū Jaʿfar also studied a number of other mathematical problems. He stated that the equation $x^3 + y^3 = z^3$ did not have a solution in positive integers, but he was unable to give a correct proof. He also worked on the isoperimetric problem, and he wrote a commentary to Book X of Euclid's *Elements*.

In astronomy, Abū Jaʿfar's main work was the ► [Zīj al-ṣafāʾiḥ](#) (the Astronomical Handbook of Plates). A manuscript of this work has recently been discovered in Srinagar. The work deals with a strange variant of the astrolabe. One such instrument, made in the twelfth century, was still extant in the beginning of this century in Germany, but it has since disappeared. Photographs of this instrument have been published by David King. Abū Jaʿfar developed a homocentric solar model, in which the sun moves in a circle with the earth as its center, in such a way that its motion is uniform with respect to a point which does not coincide with the center of the earth.

See Also

- [al-Māhānī](#)

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Abū Kāmil

Jacques Sesiano

Abū Kāmil, Shujāʿ ibn Aslam (ca. 850–ca. 930), also known as “the Egyptian Reckoner” (*al-ḥāsib al-miṣrī*) was, according to the encyclopedist Ibn Khaldūn’s report on algebra in his *Muqaddima*, chronologically the second greatest algebraist after ► [al-Khwārizmī](#). He was certainly one of the most influential. The peak of his activity seems to have been at the end of the ninth century.

Although at the beginning of his *Kitāb fī l-jabr waʾl-muqābala* (Algebra) he refers to al-Khwārizmī’s similar work, Abū Kāmil’s purpose is radically different, for he is addressing an audience of mathematicians presumed to have a thorough knowledge of Euclid’s *Elements*. His *Algebra* consists of four main parts.

1. Like his predecessor, Abū Kāmil begins by explaining how to solve the six standard equations and to deal with algebraic expressions involving an unknown and square roots. The next section (Book II) contains, as in his predecessor’s work, six examples of problems and the resolutions of various questions, but the whole is notably more elaborate and geometrical illustrations or proofs are systematically appended. With Book III comes a difference, already hinted at in the introduction to the treatise: the problems now contain quadratic irrationalities, both as solutions and coefficients, and require notable proficiency in computing. Quadratic irrationalities may thus be said to enter definitely the domain of mathematics and no longer be confined to their Euclidean representation as line segments.
2. These extensions found in Book III are put to immediate use in the resolutions of problems involving polygons in which the link between their sides and the radii of a circumscribed circle is reducible to a quadratic equation – since they are all constructible by ruler and compass.

3. The subsequent set of quadratic indeterminate equations and systems is most interesting. The methods presented are similar to those of Diophantus’s *Arithmetica*, but there are new cases and the problems are presented in a less particular form. Abū Kāmil surely relied on some Greek material unknown to us.
4. A set of problems which are, broadly speaking, applications of algebra to daily life are directly appended to the former. Some of these, which correspond to highly unrealistic situations, belong more to recreational mathematics. The inclusion of such problems in an algebraic textbook was to become a medieval custom, with both mathematical and didactical motives. The *Algebra* ends with the classical problem of summing the successive powers of 2, which, from the ninth century on, became attached to the 64 cells of the chessboard.

Abū Kāmil’s Arabic text is preserved by a single, but excellent, manuscript. The *Algebra* was commented upon several times, in particular in Spain, and the first large mathematical book of Christendom, Johannes Hispalensis’s *Liber mahameleth*, is basically a development and improvement of parts *a* and *d*. Despite the *Algebra*’s importance in Spain, no Latin translation was undertaken until the fourteenth century, when Guillelmus (presumably: de Lunis) translated half of it (up to the beginning of part *c*). This translation is better than Mordekhai Finzi’s fifteenth century Hebrew one, which, however, covers the whole work. Since these translations were late, Abū Kāmil had no direct influence in the Christian West. Similar material, however, may be found in writings of Leonardo (Fibonacci) of Pisa (fl. 1220).

Abū Kāmil also wrote *Kitāb al-ṭair* (Book of the Birds), a small treatise consisting of an introduction and six problems all dealing with the purchase of different kinds of birds, of which one knows the price per unit, the total number bought and the amount spent (both taken to be 100). Since there are more unknown kinds (three to five) than equations, these linear problems are all indeterminate. Abū Kāmil undertook to

determine their number of (positive integral) solutions, which he found to be, respectively, 1, 6, 96 (correct: 98), 304, 0, 2676 (correct: 2,678). Although such problems are frequently met in the medieval world, Abū Kāmil remained seemingly unparalleled in his search for all solutions in various cases.

Kitāb al-misāḥa wa'l-handasa, or *Kitāb misāḥat al-araḍīn* (On Measurement and Geometry) is an elementary treatise on calculating surfaces and volumes of common geometrical figures. Since it is meant for beginners, demonstrations and algebra are left out. Why Abū Kāmil found it necessary to write such an elementary book becomes clear when he describes some of the formulas then in use by official land surveyors in Egypt.

Finally, *Kitāb al-waṣāyābi'l-juḍūr* or *Kitāb al-waṣāyābi'l-jabr wa'l-muqābala* (Estate Sharing Using Unknowns, or Using Algebra) applies mathematics to inheritance problems. Abū Kāmil begins by explaining the requirements of the Muslim laws of inheritance and discussing the opinions of known jurists.

Bibliographic sources inform us that Abū Kāmil also wrote another treatise on algebra, and a further one on the rule of false position.

Note that two of the subjects included by ► *al-Khwārizmī* in his *Algebra* were treated by Abū Kāmil in separate works. From that time onward, algebra textbooks adopted the same form as his.

See Also

- [Algebra in Islamic Mathematics](#)
- [Algebra, Surveyors'](#)
- [Mathematics Practical and Recreational](#)
- [Number Theory in Islamic Mathematics](#)
- [Surveying](#)

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Abū Ma'shar

Richard Lemay

Arabic sources such as the *Kitāb al-Fihrist* give the date of Abū Ma'shar al-Balkī's death as 273 of the Hegira, which is AD 886, stating that he was over 100-years old. Since he was of Persian (Afghan) origin these may well be solar years rather than the lunar years of the Muslim calendar. Therefore his age at his death could have been reckoned as “over” 100 years if counted in lunar years in Muslim fashion, or else as 100 solar years. David Pingree claimed to have found the exact date of his birth to be August 10, 787 in a natal horoscope in Abū Ma'shar's *Nativities*. The trouble with this calculation is that Abū Ma'shar himself, in *Mudhākarāt* (Recollections), lamented the fact that he did not know the exact date of his birth and had to rely therefore on a “universal” horoscope he had drawn up. The *Mudhākarāt* then supplies the basic elements of this universal horoscope. Matching these data with Pingree's, it is probably safe to consider the year 171 H/AD 787 as his birth date.

Abū Ma'shar, known in the West as Albumasar, was born in Balkhī in Khurāsān, actually Afghanistan, and seems to have lived there and acquired a reputation as an astrologer

much before he came to settle in Baghdad during the reign of the Caliph ► [al-Ma'mūn](#) (813–833), shortly after 820. He lived in Iraq until the end of his life in 886. He must have traveled, at least up and down the Tigris, since in the *Mudhākarāt* he is shown refusing to embark on the stormy waters of the Tigris. He died in Wasit, a city situated in the Sawād, midway between Baghdad and Basra.

Abū Ma'shar's early years are clouded in confusion because of an error committed by the earliest and most important Arab bibliographer, Ibn al-Nadīm (1970), in his *Kitāb al-Fihrist*. Writing in the late tenth century, nearly a century after Abū Ma'shar's death, al-Nadīm (d. ca. AD 987) apparently confused Abū Ma'shar the astrologer from Balkh with another Abū Ma'shar, called an-Najīh, who lived in Medina but died in Baghdad AD 787, the year of Abū Ma'shar's birth.

Once settled in Baghdad, where he spent the remaining 60 years of his life, Abū Ma'shar seems to have been involved in its cultural activity, but also in its tumultuous civic life at a time when "nationalisms" in the form of the *Shu'ūbiya* (non-Arabs) were raising their aspirations to cultural parity with the dominant Arabs. Abū Ma'shar's reputation as an astrologer, his newly found friendship with ► [al-Kindī](#), and the credit he gained through astrological predictions assessing the power of rulers must have opened for him the doors of the political and learned elite of Baghdad. Al-Nadīm relates an episode in which Abū Ma'shar was punished with lashes by the Caliph for a realistic prediction that the Caliph disliked. Both Abū Ma'shar and al-Kindī, using an intricate system of astral conjunctions inherited from the Sassanian tradition, attempted to anticipate the duration of the Arab rule. In his *Risāla* (Epistle) on the duration of the rule of Islam, al-Kindī tried to comfort the ruling Caliph by giving the Arab rule a minimum span of some 693 years, longer than Abū Ma'shar's prediction. In fact Abū Ma'shar gives a total of 693 years, just as al-Kindī did. Still, in combination with the parallel scheme of the two maleficent planets Saturn and Mars affecting the meaning of the conjunctions of Saturn and Jupiter, Abū Ma'shar tended to reduce the duration to some 310 or

330 years only, which would bring the end of Arab rule closer, thus encouraging the aspirations of the *shu'ūbiyya*.

The *Mudākarāt* of Abū Sa'īd further tell us that, along with other astrologers, Abū Ma'shar accompanied the army of al-Muwaffaq in its campaign against the rebellious Zanj. Astrologers were used by both sides during these civic troubles. Abū Ma'shar's credit as an astrologer served him in these circumstances, for he may have been consulted by both sides in the Rebellion. At any rate he died in the city of Wasit, south of Baghdad, a city which had seen the farthest advance of the rebellious Zanj army and had been reconquered only shortly before by al-Muwaffaq.

The *Fihrist* credits Abū Ma'shar with 36 works, to which David Pingree adds six more. The list has remained fairly the same for all later bibliographers. This holds true for the original Arabic works as well as for the numerous translations into Latin, Greek, Hebrew, and medieval Romance languages. The uncertainty is due to a number of factors. Abū Ma'shar may have produced some works in several versions or editions. He has been imitated in a number of ways by later Arab authors, some of whom displayed his name prominently at the beginning of their own work, thus complicating the task of the bibliographer. Above all there is a lack of any systematic survey of Abū Ma'shar's production. In addition to the confusion still affecting the Arabic originals, a number of Abū Ma'shar's works were translated into so many media during the Middle Ages that the task of surveying the authentic remains is enormous. This illustrates the immense popularity enjoyed by Abū Ma'shar in the West.

See Also

► [Astrology in Islam](#)

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Abū'l-Fidā'

Emilia Calvo

Abū'l-Fidā' ʾIsmāʿīl ibn ʿalī ibn Maḥmūd ibn Muḥammad ibn ʿUmar ibn Shahanshāh ibn Ayyūb ʾImād al-Dīn al-Ayyūbī was a prince, historian, and geographer belonging to the Ayyūbid family. He was born in Damascus, Syria in AD 1273 and soon began his military career against the Crusaders and the Mongols. In AD 1299 he entered the service of the Sultan al-Malik al-Nāṣir and, after 12 years, he was installed as governor

of ḥamā. Two years later he received the title of al-Malik al-ṣāliḥ. In AD 1320 he accompanied the Sultan Muḥammad on the pilgrimage to Mecca and was given the title of al-Malik al-Muʾayyad. He died at ḥamā, Syria in AD 1331.

Abū'l-Fidā' is the author of some poetic productions, such as the version in verse of al-Māwardī's juridical work *al-Hāwī*. However, his celebrity is based on two works which can be considered basically compilations of earlier works which he elaborated and completed. One of them is the *Mukhtaṣar Taʾrīkh al-bashar* (A Summary on the History of Humanity) written in AD 1315 as a continuation of the *Kāmil fī-l-taʾrīkh* of Ibn al-Athīr. It was divided into two parts: the first was devoted to pre-Islamic Arabia and the second to the history of Islam until AD 1329. It was kept up to date until AD 1403 by other Arabic historians. It was translated into Western languages and became the basis for several historical syntheses by eighteenth-century Orientalists.

Abū'l-Fidā''s most important scientific work is *Taqwīm al-buldān* (A Sketch of the Countries) written between AD 1316 and 1321. It consists of a general geography in 28 chapters.

This book includes the problems and results of mathematical and physical geography without touching upon human geography or geographical lexicography. There is a table of the longitudes and latitudes of a number of cities, including the differing results found in the sources, setting up a comparative table for geographical coordinates. Among the sources of the book are geographers such as Ibn Hawqal and Ibn Saʿīd al-Maghribī.

This work was translated into German, Latin, and French between the sixteenth and the nineteenth centuries, making a significant contribution to the development of geography.

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Abū'l-Šalt

Julio Samsó

Abū'l-šalt is known as Abū'l-šalt al-Dānī. He was an Andalusian polymath born in Denia in 1067. In about 1096 he went to Egypt where he lived for 16 years. An unsuccessful attempt to rescue a boat loaded with copper which had sunk in the harbor of Alexandria cost him 3 years in prison, after which he migrated to Mahdiyya (Tunis) where he died in 1134.

He wrote about pharmacology (a treatise on simple drugs, *Kitāb al-adwiya al-mufrada*, translated into Latin by Arnold of Vilanova), music, geometry, Aristotelian physics, and astronomy, and he seems to have been interested in a physical astronomy, different from the Ptolemaic mathematical astronomy which predominated in al-Andalus. His treatise on the use of the astrolabe, *Risāla fī-l-'amal bi-l-aṣṭurlāb*, written while he was in prison, probably introduced into Eastern Islam the characteristic Andalusian and Maghribi device, present in the back of Western instruments, which establishes the relation between the date of the Julian year and the solar longitude. He is also the author of a short treatise on the construction and use of the equatorium, *ṣifāt 'amal safiḥa-j-āmi'a tuqawwim bi-hā-jamī' al-kawākib al-sab'a* (Description of the Way to Use a General Plate With Which to Calculate the Positions of the Seven Planets) which follows the techniques developed in al-Andalus by Ibn al-Samḥ

(d. 1035) and ► [Ibn al-Zarqāllu](#) (d. 1100), although it also presents original details which show his ingenuity. He probably reintroduced this instrument in the Islamic East where it had appeared in the tenth century but was later forgotten until it was recovered by al-Kāshī (d. 1429).

See Also

► [Ibn al-Zarqāllu](#)

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Abū'l-Wafā'

Yvonne Dold-Samplonius

Abū'l-Wafā' al-Būzjānī, Muḥammad ibn Muḥammad ibn Yaḥyā ibn Ismā'īl ibn al-'Abbās, was born in Būzjān (now in Iran) on 10 June 940. After he moved to Baghdad in 959, he wrote important works on arithmetic, trigonometry, and astronomy.

Abū'l-Wafā' provided new solutions to many problems in spherical trigonometry and computed trigonometric tables with an accuracy that had not been achieved until his time. He made astronomical observations and assisted at observations in the garden of the palace of Sharaf al-Dawla. Finally, he wrote two astronomical handbooks, the *Wāḍih* ► [Zīj](#) and *al-Majisfī* (*Almagest*). More information about Abū'l-Wafā''s

tables must be obtained from *zījes* that have incorporated material from his works, such as the *Baghdādī Zīj*, compiled shortly before the year 1285 by Jamāl al-Dīn al-Baghdādī. A solar equation table attributed to Abū'l-Wafā' occurs in it.

Several later *zījes* incorporate Abū'l-Wafā''s mean motion parameters. Various sine and cotangent values which he gave in the extant part of *al-Majisī* are equal to the values found in al-Baghdādī's sine and cotangent tables. Furthermore, al-Baghdādī's table for the equation of daylight was computed by means of inverse linear interpolation in a sine table with accurate values to four sexagesimal places for every 15° of the argument, and Abū'l-Wafā' is known to have computed an accurate sine table with just that format.

In *Risāla fī iqāmat al-burhān 'alā 'l-dā'ir min al-falak min qaws al-nahār wa'rtifā' nisf al-nahār wa'rtifā' al-waqt* (On Establishing the Proof of the [rule for finding the] Arc of Revolution from the Day Arc, the Noon Altitude, and the Altitude at the Time), Abū'l-Wafā' deals with a fundamental problem of ancient astronomy that of finding the time in terms of solar altitude. He mentions in the introduction that the formula stated by Ḥabash al-Hāsib (fl. 850) is only approximate. Abū'l-Wafā' gives three proofs of the formula. The procedure of the first two proofs deals entirely with rectilinear configurations inside the sphere, in spite of the fact that the relation being investigated concerns arcs on the surface of the sphere. This technique was characteristic of Hindu spherical astronomy, as well as that of the Greeks prior to the application of Menelaus' Theorem. The method used in the third proof consists essentially of two applications of the Transversal Theorem. Contrary to Hindu trigonometry and most Islamic astronomers, Abū'l-Wafā' was one of the few who defined the trigonometric functions with respect to the unit circle, as is the case nowadays. In *Fī ḥirāfat al-ab'ād bain al-masākin* (On the Determination of the Distances Between Localities) Abū'l-Wafā' gives two rules for calculating the great circle distance between a pair of points on the earth's surface. He applies both to a worked

example: given the terrestrial coordinates of Baghdad and Mecca he calculates the distance between them, a matter of some interest to Iraqi Muslims undertaking the pilgrimage. The first method employs standard medieval spherical trigonometry and can be regarded as a byproduct of a common procedure for calculating the *qibla*, the direction of Muslim prayer. It is called by ► al-Bīrūnī "the method of the *zījes*." The second method is less ordinary and its validity is not obvious. In addition to the tangent function, it employs the versed sine, a term Abū'l-Wafā' does not use in the treatise studied above, but which appears frequently in the literature. The origin of this second rule might stem from the so-called *analemma method*, a common and useful ancient technique for solving spherical astronomical problems. The general idea was to project or rotate elements of the given solid configuration down into a single plane, where the desired magnitude appeared in its true size. The resulting plane configuration was then solved by constructions to scale or by plane trigonometry. Aside from the trigonometry, the text is of interest as an intact example of medieval computational mathematics. Numbers are represented in Arabic alphabetical sexagesimals throughout. The results of the multiplications suggest that all operations were carried out in sexagesimal arithmetic, with none of the very common intermediate transformations into decimal integers. Trigonometric functions and their inverses are carried out to four sexagesimal places. Al-ḥubūbī challenged Abū'l-Wafā' to produce and prove a rule for calculating the area of a triangle in terms of its sides. In his *Jawāb Abī al-Wafā' Muḥ ibn Muḥal-Būzjānī 'ammā sa'alahu al-Faqīh Abū 'Alī al-ḥasan ibn ḥārith al-ḥub ūbī fī misāḥat al-muthallathāt* (Answer of Abū'l-Wafā' to the Question Put to Him by the Jurist Abū 'Alī al-ḥasan al-Ḥubūbī on Measuring the Triangle), Abū'l-Wafā' gives three such rules. None of these is identical with "Heron's Rule," but all are equivalent to it. The earliest work on finger reckoning that has survived is Abū'l-Wafā''s *Fīmāyhtāju ilaihi l-kuttāb wa-l-ummāl min 'ilm al-ḥisāb* (On What Scribes and Officials

Need from the Science of Arithmetic). As the name implies, it was written for state officials, and therefore gives an insight into tenth-century life in Islam from the administrative point of view. Three more works demonstrate Abū'l-Wafā's interest in practical mathematics: *Fīmā yahtāju ilaihi as-sānī'min a'māl al-handasīya* (On the Geometrical Constructions Necessary for the Craftsman), written after 990; *al-Mudkhal al-ḥifẓī ilā ẓinā'at al-arithmāṭiqī* (Introduction to Arithmetical Constructions); and *Risāla al-shamsīya fī l-fawā'id al-ḥisābīya* (On the Benefit of Arithmetic).

On What Scribes and Officials Need, written between 961 and 976, enjoyed widespread fame. The first three parts, "On Ratio," "On Multiplication and Division," and "Mensuration," are purely mathematical. The other four contain solutions of practical problems with regard to taxes, problems related to harvest, exchange of money units, conversion of payment in kind to cash, problems related to mail, weight units, and five problems concerning wells. In this compendium Abū'l-Wafā' systematically sets forth the methods of calculation used by merchants, by clerks in the departments of finance, and by land surveyors in their daily work; he also introduces refinements of commonly used methods and criticizes some for being incorrect. Considering the habits of the readers for whom the textbook was written, Abū'l-Wafā' completely avoids the use of numerals. Numbers are written in words, and their calculations are performed mentally. To remember the results of intermediary steps, calculators bent their finger joints in conventional ways which enabled them to indicate whole numbers from 1 to 9,999. This same device was repeated to indicate numbers from 10,000 onward. All procedures, often quite complex, are only described by words. This treatise on practical arithmetic provides the model for all the treatises on the subject from the tenth to the sixteenth centuries.

He is cited as a source or an authority, but more often can only be discerned underneath. In the *Geometrical Constructions Necessary for the Craftsman* Abū'l-Wafā' discusses a host of interesting geometrical constructions and proofs.

He constructs a regular pentagon, a regular octagon, and a regular decagon. The construction of the regular pentagon with a "rusty" compass is especially noteworthy. Such constructions are found in the writings of the ancient Hindus and Greeks, but Abū'l-Wafā' was the first to solve a large number of problems using this compass with fixed opening.

Renaissance Europe had a great interest in these constructions. The possible practical applications (such as making decorative patterns) may have been an additional motivation for studying things like a regular (or perhaps equilateral) pentagon inscribed in a square. However, the importance of such applications should not be overestimated. In proposing his original and elegant constructions, Abū'l-Wafā' simultaneously proved the inaccuracy of some practical methods used by the craftsmen.

To honor Abū'l-Wafā', a crater on the moon was named after him. He died in Baghdad in 997 or 998.

See Also

- [Algebra, Surveyors'](#)
- [Ḥabash al-Ḥāsib](#)
- [Mathematics Practical and Recreational](#)
- [Qibla and Islamic Prayer Times](#)

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Acoustics at Chichen Itza

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A Chirp Echo from El Castillo Pyramid

At Chichen Itza in Mexico, there is a Mayan ruin with a pyramid named El Castillo that produces an echo in response to a handclap. According to some authors, it sounds like the chirp of a quetzal bird. It was felt by Lubman and others that the periodic structure of the central staircase (see Fig. 1) is responsible for the chirp-like sound of the echo (Lubman, 1998a, b). Declercq, Degrieck, Briers, & Leroy (2004) performed a

spectral analysis of the echo sound as recorded by Lubman and tried to find an explanation by applying optical diffraction theory to the periodic structure of the steps of the pyramid. Bilsen (2006), on the other hand, proposed an explanation based on auditory pitch theory, by considering the detailed time pattern of sound reflections from the steps of the staircase.

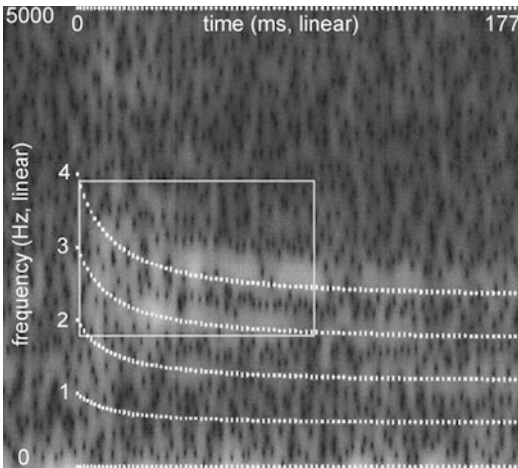
In Fig. 2, the gray-scaled background constitutes the sonogram of the chirp echo as reproduced from Fig. 8 of Declercq et al. (2004). Time is plotted horizontally on a linear scale (total span 200 ms), and frequency is plotted vertically on a linear scale from 0 to 5,000 Hz. Note that the lighter areas in this sonogram suggest the presence of spectral energy at the second, third, and fourth “harmonic” of a gliding fundamental frequency. These gliding harmonics are indicated by the dotted lines as predicted by the theory of repetition pitch.

Repetition Pitch Theory

A sound like a handclap contains spectral energy smeared over a wide range of frequencies. We consider the idealized case of a short pulse with a white spectrum (compare white light). When

Acoustics at Chichen Itza, Fig. 1 The El Castillo pyramid at the Mayan ruin at Chichen Itza in Mexico





Acoustics at Chichen Itza, Fig. 2 Gray-scaled sonogram after Declercq et al. (2004, Fig. 8) of the chirp echo recorded by Lubman (1998b). Time is plotted horizontally; frequency is plotted vertically. White dotted lines represent the 1st, 2nd, 3rd, and 4th “harmonic” following repetition pitch theory (see text below)

such a sound is mixed with the (delayed) repetition of itself, a compound signal is obtained having a rippled spectrum with peaks and valleys at equal distances in frequency (compare interference in optics). Specifically, the power spectrum of a white signal with one added repetition is a cosine function of frequency (see continuous bold-faced lines in Fig. 3) with spectral maxima at multiples of a “fundamental” f_0 corresponding to the reciprocal value of the delay time τ .

With such a signal, a listener generally perceives a pitch, repetition pitch (RP), corresponding to the fundamental (which, by the way, need not necessarily be present in the physical signal). Extensive psychophysical experiments in the past have shown that, in principle, RP can be predicted correctly by alternative theories, specifically (1) by neural signal processing described as autocorrelation on the temporal fine structure of the cochlear signal (Bilsen & Ritsma, 1969/1970), (2) by internal-spectrum matching as imagined in Fig. 3 (Bilsen, 1977), or (3) by correlation-like processing performed on the harmonics resolved in the cochlea (e.g., Yost, Patterson, & Sheft, 1996; see also Hartmann, 1997, pp. 361–376).

The Chirp Echo Modeled as a Gliding Repetition Pitch

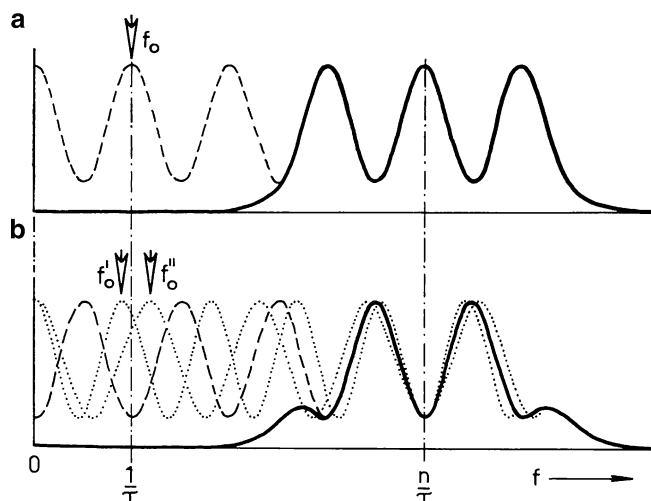
Adopting the data of pyramid dimensions, handclap, and sound recording positions, from Declercq et al. (2004), the drawing of Fig. 4 was obtained (Bilsen, 2006, Fig. 2). The steps of the staircase are numbered $n = -7$ to 84, with $n = 0$ being the step at ear (microphone) height. Dimensions are given in meters. Paired reflections (repetitions) from successive steps are considered as pairs of pulses with inherent delay τ_n , equal to the sound path differences $\{S(n+1) - S(n)\}$ divided by the speed of sound. From the reciprocal values, $1/\tau_n$, a theoretical sonogram (see Fig. 5) is calculated, showing a cosine shape along the vertical (frequency) dimension and a gliding “fundamental” together with its “harmonics” (maxima) in the horizontal (time) dimension.

For easy comparison with the sonogram of the recorded chirp echo (see Fig. 2), dotted lines are superimposed on the sonogram (total span 200 ms) so that the 177-ms span of the model (91 dots) coincides as well as possible with the extent of the lighter areas of the sonogram in the horizontal direction. Each dotted line represents one of the first four harmonics numbered 1 through 4, with each dot representing the instantaneous value of an RP harmonic. The calculated fundamental glides from 796 to 471 Hz within a time span of 177 ms. Horizontal dotted lines at 0 Hz and 5 kHz coincide with the frequency scale of the sonogram. It can be concluded that the dotted lines fit nicely to the lighter regions in the sonogram, which proves the adequacy of RP theory.

By informal listening to a synthesized RP glide following the above model, basic similarity with the chirp recorded by Lubman was observed. This confirms also the perceptual relevance of the present considerations (<http://fabilsen.home.xs4all.nl>).

Chichen Itza Compared to Chantilly

In 1693, Christiaan Huygens standing at the foot of the majestic staircase in the garden of the castle

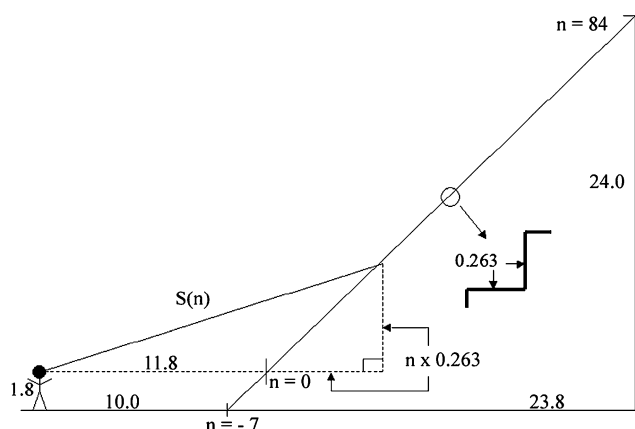


A

Acoustics at Chichen Itza, Fig. 3 Here it is imagined how the brain might “calculate” a repetition pitch corresponding to the (absent) fundamental frequency f_0 by making a best harmonic fit to the spectral maxima present in a signal. (a) Harmonic case (delayed signal

added) with harmonically related spectral maxima at n/τ for $n = 3, 4$, and 5 . (b) Ambiguous case (delayed signal subtracted) with spectral maxima for $n = 3\frac{1}{2}$ and $4\frac{1}{2}$ giving rise to two alternative pitches f_0' or f_0''

Acoustics at Chichen Itza, Fig. 4 Schematics of El Castillo pyramid with source/receiver position and step dimensions in meters. Steps are numbered $n = -7$ to 84 (Note: n different from n in Fig. 3) (After Bilsen, 2006, Fig. 2)

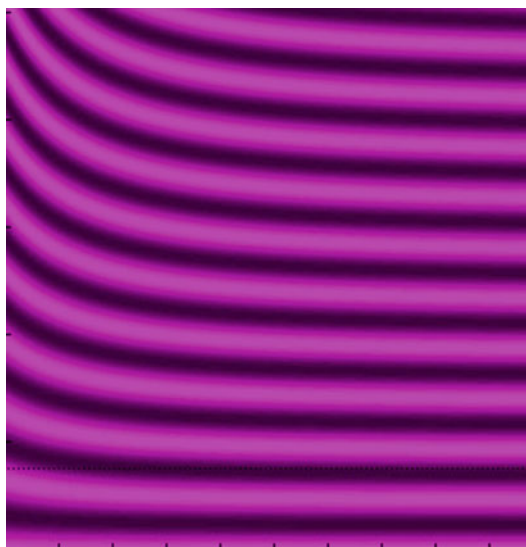


of Chantilly in France (see Fig. 6) made the following observation (translated rather literally by the present author from old French) (Huygens, 1693[1905]):

When one is standing between the staircase and the fountain, one hears from the side of the staircase a resonance that possesses a certain musical pitch that continues, as long as the fountain spouts. One did not know where this tone originated from or improbable explanations were given, which stimulated me to search for a better one. Soon I found

that it originated from the reflection of the noise from the fountain against the steps of the staircase. Because like every sound, or rather noise, reiterated in equal small intervals produces a musical tone, and like the length of an organ pipe determines its own pitch by its length because the air pulsations arrive regularly within small time intervals used by the undulations to do the length of the pipe twice in case it is closed at the end, so I imagined that each, even the smallest, noise coming from the fountain, being reflected against the steps of the staircase, must arrive at the ear from each step as much later as the step is remote, and

this by time differences just equal to those used by the undulations to travel to and fro the width of one step. Having measured that width equal to 17 in., I made a roll of paper that had this length, and I found the same pitch that one heard at the foot of the staircase.

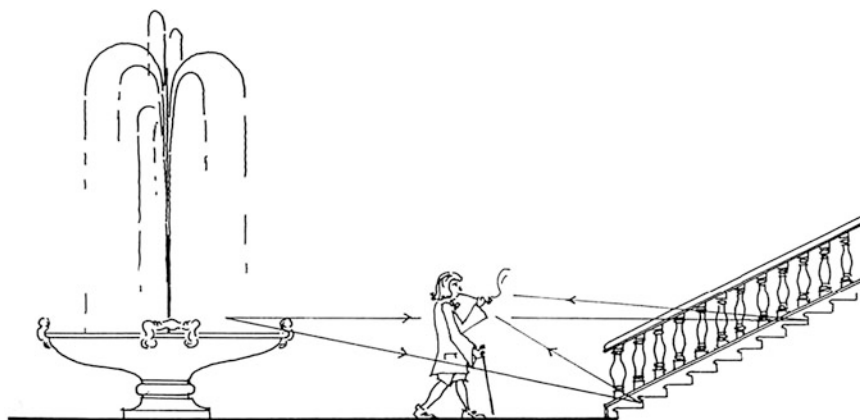


Acoustics at Chichen Itza, Fig. 5 Theoretical sonogram following repetition pitch theory and the El Castillo dimensions of Fig. 4. Frequency is plotted vertically; time is plotted horizontally on linear scales

Having established that the pitch was heard only when the fountain was working, he returned in winter when snow obscured the shape of the steps and he confirmed the absence of the pitch although the fountain was switched on. It is really a great experiment, tackling and controlling separately the two main physical factors responsible for the specific pitch.

Of course, Huygens did not possess our present knowledge of auditory theory, nor did he have knowledge of the psychophysical properties of repetition pitch. But having to do with many regular repetitions instead of only one, he could immediately draw an analogy with the musical tones from organ pipes. Thus, acoustically rather than physiologically, his explanation was adequate.

Huygens' observations were confirmed at later occasions by handclapping. Due to the rather large distance of the fountain or handclap position from the staircase, the smaller extent of the staircase, and the near horizontality of reflections, acoustic registrations show a regular reflection pattern in time, resulting in a rather stationary repetition pitch of 370 Hz equivalent.



Acoustics at Chichen Itza, Fig. 6 Christiaan Huygens at Chantilly as imagined by F. M. M. Bilsen (After Bilsen & Ritsma, 1969/1970, Fig. 1) (Note that, in reality, the

fountain or handclap position is at greater distance from the staircase)

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Acoustics in Chinese Culture

Chen Cheng-Yih

A sound is perceived in terms of its pitch, loudness, and tone quality characteristics. The Chinese term for pitch is *yīn lǚ* or simply *lǚ*. Early mentions of pitch in connection to its function in ode singing, in musicology, and in the standardization of measures and weights are found in the *Yú Shū* (*The Book of Yü*). The Chinese used the terms *qīng* (clear) and *zhuó* (muddy) to describe, respectively, the high and low pitches.

In remonstrating the decision of the High King Jǐng of Zhōu to have the Wǔ-Yì bell melted down and converted into the Dà-līn bell of lower pitch, minister Shan Mǔ Gōng stated in 522 BCE:

The ear functions harmoniously within a certain range of high and low pitches. The determination of this pitch-range should not be left for individuals. For this reason bells constructed by our ancient kings never exceeded their corresponding size in *jūn* (unit) and weight in *dàn* (unit). This is where the specifications of measures and weights for pitches originated.

This statement, recorded in the *Guó Yǔ* (*Discourses on States*), reveals that the early Chinese were aware of the existence of an audible pitch range.

A description on the development of the 12 pitches preserved in bells from antiquity is provided by music master Zhōu Jiū. He says that the reason that ranges and degrees can be established for pitch is due to Shén Gǔ of antiquity, who investigated and determined the *zhōng shēng* (middle tone) as the reference. The degrees of the pitches and tuned bells are the standards observed by all officials. From the *zhōng shēng*, one first establishes 3 pitches, then levels them out evenly into 6 pitches, and finally brings them to completion in 12 pitches. This is the *dào* of nature.

This suggests that the 12-pitch system was derived from “trichords”. An early example of a trichord is provided by three jade stone-chimes unearthed from a pit of the Yin ruins (ca. thirteenth century BCE) at Anyang; they not only are capable of producing tones but also have their pitch names engraved on the stones.

Early evidence for pitch standardization mentioned in the Chinese text is provided by the common notes found among the unearthed musical instruments. The most significant archaeological evidence is provided by the pitch pipes unearthed in 1986 from a Chǔ tomb (M21) of the Warring States period located at the present Yǔtáishān in Jiānglǐng, Hǔběi province. These pitch pipes, made of nodeless ► **bamboo** (open ends)

with different lengths and diameters, are the earliest specimens currently available. Though broken, four of the pitch pipes still had readable inscriptions, providing not only the names of the pitches, but also explicit statements on assigning pitches through the usage of the character *dìng* (literally to fix or determine). From the measured frequencies of the unearthed Marquis Yǐ set-bells, one obtains for the Huáng-zhōng pitch a measured frequency of 410.1 vib s^{-1} in the fifth century BCE.

In Chinese, the louder sound is called *dà* and the softer one *xì*. The modern Chinese term for loudness in acoustics is *yīn-liàng*. An early discussion on loudness is found in the *Guó Yu* on the arrangement of instrument in an orchestra, in which harmony and balance are considered essential.

An obvious question on loudness is its role in audibility. Lǎo Zǐ made some interesting observations which seem to have some bearing on the threshold of hearing. We have from the *Dào Dé Jīng* (Canon of the Virtue of Dào) the statement: That which is listened to but not heard is called *xī*. The term *xī*, as it is defined here, relates to the term *xī-shēng*, which Needham translates as “tenuous note”.

At the time of Lǎo Zǐ, concepts such as frequency and intensity had not yet been developed. Lǎo Zǐ could not have distinguished the audibility of *xī-shēng* in relation to its frequency and intensity. But he probably was aware that most *xī-shēng* are low-pitch sounds and that their audibility depends sensitively on loudness. Thus, when he said that the loud sound contains *xī-shēng*, he was probably referring to the audibility of those *inaudible* low-pitch sounds at a louder level.

Tone quality is the perception of sound in relation to the dynamic structure of the sound. The Chinese term for tone quality is *yīn-zhì* and in classic usage simply *yīn*. The early Chinese acousticians identified tone quality with the sound-producing material and began to classify sounds in accordance with such materials. Eight distinct tone qualities known simply as *bā-yīn* (eight tones) are identified with eight such sound-producing materials.

Early mention of the “eight tones” is found in the *Yú Shū* and *Zhǒ Zhuàn*. Other than being responsible for instituting music with the two sets of six pitches, the Grand Music Masters (*Dà-Shī*) were also responsible for making sure that all music was composed in pentatonic intonations: *gōng*, *shāng*, *jué*, *zhí*, and *yǔ*, and that all music was performed in eight tones: *jīn* (metal), *shí* (stone), *tǔ* (clay), *gé* (skin), *sī* (silk), *mù* (wood), *páo* (gourd), and *zhū* (bamboo).

Each of these sound-producing materials represents a basic tone quality. In 1936, Schaeffner commented that the *bā-yīn* was “probably the oldest extant classification of musical instruments in any civilization.” Needham and Robinson compared the *bā-yīn* classification with the Greco-Roman classification of musical instruments, namely wind, stringed, and percussion instruments, and concluded that the Greco-Roman classification was more scientific. The point that needs to be emphasized here is that the *bā-yīn* classification was based on tone qualities and not on musical instruments, even though there is an intimate connection between the two. It is important to note that each complex tone has its own unique characteristic harmonic spectrum and wave form. There does not yet exist a satisfactory system for classifying tone quality. The fivefold classification of ideophones, membranophones, chordophones, electrophones, and aerophones is again a classification based on musical instruments.

In addition to the tone quality of sound due to the sound-producing materials, the ancient Chinese were also interested in the variation in tone quality coming from the configuration of musical instruments and the different ways of playing musical instruments. Twelve sounds are specified in the *Zhōu Lǐ* to identify tone qualities with the configurations of the musical instruments. According to the *Lǚ-Shì Chūn-Qiū* of 239 BCE, the techniques of exploiting timbre with overtones had reached a high level of art in *qín* (half-tube zither) playing. Indeed, in the playing the ancient lute (*gu qín*) with no frets and markings, each note could be played with a variety of subtleties in touch.

The Physical Nature of Sound

As described in the *Kǎo Gōng Jì* (The Artificers' Record), sound is produced by vibrations, and there is a relationship between the thickness of the vibrating walls and the pitch of the sound produced by the vibration.

In Chinese classic usage, the character *jī* means rapid (or fast) and *shū* means slow. Thus, sound produced by rapid vibration is called *yīn jí* (or *shēng jí*) and by slow vibration *yīn shū* (or *shēng shū*). Such technical terms are found in the description of acoustics of bells, stone-chimes, and drums in the *Kǎo Gōng Jì*. It is important to appreciate the relation between this terminology and the terminology for pitch. The terms *qīng* and *zhuó* for high and low pitches represent the perceptive description of sound in relation to the rate of vibration, while the terms *yīn jí* and *yīn shū* represent the physical description of sound in relation to the rate of vibration.

An explicit statement on the direct relation between the physical and perceptive descriptions of sound is found in the *Guǎn Zǐ* (The Book of Master Guǎn), in which it is stated that the sound of rapid vibration has a high pitch.

According to the *Kǎo Gōng Jì*, Chinese bell-makers examined the audibility of a bell's sound at a distance and discovered that the audible distance of a strike tone depends on the interplay of the diameter and the length of the bell. Such an experimental investigation on the dependence of the audible distance of a bell's sound on the dimensions of the bell was a significant step toward a scientific inquiry into the physical nature of sound propagation. The early Chinese probably looked to the propagation of a disturbance in water as a mental image for the propagation of sound. This is suggested by the hydraulic terms, *qīng* (clear) and *zhuó* (muddy). Thus, the analogy between the expanding pattern of ripples on water and the propagation of sound in the air probably also began early in Chinese civilization. However, no extant record with explicit mention of this mental connection between waves in water and in air is available earlier than the work of Wáng Chōng of the first century AD.

An important physical phenomenon of sound that was discovered early in Chinese civilization is resonance. In the *Zhuāng Zǐ* (The Book of Master Zhuāng), there is a passage attributed to Lǚ Jù of Western Zhōu, in which he says that the striking of the *gōng* note of one zither causes the *gōng* note of the other zither to vibrate, and that the same is true of the *juē* note, because the notes are of the same pitch.

The resonance phenomenon of Lǚ Jù achieved wide recognition in ancient times. The principle of resonance was later summarized in the statement "*shēng-bǐ zē-yìng*." This contains two key technical terms, *bǐ* and *yìng*. The term *bǐ*, which literally means "comparison," is coined to represent "matching in pitch," a condition for resonance first pointed out by Lǚ Jù, and the term *yìng*, which literally means "respond," is coined to emphasize the sympathetic aspects of the vibrations in resonance. These technical terms became common in subsequent accounts of resonance in sound.

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Acupuncture

Yun-tao Ma

Terminology

1. *Zhen Jiu* (针灸)/acupuncture/acumoxology. The term “acupuncture,” meaning “using needles to pierce” (*Webster’s College Dictionary*), is translated from the Chinese term *Zhen Jiu*, in which *Zhen* means “using needling to pierce” and *Jiu* refers to burning Moxa (Moxa refers to dried, pressed leaves of Mugwort (*Artemisia vulgaris*) burned on or above the skin to stimulate an acupuncture point or serve as a counterirritant) on the acupoints. ► [Moxibustion](#) refers to the application of heat stimulation with a moxa roll or cone on the point or affected site instead of using a needle. In Chinese, the term *Zhen Jiu* is often used as one concept, so, a new term *acumoxology* has been used to translate the original meaning of *Zhen Jiu*. The term “acumoxology” will be used if the text refers to both burning moxa and needling.
2. *Jing Luo* (经络)/meridian/channel/vessels. The English words meridian, channel, or vessel have been used to translate the Chinese term *Jing Luo*. Historically the concept of *Jing Luo* was related to arterial vessels; in this text the term vessel is used for the Chinese term *Jing Luo* instead of meridian or channel.
3. Chinese classic literature. There are often different English translations for the titles of the same Chinese classics. In this article, all Chinese classics are spelt first with Chinese Pinyin and then by an English translation, as, for example, ► [Huangdi Neijing](#) (Yellow Emperor’s Inner Canon). If the same title appears again in the text, only the Chinese Pinyin transliteration is used.

Sociohistorical Evolution of Acumoxology

Acupuncture is an ancient healing practice which appeared in different civilizations. Documents indicate that needling treatments were found in ancient Egypt, Greece, India, Japan, and China. Nevertheless, only the Chinese have nurtured this healing practice into a systemic medical modality which consists of clinical experiences accumulated for thousands of years and the theories gradually developed to explain these experiences. All branches of Traditional Chinese Medicine (TCM), herbology, tuina, (Tuina utilizes soft tissue manipulation, acupoints, external herbal medicines, therapeutic exercise, and structural realignment methods to treat a wide variety of musculoskeletal and internal organ disorders) and Qigong (Qigong is a Chinese healing art using a series of gentle focused exercises for mind and body) have absorbed some concepts from classic acumoxology.

Chinese archeological records suggest that stone needles (*bian shi*), the earliest tools for acupuncture, were invented to treat diseases during 8000–4000 BCE of the Neolithic Age. Later, bone, ► [bamboo](#), bronze, and other metals like iron, silver, and gold were used to make needles. Today most of the clinical needles are made of stainless steel. *Mai Shu* (The Book of Vessels), the earliest document of acumoxology, appeared between the fourth and third centuries BCE. The first TCM classic *Huangdi Neijing* (Yellow Emperor’s Inner Canon) discussed vessel theories, clinical principles of acumoxology, needling methods, and needling tools. However, *Huangdi Neijing* is neither systemic nor rigorously structured. It is a collection of medical treatises by authors of different times possibly from the period of Warring States (475–221 BCE) to the Han Dynasty (206 BCE–AD 220). The first book specifically devoted to acumoxology was *Huang Di Ming Tang Jing* (The Yellow Emperor’s Canon of Bright Hall) in the Han Dynasty. Another book, *Jiu Fang* (Prescriptions for Moxibustion), came out in the period of Three

Kingdoms (AD 220–280). Thus all the basic elements – the theories, acupoint system, methods of needling and moxibustion, and treatable diseases – were organized into a system of acumoxology.

The Ministry of Health of the Tang Dynasty (AD 618–907) designated acumoxology as one of the five medical specialties and appointed medical doctors to teach and practice acumoxology in a royal institute. The government of the Song Dynasty (AD 960–1264) published an official document of acumoxology, *Tong Ren Shu Xue Zhen Jiu Tu Jing* (Standard Atlas of Acupoints on Life-Sized Bronze Human Statue for Acumoxology), in AD 1026. This document clarified the location and indications of 354 acupoints and assigned them into 14 vessels. This is the first standardization of acumoxology in history. After the Song dynasty, a notable theoretical development in acumoxology includes prescriptions of acupoints according to the time of the day and seasons (*Zi Wu Liu Zhu*) or differential diagnoses (Differential diagnosis is the determination of which one of two or more diseases or conditions a patient is suffering from, by systematically comparing and contrasting their clinical findings) (*Bian Zhen Lun Zhi*) and a variety of needling manipulation techniques. Acumoxology as a medical practice declined after the Ming Dynasty (AD 1368–1643), especially when the Chinese agricultural culture confronted the Western industrial and scientific culture ever since the middle of the nineteenth century.

After the founding of the People's Republic of China (1949), application of modern science to traditional medicine was politically advocated and financially supported by the new government. Some of the best scientists and clinicians trained in Western science were encouraged to study and modernize traditional medicine. In 1972, successful cases in acupuncture anesthesia were reported in the US (American interest was triggered in 1972 by a rumor that New York Times reporter James Reston had received acupuncture anesthesia for an appendectomy while visiting China during President Nixon's historic

visit. Actually, he had had standard anesthesia and received acupuncture for postoperative cramps); this increased interest in acupuncture in both professional circles and for the public. Acupuncture became the most studied subject of all alternative medical modalities internationally. Enormous quantities of research data have been obtained from laboratories and clinics in many countries and have justified the scientific basis of acumoxology. Because of this intensive research, the trend to biomedicalize acumoxology and integrate it into mainstream medicine began in both China and the West.

Historical Development of Acumoxologic Theories

How Acupoints Were Discovered

Ancient Chinese doctors believed that a vital force, *qi*, flowed inside the vessels of the human body. They felt the quality of *qi* pulsation at multiple pulsing points on the body and used this to diagnose diseases. They also needled these pulsing points to treat diseases. These points became the earliest acupoints. As clinical experience accumulated, effective but nonpulsing acupoints were discovered and recorded.

The Origin of Vessel Theories

Early acumoxologic theories were formed from empirical facts. For example, ancient doctors found that needling certain pulsing loci on the dorsum of the foot and medial part of the lower leg was more effective than other points in treating pain or other symptoms of the genitals, lower abdomen, and lumbar areas. Thus they drew lines to connect the effective needling points with the parts of the body that were most affected by the needling, making a visible representation which connected all the points and related body parts together. In this example the pulsing points on the dorsum, the medial leg, the genital area, the lumbar area, and up to the tongue were connected. They believed that

these symptoms were related to the imbalance of the “liver,” and thus the “liver vessel” was gradually formulated. However, different doctors at different times formulated different “liver vessel” maps.

The Historical Integration of the Various Vessel Theories into a Single System

► **Huangdi Neijing** (Yellow Emperor’s Inner Canon) integrated the various channel theories into one system. However, inconsistencies in this book reveal that the authors had differing medical experience from different historical periods. In the years that followed the appearance of the *Huangdi Neijing*, acumoxology continued to evolve by incorporating more theories, and an ever-increasing number of acupoints and channels, into the existing system. When clinical realities did not fit into an existing theory, the facts were often modified to ensure the continuance of the theory. New theories coexisted with old ones. Thus classical acupuncture as we know it today is made up of theories and clinical experiences that are valuable, but they are mixed with fallacious concepts and imperfect explanations.

Daoist Philosophy Guided Both Theories and Clinical Practice

“The universe and humans are one” (*Tian Ren He Yi*) is the central thinking model of Daoism. Its ► **Yinyang** (Yinyang is a Daoist symbol of the interplay of forces in the universe. In Chinese philosophy, yin and yang represent the two primal cosmic forces in the universe. Yin (moon) is the receptive, passive, cold female force. Yang (sun) is masculine, representing movement and heat. The Yinyang symbol represents the idealized balance of the forces; they demonstrate equilibrium in the universe) and *Wuxing* (The theory of the five phases looks at five interrelated forces that have specific relationships to one another. Each of the elements has corresponding organs, emotions, colors, tastes, tissues, human sounds, and countless other correspondences. For example, an Earth person likes late summer, singing and sweet tastes) (five phases: metal,

wood, water, fire, and earth) models have been applied to the human body, its anatomy, pathophysiology, and acumoxology. All 14 vessels are classified into Yin and Yang vessels and within each vessel the important acupoints below elbow and knee are ascribed to five phases such as fire point, water point, etc. When treating diseases, the nature of Yin or Yang vessels and the phases of the points are synthesized to form the prescription according to the principle of Yinyang balance.

The “Pearls” of Classic Acumoxology Theory

Since the 1960s, international scholars and scientists have conducted research, but they still cannot verify the vessel entities. Both historical documents and clinical trials clearly show that the most valuable discovery in acumoxology theory is the interrelatedness between the parts of the body surface, and between the parts of the body surface and the internal organs. These are the immortal “pearls” of classic acupuncture. The classic 14 vessels are just tentative theories used by ancient medical sages to explain this interrelatedness of human body.

The Internationalization of Acumoxology

During the Tang Dynasty (AD 618–906), Korean and Japanese students were sent to China to study medicine and other subjects. Acumoxology, massage, and herbal medicine were first taught in a Korean medical school in AD 692. In Japan, specialized faculty taught acumoxology as part of a 7-year course in the Imperial medical school established by the emperor in AD 702.

Jesuit missionaries introduced acupuncture to Europe in 1683. Acupuncture was taught in French hospitals and was practiced by some doctors in Germany, The Netherlands and England. Acupuncture therapy has remained in European countries since the eighteenth century. An American doctor, William M. Lee, learned acupuncture from a British doctor and published his paper

on using acupuncture for rheumatism in 1836. Sir William Osler, in his *The Principles and Practice of Medicine* (8th ed., 1909), suggested acupuncture therapy for low back pain. Acupuncture was reintroduced into the US in 1972 from China after diplomatic normalization between the two countries.

Since the 1950s, doctors of the former Soviet Union and Eastern European countries have studied acupuncture from China and they still practice acupuncture in hospitals today.

In 1975, three international acupuncture training centers were set up to train worldwide healthcare professionals in China. The World Health Organization (WHO) has offered enormous support to spread acupuncture therapy in developing countries. In 1989, WHO approved the *Standard International Acupuncture Nomenclature* which has been used worldwide. In 1994 and 1999, WHO issued the *Standard for Clinical Acupuncture Research and Guidelines on Basic Training and Safety in Acupuncture*.

Medical Differences Between Acumoxology and Chinese Herbal Medicine

There is a difference between acumoxology and Chinese herbal medicine, although they have absorbed theories from each other. First, acumoxology developed its special *Jing Luo* (vessel) theories, while Chinese herbal medicine applies *Zang Xiang* (Visceral concepts) theories. Second, the same acupoints can be applied to different symptoms, while herbs, more or less, have specific therapeutic indications. Third, the method of differential diagnosis is essential in herbal medicine while it is not necessary in acumoxology.

Medical Differences Between Acupuncture and Moxibustion

Acupuncture needling inoculates minor lesions inside the soft tissues including nerve tissue.

This needling-induced lesion stimulates neuroimmune response involving the cardiovascular and endocrine systems. Fresh cells will replace this needle-induced lesion within 2–5 days. Most ▶ [moxibustion](#) has the same physiological effect as needling does, but no lesion is introduced into the tissue. Traditional pus-making moxibustion (*hua nong jiu*) burns the skin and makes huge superficial lesions which produce a longer effect.

Medical Differences Between Acupuncture and Western Conventional Medicine

In general, acumoxology therapy does not target any particular cause(s) of a symptom(s) or disease(s); it just activates the self-healing potential of the built-in biological survival mechanisms to normalize the physiologic processes and let the body heal. Acumoxology treats the whole body and produces no side effects, but the efficacy is achieved within a physiologically healable limit. Western conventional medicine tries to eliminate or correct the causations of the diseases by manipulating the chemistry and biological structure of the body first. The body then recovers from the impairment of both the disease and the medical intervention. This strategy may be accompanied by some side effects.

Biomedicalization of Classic Acumoxology

The medical value of acupuncture has been recognized internationally, especially in cases in which Western medicine has been unable to cause healing, but it has been challenged for its scientific justification in both Western and Eastern countries as modern sciences predominate in every field. Since the 1960s, acupuncture has been the most researched subject of traditional folk medicine in both China and the West, from the molecular to the organismic level, using new technologies in anatomy, neuroscience and

immunology laboratories and evidence-based, double blind, statistical methods in clinics. Sufficient data have verified that acumoxology shares the same biomedical basis with Western medicine, and also indicate that acupuncture can be understood, taught, and practiced in biomedical concepts. Historically acupuncture has been acculturated many times when it was adopted by different host cultures. Thus, during this new acculturation, the biomedicalization of classic acumoxology becomes both possible and necessary. In September 2004, two new biomedically oriented textbooks were published. *Acumoxology Course for International Students* was published in China and *Biomedical Acupuncture for Pain Management: An Integrative Approach* was published in the United States. The two textbooks emphasize the new developments and new trends in acumoxology while maintaining its traditional medical values and philosophy. The fact that they were published simultaneously represents the biomedicalization of acumoxology in both China and the West.

What Diseases Can Acupuncture Treat?/ How Effective Is Acupuncture Therapy?

Both clinical and laboratory data suggest that acupuncture and moxibustion are physiological therapies which result in self-healing, which is coordinated by the nervous system and mediated by the immune, endocrine, and cardiovascular systems. In 1979 WHO suggested a list of disorders and conditions for which acupuncture is effective, including neurological, musculoskeletal, respiratory, gastrointestinal, mouth, and eye problems. Nevertheless, WHO also made the statement that “this list was not based on controlled clinical research and cannot be considered authoritative nor does it reflect WHO’s view in any way.” This uncertainty can be clarified as we understand the physiological basis of acupuncture. Acupuncture does not target any specific symptoms or diseases but just normalizes physiologic processes to activate self-healing. The results of this self-healing depend on (1) the healability of the symptoms, and

(2) self-healing capacity maintained by the patients. Thus, the same symptoms can be cured in some patients, or can be partially relieved in other patients but do not respond to acupuncture at all in a few patients. The information of healability may be obtained from medical examination. To estimate the self-healing capacity, readers may refer to the textbook *Biomedical Acupuncture for Pain Management: An Integrative Approach*.

Limitations of Acumoxology Therapy

As acumoxology normalizes physiological processes to activate self-healing, it works better for conditions resulting from physiological abnormalities. For example, if low back pain is caused by inflammation of soft tissues, acumoxology will cure it in most patients. If the low back pain is caused by a tumor of the spinal cord, acumoxology may provide only temporary pain relief. The former condition is an *acupuncture* remedy, while the latter is an *acupuncture-aided treatment*. In cases of acupuncture remedy, faster and more stable results can be obtained if conditions are treated at their early stage.

Questions Remaining

Today we understand acumoxology in terms of its physiological basis even better than some medical procedures used in conventional medicine, but, as in any field of science, more new questions arise after old mysteries have been clarified. There are many unanswered puzzles in acumoxology. For examples, what is the biological basis of the inter-relatedness between different parts of human body as classic *Jing Luo* (Vessel) phenomena demonstrate? What symptoms or disorders are more amenable to acupuncture remedy or acupuncture-aided treatment? How are diseases related to particular acupoints? What acupoints should be selected for particular symptoms? How does needle manipulation influence the results? Clarification of these and other questions will improve clinical results of acumoxology.

See Also

- Five Phases (Wuxing)
- Medicine in China
- Yinyang

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Acyuta Piṣāraṭi

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Acyuta Piṣāraṭi (ca. 1550–1621) was an astronomer from the south Indian state of Kerala. He came from the village of Ṭṛkkaṇṭiyūr near Tirūr in southern Malabar. Born in an *ampalavāsi* (temple servant) caste, he belonged to a long and illustrious line of mathematicians and astronomers that commenced with Saṅgamagrāma Mādhavan (ca. 1340–1425) in the fourteenth century and continued up to Kṛṣṇadāsan (1786–1812) in the nineteenth. He was a student of the redoubtable Jyeṣṭhadevan (ca. 1500–1610) and was teacher to the great grammarian and devotional poet Melpattūr Nārāyaṇa Bhaṭṭatiri of the *Nārāyaṇīyaṃ* fame. His patrons included Ravi Varma, the chief of Veṭṭaṃ near Ponnāni, and the Taṃprākkaḷs of the Ālvāṇcēri family.

Acyuta Piṣāraṭi studied medicine, poetics, and grammar and wrote the *Praveśaka*, an introduction to Sanskrit grammar. But his fame rests on

the contributions he made to the development of astronomy. In the *Spuṭanirṇaya* written before 1593, he showed that the Moon moves on its own orbit that differs marginally from the ecliptic used to measure its longitude. He proposed a correction to the calculation – which is called the “reduction to the ecliptic” – and further elaborated it in his *Rāśigolasphuṭanīti*: Multiply the tabular cosine and sine of the difference between the Moon and the node and the product by the tabular versine of the Moon’s maximum latitude. Divide this by the tabular cosine of the latitude for the given moment and divide the quotient further by the tabular radius. In modern terms, when λ is the correction required, α the difference in longitude between the node and a planet, β the maximum latitude, θ the actual latitude, and r the tabular radius, we have

$$\sin \lambda = \frac{\sin \alpha \times \cos \alpha \times \text{Versine } \beta}{\cos \theta \times r}$$

$$r \sin \lambda = \frac{r \sin \alpha \times r \cos \alpha \times r \text{Versine } \beta}{r \cos \theta \times r}$$

$$\sin \lambda = \frac{r^3 \sin \alpha \times \cos \alpha (1 - \cos \beta)}{r^2 \cos \theta \times r}$$

$$= \frac{\sin \alpha \times \cos \alpha (1 - \cos \beta)}{\cos \theta}$$

As $\sin \lambda$ tends to be more or less equal to λ for small values of λ , we have

$$\lambda = \frac{\sin \alpha \times \cos \alpha (1 - \cos \beta)}{\cos \theta}$$

It is striking that Acyuta Piṣāraṭi was a contemporary of the Danish astronomer Tycho Brahe (1546–1601) who proposed the reduction to the ecliptic for the first time in Europe in his book *Astronomiae Instauratae Progymnasmata*, published posthumously in 1602.

The *Spuṭanirṇaya* became an influential work among astronomers in Kerala in the seventeenth and eighteenth centuries. No less than nine works were composed during this period to elaborate upon Acyuta Piṣāraṭi’s formulations.

Acyuta Piṣāraṭi was a champion of new methods in astronomy. In the *Uparāṅakriyākrama*, he presented innovative methods for computing eclipses. The *Karaṇottama*, which deals among other things with gnomonical shadow (*chhāyā*) and the complementary situation of the Sun and the Moon (*vyatīpāta*), also draws attention by its novel computational methods. This work deploys the *ḍṛggaṇita* system of mathematics developed by Saṅgamagrāma Mādhavan's student Vaṭaśseri Parameśvaran (ca. 1360–1460). Acyuta Piṣāraṭi claims in this work that he was only trying to make known in writing what was preserved secretly (*gopyatvena*) by masters in the line of Parameśvaran and others (*parameśvarādi parīkṣaka paramparayā*). Piṣāraṭi also excelled in astrology. He wrote the *Jātakābharaṇapaddhati*. His *Horāsāroccaya* was based on Śrīpati's *Jātakapaddhati*. His other works include terse tracts on astronomy, like the *Chāyāṣṭaka* on the Moon's gnomonic shadow, and a commentary on Saṅgamagrāma Mādhavan's *Veṅvāroha*. It is likely that he also wrote the anonymous *Uparāṅgaviṃśati*.

It will not be an overstatement to say that Acyuta Piṣāraṭi was the last great astronomer of premodern Kerala. Although his successors refined the existing theories at different times, never again was so original a contribution as the reduction to the ecliptic made in the region before the arrival of modern education.

See Also

- [Astronomy in Medieval India](#)
- [Mādhava of Saṅgamagrāma](#)

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Agriculture in Africa

Paul Richards

According to the philosopher Hegel, Africa was the inert mass around which the history of consciousness pivoted in its journey from East to West. Even today one still encounters the view that sub-Saharan Africa is exceptionally backward in science and technology, and has no indigenous intellectual history worth the name. Judged by the conventional standards of modernity, e.g., statistics on literacy and education, Africa does indeed seem a “backward” continent; but against this we must consider the crucial part played by the African savannas in the story of human evolution; human intellectual development was shaped by challenges set by the African environment. The legacy is still perhaps apparent in the continent's exceptional linguistic diversity and an enduring facility among its peoples for coping with severe environmental challenge. Until recently, however, African indigenous knowledge of environmental resources has failed to register in conventional histories of science and technology, due in large part to the distinctive resource endowments and consequent agrarian history of large parts of the continent.

Population density, historically, has been low over much of sub-Saharan Africa, and was depressed further by the slave trade and the wars and epidemics associated with colonial conquest. This has meant an emphasis (contrary to the trend of agrarian history in Asia) on land-management strategies that efficiently deploy scarce labor, but in settings ill-suited to plough agriculture or mechanization (contrary to experience in Europe and North America). In place of labor-intensive leveling, drainage, and installation of irrigation, for example, African cultivators typically have sought to make use of diverse soil and land conditions as they find them. This requires emphasis on what might be termed “mix-and-match” approaches, e.g., maintaining different animal species in the pastoral herd, selecting a range of

crop types adapted to different soil and land conditions, using different crop types in the same field (inter-cropping), or by ingenious dovetailing of a complex and varied portfolio of productive activities (hunting and gathering, shifting cultivation, tree-crop cultivation).

This emphasis on versatility above specialization has been of particular importance in those extensive tropical regions in sub-Saharan Africa blighted by insect-borne disease (notably malaria and sleeping sickness), climatic irregularities, poor soils, and lack of irrigation opportunities. Here, characteristically, human groups tend to invest heavily in the social “software” of agrarian relations rather than the “hardware” of technology and land improvement. Groups facing periodic drought may prefer to devote attention to the cooperative social relations that sustain an “optimal foraging strategy” rather than tie up large amounts of labor in costly land improvements such as irrigation systems. In an outright disaster social investments are portable, but land improvement is fixed and may have to be abandoned.

The knowledge and mental attitudes that support versatility among hazard-prone resource users do not lend themselves readily to the writing of conventional history of technology. Historians whose ideas have been formed against a background of more steadily evolving agrarian technological traditions in Europe and Asia have been at times tempted to conclude that African agriculture is deficient in technical expertise. Local knowledge tends to be regarded as makeshift and perhaps even irrational. Shifting cultivators and pastoralists, more anxious to meet the next challenge than celebrate past achievements, may have unwittingly reinforced these misperceptions. For Mende rice farmers in Sierra Leone several “traditional” techniques are colonial innovations - the local notion of tradition is simply “something that works.” Sometimes, sensing potential damage to a good practical skill from wordy rationalization, African resource users may even seek to deny that they know anything useful about the topic under discussion. Outsiders end up perceiving a technological void where none exists.

Many schemes were set up during the colonial period to assist African farmers to climb across

these imagined gaps in what was thought to be a fixed ladder of agro-technological progress. Colonial reformers concentrated at first on European innovations such as sickle and plough, only to be beaten back by African preferences for panicle selection in harvesting as a means to maintain the varietal distinctiveness of planting materials, or for the hand hoe as a superior means to maintain soil physical quality under difficult tropical climatic conditions. Later, it was supposed that Asia was the proper yardstick against which to measure the backwardness of African agrarian technology, and first steps were taken to transform African agriculture according to Asian experience. This culminated in efforts in the 1970s and 1980s to replicate the Asian Green Revolution in Africa, using fertilizer-responsive high-yield crop types under intensive management. Asia-to-Africa technology transfer repeatedly foundered on the issue of labor. Innovations for Asian farmers needed to be labor-absorbing, but for African farmers (not threatened, historically, to anything like the same extent by population pressure on land) labor-efficiency was often the criterion of greatest relevance.

During the colonial period in Africa a significant minority of long-serving agricultural officers came to appreciate that rural people did in fact have a considerable fund of valid practical knowledge of agriculture and the environment. This coincided with the rise of scientific ecology and related disciplines during the 1930s and 1940s; foresters, economic botanists, soil scientists, and veterinary officers were particularly active in recording African indigenous knowledge of agriculture and the environment, and in drawing parallels between these local concepts and emergent ideas in ecology and related disciplines. Perhaps the single most striking of these instances is the letter to the scientific journal *Nature* in 1936 by the Tanganyika-based soil scientist Milne, proposing the concept of the soil catena as a regularly recurring chain of soil types controlled by topography. African soils tended to be very old, and showed the influence of underlying rock types much less than in Europe. The concept of soil catena, by emphasizing topography and downplaying the role of

geology, provided a much better guide to the way the soils had formed, and to how African farmers typically used their soils. Throughout the tropical zone, but especially where seasonal variations in rainfall distribution are most marked, farmers secure food supplies during the preharvest hungry season and spread their labor burdens by systematically planting up and down slopes, carefully matching different crops or crop types to the different soils within the catenary sequence. The catena rapidly became established as a basic organizing concept in tropical soil science throughout the world; Milne's letter to *Nature* makes clear its African roots by using the Sukuma terms employed by local farmers to categorize the different soils within the chain.

This is in stark contrast to earlier official thinking about land systems on the other side of the continent, in Sierra Leone. After famine in 1919, caused not by local agricultural incompetence but the loss of harvest labor resulting from the influenza that tracked colonial troops to their homes from the battlefields of Europe, the colonial governor Wilkinson sought (as he thought) to transform Sierra Leonean rice farmers from being shifting cultivators farming rain-fed up lands into permanent cultivators of irrigated valley-bottom lands along Asian lines. Moving local farmers from the tops to the bottoms of their valley slopes was for Wilkinson a shift of epochal proportions, through which the "ignorant" African would be able to catch up a 1,000 years of agrarian technological history in a matter of a few years. The official of the Madras Department of [Agriculture in India](#) employed by the Government of Sierra Leone to set things in motion requested to be sent home after nearly 2 years working with local farmers, on the grounds there was little if anything he could teach them that they did not know already, and that in any case they obtained better yields from similar resource endowments than farmers in Madras. However, the belief that there was something decisive about a shift from upland to valley-bottom farming survived into the modern period, and received a new boost from the example of the Green Revolution in the 1960s. This insistent categorical contrast on "uplands" and "wetlands" remains in stark

contrast to local farmers' knowledge and practice in which seed types and labor resources are invested up and down catenary sequences, and across the upland-wetland divide, according to circumstances. Standing on the boundary between the rain-fed and water-logged soil types in their farms, Sierra Leonean peasants repudiate any gap between themselves and more technologically advanced farmers in Asia, and see instead only an opportunity for flexible adjustment to changing conditions. Recently, mathematicians have begun to provide formal tools with which to grasp the fuzzy logic that underpins this kind of cognitive flexibility, typical of African indigenous knowledge of environmental resources.

Rice farming on the western coast of West Africa is of considerable antiquity, and based on the domestication of the African species of rice (*Oryza glaberrima*). Due to contacts arising from the slave trade we have quite rich documentary sources concerning indigenous agricultural knowledge for this part of Africa at an early date, including a number of accounts from the seventeenth and eighteenth centuries specifying the way in which farmers matched planting materials to different soils, so spreading labor peaks and minimizing preharvest hunger. Today, rice farmers in the region continue to research this relationship whenever they encounter new material (e.g., accidental introductions, or new types that arise as spontaneous crosses). This knowledge of and interest in management of crop genetic resources is widespread in Africa, and is perhaps the single most important aspect of the legacy of indigenous agro-technological knowledge on the continent. Today it is threatened by social dislocation (including the effects of warfare) and agricultural modernization (including the spread of modern cultivars and labor-efficient harvesting technology).

African contributions to crop biodiversity management have been undervalued in the past, with some exceptions, because several of Africa's indigenous food crops are not widely known elsewhere (e.g., *Digitaria* millet in West Africa, *teff* in Ethiopia, and finger millet in eastern and central Africa). Vavilov recognized the Ethiopian Highlands as a major center of crop biodiversity, but a number of important crops

originating in Africa are scattered more widely (e.g., African rice, white yam, sorghum, and oil palm). Greater recognition is still needed for the historical role played by Africa's farming populations in identifying, shaping, and conserving these genetic resources. In this context it is interesting to note the systematic efforts made by Thomas Jefferson in the 1790s to establish African rice in the United States. Jefferson was convinced that the hardy dryland cultivars selected and maintained by West African farmers would help reduce some of the health problems associated with rice farming in the coastal zone of South Carolina, and had a cask of upland rice imported from the coast of what is today the Republic of Guinea for distribution among inland planters in South Carolina and Georgia. Earlier, South Carolina rice planters had shown a preference for slaves from the coastal rice-growing regions of West Africa, and it is possible that the tidal-pumped wetland rice cultivation systems of the tidewater zone drew upon African technological expertise in this field. Historical examples such as these help correct the erroneous notion that the transfer of agricultural knowledge and technology between Africa and the rest of the world has been a one-way process.

During a period of aggressive modernization of African agriculture following the end of colonial rule the work of documenting and understanding African systems of resource knowledge and management, begun by ecologically oriented technologists in the colonial period, was kept alive only by a handful of enthusiasts. Special mention should be made of African pioneers such as George Benneh in Ghana and Uzo Igbozurike in Nigeria. However, interest in local knowledge systems expanded enormously in the 1980s and 1990s, after the failure of many "high-tech" schemes to promote rapid change in African agriculture. A number of agricultural and other scientists now see indigenous knowledge as a resource for orthodox science (farmer experimentation attracts particular attention). Recent studies have highlighted the specialist knowledge of Africa's women farmers, pointed to the complex ways in which indigenous technical knowledge of the environment is bound up with social

relationships of production and consumption, and drawn attention to local knowledge in biodiversity conservation. The ratification of an international convention on biodiversity, adopted by the United Nations' Rio de Janeiro Conference on Environment and Development in 1992, gives indigenous agricultural knowledge a new visibility, and status in international law. Questions of ownership and preservation of Africa's abundant legacy of indigenous knowledge now attract attention, though some concern has been expressed that this might serve to ossify such knowledge, and reduce its practical utility.

See Also

- [Colonialism and Science](#)
- [East and West](#)
- [Environment and Nature in Africa](#)
- [Ethnobotany](#)
- [Food Technology in Africa](#)
- [Knowledge Systems: Local Knowledge](#)

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Agriculture in China

Francesca Bray

China is a vast country covering roughly the area of Europe. Because much of it is steep mountains or fragile grasslands, only about 10 % of China's total area is suitable for farming (see *Online resources* for some useful maps). However, intensive patterns of land use, increasingly refined over the centuries, sustained high levels of population

and production throughout much of the imperial period. The modernization of farming in the West has characteristically involved increasing the size of farms or managerial units while substituting machines or other industrial products for human labor. In China the process was reversed: farms and equipment became smaller and inputs of human skills intensified. There is a fierce debate among historians as to how this long-term trend should be interpreted. Some see it as a “technologically blocked” system, incompatible with the emergence of capitalism, in which farming families had to work ever harder for smaller returns. Others argue that the farming system of China and the rural manufactures and commercial networks that grew up around it constituted a flexible and dynamic economic system which not only generated internal prosperity, but played a key role in stimulating and shaping the emerging global economy of the modern world (see BOX). The unusual quantity of agricultural treatises and economic or policy documents that have come down to us from the imperial era help fuel and complicate this important debate as to whether “modernity” is a Western or a worldwide phenomenon. In either case, the current social and environmental critiques of contemporary “productivism” and of the problems generated by industrial agriculture suggest the value of looking more carefully at such alternative paths to development as the progressive intensification of land-use typical of Chinese agriculture.

China has several different farming regions, ranging from the chilly plains of the Northeast where the main food crops are soybeans, sorghum, spring wheat, and corn, to the lush tropical gardens of Hainan Island where the year-round growing season allows constant cropping, including two crops of rice (Bray, 1984, pp. 9–27; <http://www.luptravel.com/worldmaps/china39.html>). Broadly speaking, however, China has two distinct farming traditions that correspond to climatic zones. North China has sparse and irregular rain that falls mostly in the summer; the winters are long and cold. The uplands of the interior are formed of thick deposits of fertile loess; over the millennia the Yellow River has eaten away at the primary loess and deposited it as silt on the alluvial

plains downstream. The main constraints on agricultural productivity in the Northern region are the relatively short growing season (between 5 and 8 months) and the lack of water. It is seldom possible to grow more than one crop a year. The typical crops are those which do well with little water: millets, wheat, sorghum, cotton, and beans.

From the Yangzi plains south, the climate is semitropical. Rainfall is much heavier and spread throughout the year. As a result much of the natural soil fertility has been leached away, but irrigated rice fields counteract this effect. They build up their own fertile microecology that allows the same field to produce two or even three harvests a year, depending on the latitude. The growing season ranges from 9 months to year round. Rice is the staple, grown everywhere in the Southern zone; other important crops are winter wheat, maize, sweet potato, sugar, tea, and cotton along the Yangzi.

The distinction between a Northern and a Southern tradition has its roots in prehistoric times. The earliest Chinese farming villages date from the sixth millennium BCE, much later than those of the Fertile Crescent. Archaeologists used to consider that farming diffused throughout the Old World from that single center; the current evidence suggests however that within China itself there were at least two independent centers of plant domestication. At the 5000 BCE Neolithic site of Banpo, in the loesslands of Northwest China, the dryland crop of *Setaria* millet was grown (Bray, 1984, p. 434). The village of Hemudu, built in the marshes near the mouth of the Yangzi at the same period, grew large quantities of wet rice (Bray, 1984, p. 481). Though some archaeologists believe they have now discovered evidence of domesticated rice in sites in Central and Southern China dating back as far as 10000 BCE (An, 1999), most of the early evidence for farming in China is no earlier than Banpo or Hemudu.

Land was a scarce resource from very early times. Unlike the pattern of development in the West, where capital was invested in draft animals, equipment, and machines to substitute for labor, in China the historical trend was towards increasing the productivity of land through the application of skilled labor and cheap small-scale

inputs. With one or two rare exceptions, economies of scale did not apply. The roots of this relationship between land, population, and labor developed very early in China's history.

From the sixth to the fourth centuries BCE, several states battled for control of all China; the states with most men to fight and most grain to feed them emerged as victors. A fiscal policy based on peasant contributions of grain, textiles, and services became the norm. A strong state was one with a large population of skilled farmers. As a political philosopher of the third century BCE put it: "Therefore it is said: Where a hundred men farm and one is idle, the state will attain supremacy; where ten men farm and one is idle, the state will be strong; where half farms and half is idle, the state will be in peril." This is why those, who govern the country well, wish the people to take to agriculture' (*Shangjun shu*, trans. Duyvendak, 1928, p. 191). This remained the basic view of Chinese statesmen through the unification of the empire in 221 BCE right up to the end of the Maoist era. For over 2,000 years officials encouraged farming and took an active role in developing and diffusing knowledge and techniques. They fostered labor-intensive peasant farming and tried to control the accumulation of land in the hands of the rich. Successive medieval regimes confiscated land from the wealthy and redistributed it to peasants to ensure that it provided a livelihood for as many people as possible.

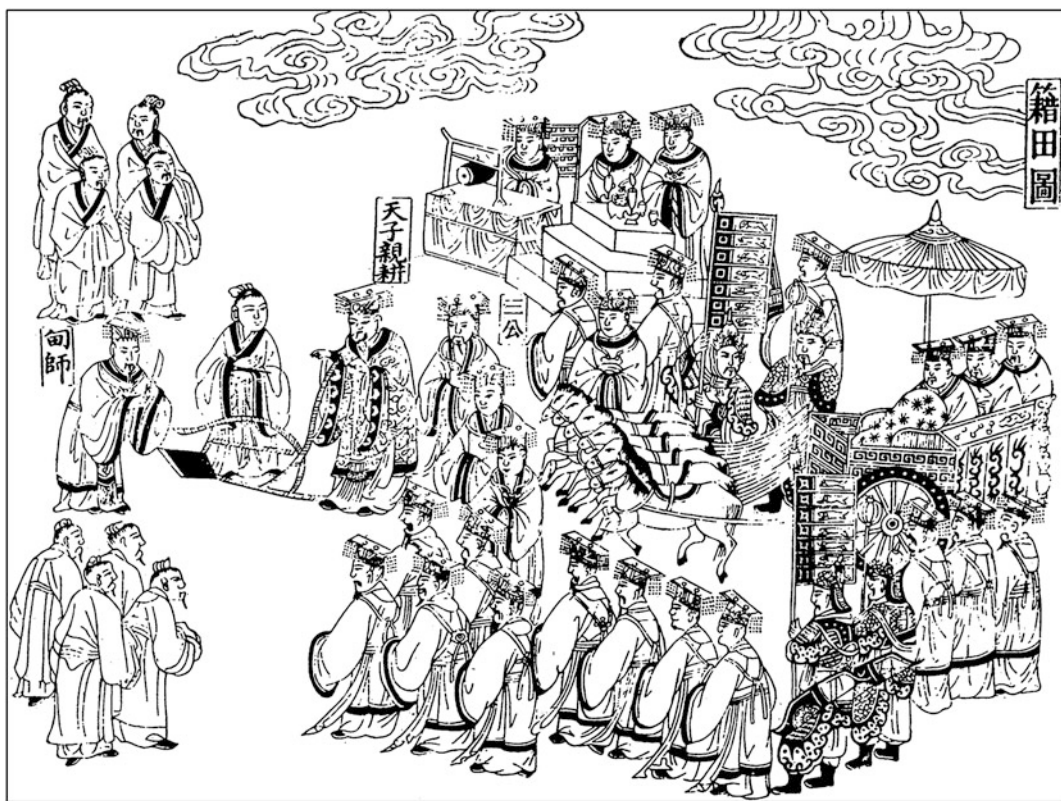
In part this intensity of land use was made possible by the particularities of Chinese farming systems. No arable land was wasted. There were few pastures in China proper. The main sources of animal protein were pigs, poultry and fish, and draft animals (oxen and mules in the North, water buffalo in the South) grazed on rough land (Fig. 1). The practice of fallowing seems to have died out as early as 2,000 years ago in parts of North China. Crop rotations alternated soil-enriching crops like beans with cereals; all human and animal waste was composted and returned to the fields. Medieval states in the North allocated approximately 6 acre of land to support a family. Land was even more intensively used in the South. By the seventeenth century, some fields in the South produced two crops of



Agriculture in China, Fig. 1 Water buffalo and herdsman. The sound of the herdsman's flute echoing up some distant valley was a common element in Chinese poetry, but here the agronomist Wang Zhen (see below) is illustrating the flute as one of the indispensable implements of a rice-farming household. Wang Zhen, *Nongshu*, Ming edition of 1530, 13/7a

rice and another of tobacco or vegetables each year. In the early twentieth century families in the most densely populated regions lived off under a tenth of an acre of rice land.

The tax system meant that improving agriculture was a key concern in Chinese state policy from the very beginning (Wong, 1997, p. 90), and many of the most important works on agriculture were written by members of the official elite in their capacity as civil servants (Fig. 2). Imperial compilations and works by civil servants aimed at a readership of local officials who would pass on the information to the farmers under their jurisdiction. They tended to stress practical details of husbandry, including innovations that could be introduced, and they emphasized subsistence production. Other works, written by landowners who



Agriculture in China, Fig. 2 Wang Zhen wrote his agricultural treatise of 1313 after service as magistrate in both Northern and Southern provinces; he hoped his work would help disseminate advanced technology and improved techniques. He begins with a section on the importance of official encouragement of farming. This included not only practical but also symbolic measures

such as the New Year imperial plowing ceremony, where the emperor plowed a ceremonial furrow before the Temple of the God of the Soil in order to ensure good harvests throughout the empire. In this highly stylized rendering, an emperor of ancient times is shown holding the strut of a plow to the left of the picture (Wang Zhen, *Nongshu*, 7/4a–b)

ran their own farms, were written for fellow landowners; these works usually included discussions of labor, prices and estate management (Bray, 1984, pp. 47–80) (Fig. 3).

The earliest extant agricultural treatise belongs to the second category. It is entitled *Qimin yaoshu* (Essential Techniques for the Peasantry); the author, Jia Sixie, completed its ten volumes in around AD 535 (Bray, 1984, pp. 55–58). It describes the agriculture of the dry regions of the Yellow River plains. Perhaps its most striking features are the detailed descriptions of how careful and repeated tillage techniques (different depths of plowing, sowing with a seed-drill, harrowing and hoeing, all techniques requiring the use of several oxen or mules)

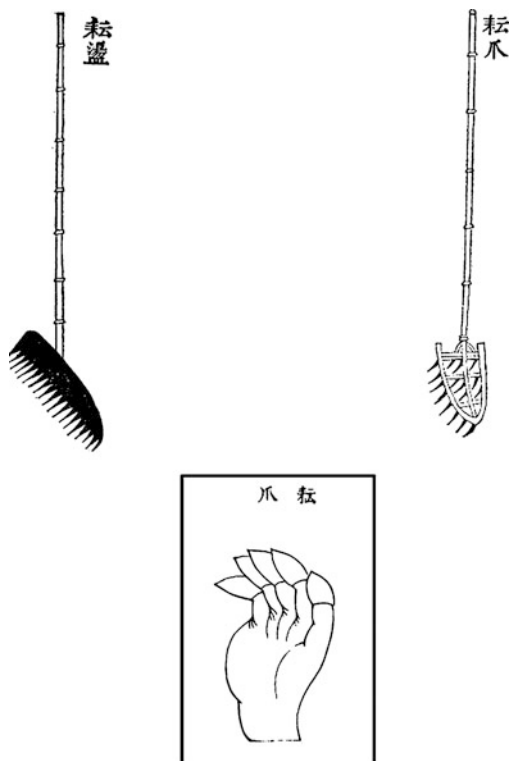
were used to conserve soil moisture in a dry climate, and crop rotations were used to increase fertility. We can reconstruct much of the equipment mentioned by Jia from somewhat earlier tomb paintings, as well as archaeological discoveries of huge state iron foundries from the first century AD, that mass-produced cast iron plowshares, moldboards, and the iron shoes of seed-drills. Together with Jia's numerous citations from earlier Northern works, this evidence confirms that the *Qimin yaoshu* represented the culmination of a long Northern tradition of productive estate farming that was dependent on large acreages and heavy capital investment in equipment and draft animals. It was a form of centralized estate farming that peasant farmers



Agriculture in China, Fig. 3 The harvest feast held by a landlord (shown seated right in front of his family altar) for his tenant farmers (*Bianmin tuzuan*, 1593 edition, 1/8a)

could not afford or compete with (Bray, 1984, pp. 587–97). The *Qimin yaoshu* was the last of the great works focused on the Northern system.

Repeated wars and invasions ravaged the Northern plains in medieval times. In the eleventh century the loss of the North to the Khitan finally established the Yangzi region as the political and economic center of Song dynasty China. The estates of the Northern aristocrats disintegrated, and as under-equipped peasant farmers did their best to scratch a living from a few acres of dry soil, the North became a backward region compared to the fruitful South. Migrants flooded into the Southern provinces from the North, and the state sought to encourage more productive agriculture by every possible means. Irrigation works were improved, seeds were handed out, information distributed, and cheap loans and tax breaks offered – the scope was similar to the Green Revolution of the 1970s, as was the impact on



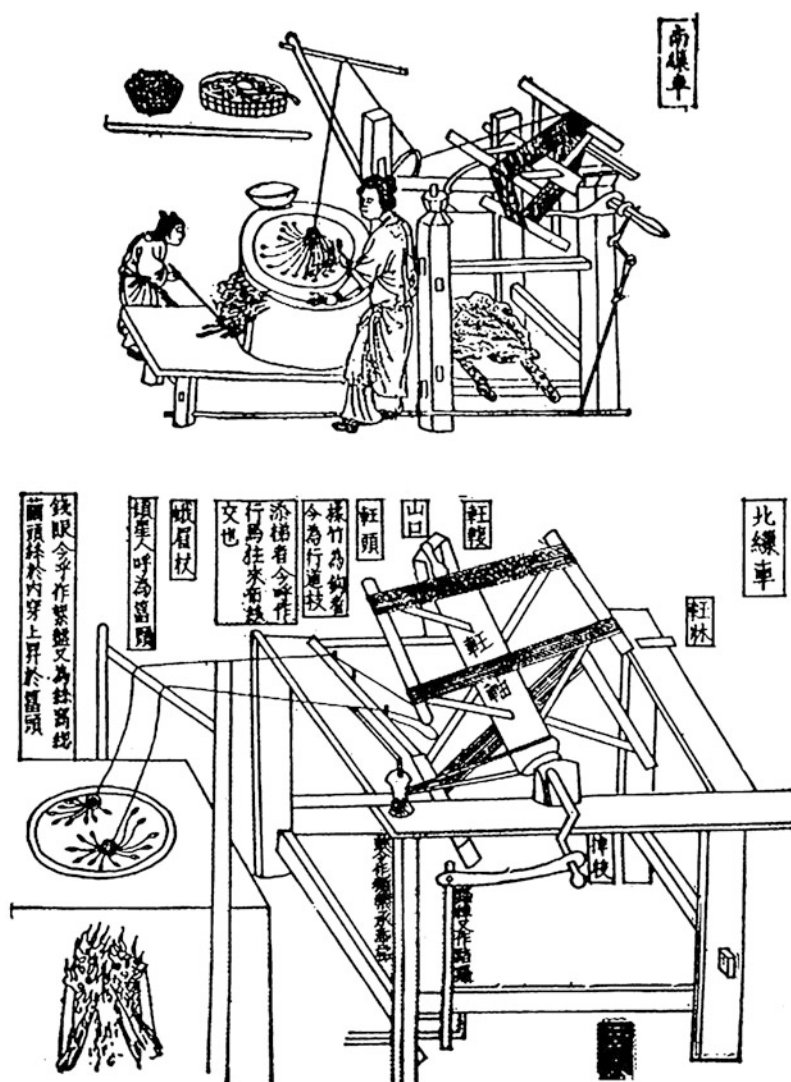
Agriculture in China, Fig. 4 Varieties of tools for weeding rice fields depicted by Wang Zhen. On the top left is a simple rake. The hinged rake at the right was a new invention from the lower Yangzi which Wang described with great enthusiasm, hoping that it would relieve farmers of much back-breaking work going through the young rice on their hands and knees. The “weeding claws” at the bottom were made of ► bamboo and helped farmers grub up weeds at the roots (*Nongshu* 13/27–29)

production (Bray, 1986; Elvin, 1973). One particularly fruitful venture was the introduction of quick-ripening rices from Vietnam that allowed rice farmers to double crop their fields, alternating winter wheat or barley with rice.

Several important agricultural works were published during the Song, but the landmark of the period dates from the Yuan (Mongol) dynasty. In 1313 Wang Zhen published a *Nongshu* (Treatise on Agriculture) several hundred pages long. His aim was to describe local innovations so that they could be adopted elsewhere (Bray, 1984, pp. 59–64). He included detailed woodblock illustrations of farming tools (Fig. 4), machinery (Figs. 5 and 6),

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Fig. 5 Silk-reeling machines typical of Northern China (*below*) and the Yangzi region (*above*). Rural women produced almost all the silk thread and much of the silk cloth in circulation at the time when Wang Zhen was writing, but later silk weaving moved into suburban workshops where most of the workers were men (*Nongshu* 22/26a–27b)



irrigation equipment (Figs. 7 and 8), and various types of terraced or dyked fields that permitted the extension of farming into mountainous or marshy lands (Figs. 9 and 10). The treatise depicts a system of family farming in which poor peasants with little capital invested intensively in labor, skills, and low-cost inputs. This was the farming system that formed the basis for the commoditization and expansion of the rural economy in succeeding centuries (Bray, 2000, pp. 25–41).

Wang Zhen's *Treatise* was the paradigm for later works, including imperial compilations and the magisterial *Nongzheng quanshu* (Complete

Treatise on Agricultural Administration) by the statesman Xu Guangqi, completed in 1639. Xu was a polymath and Christian convert who served for some years as Grand Secretary of China. The *Nongzheng quanshu* advocates a balance between the production of essentials (cereals for food and fiber crops for textiles) necessary for the health of the central state, and cash crops and handicrafts that would ensure a prosperous rural economy. Xu was also preoccupied with population pressure and the need to expand the arable area and improve yields; he devotes long sections of his treatise to land reclamation and improved irrigation techniques, to his own experiments

木綿紡車



Agriculture in China, Fig. 6 Spinning wheel for making cotton yarn. When Wang Zhen was writing in the early fourteenth century, cotton was just beginning to replace other vegetable fibers as the most common everyday cloth, and Wang provides copious documentation about the techniques and equipment involved. *Nongshu* 25/6b

with manures and commercial fertilizers such as lime and bean cake, and to crops like sweet potatoes that can be grown on poor land (Bray & Métaillé, 2001).

Landowners wrote a number of other works in the Southern tradition. In striking contrast to the *Qimin yaoshu*, however, the landowners themselves farmed only a few acres and rented the rest out to tenants. The main criteria for selecting a suitable tenant were his skills and experience, and his assiduity at work; capital assets were not a consideration as they would have been for a contemporaneous English capitalist landowner. The main difference between landowner and tenant lay in the ownership of land; it did not extend to differences in the scale of the farm, or in the range and size of equipment (Bray, 1986, pp. 113–119). In this highly intensive and skilled farming system there were no economies of scale, and anyone who owned more than an acre of rice land

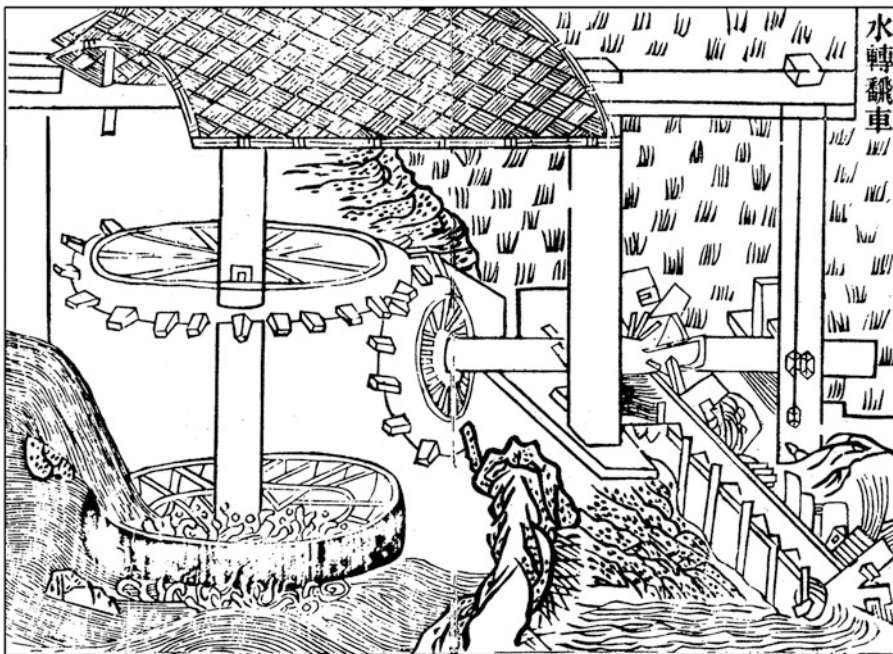
would seek a tenant to farm the surplus. If levels of agricultural expertise were reckoned simply by the complexity of farm machinery or by levels of capital investment, then the farming methods of the eighteenth and nineteenth centuries might be reckoned a decline from those of 800 years earlier, for as average farm size diminished many peasants abandoned animal-drawn implements in favor of hand tools. However, if we look at the productivity of land, we see a different picture. Improvements in water control, in fertilizing (Fig. 11), in the spacing of plants and the breeding of varieties enabled China's peasant farmers to increase the total output of crops at a rate that kept up with population growth until about 1800 (Li, 1998a, 1998b; Perkins, 1969). This intensive small-scale farming also supported a diversified rural economy of small industries and handicrafts that fed into national and international trade networks (Bray, 2000; Daniels, 1996; Gardella, 1994; Marks, 1998; Mazumdar, 1998; Pomeranz, 2000; Rawski, 1972) (Figs. 12 and 13).

The great inventions of Chinese agriculture are anonymous, the collective achievements of peasants recorded by servants of the state. Many important innovations occurred in the densely populated heartlands where pressure on land was most intense. There has been a tendency for Chinese historians past and present to assume that political and technical superiority went together, and that the Chinese taught civilization to the barbarians. However, several features crucial to Chinese high farming came not from the center but from the periphery. The technique of transplanting rice, fundamental for the development of intensive wet farming, was practiced by Thai-speaking populations in the Canton and Tonkin regions when they were conquered by China 2,000 years ago (Bray, 1984, p. 279). Terraced fields probably spread northwards into China from Vietnam and Yunnan, reaching the Yangzi region by the fourteenth century (Bray, 1984, pp. 123–26). Tea was introduced from Tibet and Western Sichuan some time before the eighth century (Smith, 1991). The techniques of cotton cultivation and processing were introduced to the Lower Yangzi from Hainan Island around the thirteenth century (Kuhn, 1988).



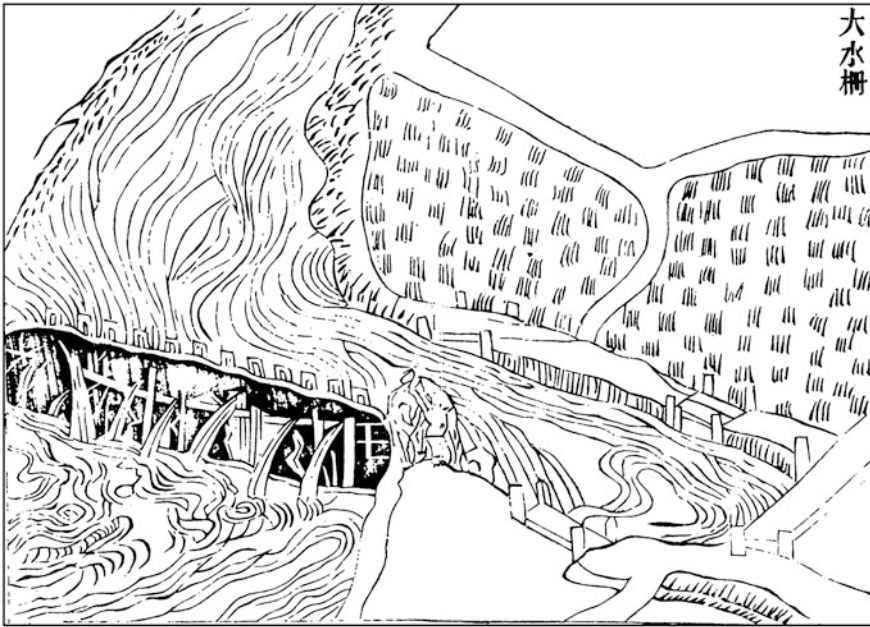
Agriculture in China, Fig. 7 Chain pump operated by two men. These light, portable pumps could be made quite easily by local carpenters and they would be moved from

field to field as each needed irrigating or draining (Wang Zhen, *Nongshu* 19/7a–b)



Agriculture in China, Fig. 8 Water-driven chain pump. Water mills were an essential element in medieval Chinese industry, as they were in Europe, and Wang Zhen also illustrates water mills of the kind used to

power millstones, the bellows for metal foundries, and multiple trip hammers for fulling cloth or mixing clay for potteries (*Nongshu* 19/11a–b)



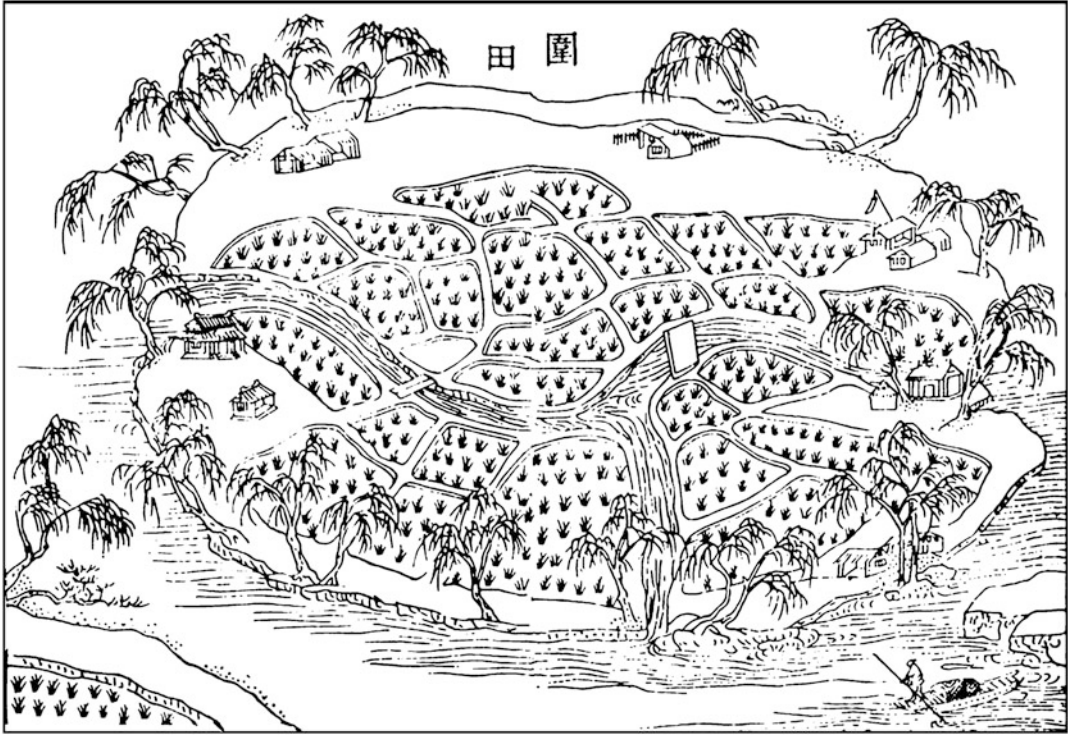
Agriculture in China, Fig. 9 A large sluice across a river, with irrigation channels leading off into padi fields (Nongshu 19/2a–b)

Although there was no indigenous development of experimental agricultural science or engineering, Western agronomists found much to admire in traditional Chinese farming in the early twentieth century, particularly its careful husbandry and sustainability. Also traditional agronomic strengths such as crop breeding, have allied fruitfully with modern science. For example, Chinese geneticists used their vast range of local rice varieties to develop the first semi-dwarf high-yielding *indica* strains in the 1960s, several years before “miracle rices” were released by the International Rice Research Institute in the Philippines (Harlan, 1980).

Extra: Chinese Agriculture and the “Great Debate”

Until recently comparative historians of economics or of science and technology tended to treat non-Western civilizations like China (or the Islamic world, or the Mayan empire) as *failed* or *blocked systems*. The most interesting question to ask about them was: Why did they fail to follow

the European pattern of historical progress to industrialization, capitalism and modernity? Even Joseph Needham, who dramatically documented so many fundamental contributions of Chinese civilization to early science and technology, believed that China’s creativity and ingenuity ground to a halt in about 1400. Needham was inclined to blame this on the mindset of the governing elite (“bureaucratic feudalism”). In 1973 Mark Elvin published a highly influential study in which he argued that the problem lay primarily with the technologies and organization of production, beginning with farming and the associated system of household manufactures. Unlike in early modern Europe, Chinese landlords and merchants saw no reason to invest in new technology in order to increase production or profits because smallholder farmers and household manufacturers, who were already highly productive, were always able to raise output a little more by increasing the family’s inputs of labor. Elvin argued that by about 1400 or 1500 this system of small-scale commodity production had reached a point of technical stagnation and diminishing returns to labor, an “involutionary”



Agriculture in China, Fig. 10 A polder (protective dyke) surrounding a block of rice fields reclaimed from swamp or the shallows of a river. Drainage channels run through the middle, and houses nestle among the willow

trees planted along the high surrounding dykes (This illustration from 1742 is based on an original in Wang Zhen's *Nongshu*. *Shoushi tongkao*, 1742 edition, 14/5b)

system or “high-level equilibrium trap” that precluded indigenous transformation and encouraged overpopulation, impoverishment and the devastation of the environment. Only the forced confrontation with the modern Western powers in the nineteenth century offered China the opportunity to break out of this trap (Elvin, 1973). In the mid-1980s Philip Huang began to elaborate on Elvin's analysis and on Chayanov's theories of peasant self-exploitation through the lens of farm management and market participation, to lay out a theory of late imperial China's “growth without development” (Huang, 1985, 1990; see also Goldstone, 1996).

Since the late 1990s a revisionist trend has come to prominence, stimulated by scholarship that has reconsidered the roots, nature and trajectories of the Industrial Revolution in the West. Jan de Vries' concept of “industrious revolution” suggests close parallels between early modern

Europe, China and Japan. de Vries (1994) argues that between roughly 1550 and 1850 households in northwestern Europe steadily increased their working hours and allocated more of their labor to specialized production for the market. This was not “involution,” however, for they freed time for this work by purchasing some goods that they had previously made for themselves. The profits they made by their sales allowed them to purchase more consumer goods. Though they sacrificed some leisure hours, this brought them higher living standards. Historians and social theorists including André Gunder Frank (1998), Bin Wong (1997, 2003), and Ken Pomeranz (2000, 2003) have argued that this was also true of much of China through the late imperial period.

A slightly different angle is taken by historians whose research suggests that sometimes increased farming output was achieved without additional labor. There were a range of

Agriculture in China,

Fig. 11 Fertilizing the rice seedlings in the nursery bed before transplanting (*Gengzhi tu*, Yongzheng imperial edition of 1742, 1/8b)



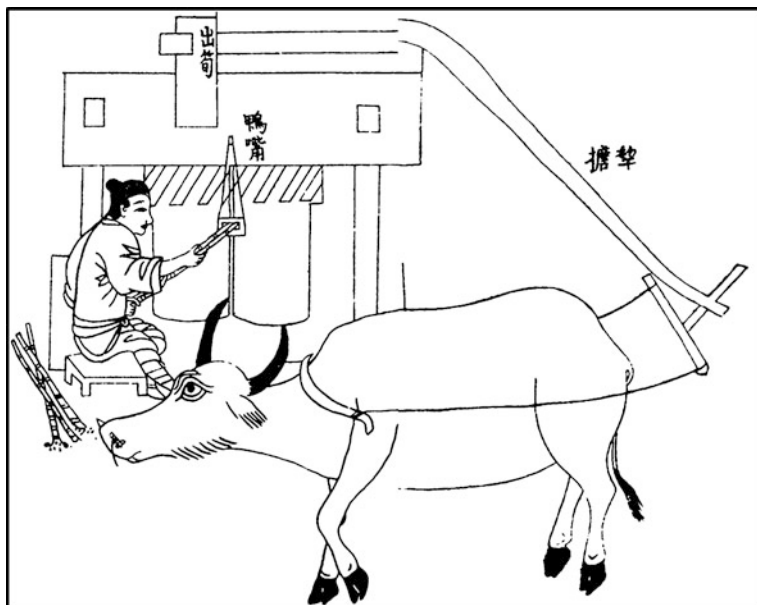
improvements in farming technology that did not involve labor-saving machinery per se yet made it possible to raise farming output without increasing labor inputs (Bray, 1986; Li, 1998a, 1998b; Shiba, 1998). The steady expansion of inter-regional or international trading networks allowed growing numbers of rural households to specialize in commercial production while buying food and other necessities on the market (Daniels, 1996; Gardella, 1994; Marks, 1998; Mazumdar, 1998), and government policies for

monitoring and regulating grain distribution and prices helped reduce the risks of such market dependence (Hamilton & Chang, 2003; Marks, 1998; Wong, 1997). Local specialization was another factor that could raise output without necessarily leading to involution.

The revisionist historians stress that until at least 1800 China was the world's chief producer and exporter of manufactured goods. It was trading from a position of strength: from the sixteenth well into the eighteenth century, three quarters of

Agriculture in China,

Fig. 12 Sugar mill with vertical rollers, depicted in Song Yingxing's technical treatise on crafts and industries *Tiangong kaiwu* of 1637. This type of mill had apparently come into use in the chief sugar-exporting regions of China, namely the Southeastern provinces of Fujian and Guangdong, shortly before Song wrote his book. Song describes a variety of sugars, some for internal trade and some for export to Europe (*Tiangong kaiwu*, 1637 edition, 6/2a–b)



Agriculture in China, Fig. 13 Picking cotton. A group of young women is hard at work, while a granny and a little boy, helpfully carrying a wicker basket round his neck, look on. This is from a short illustrated work written

by the Provincial Governor of Zhili (the Beijing region) in order to encourage rural women to take up cotton production. Wood block print of 1808 based on the original painting of ca. 1765 (*Shouyi guangxun*: 1/14b–15aBox)

all the silver produced in the world ended up in China (Atwell, 1998; Brook, 1998; Flynn, Frost, & Latham, 1999). Not only was China a key actor in generating the economic configurations of world trade that catalyzed the rise of the modern West (Arrighi, Hui, Hung, & Selden, 2003; Frank, 1998), but life expectancy and living standards of rural households in around 1800 compared favorably with those in the most advanced regions of Western Europe at the time (Pomeranz, 2003). Hamilton and Chang (2003) go so far as to claim that from as early as 1500 China should be thought of as a mass-consumption society. Moreover, many of the revisionist scholars argue, early modern China's political, social and economic institutions were not inherently incompatible with or antagonistic to industrial capitalism, nor even to today's global capitalism: the legacy of the late imperial era is clearly visible in China's national and international renaissance today (Arrighi et al., 2003; Hamilton & Chang, 2003).

The debate continues to rage, and given the patchy nature of the data both for Europe and for China it is likely to continue to seethe for some time. Often we find strong disagreements over the interpretation of the same data. In his magisterial new study of China's environmental history, for example, Elvin (2004) presents levels of deforestation in 1800 as proof that population growth and path-driven technologies had trapped China into a situation where it was probably more environmentally degraded than northwest Europe at the same time, while Pomeranz (2003) represents what he sees as roughly similar levels of deforestation in France and China around 1800 as a triumph of the Chinese political economy and its sustainable resource use.

The critical rethinking of the long-term logics of economic and technological development which we see in the revisionist scholars' work clearly owes much to the questioning of "master narratives" in postcolonial theory and critical studies of science and technology. Social and environmental critiques of productivism, together with new models of productive efficiency that emphasize decentralization, smaller scale and flexibility, provide a broader

intellectual context for these new perspectives on the achievements or shortcomings of the imperial Chinese agrarian economy, as does China's meteoric rise as an economic and industrial powerhouse since the economic reforms of 1979.

See Also

► [Food Technology in China](#)

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- On contemporary economic issues concerning Chinese agriculture, see the UC Davis site <http://aic.ucdavis.edu/research1/chinaeconomics.html>
- The Food and Agriculture Organization (FAO) webpage on China <http://www.fao.org/countryprofiles/index.asp?lang=en&ISO3=CHN> is an excellent source for a wide range of studies and statistics on contemporary agricultural issues in the People's Republic of China, including themes like sustainable development. It also offers a useful set of interactive maps which include maps showing elevation, slope, precipitation, length of growing period and major environmental constraints as well as more conventional maps of political boundaries, population, communications, etc.

Agriculture in India

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Some Online Resources

Another useful online source for maps of China and its contemporary provinces, with good information about regional history, contemporary economics, climate, agriculture, cuisine, etc., is the Web site of the *South China Morning Post*, the Hong Kong English-language newspaper: <http://china.scmp.com/map/>
China Facts and Figures provides useful statistics on contemporary agriculture in its section on "Economy"; the English-language Web site for 2003 is <http://www.china.org.cn/english/eng-shuzi2003/>

The Harappan culture related to the earliest agricultural settlements in the Indian subcontinent is dated between 2300 and 1700 BCE. The crops of the Harappan period were chiefly of West Asian origin. They included wheat, barley, and peas.

Of indigenous Indian origin were rice, tree cotton, and probably sesame. Rice first appeared in Gujarat and Bihar, not in the center of the Harappan culture in the Indus Valley. There is some rather doubtful evidence that African crops were also grown by the Harappans. There is a record of sorghum (*jowar*) from Sind and *Pennisetum* (*bajra*) from Gujarat. The earliest record of the African cereal, *Eleusine coracana* (*ragi*) is from Mysore, about 1899 BCE. The Southeast Asian crops of importance to India are sugar-cane and banana, and they both appear in the early literary record. Crops of American origin include maize, grain amaranths, and potato. The dating of the introduction of maize is uncertain, the characteristics and distribution of some forms being such as to lend support to the view that they reached India in pre-Columbian times. Crops of the Indian subcontinent have influenced the agricultural development of ancient Egyptian, Assyrian, Sumerian, and Hittite civilizations through their early spread to these regions of the Old World. The Buddhists took several Indian crops and plants to Southeast Asian countries, and there was much early exchange of plant material with Africa. The Arabs distributed crops such as cotton, jute, and rice to the Mediterranean region in the eighth to tenth centuries AD. There was also a reciprocal exchange of several New World domesticates.

Agriculture Today

India is characterized by a wide variety of climates, soils, and topographies. It is rich in biodiversity and a seat of origin and diversification for several crop plants such as rice, millets, pigeon pea, okra, eggplant, loofah, gourds, pumpkin, ginger, turmeric, citrus, banana, tamarind, coconut, and black pepper. Because India is ethnically diverse, traditional agriculture is still practiced in many places. There are about 100 million operational holdings, and the country has over 20 % of the world's farming population.

India has different ecosystems such as irrigated, rain fed, lowland, upland, semideep/deep

water, and wasteland. Agriculture is primarily rain fed (rain dependent); it supports 40 % of the human population, 60 % of cattle, and contributes 44 % to the total food production. Owing to differences in latitude, altitude, variation in rainfall, temperature and edaphic diversity, great variety exists in crops and cropping patterns.

There are two important growing seasons in India: the *Kharif* or the summer season, especially important for rice; and the *Rabi* or the winter season in which major crop grown is wheat. The *Kharif* crop is primarily rain dependent, and the *Rabi* is relatively more reliant on irrigation. The *Kharif*/rainy season cropping patterns include major crops such as rice, sorghum, pearl millet, maize, groundnut, and cotton. The *Rabi*/winter season cropping patterns include important crops like wheat, barley and to some extent oats, sorghum, and gram/chickpea. Mixed cropping is also practiced, especially during the *kharif* season. Pulses, grain legumes, and oilseeds are grown with maize, sorghum, and pearl millet. Brassica and safflower are grown mixed with gram or even with wheat. Under subsistence farming, on small holdings, mixed cropping provides food security and is consumption oriented.

India is the major producer of a number of agricultural commodities including rice, groundnut, sugar-cane, and tea. Food grains constitute roughly two-thirds of the total agricultural output. These consist of cereals, principally rice, wheat, maize, sorghum, and minor millets. India is the second largest producer of vegetables next to China. Mango accounts for almost half of the area and over a third of production; banana is the second largest and is followed by citrus, apple, guava, pineapple, grape, and papaya. Of nonfood cash crops, the most important are oilseeds especially groundnut, short staple cotton, jute, sugar-cane, and tea.

Owing to improvements in recent years there has been widening of inter-regional disparities in agricultural production and productivity. Regions such as the north and north-west and the delta regions of peninsular India have prospered under assured irrigation, but dryland and semiarid regions have not done so well.

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Agriculture in Indonesia

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The map of Indonesia suggests a high diversity in types of agriculture. The archipelago has countless different islands that stretch out over thousands of kilometers from east to west, above and below the equator. It has a rich biodiversity and the techniques the people developed to benefit from the natural environment have distinct features on each of the islands. Despite all this diversity, some clear patterns can be detected, based on three major factors. The first is the monsoon climate that divides the year into a dry and wet season with an overall high precipitation of roughly 1,700–3,000 mm in the lowlands and to over 6,000 mm in the mountainous regions. The combination of high rainfall and, for tropical conditions, not excessively high temperatures throughout the year creates a favorable climate for many different crops. The geology and elevation of the landscape is a second factor. The islands are positioned on the edges of different tectonic plates, resulting in vast mountain areas with a high number of (active) volcanoes. The eruption of volcanic ashes and the erosion of

volcanic rock can create fertile ground for agriculture. In cases where volcanic sediment makes favorable soil conditions, people have used the topography to exploit this natural fertility. Such conditions are typically found on Java and Bali and some other smaller islands or parts of bigger islands. The bunded rice field (*sawah*) is a catchment for eroded sediments brought along by water from rivers and streams coming from the mountains. The Indonesian people constructed *sawahs* wherever possible but mostly in the lowlands on Java and on the hillsides, forming the now famous terraced landscapes of Bali. In most of the other main islands, these favorable conditions are found much less often. The availability of rice as a staple crop is a third determining factor. Rice was and is the main food crop in the entire archipelago. The only exceptions are the eastern areas, mainly the Moluccas and Western New Guinea, where sago, a starchy substance, was processed from the soft interior of palms, primarily the species *Metroxylon sagu*. It is likely that these communities survived for long periods of time solely on a combination of arboricultural techniques supplemented with hunting. This implies a reliance on the rainforest without additional agricultural techniques for (semi-) permanent crop production (Ellen, 2004). In all other places, the domestication and cultivation of rice formed the core around which many agricultural techniques developed.

The climatic and geological conditions predominantly found on Java and Bali have resulted in a domestication process of rice that is specific for this region. Asian rice (*Oryza sativa*) has two main subspecies (or varietal groups): *indica* and *japonica*. The latter varieties typically grow in more temperate climates but are also found in tropical areas. In Indonesia a morphologically distinct group of these tropical japonicas has developed, commonly known as javanica or bulu in the local language (Vaughan, Lu, & Tomooka, 2008). The most visible characteristic of the bulus are seeds with long awns (bristle on top of seed). Characteristics that mattered most for farmers are lower sensitivity of these varieties for drought, variation in day length, intensity of sunlight, and transplanting time. These latter

characteristics also make these varieties have a longer growth duration, the time between sowing and ripening. The yield potential of indica varieties is better on poorer soils, but this was not an issue for the better soils of Java, Bali, and similar places. The characteristics of the bulus allowed farmers to be more flexible in sowing, transplanting, and harvesting of rice, resulting in an overall high labor productivity. Moreover, there was a wide range of bulu varieties available to farmers. Rice, an inbreeding crop, usually produces very few natural crosses but outcrossing is relatively high in the bulu group. Farmers selected the spontaneous crosses and observed their performance in a mix and match strategy to optimize yields under different field conditions. In fields with less advantageous soil and water conditions, as mostly found on mountain slopes, indica varieties were preferred. Early colonial writers acknowledged the varietal diversity of rice on Java and other islands, but only in the early twentieth century did agronomists recognize bulus as a different subspecies and came to understand its role in farm cultivation strategies and techniques (Maat, 2001). The dominance of bulu varieties on Java and similar places gradually disappeared in the twentieth century. Improved irrigation infrastructure introduced by Dutch engineers facilitated two rice crops per year. As a result, indica varieties, having a shorter growth duration, came to dominate (Van der Eng, 1994). Colonial rice breeders tried to maintain some of the favorable characteristics of bulus through crossbreeding with indica varieties. One of the successful lines of these crosses was taken up in the 1960s by the International Rice Research Institute to develop the fertilizer-responsive variety IR8 that was massively introduced in Indonesia in the early years of the green revolution. The productivity levels realized for rice in the twentieth century using science-based technologies thus built on a much longer process of intensification set in motion by the Indonesian farmers.

The combination of specific rice varieties and climatic and geological conditions that dominated Java and Bali over, most likely, several millennia played a major role in the economic

prosperity and contributed to a high population density in these islands. Although archaeological evidence of early times is sparse, inscriptions from about the ninth century testify the presence of large and prosperous communities across the islands (Wisseman Christie, 2004). The preference for bulu varieties makes clear that the high labor productivity in agriculture in these areas is not merely an effect of a fortuitous natural environment but involves tested strategies and techniques to optimize intensive wetland rice cultivation with various other forms of crop production in the wet monsoon season and the dry season. The control of land by local communities was left untouched by state formation that came together with the introduction of Hindu and Buddhism, followed later by Islam, creating social structures that favored the intensification of agriculture. The presence of different religions testifies frequent interactions with mainland Southeast Asia, India, and other regions. Intensive regional trade relations and global connections since early colonial settlements implied the introduction of new agricultural crops and the distribution of crops and crop varieties across the Indonesian islands. From about 1,500, rice was no longer the single source of carbohydrates (Boomgaard, 2003). Communities could thus further grow as the new crops allowed them to expand their agricultural activities on soils less suited for rice. Colonial trade relations also were an incentive to produce crops that were initially produced solely for distant markets but became fully integrated in the local economy and diet. Coffee, introduced on Java by the Dutch in the early eighteenth century, is just one example.

The wealth of the Javanese and Balinese states and subsequent emphasis of colonial administrations resulted in a much wider availability of sources about agriculture on these islands compared to other places. This correlates with an overall bias in early colonial history that depicts the farming systems on Java and Bali as most advanced and exemplary for a development trajectory other islands inevitably had to follow. In these evolutionary projections, the sago cultures in the east are typically portrayed as most primitive. In between are agricultural practices known

as shifting cultivation and semipermanent forms of agroforestry. These types of farming dominate in the mountainous and forested areas of Sumatra, Kalimantan (Indonesian Borneo), and Sulawesi. They require a variety of different techniques, mainly felling, clearing, and burning of a piece of forest for the cultivation of annual crops. Farming these fields for one up to three harvests is typically combined with planting perennial shrubs and trees, collecting forest products, and hunting. This is either practiced in a cyclical pattern by mobile communities or in more sedentary forms that combine the cultivation of permanent fields with clearing additional pieces of forest for temporary or permanent use. Except for the eastern sago cultures, rice is the main staple and the first crop to be sown after clearing. Similar to more permanent rain-fed upland fields (*tegal*), other crops are grown in between or immediately after the rice crop and later crop introductions further diversified these systems. The representation of the various forms of agroforestry as more primitive and necessarily to be replaced by permanent agriculture on the basis of *sawah* rice fields is partly a colonial projection of developments on Java where shifting cultivation was commonly found but rapidly declined over recent centuries. Moreover, a late and overall low presence of administrators and researchers on Sumatra, Kalimantan, and Sulawesi resulted in low and superficial information about these farming systems. More profound and nuanced understandings emerged from recent anthropological and historical research (Dove, 1985a; Henley, 2011). However, the negative bias against shifting cultivation must be understood primarily from colonial economic and political interests on these islands that continued in similar forms in the policies of Indonesia after independence (Dove, 1985b).

The introduction of cash crops for global markets, set in motion by early colonial explorations, rapidly expanded after the 1860s and profoundly changed the agricultural landscape on various Indonesian islands. The colonials introduced large estates, managed by European private companies and made productive with large numbers of contract laborers. Indonesia became a major

supplier of agricultural produce for international markets. In the first half of the twentieth century, Java dominated the international market for the antimalarial quinine and had a highly productive cane sugar sector. Sumatra tobacco became a brand name in Europe and oil palm and rubber estates supplied the Western industries. The late colonial plantations were in many respects foreign introductions. Earlier, larger plantation-like farms were present on Java and some other islands, mainly for coffee, tea, spices, and sugarcane, but those were mostly managed through contracts with local rulers who arranged community farm labor for the delivery of the products. The modern estates were run by European capital investments, and imported tools and machinery. Laborers were recruited from other islands and outside Indonesia. In Sumatra, Kalimantan, and Sulawesi, these enterprises stood in sharp contrast with the shifting cultivation practices of the local farmers, leading to continuous tension and frequent conflicts. A zone of intensive plantation production is the northern region of Sumatra. There, the land hunger of the European enterprises and differences between colonial and local land rights were the source of an ongoing struggle over land ownership and borders (Pelzer, 1978). Likewise, the recruitment of tens of thousands of laborers from outside Sumatra, working on the estate lands and processing the products for low wages under harsh conditions, not only implied a long-fought battle over labor conditions but also confronted the colonial administration with issues over settlements for the workers, land rights, health, and social order (Stoler, 1985).

It is no surprise that the soils in the forested regions of Sumatra, Kalimantan, and Sulawesi are suited for tree crops like rubber and oil palm or shrubs producing pepper or fibers. With markets in reach, local farmers eagerly adopted these crops as an additional and often main source of income. This leads to an extensive smallholder production of these industrial crops in subsequent decades. Unlike the estate monocropping, farmers integrated the cash crops in their shifting cultivation practices. The technique had several advantages, for example, a reduced disease

pressure, leading to low production costs and good-quality produce. Moreover, the variety of crops grown in the local systems made the farmers much less vulnerable to price fluctuations of cash crops. This, for example, resulted in a prosperous smallholder rubber production on Borneo (Dove, 1993). The competition with plantation production and the rivalry over land and forest products, the latter resulting out of colonial forest management and timber production, motivated a negative assessment of the shifting cultivation practices. In addition, the large inflow of contract laborers and the growth of urban trade centers like Medan (Sumatra) resulted in a growing dependency on rice imports. This was a general concern for the colonial administration, coming to a climax in the late 1910s when access to overseas markets became vulnerable due to World War 1 and harvest failure in the immediate postwar seasons. The plantation companies and the colonial government, assuming that farmers on Sumatra were ignorant about growing rice properly, experimented with mechanized rice schemes and set up a migration program to transfer Javanese farmers to Sumatra, expecting they would bring their intensive rice-growing systems with them (Maat, 2014). The ill-informed colonial policies thus worked against rather than stimulated the skillful practices of the farmers and their capacity to include new crops, techniques, and methods into their farming systems.

There are no records of early local scientific accounts of agriculture, although connections with India and mainland Asia, witnessed by the Hindu and Buddhist influences, in combination with early state formation, may have produced systemized knowledge of agriculture by administrators. The earliest written records of agriculture were part of botanical investigations from naturalists who were recruited by the Dutch East India Company (VOC). The emerging colonial state and scientific explorations from the early nineteenth century resulted in a growing number of descriptions of many different parts of the archipelago. The reports include detailed accounts of crops, crop varieties, cultivation practices, and related cultural events and festivities. By the late nineteenth century, specialized

agricultural research became institutionalized in private experiment stations, the botanic garden in Bogor, and further developed from the first decade of the twentieth century under the colonial Department of Agriculture (Boomgaard, 2006; Maat, 2001). With few exceptions, all these studies were written in Dutch. Although much of the investigations were targeted at cash crops, there was also a substantial set of studies into Indonesian agricultural technologies and practices. In particular the colonial agricultural extension service that employed Dutch and Indonesian agricultural experts produced a substantial number of studies of the farming techniques, tools, and production methods in different regions. A substantial number of these agronomists challenged the common view of a backward and irrational farming community, showing that local strategies and techniques made sense given the environments in which the farmers worked. Their argument to experiment with innovations that build on the local techniques rather than introducing Western examples resonated well with similar criticism on the introduction of Western technological models in the late twentieth century (Maat, 2011). The recent concerns about the environmental impact of agriculture, climate change, and dependency on fossil fuels may foster a renewed attention for the techniques and methods farmers have employed and improved over the ages in the variety of ecological settings the Indonesian archipelago has to offer.

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Agriculture in Japan

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The land in Japan has distinctive characteristics which make it suitable for plant production, being

influenced by favorable ecological conditions. Because of this, intensive agriculture with paddy rice has been the basis of most economic activity over the last 2,000 years, and the people stayed predominantly agricultural until recently. However, Japan has since been transformed into a heavily industrialized society with a remarkably rapid growth of its economy after the Second World War. Now the Japanese have almost abandoned their traditional food culture, which depends on rice plus other supplemental grain foods, diverse vegetables, mountain plants, and sea products. They have instead been paying large amounts of money in order to incorporate Westernized fatty and protein-rich foods from all over the world into their cuisine. Rice consumption has decreased dramatically in the last half century, and the daily intake of nutritious foods such as meat, milk, and other dairy products has increased remarkably, leading to a high demand for luxury foods. Within the Japanese agricultural sector, only rice is produced to the level of national self-sufficiency, while only 50 % of the products derived from animals – themselves raised by concentrates (feed grains) which are nearly 100 % imported – is supplied domestically (Table 1).

The early postwar effort to increase the production of food to meet national requirements actually led to a serious problem from around 1960, when the Japanese economy as a whole began to boom and agriculture began to decline. Rice cultivation narrowly survives with increased abandonment of agricultural fields and deterioration of sub-natural environments which the Japanese people had created over the past 2,000 years. The present situation with Japanese agriculture is the degradation of the rich, green nature of the country that people had long admired as *Mizuho-no-kuni* (the land of vigorously growing rice plants).

Influential Trends of Geography and Climate in Japanese Islands for Farming

Japan is a typical island country expanding along the far eastern edge of the temperate Asian

Agriculture in Japan, Table 1 Domestic supply, importation, and domestic demand of various foodstuffs in Japan^a

Products	(A) 2012 ^a			(B) 1962 ^a			Increasing ratio of demand in 1962–2012 (A/B)
	Domestic supply (in 1,000 t)	Imported (in 1,000 t)	Self-sufficiency (%)	Domestic supply (in 1,000 t)	Imported (in 1,000 t)	Self-sufficiency (%)	
Rice	8,692	848	91.1	13,009	182	98.6	0.72
Wheat	858	6,578	11.5	1,631	2,490	39.6	1.80
Barley	172	1,896	8.3	1,726	0	100.0	1.20
Soybean	236	2,727	8.0	336	1,284	20.7	1.83
Vegetables	11,974	3,302	78.4	12,245	16	99.9	1.25
Fruits	3,027	5,007	37.7	3,387	245	93.3	2.21
Milk	7,608	4,191	64.5	2,526	357	87.6	4.09
Beef ^b	514	722	41.6	153	4	97.5	7.87
Pork ^b	1,295	1,141	53.2	322	0	100.0	7.57
Broiler ^c	1,457	736	66.4	155	0	100.0	14.15
Hen's egg ^d	2,507	123	95.3	981	0	100.0	2.68

^aDemand and supply table of agricultural products; Ministry of Agriculture, Forestry and Fishery, Japan

^bIn carcass weight

^cIn fresh body weight

^dIn sold amount

continent. The Japanese archipelago covers a vast sea area including 6,852 islands that extend from subtropical Ishigaki (24°N, 124°E) to the northernmost point of Hokkaidō at Wakkanai (46°N, 142°E). It shows diverse landscapes and meteorological conditions, but most of the area has a temperate, oceanic climate. The total land area is less than 380,000 km² (only one-thirtieth of the territory of China), and the four main islands of Hokkaidō, Honshū, Shikoku, and Kyūshū are dominated by steep mountains that often reach to 1,000 m or even more above sea level. Because of mountainous nature of the islands, the amount of flat land suitable for cultivating crops is less than 15 % of the total area of land (Table 2).

In spite of its more or less cold winter, Japan benefits from a longer warm season and yearlong rainfall mostly above 1,000 mm per year (Fig. 1), both of which are indeed useful for high-yielding crop cultivation, particularly for paddy rice. However, the climatic condition also accelerates harmful weed generation that disturbs pure stand formation of cultivated crops. The generally warm, moist climate (almost similar to tropical forests during summer seasons), which provides high organic produce, has led to vegetation with forests spreading throughout the archipelago.

These geographical features present Japanese farmers with a difficulty in scale economy of their farming and force them to do continual hard work in almost all the seasons to improve yield potential per unit area.

Delayed Start of Paddy Rice Agriculture and Its Remarkable Growth from the Very Beginning

In spite of its rich potential for crop production, the actual start of paddy rice cultivation did not occur until several thousand years after its origin in the Yangtze River basin in the nearby Asian continent. Around 2,400 years ago, when the Jōmon Period (ca. 10, 000 BCE – 400 BCE; this period was dominated by hunting and gathering characterized with straw-rope patterned [=jōmon] pottery) was declining, the arrival of new immigrants from the continent brought techniques for paddy rice cultivation with their own cultivars. As the Yayoi Period (ca. 400 BCE–ca. 300 CE, so-called from the place in Tōkyō where the new type potteries were first unearthed) started, it replaced the lifestyle based on hunting and gathering with one based on the cultivation of

Agriculture in Japan, Table 2 An abstract of land size, vegetation, and agricultural land use in Japan

Item	Area (km ²)	Ratio (%)
(A) Total land size of Japan ^a	377,960	100.0
Hokkaidō	83,457	22.1
Honshū ^d	231,121	61.1
Shikoku	18,793	5.0
Kyūshū	42,194	11.2
Okinawa (Ryūkyū Islands)	2,277	0.6
(B) Total arable lands ^b	45,490	12.0
Those used for paddy rice ^b	24,690	6.5
(C) Forests ^b	244,616	64.7
(D) Grasslands ^c	22,337	5.9

^aStatistics Japan (2014)^bAgricultural statistics (2013)^cMostly seminatural grasslands. Green census, Japan (1983)^dIn general, Honshū (=Main Province) is geographically divided into five regions, i.e., Tōhoku, Kantō, Chūbu, Kinki, and Chūgoku (see Fig. 1)

rice supplemented with various crops. Because irrigation techniques had been rather primitive and not as sophisticated as in China when the rice culture was introduced, swampy areas along mountain streams and basins were primarily used for cultivation. Indeed, wooden farm implements such as hoes and spades were already very popular for working with improved japonica-type rice varieties together with preparing and transplanting skills of rice seedlings (a lot of transplanted rice stubbles were traced at various archeological sites of the Yayoi Period). It looks as if Japanese agriculture had been consistently staying at an intensive and labor-consuming nature since its origin.

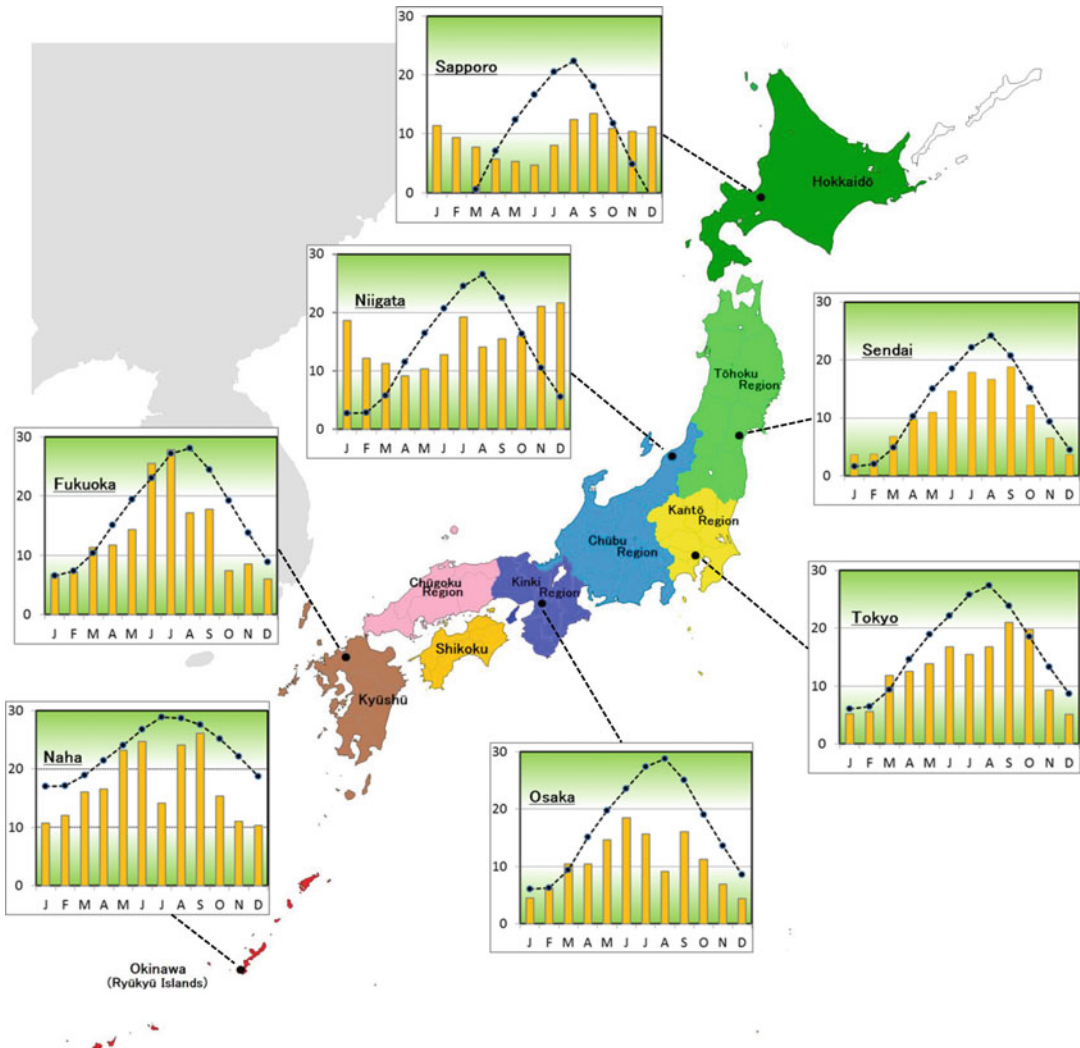
Soon after the introduction of paddy rice in northern Kyūshū around the fourth or fifth century BCE, paddy rice production and its associated technology began to spread eastward into Shikoku Island and Kinki region (the southern Honshū near present Ōsaka) where the Yamato Court later gained supremacy over all of Japan. At least 2,000 years ago, they arrived in the Kanto region (areas around today's Tōkyō) and subsequently moved toward north into the Tōhoku (northern Honshū) region. Large Yayoi remains

of paddy fields discovered at Taruyanagi in Aomori Prefecture at the northernmost end of Honshū (42°N) demonstrate that the diffusion of rice cultivation was very rapid and took only several hundred years at most, despite a large distance and different climates between northern Kyūshū and northernmost Honshū. Through experiments, Sato (1992) has endeavored to show that domestically improved thermosensitive cultivars, which ripened quicker and earlier, were probably responsible for this rapid progress of rice cultivation in cooler areas.

Development of Farming System in Ancient and Medieval Ages

Although the traces of upland rice and other miscellaneous grain cultivation were detected in various archeological sites of late Jōmon Periods, the beginning of the Yayoi Period should be thought of as the real dawn of agriculture in Japan. Because of the surplus production of introduced paddy rice agriculture, it soon brought about social arrangements with class distinctions. Remains at the Yoshinogari archeological site in northern Kyūshū demonstrate that the agrarian society of that time tightly created the construction of circular trenches protecting against their enemies and had a state-like political structure in which social stratification became clearly visible (Fig. 2). A Chinese history book in the second century CE noted long-lasting disturbances among tiny tribal countries in western Japan struggling for supremacy among their districts.

A much higher technology for agriculture developed in the subsequent Kofun Period (ca. 300–700 CE; Kofun refers to ancient tomb mounds prepared for central and local rulers). Social and technological progress came with the introduction of advanced iron implements (those hoes, plows, and spades led to deeper soil tillage), maintained waterways, reservoirs, canals, and the orderly planting of rice, all of which resulted in higher yields and the further expansion of arable land. These developments were probably accompanied by a change from using stone knives to clip off the progressively developed panicles of



Agriculture in Japan, Fig. 1 Regions and climates of Japanese Archipelago – seasonal changes of mean air temperature (°C, —●—) and precipitation (×10 mm, ■) in various locations from Hokkaidō to Okinawa. Average of past 30 years from 1981 to 2010 was shown (Statistics

of Japan 2014, Ministry of Internal Affairs and Communications). Months below 0 °C were excluded in the case of Sapporo (Outline map is delivered from the website of CraftMAP. <http://www.craftmap.box-i.net/>)

genetically diverse rice population to using sickles to harvest the aboveground parts of genetically identical crops with their heads attached.

Through these developments, the Yamato Court finally held supremacy over rival countries and was able to carry out social, economic, and political reforms known as the Taika Reform (Taika is the name of the era between 645 and 650 CE, which was first recorded in Japan) that promoted a centralized state similar to that in the

ancient empire of China. In 701, the legal system, known as Ritsuryō (Criminal and Civil Laws), was established to govern the whole country except for Hokkaidō (which was not yet Japanese territory). Under the Ritsuryō system, canal improvements, reclamation of new paddy fields, and rezoning of regular-size fields were all planned by the central government in an effort to significantly increase agricultural production. However, the Japanese people did not develop

Agriculture in Japan,

Fig. 2 Yoshinogari Archeological Site in Saga Prefecture, North Kyūshū. The site was first excavated around 1990, and a wide area of state-like settlements that developed in the Yayoi Period became apparent through a series of investigations



customs for raising livestock and poultry for consumption because Buddhism became the official religion in the eighth century. Since then, they depended greatly on rice as their main food and supplemented it with various other grains and plants with the occasional addition of fishes. These characteristics of farming and cuisine that date back to the period of consolidating central power in the archipelago continued over the centuries until the beginning of the modern age.

Although the best yields of rice in the Nara Period (710–794) were supposed to be less than 1,000 kg per hectare (Furushima 1947; just one-sixth of the present yield in Japan), that figure was surprisingly high when compared to yields of wheat in England during the same period (Evans 1975). The introduction of rice was also advantageous for efficient food supply at the time because it required basically no fallowing of fields when they were regularly fertilized and properly maintained. Thus the paddy rice farming which originated at early Yayoi Period led to a steady increase of population size, in parallel with steady development of cultivation techniques and further expansion of paddy rice fields. In the Nara Period, the official record noted more than five million citizens in Japanese territory (Kitō 2000; cf., about 70,000 people were estimated to live in the latest Jōmon Period [Habu 2004]).

Governmental power under the Ritsuryō system, however, began to collapse in the middle of the Heian Period (794–1192), as private territories of powerful aristocrats, temples, shrines, and clans emerged as *shōen* (manors). As central rule became weaker and weaker because of the social changes in the late Heian Period, officials in district branches and wealthy farmers began to arm themselves, and their influential leaders formed bands of warriors known as *samurai*. After a long struggle between samurai bands in various areas, the remaining two most powerful bands – Genji and Heishi – fought for national supremacy in the twelfth century. The war finished with the Genji in power and the beginning of the Kamakura Period (1192–1333) in which Japan became to be ruled by a samurai government (the first shogunate). In this feudal period, a relationship developed between lords and vassals from the samurai class, in which the latter usually engaged in agriculture and managed their farmlands as well as providing military service for wartime.

The establishment of manors and the intensification of agriculture in each locality resulted in a further rise of agricultural output that led to a second boom in land reclamation for paddy fields, and surplus agricultural products were gradually commercialized to create markets in various regions. Attempts at double-cropping in

paddy fields first emerged in the Kamakura Period, probably trying to raise additional winter harvests in lean years at the beginning. Later it was established in wider areas (particularly in western Japan) as a peculiar rotational cultivation system with rice for the main crop plus wheat, barley, or rape for the winter crop, which was not so popular in other East Asian areas.

The increasing economic strength of various lower classes, however, weakened the central power of the samurai government and drew Japan into a period of civil wars in the latter part of the Muromachi Period (the reign of second shogunate Muromachi, 1338–1573). Dominant feudal powers in various regions began fighting each other in an era known as the Sengoku Period (1467–1598; Sengoku refers to warring states). During that time, improving agricultural production and expanding arable land were the greatest concerns for powerful territorial lords (Sengoku Daimyō; *daimyō* originally meant “great paddy-field-owners”) because of the possibility of imminent warfare. They took careful control of paddy fields in their territories and expanded areas even in hilly diluvial plains by using the construction skills they had earned through their preparation for civil war.

Unique Development of Farming During Edo Period in the Premodern Age

After taking over the entire country, Hideyoshi Toyotomi implemented a cadastral survey (Kenchi) known as Taikō-Kenchi (Hideyoshi was known by the title of Taikō) from 1582 to 1598. The survey involved measuring each paddy field, ranking their productivity to assess the tax base, and registering of individual landowners. It established the Kokudaka (productivity, *koku* being a unit of measurement for rice) system in which arable lands were legally graded in terms of average productivity. This brought an end to the system of direct rule by feudal lords and determined land tenureship for small-scale farmers based on nuclear families. Ieyasu Tokugawa defeated the Toyotomi family in the Battle of Sekigahara (1600) and completed the process

of unifying Japan by establishing a new shogunate. Under the Tokugawa family, Japan in the Edo Period (1603–1868) flourished in the Sakoku (seclusion from other countries) policy, and each of the surviving Sengoku Daimyō was regulated by the Shōgun (military general) Government established in Edo (present-day Tōkyō).

Because the daimyō could no longer acquire more territory because of the strict Tokugawa regulations, the only way that they could expand their power was to reclaim land or to improve their fields to get better yields (mainly of rice). This led to improved irrigation systems within the big river basins and diluvial tablelands that could not previously be well controlled and utilized; they also improved technology for crop cultivation. The average rice yield was recorded as nearly 2,000 kg per hectare in the later period. Hence, political stability and technical innovations in agriculture brought another population burst in this premodern age, resulting in the dramatic increase in a shorter period from ca. 10 million people counted in late Sengoku to more than 30 million in the middle of Edo Period (Kitō 2000). However, this increase soon reached the ceiling in social stagnation.

Despite the overall developments in agriculture, however, the farmers who got their own lands through the Taikō-Kenchi were strictly restricted to move or even to choose another livelihood under the tightened feudal system. Furthermore, a great deal of their harvested rice was collected by the daimyō as a tax (*nengu*) which left the farmers with relatively little rice and therefore, a spartan existence, particularly in earlier Edo Period. Under such a severe regime, and because of it, many farmers made remarkable improvements in technology for raising field crops other than rice, especially for those which were cultivated on upland. Winter harvests from double-cropped paddy fields were also valuable fruits for farmers as they were often excluded from the *nengu*.

The use of human manure as a fertilizer was an important development at this time; it was used for higher production in intensively managed paddy and upland fields. In fact, all of human feces and urine were carefully collected

and stored for fermentation by each farmer. From Edo or some other big cities as Ōsaka and Kyōto, most of the “night soil” was transported to nearby rural areas where cash crop cultivation was flourishing. It may be said that the Edo people who lived more than 200 years ago had almost completed the thorough use of resources and the technological improvements in recycling that are informative even for today’s societies.

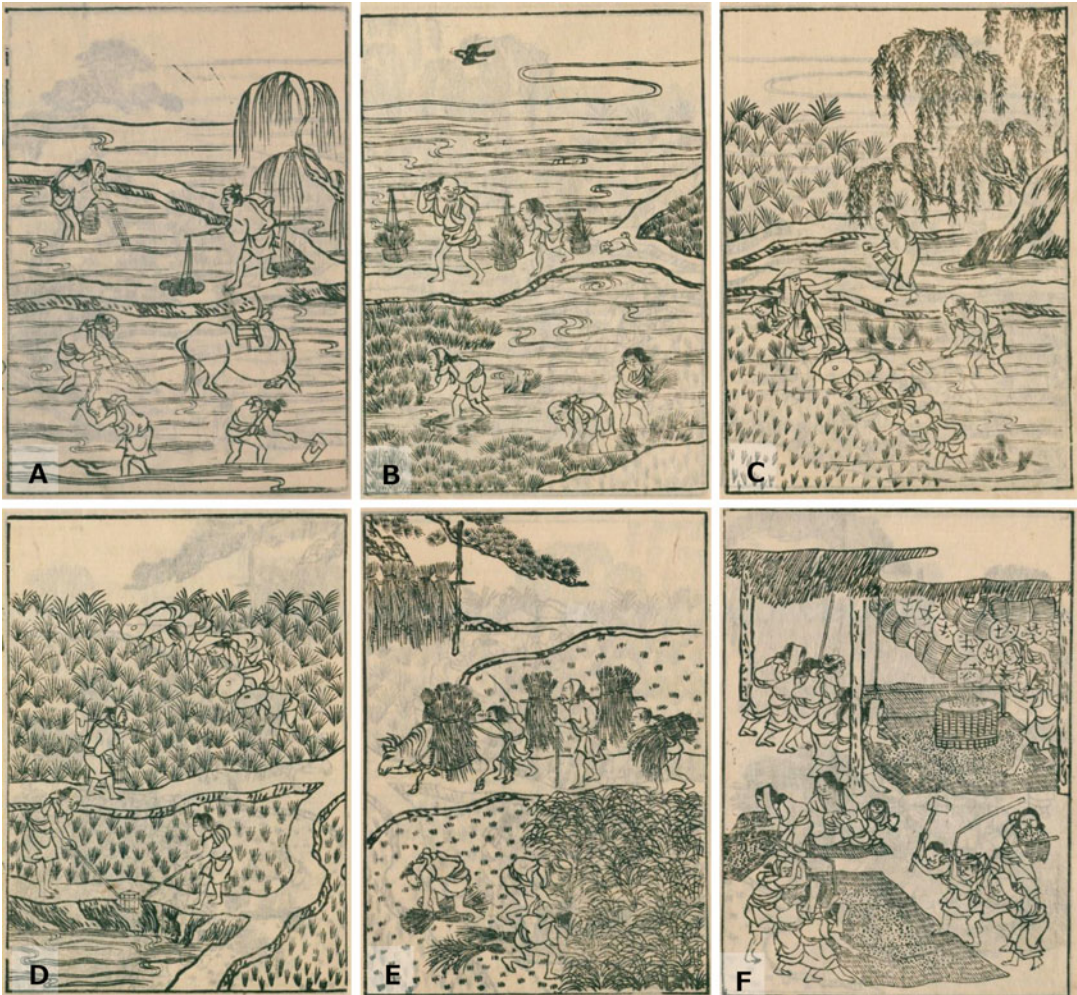
In the Edo Period, many books called *nōsho* (writings on agriculture) were written in various areas, and some of them were published in xylography and distributed widely. Publications to describe agricultural technology and various local cultivars contributed to further technological improvements and examination of traditional cultivars. Among others, the most notable work in the first half of Edo Period was *Nōgyō Zensho* (Complete Writings on Agriculture, 1697) by the lordless samurai Yasusada Miyazaki (1623–1697) in northern Kyūshū. This book provided practical instructions based on the author’s comprehensive knowledge acquired over the years, while the basic style of the book followed the famous Chinese *Nóngzhèng Quánshū* (Complete Book on the Administration of Farming, 1639) which was written by Xú Guāngqǐ late in the Ming Dynasty. Miyazaki had long regretted that the life of farmers required hard labor and low incomes because of their paucity of knowledge about the principles of agriculture (Fig. 3), so he published information about the available scientific principles and technology that was easily put to use anywhere in the country. In a sense, an original agricultural science, rooted in the traditional culture of Japan, came into existence by this work. His book greatly influenced agriculture throughout the Edo Period, and it was reprinted repeatedly over 150 years, almost until the end of Edo Period.

The Tokugawa shogunate built many roads which originated in Edo or Ōsaka in the seventeenth century. Various sea routes for shipping were also established, so an integrated system of transportation throughout all of Japan was progressively built with progressive development of a market economy in the latter Edo Period. In this

situation, Nagatsune Ōkura (1768–1860), one of the most famous scholars of agriculture late in the Edo Period, wrote many volumes on agriculture and particularly made efforts to publish various textbooks about cash crops. He also prepared manuals on agricultural equipment and wrote about plant protection. The application of this knowledge and those techniques resulted in the prosperous cultivation of rapeseed, cotton, and other industrial crops in the Kinki region and the rise of the processing industry near Ōsaka that increased the amount of merchandise available for distribution.

Despite the remarkable growth in productivity, farming throughout the Edo Period still depended on human power, and the merit of scale was hardly found. Although plowing with draft animals was practiced to some degree in and around the Kinki region, it did not spread throughout the country, partly because the traditional long-soled plows they used were less efficient than hoes for deep tillage in paddy fields to get a higher yield with a higher level of fertilizer use. Hence, the labor-intensive cultivation continued to dominate and relied on specialized hoes and spades just handled by man power. In his *nōsho* (An Investigation of Usefulness of Various Agricultural Tools), Nagatsune Ōkura illustrated a diverse range of hoes modified for various purposes or soil conditions (Fig. 4). The intensive farming system without any convenient machinery had lasted until quite recently, just supplemented by step-by-step fine tuning of hand-operated tools.

Another example of prosperous development of Japanese farming was found in sericulture in the late Edo Period. A lot of novel techniques were invented by farmers in various places of silk production (a *nōsho* on sericulture written by devoted sericulturist Morikuni Uegaki (1753–1808) was even translated into French in 1848 when the country was not opened to the West yet). Instances included thermal management of silkworm development and crossbreeding of various productive strains; both of these scientific technologies were not well distributed yet in Western countries of those days. These technologies developed during the premodern



Agriculture in Japan, Fig. 3 A rice cultivation calendar in *Edo* Period, starting with the field preparation in spring and ending with the harvest processing in autumn (cited from the website of National Diet Library, Tokyo). The illustration was shown at the introduction of Miyazaki's famous book – *Nōgyo Zensho*. Farmers had to work very

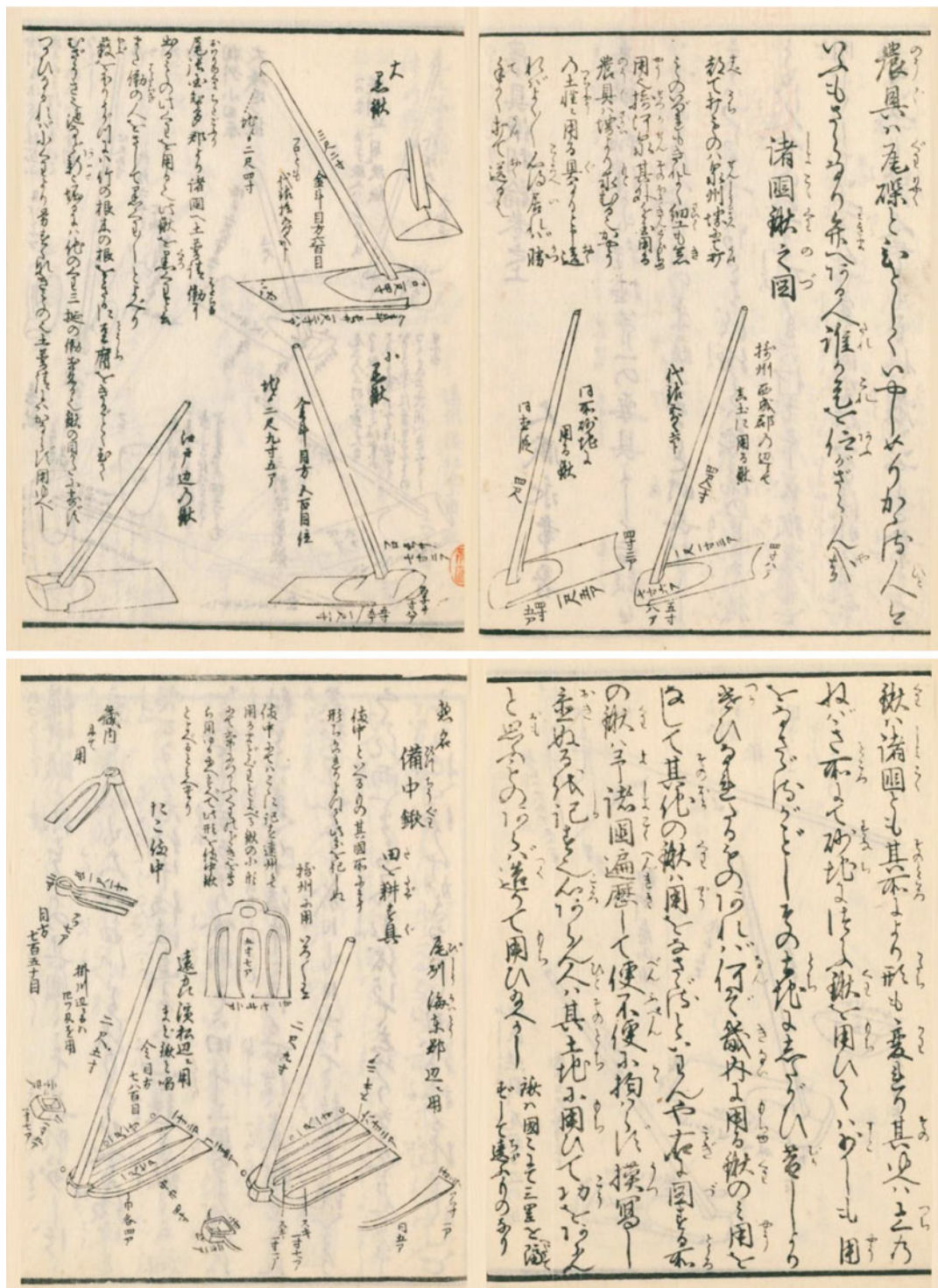
hard for the care of growth and maturation of paddy rice plants from early spring to the middle of autumn without any vacant days. (a) Preparing rice seedlings and paddy fields. (b) Carrying seedlings for transplant. (c) Transplanting seedlings. (d) Taking care of growing rice plants. (e) Harvesting rice. (f) Processing harvested rice

age later contributed to the further development of sericulture and silk-spinning industries in following Meiji Period.

Modernization in Japanese Agriculture After the Meiji Restoration

In the second half of the nineteenth century, Japan decided to open itself to international relations after a 200-year-long *Sakoku*. The

Tokugawa regime lost its ability to govern effectively, and the feudal system finally came to an end in 1868. The new government under the restored emperor declared the beginning of the Meiji Period (1868–1912) and began to modernize Japan along contemporary Western lines. As Japan had almost no particular source of revenue except for agriculture at that time and since 80 % of the population belonged to the agrarian class, the collection of land taxes was of great concern to the new government. Introducing Western



Agriculture in Japan, Fig. 4 Various kind of hoes illustrated in *Nōgu Benri Ron* (An Investigation on Usefulness of Various Agricultural Tools) written by Nagatsune

Ōkura late in the *Edo* Period (cited from the website of National Diet Library, Tokyo). He made a detailed investigation on the variation of different kind of hoes that were

agricultural technology (*Taisei nōgaku*) was therefore an urgent project for the government, which wanted to increase the wealth and military strength of the country in order to catch up with European powers and the United States in a short amount of time.

However, the modernization of Japanese agriculture at the outset was not as successful as it was with industrialization, because the earliest foreign experts invited into the country simply tried to bring their own style of agriculture without any modification and did not consider the different state of affairs that existed between Japan and their homelands. However, a few European scientists used a different approach to developing Japanese agriculture by evaluating traditional technology and knowledge. For instance, Max Fesca from Germany made a huge scientific effort at analyzing traditional Japanese techniques of cultivation, applying Western technology to suit the needs of Japanese agriculture, and developing new technology for practical cultivation. *Rōnō* (*rōnō* refers to farmers with outstanding farming knowledge), who had fully mastered the knowledge and skills of traditional agriculture that had already been systematized in the Edo Period, also played an important role in the modernization of traditional agricultural technology and its extension throughout the country in the late nineteenth century.

In the early twentieth century, Japan had nearly completed establishing a public system of education and scientific research based on Western models with a modernized governing system. As centralized power became stronger through and after the First World War, various research results achieved at institutes and universities contributed to the remarkable increase in agricultural production from 1920 to 1940. Large-scale land innovation and wide distribution of chemical fertilizers also accelerated the progress. Studies on the genome of wheat strains by Hitoshi Kihara, the autumn deterioration of

paddy soils by Matsusaburō Shioiri, and the selection of the famous Nōrin No. 10 wheat variety (Nōrin is the abbreviation for the Ministry of Agriculture and Forestry) were all world-renown accomplishments prior to the Second World War.

Through repeated crossing with various native cultivars from Mexico, for instance, the Nōrin No. 10 later obtained high-yielding dwarf cultivars, which increased wheat production in developing countries dramatically through the “Green Revolution.” Also pursued was the concept of “synchronism in tillering and tiller development in rice, wheat, and barley crops” established by Tsukuda Katayama, which led to precise technology for monitoring the growth and improving the yield of rice and other grain crops (Fig. 5). In Western countries, phyllochron (leaf appearance interval) studies were initiated in the last 40 years to take precise control of the growth of improved wheat and other crops. In fact, Katayama and his students completed the principle of phyllochronic development of grain crops more than 60 years ago, although the original studies, written mostly in Japanese, were hardly read by Western researchers.

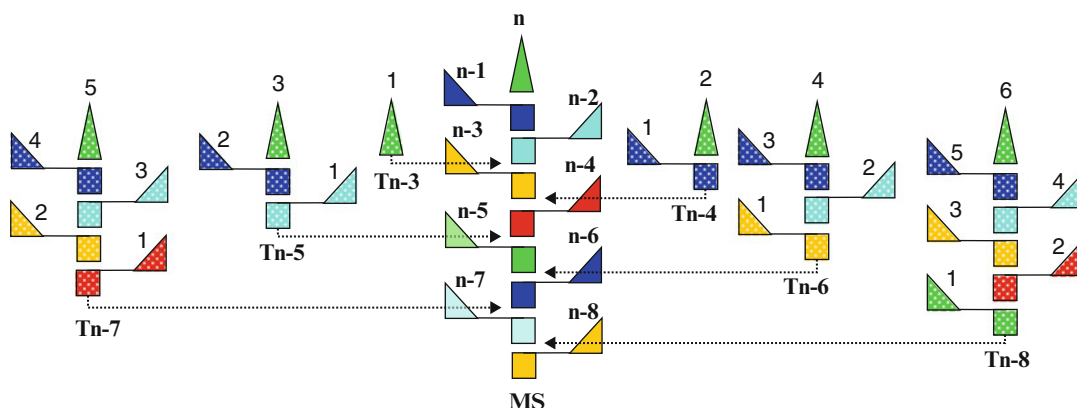
The scientific achievements made before the Second World War principally contributed to higher productivity (approaching to the level of 4,000 kg per hectare in case of rice); however, the farming system still remained unchanged in a traditional, labor-intensive state for individual farmers and villages.

Transfiguration of Traditional Agriculture After the Second World War

Invasive Imperial Warfare against the Allied Powers throughout the 1930s to 1945 came to an end with the unconditional surrender of the Japanese Empire. This defeat gave the Japanese people an opportunity to replace an autocratic system with a representative democracy akin to

Agriculture in Japan, Fig. 4 (continued) carefully modified for various cultivating purposes in various districts. *Top*: a comparison of different forms of *hiraguwa*

(plowing hoes). *Bottom*: a comparison of the size and form of each part of *bitchuguwa* (cultivation hoes)



Agriculture in Japan, Fig. 5 A schematic illustration of Katayama's Concept on tillering regularity in rice, wheat and barley plants—the synchronism in tillering and tiller development. Mother shoot (MS), which forms her leaves in constant interval in any order, generally bears her daughter tillers regularly in parallel with successive leaf formation of MS, so that the new tiller appearance at the age of 'n'th leaf emergence of MS usually becomes apparent at the leaf axil of n-3 and the new-born tiller develops further with homologous leaf formation, resulting in successive increase in leaf number in lower daughter tillers. Thus the grain crop plant is an integrated unit of synchronously appeared tillers in various orders and synchronously developed leaves on synchronized tillers while showing different appearance. In the

figure, (▲) indicates the top elongating leaf on any time. (◻) in various color denotes the expanded mature leaf attached to any node (◻) of MS or daughter tillers. Arrow is the position of the leaf axil with which successive daughter tiller is subtended. Daughter tillers are numbered acropetally with the codes as ...Tn-5, Tn-4, and Tn-3, being subtended by ...'n-5'th, 'n-4'th, and 'n-3'th leaves of MS, respectively. Number noted by each leaf of daughter tiller indicates the leaf position as counted from the initial foliage leaf of each tiller. Leaves with the same color denote the synchronous emergence (and analogy in size) on different tillers. The Katayama's Concept shown above had been very useful tool for developing the intensive technology in rice plant cultivation in Japan during the Postwar period

those in Western Europe and the United States. A thorough land reform was undertaken under the strict regulation of occupying powers, mainly the United States. The abolition of parasitic landlordism (*jinushisei*, the system which became dominant very quickly after the Meiji Restoration) and the creation of independent farmers, mainly from the ranks of previous tenant farmers, were achieved in a short time. The newly created independent farmers struggled to improve their yields of rice, even though their small, scattered landholdings put them at a severe disadvantage.

In the early postwar period, the most prominent popularization occurring in farmlands was the almost Japanese original machine called *kōunki* (cultivator) which reduced the amount of hard work required from farmers and stimulated agricultural growth in the first decade after the war (Fig. 6).

Remarkable progress was also made in the technical development of farming materials

such as pesticides, insecticides, herbicides, and plastic films used for soil mulching and simplified greenhouses, all useful for small-scale, intensive agriculture. Advances in efficient fertilization, such as topdressing of nitrogen at the ear-formation stage of rice proposed by Shingo Mitsui, led to stable, high rice yields as well. When the farmers achieved an abundant harvest of 12 million tons of rice grain in 1955, the government declared that the country was in "no postwar situation any longer!"

Japan experienced rapid economic growth from 1955 to 1973, when an international oil crisis interrupted its progress. The Basic Agricultural Law (*Nōgyō Kihonhō*) was enacted in 1961, when a massive outflow of labor from the countryside had become apparent, in order to make farmers economically self-reliant with incomes about the same as those for urban laborers. The law concentrated on improving the productivity and efficiency of labor in agriculture through



Agriculture in Japan, Fig. 6 Kōunki, innovative cultivators that were intensively refined during the early postwar period in order to improve labor efficiency in small-sized fields that were usually covered with heavy wet soils. The improved machines achieved the easier and

quicker farming practices in labor-intensive agriculture, relieving farmers who had previously been forced to work (A scene showing students from Hokkaidō University, 1976. Photo taken by Michiaki Ito, Niigata University. Used with his kind permission)

Agriculture in Japan, Fig. 7 Improved rice transplanter in action in paddy rice fields of a part-time farmer that owns 3 or 4 ha of land. Those part-time farmers normally complete routine tasks in 3 or 4 days during holidays in early May (Photo taken by Mutsuyasu Ito)



mechanization; the government did in fact succeed in improving agricultural labor productivity. Thus, rapid economic growth after the Second World War improved the standard of living for farmers – much more quickly than had been the case in Europe – and they have been relieved of a lot of heavy labor by such machines as four-wheeled tractors, rice transplanters, and rice

harvesters (Figs. 7 and 8, both being Japanese originals) as well as various unique farming tools useful for Japanese intensive agriculture. However, the changes also created a serious inconsistency for the existence of traditional agriculture, which had been progressively systematized during the hundreds of years of farmers struggle. The double-cropping system with rice

Agriculture in Japan,
Fig. 8 A rice combine harvester in action to harvest the yield of well-ripened rice crop, being easily operated by an aged farmer. Rice harvesting, which was once one of the most labor-intensive farming activities, is now usually completed by low number of workers – around one person/hectare/day or less (Photo taken by Mutsuyasu Ito)



and winter crops, almost a Japanese original technology, is indeed disappearing now.

The population of farmers, in consequence, decreased dramatically to about 3.3 % (in 2014, they are mostly above 60 years old) of the Japanese total work force in the past half century, and most of them are now living as part-time farmers dependent to a large extent on other industries. In the meantime, Japan has been simply exhorting the agricultural sector to be efficient economically; hence its output of such crops as wheat, barley, soybeans, and buckwheat gets beaten in international competition. Rice cultivation now narrowly survives harvesting ca. 8 million tons every year but is preferentially dependent on being located in optimal environments as well as the official policy of protection. The current, apparently irreversible trend foreshadows the increasing abandonment of agricultural land usage, further alienation of seminatural environments, and the inevitable decline of Japan's original agricultural practices and traditions which had been developed over almost two millennia.

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Agriculture in South and Central America

Karl H. Schwerin

Conquest of South and Central America by the Spanish and Portuguese in the sixteenth century was rapidly followed by the introduction of Old World crops. These included both those familiar to European farmers, such as wheat, barley, oats, and many temperate vegetables and fruits catering to European food tastes, as well as tropical crops from Africa and Asia, such as bananas and plantains, sugar cane, and rice. At the same time many American crops were carried to the Old World – the most important being maize, potatoes, manioc, beans, and squash.

From the time of conquest to the present, agriculture in this region has been dichotomized between small-scale subsistence farming and large-scale monocrop operations producing for profit. Their development is summarized here.

Some native agricultural methods continued, such as ► [swidden](#) agriculture in temperate and tropical forested regions, field cultivation with the foot plow in the Andes, and intensive *chinampa* agriculture in central Mexico. Other techniques such as terracing declined, or as with raised fields, disappeared altogether. The small farmers incorporated some European crops as staples – wheat in Mexico (principally among mestizo farmers), barley in the Andes, onions, cabbage or collards almost everywhere. Bananas and plantains spread rapidly throughout the tropics. Agricultural technology continued much as before contact, perhaps because it was appropriate to traditional agriculture which, though small-scale, was highly productive.

Although early colonial institutions such as the *encomienda*, *corregimiento*, and *repartimiento* were designed to exploit native labor and mineral resources, they also produced surplus foodstuffs to support the European population, mining, and colonial administration. As native populations declined, large land holdings were granted to



Agriculture in South and Central America, Fig. 1 Cachama. Bananas and manioc in a morichal field, Cachama, Venezuela. Drained field in a moriche swamp, Karinya Indians. 1962 (Photo by Karl H. Schwerin)

Spanish and Portuguese immigrants. Some were cultivated dilatorily, but others were transformed into plantation enterprises producing sugar, tobacco, cacao, indigo, or cochineal (a red dye obtained from the crushed dried bodies of female cochineal insects, used to color food and drinks and to dye fabrics) (also cattle, sheep, and horses) which soon supported a lucrative trade with the home country. Most plantations were dependent on slave labor. Sugar, consumed raw or distilled into *aguardiente* or rum, became the principal economic enterprise in Brazil and the Caribbean, and was particularly dependent on slave labor.

By the eighteenth century mining became concentrated in a few rich areas. Agriculture acquired more importance in the colonial economy. Land grants were increasingly cultivated to supply colonial needs for food grains and raw materials such as cotton. The *hacienda* became

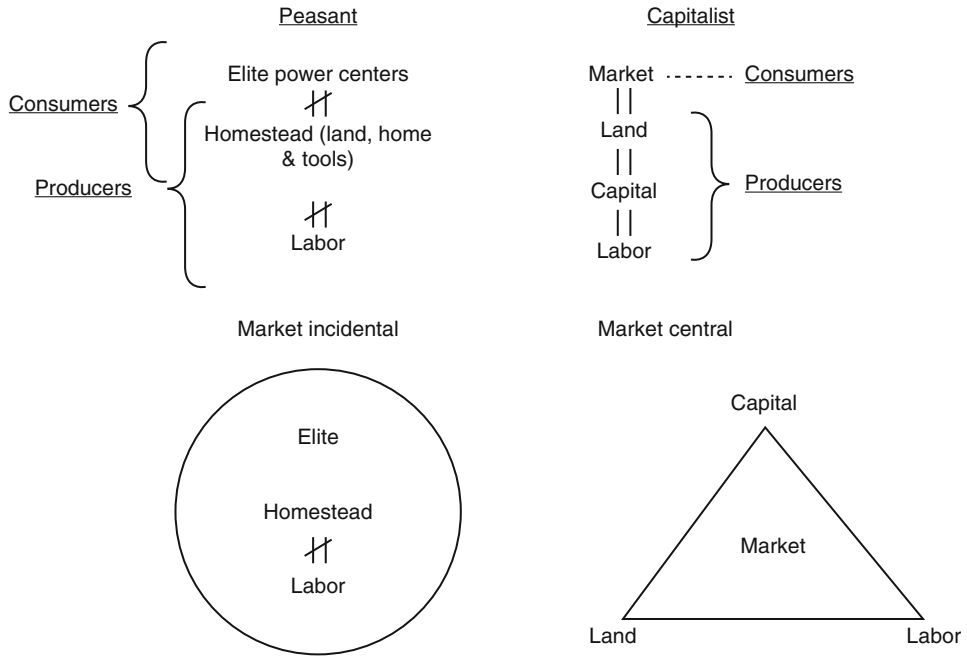


Agriculture in South and Central America, Fig. 2 Mamo. Bananas, sugar cane, manioc in a morichal field, Yavito, Rio Yabo. Typical drained field in Yavito, in

a moriche swamp. Karinya Indians. February 1962 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 3 Mamo. Fruit trees in patio 1967, Mamo, Venezuela. House garden. Karinya Indians. July 1967 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 4 The peasant economy versus the capitalist economy



Agriculture in South and Central America, Fig. 5 Maize field. Mexico, Tenancingo, Tlaxcala, Mexico. Typical peasant maize field. June 1957 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 6 Mamo. Maize field. Maize field and shelters of Francisco Vasquez, Isla La Isabel, Venezuela. Karinya Indians. February 1962 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 7 Forest and maize fields, Michoacan, Mexico. August 1962 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 8 Mamo, maize field on Isla La Isabel, Venezuela. Karinya Indians. February 1962 (Photo by Karl H. Schwerin)

the vehicle for accomplishing this production. Labor was secured through mechanisms such as debt peonage and was administered in such a way that it was almost impossible for the individual laborer to break free.

After independence early in the nineteenth century, slavery was gradually abolished throughout the Americas. The hacienda, however, continued as a major system of ensuring agricultural labor. It only began to disappear with the Mexican Revolution of 1910. Though much less important today, it continues to operate in some Andean countries and in parts of Brazil.

The nineteenth century was marked by widespread expansion of agricultural capitalism in the form of plantation systems producing a wide variety of crops for industrial and consumer markets in Europe and North America. These included *henequen* (fiber obtained from the leaves of the henequen agave plant, used in making rope, twine, and coarse fabric) from the Yucatan, bananas in Central America, and sugar

in the Caribbean and Brazil. Coffee, one of the most profitable crops, was widely introduced, from Mexico to Brazil. In Mexico and parts of Central America, small farmers produced it; in Costa Rica and Colombia medium sized farmers were the rule; elsewhere large coffee *fincas* predominated. Particularly in the latter case, land was intensively exploited, without efforts at conservation or improvement, leading to rapid deterioration in soil quality and declining production. Where land was abundant, the response was to clear virgin land and plant new coffee groves. Uruguay and Argentina became major world producers of wheat, owing to the rich Pampean soil. In both Brazil and the pampas, immigrant labor was employed to clear the land, in exchange for temporary usufruct of part of the cleared area. Evicted after a time in favor of the landowner, some immigrants acquired their own (usually smaller) farms, but most withdrew to the cities, leaving only the larger *fincas* and *estancias* as significant agricultural producers.



Agriculture in South and Central America, Fig. 9 Tenancingo. Harvesting beans. Tenancingo, Tlaxcala, Mexico. Don Eleuterio Guzman pulling up bean plants in a maize field. July 1957 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 10 Tenancingo. Don Eleuterio Guzman harvesting beans in a maize field. Tenancingo, Tlaxcala, Mexico. July 1957 (Photo by Karl H. Schwerin)

Several different systems of agricultural exploitation can be identified in this region today. Yet agriculture has declined in importance in national economies throughout the century, dropping precipitously since 1980. Only in Central America, Mexico and Brazil is 15–30 % of the work force still farming, in most countries only 10 % is still employed in agriculture, which represents less than 10 % of the GDP for the region.

The persistent dichotomy between large, extensively cultivated holdings (*latifundio*) and small, intensively cultivated properties (*minifundios*) survives today. Though these are sometimes geographically separated, they frequently occur interspersed with each other

interacting as a symbiotic whole. This dichotomy is also at the root of many economic and social problems. Although precise data on distribution of agricultural landholdings have not been reported since the 1970s, the extreme bimodal distribution has probably not changed significantly. In El Salvador, Guatemala, and Peru more than 90 % of agricultural landholdings were under 10 ha, yet represented only about 30 % of the area. In contrast, 26 % of the area in Guatemala and 61 % of the area in Peru were larger than 1,000 ha, yet represented less than 0.5 % of the holdings.

Some small-scale specialized farming techniques survive in scattered locales, such as localized irrigation systems, *chinampas* in the Valley of Mexico, drained fields among the Karinya in

Agriculture in South and Central America,

Fig. 11 Mamo. Threshing beans. Ramón Antonio Vásquez threshing out beans by beating them with a pole. Isla La Isabel, Venezuela. Karinya Indians. March 1962 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,
Fig. 12 Manioc field, Kuri, Rio Platano, Honduras. Miskito Indians. January 1981 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,
Fig. 13 Cachama. Teresa Tamanaico pulling, up (harvesting) manioc tubers. Cachama, Venezuela. Karinya Indians. July 1962 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,
Fig. 14 Cachama. Teresa Tamanaico stripping manioc tubers from uprooted plants. Cachama, Venezuela. Karinya Indians. July 1962 (Photo by Karl H. Schwerin)

eastern Venezuela (Figs. 1 and 2), or terraces and lazy beds in Mesoamerica and the Andes. Traditional methods of agriculture generally promote ecological stability both because environmental disturbance is minimal and because the agroecosystem is stable. Unfortunately, development, modernization, and institutional pressures from the larger society often lead to abandonment of these techniques, in spite of their suitability to local conditions and often exceptional productivity. Thus most irrigation has been modernized and commercialized and relies on pumping, reservoirs, and lined canals. Yet there are efforts in some places to reintroduce ancient agricultural techniques, like ridged fields in the Titicaca Basin, which have proven superior to current practices. Many traditional practices should be preserved in order to exploit their productive advantages, utilize marginal microenvironments, maintain crop diversity, and minimize production risks.

► **Swidden** agriculture or shifting cultivation is still widely used in forested regions. It may support as many as 50 million people. It is relatively productive and successfully integrated into the ecological regime of the tropical forest, yet requires less labor than many other methods. It is a technology that does not require capital investment or

Agriculture in South and Central America,

Fig. 15 Cachama. Teresa, Luis and Delia Tamanaico, loading manioc tubers into a basket to be carried home, for processing. Cachama, Venezuela. Karinya Indians. July 1962 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,

Fig. 16 Tenancingo. *Maguey* (*Agave* sp.) Tenancingo, Tlaxcala, Mexico. Nearly mature maguey plants planted along edge of field. July 1957 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,

Fig. 17 Tenancingo. Collecting *agua miel*. Tenancingo, Tlaxcala, Mexico. Mature maguey plant (*Agave* sp.) with heart carved out to create a cavity for collecting the sap or *agua miel*-subsequently fermented to produce pulque. July 1957 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,

Fig. 18 San Pedro. Hacienda peons. Hacienda San Pedro, Cañar, Ecuador. 1970 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,

Fig. 19 San Pedro. Team of oxen. Hacienda San Pedro, Cañar, Ecuador, José Narvaez loading plow on yoke to carry to field. 1970 (Photo by Karl H. Schwerin)

**Agriculture in South and Central America,**

Fig. 20 San Pedro. Plowing field with oxen 1. Hacienda San Pedro, Cañar, Ecuador, 1970 (Photo by Karl H. Schwerin)



energy subsidies. When associated with sparse populations its environmental impact is minimal, perhaps even beneficial by stimulating renewed forest growth. When intensified to the point that the forest can no longer replace itself, swidden may produce widespread environmental

degradation. Rapid population growth throughout Latin America has spurred migration in search of farmland in lowland tropical forests from the Peten and the Caribbean coast to the Amazon basin. Resulting widespread deforestation has had serious ecological repercussions.

Agriculture in South and Central America,

Fig. 21 San Pedro.
Plowing field with oxen
2. Hacienda San Pedro,
Cañar, Ecuador, 1970
(Photo by Karl
H. Schwerin)



Agriculture in South and Central America,

Fig. 22 Wheat harvest
1. Hacienda El Colegio,
Cañar, Ecuador.
Mayordomo Augusto
Urgiles oversees the cutting
of wheat. October 1969
(Photo by Karl
H. Schwerin)



One agriculture technique, the house garden, is nearly ubiquitous among small farmers, even in towns and cities. Their species diversity is high, providing supplementary food, condiments, herbs, medicinal remedies, fuel, fertilizer, and ornamental plants (Fig. 3).

Peasant farmers conduct most small-scale agriculture. A true peasant owns or controls his

land, runs his own operation and makes his own decisions independently. The primary production objective is for subsistence and survival. Peasants do not think in capitalist terms, but instead are oriented around the homestead (land, home, tools), which cannot be converted or exchanged for other means of production (see Fig. 4). Because cash is limited, the peasant cannot afford

Agriculture in South and Central America,

Fig. 23 Wheat harvest
2. Hacienda El Colegio,
Cañar, Ecuador October
1969 (Photo by Karl
H. Schwerin)



Agriculture in South and Central America,

Fig. 24 Wheat harvest
3. Hacienda El Colegio,
Cañar, Ecuador, October
1969 (Photo by Karl
H. Schwerin)



to take risks; he often resists trying new crops and techniques; technology remains traditional (paleotechnic).

The strength of peasant farming is its heterogeneity and diversity. Planting a variety of crops, in several locales, under varying conditions, minimizes risk. The most important crops are starchy staples – grains or root crops – and legumes; perhaps supplemented by a high value

cash crop – tomatoes, coffee, or narcotics (Figs. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17).

Large holdings can be roughly divided into haciendas, estancias, plantations, and agroindustrial enterprises. Hacienda organization represents a unique adaptation to abundant land and scarce capital. Labor to work the estate is attracted by offering small subsistence plots to



Agriculture in South and Central America, Fig. 25 San Pedro. Threshing barley with horses. Hacienda San Pedro, Cañar, Ecuador. Joaquín Fajardo,

Cayetano Tenesaca, Corazón Murudumbay and Juan José Tacuri threshing barley September 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 26 Planting potatoes. Hacienda El Colegio, Cañar, Ecuador. September 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 27 San Pedro. José Narvaez planting *ocas*. Hacienda San Pedro, Cañar, Ecuador. September 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 28 San Pedro. José Narvaez planting *ocas*. Hacienda San Pedro, Cañar, Ecuador. September 1969 (Photo by Karl H. Schwerin)

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local smallholders or landless laborers (most commonly known as *peons*). Traditionally little or no wages exchanged hands; today real wages may actually be paid, although they are often seriously in arrears because capital remains scarce. For the same reason haciendas try to be self-sufficient in terms of basic needs. They also tend to be inefficient, relying on antiquated technology and cultivating only a small area of the best land, leaving the rest uncultivated or in the hands of the workers. Yet their production of staple cereals and tubers, or milk, meat, and wool may contribute significantly to national economies. Hacienda property may be viewed more as a basis for prestige or a hedge against inflation than as an income producer. For this

reason, as well as scarce capital, haciendas also tend to resist innovation. Most surviving haciendas are found in highland areas of the Andes and Mesoamerica, though they have also been the object of land reform from Mexico to Bolivia, Peru and Ecuador (Figs. 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29).

Estancias are large holdings devoted to livestock production found mostly in the Southern Cone and northern Mexico, although in recent years cattle production has expanded rapidly in the Amazon lowlands and Central America to feed the North American demand for hamburger and processed meats.

The modern plantation contrasts with the traditional hacienda in that it is fully and efficiently

Agriculture in South and Central America,

Fig. 29 Peons harvesting *mellocos* (*Ullucus tuberosus*). Hacienda El Colegio, Cañar, Ecuador. September 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America,

Fig. 30 The hacienda and the plantation

CHARACTERISTICS OF THE PLANTATION

Distinguishing Characteristics of the Plantation

1. Sharp separation of classes
2. Capitalistic enterprise
3. Monocrop specialization
4. Continuous commercial production

Hacienda lacks these, tends toward self-sufficiency

plantation - A capitalistic type of agricultural organization in which a considerable number of laborers are employed under unified direction and control in the production of a staple crop for sale to an external market. (Sidney Mintz)

Contrasts Between the Hacienda and the Plantation

<u>Hacienda</u>	<u>Plantation</u>
abundant land	pervasive control of the land
scarce capital	abundant capital
pervasive control of labor	scarce labor, often mobile
tries to avoid wages	relatively high wages
ownership by family or traditional institution (church, government)	ownership by company or corporation
personalistic & paternalistic	universalistic & impersonal
economically inefficient	economically efficient
paleotechnic	neotechnic, often highly mechanized
produces for domestic market	produces for external market
participates in regional and national power structure	participates in international power structure



Agriculture in South and Central America, Fig. 31 Field of pyrethrum (*Chrysanthemum* spp.). Highland Ecuador. June 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 32 San Pedro. Laborers from Chimborazo Province hoeing pyrethrum 1. Hacienda/Plantation San Pedro, Cañar, Ecuador February 1970 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 33 San Pedro. Laborers from Chimborazo Province hoeing pyrethrum 2. Manuela Transito Balente and

Transito Illapa Hacienda/Plantation San Pedro, Cañar, Ecuador February 1970 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 34 San Pedro. Floreras (peon women) picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 35 San Pedro. Olga Jachero picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)



Agriculture in South and Central America, Fig. 36 San Pedro. Olga Jachero picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)

operated with large amounts of capital (see Fig. 30). The plantation generally concentrates on monocrop specialization with the aim of continuous commercial production, usually for export. Although their proportion of total agricultural production has been declining, plantation crops such as sugar, coffee, bananas, pineapples, oil palm, cotton, tobacco, maize, and wheat continue to be the major source of foreign exchange for several countries (Figs. 31, 32, 33, 34, 35, 36, 37, and 38).

Large farms in central Chile, Northern Mexico, and Central America have also adopted this mode, producing fruits and vegetables for the winter market in North America. Production and marketing of feed products (maize, sorghum and millets, soybeans) and oilseeds (safflower,

soybeans, cottonseed) have become important in Brazil, Argentina, Colombia, Guatemala, El Salvador, and Mexico. Commercial farming is almost always profitable, but profits increase exponentially with the size of the operation. They generally practise monocropping with chemical additives such as fertilizers and pesticides. Since larger commercial farmers participate in the international economy, they can survive bad years by falling back on economic institutions (loans, savings, insurance) to carry them through.

The North American Free Trade Agreement (NAFTA) has had serious repercussions in Mexico. Imports of agricultural products produced cheaply by large US and Canadian agribusinesses has undercut the production of small and medium



Agriculture in South and Central America, Fig. 37 San Pedro. Lucrecia Alvaros picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969 (Photo by Karl H. Schwerin)

sized farmers in Mexico, forcing many to abandon the land, often moving to the cities in search of alternative employment.

Social consequences of these developments are that the peasantry is losing control over its productive processes and is being transformed into a rural proletarian underclass that is being exploited as the primary labor force. These factors have deeply transformed production relations within the agricultural sector, resulting in the modern agroindustrial complex. As a result of increasing commercialization of agriculture, the production of cash crops for export and industrial use has expanded at the expense of the production of basic food crops, leading to significant imports in many countries of basic foodstuffs (Tables 1 and 2).

Efforts at agricultural modernization vacillate between large, capital intensive projects and smaller “appropriate” technology, designed especially for small farmers. However, the bias is toward large-scale projects that are highly visible and politically profitable, but which are often viable only for the short term. In any case they are rarely beneficial to the small farmer.



Agriculture in South and Central America, Fig. 38 San Pedro. Peon women picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador. August 1969 (Photo by Karl H. Schwerin)

Agriculture in South and Central America, Table 1 Most important crops for domestic consumption in Latin America

Maize	59,817
Manioc	29,633
Rice	23,217
Wheat	22,452
Potatoes	16,997
Dry beans	5,117
Sweet potato	1,796
Barley	1,646

From *Statistical Abstract of Latin America*. v. 38, 2002. Data for 1999 (in thousand metric tons)

Agriculture in South and Central America, Table 2 Export and industrial crops for Latin America showing principal exporting countries, 1999

	In thousand metric tons	Export value (millions of US dollars)
Cotton (Brazil, Argentina, Paraguay)	1,164	261
Sugar cane	539,308	4,457
Coffee	3,693	7,912
Bananas	22,279,000	2,816
Maize (Argentina, Paraguay)	13,183	832
Soybeans (Argentina, Brazil, Paraguay)	5,141	2,481
Wheat (Argentina)	14,500	999

From *Statistical Abstract of Latin America*. v. 38, 2002 and *International Trade Statistics Yearbook*, 2001

See Also

- [Food Technology in Latin America](#)
- [Potato: Origins and Conservation of Potato Genetic Diversity](#)
- [Swidden](#)

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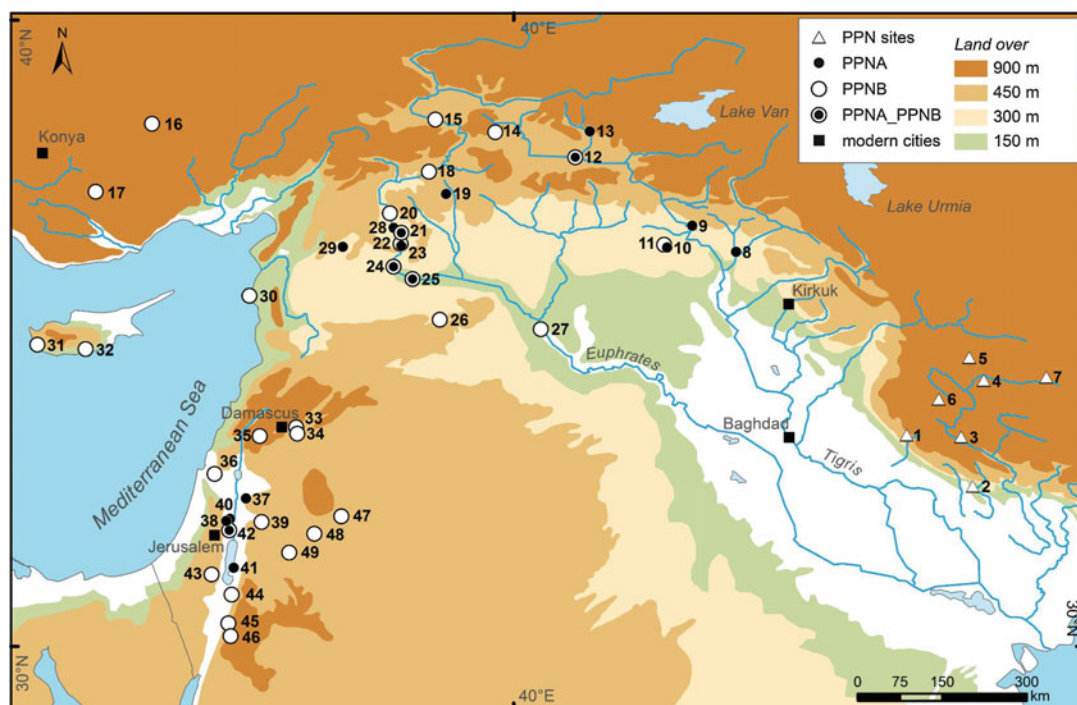
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Agriculture in the Ancient Near East

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Agriculture in the ancient Near East is a topic mainly studied by archaeologists and philologists who contribute to our knowledge with the earliest archaeological evidence of cultivation as well as with complex descriptions of field management through the study of cuneiform texts. Extensive contributions also derive from biological and environmental sciences studying the genetics and origins of our modern crops and the ancient environmental conditions of agricultural development by investigating archaeobotanical, zooarchaeological, and



Agriculture in the Ancient Near East, Fig. 1 Location of the earliest archaeological sites with cultivated and/or domesticated species in the Fertile Crescent: (1) Chogha Golan, (2) Ali Kosh, (3) Chia Sabz, (4) Ganj Dareh Tepe, (5) Sheikh-e Abad, (6) Jani, (7) Tepe Abdul Hosein, (8) M'lefaat, (9) Nemrik, (10) Qermez Dere, (11) Magzalia, (12) Körtek Tepe, (13) Hallan Cemi, (14) Cayonu, (15) Cafer Hoyuk, (16) Asikli Hoyuk, (17) Can Hasan III, (18) Nevali Cori, (19) Göbekli Tepe, (20) Akarcay Tepe, (21) Djade, (22) Halula, (23) Jerf al Ahmar, (24) Mureybet, (25) Abu Hureyra, (26) El Kowm I and II, (27) Bouqras, (28) Abr, (29) Qaramel, (30) Tell Ras Shamra, (31)

Kissonerga, (32) Parekklisha-Shillourokambos, (33) Tell Ghoraifé, (34) Tell Aswad, (35) Tell Ramad, (36) Yiftah'el, (37) Iraq ed Dubb, (38) Gilgal, (39) 'Ain Ghazal, (40) Netiv Hagdud, (41) Dhra, (42) Jericho, (43) Nahal Hemar, (44) Wadi Fidan, (45) Beidha, (46) Basta, (47) Dhuweila, (48) Azraq 31, (49) Wadi Jilat 7; PPNA: Pre-Pottery Neolithic A (9800–8700 BC), PPNB: Pre-Pottery Neolithic B (8600–7000 BC), PPN is applied to Iranian sites, because PPNA and PPNB have additional cultural connotations that do only apply to sites in the western and northern part of the FC

geoarchaeological remains from archaeological sites in this large geographic area.

This article sets a geographic focus on the Fertile Crescent, an area of relatively high precipitation that stretches from the Levant in the west to the Turkish-Syrian border in the north and Iraq and Iran down to the Persian Gulf in the southeast. The Fertile Crescent is the area where agriculture is known to have evolved and developed into an economy that supported the emergence of ancient civilizations (Fig. 1). The close relationship between cultural and agricultural development defines the structure of this entry with tripartite division into (1) emerging agriculture in Neolithic populations; (2) the

establishment of agricultural production, expansion of human populations, and genesis of first cities; and (3) complex agricultural systems in city-states and oriental empires until roughly 300 BC.

Emerging Agriculture

Considered as the basis for the development of early civilizations, agricultural beginnings reach back more than 12,000 years. Archaeological and archaeobotanical research in the Fertile Crescent during the last decades decisively determined our current knowledge on the earliest findings of

systematically gathered wild progenitor species of modern crops in the late Upper Paleolithic period (ca. 21000 BC), on the cultivation of wild cereals, and on the appearance of first domesticated species in the Aceramic Neolithic (syn. Pre-Pottery Neolithic) period.

The first domesticated species in the Fertile Crescent are einkorn (*Triticum monococcum* ssp. *monococcum*), emmer (*Triticum turgidum* ssp. *dicoccum*), barley (*Hordeum vulgare*), lentil (*Lens culinaris*), garden pea (*Pisum sativum*), chickpea (*Cicer arietinum*), bitter vetch (*Vicia ervilia*), and linseed (*Linum usitatissimum*) (Fig. 2). Singular finds of broad bean (*Vicia faba*) and grass pea (*Lathyrus sativus*) have also been discovered in the Aceramic Neolithic, but become frequent only from the late Neolithic onwards. Possibly also rye belongs to the early domesticated species, as recorded at Abu Hureyra and a number of other sites (Hillman, Hedges, Moore, Colledge, & Pettitt, 2001). It disappears from the Fertile Crescent during the early Holocene and has its comeback only in the Central European Iron Age. Remains of free-threshing wheat (*Triticum aestivum/durum*) also occur very early, but become abundant not before the Early Bronze Age. Horticulture starts much later than the cultivation of cereals, pulses, and linseed – in the Chalcolithic period at earliest.

While the use of plants in subsistence has already been demonstrated for Paleolithic sites, the so far oldest evidence for systematic large-scale gathering of wild cereals dates to 21000 BC and derives from late Upper Paleolithic Ohalo II in Israel. The cultivation of wild cereals started between 9500 and 9000 BC in the Aceramic Neolithic (syn. Pre-Pottery Neolithic) period at a small number of sites (e.g., Jerf el Ahmar, Syria, or Chogha Golan, Iran).

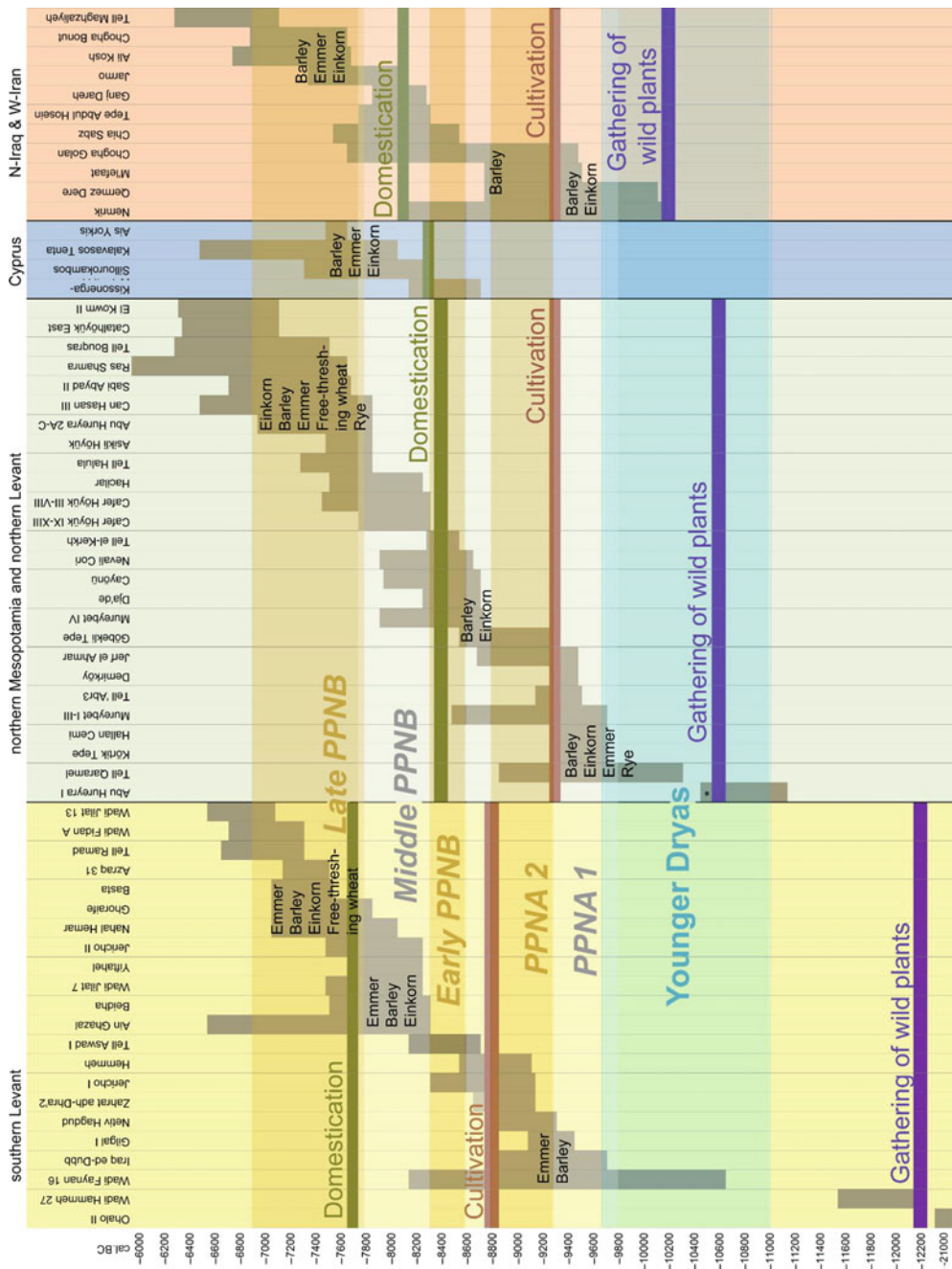
Populations of Aceramic Neolithic sites with evidence of pre-domestication of wild cereals continued hunting wild sheep and goat, while for some of the sites, the beginning management of these animals is suggested (Zeder & Hesse, 2006). Early settlements of cultivators are often accompanied by storage structures, ground stone tools such as grinding stones and mortars, and, as concerns possible, harvesting tools, sometimes

yield blades with sickle gloss (Riehl, Zeidi, & Conard, 2013; Fig. 3). During these periods changes in the settlement structures were also observed and related with population growth and social change, including monolithic communal architecture.

Until recently important questions on the emergence of agriculture were addressing the timing and the localization of early domesticated species. There is meanwhile agreement that domesticated species occurred in a number of archaeological sites throughout the Fertile Crescent (multiple origins model; Fuller, Willcox, & Allaby, 2011) more or less simultaneously from the PPNB onwards and started to dominate plant assemblages from the mid-PPNB (Pre-Pottery Neolithic B; 8300–7500 BC) onwards (Nesbitt, 2002; Fig. 2).

Domesticated species evolved through the management of their wild progenitors; thus the identification of cultivation of the wild progenitor species (syn. pre-domestication cultivation) is essential for our understanding of how hunter-gatherers evolved into farmers. Pre-domestication cultivation began more or less simultaneously, but the crop species cultivated varied in the different areas (Willcox, 2013). Archaeobotanical data suggests that the transition from pre-domestication cultivation starting around 9500 BC to the first occurrence of domesticated phenotypes took several hundreds of years; thus archaeobotanical and archaeological research questions on the emergence of agriculture now address the reasons for the slow development of agriculture, while some genetic studies on modern cereal crops still favor models of a rapid transition to agriculture.

The role of climate has been frequently discussed as one potential main release factor for the emergence of agriculture. While earlier studies were attributing more relevance to the cooler climatic conditions of the Younger Dryas, suggesting a decrease of resources to have pushed hunter-gatherers into agriculture, recent research acknowledges regional variation of climatic effects due to the very diverse geomorphological layout and rather focuses on the warmer and moister conditions during the early



Agriculture in the Ancient Near East, Fig. 2 Timeline of levels of plant management throughout the Epipaleolithic and Aceramic Neolithic periods in the different regions of the Fertile Crescent



Agriculture in the Ancient Near East, Fig. 3 Archaeological tools with potential agricultural use from the Aceramic Neolithic site of Chogha Golan (Iran); from *left to right*: mortar, pestle, blades

Holocene to have provided an ideal environment for larger-scale cereal cultivation. Also the end of the early Neolithic (PPNB cultures) has been related to climate fluctuations – the 8200 BP event, respectively (Bar-Yosef, 2009).

Most of the local evidence for climate effects on subsistence development is however currently too coarsely resolved to allow general conclusions on the relationship between climate fluctuations and the emergence of agriculture. Future research will have to focus on local paleoclimate archives in the direct vicinity of archaeological sites to address questions of interactions between people and climate.

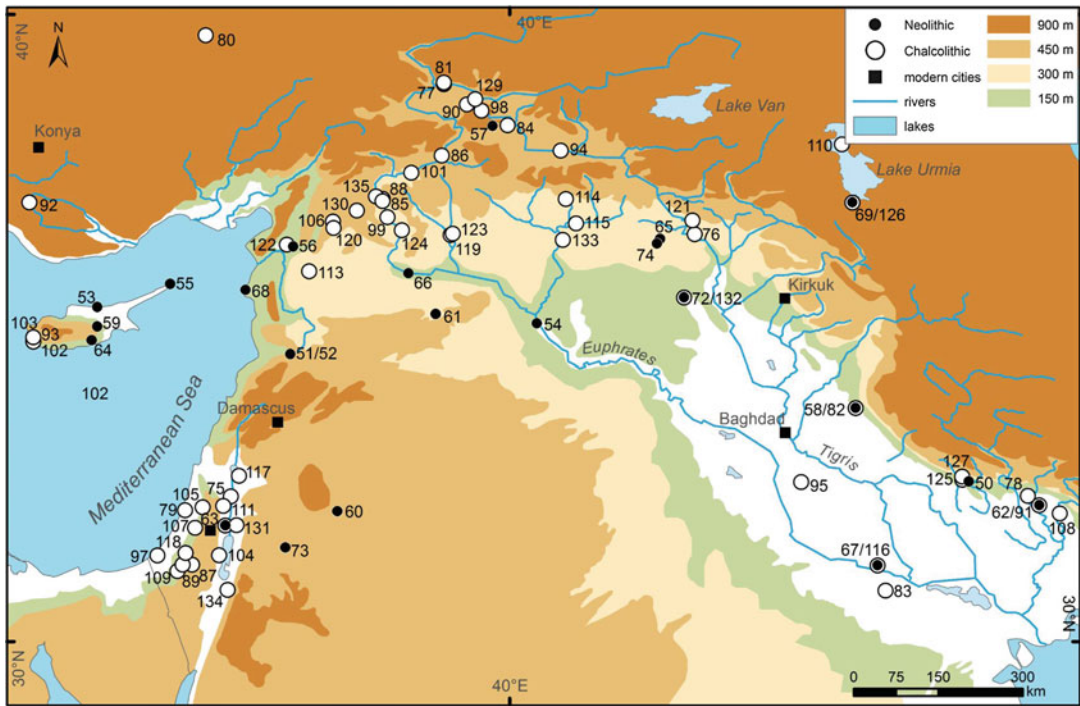
Established Agricultural Societies

While the emergence of agriculture fascinated many researchers, much less is known on agriculture in settlements of the Pottery Neolithic (syn. late Neolithic: 6800–5300/5200 BC), while there is more information again on Chalcolithic (5200–4000 BC) agriculture (Fig. 4).

For the late Neolithic a variety of cultures overlapping in space and time has been defined, such as the Hassuna (c. 6500–6000 BC), Samarra (c. 6000–5500 BC), or Halaf cultures (c. 6000–5400 BC), with settlements of very diverse size, duration, and layout. Although

some settlements were very large and of long-term occupation (e.g., Tell Sabi Abyad or Tell Halula), small, temporary sites were much more frequent, suggesting that the population had a high degree of mobility (Akkermans & Schwartz, 2003).

As concerns agriculture, this period may be seen as a consolidation period when domesticated species had completely replaced their wild progenitors; cultivation on extended territories and intensive storage along with an increase in pastoralism took place, which allowed population growth (cf. Neolithic demographic transition). Agriculture was cereal based with mainly barley and emmer wheat. Free-threshing wheat is also present in larger numbers in some Syrian settlements, while einkorn is better represented towards the coast in Palestine, Cyprus, and Turkey. All other early Neolithic crop species continued to be cultivated. Despite a focus on crop species, wild plants still seem to play a major role in the human diet, and similarly hunting contributed largely to subsistence. Although ancient people were always using a wide array of plant food, the cultivation of vegetables is extremely difficult to prove, because in contrast to seeds and fruit stones, their soft tissues preserve rarely in the archaeological context and they are extremely difficult to identify. Therefore knowledge on vegetable cultivation mainly derives from the textual evidence of the Early Bronze Age onwards



Agriculture in the Ancient Near East,

Fig. 4 Archaeological sites of the late Neolithic (Pottery Neolithic) and Chalcolithic periods with archaeobotanical information: (50) Ali Kosh, (51) Arjoun, (52) Arjoun, (53) Ayios Epiktitos Vrysi, (54) Bouqras, (55) Cape Andreas Kastros, (56) Catal Hoyuk, (57) Cayonu, (58) Choga Mami, (59) Dhali Agridhi, (60) Dhuweila, (61) El Kowm I, (62) Jaffarabad, (63) Jericho, (64) Khirokitia, (65) Magzalia, (66) Tell Abu Hureyra, (67) Tell el'Oueili, (68) Tell Ras Shamra, (69) Tepe Hasanlu, (70) Tepe Musiyan, (71) Tepe Yahya, (72) Umm Dabaghiyah, (73) Wadi Jilat 7, (74) Yarim Tepe I, (75) Abu Hamid, (76) Arpachiyah, (77) Aswan region, (78) Bendebal, (79) Bnei Beraq, (80) Çadır Höyük, (81) Cayboyu (Aswan), (82) Choga Mami, (83) Eridu, (84) Girikihacian, (85) Hacinebi Tepe, (86) Hassek Höyük, (87) Hirbet el-Msas (Tel Masos), (88) Horum Höyük, (89)

Horvat Beter, (90) Ikiztepe, (91) Jaffarabad, (92) Jawa, (93) Jericho, (94) Kenan Tepe, (95) Kish, (96) Kissonerga, (97) Kissufim Road, (98) Korucutepe, (99) Kosak Shamali, (100) Kumtepe, (101) Kurban Höyük, (102) Lemba-Lakkous, (103) Mylouthkia, (104) Nahal Mishmar, (105) Nahal Qanah Cave, (106) Oylum Höyük, (107) Sataf, (108) Sharafabad, (109) Shiqmim, (110) Tappeh Gijlar, (111) Tel Saf, (112) Tell Abu Matar, (113) Tell Afis, (114) Tell Aqab, (115) Tell Brak, (116) Tell el'Oueili, (117) Tell Esh-Shuna, (118) Tell Halif, (119) Tell Hammam et-Turkman, (120) Tell Ilbol, (121) Tell Karrana, (122) Tell Kurdu, (123) Tell Sabi Abyad, (124) Tell Shiukh Fawqani, (125) Tepe Farukhabad, (126) Tepe Hasanlu, (127) Tepe Sabz, (128) Tepe Yahya, (129) Tepecik, (130) Tilbeshar, (131) Tuleilat Ghassul, (132) Umm Dabaghiyah, (133) Umm Qseir, (134) Wadi Fidan, (135) Yarim Höyük

(Waetzoldt, 1987). The occasional presence of storage of wild plant seeds in Neolithic sites (Fairbairn, Martinoli, Butler, & Hillman, 2007) suggests a broad-spectrum economy rather than specialized agricultural production. On the other hand, irrigation techniques as evident for the central Mesopotamian Samarra culture (e.g., Choga Mami; Helbaek, 1972) imply collective aims to increase crop yields in these societies which consequently led to a higher degree of specialization. In a highly variable landscape like the Fertile

Crescent as a whole, with regionally strong susceptibility to drought, people were settling in regions where freshwater was easily available, even in the regions of higher precipitation such as northern Syria during the Neolithic Halaf period, where most of the sites were located close to flowing water.

The Chalcolithic period is associated with a range of changes in the organization of subsistence and lifestyle. The southern Iraqi site of Tell al-Ubad (6500–3800 BC) is name giving for the

cultural traditions of the Chalcolithic. The Ubaid culture expanded into northern Mesopotamia roughly 1,000 years later and is considered as the starting point towards urbanization and the basis for the later Sumerian civilizations in the south. Small cities and religious centers developed in this area (e.g., Eridu), and together with a precursor of the later emerging writing system, the beginnings of controlling trade were set (Nissen, 1999).

Farmers of the southern Mesopotamian Ubaid culture were applying irrigation techniques on the alluvial soils of the Euphrates resulting in high yields which supported rapid population growth. The presence of early irrigation has been recognized also in the geoarchaeological record, i.e., directly in the forms of canals and indirectly by the location of archaeological sites in regions of low mean annual precipitation (Wilkinson, 2003).

The Chalcolithic period is also closely related to the beginnings of horticulture. As it requires the technological knowledge of vegetative propagation, it is generally considered to have developed after grain agriculture had been fully established. In contrast to cereal agriculture, there is also a higher necessity of a year-round sedentary lifestyle to protect the plants from pests and browsing damage which should have resulted in a generally lower mobility at least for parts of the population.

In the archaeobotanical record, the morphological differentiation between wild and domesticated fruit stones is generally problematic which explains the difficulty to determine the precise beginnings of fruit domestication. Also the extent of fruit cultivation is impossible to assess without textual sources which are available only from the Early Bronze Age onwards.

While single olive stones occur at least since the Aceramic Neolithic or even earlier (e.g., at Epipaleolithic Ohalo II/Israel), they become more frequent in the Chalcolithic period. The natural distribution of wild olive (*Olea europaea* ssp. *oleaster*) follows the Mediterranean coast, limited in distribution into the inland regions of the Fertile Crescent through summer drought. This explains the presence of olive mostly in the

western part of the Fertile Crescent during the Chalcolithic period. Olive finds from further inland Early Bronze Age sites are discussed for their origin, as irrigation practice may well have allowed olive cultivation outside its natural distribution area, while trade of economic products already played a certain role and may have equally contributed to the extended area of findings. A comparatively moister climate during the early to mid-Holocene may have also played a role in ancient crop plant distribution differing from modern patterns (Riehl, Pustovoytov, Weippert, Klett, & Hole, 2014).

In contrast to olive the natural distribution of wild grape (*Vitis vinifera* ssp. *sylvestris*) extends further inland along the lower foothills of the Taurus Mountains between southern Turkey and northern Syria. Its archaeological finds therefore extend further into these inland regions during the Chalcolithic period. Although earliest finds of grape date back to the Neolithic period, its domestication in the Fertile Crescent has long been considered to have happened during the Early Bronze Age. However, recent findings, such as the Chalcolithic winery of Areni in Armenia (4000 BC), suggest possibilities of earlier or simultaneous cultivation outside the Fertile Crescent (Barnard, Dooley, Areshian, Gasparian, & Faull, 2011).

As with the two previous fruit crops, fig (*Ficus carica*) has been found in early prehistoric sites, but its domestication probably occurred during the Chalcolithic period, although there are claims for domestication at Aceramic Neolithic Gilgal I/Israel (Kislev, Hartmann, & Bar-Yosef, 2006). Seeds of wild fig are indiscernible from domesticated seeds and a final proof of very early domestication is therefore pending. Its relatively large size and high content in carbohydrates may explain its attractiveness for gathering humans.

Date (*Phoenix dactylifera*) is mainly found in archaeological sites located within the natural distribution area of the tree which is south of 32°N latitude. Beside of some very early finds, date stones appear domesticated around 4000 BC in southern Mesopotamia at the site of Eridu and a number of other Chalcolithic sites in Iraq, Iran, and Jordan. It becomes a very important

economic plant in later history, i.e., during the Early Bronze Age when oasis agriculture developed (Tengberg, 2012). Rosaceae fruits (apple, pear, plum, cherry) need grafting/vegetative propagation and are intensively cultivated not before classical antiquity (Greek and Roman times).

The end of the Chalcolithic has been related with diverse catastrophic events, including invasions and climate change, i.e., the 5200 BP event (Bar-Matthews & Ayalon, 2011). Such an event, as recorded for the western part of the Fertile Crescent, may have resulted in increased interannual variation in precipitation and extended droughts that would have affected yields. Although the $\delta^{13}\text{C}$ record in Chalcolithic barley grains reflects increased drought for Tell esh-Shuna in Jordan and Tell Shioukh Faouqani in northern Mesopotamia, the effects in other regions of the Fertile Crescent of such climate fluctuations may have been very diverse (Riehl, Pustovoytov, Weippert, Klett & Hole, 2014).

Complex Agricultural Systems

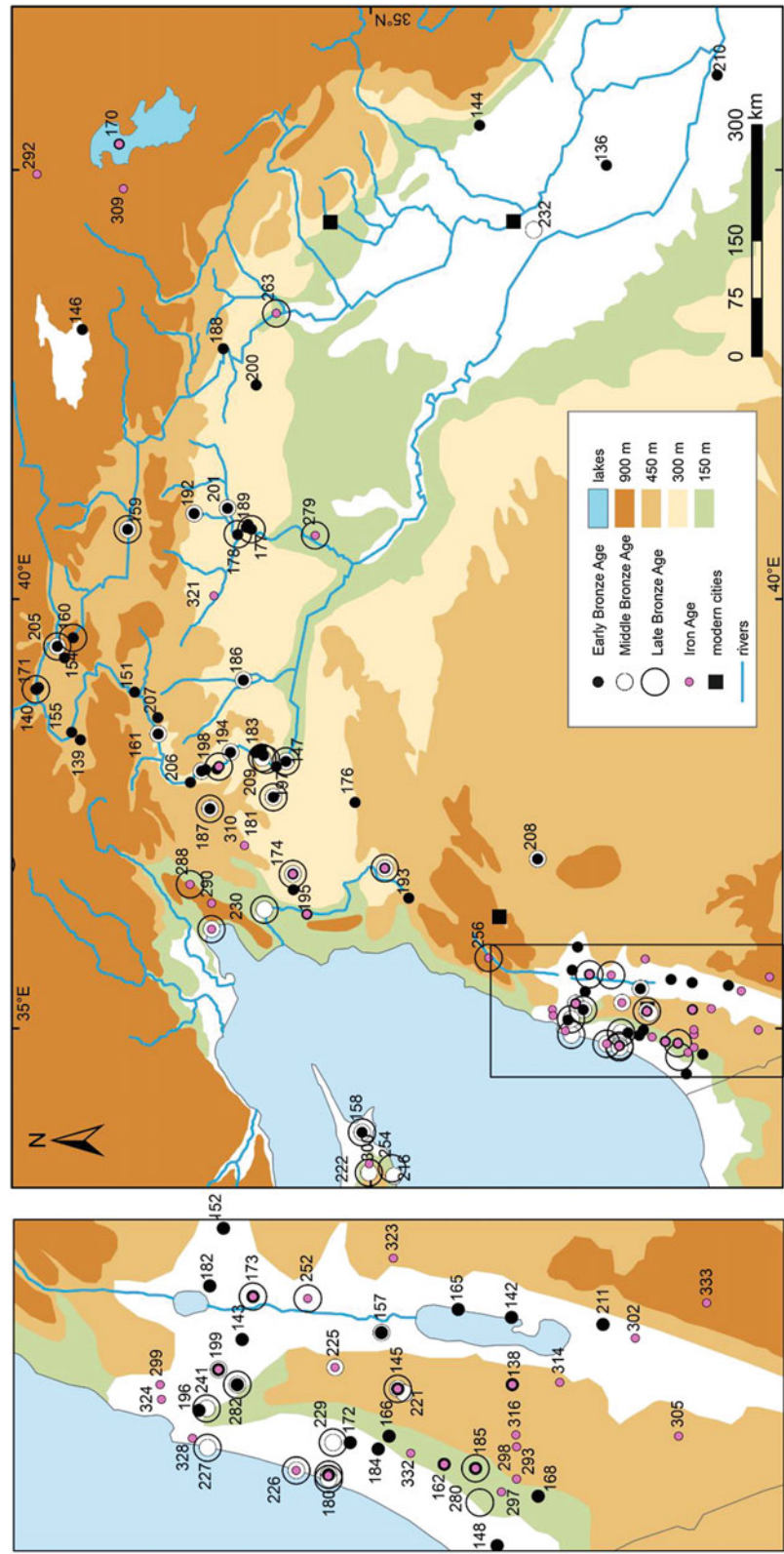
The city-states and empires of the Bronze and Iron Ages and their sociopolitical layout under numerous different kings cannot be discussed here in detail (for more information, see Akkermans & Schwartz, 2003; Van De Mierop, 2003; Nissen, 1999; and other textbooks). There is a massive amount of data on agricultural techniques in southern Mesopotamia from cuneiform texts (various volumes of the *Bulletin on Sumerian Agriculture*), while information on agricultural production in other regions of the Fertile Crescent also derives from archaeological and archaeobotanical studies (Fig. 5).

The Uruk period (4300–3100 BC), the transition from the late Chalcolithic Ubaid into the Early Bronze Age period, combines all attributes of increasingly complex societies, such as population growth and progressive social stratification, including side effects of competition for resources and the need for institutionalized organs coordinating the more and more complex processes within the society. The development of

writing in form of pictograms supported the increasing complexity of administration.

These developments were part of the urbanization process which was naturally bound to increasing agricultural yields which were particularly profitable in regions with developed irrigation systems (Postgate, 1992). Geoarchaeology considerably contributes to our knowledge of how these systems functioned and could be maintained in the face of changing environments and increasing food demands from rising populations. Five stages in the development of Mesopotamian irrigation systems can be discerned from their initial development in pre-historic times to their demise starting in later Islamic times (Wilkinson, 2003, chap. 5).

With the beginning of the Early Bronze Age, cities of various ranks evolved also in upper Mesopotamia and Syria, although the type of city-states, based on agricultural surplus, only becomes evident from 2600 BC onwards. The processes that started in the Chalcolithic period continued in the following Early Bronze Age Jemdet Nasr (3100–1900 BC) and Early Dynastic (2900–2334 BC) periods when the plow was developed and agricultural surplus was used for importing other goods into the south, such as construction wood and mineral resources through long-distance trade. Trade of agricultural products such as olive oil and grape wine is well documented in cuneiform sources from the Early Bronze Age (e.g., Ebla/Tell Mardikh 2400 BC) onwards as well as in later archaeological finds, such as the Late Bronze Age shipwreck of Uluburun (Haldane, 1993). While single oil presses are known from the Mediterranean region during the Chalcolithic, they only become more frequent during the Early Bronze Age. Agricultural surplus production was regionally intensified by focusing on few crop species with reliable yields, such as barley which was a main crop in many northern Mesopotamian cities (e.g., Emar; Riehl, Pustovoytov, Dornauer, & Sallaberger, 2012). The broad spectrum of crops observed since the Neolithic was however still cultivated, but barley became the most abundant cereal crop during the Early Bronze Age. Free-threshing wheat was cultivated particularly in inland



Agriculture in the Ancient Near East, Fig. 5 Archaeological sites of the Bronze Age periods and the Iron Age with archaeobotanical information (locations with multiple numbers are multi-period sites; only the first number appears in the map): (136) Abu Salabikh, (137/212/289) 'Atfala, (138/291) Arad, (139) Arslantepe, (140/141/249) Aswan region, (142) Bab'edh Dhira, (143) Beth Shean, (144) Choga Mami, (145/213/251/295) City of David, (146) Dilkaya Höyük, (147/214/253) Emar, (148) En Besor, (149) Gre Virike, (150) Hajji Ibrahim, (151) Hassak Höyük, (152) Hirbet ez-Zeraqon, (153) Horum Hüyük, (154) İkiztepe, (155) İmamoglu, (156) Jawa, (157/215) Jericho, (158/217/255) Kalopsidha, (159/218/257) Kenan Tepe, (160/259) Korucutepe, (161/220) Kurban Höyük, (162/304) Lachish, (163/261) Malyan, (164/223) Mezraa Höyük, (165) Numeira, (166) Sataf, (167) Shahr-i Sokhta, (168) Shiqmim, (169) Sotira Kaminoudhia, (170/315) Tappeh Gijlar, (171) Taskun Mevkii (Aswan), (172) Tel Dalt, (173/267/318) Tell Abu al-Kharaz, (174/228/268/319) Tell Afis, (175) Tell al-Raq'a i, (176) Tell al-Rawda, (177) Tell Atij, (178/271) Tell Bderi, (179/231) Tell Brak, (180/233/272/320) Tell el Ifshar, (181) Tell el'Abd, (182) Tell Esh-Shuna, (183) Tell es-Sweyhat, (184) Tell Gezer, (185/275/322) Tell Halif, (186/236) Tell Hammam et-Turkman, (187) Tell Jerablus Tahtani, (188) Tell Karrana, (189) Tell Kerma, (190) Tell Matsuma, (191/237/277/325) Tell Mishrifeh, (192/238) Tell Mozan, (193) Tell Nebi Mend (Kadesh), (194/239) Tell Qara

settlements, while emmer wheat was represented with higher proportions in the coastal regions. Particularly for the sites in the north (e.g., Urkesh/Tell Mozan), knowledge on ancient agriculture is well founded on bioarchaeological results (Doll, 2010; Riehl, 2010b). While in the drier south irrigation was necessary to receive sufficient yields to support large populations, farming was mostly rain-fed in the north, although the water of the rivers Khabur and Euphrates could have been used occasionally for irrigation of specific crops, as is evident for later periods at the upper Euphrates (Riehl 2010a).

While potential weed species are already identified in Aceramic Neolithic sites, and in these contexts interpreted to indicate early cultivation of wild progenitor species of modern crops, they are much more numerous from the Bronze Age onwards and have been used by archaeobotanists to investigate local crop husbandry practices at some archaeological sites (van Zeist, 1993).

Textual evidence suggests that the central organization of the northern Mesopotamian city-state included the majority of the inhabitants and that agriculture was organized as collective labor (Sallaberger & Ur, 2004), which would correspond to organizational forms in southern Mesopotamia, although irrigation was not a significant part of labor organization in the north. Redistribution of the communally harvested crops according to status seems to have been the rule. For southern cities very detailed information on the organization of crop and animal husbandry, including administrative management, is

available from textual records (e.g., Hruska, 1990; Powell, 1984). As taxation could have been a problematic burden particularly in years with crop failures, the economic relations to the north and other regions for subsidizing were a significant political aspect. Increasing population pressure particularly in the south is considered to have provoked competition for resources between different city-states during the Early Dynastic period which was accompanied by developing dynasties and war.

Shortly before the end of the Early Bronze Age, the Akkadian Empire (2334–2193 BC) becomes dominant in the whole region of southern and northern Mesopotamia and beyond. In the south the third dynasty of Ur came into power in the twenty-first century BC for a short time. Involved into diverse warfare, accompanied by famine, it came to an end around 2004 BC. The collapse of the Akkadian Empire at the end of the Early Bronze Age has frequently been related with the Holocene climatic fluctuation of 4200 BP (Staubwasser & Weiss, 2006). It corroborates the geoarchaeological record in the region, indicating a distinct change in the regime of water streams from relatively stable, moderately strong water flows to increasingly rare, erratic, and stronger flows, which suggests increasing aridity (Riehl et al., 2012). As large-scale environmental change is generally related to bottlenecks in agricultural production and accompanied by migration (e.g., the nomadic Amorites), upheaval, raids (e.g., invasions of the Gutians), and war may have contributed to the collapse of the empire, similarly as with Ur III. In fact, archaeobotanical

Agriculture in the Ancient Near East, Fig. 5 (continued) Quzaq, (195/326) Tell Qarqur, (196) Tell Qashish, (197) Tell Selenkahiye, (198/281/330) Tell Shiukh Fawqani, (199/240/282) Tell Taannach, (200) Tell Taya, (201) Tell Zagan, (202/242/284) Tepe Farukhabad, (203/243) Tepe Hissar, (205/244/285) Tepecik, (206/245/286) Tilbeshar, (207) Titris Höyük, (208/246) Umbashi, (209/247/287) Umm el-Marra, (210) Ur, (211) Wadi Fidan, (216) Kalavassos village, (219/258/303) Kinet Höyük, (221) Manahat, (222/262) Marki-Alonia, (224/264/308) Pirak, (225/311) Shiloh, (226/265/317) Tel Michal, (227/266) Tel Nami, (229/269) Tell Aphek, (230/270) Tell Atchana, (232) Tell ed-Der, (234/273) Tell Gerisa, (235/274) Tell Hadidi, (241/283) Tell Yoqneam, (243) Tepe Hissar, (248) Apliki, (250) Ayios Dhimitrios, (252/296) Deir'Alla, (254) Hala Sultan Tekke, (256/301) Kamid el-Loz, (260) Kusakli, (263/306) Nimrud, (276) Tell Hwes, (278) Tell Munbāqa, (279/329) Tell Schech Hamad, (280) Tell Sera, (288/334) Zincirli, (290) 'Ain Dara, (292) Bastam, (293) Beer-Sheba, (294) Çadir Höyük, (297) En Rahel, (298) Hirbet el-Msas (Tel Masos), (299) Horbat Rosh Zayit, (300) Idalion, (302) Khirbet en-Nahas, (305) Moa, (307) Nush-i Jan, (309) Qal'eh Ismail Aqa, (310) Rifa'at, (312) Susa, Ville Royale, (313) Tahirbaj Tepe, (314) Tamara, (316) Tel 'Ira, (321) Tell Halaf, (323) Tell Hesban, (324) Tell Keisan, (327) Tell Qasile, (328) Tell Qiri, (332) Tzafit, (333) Udhrum

barley from this region shows increased drought stress in the second half of the Early Bronze Age (Riehl, Pustovoytov, Weippert, Klett & Hole, 2014). Extended drought may have also strongly affected agricultural production further south by decreasing yields and increasing soil salinity which has been already discussed in earlier works on southern Mesopotamian agriculture (Jacobsen & Adams, 1958).

During the Middle Bronze Age (c. 2000–1500 BC), the major empires of Babylonia (c. 1894–539 BC), a foundation of the nomadic Amorite dynasties, located in southern Mesopotamia, the Old Assyrian Empire (c. 2000–1400 BC) in the area of the upper Tigris river in northern Mesopotamia, and the Hittites (2000–1200 BC) were controlling the Near East, probably with a certain continuity of economic interests that already existed during the Early Bronze Age.

The political history of the Middle Bronze Age empires is well documented in ancient texts, and there is equally comprehensive information on agricultural organization in the middle Euphrates region (Lafont, 2000) and crop products in the Hittite area of influence in central Anatolia (Hoffner, 1974).

While the middle and lower Euphrates regions are bare of any archaeobotanical studies, some few results from Hittite settlements in Anatolia indicate a broad-spectrum plant production with additional crop species, such as einkorn (*Triticum monococcum*), spelt (*Triticum spelta*), or millet (*Setaria italica*), that are not cultivated farther south. This supports the importance of cereals in the Hittite economy as suggested by the cuneiform evidence, indicating a high diversity of names describing different types of bread. Lentil is the generally preferred pulse crop, as archaeobotanical studies mostly in northern Mesopotamia and the Levant suggest, although its cultivation slightly decreases during the Middle Bronze Age. The reduction of some of the pulse crops with higher water requirements corroborates a general trend in the Middle Bronze Age which has been interpreted as a shift in agricultural production towards more drought-resistant species as a consequence of increasing aridity with the end of the Early Bronze Age (Riehl,

2009). In most of the Syrian archaeological sites, barley is the main crop. At the middle Euphrates city of Mari, the lack of man power for cultivating the fields was a problem leading to local underproduction which forced the palace to acquire barley on the market (Lafont, 2000).

For Babylonia, there is no indication of economic decline in the first three centuries of the second millennium, although in the north political conflict and continuous change of political regimes and economic structures seems to have been the rule during the Middle Bronze Age.

The Late Bronze Age saw a number of different competing kingdoms and powers, expanding and retreating in the different geographic areas of the Fertile Crescent (for details on the political and cultural history, see Nissen, 1999) which probably had its effects on agricultural economy.

An influential Hurrian state in northern Mesopotamia at the transition from the Middle to the Late Bronze Age was Mitanni (1500–1300 BC). The end of the Middle Bronze Age is marked by the attack of the Hittites on Yamkhad, a northwestern Mesopotamian kingdom with its center at modern day Aleppo.

Material culture and the continuation of important empires such as the Hurrians and Hittites suggest an even transition to the Late Bronze Age (Akkermans & Schwartz, 2003). Some Hurrian settlements already existed during the Early Bronze Age (e.g., Urkesh/Tell Mozan). Egypt was also strongly represented, particularly in the area of modern Syria. Overseas trade played an increasing role and was a sign of, and a means for, the international character of a large number of territorial states, shaping agricultural production for specific needs, such as olive oil and wine.

Although with the transition from the Middle to the Late Bronze Age, many powerful cities disappeared, and discontinuation of administrative and scribal practices decreased, in terms of cultivated crop species, there is no particular difference visible between Middle and Late Bronze Age agriculture, despite a possible intensification of olive cultivation through extending the production area into the northern Levant and the upper Euphrates region (Riehl et al., 2012).

The end of the Bronze Age has often been explained as a consequence of the putative invasion of the Sea Peoples. Aside from political conflicts, economic decline has been proposed as a reason for the collapse of the Late Bronze Age civilizations as well as a climatic impact (Bond event no. 2).

The global cooling event between 1200 and 700 BC (Bond et al., 2001) corresponds well with the stable oxygen isotope data from Lake Van (Litt et al., 2009) and thus might have had an impact on Near Eastern agriculture. A climatic reasoning has also been discussed in the literature before, as the “1200 BC hypothesis” of increased aridity (Neumann & Parpola, 1987), supported by archaeoclimatological models (Bryson, Lamb, & Donley, 1974). Similarly Rohling, Hayes, Mayewski, and Kucera (2009) have suggested that the cooling period at the end of the Late Bronze Age adversely affected the agricultural quality in the northern and northeastern regions of the Aegean, thus triggering end-of-Bronze Age migrations.

Most likely complex interactions between political and ecological factors were responsible for these massive supraregional changes. Complete restructuring of the society must have taken place due to large-scale nomadization, migration, internal population movements, and technological and trade network changes. How these changes influenced agricultural organization is still unclear, but there is also some evidence for the maintenance and restoration of the lower Khabur and middle Euphrates canals by local rulers (Fales, 2008).

With the beginning of the first millennium BC, the political situation in the Near East had become more stable, and a new network of states arose, which becomes tangible in the ninth century BC by written records again. Iron Age Syria has been characterized as a region of numerous small states, which was absorbed into the provincial systems of vast multiregional empires (Akkermans & Schwartz, 2003). The generally broadening network of commercial connections doubtlessly had an influence on agricultural production.

Agricultural organization during the Neo-Assyrian Empire (934–609 BC), which

embraced practically the whole Near East, was the planned distribution of rural labor forces, the installation of large-scale irrigation systems, and a centralized program of rural land settlement policy (Bagg, 2000). Agricultural surplus was also possible due to a dense rural population.

New crops appear in the archaeobotanical assemblages, such as cotton (*Gossypium* sp.), pomegranate (*Punica granatum*), and cucumber (*Cucumis sativus*), most of them requiring irrigation in areas of irregular and low rainfall. This corroborates the importance of irrigation as is evident from the texts. Changes in persisting crop species are particularly visible in free-threshing wheat and grape ubiquities, which occur generally more often in the archaeobotanical record of the Iron Age (Riehl, 2009) and which are confirmed by the textual evidence of numerous vineyards in northern Mesopotamia. The larger body of textual evidence from the first millennium also reveals more linen textiles than in the second millennium. Flax for linen production requires additional irrigation. Still, the textual evidence is almost exclusively for the import of linen as tribute from Syria to the Neo-Assyrian Empire. Only later during the Neo-Babylonian period (626–539 BC) do we find evidence for more frequent linen cultivation. Olive is not frequently mentioned in ancient texts, but the import of olive oil from the west is attested, corresponding with the archaeobotanical record. A local increase in the water supply is also visible in the Iron Age $\delta^{13}\text{C}$ values (Riehl, Pustovoytov, Weippert, Klett & Hole, 2014).

Perspectives

Although substantial contributions are available from ancient philology, archaeology, and the natural sciences on different aspects of ancient Near Eastern agriculture, no systematic overview has been published yet, which is partly due to the diversity of the sources and the methodological problems of interpreting these sources within a wider framework.

The rich textual record of cuneiform tablets, which has been estimated to number more than

500,000 texts, covers a broad range of information related to agriculture that has not yet been systematically analyzed. Archaeobotanical databases (e.g., www.ademnes.de) comprise millions of seed records from Near Eastern sites. Local geoarchaeological studies, including geographic information system (GIS)-based analysis of satellite imagery and modeling, have been published and helped with the identification of settlement and land use patterns as aspects of early economic systems in some few regions of the Near East. Additional independent methods, such as stable carbon isotope analysis, which has been used for investigating water stress on crop plants during their grain-filling period, can help verify these results. Syntheses of these different data sources, after careful analysis of the methodological problems, will provide more comprehensive results on ancient agriculture in the near future, which may be also of some relevance to issues of conservation of genetic resources in the Near East.

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Agriculture in the Islamic World

Lucie Bolens

The success of classical Islamic agriculture is due to the adaptation of agrarian techniques to local needs, and this adaptation itself is due to a spectacular cultural union of scientific knowledge from the past and the present, from the Near East, the Maghreb and Andalusia. A culmination more subtle than a simple accumulation of techniques, it has been an enduring ecological success, proven by the course of human history.

In the definitions which open the *Kitāb al-filāḥah* (Book of Agriculture), this function is

said to be blessed by God because it has as its end the production of the sustenance of life. Agriculture consists of restoring to the earth what has been furnished by harvesting from it, by fertilizing, watering and making efforts to avoid the problems caused by excessive heat. This restoration to the soil implies a knowledge of the whole – the soils, the plants, the most suitable tools. Balance (*mizān*) is the aim, or reciprocity between what is taken from the earth and what must be given back in order to make this vital alliance with Nature endure.

The complex union of facts with the general conjunction of the Mediterranean world between the eleventh and the fifteenth centuries means that a de-positioning of history is indispensable for understanding a crisis as well as a success. No progress is linear, and it is always useful to draw inspiration from the aleatory nature of history, in order that this discipline, fundamentally cultural, may also have a practical impact.

The successional right of the four Islamic judicial schools permits “holdings” according to a customary right which is similar to the right to private property of the Romans. Royal power encouraged territorial expansion among the princes of the blood and high officials of the state.

From a historical point of view, the important thing is the fact of reciprocal information throughout the *Dār al-Islām* (the Islamic world). There emerges the impression of a coherent school and a general movement – of people, goods and ideas – from the East to the Islamic West.

The ancient tradition, prolonged and recovered from the ancients (*al-Alwālī*), integrated the ideas of fourth century scholars like Aristotle, Dioscorides, Galen and Anatolius Democritus with those of the botanists of the ninth century and contemporary scholars of geponics, the art and science of cultivating the earth. If the mysterious *Filāḥat al-Nabaṭiyyah* (Nabataean Agriculture, by Ibn Wahshiyyah, ca. 1,000) traces the origins of agriculture back to Adam, those who lived in the classical age were equally inspired by knowledge obtained from anonymous farmers who retained the memory of ancient ways. Tradition and scientific curiosity have not always been at odds with each other.

On a religious level, the earth and water, as in the Hebraic tradition, belong to no one person; they belong to God. Historical accounts of Islamic expansion distinguish between Arab lands and lands situated in the conquered countries. Under the early caliphs, Arab lands were surveyed and registered. A basic tax was established, 10 *dirhams* for a *jerib* of grapes, 8 *dirhams* for a *jerib* of palm trees, 6 on a *jerib* of sugar cane, 2 on barley. The *jerib*, a unit of measure, equaled 360 cubits, according to al-Mawardī. The lands of people who freely converted to Islam were subject to a deduction of a tenth, *dīme*, varying according to province and century from the eighth to the twentieth centuries. In Andalusia, the tax was one-fifth. After the Reconquista, the farmers there continued to be called *quinteros*.

Lands which were forcibly conquered were redistributed. Al-Wanshārīsī, a fifteenth century Maghreb legal expert, notes numerous examples for studying classical Islamic agriculture in Andalusia and the Maghreb.

Collective lands, *jema'a*, existed in certain parts of *Dār al-Islām*, used for the movement of flocks of large and small grazing stock. Cultivated land was also divided up legally and parceled out.

“Tributary” lands were conquered lands lying outside Arabia, beginning with Syria (Sham). They were considered lands not belonging to anyone, the property of the state or the caliph. By contrast, they were left to their former owners, according to a right of use. A land tax called *kharaj* was paid to the Treasury (*bayt al-māl*) and the amount of tax was set according to the quality of the soil. From the 700s, the principle was applied in the form of a supplemental tax to Jews, Christians and Sabeans, being the *Ahl al-kitāb* (People of the Book), or *dhimmis*.

Individual land holdings were called *iqṭā'*; they were lands grafted to a private individual according to clauses which were more or less restrictive depending on rents. All lands which the caliph gave to his subjects so that they might transform and cultivate them were so designated. *Waqf* lands were lands granted by private individuals to mosques, hospitals, schools and other

charitable institutions. They are often translated as charitable properties. They were not subject to land speculation.

All these lands, except for the *waqf* properties, could be the object of commercial transaction – sale, rent, or purchase – which had nothing to do with feudal land statutes. In the twelfth century, the Sevillian Ibn Abdūn, in his *Treaty of hisbās*, encouraged personal appropriation of land as a means of stimulating economic growth.

The information which appears in the documentation needs examining. It is based on experimentation which resulted in the shattering of prior philosophical premises. Empiricism appeared to be the condition of renewing knowledge and techniques. Ibn al-ʿAwwām writes: “I affirm nothing which seems right to me without having proven it in numerous experiments”. In agriculture, the results refer to the practical successes of sheaves of grain, fruits, or taxes.

The theory of climates, *al-iklim*, compares Andalusia with Iraq and makes pertinent constant reference to Nabatean agriculture.

“Indeed”, writes Ibn al-ʿAwwām, “what suits our country is the result of what comes from the concordance of tradition with experimental results”. The respect for ecological balance – *mizān* – between the soil, the micro-climate, and various cultivated plants guarantees the success of the harvest. The “weather” governs the results, and the seasons are stated in the “Calendar of Seville” according to their names in Syrian, Persian, Hebrew and in indigenous romance languages. More subtle than a syncretism, it was a question of a whole society.

Islamic agriculture had, at first, been Arab agriculture, since Islam first appeared in the Arabian peninsula, among the Bedouins and camel drivers. Around the big cities, agriculture was the agriculture of the oasis, a natural miracle brought about by the presence of water in a desert of sand and stones. The history of agriculture in Islamic countries, established over a long duration as Fernand Braudel has described, is made up of a fundamental unity. The first great geo-climatic regions were sub-arid dominants around the Mediterranean basin. The Umayyad empire, then the Abbasid empire,

finally integrated the sub-tropical regions with temperate ones. However, the essential originality of Islamic agriculture is still linked to the Mediterranean regions and to the fluvial valleys. The first Islamic empires and the caliphate of Andalusia owed their agriculture to the great rivers carrying water and fertilizing silt (alluvium); the Tigris, Euphrates, Nile, Guadalquivir and the Guadiana all gave both soil and waterless, sun baked lands.

Between the seventh and the thirteenth centuries, the displacement of peoples and technical skills gave rise to a migration of cultivated plants, from the East towards the West, from subtropical zones towards the Mediterranean basin, from the monsoon regions to semi-arid lands; from China towards Persia, passing through India; and from Afghanistan towards the Fertile Crescent and the Maghreb, creating in its passing the gardens of Sicily and of Andalusia. Just as the ancient Romans constructed aqueducts and waterworks to provide food on a scale for the cities and municipalities which were their centres of power, so the Islamic empire, founded on caravan cities, also wove a net across the countryside of hydraulic equipment for agricultural adaptation, for example *acequias* [an earthen channel that conveys water], *qanats* [a water management system] and *norias* [a stone grinding wheel]. In spite of the progressive climatic diversification which occurred as the area ruled by Islamic law increased, from the Sudan to the Caspian seaports, from the Straits of Gibraltar to the boundaries of the Ottoman Empire and to India, the determining character of their agricultural system remained the adaptation of irrigation to local and regional needs and the spread of plant species away from their original ecosystems.

The spread of agricultural land and the intensification of irrigation in sub-Iberian regions which tended to be hot and very humid sub-arid areas were spectacular. Legal aspects of land holding were closer to those of Rome and Byzantium than the medieval West. Individual property ownership was actively encouraged.

Technological and cultural methodologies were informed by the need for renovation while

remaining empirical. Among the agrarian jobs, that of the autumn harvest is characteristic in that the human job prevails over the financial investment. The swing plough was preferred over the heavy Brabout plough of the French colonist; not exposing the deep beds of cultivated land to erosion and intense heat was the golden rule of ecology in Andalusia. In the golden Andalusian age, this protection of the Mediterranean soils was subject to laws of a scrupulously careful ecology. The *mishā*, a heavy, hand-held spade was the tool for restoring the soil. The object of such agriculture was closing the soil, not opening it.

Among agricultural systems, the biennial rotation of crops is essential for maintaining fallow fields. Biennially or by a more complex number of years, but always by an even number, the rotation of crops shows a deep understanding of the plant world. The refertilization of soil, the base of all agriculture, comes about through the joint knowledge of plants and soils, the mastery of botanical and edaphic science. In Andalusia, well before the era of the English physiocrats of the 1800s, this agriculture revolution was closely based on high level of knowledge of the life sciences and on a love of nature which was the common gift of both the Islamic and the Hebraic tradition.

Certain plants modified dietary habits, for example sorghum, a common basis of diet in Asia and Africa; rice in flooded areas; sugar cane which is used for preserving and for therapeutics; the eggplant transported by the Jews in the second diaspora; citrus fruits from China; durum wheat from Africa, a nutritional mainstay in the form of bulgur and couscous; watermelons; and banana trees, acclimated in Egypt before arriving in the Maghreb and Andalusia.

The cultivation of other plants influenced styles and types of clothing throughout the Islamic regions. There was cotton, introduced to Andalusia after the arrival of the Kurd Ziriya in the 900s, dye plants which brought a passion for Persian and Indian colours to the puritanical Berbers, and perfume which supplied the base of a whole range of products, such as lotions, salves, and soaps, and which was manufactured from the

almost limitless supplies of fragrant flowers from Turkey and Morocco.

With a deep love of nature and a relaxed way of life, classical Islamic society achieved ecological balance, a successful average economy of operation, based not on theory but on the acquired knowledge of many civilized traditions, a society which wanted to live without the spectre of famine and hunger.

Colonialism seriously upset the traditional agricultural balance in order to increase profitability for the colonizers. This has been widely written about and is proven today by global economic realities. In the 1900s, colonial settlers and city authorities (wrongly) interpreted the indigenous practice of transhumance (moving flocks of animals from one area to another) as non-ownership of land. This distortion of a multisecular custom of complement between plant and animal husbandry (for example, in the Maghreb) caused grave damage to the native economy. Colonial agriculture thus found pseudo-legal advantages in a vast redistribution of land, which brought great economic benefit to the colonial settlers who had come out from the cities and towns.

We are witness today to the slow recovery of agrarian balance in former colonies like Algeria.

See Also

- [Irrigation in the Islamic World](#)
- [Qanat](#)
- [Technology in the Islamic World](#)

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Agriculture in the Pacific

William C. Clarke

The environments where traditional agriculture was practiced in the Pacific Islands ranged from frost-prone but gardened mountain slopes at 8,500 ft (2,600 m) in Papua New Guinea to tiny atoll islets lying scarcely above the reach of the waves in the always warm equatorial ocean. Heavy downpours almost everyday keep some places in the Pacific Islands permanently humid; short wet seasons followed by long dry spells characterize the rainfall in other places. Still others with almost no rainfall are true deserts. Some single islands contain this whole range – the big island of Hawaii, with its high, massive volcanoes and its sharply contrasting windward and leeward coasts, is a notable example of such climatic variety. A comparable dissimilarity exists in Pacific Island soils, with some young volcanic soils being highly fertile, whereas on atoll islets the only natural soil material may be rough coral rubble, which is alkaline, has a very low water-holding capacity, contains little organic matter, and is unable to supply plants adequately with many of the nutrients required for vigorous growth.

Traditional Pacific Island agriculturalists met this wide range of often challenging conditions with an even wider range of agronomic techniques and crops, which enabled food production on all but the most barren islets or at the highest elevations of the larger volcanic and continental islands. This universe of agroecosystems included elaborate terracing and irrigation to grow the water-loving taro, massive drainage

works to grow less water-tolerant crops such as sweet potatoes, mulching and composting to enrich the soil and to slow water loss, planting crops in built-up mounds of soil to encourage cold-air drainage and so lessen frost damage, planting in excavated pits to reach the water table on dry atoll islets, and (in systems of shifting cultivation) the use of forest or woodland fallow – planted in some places, spontaneously natural in others – to restore fertility to soils after they had been gardened.

The Origin and Evolution of Pacific Island Agriculture

When, from the sixteenth century onwards, European explorers began to encounter the sophisticated Pacific Island agriculture then practiced, it was not surprising that some of them believed they had sailed to a Garden of Eden, where breadfruit trees and coconut palms provided food without work, and where only a little labor was needed to make irrigated terraces of taro bear heavy harvests of starch-rich corms or tilled beds of sweet potatoes produce many baskets full of nutritious tubers. Initially, Europeans saw this productive agriculture as though it were some sort of a divine gift given to the Pacific Islanders, who had been favored with gardens and orchards that yielded unchangingly through time and that remained continuously in harmony with local environments. It is now clear on the basis of the extensive research into Pacific prehistory carried out only over the past few decades that such a view is far from accurate.

Pacific Island agriculture has never been static. It has been evolving constantly from its beginnings, as migration led people to new environments where there were previously unknown wild plant species, as the agriculture itself changed the environment, as the need for food expanded with growing island populations, as new crop plants were introduced, or as the agriculturalists experimented and introduced productive innovations. The Pacific Island agriculture first seen by Europeans was only an instant snapshot of a long and very dynamic history.

Twenty-five years ago it would have been asserted confidently by many scholars that Pacific Island agriculture had originated in southeast Asia and that Pacific Island cultivated plants had been domesticated in that same hearth. All that the ancestors of Pacific Islanders had done was to carry the Asian techniques and crops with them as they dispersed to the farther oceanic islands. It was recognized that the sweet potato and a few other less important crops did not fit this scenario, having been shown to have originated in the American tropics. However, the presence of these exceptions was explained away by various, often fanciful, theories of migration or simply as the result of introductions by Portuguese or Spanish voyagers during the fifteenth and sixteenth centuries – though recent archeological research in the Cook Islands (central eastern Polynesia) shows the sweet potato to have been present there by about AD 1000.

We know now that although some plants of Southeast Asian origin and domestication were transferred without significant change far into the Pacific (some species of yam, for instance), there is also evidence in support of early indigenous domestication and development of agriculture in the Pacific, specifically in western Melanesia (Solomon Islands and the island of New Guinea). The length of occupation there (at least 40,000 years in New Guinea) is more than sufficient for the experimentation necessary for independent domestication. And chromosomal and paleobotanical studies now indicate that plants that may have been domesticated in this region include sago, one type of *Colocasia* taro, one kind of banana, sugar cane, *Canarium* (a nut-bearing tree), *Saccharum edule* (a relative of sugar cane with an edible inflorescence), *kava* (the ritual and social drink still important in many parts of the Pacific Islands), and a variety of other plants, including several fruit trees. This attention to trees and the creation of orchards is a characteristic of food production all across the Pacific and was probably carried by itinerant colonist-cultivators from its place of origin in western Melanesia to Polynesia and Micronesia.

Further, especially strong evidence for the early development of agriculture to the east of southeast Asia comes from an archeological study in the Papua New Guinean highlands at a place called Kuk. A great deal has been written about Kuk, and the evidence has been interpreted in various and changing ways, but there is general agreement that Kuk demonstrates a long history of agricultural development, beginning about 9,000 years ago and involving, among much else, an ever-growing complexity of drainage works and water control in a large swamp, changes over time in cropping combinations from mixed gardens to taro monoculture to sweet potato dominance, responses to deforestation and land degradation brought about by shifting cultivation on the surrounding slopes, and the development of planted or encouraged tree fallows. Kuk, as well as evidence from pre-history elsewhere in the Pacific, shows that a dynamic agronomic and botanical science has long existed in the Pacific, in terms both of basic understanding and applied techniques. The origins of agriculture in the Pacific can now be said to have a time depth comparable to that of better known sites in southwestern Asia and tropical America.

No less mistaken than the view that traditional agriculture has been static in the Pacific Islands is the view that it has always been in harmony with its environment. Rather, as in the history of any dynamic agriculture, there have been episodes of deforestation, serious soil erosion, land degradation, and crop failure. Pacific Islanders did what all peoples, especially pioneers, do: in their efforts to make a living, they actively manipulated, modified, and, at times, degraded the ecosystems in which they lived, producing environmental changes that in turn required ecological adaptations and social adjustments. Considering the whole landscape, the most widespread of the human-induced changes in the prehistoric Pacific has been deforestation, with the cleared forests replaced by grasslands that required cultivation techniques different from those associated with forest-fallowed gardens. In many places, fire-maintained fern grass savannas underlain by infertile, eroded, or

truncated soils came into existence or were extended by agricultural activities. This distinctive plant – soil complex is known as *toafa* in several Polynesian islands and as *talasiga* in Fiji. These dramatic landscape changes resulting from pioneering clearance for agriculture did not, however, bring unmitigated environmental degradation. Rather, in many places, they resulted in what has been termed “landscape enhancement,” whereby the eroded soil transported down the slopes filled in the lower valleys and created swampy zones that were ideal sites for what came to be sustained yield, intensive cultivation of wetland taro. Other responses included the development of dryland cultivation techniques to cope with the changed agricultural environment, irrigated terracing, and an elaborated use of trees.

Traditional Agriculture in the Pacific Islands

The wide range of agricultural systems and techniques devised by Pacific peoples over millennia can be considered as ways of solving the agronomic problems presented by the great variety of island environments. For instance, in forested areas of low population density, soil fertility was maintained by simple no-tillage shifting cultivation wherein natural forest fallow rehabilitated the soil after gardening. Where forest was diminished, leguminous or other nitrogen-fixing trees (such as *Casuarina* spp.) were encouraged or planted. In grasslands a variety of mulching and composting techniques were developed. On atolls where soil was poor or absent and rainfall often low, Islanders created an ingeniously productive and sustainable agricultural environment for the giant swamp taro (*Cyrtosperma chamissonis*) by excavating a pit to reach the water table (“the freshwater lens”) below the coral rubble and building up fertile soil in the pit by composting leaves of breadfruit and several other wild or semidomesticated trees as well as seaweed, pumice, and other materials.

The management of wet and dry conditions by irrigation and drainage was widespread and

ranged from very simple ponds and small ditches to elaborate, kilometer-long, stone-lined channels and extensive hillside terracing. Irrigation and drainage were not necessarily spatially exclusive in that the ditches that drained water away from sweet potato beds were used to provide a moist growing site for taro and other water-loving crops. Water control may also have been used to control insect pests. As population densities increased or as political control expanded enabling greater labor mobilization, some systems of wet cultivation of taro in Polynesia became very intensive, productive of yields as high as from 30 to 60 metric tons per hectare.

The agricultural tool kit of the traditional Pacific was simple, mostly derived from unprocessed natural materials: wood, plant fiber, stone, shell, and bone. Wooden spades were elaborated in places where tillage and swamp cultivation was common. Wooden hoes were made here and there but were rare. The paramount agricultural tool was the digging stick. Used for loosening soil, digging roots and corms, making holes for planting and house posts, or as poles for carrying burdens, digging sticks ranged in size from heavy, 2-m, two-man tools used cooperatively to turn grassland or swampland sod to the light sticks used by girls to open shallow holes in soft forest soil. They remain widely in use today, and modern technology has yet to find a better tool for planting taro.

Before being replaced by steel tools, stone adzes and axes were effective in opening vast areas of forest and were far more sophisticated than they might seem at first glance. For instance, the cutting edges of stone axes might be faceted and asymmetrical to make resharpening more effective and to prevent the blade sticking in the tree during felling. Wooden spades and the way they were handled had similarly subtle attributes.

Organization of agricultural labor varied across the Pacific, with, for example, men doing the clearing but women most of the gardening in Melanesia, whereas in Tonga and Samoa in Polynesia men carried out all the agricultural tasks. Traditional Pacific livestock comprised the pig and chicken. Pigs were of great importance ritually and socially in many places and were a way to

“bank” the food produced in tuberous starchy vegetables, which did not store well. During the periods when pigs were being accumulated for ceremonial feasts, considerable land and agricultural labor would be devoted to producing their food.

Like all traditional agriculturalists, Pacific Islanders possessed an enormous store of knowledge about both the domesticated and the wild plants and animals in their environment. This indigenous knowledge was organized by means of complex folk taxonomies that provided a framework for pleasurable intellectual activity as well as serving practical purposes. Similarly, aesthetics was a part of Pacific Island science of agriculture and land use management. Pacific people in traditional landscapes enjoyed the arrangement of productive diversity all around. Medicine here, perfume there, fiber in the hibiscus stem, fruit, timber, edible leaves, and so forth. There is a strong aesthetic pleasure in these observations of utilitarian diversity. As Malinowski (1935) wrote about the Trobriand gardens he made famous in Papua New Guinea:

The gardens are, in a way, a work of art. Exactly as a native will take an artist's delight in constructing a canoe or a house, perfect in shape, decoration and finish, and the whole community will glory in such an achievement, exactly thus will he go about the laying out and developing of his garden. He and his kinsmen and his fellow-villagers as well, will be proud of his labours. . . . During all the successive stages of the work, visits are exchanged and mutual admiration and appreciation of the aesthetic qualities of the gardens are a constant feature of village life.

In the Pacific, as elsewhere, the complexity of traditional agriculture has undergone a simplification in modern times. Polycultural gardens of subsistence crops have been replaced by monocultural stands of commercial crops such as coconuts, ginger, coffee, and citrus. Intensive systems of irrigated taro or dryland yam cultivation have fallen out of use, often replaced by the less demanding cassava (manioc). On the other hand, with the current interest in locally based sustainable development, there is a growing concern to revive some of the indigenous traditional systems that served Pacific Islanders well in their past.

See Also

► [Agroforestry in the Pacific Islands](#)

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Agriculture of the Ancient Maya

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The Maya are a diverse group of Native Americans, who speak 31 languages within the

Mayan Language Family. They live in Southern Mesoamerica, in Mexico from Chiapas through Yucatan and south through Guatemala in the Peten lowlands and mountainous highlands and into Belize, Honduras, and El Salvador. Settlements started as early as 2,000 BCE along the mangrove coastal margins of the Pacific, but most settlements started after about 1200 BCE, with identifiable ceramics, and lasted through the Pre-Classic 1200 BCE to BCE 250 and the Classic Period from (BCE 250) to (BCE 850). Declines or transitions punctuated their history at the end of the Pre-Classic, perhaps in the Middle Classic, (BCE 500), the sharp decline often called the Maya “Collapse” in ninth century (BCE), and the population collapse due to the diffusion of European diseases and conquests starting in the sixteenth century. All but the last of these major transitions are regional, and the most famous is the Terminal Classic Collapse of the ninth century (BCE), which occurred in the central lowlands of Guatemala’s Peten state and adjacent Belize, Honduras, and Mexico’s Chiapas and southern Yucatan. Much of the writing about the Maya, including about its agriculture and environment, focuses on this Terminal Collapse and the Late Classic period (BCE 550–850) that preceded it though more and more publications are dealing with both the pre and post classic periods. The terminal classic in the central Lowlands represents an end to this intensive urban and agricultural civilization’s great achievements in building, writing, art, astronomy, and agriculture, and the relatively quick return of tropical forests that enveloped the temples and terraces that had functioned for centuries.

The Maya World has two main geographic divisions: volcanic highlands and limestone lowlands. The highlands center on a series of north-south running and variably active volcanoes along the Pacific Coast side, which abut a complicated series of metamorphic and sedimentary rocks to their east. The Maya farmed these slopes and river valleys from Chiapas, Mexico into Guatemala, Honduras, and El Salvador. These uplands generally have deep and fertile soils, though rainshadow driven dryness, steep slopes,

some poor soils, and seismic volcanic events have limited subsistence in different places at different times. The lowlands mainly refer to the limestone Yucatan platform ranging from Mexico, through Guatemala, to Honduras. Within this division are the karst plains of the northern Yucatan with no rivers but sinkholes, the faulted, karstic central and southern Yucatan, the more complicated geology to the south (including the granitic Maya Mountains); and the surrounding coastal zones with rivers and more coastal resources.

Climate also varies significantly across this region, from the semi-arid northwest Yucatan with about 500 mm of annual rainfall to the high elevations of the Maya Mountains that receive almost ten times more rainfall. Generally, the lowlands receive about 1,000–2,000 mm of rainfall and most of the region does have a distinct dry season from December to May that must be figured into every agricultural practice and adaptation in the region. These general regions all provide different potential resources and limitations for agriculture. One limitation for the whole region was recurring drought that corresponds to cultural declines especially with the Terminal Classic Collapse (Hodell, Brenner, & Curtis, 2000).

Research into Maya agriculture is long and rich. The start of agriculture in the Maya World comes from the earliest evidence of maize in the floodplains of coastal Veracruz by about 7,000 BP and evidence from starch grains for root crops in nearby Panama comes about the same time (Piperno, Ranere, Holst, & Hansell, 2000). This beginning of Mesoamerica’s great triumvirate of staple crops – maize, bean, and squash – comes with the spread of extensive ► [swidden](#) or *milpa* farming and perhaps floodplain farming. This shows up in the Maya Heartland of Guatemala’s Peten and nearby Belize from about 5,000 to 4,000 BP as increased charcoal and pollen from the weeds that usually accompany agriculture. Pollen from maize and manioc actually show up before 5,000 BP in Belize (Jones, 1994; Pohl, Pope, Jones, Jacob, Piperno et al., 1996).

In the early twentieth century, scholars viewed swidden agriculture as the means for how the

ancient Maya fed themselves because many had observed *milpa* farming across the region and studies showed that it provided a level of subsistence needed for the dispersed populations of a tropical forest civilization. In the 1960s, though, many scholars came to see the *milpa* as insufficient to feed the growing estimates of ancient Maya populations. Many regional surveys started showing more and more large-scale Maya sites that must have had high populations, and studies for decades had reported evidence for intensive forms of agriculture, including extensive, well-made terraces.

The agricultural staples of the Maya worlds were of course maize, beans, and squash, though there were a host of other possible and known crops like cassava, sunflower, amaranth, and many other fruits and vegetables, whether cultivated or collected. There were also sources of meat from turkeys, ducks, doves, deer, fish, and other animals, though what role they played in Maya agriculture and what proportion of Maya diets they made up is still not well known. Cacao was certainly an important commodity grown in different environments over much of the Maya Lowlands. Since we know from documents and archaeological evidence that the Maya and other Mesoamerican peoples highly prized cacao, scholars have tried to identify cacao in many possible ways: by noting the requirements of the crop, using ethnohistorical information, and looking for pollen and other fossil evidence. Tobacco, cotton, palms, and many others were nonsubsistence crops. This cornucopia of known foods has also fueled discussion of other possible staples to feed large populations and solve the riddle of Maya subsistence (Dahlin et al., 2006). Scholars have found evidence for use of many other crops like agave and many arboreal ones like ramon or breadnut (Gomez-Pompa, Salvador Flores, & Aliphath Fernandez, 1990).

Forms of Agriculture

We should note that we still know little about the agriculture of the ancient Maya, but many traditional and novel techniques are turning up more

evidence with each field season (Beach, Luzzadder-Beach, & Dunning, 2006b). Traditional research tools are still the backbone of research and include regional survey, sampling, mapping, and archaeological excavation. Adding to these methods have been an array of steadily improving geophysical, chemical, and biological methods. Each of these methods are whole subjects in themselves but we should not divorce a discussion of the methods from the findings, because techniques change and may make findings obsolete. For example, remote-sensing technologies have added to our breadth of knowledge, but some radar images have produced false-positive identifications for vast wetland agriculture in areas that are not even wetlands.

We can divide ancient Maya Lowlands agriculture into upland and lowland forms and outfield and infield forms. Upland agriculture occurred on well-drained and seasonally drained soils and lowland farms had to contend with seasonally or perennially high water tables. Outfields simply refer to fields at some distance from Maya sites and infields were agricultural areas within or adjacent to sites and thus more likely the focus of intensification techniques.

One type of infield in Maya societies is kitchen gardens or solares, which is still a common feature of traditional and indigenous communities. These, like similar farming systems around the world, are intensive, high input, close-to-home adaptations for growing crops. Kitchen gardens often use polycultural methods that grow as much on small areas as possible by arranging crops at different levels or canopies. Ethnohistorical studies have found that polycultural gardens produce about 11 % of domestic caloric intake and few bulk staples, focusing more on dietary supplements, medicinals, ornamentals, and ritual objects. Archaeological evidence such as the size of walled areas around mounds may however, suggests greater pre-Hispanic contributions from kitchen gardens at certain periods (Beach et al., 2006b).

In uplands, *milpa*, or slash and burn farming, is the mainstay of nonintensive agriculture. A *milpa* is small farm that *milperos* slash and burn usually toward the end of dry season

(from December to May). *Milperos* slash the tropical forest vegetation today with metal machetes (or more mechanized implements) but had to use stone tools in antiquity. They would slash vegetation, including girdling trees to make the vegetation dry enough to burn, and thus produce enough wood ash to enrich and prepare the seed bed for planting. They would usually plant multiple crops (e.g., corn, beans, squash, and chilies) in each milpa and indeed prepare more than one milpa every year to insure against the vicissitudes of climate (e.g., drought and hurricanes) and pests in these seasonally dry tropics. Each milpa might remain productive for 2 or 3 years and then weed competition and nutrient depletion would drive farmers along to new areas to slash and burn. Farmers might return to the old milpas after fallows of 10 or more years and restart the process. Although this is extensive agriculture, farmers might intensify this by shortening the fallow time, but this requires more labor for weeding and fertilizing (Beach et al., 2006b).

Upland agriculture occurred along slopes of varying degrees and, for any semblance of long-term sustainability, required conservation techniques to limit soil erosion in the Maya Lowlands, where the limestone soils were already thin, and in the Highlands, where slopes are much steeper and longer. We have substantial evidence that soil erosion, in lake sedimentation and buried depression soils, started early, by about 3,000 BP, in the Maya Lowlands. Rates of erosion only rise when major drivers of erosion occur and the main evidence for such drivers is the coincidence of weed and crop pollen, charcoal, and mineral sediments. These link deforestation and Maya farming together with increased runoff, caused by some combination of decreased transpiration and infiltration into soils. The increased erosion may have also coincided with another erosion driver, namely moving deforestation onto steeper slopes, where gravity can act to accelerate overland flow and all major types of water erosion. Modern evidence in this region shows that erosion rates are very high after deforestation and soils erode to bedrock surprisingly fast. Some scholars have even linked soil erosion

with the Terminal Maya Collapse (Beach, Dunning, Luzzadder-Beach, Lohse, & Cook, 2006a).

Ancient Maya farmers, like early farmers everywhere, had to adjust their early pioneering experience. They had several options that all required more labor inputs: conservation techniques on slopes or management of flat or depression environments. The least laborious options would have been to farm flat areas, but there were too few flat areas that were not seasonally waterlogged around the settlement-carpeted limestone, karstic ridges of much of the central Maya Lowlands.

Upland Agriculture and Terrace Systems

In many places around the Maya Lowlands are large tracts of terraced lands. Indeed, travelers have mentioned terraces since at least the early twentieth century, and they have since identified many types of terraces that take advantage of specific slope situations. Terrace systems are intensive forms of agriculture that attempt to engineer slopes to make them sustainable. Indigenous terrace systems, starting more than 5,000 years ago, are nearly a universal human adaptation to farming on steep slopes, with several ancient terrace systems such as those in the Philippines, recognized as UNESCO World Heritage Sites. The factors that make steep slopes unsustainable are thin soils that cannot store enough water or nutrients and extremes of water: either too much destructive overland flow or too little to support crop needs during the dry season. Thus for terracing to be worth the heavy labor efforts, farmers must build up soils, minimize the impacts of overland flow, and maximize soil moisture for the growing season. Terrace systems also must return nutrients harvested in crops to maintain crop yields over time. Studies have thus attempted to find evidence for soil depletion coinciding with the Terminal Classic Collapse as well as find evidence for terrace soil maintenance from night soil, composted waste, and wetland organic matter (Turner, 1974; Beach, Luzzadder-Beach, Dunning, Hageman, & Lohse, 2002).

Terraces must function to slow the destructive force of overland flow, divert water away or to soils, help drain excess water, and dam up soils and potential fertility. There are surprisingly common terrace remnants left in the Peten after more than a thousand years and most tend to be engineered from limestone boulder dams, though some are earthen and some might have been vegetative hedges as well, which have left no obvious traces. The terrace dams were either single rows of large boulders or double rows of boulders with gravel, cobble, and ceramic fills. They often had gravel bases and cobble buttresses and some still testify to pre-Maya times with soils buried below the terrace dams and below soil sequences that filled in behind the dams unintentionally or by active human manipulation. Terraces occur in many slope positions: contoured around slopes, across channels, as boxes with little slope, around crests, and prominently at the base of slopes. Some landscapes have all types; others only have one. Since each has a different slope position, each creates a different microenvironment with different soil moisture conditions and aspects or orientations to the sun. In most cases a large part of the terrace system has eroded away, and, thus, our real evidence for an agricultural landscape integrated with diversion canals is often only theoretical.

All of the terrace types are common, though box terraces are much smaller and more easily expunged by tree roots and slope wash. Some scholars have linked these systems with intensive nursery crops that could be replanted at some point in their lifecycle. Footslope terraces show up in many places because they are usually constructed of larger boulders that persist through time. These may have functioned to build up some areas above water tables in large, low elevation seasonal wetlands. Hence, we think the base of slopes that often ring depressions was an important focus of agriculture, where soil depth, fertility, and moisture could have been managed to lengthen the growing season. Likewise, upland sinkholes, called *aguadas* or *rejolladas*, could also have been a focus for agriculture because soil depths, fertility, and moisture could have been managed to lengthen growing seasons.

Some evidence exists for early terrace adoption, perhaps by 2600 BP, though most evidence of terracing coincides with the other large-scale building of the Late Classic period. Many sites in the Maya world, such as Caracol, La Milpa, the Rio Bec, Xunantunich, and the Petexbatun, had widespread terracing by the Late Classic period, though other notable sites like Copan and the Central Peten lakes region provide only meager evidence (Beach et al., 2002, 2006a, 2006b; Beach & Dunning, 1995).

Another form of upland soil management is field ridging, which looks like plowed furrows but required significantly more labor in Maya societies where beasts of burden were not available. Field ridging has been reported in many parts of Mesoamerica, but the most significant are the preserved fossil ridges in the ash covered, Maya Pompeii site of Ceren, El Salvador, which blankets a Classic Maya village from ca. BCE 650. The low ridges formed the seedbeds, and maximum air and water drainage could occur in the furrows. At Ceren, only one of eight excavated fields was in fallow, probably indicating much more intensive farming on these fertile, volcanic soils than could be possible in lowlands milpas that required years of fallow or heavy fertilizing and weeding (Beach et al., 2006a, 2006b).

Lowland Intensive Agriculture

Lowland agriculture takes advantage of low sites where erosion is not significant, but water management is necessary to provide enough water in dry sites and enough root aeration in wet sites. These areas do not suffer from much erosion but all agricultural lands must still be fertilized for intensive long-term cropping.

One particular Maya region provides an interesting case study: the northwest Yucatan site of Chunchucmil. Here the soils are thin or nonexistent and the rainfall is spotty and low; yet this Maya site had many thousands of inhabitants around BCE 400–600, where today a few hundreds have trouble growing enough food. Milpa farming today produces only a small fraction of

food requirements, but somehow high populations occupied this region ca. 1,500 years ago. Thus, either they imported food based on some other trade commodity or they used some extremely intensive systems. One line of evidence lies in the numerous polygonal wall systems around habitation mounds and surrounding empty lands. The walls only tell us that groups were trying keep predators or people out, and scholars are looking for every line of evidence about manufacturing and markets that might have functioned to provide trade goods for food from elsewhere. But these may also have been intensive kitchen gardens with traditional or special crops that were heavily fertilized with all possible wastes the site and organic matter from nearby wetlands. Modern farmers do enhance their solares this way, and we can balance subsistence for large ancient populations by maximizing infield, arboriculture, and surrounding outfield production (Dahlin et al., 2006).

Another type of agriculture that occupies the middle ground between uplands and lowlands is *bajo* or karst-depression agriculture (Beach et al., 2002; Dunning et al., 2002). This ranges from cropping that occupies the backslopes of small sinkholes of a hectare or less called *aguadas* or *rejolladas* to cropping into and around large seasonal sinks called *bajos* that are sometimes many square kilometers. Pollen of maize, cassava, and other crops in bajo sediments shows evidence of nearby agriculture, and excavation of surrounding terrace berms may show soil and water management in these “ecotonal” zones, i.e., regions that straddle two ecosystems.

Agriculture in these bajos was similar to agriculture in seasonally flooding valleys. In these environments, farmers had to manage water extremes, flooding in the wet season and insufficient soil moisture in the dry season. One globally widespread adaptation to such environments is a risky but productive technique called flood recession agriculture. Farmers using this technique plant into the wet soils of receding floods to take advantage of plenty of soil moisture that might get a crop through the dry season. As does all farming to varying degrees, this plays the probabilities of potential drought and enough seed-corn

to persist through recurrent floods. Farmers could also more actively manage soil moisture by ditching, draining, and damming.

Another option for intensive farming was manipulating perennial wetlands (Duzzader-Beach & Beach, 2006). All over the Maya Lowlands perennial wetlands bear witness to a wide diversity of rectilinear features that look like cobwebs or other polygonal patterns from the air. Early on scholars suggested that these may be relicts of ancient Maya intensive wetland cultivation because the patterns look similar to the historical Mexica wetland plots or *chinampas* around the Basin of Mexico, which, like the terraces of the Aztec Realm, were highly productive systems. These *chinampas* are still very much working plots in Xochimilco on the outskirts of Mexico City, though today they are more for flowers and tourists than subsistence.

Farming wetland fields requires using plants that can grow in saturated soils or manipulating the soils and water table. Indeed, one explanation for the polygonal field patterns is that they are simply ditches to drain the fields and lower the water table below the root zone of typical crops. Thus such drained fields could function as long as there was a lower part of the landscape where water could be drained. A more elaborate model is a raised field, in which the ditches are built and the excavated soils and organic matter are used to build up and fertilize the soil plots. In both models, canals can be occasionally cleaned out and used to renew fields. In the Aztec fields, alder and willow trees were planted around the field edges to protect the sides from slumping and erosion (Armillas, 1971). An even more elaborate model envisions a complex of farming and aquaculture akin to the productive but laborious Chinese rice paddy, aquaculture systems.

There are also more natural explanations for the polygonal wetland patterns. These range from human ditching in response to sea level rise and ground water rise to differential expansion patterns caused by a landscape building up from gypsum precipitating from saturated ground and surface waters. The first explanation sees wetland ditching as a Pre-Classic agricultural adaptation to wetland formation, though in the broader

region other research teams saw the same patterns as evidence of Late Classic intensive cultivation with copious evidence for maize. The differential heave explanation does not discount the possibility of human modification of polygonal field patterns but argues for a landscape co-evolving from human and natural factors.

Another hypothetical use of wetlands for agriculture comes from the rock alignments of north-eastern Yucatan. Perhaps these rock-aligned wetlands were used to raise algae or periphyton, which are cyanobacteria communities that have fertilizer and pesticide characteristics. Or, perhaps these were dryland plots created before sea level rise made these wetlands. In either case, Maya scholars have attempted to use every line of evidence and push the limits of science to come up with explanations for Maya subsistence. Sometimes they have pushed too far and too fast, but it was usually in the spirit of seeking out explanations for the profound and vexing riddles of the past.

Debates about all forms of ancient agriculture underscore the difficulty of understanding ancient subsistence. We only have the lines of evidence and no historical accounts. Thus, we have vast terrace systems, walled fields, ridged fields, and numerous wetland polygons that coincide with millions of house mounds and massive buildings from especially the Late Classic. We have evidence of buried soils, elevated chemicals, fossil seeds, pollen, and other proxies of the past.

Since there are many types of intensive and extensive agriculture from around the Maya realm, many Maya scholars think the ancient Maya used heterogeneous types of farming, adapted for the different landscapes, soils, and climates of the region. Many Maya sites are on ecotones, such as at bajo edges and ridges that lie between two and more environments. Around the sites, evidence for many agricultural adaptations often occur. This makes us guess that, where possible, ancient Maya farmers tried to do with intensive systems what contemporary, traditional Maya farmers do in milpas: minimize risk by taking advantage of a diversity of sites. What is different about ancient Maya farming,

however, are the many kinds of intensive agricultural systems with their extremely high labor demands.

See Also

- [Ceramics: Maya Pottery](#)
- [Swidden](#)

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Agriculture: Ancient Methods

Alexia Smith

Today very few communities subsist upon hunting and gathering, with the majority of the world's population living a sedentary life dependant upon agriculture. The shift from gathering wild plants and hunting wild animals to dependence upon crop production and animal herding took place independently in different parts of the world at different times. The earliest development of agriculture is widely thought to have occurred around 12,000 years ago in the Fertile Crescent of Southwest Asia. The Fertile Crescent forms an arc leading up the Levant from the Negev Desert of Israel to southeastern Turkey, turns east along the Taurus-Zagros mountain chain, and then south between the Tigris and Euphrates rivers down to the Persian Gulf. Independent development of agriculture occurred later in South and North China, Central America, South Central Andes, the Eastern United States, sub-Saharan Africa, and perhaps Papua New Guinea.

Food Production Terminology

The ways in which societies throughout the world have organized food production varies greatly through time, and the terminology used to discuss

early agriculture underscores the diversity of methods that can be used to produce or acquire food. In its widest sense, agriculture refers to the cultivation of crops and the rearing of animals. Animal husbandry refers to general animal rearing, whereas pastoralism describes a socio-economic specialization in production where animal rearing forms the primary economic endeavor of a community. The methods of production can vary widely, including nomadic pastoralism, which involves permanent migration and seasonal transhumance – where animals are moved periodically from a home base to pasture land. The term cultivation describes the preparation of land and tending of crops, which can include large- or small-scale crop production and slash-and-burn agriculture. Horticulture relates specifically to the production of fruits, vegetables, and flowers, and in preindustrialized societies was usually garden-based. Domestication is more difficult to define and there is no universally agreed upon definition. In general, however, domestication refers to the selection of desirable traits in plants and animals that leads to the genetic modification of a species, and reduces its ability to reproduce without intervention by people. Desirable traits may include reduced aggression in animals, allowing them to be controlled more easily, or ease of harvest and greater yields in plants. It is possible, therefore, to cultivate wild plants with domestication occurring only when selection processes affect natural reproduction mechanisms.

Evidence for Ancient Agriculture

Throughout the world, writing or notation systems developed well after the beginnings of agriculture, so there are no texts documenting the transition and our knowledge is based entirely on archaeological observations of plant and animal remains, changes in settlement size and patterns, storage facilities, and tools. Zooarchaeology examines ancient interaction with animals. The species, age, and sex of animal bones retrieved from archaeological sediments can be determined by reference to modern

comparative skeletal material, and this information can be used to examine herding and hunting strategies. Paleoethnobotany or archaeobotany examines plant use in the past. Plant remains are preserved on archaeological sites predominantly through charring, an accidental process that renders them inert to bacterial or fungal decay; less frequently plant remains become preserved through waterlogging, desiccation, freezing, proximity to toxic metals, or indirectly by leaving an impression in ceramic vessels. Excellent preservation conditions are provided under waterlogged and desiccated conditions, although such finds are in the minority and are generally restricted to lakes and coastal margins or deserts. Charred remains are retrieved using flotation, whereby an archaeological sediment sample is placed in a large container of water and, following gentle agitation, the plant remains float to the surface where they can be collected. The remains are identified based on morphological similarity to modern reference material, and knowledge of crop and weed assemblages can be used to investigate a number of topics including crop domestication and methods of crop production, harvesting, and processing. Until recently, most paleoethnobotanical research had focused upon identifying cereal, legume, fruit, and weed seeds in the archaeological record but now, following pioneering work by Hather, increasing emphasis is being placed upon identifying tubers and investigating the role that vegetables played in the ancient diet. Such research is in its infancy, however, so the importance of horticulture in antiquity is likely underestimated.

Theories Explaining the Origins of Agriculture

A number of theories have been proposed to explain the origins of agriculture. Since farming was developed independently in different locations, the motives likely vary reflecting local social, cultural, environmental, and climatic factors. In Southwest Asia, the change occurred during a period of climatic amelioration after the Younger Dryas, a cold period marking the end

of the Pleistocene and the beginning of the Holocene. Building upon work by Raphael Pumpelly, V. Gordon Childe argued in the 1930s that climatic deterioration forced people to concentrate within small oases and that these new conditions would have stimulated cultivation. His “Oasis” or “Propinquity” theory is not supported by paleoclimatic data, does not adequately explain the changes, and furthermore is viewed as too environmentally deterministic. To its credit, however, the theory stimulated much research on the origins of agriculture. In the 1960s and 1970s, Binford, Cohen, and Hassan put a number of related “Push” models forward. They argued that population growth or climatic change disrupted the food balance and provided the necessary incentive to begin cultivating crops. These models have also been criticized for being oversimplistic and monocausal as well as deterministic. Flannery expanded upon Binford’s ideas and proposed a “Broad Spectrum Revolution”. Citing data from Southwest Asia and Mesoamerica, Flannery argues that prior to the dependence upon agriculture, people greatly widened the range of plant and animals exploited, and developed new tool types, different methods of storage, and gained familiarity with other food resources. These changes created the necessary preadaptations for cultivation, which he argued most likely occurred in marginal areas on the fringe of production, where wild resources were less abundant. The Broad Spectrum model is largely supported by both plant and animal data from Southwest Asia. Recent research at Ohalo II, a waterlogged site off the coast of the Sea of Galilee where preservation conditions are excellent, has underscored the importance of wild cereal collection by preagricultural groups approximately 23,000 years ago, well before the beginning of farming. Lastly, following critiques of the use of external factors and system analogies to explain change in the past, a number of social or “Pull” theories have been sought to explain the origins of agriculture. Bender and Hayden argue that domestication took place in resource-rich areas and that the ready availability of large amounts of specialty food may have led to social changes within preagricultural societies,

placing greater emphasis on competitive feasting. This, in turn, would have elevated the demand for resources, acting as a precursor for cultivation and later animal herding.

The Rise and Development of Agriculture in Southwest Asia

The first domesticated crops in Southwest Asia include cereals (emmer wheat, *Triticum dicoccum* Schübl.; einkorn wheat, *T. monococcum* L.; and two-row hulled barley, *Hordeum vulgare* subsp. *distichum* (L.) Thell.), leguminous crops (lentil, *Lens culinaris* Medik.; pea, *Pisum sativum* L.; chickpea, *Cicer arietinum* L.; bitter vetch, *Vicia ervilia* (L.) Willd.), and flax (*Linum usitatissimum* L.), which together form the “founder crops” of Neolithic agriculture. Early farmers selected cereals with plumper, larger grains and ears that did not shatter easily, leading to greater yields and enhanced efficiency of harvesting. Transitional forms of domesticated plants and animals and their wild predecessors can be difficult to identify from the archaeological remains, but the available evidence suggests that the process took place quickly over several centuries.

Animal domesticates include sheep (*Ovis aries*), goat (*Capra hircus*), pig (*Sus scrofa*), and cattle (*Bos taurus*), each of which were ecologically and behaviorally suited to domestication due to their general diets, ability to breed in close conditions, social nature, and dominance hierarchy. Due to the selection of more docile animals, domesticated fauna tend to be smaller than their wild predecessors. The domestication of each species took place in different locations throughout Southwest Asia after communities had become sedentary and begun cultivating crops. Later a wide range of specialized pastoral practices was developed.

The adoption of agriculture in Southwest Asia was termed the “Agricultural Revolution” or the “Neolithic Revolution” by V. Gordon Childe, and it was truly revolutionary since it marked a drastic shift in the way people obtained food, placing greater emphasis on using land for production.

It also involved the need to maintain and protect seed stores for the following year as well as ensure that animals were kept alive and well until they were deemed fit for slaughter. Intensive cultivation is associated with increased sedentism, which provides different opportunities for building social relationships and spacing births. Furthermore, with the accumulation of surplus crops, differential wealth could be accumulated, enabling parts of the population to be freed from farm labor. This in turn allowed for the development of institutionalized craft specialization and, some time later, the rise of urbanized state-level societies with social hierarchies, bureaucratic and administrative systems, long distance trade, monumental and public architecture, and some form of writing or record keeping.

The Construction of Cities and the Secondary Products Revolution

The first urban centers arose in Mesopotamia, the land between the Tigris and the Euphrates in modern-day Iraq around 5,500 years ago. Shortly later, urban centers developed in Egypt. Both developed along river courses and the use of irrigation to enhance crop yields is thought to have been instrumental in the rise of these city-states. Ancient irrigation canals dating between ca. 5,500 and 5,000 years ago have been located in Mesopotamia. The construction of earthen structures to control the natural flooding of the Nile banks in Egypt likely played a similar role. Concomitant with the development of cities in Mesopotamia and Egypt, an agro-economic shift took place in between these regions in the Levant, perhaps stimulated by enhanced trade with adjacent regions. The Mediterranean economy, including cultivation of cereals and legumes, viticulture and olive production, and herding of sheep and goats, together with use of animal drawn ploughs became widely established for the first time. Sherratt refers to these changes in agricultural production as the “Secondary Products Revolution,” which placed greater emphasis on the use of animals for traction and for secondary products such as milk, blood, wool,

and dung. Most early ploughs would have been constructed from wood, but because of their perishable nature, they do not readily preserve intact in the archaeological record. The earliest depictions of a plough, which likely postdate its invention, come from cylinder seals from Mesopotamia, dating to approximately 4,300 years ago, and terracotta figurines of yoke-bearing oxen from the Greek site of Tsoungiza dating to the Early Bronze Age. The ard, which scratches the surface of the land was developed first, with mould-board ploughs that turn soil and create furrows being developed much later. Prior to the invention of the plough, fields would have been prepared by hand, so the shift allowed larger tracts of land to be cultivated. This effect was intensified during the Iron Age, beginning around 3,200 years ago, with the manufacture of iron agricultural tools, rather than flint and bone sickles or wooden ards.

The exploitation of animals for milk and wool in Southwest Asia is reflected in animal bones that document the preferential culling of young males and the tending of a larger number of female animals to an older age. In order to release milk freely to people, lactating animals need to be separated from their young and become accustomed to being milked by hand, so initial attempts at milking were likely a perilous endeavor.

Zeder and McCorriston argue that the raising of sheep for wool fiber greatly modified the agro-economics of Southwest Asia, and led to a reduced reliance upon flax fibers; the local importance of wool as a commodity in northern Syria allowed urban centers that controlled its production to prosper. Concomitant with the rise of urban societies, the need for a recording system developed in order to log economic transactions. The invention of writing provides an additional window into agricultural production in antiquity. Clay tablets from Uruk in modern-day Iraq, dating to ca. 4,400 years ago, provide the earliest evidence of writing in the world with initial documents being used to list commodities. An extensive archive of cuneiform tablets was found at the site of Ebla in Syria, approximately 60 km south of Aleppo. These texts, dating to between 4,400 and 4,350 years ago, represent the earliest written

reference to olive and grape production, although archaeological evidence of the plant remains predates the texts by almost a millennium. Since textual accounts and archaeological data provide different insights into past societies, this example demonstrates how the two records can be used to complement one another. Other cuneiform texts include the “Farmer’s Instructions” from Mesopotamia dating to ca. 3,800–3,600 years ago. Civil has interpreted the text to be a Sumerian agricultural manual which outlines instructions from an old man to his son on how to prepare a field for irrigation; how and when to harrow, plough, sow seeds, inspect, harvest, thresh, and winnow the crop; maintain tools; as well as describing a desirable work ethic. It is likely that the text was used to teach scribes how to write Sumerian, since the content of the text would have been familiar to many.

Early Agriculture Outside of Southwest Asia

Following the development of agriculture in Southwest Asia, farming began to be practiced in Turkey and then Greece, followed by the rest of Europe. Models of this spread are debated, with some arguing for movements of people and other arguing for a transfer of ideas and new technology. New evidence based on plant data suggests that a complex mix of both was involved. Based on radiocarbon-dated finds of plant remains, the spread took place at an estimated rate of 1 km/year, likely being adopted in fertile river valleys first.

Independent domestication of plants and animals took place in Southeast Asia approximately 8,000–7,500 years ago, with distinct modes of production evolving along the Yellow River in northern China and the Yangtze to the south. One of the most important domesticates from China is rice (*Oryza sativa* L.); rainfed lowland rice was grown initially, followed some time later by upland and deep-water rice. Due to the natural distribution of wild rice, which extends from India eastwards across China to the coast, the center of domestication was thought to lie in the

southern part of China, but new finds of early domesticates in the Yangtze valley have expanded this range. Ongoing research and more extensive excavations are required until the debate regarding the location of rice domestication can be resolved fully. By approximately 7,000–5,000 years ago, rice production spanned large areas of Southeast Asia and India. Early tools found at the waterlogged site of Hemudu in China, dating to ca. 7,200 years ago, include two digging implements constructed from a water buffalo scapula (shoulder bone) attached to a wooden handle, but such finds are exceptional and as with other areas, the full range of early agricultural implements is unknown.

Further to the north, between the highlands and the plains along the Yellow River, rainfall tends to be lower and drought-tolerant species were chosen as the first domesticates. Here, broomcorn millet (*Panicum miliaceum* L.) and foxtail millet (*Setaria italica* [L.] Beauv) became important crops for Peligang communities just over 7,000 years ago. Dogs, pigs, chickens (*Gallus gallus domesticus* L.), and water buffalo (*Bubalus bubalis* L.) were the most important animal domesticates, although wild resources including various nuts, jujube dates (*Zizyphus jujuba* Mill.), and deer remained important components of the diet. It is likely that chickens were first domesticated just after 8,000 years ago in northern China.

Agriculture developed in the Americas later than in the Old World. In North America, early crops include goosefoot (*Chenopodium berlandieri* Moq.), sunflower (*Helianthus annuus* L.), and marsh elder (*Iva annua* L.). Within Mesoamerica, most research has centered along the Oaxaca and Tehuacán valleys of Mexico; important domesticates include maize (*Zea mays* L.) derived from the annual grass teosinte, squash (*Cucurbita* spp.), beans (*Phaseolus vulgaris* L.), avocado (*Persea americana* Mill.), dog, turkey, and perhaps cottontail rabbit. Maize domestication is widely thought to have occurred around 7,000 years ago, but this date has recently been disputed; new radiocarbon dates of the oldest known domesticated corn cobs places them at approximately 4,600 years old. Cocoa

(*Theobroma cacao* L.) also became an important domesticate in Mesoamerica. The Nuttall Codex, dating to AD 1051, depicts an early use ritual of cocoa. Further south in the Andes, llama (*Lama glama*), alpaca (*Lama pacos*), and guinea pigs (*Cavia porcellus*) were herded. Important crops include quinoa (*Chenopodium quinoa* Willd.), and tubers such as oca (*Oxalis tuberosa* Mol.), mashua (*Tropaeolum tuberosum* Ruiz & Pav.), ullucu (*Ullucus tuberosus* Caldas.), and potatoes (*Solanum tuberosum* L.). Drawings of agricultural scenes by conquistadores in the 1500s depict the use of foot ploughs and hand hoes in the Andes.

Within Africa, agriculture first arose in the Nile Valley of Egypt, following the introduction of sheep, goat, cattle, and cereals, around 6,500 years ago from areas to the north. Independent innovation and domestication of local, indigenous species occurred between 5,000 and 3,000 years ago in a band between the Sahara and the equator, at a time when rainfall was higher than today. Important domesticates include cattle, sorghum (*Sorghum bicolor* [L.] Moench.), pearl millet (*Pennisetum glaucum* [L.] R. Br.), and much later, dating to around AD 200, African rice (*Oryza glaberrima* Steud.). African rice is still grown in parts of West Africa, although Asian varieties originally domesticated in China predominate today.

Continental Transfer of Crops

Throughout the world, the form that early agriculture took reflects, for the most part, an adoption of locally available plants and animals, with cereals such as wheat, barley, millet, and rice predominating in the Old World, and potatoes, maize, and squash predominating in the New World. There are numerous examples of people adopting non-native species throughout history, however, which demonstrates the dynamic nature of agricultural production and underscores how food production forms an integral component of social histories. The potato, for example, a native of Chile and Peru, was first introduced into Northern America and Europe during the late

1500s, after which time it became an important crop. By the 1800s, it formed the dominant staple in Ireland and the spread of potato blight resulted in the great famine that began in 1845. Tomatoes (*Lycopersicon esculentum* Mill.) were also introduced to Europe from Tropical America by Spanish conquistadors and Atlantic slave traders in the mid-1500s. Tomatoes were initially treated with suspicion due to their perceived similarity to deadly nightshade which was associated with witchcraft; they later became viewed as aphrodisiacs, rendering them the common name, “love apples.” The introduction of maize, beans, cassava, and potatoes into West Africa during the Atlantic slave trade of the 1500s is particularly noteworthy. McCann provides a history of the adoption of maize throughout Africa and today it has become an important staple at the expense of indigenous crop. In Zambia and Malawi, maize contributes more than 50 % of the caloric content of people’s diet, greater than that in Mexico where the plant was originally domesticated, and this has resulted in a drastic narrowing of dietary breadth. Indeed, in all parts of the world, reliance upon agriculture has led to a more restricted diet than that consumed by hunting and gathering communities. Examination of paleopathology within early agricultural communities in both the Old and New worlds has shown that farming led to an initial decline in general health and nutrition.

Water Management

Through time, people have increasingly adapted their environment to grow the crops that they desire. Limits exist to the extent that the landscapes can be modified, and these limits have shifted through time as technology has evolved and as labor divisions and economic incentives have shifted. The choice of what and where to grow crops is not, therefore, always predicated upon environmental considerations, and social or economic factors can weigh more heavily. Nabatean farmers at Avdat in the Negev Desert of Israel, for example, situated their settlements at strategic locations along spice trade routes during

the first century BC, and were able to grow crops in areas that received limited amounts of rainfall by using water harvesting techniques. Depending upon the timing and distribution of rainfall throughout the year, rainfed farming cannot generally be practiced in areas that receive less than 250 mm per annum. By clearing rocks from the hillsides and placing them in long lines running down slope, the thin soils were exposed to rainfall, encouraging them to slake and enhance runoff. Rainfall was then channeled down the slope into the valley bottom where walls constructed across the valley impeded the flow, minimized soil erosion, and enhanced infiltration of water into the soil allowing crops to grow successfully.

An equally ingenious method of water control was employed in South America where raised fields were used to grow potato. Raised fields have been found in dense concentrations in the Lake Titicaca area of Bolivia and Peru, and from above resemble a patchwork of fields. Raised fields were created by digging a network of ditches and placing the excess soil on top of the field to be cultivated. The fields provide optimal conditions for crop production in this area where weather conditions can be unpredictable; water can be maintained in the furrows between the fields and used for irrigation during dry spells, it can be drained away through the channels following heavy rainfall, and it also helps minimize diurnal temperature shifts, thereby reducing the risk of frost damage. There has been some interest in reintroducing this form of cultivation on a large scale today as part of the sustainable development movement, and while there are many benefits from an agronomic perspective, it is not clear how practical the construction and maintenance of raised fields would be from a social perspective because they require large investments of time. In the past they were likely constructed with *corvée* labor.

It is difficult to determine exactly when irrigation was first practiced because canals do not always preserve well and, additionally, preserved features can be difficult to date. Informal watering is likely as old as cultivation itself, particularly within food gardens close to the home, but more formal irrigation did not develop

until much later. The earliest forms of irrigation would have employed water diversion structures such as deflection dams and gravity canals as seen in Mesopotamia; it was not until Roman times that engineering developed sufficiently to allow for water to be lifted from a river and distributed onto an adjacent field. Early examples of norias (water-powered wheels that scoop water), can be found in the more arid parts of the Roman empire including Syria, North Africa, and Spain. Horizontal wheels were also commonly used for irrigation during the Tang Dynasty (AD 618–907) in southern China, and may have been used as early as 200 BC. The Archimedean screw, invented by Archimedes during the third century BC, uses a helix placed at a 45-degree angle within a tube to raise water when rotated. Despite these developments, as well as the invention of drip and sprinkler irrigation much more recently, floodwater farming continues to be a highly effective method of irrigation where topographic conditions are suitable. It was heavily utilized by the Hohokam of the Sonoran Desert in south Central Arizona, between AD 200 and 1450 to support large communities in an area of low rainfall.

Terracing

Other modifications to the environment include terracing and the cultivation of hill slopes. Due to erosion, ancient terraces are not always preserved, although examples do exist. Terraces can also be difficult to date, but based on embedded pottery finds, terracing may have been practiced in Southwest Asia during the Early Bronze Age around 5,000 years ago, perhaps being prompted by a greater demand for olive and grape commodities such as oil and wine associated with the rise of urban life in Egypt and Mesopotamia. Extensive tracts of terraced hillsides are also evident in the Peruvian highlands where numerous varieties of potatoes were grown, as well as throughout Indonesia where sophisticated methods of terrace maintenance and water use were developed and integrated into the social and religious calendar.

Soil Fertility Management

Assessing early methods of soil fertility management is more difficult since they leave fewer traces in the archaeological record and are not always documented in textual accounts. The practice of fallowing, or leaving land uncultivated for a year or more, is believed to have been an important method and it forms an integral role in slash-and-burn agriculture (swidden) that has been documented in tropical counties in Asia and Africa. In more arid areas, where slash-and-burn is not a feasible method of production, the need to maintain soil fertility was likely recognized following the first cultivation of crops, but little is known about the methods, if any, that were used. In northeastern Syria, Wilkinson observed scatters of pottery sherds surrounding large sites dating to the Bronze Age, which he interprets as non-perishable remnants of night soil or urban waste used to fertilize the fields. Since leguminous crops such as lentil, pea, and bitter vetch that fix nitrogen in the soil were important crops during the Bronze Age, it is also likely that crop rotations may have been used to maintain soil fertility, but it is difficult to assess this with any degree of certainty from archaeological evidence. It seems probable, however, that some form of crop rotation in Southwest Asia was practiced much earlier than the formalized introduction of the Norfolk four-course rotation of wheat, barley, clover, and turnips that was adopted in Europe, predominantly England, during the late 1600s and early 1700s.

More Recent Developments

Within the past century, the large-scale introduction of mechanized farming has greatly increased the efficiency of preparing land and harvesting crops. Mechanization has not been adopted uniformly throughout the world, however, and in many developing countries, animal traction is still relied upon for field preparation. The Green Revolution of the 1960s also markedly changed production following the introduction of high-yield varieties of wheat and rice throughout

numerous developing countries, notably in Asia. These varieties required a strictly defined regimen of fertilizer and pesticide application for optimal growth. While many farmers enhanced yields, many of the poorer farmers whom the improved grain was intended to help were not always able to afford the prescribed chemical fertilizers and pesticides and, as a consequence, yields sometimes fell below those obtained from local varieties. While farmers have long recognized the benefits of local varieties for subsistence agriculture, the lessons from the Green Revolution prompted numerous agricultural development agencies and agricultural research stations around the world to compile seed banks to store diverse crop varieties for future generations.

The most recent, and potentially revolutionary, change in agricultural technology concerns the development of genetically modified crops. From agriculture's earliest inception, selection of species with desirable traits has led to genetic change; this selection became formalized with intentional cross breeding. The creation of genetically modified crops differs from cross breeding in that DNA is physically spliced, potentially from one species to another. Genetic modification offers enormous potential to develop crops that are able to grow productively under adverse conditions, or which contain medicines or vaccinations that can be used in remote areas without refrigeration. Such crops have not been widely accepted, however, and studies examining potential environmental, economic, and social impacts continue. It is possible to produce seed stock that will yield sterile grain that cannot be used to replant the following season. While this development protects the economic investments of the producer, it has raised enormous concerns among subsistence farmer who would not be able to use harvested crops for reseeding. The debate is likely to continue for some time.

In the eighteenth century, Reverend Thomas Malthus expressed his views regarding the balance between population growth and food production, claiming that due to the inelasticity of food supply, once population levels increased beyond the "carrying capacity" of the land, the surplus population would be eliminated either by

direct starvation, or by positive checks such as misery and vice or moral restraint. Boserup counter-argued that population pressure would stimulate the creation of new methods of production that would enhance yields. The historical developments of agriculture through the ages demonstrate periodic innovation which has allowed the carrying capacity to increase. The relationship between population and carrying capacity is enormously complex and while people have continually adapted agricultural technology in order to enhance yields, as Amartya Sen has argued, social factors play an equally important role in ensuring that people are fed.

See Also

- [Animal Domestication](#)
- [Potato: Origins and Conservation of Potato Genetic Diversity](#)
- [Rainwater Harvesting](#)
- [Swidden](#)

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Agriculture: Origins of Agriculture in Brazil

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What caused people to cultivate the land? There are at least two main hypotheses, which try to produce an answer to what is regarded as one of the most fascinating issues in our cultural history. The first postulates climate restrictions, while the second defends the gradual shortage of extractive resources imposed by increasing demographic pressure. We ought not to discard either of them and even the combination of both, especially because agriculture emerged in diverse points and times, in a wide variety of environments. The oldest appeared in the “fertile crescent” of

the Middle East 10,000 years before the present (BP) and in Mesoamerica 9,000 years BP.

However, whatever the motivations that led to systematic and lasting cultivation of the soils, the agricultural awakening did not emerge quickly. It would have taken thousands of years until we could understand plant reproduction, leading us to imitate the natural process in supervised planting beds.

The first vegetable gardens incidentally appeared by the spontaneous sprouting of wasted seeds during the handling and preparation of meals or from those that had been thrown as offerings over the mausoleums. However, when judged by the behavior of Brazilian Indians as witnesses of their ancestors, the formation of the first garden plots was deliberate.

It is explicit in açai palms (*Euterpe oleracea*) in the Amazon or jussara palm (*Euterpe edulis*) in the Atlantic rain forest where the coexistence of fruits, seeds, and seedlings in the most varied stages of development offers an example of ontogenetic succession. These scenarios did not go unnoticed by the locals that frequently visited such redoubts not only to collect victuals but also to surprise the hunted animals that were equally attracted by the abundance of food.

As many studies show, the handling of such resource islands through the cleaning and removal of undesired plants, and consequent intensification of edible species, and the seedling transplant for the formation of home orchards and even along tracks are customary practices in Brazil. This includes peoples that do not have other agricultural provisioning systems as some ethnicities of macro-Jê that honor their newborn children with a planting of seedlings, or seeds of fruit trees, mainly pequi (*Caryocar brasiliense*). For many peoples, perennial agriculture has been around for a long time. One of the oldest documents that systematized the agricultural practice of Brazilian natives, dated 1,583, says that the perennial peanut was the only common cultivar in the vast region of Mato Grosso. Even now, perennial agriculture continues to be important for many peoples, because for the Indians, their growing areas are not restricted to their

surroundings but are also scattered throughout their territorial domains, as a stock provision.

In the literature, agriculture is customarily focused on a single cultivation of temporary plants, because then there is a homogeneous harvest in a short term. Without any doubt, this type was the most used among farmers around the world, having prospered especially in regions with great climatic seasonality. More than this, these crops need intensive care and surveillance, so a feed function becomes a founding element of sedentary societies with a complex work division.

But perennial agriculture also has its benefits, particularly for the Brazilian way of living. The outdated idea that the peoples of Brazil were nomads, compared with Mesoamerica, flourished because the tribes relocated according to the abundance of resources and soil fertility, keeping the link with the “old villages” with frequent visits to the old orchards. The relationship of plant production to labor unit is favorable to perennial cultures, and the lack of assistance renders the temporary ones impossible. Among the Kuikuro Indians, for example, the handling of orchards limited the people to sporadic cuts of lianas and the fertilization of trees by gathering dry leaves to the bottom part of the plant. Moreover, for peoples whose calendar is based on flowering and fruiting, the orchards in the new villages signaled what was happening inside the territory, optimizing the return to the old sites and even the harvesting of wild specimens.

However, if perennials represented agricultural dawning for many nations, the development and consolidation of agriculture was reached with the growing of some temporary cultivars. Among them are calabash, sweet potato, and cassava (*Manihot* spp.). It is of this Euphorbiaceae family that flour and beiju are produced, the food basis of Brazilian ethnic groups. Also it is from that family that fermented drinks are extracted such as the jacuba and other products such as starch for ceramics and poisons for hunting and fishing. As part of a cultural heritage, because cassava is in many Indian myths, the preservation of typical varieties is so rooted in the identity of the tribes

that anthropologists use the plant varieties to recognize various ethnic groups. Therefore, the peoples of the Amazon owe their agricultural origin to the cultural diffusion derived from the Andean Center, typified by the use of *mandioca brava* (angry cassava), a local variety of cassava. The nations of Central Brazil seem to have received this influence from coastal groups, with the main use of *mandioca mansa* (soft cassava), both initiated concurrently, about 3,000 years AP.

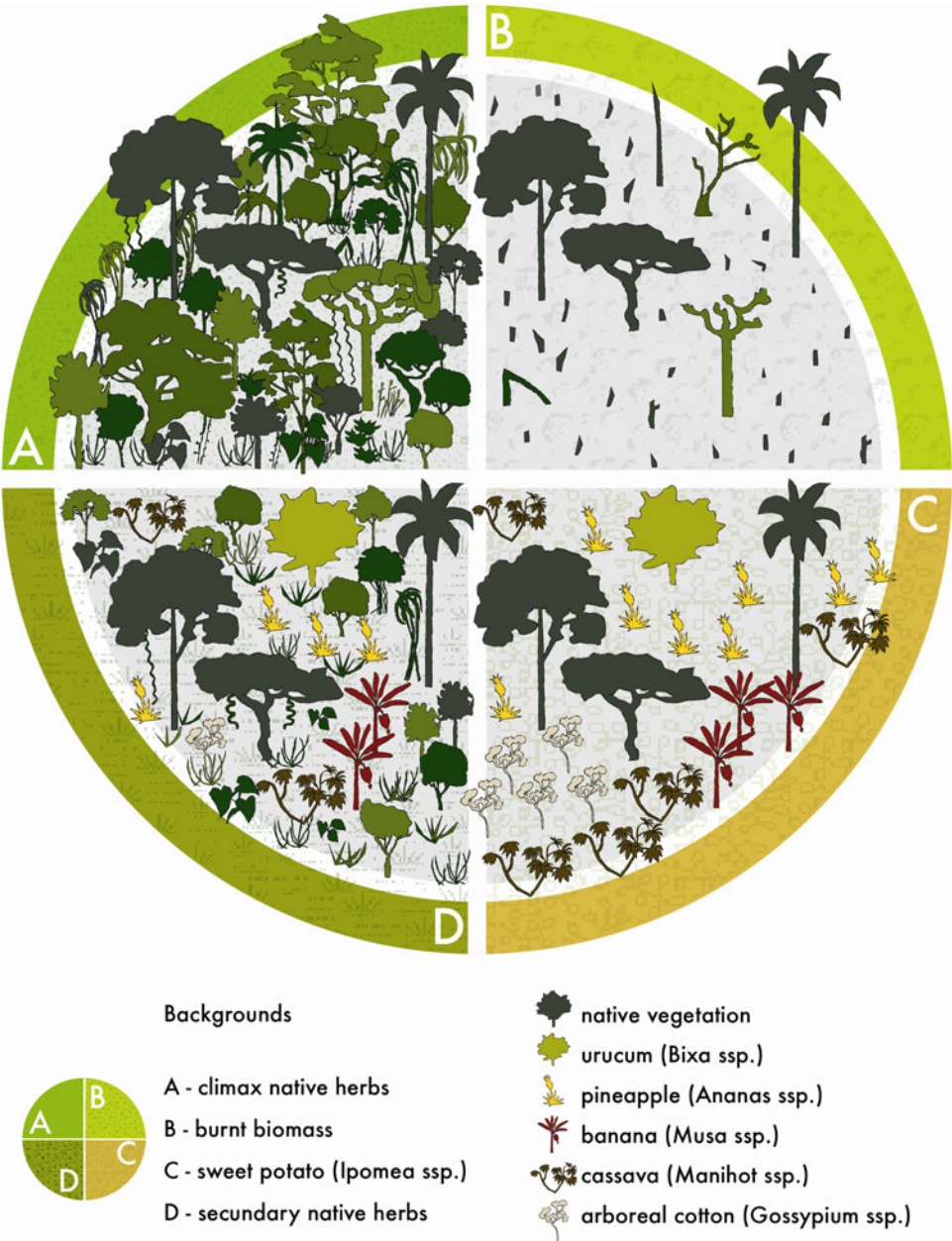
At the end of the nineteenth century, in the travelogues of his travels through the savannas of Brazil, naturalist Karl von den Steinen describes the curious case of an Indian that became fascinated with “matchsticks” and attempted to plant them in a vegetable garden. Perhaps 3,000 years ago, other Indians had the same idea but used branches of wild cassava, and met with success, since using the cuttings of the plant is the most efficient way to establish a cassava plantation. In fact, Carl Sauer, in an extensive review of the subject, affirmed that between Rio de Janeiro and Salvador, thousands of varieties of cassava were cultivated, proposing the simultaneous and independent origin in many points of the coast. Only as an illustrative example, a survey of 1980 showed the Amazonian tribes preserved 19–75 varieties of cassava per tribe and in some cases with the outstanding rate of 2.2 varieties per inhabitant.

Despite the unquestionable nutritional and cultural relevance of cassava, indigenous agriculture systems cannot be understood except as a complex arrangement that is genuinely agroecological. Nothing caused more indignation among the settlers than the apparently chaotic way the Indians organized their plantations. Brazilian agriculture was not only characterized by polyculture but also by multifunctionality. Wild and domesticated species and temporary and permanent varieties in the mixed and companion crops of foods, seasonings, fibers, dyes, drugs, and cosmetics shared the same space. Figure 1c illustrates a real case observed among the Wajãpi rena Indians in this circumstance with the introduction of banana – one of the most exotic plants adopted by the Indians.

Most importantly, this shows a much deeper and more complex dimension of the agrarian systems – the work division and temporary administration, initiated by the choice of a forest fragment. Where science sees only four sequential stages – primary, secondary, late secondary, and climax forest – the Indians see tens of physiognomic and functional types according to the soil, draining, and the flora and fauna. Judging by the social organization of the Kaiapó, the agricultural calendar was dictated by responsible elders and also by the choice of genres to be planted. Shamans were also consulted to establish the ones that would be limited, depending on the needs of the tribes. They indicated the species that should be spared, while the war chiefs recruited men for the clearing of the branches and collection of fruits and honey after cutting down the bigger trees, allowing the clearing areas to dry for a few months. In the *coivara* or “slash-and-burn” system, permission to set fires, generally announced in festive events, is proclaimed by the chief who also announces the transference of agriculture activities to women, who would take over the responsibility to prepare the land, sow, and harvest the production.

The cleaned land for the plantations would be cultivated for 3 or 4 years, by opening regular holes with the help of pointed sticks, each hole receiving a few seeds or transplant branches. Weeds were controlled and manually removed, with the use of stakes and more rarely shovels. This work only stopped when the fruits or tubers ripened, so then they could be harvested and taken to the villages in baskets, inside of which the separation of grains and the cleaning of the roots were carried out. Four years after the planting, a new forest fragment would be put into the cultivated site, which would be set aside for up to five decades in a rotation system.

Agriculture thus provided an efficient source of food. However, the indigenous agricultural system of slash and burn cannot be understood except as it is combined with the systems of collecting and hunting, chiseled by mysticism, and the division of labor. In many tribes, where the agricultural product was not too important, there were still elaborate planting and harvest



Agriculture: Origins of Agriculture in Brazil, Fig. 1 The Brazilian Indian agriculture rotation. (a) Forest, (b) the tillage preparation from *coivara* or “slash-and-

burn” system, (c) the companion and multifunctional planting of *roça*, and (d) the fruitfully fallow of *capoeira* in an old village (Illustrated by Elisa F. Serafim)

rituals. In other cases, the frequent displacement went along with the search for new forest areas to be exploited. The mobility of these nations caused the function of reinforcing the internal hierarchy of the group. Hunting and the protection of the territory, as signs of courage, sustained

men’s dominance over the collecting and horticulture being carried out by the women.

One last issue should be clarified. About 35 % of Brazil originally consisted of savanna-field biomes, more than 3/4 of these represented by the Cerrado-Brazilian savannas, where the forest

formations are restricted to gallery forest or isolated in small spots known locally as *capões* (*caá páu* – or in Tupi language “island” of “woods”). Even in the savanna, agriculture was almost exclusively associated with these restricted forest fragments. However, why was planting only done in forests?

Naturalists, traveling the interior of Brazil, asked this same question many centuries ago. The oldest answers are that this was part of the cultural heritage. The natives of the savannas owe their ancestry to the nations arising from the Amazon forest, so that the Indians kept the forested agriculture dependent as a social rule. The oldest human fossil of the American continent, Luzia, a 12,000-year-old woman, was found in the Brazilian savannas. More than this, lithic artifacts from the northeast of the country – another non-forest biome distant from the Amazon – suggest the presence of hominids for at least 30,000 years. Even if we are conservative, we should admit that there was a continual flow of Paleo-Indians from the Amazon to the savanna between the 12,000 years since the arrival of humans in the savannas and the 3,000 years since the development of cassava in this region. This appears to be unlikely.

The second group of answers relies on the microclimate and pedological conditions of the forests. In general the gallery forest soils are more humid and fertile than the savanna soils, especially after the burning of thick vegetation, which adds the minerals of the ashes to the subsistent organic matter. The Bakairí Indians of the savanna told the tale of the stupidity of the deer that tried to cultivate cassava in the savanna. Moreover, savanna soils in Brazil have high contents of aluminum, a great competitor for nutrients, and the ignorance of soil corrective means as a standard between the Indian nations of the Central West would be an additional factor.

Not discarding this hypothesis, I choose an alternative, which was inspired by Ester Boserup concerning labor productivity. With an agricultural system totally dependent on coivara – slash and burn – the Indians noticed that the forests are easily handled as they are more sensitive to fire. Fewer men could open clearings and cultivate

them without the need to employ tools or other costly efforts to control the development of herbaceous helophytic species, a limiting factor in the savannas.

Considering the savanna is a pyroclimate biome, the use of fire tends to contribute to the thickening of the herbaceous strata, naturally aggressive and dominating in open physiognomies. The burning system is still used today by commercial cattle breeders in Brazil. The indigenous populations of the time, not having hoes, which are essential for removing meadow grasses, Cyperaceae, and dicotyledonous herbs, probably were not able to meet the production threshold that would make the cultivation sites as an alternative to collecting. Even considering the hypothesis of the advent of such tools, the experience of other agricultures in the world showed it would take large human contingents and exhaustive work to be able to cultivate the soil. We had neither high demographic densities, nor typical tools for the control of herbs in savannas, nor organized specific work that could suggest the agriculture practice in the cerrados.

The convenience of fire and the employment of few men to prepare the forestlands, originally more fertile, led to agriculture over forests, as the most profitable. The forest agriculture of slash and burn became the prevailing agricultural method among the horticulturist people, even in the savannas.

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Agroforestry in Africa

Arnold Pacey

Agroforestry is not a new idea; it is merely a new word used by scientists to describe ancient land use practices operated by farmers in many parts

of the world. Other names stressing different aspects of the same technique include forest farming, forest interculture, layered gardening, and multistorey farming. The latter word has been used in West Africa to refer to a system where crops are produced from the same area of land at several levels or storeys, ranging from tops of trees (oil palms, for example), to ground crops beneath the trees, and to root crops below ground (yams, cocoyams, cassava).

Rediscovery of such farming methods during the last third of the twentieth century was linked to a realization that imported western techniques in tropical Africa had often led to soil erosion and loss of fertility. Cleared fields planted with single crops in the western manner left the soil acutely vulnerable to damage by heavy seasonal rainfall. By contrast, trees gave protection against erosion during rainstorms, while their leaf litter helped maintain soil fertility.

During the 1980s and 1990s, professionals working on this topic, notably at the International Council for Research on Agroforestry (ICRAF) in Nairobi, came to see agroforestry as a holistic approach to land use, using combinations of trees and shrubs with crops, pastures, or animals. What this means in practice depends on climate and environment, for there are different traditions of agroforestry in semiarid tropical regions, in rainforest areas, and in more temperate zones.

In the West African Sahel, traditional customs of retaining and using sparse tree cover in coordination with livestock raising and cropping tended to moderate the effects of high temperatures and low rainfall and to conserve plant nutrients while making possible a diversity of products, not all of which would suffer when droughts led to crop failure. Whilst many tree and shrub species were involved, one tree in particular, *Acacia albida*, was of such value in the western Sahel that it was often regarded as sacred, and there were severe punishments for its unauthorized felling. Because it is a leguminous, nitrogen-fixing species, yields of millet and sorghum sometimes increased greatly when grown in fields which had a scatter of trees of this type. Its leaves and seed pods were a nutritious fodder

Agroforestry in Africa,

Fig. 1 A form of agroforestry in West Africa sometimes known as multistorey farming. The upper storeys are represented by oil-palm and banana crops. Below that is the cereal crop, maize (corn). Nearer ground level are beans and melons, whilst in the “basement” are the main root crops. Left to right the latter are yams, cocoyams and cassava. This somewhat compressed view does not reflect realistic spacing, in which maize would be in open glades and more shade-tolerant species under trees (Illustration by Hazel Cotterell based on sketches by Pacey (1990, p. 200))



for livestock. Materials were obtained from it for the preparation of medicines, and its timber was useful in building.

Another species of importance, particularly in Sudan, was *Acacia senegal*, which produced gum arabic, and was grown in conjunction with millet and other crops in a 20-year rotation. With the disruption of this and other cropping systems, sometimes in favor of more “modern” methods, the productivity of the land, and the number of people it could support, was greatly reduced.

In rainforest areas, the retention of tree cover on land where crops are grown is even more important. Oil palm is particularly valuable in West Africa as a tree yielding a valuable crop yet also offering protection of the soil against erosion, and banana may be grown in the same context (Fig. 1). Crops grown at ground level under these trees traditionally include a great variety of beans, squashes, and leafy vegetables, with cereals in more open, sunnier glades.

Many early innovations in agroforestry arose when crops were introduced into new areas. Thus

over the last 1,500 years, African agroforestry has incorporated bananas and the Asian yam from Indonesia, then later, cassava and other crops from the Americas. Recently, though, agroforestry has been researched and repackaged by scientists, then taught to farmers by extension workers as if it were something new, with its origins in traditional practice heavily disguised.

One example of an innovation that arose from scientists’ observing traditional practices is “alley cropping”. This is said to have arisen when an Indonesian scientist working in Nigeria saw farmers planting a tree species on fallow land to speed the regeneration of the soil. He was led to experiment with trees that could be cut back prior to planting a corn crop, but which would grow up again quickly after the crop was harvested. The Alley Farming Network for Tropical Africa (AFNETA) was set up in 1989 to promote sustainable cropping systems based on alley farming and other ideas drawn from agroforestry practice, and in the 1990s it was developing and disseminating such farming methods in 20 African countries.

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Agroforestry in the Pacific Islands

William C. Clarke

The planting of trees together with the cultivation of annual crops, a combination now generally termed agroforestry, has been strongly promoted in recent years as a way to prevent land degradation and to increase total production of food and useful products from a unit of land. Throughout the Third World, development agencies and government departments of agriculture and forestry have been advocating agroforestry as a way to harmonize forests with farming, or as a way to make up, at least partially, for the destruction of natural forests and their replacement by pasture or by fields of annual crops. In the Pacific these modern, aid-funded attempts to promote agroforestry are ironic, for they take place in a region where agroforestry systems were developed thousands of years ago and where hundreds of species of trees are still used in a bewildering variety of ways.

At least a few trees even have a place in the popular imagination about the Pacific Islands.

If asked what particularly characterizes the landscape of the islands, most people would think of a line of coconut palms overhanging a beach beside a coral-reef lagoon. They might also envision the stately and strikingly beautiful breadfruit tree, whose yield of starchy fruit so enchanted Captain Cook and his companions on the first European visit to Tahiti and subsequently led to Captain Bligh's famous voyage to Tahiti in H. M. S. *Bounty* to collect breadfruit cultivars for the West Indies. These conceptions of coconut palms and breadfruit trees in Pacific landscapes are accurate enough, but they only begin to suggest the full significance of trees, both domesticated and wild, in the lives of traditional Pacific peoples.

Recent chromosomal and paleo-botanical studies in the Melanesian islands of the western Pacific reveal that the domestication of plants extends back in time there for thousands of years, thus demonstrating that agriculture evolved endogenously in the Pacific region, rather than being solely or mainly the result of a direct transfer from southeast Asia, as had been believed previously. Plants that may have been domesticated in western Melanesia include – aside from important short-term crops such as *Colocasia* taro and sugar cane – a remarkable number of trees or shrubs. This early emphasis on arboriculture – the cultivation of trees and shrubs – was eventually transported all across the Pacific by the voyaging colonist cultivators, to be incorporated into production systems everywhere and to beget the typical tree-filled environs of human settlements in Polynesia and Micronesia.

Archaeological evidence for a well-developed arboriculture at least 3,500 years ago comes from the Mussau Islands, which are now part of the country of Papua New Guinea. Tree species already in use then included: coconut, two or three species of *Pandanus*, *Inocarpus fagifer* (the "Tahitian chestnut," which remains one of the most important Oceanic arboricultural species), *Canarium indicum* (a nutritionally substantial "almond"-producing tree in Melanesia), *Spondias dulcis* (the vi-apple, now of very wide distribution in the tropical Pacific), and other useful trees such as *Pometia* (which provides

edible fruit, medicine, and other products), *Pangium* (seeds edible after treatment to remove the poisonous component), *Terminalia* (edible “beach almond,” useful timber), *Burckella* (edible fruit), and *Calophyllum* (timber favored for many uses, sticky sap used for caulking canoes). There is also evidence for the early domestication in the Pacific of several species of sago palm (used in some places to produce starch for food, elsewhere its leaves used as long-lasting house thatching), one kind of banana, and kava (a sprawling shrubby plant, the pounded stems and roots of which are used to make the ritual-social drink long important in many parts of the Pacific).

Over 400 species of trees or tree-like plants have been identified as having widespread or localized economic, cultural, and ecological importance in the Pacific Islands. The adoption of these many kinds of trees for human purposes is the cumulative result of a selection process that occurred over thousands of years and that involved both the domestication of previously unknown species encountered when Pacific voyagers landed on uninhabited islands as well as the deliberate transport from island to island of plants already known to be useful. The trees and their products served Pacific peoples in a great variety of ways. For instance, ecologically, trees provided, among other services, shade, erosion control, wind protection, beach stabilization, soil improvement, and frost protection (at high elevations in New Guinea). Cultural and economic uses included, among many others, house timber, firewood, tools, weapons, fishing equipment, abrasives (for example, the “sandpaper” leaves of some fig species), gums and oils, fiber, beverages (for example, the fluid from coconuts, immensely important for drinking on dry atoll islets), caulking, stimulants, medicines, and love potions and perfumes. Many Pacific trees are also of great importance nutritionally. For example, in various places people depend heavily on one or a combination of staple foods from coconut, breadfruit, bananas, sago palm, or several species of *Pandanus*. Many other species provide supplementary and snack foods. Although many tree foods are energy-rich in carbohydrates or

vegetable fats or both, it is in other nutritional essentials that they often excel, compared with the starchy root-crop staples. Several fruits are excellent sources of provitamin A; others provide B-complex vitamins or are rich in vitamin C. Most seeds and green leaves from trees (which are widely eaten) are good sources of plant protein and various micronutrients. Spices and sauces derived from tree products can also be of great nutritional and culinary significance. An oily sauce made from the huge red fruit of a *Pandanus* species in highland New Guinea provides a rich, nutritious condiment for many otherwise bland foods. Or coconut milk or cream (squeezed from the coconut flesh) is widely used in cooking in coastal areas, and in places is aged or fermented with sea water and other flavorings to make a tasty sauce that enhances local cuisines.

The multipurpose nature of many Pacific trees in providing a diversity of different products or services to people is well exemplified by the breadfruit. Its straight trunk is valued for canoe hulls; the inner bark is used to make bark cloth in some areas; the tree’s thick, milky sap is used for caulking canoes, as adhesive for bark cloth, and as chewing gum; its large leaves are used as plates and for wrapping food for cooking in earth ovens; the dried inflorescence is burnt as a mosquito repellent; and the fruit is eaten cooked as a staple or important supplementary food in most areas of Polynesia and Micronesia and as a supplementary food in Melanesia, where seed-bearing varieties are often more important than the seedless varieties used as a staple food in Polynesia.

Like most trees, the breadfruit’s production of fruit is seasonal, so that people dependent on it for food can expect periods of food shortage recurrently each year. Pacific-Island peoples developed two solutions to this problem. First, high intraspecies diversity had been developed in breadfruit (and most other domesticated crops) by centuries of observation, selection, and transportation of promising varieties from place to place. As only one example of the prolific number of named cultivars that might have been accumulated within a single species, the volcanic island

of Pohnpei in Micronesia is reported to have 150 named varieties of breadfruit. Generally, each of the many cultivars followed its own distinct calendar, so that production of breadfruit on atolls and high islands of Polynesia and Micronesia (or, to give another example, the yield of *Pandanus* fruits in highland New Guinea) is staggered over a much longer period than would be available from a single cultivar or individual tree. The second way in which the availability of food from breadfruit was extended over the year was by the pit fermentation of the fruit so that it could be stored. Unlike grains, there were few Pacific-Island indigenous foods except yams (*Dioscorea* spp.) that if unprocessed last long in storage once harvested. Because harvested breadfruit lasts only a few days, a way had to be found whereby the seasonal surpluses could be accumulated for later use. The method developed was pit storage. After the ripe fruit was peeled and cored, it was preserved by a process of semianaerobic fermentation, involving intense acidification, which reduces the fruit to a sour paste that lasted in storage for decades. The pits, which served both as fermentation chamber and storage area, were dug in clay soil to prevent water seeping in and then lined with stones, woven mats, and a variety of leaves to keep soil from mixing with the breadfruit paste. Modern food analysis shows that the fermented product contains more carbohydrate, fat, protein, calcium, iron, and B vitamins than the fresh fruit. The pits of breadfruit paste also provided a reserve food supply after tropical cyclones, or hurricanes, devastated gardens and orchards or during times of warfare. Packages of the baked fermented paste wrapped in leaves also provided a portable, long-lasting food for sea voyages.

Although trees had a great significance in people's lives almost everywhere in the traditional Pacific, the hundreds of species utilized were combined in a great variety of unique agroforestry systems, each distinct to particular locales spread over hundreds of islands, each with a unique environment and each occupied by a distinct group of Pacific peoples, with their own particular history and set of agricultural techniques. In forested areas of low population

density where shifting cultivation was practiced, a mixture of certain trees might be planted in old gardens, creating orchards that produced food, fiber, and other products for decades while also serving as a kind of fallow for the garden soil, which eventually would be reused. The spontaneous secondary forest in such areas came to be everywhere dotted with valuable trees, remnants of past orchards and gardens. Elsewhere, in drier, more heavily populated areas where complex irrigation channels had been built to bring water to permanent plots of taro, there might also be permanent and highly diverse tree gardens surrounding the irrigated plots and shading the villages. On atolls, with their severe environmental constraints, a particularly intensive form of agroforestry had been developed to support the often high population densities. Spread through a matrix of planted coconut palms, which were particularly common and immensely useful on atolls, were a variety of other domesticated trees including species of *Pandanus*, breadfruit, and a native fig. As in much of the Pacific, what might look like an untouched natural forest to an uninformed eye was in reality a managed agroforest in which almost every tree was known and owned by an individual or a family and served at least one valuable purpose if not several. Unfortunately, a variety of present-day socioeconomic factors and changes are leading to a decline of traditional agroforestry in the Pacific region.

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Agroforestry: Agri-Silviculture

Harold Olofson

Agri-silviculture is the intercropping of timber and fuelwood species and/or fruit and other useful trees with vegetables and other crops in a common space, at the same time. It may characterize a harmonic ► [swidden](#) (see ► [Agroforestry: Harmonic Swiddens](#)) where fallow periods are sped on their way toward full fertility and a forest architecture by the purposive planting and protection of leguminous and fruit trees in the cropping period or afterwards. Or it may be found in permanent farms. In the first case, we can refer to such swiddens as accelerated swiddens, to be distinguished as a term from the Food and Agriculture Organization's "accelerated fallow" to refer to swidden fallows which, because of population pressure, must be planted to food crops before they have recovered full fertility. In agri-silviculture, the sylvan component of the field is cultivated through practices like weeding and thinning. Agri-silviculture is an example of Alternative Forest-like Structures (AFS) because of the presence of arboreal species which provide some values of the forest. It is also a simultaneous polyculture. Indigenous examples follow.

Within swiddens themselves we frequently find that swiddenists are making efforts to encourage reforestation at a very early stage by interplanting forest trees and tree crops. These are then simultaneously harmonic, polycultural swiddens, as well as examples of agri-silviculture. Agri-silviculture is one type of indigenous agroforestry that seems identical with some of the ideas which modern agroforestry has adopted. From various anthropological

sources on the Lingnan Yao of Kwangtung Province, China, which were written in the first third of this century, a summary of their agri-silviculture has been constructed.

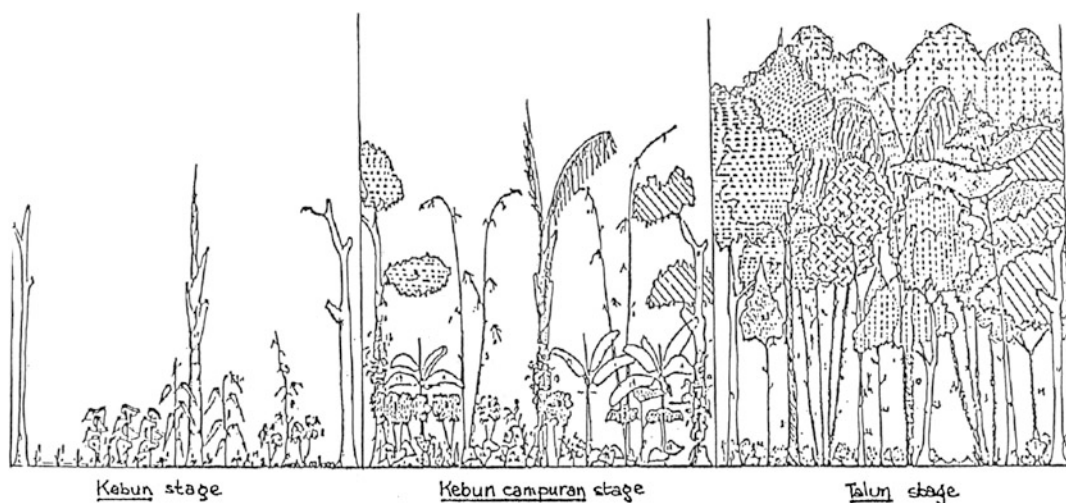
The first year after burning, a swidden is used mainly for mountain rice and maize; the second year for sweet potatoes; and the third year for taro. Simultaneously with the first planting, seedlings of various economically important trees are put in the ground. At the end of 3 years, these are large enough to discourage further growth of weeds and grasses. The swidden is thereafter fallowed for 18 or 19 years until the trees are large enough to be cut for timber (Lebar, Hickey, & Musgrave et al., 1964, pp. 82–83).

They go on to say that cedar and ► [bamboo](#) are also planted in the swidden. The Lingnan Yao apparently have had a symbiotic relationship with the Han Chinese. The Yao are skilled neither in timber extraction nor in woodwork. In exchange for allowing the Chinese to take most of the timber and other forest products, the Yao receive rice, paper, cloth, salt, guns, and the skilled carpentry of the Chinese. Thus while the Yao grow the timber, the Chinese cut it and transform it into useful shapes (Lebar et al. 1964, pp. 82–83). A search should be made for indigenous agroforestry models among other South China cultural minorities.

Acceleration appears to begin with selective weeding in the swidden so that forest tree seedlings that have established themselves can survive. In his description of the Tsembaga Maring, Rappaport noted that one is chided for stepping on what is called "the mother of the forest" – tree seedlings that are appearing in the ► [swidden](#) but not recognized by the visitor (Rappaport, 1971, p. 122).

For the Siane of New Guinea, Salisbury provides this description of the importance of *Casuarina*:

Casuarina trees [*Casuarina equisetifolia*] provide wood for fencing, fuel, and house building, and their growth as a secondary tree cover is facilitated by the weeding of garden sites. This prevents the growth of kunai-grass, which would crowd out young casuarina roots. If the casuarinas are given a chance to establish themselves, their shade often prevents the spread of the sun-loving *kunai*.



Agroforestry: Agri-Silviculture, Fig. 1 Successional stages in the *talun-kebun* agroforest of the Sundanese, West Java (From Christanty, 1982, p. 20)

The growth of casuarinas is deliberately encouraged, and gardens are often made when a boy is born, with the explicit expectation that this will provide a crop of timber for the boy at the time of marriage, and so enable him to build a house and fence a garden for his wife. Occasionally, too, casuarina seedlings are deliberately planted in areas which no windblown seeds could reach. This happened, for example, in 1941 when Antomona clan of Emenyo tribe returned to their devastated village site, where all trees had been ring-barked following their rout and expulsion in a war. Thus casuarina trees may be considered “cultivated” plants. (Salisbury, 1962, p. 43)

Thus it was considered enough to completely conquer an enemy by ring-barking all of the casuarinas in his territory. This would mean that the vanquished would have to retreat up to the high mossy forests to make their swiddens, while their forest areas lower down might run the risk of grassy invasion, since ghost-fear would prevent these areas from being immediately assimilated into enemy territory (Salisbury, 1962, p. 48).

These accounts reveal that traditional swiddenists are frequently capable of long-term future orientation when it comes to forest regeneration, but primarily in the context of viewing the trees that are so protected and preserved as being useful to people.

Given the right economic conditions, this propensity to accelerate swiddens can evolve into a

completely stable form of horticulture with the establishment of orchards. This has been described for the Cuyunon of Palawan Island, Philippines. Many of them have made this transition since the 1930s as a response to the flourishing nearby market and port of Puerto Princesa. As an ethnographer describes it,

Orchards are usually established as an adjunct to swiddening. A farmer systematically inter-crops his newly-planted swidden with tree crops and then controls regeneration of herbaceous secondary growth until the tree crops are established (Eder, 1981, p. 95).

The land used for tree crops, which are mostly fruit of many different species, is in this example taken right out of the swidden cycle.

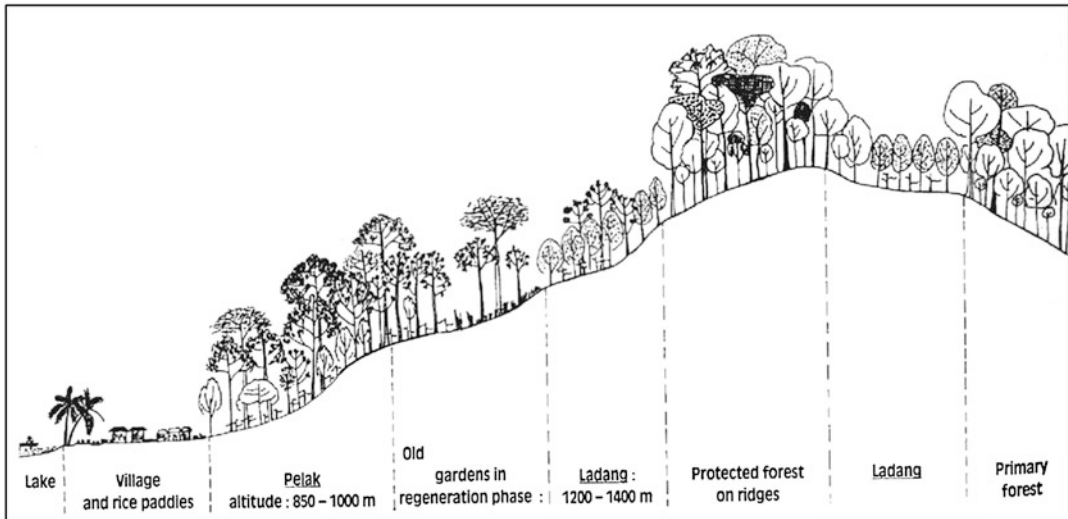
Cairns (ca. 1995) discovered that the nitrogen-fixing (even though nonleguminous) *Alnus nepalensis* (an alder) enables the Angami Naga shifting cultivators of the Himalayan foothills in northeast India to accelerate their swiddens without causing ecological damage. Oral histories collected from village elders revealed that this has been going on for 500 years, ever since alders invaded the originally opened fields and always seemed to enhance the growth of crops planted near them. The Angami came to protect individual alders (which coppice prolifically and thus are good renewable sources of firewood) and their



Agroforestry: Agri-Silviculture, Fig. 2 Partial profile of a *talun-kebun* agroforest of the Sundanese, West Java (From Michon et al., 1983, p. 126 ff)

seedlings, and through the centuries actively to plant them in their fields. This intensification of their agroforestry was probably a response to the fact that the fields had to be clustered near the village due to the hostility of neighboring communities of head-takers. Swiddenists had to be able to retreat quickly to their walled villages.

Over 2 years of cropping, the alders are pollarded for firewood twice, at the reopening of the fallow and again 12 months later. This is to allow sunlight to reach the staple crops of upland rice and pearl millet, and others. The alders are then left to grow and dominate the tree canopy in the next fallow period of 2 years. During that



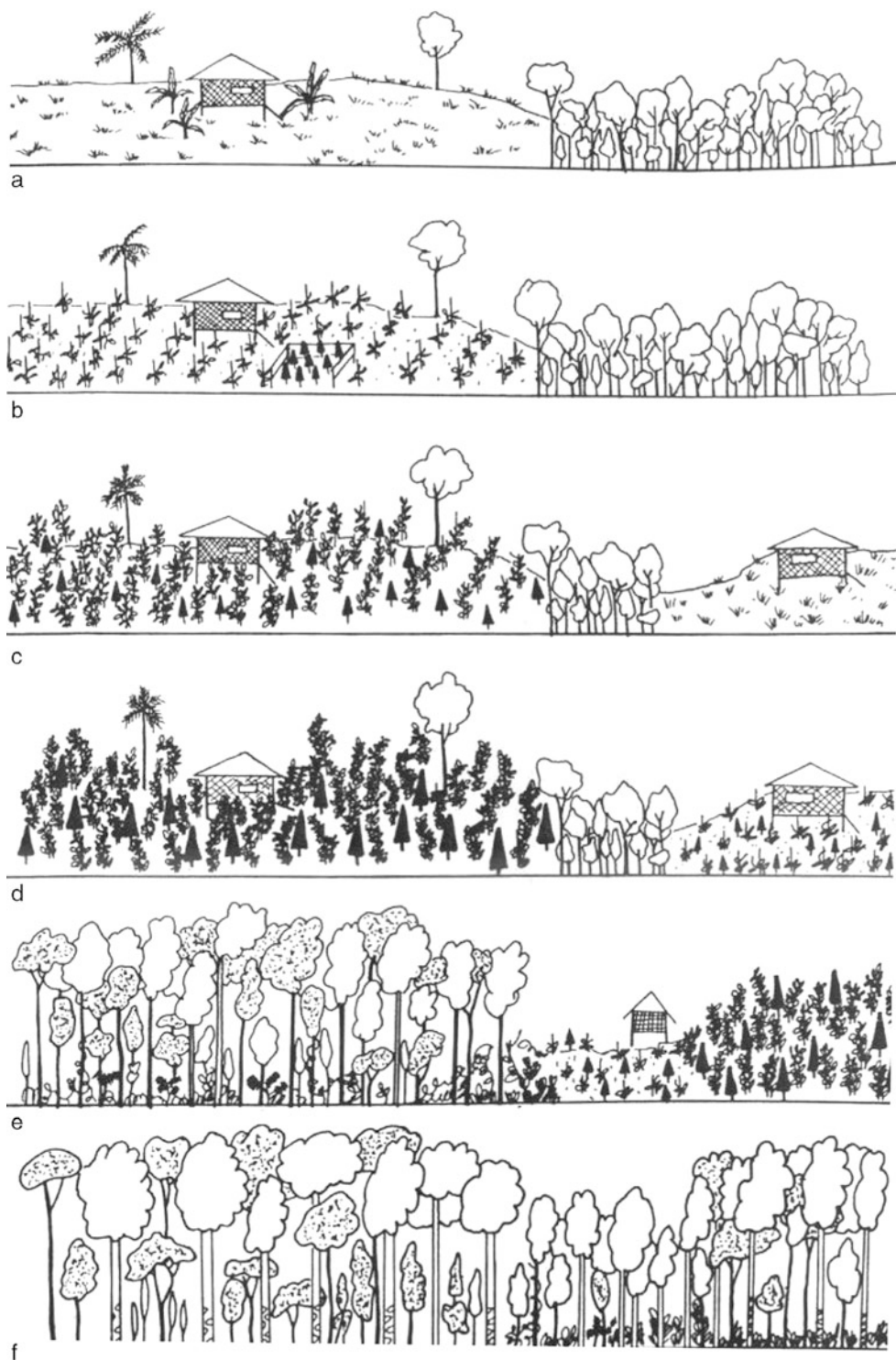
Agroforestry: Agri-Silviculture, Fig. 3 Schematic diagram of land use in Semarang village, at the edge of Kerinci Seblat National Park, Sumatra, Indonesia (*ladang* = swidden) (From Aumeeruddy-Thomas, 1994, p. 22)

fallow, the trees' "extensive roots draw nutrients from a large soil area and return them to the surface in high volumes of nutrient-rich litterfall" (Cairns, 1995, p. 7). As a result, Cairns maintains, the Angami Naga do not remember ever having suffered from this rapid succession of fallow and cropping periods. It is made possible by the presence of the alders, and "without the need of outside technologies, investment capital, or excessive labor inputs." This system is a model for how to stabilize shifting cultivation.

The Huastec Indians of Veracruz State, Mexico, manage stands of forest trees named by them *tel'om* (Alcorn, 1981, pp. 409–410). These are particularly closely managed in communities sited near markets. This can be done by adding shade-loving coffee trees into the forest, in places where some forest trees have been cut down to allow space for them. Those trees and vines which are particularly useful for construction are spared. In the shade of the coffee trees, cassava and chili peppers are planted. Furthermore, a species of valued medicinal palm, mango, and citrus trees may be added. The *tel'om* includes both primary and secondary species, as well as useful species introduced from other plant communities. The managed forest is used by women

and children for food gathering and play, and streams running through it are sites for bathing and laundering. Within a range of humanly managed plant associations moving from crop field to natural forest, the *tel'om* approaches the forest in structure, but Huastec culture has turned it into a multiple use artifact which can persist for many years as a stable ecosystem. Having originated as an enriched fallow, it need never be opened again for ► [swidden](#).

Closely related to the *tel'om* conceptually are the "village-agroforests" of the Sundanese in West Java, Indonesia. Named *talun-kebun*, these cover up to 50 % of a village's cultivated land (Christanty, 1982; Michon et al., 1983, see Figs. 1 and 2). Thus they are not to be confused with mixed dooryard gardens, which these farmers also have, for they are found further away from the residences. Architecturally imitative of the tropical forest ecosystem in their structure and bio-diversity, Michon et al. (pp. 118, 120) say that they "should be described in the same way as natural forest ecosystems" as well as "in terms of an agricultural lay-out." As in the *tel'om* of the Huastec, the Sundanese *talun-kebun* preserves wild vines, bananas, and trees. Annuals and perennials are mixed with wild and domesticated plants and livestock (chickens, sheep, and goats)



Agroforestry: Agri-Silviculture, Fig. 4 From rice field to coffee plantation to damar (*Shorea javanica*) agroforest in Krui, Sumatra (From Michon et al., 2000, p. 184)



Agroforestry: Agri-Silviculture, Fig. 5 Profile of an agroforest showing an association of timber, legume, and cinnamon tree crops, Jujun, Kerinci, Sumatra (From Aumeeruddy-Thomas, 1994, pp. 28–29)

as well. Crop species can reach up to 250 in number. This richness prevents the spread of plant pests and diseases and “represents an invaluable gene pool on an island [Java] where original forests have about disappeared” (Michon et al., pp. 118–119). Like the *tel’om*, the *talun-kebun* evolved out of the fallowing phases of an older shifting cultivation, no doubt in response to increased population pressure.

Much study has been done recently of indigenous agroforestry in Sumatra, Indonesia that has been able to restore biodiversity to the forest by incorporating cash tree crops into village forest gardens (Aumeeruddy-Thomas, 1994; Michon et al., 2000; see Figs. 3, 4, and 5).

In the agri-silvicultural form of accelerated swidden, crops may sometimes support the trees. This can occur if some of the crops are nitrogen fixing. But more importantly, food crops that are interplanted with tree seedlings

have the function of giving the farmer quick returns, which he may require before he is willing to go into the venture of a long-term investment in the form of trees interplanted with his crops.

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Agroforestry: Field-and-Grove Systems

Harold Olofson

This is the most interesting, complex, and varied form of indigenous agroforestry. The fields can be either harmonic or disharmonic swiddens, accelerated swiddens (agrisilviculture or agroforestry rotations), irrigated or nonirrigated permanent fields, or combinations of these. But they are interspersed with groves of trees that may vary along a range from predominantly wild forest species that are consciously conserved to groves largely composed of domesticated tree species planted by people. These two components may alternate or be scattered in a highly productive mosaic across the landscape of a village, district, or watershed. There may also be a tendency over a long period for some fields to become groves, and some groves to become fields, with both components thus slowly migrating across the landscape, producing in effect a very long-term agroforestry rotation. I was able to find four different types of field-and-grove systems in the literature available to me.

The Field-and-Forest

In some countries having temperate climates, these have been a feature of indigenous agroforestry. In England, patches of trees are known as copses when they are composed of species that can be managed by coppicing (cutting back trees regularly to encourage more growth). Larger woodlots and forests have been preserved for centuries as a source of game, deadwood for fuel, honey, and visual pleasure (see Rackham, 1985). But in more definite examples of the “field-and-forest,” forest resources may be more consciously pulled into the support of agriculture than they usually are in swiddening systems, where the forest tends to take on the passive role of a growing fertilizer reserve. The forest becomes more markedly a component of an agroecosystem.

In many areas of Japan, it is the custom to maintain a forest adjacent to wet-rice fields so that litter from the forest floor can be annually incorporated into the pondfield soils. This may in some measure account for the traditional high productivity of Japanese rice farmers. But the groves are subject to premature aging as a result of the fact that they are not allowed to reabsorb their own litter as food (Kira, 1976, pp. 36–37).

Some fascinating examples of field-and-forest relationships are described by Wilken (1977) for Mesoamerica. As in Japan, in western Guatemala and Mexico he observed the “transfer of the forest floor to the fields.” Leaf litter is scattered onto the fields and turned into the soil to improve its structure and moisture retention. The litter may first be placed on the stable floor, where it picks up nitrogen content from the urine of livestock. Also, forest materials may be transported to the field to provide protective microclimates, in the form of mulches to reduce radiation and evaporation from the soil and absorb the impact of raindrops, or actual shelters in the form of leaves and branches to perform similar functions and to allow cash crops to become gradually attuned to the open field. Wilken uses the term “forest structure mimicry” to describe the protective uses of litter and also the custom of letting leguminous

trees or pines to simply invade the fields, leading to an eventual replacement of the field by a grove.

Wilken, like Kira, points out that the practice of forest litter removal may have deleterious effects on the forest. However, one could easily imagine long-term experiments to determine the best system of leaf-litter removal management so that no section of the forest floor is harvested year after year, thereby at least prolonging the life of the grove.

The Field-and-Sacred Grove

A second variant of the field-and-grove type of indigenous agroforestry is found primarily among shifting cultivators who maintain forests, which they believe are inhabited by spirits or deities. These are thought of as fiercely defending their homes by visiting illness on human intruders. An excellent example is found in the Philippines among the Tagbanuwa on the island of Palawan, described by Fox (1982, pp. 163–76; for India see Gadgil and Vartak, 1976). When a Tagbanuwa selects a site in the forest for making a ► [swidden](#), it must be first determined by a religious practitioner (the shaman) whether there are malevolent spirits (*panya'in*) who claim the place. He or she enters the forest alone, makes an offering, and perhaps experiences a trance or dream in which an answer is received from the spirits. If the results are negative, the area becomes untouchable, and swiddens cannot be opened in it for the lifetimes of the shaman and the shaman's spouse. Another way of testing a potential site is described by Katherine Warner.

...A potential site was further tested for the presence of a *panya'in* by sticking a piece of ► [bamboo](#) into the ground. The next day when the bamboo was pulled out, if there was dirt sticking inside it, it was said that it was a *panya'in*'s area and that sickness would come if it was planted. Interestingly, the test that showed the presence of the forest spirit on another level gave information on the texture and suitability of the soil. If the soil is hard and stays in the bamboo, it is not quite ready to be planted, whereas if it is soft and fine textured it will fall out, indicating not only the absence of *panya'in* but also the suitability of the soil for planting. (Warner, 1981, p. 20)

The result in Tagbanuwa country has been a patchwork effect of swiddens, fallows, secondary growth, bamboo groves, useful grasses, and sacred groves, which has led to a harmonic and productive system that allowed the Tagbanuwa to live in what for swiddenists are quite large villages without depleting the nearby land. The numerous ecotones (well-defined boundaries typical of closed communities) also have insured the abundance of wildlife and game. But unlike the systems described by Wilken, forest material cannot be moved to the field, as sickness and death might follow the breaking of the taboo against trespass. However, the groves provide seed, which can reach the centers of swiddens easily since the Tagbanuwa do not arrange their swiddens in clusters. With the death of the shaman or the migration of his village, his taboo would be forgotten, and a later shaman might come in and determine the former sacred patch to be safe for swiddening. The long-term effect of this again was an agroforestry rotation between fertile sacred groves and cultivated areas.

In field-and-sacred grove systems, forest resources are not used consciously in support of agriculture. But the existence of the grove is preserved so that it can be truly available to play eventually its integral role in shifting cultivation along with all forest vegetation as the “beginning and end” of the swidden cycle, as Warner has expressed it in a nice way (1981, p. 27).

Apel (1996) describes the complex forest management of the villages of the Dai minority people in Yunnan Province, China. The bulk of their forests are “amenity forests,” which provide an aesthetic setting for each village, an expression of a value rare in tropical Asia. Watershed forests are “used forests,” recognized as providing construction timber and an adequate supply of water for each village and its rice polders. “Forests without special functions” are another kind. All types of forest have high species diversity. About 5 % of forests are considered sacred. There are three kinds of these. “Sacred natural woodlands” are wild and have been considered sacred since animist, pre-Buddhist times and are situated on hilltops adjacent to villages. Hunting, tree felling, and collecting are all forbidden there.

“Sacred groves,” purposively planted near Buddhist temples, are biodiverse, providing sanctuary for rare plants, and yield fruits for Buddhist monks. “Forest cemeteries” must be kept separate from the village at an elevation well below it. Conceptually distinct from all of these are individual “sacred trees,” especially the strangling fig (*Ficus altissima*) with its many striking features, which can be planted in sacred Buddhist groves, found wild on hilltops as the homes of spirits and sites of sacrifice to them, or scattered throughout the “used forest.” In the latter case, there is a taboo against felling the *Ficus* for use, and they serve a positive ecological function in assuring that frugivores (birds and mammals) have a food supply available to see them through periods of wider food scarcity, thanks to the characteristic of figs to bear fruit at different times. Apel claims that the taboo against cutting down the strangling fig thus prevents local degradation of the forest through overexploitation.

McWilliam (2001) has gathered significant evidence to say that probably all communities on the Island of Timor historically recognized, and many still do recognize, within the districts belonging to them, sacred (*lulic*) forests or groves, existing within government forest land, which they protect against shifting cultivation. Today, much of Timor’s forest has been denuded of vegetation, and sacred groves remain as relicts of the wider forest. Depending on the traditions of the varied cultures concerned, sacred groves may have been preserved as the “mythic origin places of local clan groups” and sites of religious sacrifice to those founding ancestors (McWilliam, 2001, p. 97). McWilliam makes a case for East Timor government support of these “forest custodial communities” as entry points for “negotiated reforestation activities,” the responsibility for which can be shared between Timorese government and villages. The basis for this survival of sacred groves, he contends, is a tradition of “rural land management and protection” which “provides a powerful source of moral authority and ecological knowledge” that could lead to sustainable conservation programs. This bold suggestion could be true for places other than Timor, as well.

The Field-and-Woodlot: The Ifugao Pinugo

The most striking example of a field-and-grove system is that of the Ifugao of the Cordillera Central mountain range in northern Luzon, Philippines. This system, which may be 1,000-years old, has been described by Harold Conklin (1980; for a review article on this see Olofson, 1980). The Ifugao are best known for their wet-rice terraces and irrigation technology on steep terrain. But few know that their woodlots, or *pinugo* as they call them, among pondfields, or at higher elevations, are almost as interesting. Sweet potato swiddens, too, are found at high elevations of a watershed. The most instructive aspect of the Ifugao woodlot is that it is made out of grassland (and secondary forest) through an intermediate ► [swidden](#) stage. To the Ifugao, making a swidden is the logical first step in reforestation. In the swidden stage, the land being used is not owned by the one making the swidden; he only has the right to use its products. But when a family member decides to grow a woodlot on this swidden, it becomes recognized by all families in the watershed that it is now owned, as a piece of land, by that individual, and its boundaries will be clearly demarcated for all to see.

The Ifugao woodlot is itself an agrisilvicultural system. The only kind of economic plant not grown appears to be vegetables and tubers, if Conklin in his account has mentioned everything. But there are plantings of trees for firewood and for the provision of building materials, utensils, furniture, tools, and religious figurines; fruit trees and grove crops such as betel nut; bamboos and rattans; and medicinal plants. According to Conklin, the species diversity exceeds that of the natural forest. The woodlot is weeded, pruned, and thinned as it grows. It has in fact grown out of an accelerated swidden. And, it might be added, that as a woodlot is harvested and ages, it reaches a later stage in its cultural successional sere.

Oftentimes, the Ifugao cluster their swiddens together, perhaps to defend them better from wild pigs by digging trenches on the edges of the cluster. When the swiddens are converted into

woodlots, the cluster is more ecologically sound as a forested expanse than would be a single cluster alone.

Besides supplying the Ifugao with numerous products, which make woodlots second only to pondfields in economic value, the woodlots are overtly recognized by the Ifugao as supportive of the terraces, though not by the use of tree litter as fertilizer (this comes from the floor of the public forest). They are well aware, rather, of the fact that they aid crucially in conserving the water needed in irrigation, and in preventing soil erosion and land slippage. Conklin found that even children could talk about this. In addition, when the woodlot becomes aged and completely harvested it can be reconverted to swidden, at which time its soil should be particularly fertile for sweet potato.

The Field-and-Mixed Home Garden

Of some importance as indigenous agroforestry are field-and-grove systems in which the grove component is the mixed tropical “dooryard,” “kitchen,” or “home” garden. The dooryard garden represents a distinct agricultural enterprise with its own integrity and often with crucial connections to the farm component. Such gardens are similar to harmonic, polycultural swiddens, except that more important in them are fruit trees, which provide a protective canopy under which other plants are grown, and that perhaps as a result of the need for closed nutrient cycling as in forests, have become permanent. Stuart Schlegel (1979) in his description of the home gardens of the Tiruray of Mindanao finds that they are in fact a terminal stage in swidden. They would thus in Tiruray be an equivalent to the Ifugao woodlot, which also develops out of ► [swidden](#), except that the Ifugao woodlot may be some distance from the house.

Home gardens are of great significance on the world’s most densely populated island, Java, where they are called *pekarangan*. First of all, this is due to their ability to protect the soil through forest mimicry. Among the first to note this was the geographer Karl Pelzer (1945,

pp. 43–47) drawing on the work of Ochse and Terra in Indonesia. Then, according to an economic anthropologist, who was also including *talun-kebun* (village-agroforests) in her statistics,

[For Java] . . . garden land . . . makes up anywhere from 15 % to 75 % of the cultivable land area, may provide more than 20 % of household income, and more than 40 % of a household’s caloric requirements. (Stoler, 1978, pp. 86–87)

Another interesting statistic comes from Terra (1966), who found that once well established and continuously producing throughout the year, the home garden grove in Java requires only five-man days of labor per year for its upkeep. Finally, Indonesian ecologists, noting that dooryard gardens in some overfarmed areas of Central Java “look like green oases in a desert of eroded hills,” have characterized them as the last line of defense against ecosystem degradation (Soemarwoto et al., 1976, p. 194). These same observers go on to suggest that they could be expanded spatially to become *talun-kebun* and begin a rehabilitation of these same uplands. In this last regard, Central Javanese home gardens are fulfilling the same function as has been reported for sacred groves in western India (Gadgil & Vartak, 1976) by representing the last patches of forest-like cover in the landscape.

Pelzer believed that mixed home gardens were not well developed in the Philippines. But recent work by Sommers (1978) has shown that they are rather widespread there, and the problem remains of diffusing them further to the many households where they are yet nonexistent or underdeveloped.

From descriptions such as Stoler’s, it is clear that Javanese home gardens are an alternative forest structure (AFS).

They often lack the orderly appearance of other forms of cultivation. They seem a haphazard array of scattered trees, untended plants, crawling vines, and decaying vegetation. In fact the lack of orderly rows and clean swept vegetation is precisely what allows *pekarangan* to produce its own natural fertilizers, and remain erosion-free even in critical watershed areas of poor land use. The multileveled “disorder” functions in part to prevent unnecessary organic waste

found under other systems of cultivation (Stoler, 1978, pp. 88–89).

She goes on to mention timber trees as one of their products.

By viewing home gardens as part of a field-and-grove system, we throw them into a wider context. The ways in which they are related to the staple field, livestock, and other gardens are probably many and varied, but not covered systematically in the literature in any one place. One thing that stands out from putting together scattered references on the dooryard garden, especially in the context of shifting cultivation combined with stable residences, is its role as an experimental site for new varieties of vegetables and even staples borrowed from neighboring people or visitors. If these do well in the dooryard, they may be grown on a wider scale and even tried out in the main field. For example, among the wet-rice growing Bontok in northern Luzon, Philippines, where sweet potato grown in swiddens is calorically more important than rice grown in mountain terraces, new varieties of sweet potato are planted first in the *doran*, which is found around the house. This area acts as a reserve for all kinds of cuttings, and also has fruit trees, green vegetables, and other root crops. From the *doran*, the cuttings may be transplanted to swiddens or fed to pigs (Yen, 1974, pp. 92, 95, 96).

This brings us to the connection between home gardens and livestock. Among the Ikalahan of northern Luzon, papaya, chayote, and sweet potato vines from the dooryard go into the special pig's cauldron in the kitchen where cooked food is prepared for them daily (Olofson, 1984). The Ikalahan pig, however, is allowed to roam freely to hunt for mast on the forest floor during the day, so it cannot contribute collectible manure for the maintenance of the dooryard plants. Among the Bontok, however, pigs are kept near or under the house and their manure can be collected and added to compost which goes into rice fields and which helps to account for the high productivity of Bontok wet rice without capital inputs (Sajise & Omengan, 1981).

In the entry on harmonic swiddens, we noted that a number of South American Amazonian Indian groups have experimented with swiddens

of much-less-than-expected species diversity, swiddens often polyvarietal in nature, to perhaps find other ways of providing some of the values of the tropical rainforest to the cropped field. Among the Siona-Secoya, one of these groups, Vickers (1983) found that home gardens had sparse and discontinuous canopies; they are also not the best examples of the AFS. However, it is important to note that Lathrap earlier (1977, pp. 729–736) had much to say about highly diverse mixed-home gardens among people like the Shipibo and Desana and found that they may have been very significant in the evolution of agriculture among South American Indians. It is worth quoting from him at a little length.

The house garden functioned as an experimental plot. New species of plants brought in from the forest or received through contact with other ethnic groups would be introduced into the house garden in a conscious effort to evaluate their potential as useful cultigens. The composition of the house garden was dynamic; . . . the potential of [new] species was constantly being investigated. . . . I would argue that the important food crops of Amazonia were ennobled in the context of these experimental plots. . . . Under the artificial growing conditions and a degree of artificial selection, they were genetically modified so as to become the supremely efficient food producers of the tropical forest system at the time of the contact period (Lathrap, 1977, p. 733).

See Also

- [Environment and Nature in Buddhism](#)
- [Environment and Nature in Buddhist Thailand: Spirit\(s\) of Conservation](#)
- [Forestry in Japan](#)
- [Swidden](#)

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Agroforestry: Field-and-Interstitial Support Trees

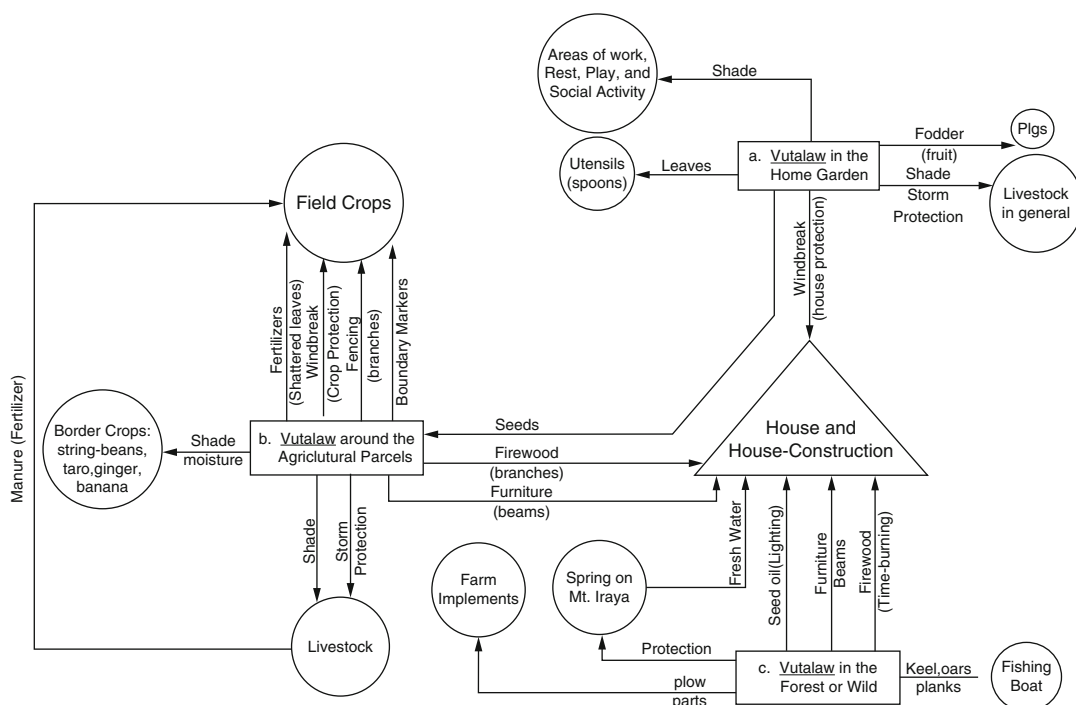
Harold Olofson

In this type of agroforestry, trees in groves or rows are separated spatially from crops, but are in a common field with them. The trees may be planted in arrangements interstitial (with small openings or gaps) to crop fields, for example, as field borders, or along the contours of a slope. In a variation, the trees and crops may be rotated in a field. In this agroforestry rotation, the trees interplanted in a mixture with crops may be cut back (coppiced) to allow crops to grow in the sun, and in a later phase allowed to take over and dominate the field for a period when their products are needed. This last essentially entails a rotation or alternation – or “separation” – of trees and crops through time. In all variations, the trees support the crops, as well as yield products of their own.

Spatially Interstitial Trees

There are many examples of trees that are spatially interstitial:

1. The planting of Osage orange in the American Great Plains as a hedge to protect fields from



Agroforestry: Field-and-Interstitial Support Trees, Fig. 1 The participation of the *vutalaw* (*Calophyllum inophyllum*) in the Ivatan agroecosystem (From Rede-Blong and Olofson (1997, p. 115). By permission of

Philippine Quarterly of Culture & Society. Thanks to Fr. Herman van Engelen for his help in constructing this illustration)

animals and then, as they grew, as a windbreak (Smith & Perino, 1981);

2. The growing of ipil-ipil for fertilizer or firewood on rice bunds in Pangasinan, Philippines (interview data);
3. A living fencerow of *Cestrum nocturnum*, guava, and forest trees to prevent the passage of pigs from a pigsty into a swiddening area among the Ikalahan of northern Luzon, Philippines (personal observation);
4. The use of ipil-ipil in contoured rows to prevent erosion on steep corn farms in Cebu (National Academy of Sciences, 1977, pp. 72–73);
5. The planting of teak on fallow boundaries by the Yoruba of Nigeria to claim ownership of the fallow (John Wyatt-Smith, personal communication), and thus probably prevent premature cropping by others; and
6. The planting in Batanes, Philippines of palo maria (*Calophyllum inophyllum*) as living

fencerows on parcel borders to mark boundaries, provide shade for cattle, windbreaks for crop protection in a typhoon-battered region, firewood, fencing material, and moist soil for plantings of ginger and beans (Rede-Blong & Olofson, 1997, pp. 110–102; see Fig. 1).

Of special interest is the use of trees to reclaim soil to fixate sand dunes, thus adding to the total arable land. A good example is the construction of living fencerows in seasonal floodplains by the Indians of Sonora, Mexico. These are arranged in such a way that they are able to capture arable soil from seasonally torrential watercourses that would otherwise erode away the area in which the fencerows have been planted. The trees are planted so as to impede the flow of water, allowing soil particles in the water to sink to the bottom of the stream (Nabhan & Sheridan, 1977). While this type of agroforestry involves the use of residual, leftover, or

boundary spaces, such trees can be of the utmost importance; they can be used to reverse the deleterious forces of nature.

Interstitial arrangements involving livestock occur where spatially interstitial trees provide fodder. A case in point occurs in Jalajala, Rizal, Philippines, where native ipil-ipil growing between (and within) upland parcels is collected and brought down to sites situated on a level lakeside plain in order to stall- or force-feed milch cows (Olofson, 1985, p. 322).

Temporally Interstitial Trees, or the Agroforestry Rotation

An interesting system that falls into this rubric has been described for the Atoni language speakers in the province of Amarasi in southwestern Timor. The system is a relatively recent innovation, but originated within and has been strongly supported by traditional institutions. It is a many-faceted response to famines caused by slash-and-burn on poor soils in a climate with a 9-month dry season, and to the spread of *Lantana camara*, which was interfering with the attempt to develop a livestock industry in the resulting savannahs, because it is poisonous to cattle:

With the systematic use of [*Leucaena leucocephala*], which had been known in Timor for centuries as a fallow plant, a significant agro-ecological change took place in Amarasi. An *adat* regulation pronounced in 1932 by the local ruler (*raja*) in accordance with his council obliged every farmer in Amarasi to plant rows of this leguminous plant with at least 3-m spacings along the contour lines on his shifting plot before abandoning it. This was intended to reduce erosion, to encourage new plant growth, and to improve soil fertility by making use of the nitrogen-fixing properties of this legume. In order to put the necessary pressure behind these regulations, each farmer was threatened with a heavy fine for failing to comply. (Metzner, 1981, p. 96)

In 1948 the government officially adopted this custom law as its own, and by 1951 *Lantana* had been significantly reduced by the ipil-ipil (*lamtoro* in Atoni), so that land-use zoning, also originating in *adat* decisions taken by the *raja* in 1938, could be most efficiently implemented to

aid in the separation of farming and grazing areas (Metzner, 1981, pp. 96–98).

It can be assumed that the ipil-ipil was planted late into the ► **swidden** because of its rapid growth, so that a succession of food crops and ipil-ipil took place, rather than a mixture, in the initial phase. In one area this use of ipil-ipil led to a situation where the farmers could make a labor-saving innovation that eventually resulted in almost permanent cultivation.

Once the *lamtoro* poles and leaves are cut they are not burnt but left on the field as mulch. Into this mulch layer maize and other crops are planted. Weeding is limited to cutting off the fresh shoots growing from the roots of the legume left in the ground. Similarly the cut-off shoots remain on the field as mulch. Since the soil is neither hoed nor turned the thin layer of topsoil is hardly disturbed. According to the farmers... even after 7 years of continuous cultivation yields were not lower than those expected from newly cleared *lamtoro* plots (Metzner, 1981, p. 100).

In this system, the growth of the trees and crops alternate over time in the same space. In most swiddens, the forest stage of the swidden cycle primarily functions as a source of fertilizer to be released by the next burning, of shade to eliminate weeds, and of seed for reforestation of fallow areas. Here the fast growth of the ipil-ipil as well as the soil enrichment caused by nitrogen fixation adds significantly to these functions, making the next cultivation of the plot possible much sooner as well as extending the cropping period. This last, in turn, makes it possible to delay fallow and to allow adjacent ipil-ipil fallows to grow more. For this reason, agroforestry rotations of temporally interstitial trees that nourish the soil could be called forms of accelerated swidden.

It is important to note here that while the tree component is kept “submerged” or cut back during the cropping phase, so that we cannot speak of a mix of growing trees and crops, this example is still one of a simultaneous polyculture. The underground portions of the ipil-ipil still play a positive role in generating nitrogen and holding the soil.

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- harmonic swiddens which is often “in the awareness” of their practitioners is to accelerate the recovery of the forest structure which was eliminated in the process of making a ► [swidden](#) in the forest, once they have to leave the swidden. This is done by paralleling or imitating in the swidden that forest structure which they have felled, or one which exists nearby. They attempt to harmonize the structure of the swidden with the nature of the environmental context in which they live. Such swiddens can be called Alternative Forest Structures (AFS). The AFS can have up to five characteristics that aid in identifying it as forest alternatives. The first three were clearly described by the anthropologist Geertz (1963) and Harris (1971).

Agroforestry: Harmonic Swiddens

Harold Olofson

Forest swiddens are clearings made in a forest by shifting cultivators, to be planted to crops. They are generally of two types, depending on the cultural traditions of the cultivators: harmonic and disharmonic.

Harmonic swiddens are found among many indigenous cultivators, and are essentially a form of agroforestry. In fact, when they are designed and managed in such a way as to enable rapid recovery of the forest after a brief period of use during which their soil fertility is depleted, they are good models for modern agroforestry. As integral agroforestry paralleling Conklin's (1961) famous classification of types of shifting cultivation, they are embedded in cultures into which members of a society are born, as part of their plan for survival. Making harmonic swiddens is learned as part of growing up in indigenous societies where they are integral to the tradition of cultivation. One of the effects of

1. There is a high diversity index of plant species in the swidden, as in the natural forest. In contrast to monoculture, which specializes in one species only, there are many species and varieties planted in the field. Thus, a swidden is a simultaneous polyculture (coined by Kass, 1976, p. 6), but a complex, not a simple one. This term covers patterns involved in mixed cropping, intercropping, interculture, interplanting and relay-planting. Also in contrast to monoculture, there are relatively few representatives of any species.
2. The vegetation is stratified into soil-protecting canopy layers, two or four in number, but usually less than in a tropical forest climax.
3. As in the natural forest ecosystem, the tight cycling of nutrients within the bounded agroecosystem is quite rapid. As has been said for the tropical forest, the AFS cannibalizes itself by quickly reabsorbing its own litter into its root systems. While this is widely believed to be true for some of the AFS described below, there is a need to confirm this through detailed agroecological studies.
4. Oldeman nicely analyzes the fourth analogy. According to him, especially in older forests, “the death of forest patches is a perfectly natural mechanism which constitutes the motor of all vegetational dynamism” (Oldeman, 1981, p. 79). Numerous accidents through time, such as earthquake, exposure to storm

winds, or the formation of goblet-shaped clearings or *chablis* by the falling of single, large, old trees cause the forest to take on the appearance of a mosaic of points on a successional sere. As Rambo (1981, p. 36) has put it, man may purposefully and systematically manipulate the forest – through an eco-catastrophe of felling and burning – to deflect the natural succession on a site back to more open conditions and thus cause a patch to enter a succession which he himself designs. Geertz called this “putting the forest through its paces.” Thus, like patches in the forest many AFS will be located on some point along a sere. Oldeman points out how it requires a good deal of art and science to preserve with some stability the analogical relationships between the cultivation cycle and the natural cycle, and to replace the wild species by domesticated ones that fill the “same functional and structural niche as their wild precedents” (Oldeman, p. 81). Like the forest, swiddens also have phases in their histories.

5. The overall effect is one of resonance between the AFS and the surrounding natural forest. The structure of the forest is imitated, planting materials may actually be brought in from the forest, and forest wildlife may flourish at the ecotone (boundary) with the AFS. In these ways, the AFS may act to reinforce the forest ecosystem.

Disharmonic swiddens may have evolved from harmonic ones, with the farmer learning to specialize to the point of monoculture or near-monoculture, with one species such as sweet potato, upland rice, or corn dominating in the field. In this process, the ► [swidden](#) loses its stratified canopies and there is a dangerous reduction of plant cover in the clearing during the cropping stage. Or, disharmonic swiddens may be cleared by land-hungry, lowland migrants to the hills or forests who may be people who have little knowledge of indigenous practices, who did not grow up in cultures traditionally skilled in forest farming.

Disharmonic swiddens have no resonance with the surrounding forest other than attracting

wildlife; they bring on the threat of soil erosion through heavy rainfall impacting on the bare soil, grassy intrusion, and a decrease of nutritional diversity in the family diet. The harmonic swidden is much more capable than the disharmonic of regenerating into natural forest during the fallow period.

Swiddens can be found on a continuum of incipient to advanced indigenous agroforestries. In the first, trees may not be a major component of the swiddens, but species of fruit trees are usually present. These incipient agroforestries may be seen as evolutionary precursors to indigenous agroforestries which put more stress on trees, usually always to support the crops. Swiddens of this nature have been reported widely for traditional peoples. For the T'boli of Mindanao, Rice has made this observation:

Usually there are three or more different crops on a given piece of land at all times and as each crop ripens and is harvested its place is taken by another. A well-developed system of inherited agricultural knowledge governs which seeds are to be planted together and in which months they can be planted for most effectiveness. This ... tends to maintain the soil fertility longer since at least one legume is usually in the soil to stimulate nitrogen fixation. Second, the land is covered more continuously and heavily, and erosion and weed control are thus more effective... (Rice, 1981, p. 77)

For the Tsembaga Maring of New Guinea, one anthropologist has described the forest-like structure of their swiddens.

In the garden as in the forest, species are not segregated by rows or sections but are intricately intermingled, so that as they mature the garden becomes stratified and the plants make maximum use of surface area and of variations in vertical dimensions. For example, taro and sweet potato tubers mature just below the surface; the cassava root lies deeper and yams are the deepest of all. A mat of sweet potato leaves covers the soil at ground level. The taro leaves project above this mat; the hibiscus, sugarcane and [*Setaria palmaefolia*] stand higher still, and the fronds of the banana spread out above the rest. This intermingling does more than make the best use of a fixed volume. It also discourages plant-specific insect pests, it allows advantage to be

taken of slight variations in garden habitats, it is protective of the thin tropical soil and it achieves a high photosynthetic efficiency (Rappaport, 1971, pp. 121–122).

The Tiruray of Mindanao have been described as having another kind of what I call resonance between the forest and the cultivated areas. This involves a virtual exchange of planting materials between the two sites. Four ► **bamboo** species, the fruit tree *Averrhoa carambola*, narra, and *Gendarussa vulgaris* are taken from the forest and planted in swiddens, gardens, at the edge of watercourses, or right at the forest boundary, while the candlenut (*Aleurites moluccana*) is planted directly in the forest (Schlegel, 1979, pp. 171–179, 194–205).

In harmonic swiddens, trees support the domesticated plants grown in the clearing by first bringing about more fertile soil conditions and then by being sacrificed through burning for fertilizer. It is difficult to see, however, how nutrients from the clearing do much in their turn to make the forest prosper. Perhaps on the edges of swiddens, where some slash or crop residues may be thrown from the ► **swidden** into the forest, or where rainwater is eroded down from the swidden, nutrients may re-enter the nutrient cycle of a small section of forest. On the field itself, only crop residues remain to act as a source of nutrients for the returning forest. It may be that young trees are able to make incredibly efficient use of such small amounts of nutrients, for on soils in which domesticated plants no longer flourish, secondary growth will oftentimes thrive.

The Lacandon Maya of Chiapas, Mexico plant numerous varieties of fast-growing root and tree crops prior to the planting of corn in their *milpas* (swiddens); these prevent soil erosion and nutrient leaching in the newly cleared field. During the rains, many other species of tubers, trees, cereals and vegetables are planted. Of great interest is the observation that the Lacandones have learned to plant several of these crops only when certain “indicator” species in the primary forest begin to flower. For each planted species, the corresponding flowering forest species is called the “foot” of that crop. “Such a system coordinates the agricultural cycle with current

environmental conditions, rather than with a fixed calendar that makes no provisions for annual variations in temperature and precipitation” (Nations & Nigh, 1980, pp. 9–11, see Table 1). Thus the Lacandones tune in to what ecologists would call the forest’s information flow. This could also be described as the dispersion of crop cycles through time.

There is also, among the Lacandones, dispersion of plants in space through their swiddens. This prevents large clusters of single species and so emulates the high species diversity index of the forest, ensuring that the ► **swidden** “becomes a living mass of food-producing plants which occupy the entire cleared area both above and below the soil.” These dispersions in space and time enable the plants to escape their herbivorous predators, and make possible a sustained yield of food throughout the year (Nations & Nigh, 1980, p. 11).

The Lacandones have evolved a swidden system wherein a swidden is only cultivated for short periods, and few weeding are done. This allows secondary species to establish themselves quickly on sites that are abandoned, so that re-opening of that space to cultivation can take place after only 2 or 3 years of fallowing, since forest growth will have been enough to provide sufficient ash fertilizer after burning. Not only that, but wild species are encouraged, and a variety of other useful plants are deliberately seeded into the *acahual* (fallow) to accelerate the reappearance of the forest (Nations & Nigh, 1980, p. 15).

The Lacandones recognize the forest as the principle factor in regulating itself. The strategy is thus to “farm” in the forest. . . not to replace the forest in order to farm (Nations & Nigh, 1980, p. 20).

All of the above is not to imply that all shifting cultivators have harmonic swiddens, as defined previously. Newcomers to forest farming do not have the required knowledge for managing forest-friendly swiddens. But traditional, integrated swiddenists also may not have swiddens that are Alternative Forest-Like Structures. Anthropological research prior to 1983 among Amazonian Indian groups living near the Equator

Agroforestry: Harmonic Swiddens, Table 1 “Foot” indicator plants: wild forest species whose flowering provides information flow to the Lacandon Maya (From Nations & Nigh, 1980, p. 12)

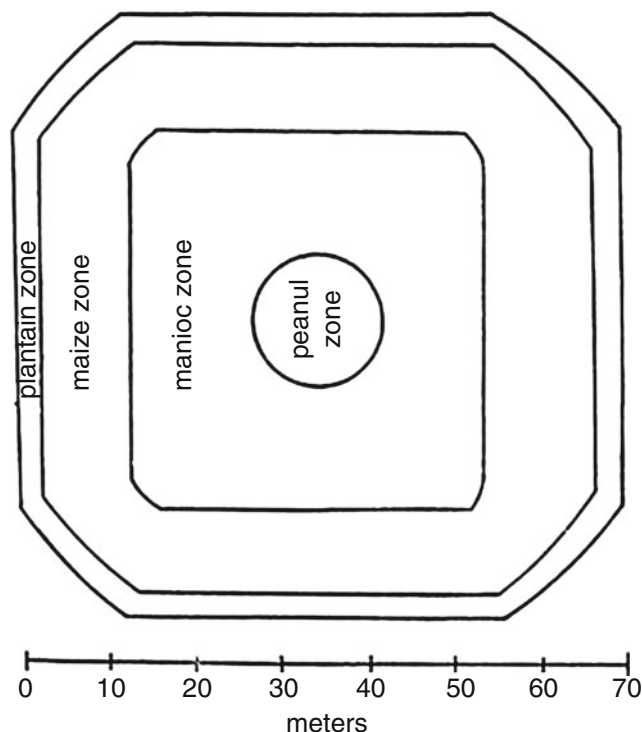
Crop				Indicator species		
Month	Region	English	Latin	English	Latin	Lacandon
January	South	Corn	<i>Zea mays</i>	Barbasco	<i>Paullina pinnata</i>	mäsh ak’
February	North	Watermelon	<i>Citrullus vulgaris</i>	Corkwood	<i>Heliocarpus donnell-smithii</i>	halo
	North	Corn	<i>Zea mays</i>	Corkwood	<i>Heliocarpus donnell-smithii</i>	halo
March	—	—	—	—	—	—
April-early	South	Corn	<i>Zea mays</i>	“White rope” vine	Unidentified	säk su’um
April-late	North and South	Corn	<i>Zea mays</i>	?	<i>Bucida buceras</i>	pok te’
May-late	North and South	Corn	<i>Zea mays</i>	Mahogany	<i>Swietenia macrophylla</i>	punah
June-early	North and South	Corn	<i>Zea mays</i>	Mahogany	<i>Swietenia macrophylla</i>	punah
	North	Rice	<i>Oryza sativa</i>	Mahogany	<i>Swietenia macrophylla</i>	punah
	North	Peanuts	<i>Arachis hypogaea</i>	Mahogany	<i>Swietenia macrophylla</i>	punah
July	—	—	—	—	—	—
August	North	Tobacco	<i>Nicotiana tabacum</i>	Black bache	<i>Guatteria anomala</i>	ek’bache
	North	Black climbing beans	<i>Phaseolus vulgaris</i>	Black bache	<i>Guatteria anomala</i>	ek’bache
September-late	North	Sweet potato	<i>Ipomoea batatas</i>	?	<i>Nectandra</i> sp.	ek’onté
October	North	Tobacco	<i>Nicotiana tabacum</i>	Wild tamarind	<i>Dialium guianense</i>	wäch
	South	Jícama	<i>Pachyrhizus erosus</i>	Water vine	<i>Vitis tillifolia</i>	yuhi
	South	Corn	<i>Zea mays</i>	?	Unidentified	k’uwan
November-early	South	Corn	<i>Zea mays</i>	?	Unidentified	piskinin
November-late	North	Corn	<i>Zea mays</i>	Barbasco	<i>Paullina pinnata</i>	mäsh ak’
December-late	North	Corn	<i>Zea mays</i>	Corkwood	<i>Heliocarpus donnell-smithii</i>	halo

in South America found a number of tribes without them, interspersed among those who do. In 1983, the journal *Human Ecology* published a symposium of papers on these groups, wherein the authors attempted “appropriate descriptions” of them, which were summarized by Beckerman (1983a). The research found, instead of harmonic features, monocropping, planting of different monocrops in concentric circles around the swidden (in one culture, the family house was always cited in the center of the swidden), and

polyvarieties of the staple cultigen (usually many varieties of cassava [manioc] mixed together). In the symposium, attempts were made to explain how these arrangements were able to perform some of the functions of the Alternative Forest-Like Structure. For example, the different varieties of cassava planted in Jivaroan gardens have a “variation of branching pattern, leaf shape, and growth period . . . promoting effective vertical and lateral exploitation of available light, warmth, and

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Fig. 1 Idealized plan view of ring-planting in a Candoshi ► swidden (From Stocks, 1983, p. 77. Permission pending)



moisture” (Boster, 1983, p. 62) that would be much the same as that achieved by the mixture of distinct species. Beckman notes that the simultaneous monocrops planted in an annular fashion among the Bari (Beckerman, 1983b) and the Candoshi (Stocks, 1983, see Fig. 1) are done so that the tallest plants are in the outer ring and the shortest in the center ring, creating a downward gradient of crop elevations from the edge to the center – a “funnel-like” effect in the garden. Stocks suggested that this arrangement reduces the shading of a shorter crop by a taller one; protects interior crops from pests by placing crops that are valued less by people but which taste best to pests on the outer rim, thus preventing satisfied pests from continuing on into the center; nourishes the crops on the edge better by placing them next to the forest; and/or disperses crops across a range of “micro-edaphic variation”. Beckerman suggested that these and other hypotheses needed agronomic field testing before they could be accepted.

Another possibility springs to mind. In the evolution of agriculture there must have been

people who initiated the practice of planting whole fields to one or a few favored staples. The first experimental monocultural fields could have been forest swiddens. Could these Amazonian Indian groups have been among the first to move in this direction? Their heavy reliance on the cassava as their staple food could have supplied a motive. The Amazonian swiddens discussed above may well represent a frozen stage in that transition, a stage continuing on today in those societies.

Swiddens of the South American rain forest which are Alternative Forest-Like Structures happened to be among the earliest studied, particularly by geographers, for example those of the Yanomamo people found in the Upper Orinoco of Venezuela (Harris, 1971). Treacy (1982) has also written of them among the Bora in southern Colombia. He makes the following very nice point for them: “. . .the notion that shifting cultivation fields are ‘abandoned’ with fallowing needs reassessment” because fruit trees, planted in the Bora swidden, continue to grow for a long period of time after final crop harvesting and the

ground around them is regularly weeded to prevent competition with fast-growing secondary forest species (Treacy, p. 16).

See Also

► [Swidden](#)

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Agroforestry: Special Systems

Harold Olofson

Certain indigenous agroforestry systems do not fit easily into a Western-science classification of such systems because, anomalously, they do not have as major components either a field of agricultural food crops or grazing livestock. Instead they involve, on the one hand, specific conserved species of forest vegetation, or sizeable conserved sections of forest, and on the other, such animal food sources as fish or bees in the place of domesticated animals or plants (although other agricultural or even agroforestry types may be found elsewhere in the village or district under consideration). Bee culture, however, is considered a branch of agriculture in some places (Commonwealth Agricultural Bureaux, 1980). Existing forest species are simply maintained as a support for either aquaculture or apiculture. These systems are not well known.

Aqua-Silviculture

The evidence for an indigenous aqua-silviculture, or combination of aquatic resources with managed forest vegetation, is thin. One possibility is a system described by Joly (1981) for a mixed Hispanic and Indian group living along rivers in upland Panama. These people train a species of riverine fish (*Brycon chagrensis*) to feed on the leaves of *Piper auritum* placed as bait in a system of stockades in family-owned pools during periods of low water. The fish absorbs the pleasant flavor of the leaves and the stockades facilitate the trapping of the fish.

It is somewhat questionable whether the plant *P. auritum* can be included in a discussion of silviculture, which pertains primarily to trees. Although Joly's discussion is unclear, it seems that this herb is not a part of the gallery forest found adjacent to the pools. It is apparently gathered from secondary forest vegetation growing

away from the river and brought to the feeder devices. It is, however, at the very least a conserved forest resource, for when clearings are made for ► [swidden](#), “clumps” of the plants are left untouched. If it requires shade, then other forest trees are involved in its conservation.

The Uanano Indians in the Uaupes River Basin in the Brazilian Amazon rainforest provide another example of indigenous aqua-silviculture. They take care to preserve particularly the forests along major rivers, by prohibiting the practice of shifting cultivation on the river margins. They know that if they interfere with those trees, they will harm the rivers’ fish populations, their major source of protein.

A Western science explanation can be made for what the Uanano perceive in doing this. The rivers in the Uaupes Basin are all blackwater rivers, full of tannins produced by the rainforest plant species as a protection against herbivores. Rains wash these tannins from the litter on the forest floor into the drainage system, where they prevent the growth of microflora which fish feed upon. These rivers generally have low levels of nutrients and primary phytoplankton. But during rainy seasons of high water in the rivers, the fish are able to swim into the forest with the rising river waters and feed on the vegetable matter (leaves, fruits, flowers, seeds, and microflora) and small animals (insects and their larvae, arachnids, crustaceans, and worms) that they can find there as “floating and decomposed matter and mud.” Observing this, the Uanano are “acutely aware” that preservation of the forest will save for them the fish as well (Chernela, [1982](#)).

Another example of aqua-silviculture has been noticed in a lakeside community in the Philippines, where the finally branching tree *Streblus asper* is maintained in farmers’ parcels. Branches are cut and submerged in the lake water for a time necessary to capture shrimp which come to shelter among them (H. Olofson, fieldnotes, Jalajala, Rizal, Philippines).

Api-Silviculture

When forest resources in the form of nectar-producing flowering trees and other plants are

consciously conserved in order to support domestic beekeeping and honey production, we have what could be called an indigenous api-silviculture. Essential to the recognition that api-silviculture exists is the knowledge that a beekeeping people can name flowering forest species important in honey production and also conserve them by, for example, not cutting them for swidden.

The protection of nectar-producing forest trees occurs among the swiddening Iraya of northern Mindoro Island, Philippines. Another aspect of their traditional conservation is the restriction of honey collection to the waxing period of the moon, thus forcing bees to swarm and to build up new hives with honey in the waning of the moon. Such customs may be stimulated by the fact that the Iraya look upon honey as a shamanic medicine (Revel-Macdonald, [1971](#)). But the Iraya are “honey hunters,” not beekeepers, having to look for such new hives by observing the flight directions of bees after those bees partake of river water. (The term “honey gatherers” would be most properly reserved for those people who know of permanent hive sites, such as those located on known cliff faces, to which they can return year after year.)

It would seem logical that if honey-hunters protect relevant trees, so also there must be examples of indigenous beekeepers who do. A good description of ritualized domestic beekeeping among the Yucatecan Maya is given in Weaver and Weaver ([1981](#)) but only the plant *Gymnopodium antigonoides* is mentioned as a recognized nectar source; they do not say whether it is protected. However, Chemas and Rico-Gray ([1991](#)) say that the Yucatecan Maya are able to identify 12 species of wild trees and weeds that are good sources of nectar foraged by bees to produce honey. They can rank these in terms of quantity, odor, flavor, color, and viscosity of the honey produced, as well as the quality of their pollen and nectar. They have a good knowledge of the flowering phenology of these trees, and know how very dry and very rainy seasons, very humid and very cool years, affect the honey produced by bees. They find that the management of

honey and pollen-producing vegetation need be only minimal. In their area, forest cutting has led to the forest being composed of mainly young trees. But this may have done little damage to the annual honey production cycle, since bees prefer to visit younger successional stages of forest growth anyway, as well as roadside plants.

The conservation of interstitial trees or of bee pasture useful to bees would be essential to growing populations who combine farming and bee-keeping, since otherwise the nectar sources would give way to the spread of crop land (see Editorial, 1981).

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It is difficult to locate references on indigenous communities which have achieved the combination of forest-grazing consciously involving silviculture. For example, one would not expect to find this among pastoralists, who have in the course of cultural evolution branched off from a way of agricultural life involving both domesticated animals and plants to concentrate on domestic animals alone – full-time pastoralists are not usually planters. They are known to graze their animals among forest trees, and to use those trees for shade for their livestock, but it is difficult to find reference to their actually having planted those trees. This type of agroforestry appears to be a very recent conception.

If they can be accepted as a people who are now, in this day, “indigenous” to their homeland, some nth-generation Caucasian New Zealanders are a good example of temperate-climate silvipastoralists (Stover, 1979). Silviculture, interestingly enough, was discovered almost accidentally and simultaneously by imaginative, private farmers and private company employees in the 1960s, not by scientific research. Observations of their schemes led to serious consideration of silvipasture in the Forestry Development Conferences of that country in the 1960s and 1970s and silvipasture was then realized as a way of reversing the historical depletion of timber resources caused by clearing land for cattle and sheep. As a response to increased timber prices, and to the lowering prices for meat and wool,

Farmers . . . have come to see trees not only as shelters for livestock both winter and summer and as sources of fuel and locally needed posts, but as another potential cash crop, albeit, a slow-growing one, that might share growing space with grass. (Stover, 1979, p. 441)

Agroforestry: Systems with Animals and Grasses

Harold Olofson

Silvipasture

Silvipasture is an agroecosystem which involves a necessarily precise combination of forest trees, livestock, and selected grasses.

The New Zealanders’ view of the role of livestock is reminiscent of the rationale for the food crops in accelerated ► [swidden](#) or food-tree crop interplantings. In the latter, the crops provided the short-term returns necessary to stimulate the willingness to plant and wait for trees on the same space, as among the Ifugao in Northern Luzon, Philippines. In New Zealand, the farmers see that

the animals provide income to cover interest costs during the period before the trees can be harvested. Silvopasture in New Zealand involves allowing livestock into well-established forest, once the potential relationships are well understood; planting trees into well-established pasture; or sowing grass among tree-seedlings on run-down land.

Agri-Silvipasture

A remarkable indigenous system involving the mix of three components – livestock, trees, and a staple crop, is found among the Fur of Sudan. This permanent system is made possible by the unique characteristics of the savannah tree *Acacia albida* (Radwanski & Wickens, 1967). Unlike almost all other trees, this legume sheds its leaves at the start of the rainy season, and plots of millet or sorghum placed directly under the trees quickly benefit from the rapidly decaying leaves, at a time when sunlight is able to reach the crop through the tree canopy. In the dry season, the trees are in leaf, providing shade for the plots below, and keeping down the temperature of the soil which is able to retain more water than otherwise. During this fallow period, livestock may be allowed to graze and rest in the shade under the trees, especially when a storm blows down the nutritious fruits of the acacia. The livestock in turn fertilize the area. They are also fed with the leaves and fruits of the tree especially collected by the Fur as fodder. And the combination of animal manure and *Acacia albida* leaves makes nitrogen plentifully available under the trees.

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Aida Yasuaki

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Aida Yasuaki, also called Aida Ammei, was born in Yamagata, Japan on February 10, 1747 (March 20, in the present calendar). Aida studied mathematics under Okazaki Yasuyuki, a mathematician of the *Nakanishi-ryu* school, from the time he was 15 years old until he reached the level of the *Tianyuanshu* technique (Chinese Algebra system).

Then he went to Edo (now Tokyo), in September 1769 and became a son-in-law of SUZUKI Seizaemon, a Samurai of the Shogun. Aida changed his name to SUZUKI Hikosuke and worked as a *Fushin' yaku*, a civil engineer. Here he came to know KAMIYA Teirei, a student of FUJITA Sadasuke (1734–1807). Fujita was a mathematician of the *Seki-ryu* school who wrote the *Seiyo Sampo* (Exact Mathematics, 1781) which was one of the best mathematical textbooks of that time.

Aida decided to become a mathematician, retired from his work, changed his name back to Aida Yasuaki, and asked Fujita if he could teach mathematics. Fujita did not accept Aida's offer because he was concerned about mistakes in Aida's *Sangaku*. (*Sangaku* is a picture board with mathematical drawings, mostly of geographical problems. They were hung on the walls of shrines and temples for praying for mathematical progress.) Aida grew angry with Fujita and wrote the *Kaisei Sampō* (Counter-argument with Seiyo Sampo, 1785).

He then founded the *Saijō-ryū* school, and both schools disputed mathematics with each other for about 20 years. This encouraged Japanese mathematics to progress to a high level. Aida published eight books, nearly 2,000 chapters of manuscript. He taught mathematics to WATANABE Hajime (1767–1839), SAITO Naonaka (1773–1844), ICHINOSE Korenaga (fl. 1819), and KANDO Seii (nineteenth century).

Aida died at Edo (Tokyo) on October 26, 1817 (December 4 in the present calendar).

The strong point of the *Saijo-ryu* school was in systematic algebraic symbols. Aida created the original symbol for “equal,” which was the first use of equal in Eastern Asia. He wrote the *Sampo Tensei-ho Shinan* (Mathematical Instruction of “Tensei-ho” (or the Tenzanjutsu technic in the Seki-ryu school)), which is one of the most systematic books describing the Japanese algebraic system.

Aida’s mathematical method was similar to SEKI Kowa’s. Aida studied the characteristics of irrational numbers. First, Aida computed the approximate value of irrational numbers by a sort of “Horner’s method” (Horner, 1819); then he computed the value of the continued fractions. An example of the root 2 is as follows:

Aida then calculated the continued fractional value of prime numbers smaller than 100. He also used the inductive method.

Approximate value	Continued fraction
$\sqrt{2} \approx 1.4142$	1, 2, 2, 2, 2, 2, 1...
$\sqrt{2} \approx 1.414213$	1, 2, 2, 2, 2, 2, 2, 1...
$\sqrt{2} \approx 1.41421356$	1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, ...

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Ajanta

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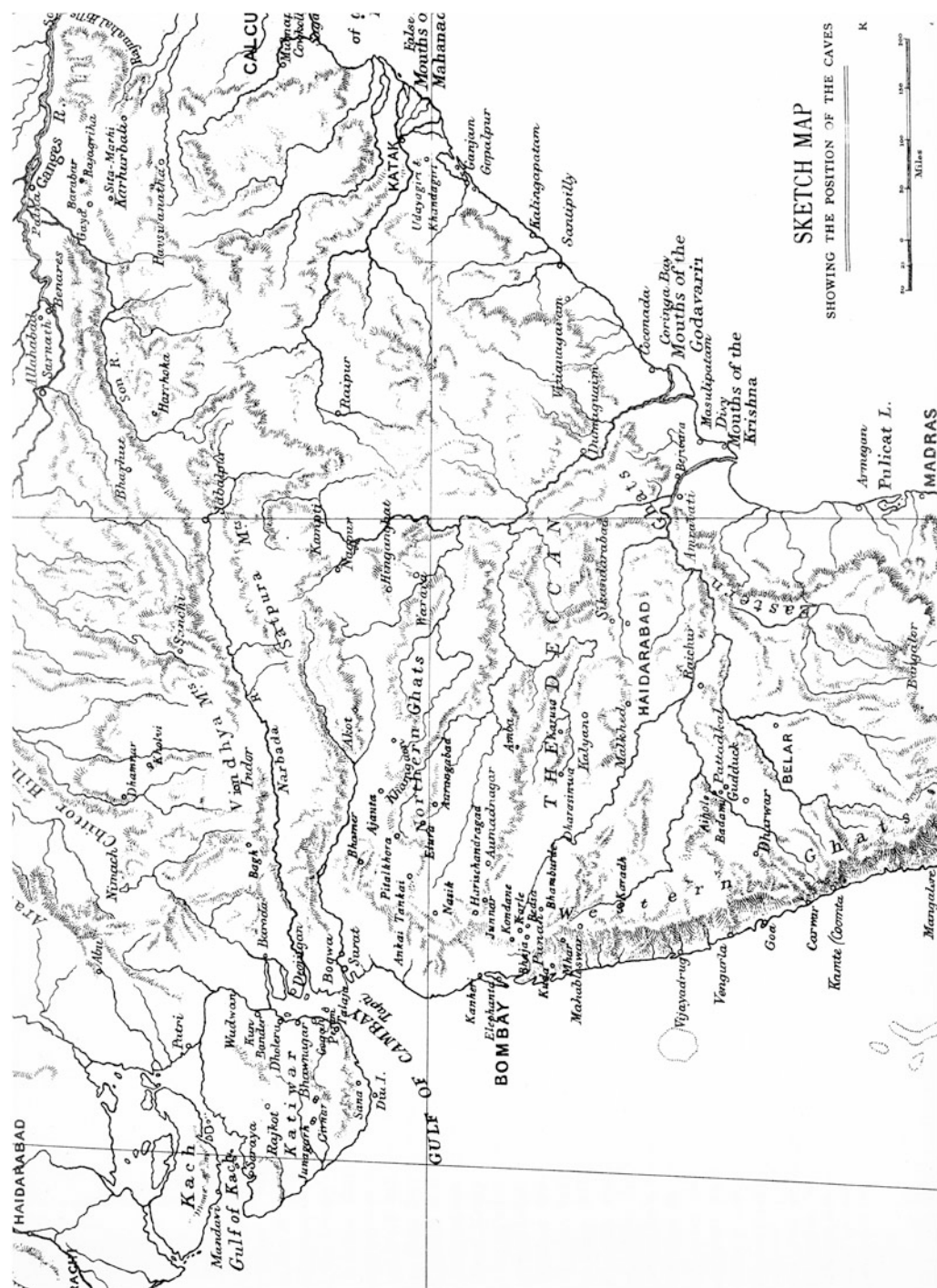
Introduction

Location. The ancient *sañghārāma* (Buddhist monastery) of Ajanta is located in the Aurangabad district of Maharashtra state in India (latitude 20°33'9.94"N and longitude 75°42'0.69"E). There are nearly 30 rock-cut edifices.

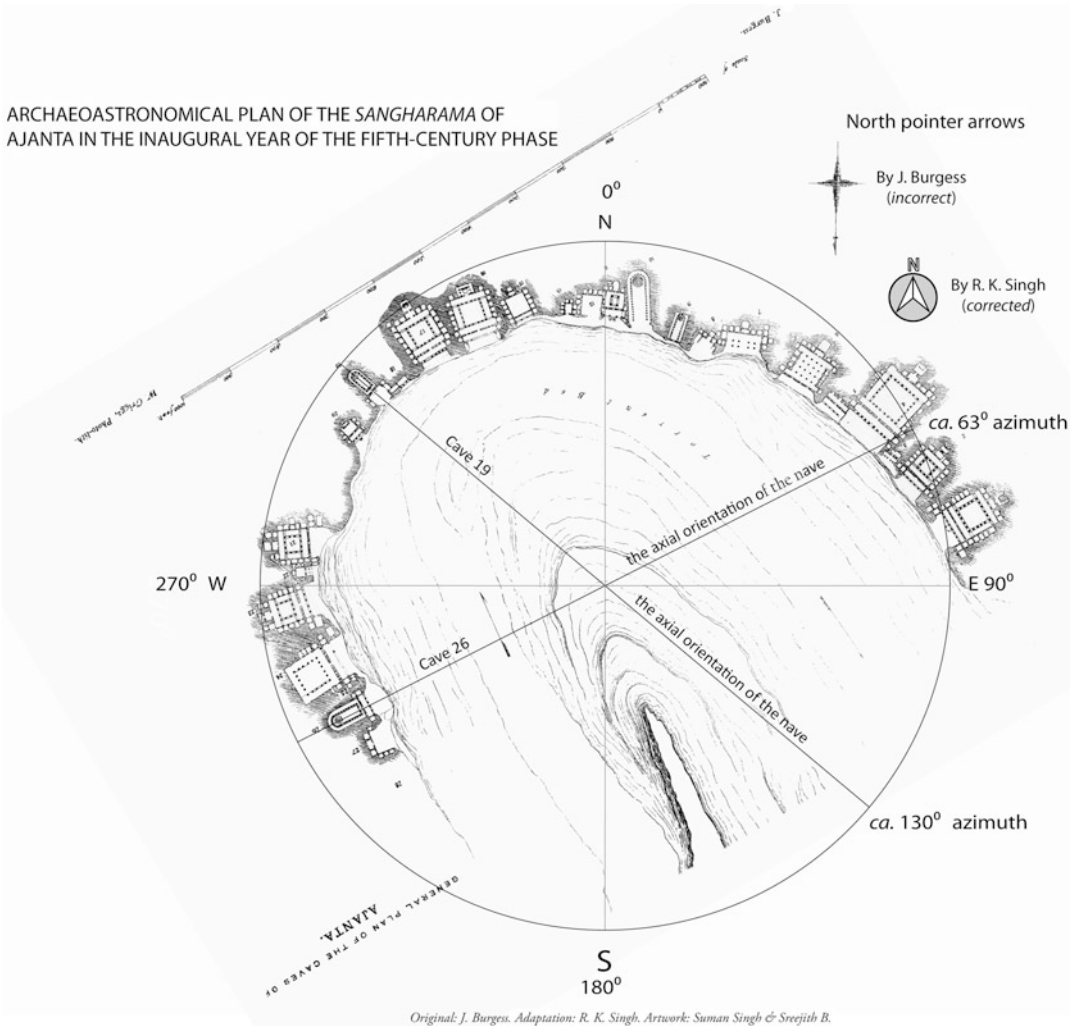
Geography. The geographical setting of the *sañghārāma* is typical. It is near a waterfall, recessed deep into the glen of a ravine. The entire *sañghārāma* is carved out of a monolithic stretch of scarp, which is in the shape of a horseshoe. The particular stretch of the scarp belongs to the Sahyādri range of the Western Ghats (*ghāt* = slope), recently listed in UNESCO’s World Heritage list as an eco-sensitive zone.

Antiquity. Chronologically, the caves are divided into two groups. The first group of five caves is dated between the third and first centuries BCE (Nagaraju, 1981). The second group of some 26 caves has been dated recently between circa 462 CE and circa 480 CE (Spink, 2009, Fig. 39).

Political background. During the first phase, the region of Ajanta fell within the dominion of the powerful Sātavāhana dynasty whose direct involvement at Ajanta is not yet known. The period of the second phase of Ajanta developed within the reign of Maharaja Hārīṣeṇa (ca. 460–477 CE) of the Vākāṭaka dynasty.



Ajanta, Fig. 1 Map showing rock-cut cave sites in India (Source: Fergusson and Burgess 1880)



Ajanta, Fig. 2 Caves 26 and 19 (the only two temples in the original plan of the fifth-century phase of Ajanta) show revealing astronomical connections. If Cave 26 is oriented to ca. 63° E-NE so as to receive the first rays of the sun on the Dhamma Day and on the first day of the varṣā

ĥaturmāsa, Cave 19 is oriented to ca. 130° E-SE so as to receive the precise alignment of the morning sun, every day, during the entire period of the subsequent, winter, ĥaturmāsa (which spans from Kārttika Pūrṇimā to Phālguna Pūrṇimā)

Classification of the Ajanta edifices. Conventionally the *layaṇas* or *śailagṛhas* (both meaning rock-cut edifices) of Ajanta are classified under different categories: *Hīnayāna* (Lesser Vehicle), *Mahāyāna* (Greater Vehicle), *ĥaitiyagṛha*, and *viḥāras*. These categories now appear to be dubious. Frontier researchers are in the process of formulating a new criteria of classification that reflects the current and advanced understanding about the monastic complex.

Architecture

Rock-Cut Architecture

Rock-cut architecture is one of the most peculiar ways in which the history of arts and architecture evolved in India. All the ancient religions of India including Hindu, Jain, and Buddhists adopted the science or art of excavating rock-cut temples, monasteries, and pilgrimage sites (Fergusson & Burgess, 1880).



Ajanta, Fig. 3 A view of the Ajanta caves from the “Viewpoint”

Ajanta, Fig. 4 The Satavahana-period temples, Caves 9 and 10 (seen in the center)



Plans

Stupa temples. *Stupas* were initially burial mounds that gradually came to be worshipped in ancient India. The Buddhists adopted the practice, for the earliest Buddhist stupas contained the relics of the Buddha. These were opened up in later times and the relics redistributed for and kept in many later stupas that were generally

made of stone and bricks. In the context of rock-cut architecture, monolithic stupa temples were excavated, which could not of course contain any relic but were worshipped with equal faith. The history of stupa temples evolved in a variety of ways in different regions. However, the most characteristic of the evolved types, as at Ajanta Caves 9, 10, 19, and 26, contain a frontcourt,

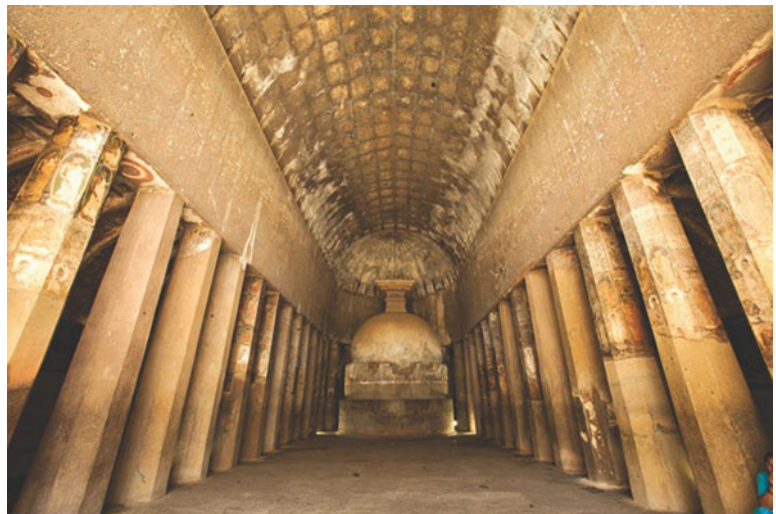


Ajanta, Fig. 5 Cave 9, interior

a high enclosure wall, a nave, the stupa at the back of the nave, a circumambulatory path divided from the nave by a colonnade, and the vault. Further evolved types may also include porches (as in Ajanta Cave 26), musicians' galleries (as in Cave 19), terraces (as in Cave 26), and even adjunct *upāśrayas* (as in Cave 26) or *maṇḍapas* (as in Caves 26 and 19) (Singh, 2012a).

Upāśrayas. The word *upāśraya* in Ajanta inscriptions denoted a place of lodging for monks. The word is still used in India in similar contexts. *Upāśrayas* of Ajanta form one of the two major varieties of architecture, the other being the temples. Therefore, lodging and worship halls were two distinct types, demanding two different types of architectural requirement. This was so in the first group of the Ajanta caves in the Sātavāhana period, and it was so even during the first few years of the site's planning and development in the fifth-century phase. Soon, however, in circa 466 CE, a revolutionary idea changed everything; the old categories were discarded, for the *upāśrayas* were converted into *maṇḍapas* or *stupavihāras*, which combined the stupa and

Ajanta, Fig. 6 Cave 10, interior





Ajanta, Fig. 7 Cave 26, interior

the *upāśraya* setting allowing the monks to dwell in the interiors of the temple. Thus, a new variety emerged when the edifices that were begun as *upāśrayas* later began to add Buddha shrines in the interiors and also created *vithikās* (picture galleries) with other elaborate decorations (Singh, 2012b).

The plan of the *upāśrayas* is simpler. The main features included a congregation hall surrounded with residential cells, many of which have rock benches and pillows. Some larger *upāśrayas* were provided with pillars in the hall, windows on the front wall, and a porch. Occasionally porticos were excavated too. They often had frontcourts. Sculptural or painted decoration was generally not the rule or requirement.

Maṇḍapas. The word *maṇḍapa* means a pavilion, still used in India. However, in Ajanta inscriptions the word is used variously to imply the presence of the Buddha. Thus, a *maṇḍapa* is not simply an *upāśraya* (hostel). Shrines of the Buddha were excavated in them (Cave 16), which were also called *caityamaṇḍapam*. Often, the plan of the *maṇḍapas* had a flight of steps for the riverbed, an ornate central gate (*torṇa-dvāra*), a frontcourt with

Ajanta, Fig. 8 Cave 7, the facade with the double portico



Ajanta, Fig. 9 Cave 2, interior



Ajanta, Fig. 10 Cave 2, the shrine area



an enclosure wall (*prākāra*), a pillared porch, and cubical hall with or without pillars, cells, and at least one Buddha shrine. The distinction of *maṇḍapas* from upasrayas may be gleaned from the fact that in the context of the *maṇḍapas* (with the anthropomorphic Buddha figures in the shrines), the word *upāśraya* has never been used in inscriptions. Instead, the words *śāityamaṇḍapam*, *stupavihāram*, and *munirājaśāityam* are used (Yazdani, 1952), as in Ajanta Caves 16 and 17 (Mirashi, 1963) and the

contemporaneous Ghaṭotkacha Cave not far from Ajanta, indicating that these are Buddha temples and not just *upāśrayas* or halls. The *maṇḍapas* that are excavated at Ajanta and depicted in the Ajanta paintings give us enough clues as to what they are, and how to interpret or classify them. In Ajanta paintings, the Buddha is often seen seated in a pavilion type of architectural setting. Actually, the architectural scheme, layout, and planning of several Ajanta caves most closely resemble the pavilion type. Such pavilions are characterized

by a pillared portico, a porch, a hall, and subjoined cells. These are, thus, elaborate pavilions. And, they are not just pavilions. Because of the presence of the Buddha, the pavilions are effectively

transformed into temples. It is for this relationship between the semantics and the syntax of the architecture of the *maṇḍapa* that the word *maṇḍapa* was used in the sense of a Buddha temple rather than a simple pavilion devoid of the Buddha's presence.

Cisterns. Because the caves are at various levels of elevation at the cliff, there was a need to excavate cisterns at the cliff. Most of the edifices have a cistern. The water harvesting technology, the method and excavation technique, and the challenges faced by the planners in their creation are seldom explored. Some Ajanta cisterns are several dozen cubit feet in measure that are capable of storing a great volume of drinking water for the daily needs of the expected residents and pilgrims. Obviously, water harvesting at such altitudes of the monolithic cliffs of the amygdaloidal traps of the Western Ghats involved special engineering and experience. Some cisterns are open to the sky, some are inside the porches (Cave 6), some are inside the outer cells on front-courts (Caves 4 and 21), and at least one was so specially treated as to require an exclusive pillared edifice (Cave 18).

Architectural Components

Staircases. Most edifices were separately approached from the riverbed through a flight of steps, which were long for high elevation (as Cave 26) and shorter for those on the lower



Ajanta, Fig. 11 Cave 1 interior rear wall, left of shrine depicting the Bodhisattva King in a Mountainous Landscape



Ajanta, Fig. 12 Cave 17, porch rear wall depicting the narrative of Kalodayin

elevation (as Cave 6). Most staircases were open to the sky, while some were also tunneled (Caves Upper and Lower 6, Cave 16 and 17). Most of them have perished or been notably damaged in the course of time.

Gates and doorways. There are many types of doorways. First, the main gates (*torṇa-dvāra*) permitted access into the precincts of the edifices which have mostly perished now, except for the bare traces of a few. They evidently had sculpted guardian figures and other carved and painted decorations. Second, there are the main doorways permitting entry into the interiors of the edifices, which are often carved with figures of humans and other creatures. Geometric, ornamental, and vegetative decorations are also included with equal charm and beauty. Third, many edifices have side doorways permitting access into the interior, many of which have decorations with various carved or painted motifs. They provide extra lighting for the interiors when the hall is larger requiring proper lighting for the painted walls. Fourth, there are shrine doorways at the hall's rear, which received special treatment, because the shrine is symbolically and structurally the center of the temple. Each shrine doorway displays unique thematic, iconographic, and aesthetic treatment. Lastly, there are the cell doorways that are bereft of sculpted decorations, for the resident monks did not require decorations. Some cell doorways have painted decorations around the frame.

Prākāras. *Prākāras* are enclosure walls around the frontcourts of some edifices (Caves 19 and 26). Whether other edifices had *prākāras* cannot be confirmed, since the front parts of many frontcourts have perished in gradual rockslides.

Frontcourts. Most edifices have exclusive frontcourts. Of the earlier group of *upāśrayas*, Cave 12 probably had one. The other two (Caves 13 and 15A) are too small to permit any frontcourt. Of the fifth-century *upāśrayas*, the earliest inaugurated ones had shallow frontcourts (Caves 8, Lower 6, 26, and 19), while those inaugurated in subsequent years were provided with wide and deep frontcourts (Caves 21, 23, 24, 1, and 2). Even the adjunct *upāśrayas* or

maṇḍapas had frontcourts (Caves 25, 27, and the lower wings of Cave 26).

Porticoes. Only few edifices have porticoes, e.g., Caves 1, 7, and 19. Cave 1 had a small double-pillared portico (now perished) and Cave 19 has a similar double-pillared portico. However, Cave 7 has the unique arrangement of two multi-pillared porticoes indicating that the edifice was special.

Porches. Both the *upāśraya* and temple types often have porches. While the stupa temple Cave 26 has a spacious pillared porch, the other stupa temple of the same fifth-century phase, Cave 19, does not have any porch. In the earlier phase, none of the two temples (Caves 9 and 10) seems to have had any porch. However, in the *upāśraya* category the larger ones were ideally provided with porches whether of the earlier period or of the fifth-century period. This is because Cave 12 of the earlier phase possibly had a pillared porch whose traces are all gone. As regards the later phase, it was the rule to provide every *upāśraya* or *maṇḍapa* with a porch, as there is no exception.

Halls. The halls of the earlier period, not only at Ajanta but also elsewhere, are smaller. Notably, the concept of the hall was rather related to the *upāśraya* type (residential). The word, *upāśraya*, itself implied a hall whose usage is not found in the inscriptions of the stupa temples wherein the Buddha was worshipped symbolically in the form of the stupa. Halls, therefore, can be said to belong to the *maṇḍapa* (literally, pavilion) type of architecture at Ajanta that has the Buddha shrines.

Cells. *Apavaraka* was the word used for the monks' cells. In earlier periods, as even today, the interior of a sacred place was never the ideal place for lodging. It was at least so by circa 466 CE in the context of Buddhist rock-cut architecture. A survey of Buddhist archaeology would reveal, as suggested earlier, that the *upāśrayas* and temples were excavated apart from each other even if physically adjoined to each other. However, a revolutionary experiment was carried out at Ajanta in circa 466 CE (Spink, 2009, Figs. 40–41) when the ideas of the *upāśraya* and the temple were combined into one architectural

composition. The earlier duality was eliminated. The two types of architecture now coexisted within one layout, within a single program. The historical invention, for it was indeed the invention of a new idea, was created right at Ajanta in that catalytic year of circa 466 CE, as noted first by Spink. The new idea was to convert the *upāsrayas* into temples. A majority of the *upāsrayas* were already underway – some halfway into the porch or some had barely exposed the hall, but some had already completed the larger part of excavating the hall, and even the interior cells – when the idea of converting the *upāsrayas* (hostels) into temples suddenly gripped the site. What followed then was the challenging process of making difficult adaptations, redesigning the whole layout; each edifice presented unique opportunities for new schemes as well as new types of difficulties.

Cells were removed at places, extra cells were carved in other places, and blank areas were utilized for excavating more cells, such as those on the porch ends, and even on the left and right outer walls flanking the frontcourt. Thus, everything was overhauled, and the cells (or the cells' inmates) remained witness to the dramatic developments. Evidently, some cells were used while the excavation work was still underway, and some were used after the main Buddha shrines were dedicated and put to worship, and some cells were never used at all for various reasons. Some of the cells were plastered from inside, and some were even painted, as in Cave 27.

Door fittings. Spink has unlocked a great mystery of Ajanta by suggesting that the cell door fittings contain a credible corpus of physical data whose analysis alone is enough to reveal the internal chronological structure of the Ajanta caves of the second phase. He has classified the door fittings into four modes: A, B, C, and D. Then, there are also A+, B+, and C+, which are advancements over the earlier types. The door modes suggest a story of internal evolution at the site, across different caves. They suggest the gradual advancement of technology, the effort of grappling with the new medium of rock-cut architecture, and the trial and error

process. It was indeed a new medium for the workers, planners, and other stakeholders, as it was after centuries that such architectural projects were started again in the monolithic medium. A survey of rock-cut architecture in India reveals that in the centuries immediately preceding the fifth-century phase of Ajanta, there was hardly such an edifice excavated in the Indian subcontinent. If there was a preexisting technology available regarding how to fix wooden doors in the monolithic doorframe of a shrine, or a main door, or a cell, the masters of Ajanta at least were not aware of them. They tried a variety of ways. The earlier efforts were really not very technological and also impractical, but the later ones are more sophisticated and sensible.

Pillars. Before the Ajanta examples, the rock-cut *upāsrayas* seldom had pillars in them. Even at Ajanta, the earlier *upāsrayas* do not have pillars. Ajanta Cave 12 that has a spacious hall does not have any pillar. In the fifth-century phase, when nearly 17 edifices were planned together in circa 461–462 CE, the plan seems to have been to provide the pillars in stupa temples alone, and not in the *upāsrayas*, which were dwelling halls. It was probably for this custom that the earliest of the fifth-century halls (e.g., Caves 27 and 15) do not have any pillar in the interiors even though the halls are reasonably larger. Soon, however, the planners felt the need of pillars in the *upāsrayas*. Accordingly, Cave 11 had four pillars added although the hall does not seem to require pillars because of its smaller size. In no time, it became a custom at Ajanta to add pillars in the halls of every *upāsraya*. The earliest pillars were octagonal without any decoration. The later pillars have 16, 32, or even 64 sides in them carved in various permutations of designs and decorations. Some such octagonal pillars were reworked in later years to suit the emerging aesthetic norms, as the site developed rapidly within a tight chronological framework of about 18 years during the reign of Hariṣeṇa.

As regards the pillars of the stupa temples, they have a long history of association and gradual development. At Ajanta, the earlier

group of stupa temples (Caves 9 and 10) have a row of colonnades on either side of the nave, which goes around the stupa at the back, thus separating the nave from the aisles as well as permitting the creation of a *pradakṣiṇā-patha* (circumambulatory path). These pillars in both the caves are octagonal without any carvings. The flat surfaces were used for paintings. However, in the fifth-century stupa temples (Caves 19 and 26), the pillars while having been arranged for defining the circumambulatory path are lavishly carved with a variety of motifs and designs. Later, they were also painted.

Shrines. Prior to the fifth-century phase of Ajanta, the shrines were to be found only in the temples where the Buddha was worshipped in the symbolic form of the stupa. The symbolic structure of the stupa was itself the shrine; it carried the presence of the Buddha. However, it was not customary to have a shrine in the *upāsrayas* (residential halls). Only isolated examples are found in the Western Deccan where stupas are seen in the *upāsrayas*.

As regards the anthropomorphic Buddha image, it is not found in the *upāsrayas* prior to the fifth-century phase of Ajanta except for the solitary example of Kanheri where a portable wooden Buddha image was found in a *maṇḍapa* type of edifice. This has been dated just before the fifth-century phase of Ajanta. Thus, it appears that the Buddha shrines of Ajanta, wherein full-sized and even larger than life-size images of the Buddha are excavated in the monolith, are really the inventions of Ajanta in the fifth century CE – a fact seldom noted in art history (save for the works of Spink). The invention, however, did not start all of a sudden; it was not, evidently, the plan in the beginning.

From circa 466 onwards, when the idea of converting the *upāsrayas* (dormitories) into temples gripped the site, every possible residential hall then was added with a shrine at the rear of the hall, no matter how many adaptations had to be made for the purpose. Studies show that such Buddha shrines have a history of their own at Ajanta, beginning from the simple to the complex, from the smaller to the larger. Even iconographically, sociologically, and politically, the

shrines underwent multiple phases of significant adaptations. For example, the Bodhisattva images were added later in them; the *upāsakas* (lay worshippers) were carved or painted, which were never a part of the original plan. Images of the donors who were either kings, queens, ministers, famous monks, or wealthy merchants or their family members were carved inside the shrine as *upāsakas* – a fact largely unnoticed in Ajanta studies.

Geology

Ajanta is geologically important too. The scarp bearing the cliff that has the caves punctured in them was actually created by the rivulet Wāghur (Tiger River) flowing down below. In fact, the seasonal river has cut out the whole gorge. Wāghur River originates from the waterfall at Ajanta and flows down to the plain of Tāpī for hundreds of miles across the fields. Near the plunge of the waterfall, there is a continuous process of head cut creating backward recession of the rock surface. Thus, the place of the head cut is receding, which can be clearly observed from the “Viewpoint” up above the *ghāṭs*.

The basalt of the amygdaloidal trap rock of the Deccan is relatively soft and has porous fissures, cracks, and flaws at places. The ancient lava flow now solidified has layers in between, which created difficult conditions for the excavators. Crystal formations in the trap were also a problem especially if they occurred at places earmarked for sculptures. Evidently, due to geological flaws the carvers had to make notable adaptations. Due to rock fall, scarp recession, and seepages, the monuments are endangered. Geologists, scientists, and archaeologists are working in tandem to find ways to preserve the heritage of Ajanta for posterity.

Paintings

Ajanta paintings have long been misunderstood as frescoes, which employ different sets of pigments, processes, and methods. They are now

Ajanta, Table 1 Identification of pigments at Ajanta

Color	Pigments	Location
White	Kaolin	All around
	Pure calcium carbonate	Dresses, architectural depictions, and figures
	Shell white	Lips, necklace, and decorations on women figures
Red	Red ochre	All around
	Red lake	Brighter red pigments all around
	Cinnabar (rare)	Identified at one place only
Yellow	Yellow ochre	Background, animals, dresses, and figures
	Orpiment and/or realgar	Decorations, tools, dresses, and animals
Green	Green earth	Leaves, dresses, background
	Orpiment with blue or organic black	
Blue	Lapis lazuli	All around (not present in the earlier group of caves of third-first centuries BCE)
Black	Lamp black	All around

Source: Singh, M. (2011), p. 90

best called murals. The paintings display a wide range of themes, which have now been fully and correctly identified by Dieter Schlingloff and Monika Zin after some attempts by earlier scholars. Broadly, there are narrative and non-narrative themes. The narrative themes deal with episodes from the life of the Buddha and the Jatakas that are the stories of the Buddha in his previous lives (Schlingloff, 2013). The non-narrative themes are either devotional or ornamental (Zin, 2003).

Pigments (by coauthor M. Singh). The pigments of Ajanta paintings have now been identified using the destructive and nondestructive methods of analysis of micro-samples (Table 1).

Some colors have been obtained by mixing the pigments, e.g., pink has been obtained by mixing white (kaolin or calcium carbonate) with red (red ochre or red lake). Orpiment or realgar is added to the pink to obtain a flesh complexion. The pigment layer is applied on dry plaster with an

organic binder, which is probably vegetable or animal glue. The carrier of the painting is a thick plaster made up of silt, vegetable fibers, dung, ground rock powder (containing quartz, feldspar, pyroxene, olivine, iron oxide, etc.), and very little mud which is about 3 to 2.5 mm thick on a rough basaltic rock support.

Over the silt plaster, a calcium carbonate layer with thickness ranging from 80 to 200 μm was applied probably to render the pictorial surfaces flat and homogeneous in color to better receive the pigment layer. The adhesive material might have been animal or vegetable glue that has all disappeared now due to its being organic.

The paintings are under serious threat due to rising humidity conditions with the influx of tourists as well as because of the microbiological and microclimatic conditions.

Plaster (by coauthor M. Singh). Ajanta paintings were executed on a layer of plaster. There are various speculations about the composition and technique of the plaster. Recently, however, the Science Branch of the Archaeological Survey of India carried out detailed scientific investigations. The mud plaster samples were analyzed using XRF, FTIR, and SEM-EDX. The samples were observed using an electron microscope, which revealed a coarse substrate with casts even larger than 200 mm. This was followed by a second layer of fine-grained finishing.

The elements present in greater quantities in the sample are calcium, silicon, aluminum, and iron. Calcium is located in the inner most layer, silicon and aluminum in the layer immediately above, and iron associated with silicon and aluminum is in the outermost layer.

The elemental map with energy dispersive microprobe indicates a layer of calcium carbonate and a layer of kaolin due to the presence of aluminum. However, a clear line of demarcation between the calcium-containing layer and the kaolin (silicon and aluminum)-containing layer is not evident.

Particle size analysis of Ajanta mud plaster shows that the plaster is nonplastic with an average distribution of silt 70–75 %, sand 9–14 %, and clay around 12–15 %. The mud plaster shows specific gravity around 2.75. From this, it can be

seen that low clay soil was used for the preparation of Ajanta mud plaster, which also contains a high amount of silt. Since such high-silt soil can be found on the bank of the Wāghur River at Ajanta, the question of its use during the preparation of Ajanta mud plaster cannot be ruled out, as there is more than 70 % silt found in this soil. This is in consonance with ancient canonical texts on the arts and architecture, viz., *Samarāṅgaṇa Sūtradhāra*, where they recommend collecting soil from riverbanks for the preparation of mud plaster. It appears that sand and aggregate were mixed in the collected soil of riverbeds for the final preparation of mud ground. The present author attempted to prepare the mud plaster of Ajanta as per the recipes of the ancient text, and the results were rewarding.

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Ajima Naonobu

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Ajima Naonobu (1739–1796), also called Ajima Chokuen, was born at Edo (now Tokyo) in 1732. Ajima's father was earning 80 *pyo* (*pyo* was an annual salary of 60 kg of rice, and 80 *pyo* was the same salary as a landlord of an 80-person village would earn, or *koku*) and a samurai warrior of Lord Shinjo (Lord Shinjo belonged to the Tozawa family) in Dewa (now Yamagata Prefecture). Ajima studied mathematics first under Irie Masataka, a mathematician of the *Nakanishi-ryu* school, then under Yamaji Nushizumi (also called Yamaji Shuji (1704–1772)), who was the third president of the *Seki-ryu* school and an astronomer at *Bakufu Temmongata* (Shogun's Astronomical Observatory). Then Ajima became an accountant of Lord Shinjo, at the rank of 100 *koku*.

Yamaji made the *Horeki (Kojutsu) Reki* calendar (Calendar Made in Horeki Era 1754), which was used from 1755 to 1797; however, this calendar was not very accurate. In order to make a new lunisolar calendar, in 1762 he started to observe the sky with Fujita Sadasuke (1734–1807), his assistant. When Fujita was appointed *Sangaku Shiha*n (Professor of Mathematics) of Lord Arima (1714–1783) in 1768, he retired from the Shogun's Observatory. After that, Ajima helped Yamaji to observe the sky and taught astronomy at Yamaji's astronomical school. Ajima wrote four astronomical manuscripts: *Jujireki Bimmo* (Introduction of the "Works and Days Calendar"), *Anshi Seiyō-reki Koso* (Professor Ajima's Studies for Western Calendars), *Ajima Sensei Bemmo no Jutsu* (Introduction of Professor Ajima's Methods), and *Koshoku Mokyū Zokkai* (Introductions of Eclipses (of the Sun and Moon)). These manuscripts were probably students' notes of Ajima's lectures.



Ajima Naonobu, Fig. 1 Ajima Naonobu's grave

The lunar crater of “Naonobu” (4.6S 57.8E) commemorated him and was named in 1976.

Ajima's works for pure mathematics were studies for logarithms, computing the values of spheres, and series. Ajima and other Japanese mathematicians studied Western mathematics indirectly, that is to say, through Chinese books such as the *Shuli Jingyun* (Mei Juecheng (1681–1763), 1723, China). Ajima studied logarithms from this book and then made a table of logarithms whose values are from 0.9 to 10^{-12} , 108 items. When Ajima used this table and these formulae

$$\log = \log X + \log Y \quad \text{and} \quad \log 0 = 1,$$

he could compute all logarithmic numbers up to 12 decimal places.

Ajima expanded Japanese mathematicians' traditional method *Tetsu-jutsu*, which uses a sort of inductive method. (*Tetsu-jutsu* was created by Takebe Katahiro (1664–1739), the second president of the *Seki-ryu* school.) Ajima computed the value of a sphere. In this case, he solved a sort of integral equation using *Tetsu-jutsu* twice.

Ajima also wrote the *Sansha San'en Jutsu* (Methods of Three Diagonals and Three Circles).

After Yamaji died, Ajima became the fourth president of the *Seki-ryu* school (or fifth, because Fujita was sometimes counted as the fourth). Ajima died in Tokyo, April 5, 1798 (May 20, 1798, current calendar) (Fig. 1).

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Al-Battānī

Julio Samsó

Abū ‘Abd Allāh Muḥammad ibn Jābir ibn Sinān al-Raqqī al-ḥarrānī al-ṣābi’ was an extremely important Islamic astronomer of the ninth to tenth centuries. He was probably born in ḥarrān before 858, and had Sabian ancestors. He lived most of his life in Raqqa (Syria) where he made most of his observations, but there is also evidence that he visited Baghdad and Antioch.

Apart from a few astrological tracts which have not been studied so far, he compiled (after 901) his *al-Zīj* (astronomical handbook with tables) also called *al-Zīj al-ṣābi’* (Sabian *Zīj*), a work which marks the stage of full assimilation of

Ptolemaic astronomy in Islam. This process had produced its first results ca. 830 with the *zīj*es which were the consequence of the program of observations undertaken in Baghdad and Damascus under the patronage of Caliph ► [al-Ma'mūn](#). Al-Battānī's ► [zīj](#) contains a set of instructions for the use of the numerical tables which have an essentially practical character. We do not find in them careful descriptions of the Ptolemaic models implied in the tables, and the author makes surprising simplifications, such as not describing Ptolemy's model for Mercury or not mentioning the equant point around which the mean motion of the center of the epicycle takes place. Nevertheless he describes, sometimes very carefully, the observations he made in Raqqa between 887 and 918, which allowed him to establish new and more precise mean motion parameters, a new eccentricity ($0;2,4,45^\circ$) for the Sun and Venus, the longitude of the apogee ($82;17^\circ$) of these two celestial bodies, a very accurate determination of the obliquity of the ecliptic ($23;35^\circ$) (the band of the zodiac through which the Sun apparently moves in its yearly course), measurements of the apparent diameters of the Sun and the Moon, and their variation in a solar year and anomalistic month, respectively. These new parameters show a clear improvement over those of Ptolemy and led al-Battānī to establish some important corrections on Ptolemaic theory such as the mobility of the solar apogee, the fact that the obliquity of the ecliptic is not a fixed value, and the possibility of solar annular eclipses.

Apart from the *Almagest* and the *Planetary Hypotheses* (used by Battānī to determine the geocentric distances of the planets), Theon's *Handy Tables* constitute a major Ptolemaic influence in the *zīj*: the planetary equation tables (with the obvious exception of those for the equation of the center of Venus), for example, derive from Theon, and al-Battānī's work constitutes one of the important instruments for the diffusion of the *Handy Tables* during the Middle Ages. The *zīj* was translated twice into Latin (by Robert of Ketton and Plato of Tivoli) in the twelfth century, as well as into Spanish (thirteenth century) under the patronage of ► [Alfonso X](#). It influenced

strongly the Latin version of the *Alfonsine Tables*, was known in Jewish circles through the summary made in Hebrew by Abraham bar ḥiyya (d. ca. 1136), and was quoted by European astronomers until the seventeenth century. Al-Battānī died in 929.

See Also

- [Abraham bar Ḥiyya \(Savasorda\)](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [al-Ma'mūn](#)
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Al-Bīrūnī

Abdul Latif Samian

Abū Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī was born on Thursday, 3rd of Dhū al-Ḥijjah, 362 H (4th September A.D. 973) at Madīnah Khwārizm. His exact birthplace is still a matter of controversy. It is conjectured that he was born

in the outskirts (*bīrūn*) of Kath, at al-Jurjāniyah, Khwārizm or at a place called Bīrūn, as implied by his nickname al-Bīrūnī. The only clue given by al-Bīrūnī was that he was born in a city in Khwārizm. The name Abū Rayḥān was given to him because of his love for sweet fragrance. Al-Bīrūnī died on 443 H (A.D. 1051).

He knew Persian but preferred Arabic, because the latter was more suitable for academic pursuit. Most of his numerous books and compendia were written in Arabic. He received some of his early education under the tutelage of the astromathematician Abū Naṣr Maṣṣūr b. ‘Alī b. Īrāq al-Jilānī (d. ca. 427 H) and ‘Abd al-Samad b. ‘Abdal Samad from Khwārizm. This is in addition to his formal elementary religious education at the *madrasah*, an institution where Islamic sciences are studied.

Al-Bīrūnī’s first patron was the Sāmānid Sultan Abū ṣālih Maṣṣūr II, who reigned in Bukhara until the city was invaded by the Ghaznavid Sultan Maḥmūd in 389 H (A.D. 999). Later al-Bīrūnī went to Jurjān to the court of Abu’l Haṣṣan Qābūs b. Washmjīr Shams al-Ma’ālī (r. A.D. 998–1012), under whose patronage he wrote *al-Āthār al-bāqīya min al-qurūn al-khāliya* (Chronology) which was completed in 390 H (A.D. 1000). Al-Bīrūnī found the Sultan indiscriminate and harsh. His next sojourn was in Khwārizm and Jurjāniyah, in the service of the Sāmānid Prince Abu’l Abbas al-Ma’mūn ibn Muḥammad II. Under his patronage, al-Bīrūnī received great respect. It was during this period that al-Bīrūnī met the physician ‘Abu Sahl ‘Isa b. Yaḥya al-Jurjānī. His *Taḥdīd nihāyat al-amākin li taṣṣih masāfāt al-masākin* (Determination of the Coordinates of Cities) was completed in A.D. 1025.

His *Kitāb fī taḥqīq ma li’l-Hind* (Book on India) was finally published in 421 H (A.D. 1030). The Ghaznavid Sultan Maḥmūd invaded and conquered the city in 407 H (A.D. 1017). Al-Bīrūnī’s other book, *Kitāb al-taḥfīm li-awā’il sinā’at al-tanjīm* (The Book of Instruction in the Art of Astrology), which was dedicated to Rayḥānah, daughter of al-ḥassan, was written in Ghaznah, A.D. 1029. Al-Bīrūnī’s *magnum opus*, *al-Qānūn al-Maṣ’ūdī fī al-hay’ah*

wa’l-tanjīm (Canon Masudicus), an astronomical encyclopedia comprising 11 treatises divided into 143 chapters, was completed at a later date, in 427 H (A.D. 1035) and was dedicated to the son of Maḥmūd, Maṣ’ūd. Apart from emphasizing the importance of astronomy, he gave accurate latitudes and longitudes and also geodetic measurements. His *Kitāb al-jamāhir fī ma’rifat al-jawāhir* (Mineralogy) was completed less than a decade later (about 435 H/A.D. 1043) and was dedicated to the Ghaznavid Prince Sultan Shihāb al-Dīn Abu’l Faṭḥ Mawdūd b. Maṣūd, Sultan Maḥmūd’s grandson. His *Kitāb al-ṣaydanah fī l-ṭibb* (Materia Medica or Pharmacology) was written toward the very end of his life.

Al-Bīrūnī lived during a period of intense scientific activity. Among his contemporaries were Ibn al-Haytham (A.D. 975–1039) and Abu ‘Alī al-Husayn ibn ‘Abd Allāh ibn Sīnā (370 H/A.D. 980–428 H/A.D. 1027). Others include Abū Naṣr Maṣṣūr ibn ‘Alī ibn Īrāq who was one of al-Bīrūnī’s patrons, Abū al-Ḥassān ‘Alī ibn Sāid ‘Abd ar-Raḥmān ibn Aḥmād ibn Yūnus who was an astronomer of distinction (d. A.D. 1009), and Abū Sahl ‘Isa ibn Yaḥya al-Masīhi al-Jurjānī (d. A.D. 1000) who was a close associate of al-Bīrūnī’s and wrote 12 books under his name.

Al-Bīrūnī was a philosopher-scientist, but science prevailed over philosophy and he appeared not to have identified himself with any school of philosophy. It was reported that he started doing astronomical observation as early as 18-years old.

In addition to his *Kitāb al-taḥfīm* (Astrology) and his *Kitāb fī ifrād al-maqāl fī amr al-ḥilāl* (The Exhaustive Treatise on Shadows) we can also find remarks which reflect his conception of nature in his other works. As an example, the introduction to his *Kitāb al-jamāhir fī ma’rifat al-jawāhir* consists of 15 *tarwīḥāh* (philosophical reflections) which give his view on the attitude of man toward nature. It is more than a book on pearls and precious stones.

According to al-Bīrūnī, God creates nature from nothing (*creatio ex-nihilo*). Concerning his views on the relationship between man and nature, in his introduction to *Taḥdīd nihāyat*

al-amākin (The Determination of the Coordinates of Cities), al-Bīrūnī explicitly refers to the *Qur'ānic* verse, "And contemplate the wonders of the creation in the Heavens and the Earth," "Our Lord: Not for naught hast Thou created (all) this" (Ch. 3: 191). Moreover, al-Bīrūnī contends, "This noble verse contains the totality of what I have explained. . ." In other words, this particular *āyāt*, out of all the other *Qur'ānic* verses, is of paramount importance to his scholarly life.

The element of transcendence is evident in al-Bīrūnī's outlook on nature. One of his major postulates is that God creates nature; al-Bīrūnī envisages from the very beginning the affinity between natural phenomena and their metaphysical causes. God creates nature through the *Qur'ānic* injunction of *kun fayakun* (Ch. 17: 163). Nature and her phenomena are nothing but the manifestation of God's initial creative act that is verbal. But God's creative act is also continuous. God always intervenes. It is different from the Cartesian worldview where God stops to intervene after the initial act of creation.

The laws of nature (*sunnat 'Allah*), which are the laws of God and which to al-Bīrūnī warrant examination, are possible because of the appearance of permanency in them. The affinity between nature, the created, and God who is the Creator points also to the element of the sacredness of nature. The study of nature through contemplation and action ought to be done within the parameters of religion, which to al-Bīrūnī is Islam. Therefore there is an esoteric and exoteric utility to religion in studying nature. In addition to the esoteric utility of studying nature, al-Bīrūnī emphasizes the exoteric aspect too. Again, in *Kitāb iḥdīd* (The Determination of the Coordinates), he states, "The Jews also need a direction, because they turn in their prayers to the Temple in Jerusalem. . . The Christian need the (direction of) true East because their elders. . . prescribed to them that they should turn to Paradise in their prayers."

Prayer (*ṣālat*) is one of the fundamental principles of Islam. It is well known that Muslims offer their prayers facing the *qibla* in Mecca. The problem for Muslims all over the world is to ensure that they are facing the correct direction

in their prayers. This is an example of what can be viewed as the exoteric aspect which al-Bīrūnī attempted to solve.

Another example is determining the time for prayer. Al-Bīrūnī devoted a whole chapter in his *Kitāb fī ifrād al-maqāl fī amr al-zilāl* (The Exhaustive Treatise on Shadows) to this problem. Studying nature should not be for the sake of studying nature; there must be a greater purpose sanctioned by religion, and in this case it is to solve the problem faced by Muslims in offering their prayers.

Al-Bīrūnī places truth as one of the noble aims of contemplating nature. "I must assay all aspects of this statement, because I do not refuse to accept the truth from any source, wherever I can find it" (*Tahdīd*). Studying nature is akin to an investigation to find out the truth. The external world can provide truth. Thus al-Bīrūnī maintains, "There is a great difference between an investigator of truth [who studies nature] and a follower of tradition." God says: "Are those equal, those who know and those who do not know" (*Tahdīd*).

Al-Bīrūnī never uses the word "science" in the sense that the word is understood today – that knowledge which is exact, objective, verifiable, deductive, and systematic. The closest term that he ever used is the Arabic word *'ilm*, which also means knowledge. *Al-'ilm* in the language of the *Qur'ān* and Sunnah (traditions of the Prophet) implies knowledge which makes man conscious of God, of His attributes, of the eternals, of the next world, and of the return to Him.

Science, to al-Bīrūnī, is a problem-solving activity. Scientists seek solutions to problems. Solving problems, which to al-Bīrūnī is analogous to "untying knots," (*Kitāb fī ifrād al-maqāl*), is the main activity of scientists. That science is a problem-solving activity and a scientific problem is a problem circumscribed by the Holy *Qur'ān* and Sunnah which needs to be solved in order for a Muslim to improve his *taqwa* (God consciousness) can be discerned by examining, in particular, the Introductions of his major books. We can see in these cases that this concept of religion is fundamental in shaping his attitude toward science as a problem-solving

activity. His *India*, for example, was written “as a help to those who want to discuss religious questions with them, as a repertory of information to those who want to associate with them.”

In another work, *Tahdīd nihāyat al-amākīn* (The Determination of the Coordinates), he clearly states another aspect of a scientific problem. “Geography is very essential for a Muslim for knowing the right direction of *qibla*.” Finding the direction of the *qibla* is an example of a scientific problem which is circumscribed by the *Qurʾān* and Sunnah.

The evaluation of the problems tackled, except in the *Tahdīd*, is not given post hoc or ad hoc. It is not the case that al-Bīrūnī solved scientific problems before thinking of their necessity, their worthiness for the *society*, viz., their legitimacy from the *Qurʾānic* and Sunnah point of view. Concerning geography and astronomy, he states: “. . . For whoever determines the longitude and latitude of this country with precision will thereby enable him to find out. . . times which are needed. . . for fasting.” Realizing the comprehensiveness of Islam as a complete way of life, he adds, “. . . the usefulness here exceeds specific religious matters and extends to worldly affairs.” Clearly, there is a sacred orientation in scientific problems. Scientists *qua* scientists should solve problems in a manner which brings them closer to God that can “yield His satisfaction (*riḍā*).”

In yet another book, *The Exhaustive Treatise on Shadows*, we can see very clearly his orientation toward scientific problems. In studying shadows, not only did he analyze shadows of this world, but also shadows in the Hereafter. He investigated in detail their differences, similarities, and the nature of their existence. He differentiated between shadows in Heaven and shadows in Hell. Thus al-Bīrūnī showed that there is a “revealed perspective” on scientific problems which the scientist should take into account. The scientist should always be mindful of the connection that the problems have to this world and to the Hereafter. The science of astronomy, for example, has its origin from the prophet Idrīs. These are examples of scientific problems in the Holy *Qurʾān* and Sunnah that from al-Bīrūnī’s point of view merit investigation.

There is an element of transcendence in seeking scientific solution. Al-Bīrūnī is always conscious of God while solving problems. He strives to be among those who “. . . remember Allah, standing, sitting and reclining and consider the creation of the heavens and the earth, (and say): O Lord; Thou created not this in vain.” Examples are abundant in his writings where he invokes God’s help. In *India*, he beseeches God to “help him to a proper insight into the nature of that which is false and idle, that he may sift it so as to distinguish the chaff from the wheat.”

Generally speaking, within the schema of contemplation, al-Bīrūnī solves problems mathematically. He considers himself a mathematician more than anything else. In *al-Qānūn al-Masūdī*, he says: “. . . I belong to a branch of mathematics (*riyāḍhi*),. . . and have been known by it and may intention never exceeded it. . .”

There are two complementary aspects of his problem solving: one is the “external” and the other is the “internal.” The “external” aspect involves more of the external senses as opposed to the “internal” aspect. The “internal” aspect heavily involves the processes of mathematical abstraction by the internal senses.

Man has to look for information, for evidence, in nature. This is an external aspect of his problem solving. “Human reason needs data and no human being can be an exception from the need of phenomena in which the mind functions” (*Kitāb al-Taḥdīd*). Al-Bīrūnī’s statement urging his readers to observe and collect data about observables shed some light on his approach to mathematical inquiry: that the process of mathematization, from the external aspect that is, should have empirical import. There are two parts related to his external aspect of this problem solving (as an act of contemplation) that warrant elaboration. First is al-Bīrūnī’s view on the manner in which one arrives at a theory and second in his perspective on theory choice.

Al-Bīrūnī attaches great importance to intense observation and putting exhaustive effort into procuring, comparing, analyzing, and synthesizing data (which includes both oral and written reports) in arriving at a theory. In fact in his *Kitāb fī ifrād al maqāl* (The Exhaustive Treatise

on Shadows), he cautions people against “ignoramus” who do not spare much effort but simply “attribute to God’s wisdom all that they do not know of the physical sciences.” The physical world is out there to be studied in order for us to internalize the greatness of God. Observation is essential to all scientific endeavors, including medicine. Al-Bīrūnī says, in the *Kitāb fī ifrād*, “through the frequency of observations he will gain in resource, both intellectual and intuitive.”

To begin with, one has to define his object of study. In the case of geology, he needs to focus his observation on “the rocks and vestiges of the past.” Observation involves seeing. Unlike Aristotle, who believed that vision was made possible by emitting rays from the eyes, al-Bīrūnī believed that rays were emitted to the eyes by the object themselves. Images are then formed in the eyes. There is no objective observation. Seeing is an experience. It is a not physical state. A retinal reaction is a photochemical excitation, a physical state. Scientists-and not their eyes-see. Al-Bīrūnī admits the possibility of the observation made by his contemporary, the astronomer Abū Saʿīd of Sistan, even though al-Bīrūnī preferred the geocentric theory. Unlike al-Bīrūnī, the latter was a proponent of the heliocentric (the sun is the center of the universe) theory. Al-Bīrūnī saw the sun rising but Abū Saʿīd saw the horizons of the earth changing in the East at dawn.

Al-Bīrūnī underscored the importance of observation not only in studying geology, but also in mineralogy. One should have keen eyesight, more so than others. Without good eyesight, it would be difficult for them to observe the minute differences and similarities in metals and precious stones.

It is through sight that mathematicians can observe nature and contemplate. Observation, which is an integral part of al-Bīrūnī’s problem solving, is not only for the sake of accumulating information. Observation is done within the schema of contemplation. For example, in his *Kitāb ifrād al-maqāl* (The Exhaustive Treatise on Shadows), he quotes a *Qurʾānic* verse (Ch. 77: 31) and states: “If one meditates on the verse, he will find two of the attributes of the shadow in the masculine form. . .” In his *Kitāb*

al-jamāhir (Mineralogy), he says: “Sight connects what we see to the signs of Divine Wisdom in creatures and demonstrates the existence of the Creator from his creation.”

Sight and hearing are two of the most important sense perceptions for gathering data for scientific inquiry insofar as observation is concerned. Both are integrated “in the heart, which is the seat of intelligence.”

Reports are equally important as observation. The scientist gathers his data from documented reports. Reports are written in several languages. Al-Bīrūnī’s preference for Arabic is not without a strong reason. Through etymological examination of the names of things, the scientist can be more informed about them. For example, there is the word *falāk* in his explanation about celestial motion. He writes in *Kitāb al-tafhīm* (Astrology), “The celestial sphere. . . is called *falāk* on account of its circular movement, like that of a whirl of a spindle. . .”

It is interesting to note that in so far as history of science is concerned, al-Bīrūnī preferred written tradition to immediate observation and he recommended *comparing* reports. Al-Bīrūnī lamented his predecessors who did not scrutinize their data.

After focusing on the problem, al-Bīrūnī collects data which are then compared and analyzed or synthesized, mainly through experiment or verbal verification (questioning the transmitters) or both, depending upon the field of study. In al-Bīrūnī’s pattern of problem solving, the stage of theorizing comes only after one has exhausted all reasonable efforts in procuring data and in comparing the results of previous or contemporary researches. It is only after he is satisfied with the amount of information relevant to the problem that he goes “from the known to the unknown, from the near distant to the far” – to wit, the inductive and deductive process.

Examples are abundant throughout his works which demonstrate this exhaustive effort. In his study of astronomy, after procuring data, he examines solutions offered by others. His study entitled “A Number of Topics Dealing with Shadows” is a case in point. In it he discusses methods for computing the length of daylight at

any time of the year used by ► [Brahmagupta](#), Vijayanandin, and Ya'qūb ibn Tāriq besides three other methods of Babylonian and Persian origin.

In the fourth chapter of *al-Qānūn al-Mas'ūdī* (Canon Masudicus), he compared results obtained by Ptolemy and one Ya'qūb al-Sehri and thereafter made the trenchant remark, "Both the methods give results correct to the second order but Ptolemy understood what he did, whilst Ya'qūb did not know what he was doing." In mineralogy, there were extensive etymological considerations in his analysis of minerals. He revised the findings of others. He did the same in his studies of medicine in his *Kitāb al-ṣaydanah* (Materia Medica or Pharmacology).

In his analysis of societies such as in *Kitāb fī taḥqīq ma li'l Hind* and *al-Āthār al-bāqiya* (India and Chronology), in subtopics where experiments could not be conducted, where most of the data is not in the form of direct observation but through oral and written reports, he examines witnesses to remove distortions in addition to comparing reports to ensure that they are as correct and accurate as possible. His emphasis is on the comparative method. In his *al-Āthār al-bāqiya*, he writes on most, if not all, of the festivals of various creeds and religions found in the regions of the Caliphate. In *Kitāb fī taḥqīq* he compares the beliefs and lifestyles of the Hindus with Buddhists, Manicheans, and Zoroastrians to what others wrote about them. Similarly in his study of the circumference of the earth, al-Bīrūnī examines the previous results obtained by astronomers under the patronage of Ma'mūn al-Rashid (A.D. 813–833), the Abbāsīd Caliph. He discovers that they reached different results. Dissatisfied, he conducted experiments in the area of Ghazz, Turks, and Jurjān.

In the external aspect of al-Bīrūnī's pattern of scientific problem solving, the problem of theory choice from his view occurs when there are several possible theories (as viable solutions) to a specific problem. In particular, the problem arises when al-Bīrūnī compares possible explanations in order to find a good one. Al-Bīrūnī does have some criteria which

determine his choice and these criteria help him in formulating a good theory. What is more interesting is that these criteria reflect his scientific acumen and his conception of God (as the "perfect scientist").

An important criterion to al-Bīrūnī is accuracy. That accuracy dictates the choice of one theory instead of another is partly because accuracy is less equivocal compared to other characteristics such as simplicity or fruitfulness. The predictive and explanatory power of theories depends on their accuracies. Al-Bīrūnī knew that accuracy is almost synonymous with exactness which certainly involves measurements. The finer the measurement, the higher the degrees of accuracy. Al-Bīrūnī's treatment on measurements, on inventing measuring instruments such as the *Yamīni* ring, the *Ustuwani* which he used "to measure the height of heavenly bodies, their apogees, time, depth of well or rivers and heights of walls, towers and hills. . ." His expertise with *al-dahj*, *sarqālah al-ma'*, *Sirāj al-Khādim*, and *naqshah*, and a particular machine that found the exact prayer times which he constructed for the mosque in Ghaznah, points to the importance of accuracy to him. More important than that, the striving for accuracy on the part of the scientist reflects al-Bīrūnī's understanding that perfect scientific knowledge belongs to no other but God because it is only He that measures perfectly.

In addition to accuracy, another criterion is novelty. Al-Bīrūnī believed that a good theory should be able to disclose new relationships of previously unnoted phenomena. A theory should help the mathematician to discover "new" aspects of God's creation, increasing his awareness of God as *al-Khāliq*, the Creator who creates everything unceasingly. An example to illustrate this is al-Bīrūnī's study of the variation in the length of the year related to the motion of the apogee where he gives the theorem "that the apogee and the perigee are the points at which the apparent velocity reaches its extreme values."

However the most important criterion is truth. Truth to al-Bīrūnī is more than a regulative principle; it is *the* regulative principle. The notion of truth is central to his conception of problem

solving. We can find that truth permeates at all stages in his pattern of problem solving outlined above. Al-Bīrūnī did not view truth as an illusive notion which, construed as such, is irrelevant to science. After focusing on a particular problem, he begins his inquiry in *al-Āthār al-bāqiya* (Chronology) by asking God to “help [him in] perceiving and realising the Truth, and facilitate its pursuit and lighten its courses. . .” In collecting as much relevant information as possible to the problem, he states in *Tahdīd* (The Determination of the Coordinates): “I do not scorn to accept truth from whatever source I can find it.” He even reminded himself in *India* to “speak the truth, even if it were against yourselves.” In *Chronology*, al-Bīrūnī perceives truth as that which is “enjoined by the holy scriptures on mankind [and] possesses its own intrinsic beauty just like justice. . .”

Al-Bīrūnī’s notion of truth is not equivalent to the popular conceptions of truth. It cannot be construed as correspondence theory of truth favored by realists. Neither can it be categorized under the coherence theory nor the pragmatic theory of truth per se. These are the reductive approaches to truth. Truth, to al-Bīrūnī, must be seen from the perspective of the *Holy Qur’ān* and *Sunnah* since the *Qur’ān* is revealed as a “guidance” (*huda*). Therefore it is interesting to note that whenever a theory which is a result of his rigorous approach is not consistent with a new discovery of an “irregularity” of nature, it points not so much to its falsity but more so to Divine Wisdom.

In light of the importance of contemplation to al-Bīrūnī, it needs to be emphasized that although al-Bīrūnī construes science as an activity of problem solving, the scientist himself is not obsessed with the problems. Rather he is obsessed with the relationship between himself and God. It is God that is central in this problem-solving activity. Therefore solving scientific problems is only a consequence of his consciousness and conception of God.

To recapitulate, nature to al-Bīrūnī is the handiwork of God. The activity of deciphering nature, of solving scientific problems, can be an act of *‘ibādah*, a “sacred” act which can raise the

status of the scientist in the eyes of God. Scientific activity to al-Bīrūnī is an activity bounded by the parameter of religion. In his quest to gain understanding of nature, he believed that one should be conscious of Divine Wisdom, which is manifested in nature and all its intricacies. It is both a theoretical and practical activity of solving problems. As a very prolific and multidimensional scholar, al-Bīrūnī did serious work in almost all branches of science in his time and his 146 treatises range from 10 to 700 pages each.

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Al-Bīrūnī and Geography

Akhtar H. Siddiqi

The geographical knowledge of the Muslims, in part derived from the Greeks and others, and contemporaneously developed and advanced by themselves, had reached a very high level of development by the tenth century. It is in this development that the work of ► [al-Bīrūnī](#) is significant. Al-Bīrūnī presented a critical summary of the total geographical knowledge up to his own time. He made some remarkable theoretical advances in general, physical, and human geography. Al-Bīrūnī did not confine himself to a simple description of the subject matter with which he was concerned. He compared it with relevant materials and evidence, and evaluated it critically, offering alternative solutions.

George Sarton identifies al-Bīrūnī as one of the great leaders of this period because of his relative freedom from prejudice and his intellectual curiosity. Although his interests ranged from mathematics, astronomy, physics and the history of science to moral philosophy, comparative religion and civilization, al-Bīrūnī became interested in geography at a young age. He is considered to be the greatest geographer of his time.

In the area of physical geography, he discussed physical laws in analyzing meteorology and climatology. He wrote of the process of streams development and landscape evolution. He introduced geomorphological enquiry to elucidate a history of landscape. He developed

the mathematical side of geography, making geodetic measurements and determining with remarkable precision the coordinates of a number of places. Some of his noteworthy contributions to geography include: a theory of landform building processes (erosion, transportation, and deposition), proofs that light travels faster than sound, explanations of the force of gravity, determination of the sun's declination and zenithal movement, and discussion of whether the Earth rotates on its axis. He described various concepts of the limits for which he seems to have had recourse to contemporary sources not available to earlier geographers. He made original contributions to the regional geography of India.

In the study of physical phenomena, including landforms, weather, and geology, al-Bīrūnī adopted the methods of the physical sciences and drew conclusions with scientific precision. Al-Bīrūnī developed a schema for physical geography: (a) terrestrial conditions, describing the shape and size of the Earth; (b) cosmic concepts, dealing with the measurement of the circumference of the Earth and the establishment of the exact location of places; and (c) classification of natural phenomena either in accordance with their nature or with their position in time and space. He studied phenomena in time (chronological science) and also tried to study them in space. In his view, geography was an empirical science.

Based on available knowledge concerning the surface of the Earth, he deduced and described the shape and forms of land surface. Al-Bīrūnī examined questions concerning the Earth's shape, size, and movement.

He explained running water as the most effective agent by which the surface of the land is sculpted. He further asserted that as the rivers of the plains of India approached the sea they gradually lost their velocity and their power of transportation, while the deposition process along their beds increased proportionately. ► [Al-Bīrūnī](#) considered the changes in the course of a river a universal phenomenon. He also recognized the influence of the sun upon the tide and suggested that heavenly bodies exert a gravitational effect on the tides.

Al-Bīrūnī recognized that the heat of the atmosphere and the Earth's surface is derived from the sun through the transfer of energy by rays, and that it varies with the length of time that the Earth is exposed to the rays. He recognized the wind's force and velocity and argued that the wind, in all its phases, is determined by certain causes.

Al-Bīrūnī noticed the peculiarities of the Indian monsoon, observed the time of its breaking, and described its westward and northward movements and the unequal distribution of rain in different areas of India.

Finally, he added that the habitable world does not reach the north on account of the cold, except in certain places where it penetrates into the north in the shape, as it were, of tongues and bays. In the south it reaches as far as the coast of the ocean, which in the east and west is connected with what he calls the comprehending ocean (*India*, Vol. I, p. 196).

In short, al-Bīrūnī recognized geography as an empirical science, and he dealt with the terrestrial globe as a whole. He stressed its nature and properties. He also tried to investigate the causes of global phenomena and described them as they existed.

See Also

- [Geography in India](#)
- [Maps and Mapmaking in India](#)

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- Al-Bīṭrūjī (fl. 1185–1192) was an Andalusian astronomer whose complete name seems to be Abū Ishāq (ibn?) al-Bīṭrūjī, Nūr al-Dīn. Nothing is known about his biography apart from the fact that his name probably derives from the region of Los Pedroches, near Cordoba, and that he was a disciple of the philosopher ► [Ibn ṭufayl](#) (ca. 1110–1185). The latter was already dead when al-Bīṭrūjī wrote his only known work, the *Kitāb fī-l-hay'a* (Book on Cosmology), which seems to have been read by the anonymous author of a book on tides dated in 1192. On the other hand, al-Bīṭrūjī's treatise was translated into Latin by Michael Scott in Toledo in 1217.
- Al-Bīṭrūjī was a member of the Andalusian school of Aristotelian philosophers composed of Ibn Bājjā (1070?–1138), the aforementioned Ibn ṭufayl, Ibn Rushd (Averroes, 1126–1198), and Mūsā ibn Maymūn (Maimonides, 1135–1204). All these authors criticized Ptolemaic astronomy due to its mathematical character which did not agree with Aristotelian physics. Al-Bīṭrūjī was, however, the only one who made a serious, although unsuccessful, attempt to create an astronomical system which could have a physical reality. In it he uses homocentric spheres in the Eudoxan tradition which he combines with

Al-Bīṭrūjī

Julio Samsó

materials derived from the Toledan astronomer ► [Ibn al-Zarqāllu](#) (Azarquiel, d. 1100). It is interesting to remark that al-Bīṭrūjī's dynamics are not exclusively Aristotelian but also use Neoplatonic concepts such as the impetus theory which he seems to have been the first to introduce into Western Islam. Al-Bīṭrūjī's system was soon known in Western Europe and became very popular among Scholastic philosophers of the thirteenth century, who considered it a serious alternative to Ptolemy.

See Also

- [Ibn Al-Zarqāllu](#)
- [Hay'a](#)

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Alchemy in China

Fabrizio Pregadio

In China, as elsewhere, alchemy is a science based on cosmological doctrines, aiming to afford (a) an understanding of the principles governing the formation and functioning of the cosmos, and (b) the transcendence of those very principles. These two facets are complementary and ultimately equivalent: the alchemist rises through the hierarchy of the constituents of being by “exhausting” (*jin* or *liao*, two words also denoting “thorough knowledge”) the nature and properties of each previous stage. He thus overcomes the limits of individuality, and

ascends to higher states of being; he becomes, in Chinese terms, a *zhenren* or Authentic Man.

While historical and literary sources (including poetry) provide many important details, the bulk of the Chinese alchemical sources is found in the *Daozang* (Daoist Canon), the largest collection of Daoist texts. One fifth of its approximately 1,500 texts are closely related to the various alchemical traditions that developed until the fifteenth century, when the extant Canon was compiled and printed. Later texts are included in the *Daozang jiyao* (Essentials of the Daoist Canon) and other minor collections. Modern study of the alchemical literature began in the present century, after the Canon was reprinted and made widely available in 1926. Among the most important contributions in Western languages are those of Needham (1978), Sivin (1968, 1976, 1980, 1990), Ho (1985), Baldrian-Hussein (1984), and Robinet (1989).

Though the underlying doctrines remained unchanged, Chinese alchemy went through a complex and not yet entirely understood development along its 20 centuries of documented history. The two main traditions are conventionally known as *waidan* or “external alchemy” and *neidan* or “internal alchemy.” The former, which arose earlier, is based on the preparation of elixirs through the manipulation of natural substances. Its texts consist of recipes, along with descriptions of ingredients, ritual rules, and passages concerned with the cosmological associations of minerals and metals, instruments, and operation. Internal alchemy developed as an independent discipline around the middle or the late Tang period (618–906). It borrows a substantial part of its vocabulary from its earlier counterpart, but aims to produce an elixir – equated with transcendental knowledge – within the alchemist's person.

At the basis of both traditions are traditional doctrines of metaphysics and cosmology. Chinese alchemy has always been closely related to the teachings that find their classical expression in the early “philosophical” texts of Daoism, especially the *Daode jing* and the *Zhuangzi*. The cosmos as we know it is conceived of as the

final stage in a series of spontaneous transmutations stemming from original nonbeing. This process entails the apparent separation of primeval Unity into the two complementary principles, yin and yang. Once the cosmogonic process is completed, the cosmos is perceived as subject to the laws of cosmology, *wuxing*, the Five Agents or Phases. The alchemist's task is to retrace this process backward. Alchemy, whether "external" or "internal," provides him with a support, leading him to the point when, as some texts put it, "Heaven spontaneously reveals its secrets." Its practice must be performed under the close supervision of a master, who provides the oral instructions (*koujue*) necessary to an understanding of the processes that the adept performs with minerals and metals, or undergoes within himself.

In order to transcend space and time – the two main features of the cosmos as it is ordinarily perceived – the alchemist should take extreme care of their correspondences to the work he performs. Space is delimited and protected by talismans (*fu*), and the laboratory (*danwu* or "chamber of the elixirs"), and instruments are properly oriented. According to some texts, heating must conform to minutely defined time cycles. This system, known as "fire times" (*huohou*) and sometimes described in painstaking detail, allows an adept to perform in a relatively short time the same work that Nature would achieve in thousands of years – in other words, to accelerate the rhythms of Nature. Bringing time to its end, or tracing it back to its beginning, is equivalent: in either case time is transcended, and the alchemist gains access to the eternal, constant present that precedes (or follows, though both terms become inadequate) the time of cosmogony and cosmology. The same is true with space: its center, where the alchemist places himself and his work, is a point devoid of dimension. From this point without space and time he is able to move at will along the axis that connects the higher and lower levels of being ("Heaven," *tian* and the "Abyss," *yuan*).

Among a variety of procedures that the sources describe in an often allusive way, and in a language rich in metaphors and secret names,

two stand out for their recurrence and importance. The first is based on lead (*yin*) and mercury (*yang*). In external alchemy the two substances are refined and joined in a compound whose properties are likened to the condition of primal Unity. In internal alchemy, lead becomes a cover name for the knowledge of the Dao (pure yang, *chunyang*) with which each being is fundamentally endowed, but which is obscured (i.e., transmuted into yin) in the conditioned state. Mercury, on the other hand, represents the individual mind. The second most important method, which is proper to external alchemy, is centered on cinnabar (*yang*). The mercury contained therein (representing as such the Yin principle contained within the yang) is extracted and newly added to sulfur (*yang*). This process, typically performed nine times, finally yields an elixir embodying the luminous qualities of pure yang. This yang is not the complementary opposite of yin, but, again, represents the one before its apparent separation into the two complementary principles.

The final object of both disciplines is represented as the preparation of an elixir commonly defined as *huandan* (lit., elixir of return). This expression, recurring in the whole literature, originally denotes an elixir obtained by bringing the ingredients back to their original condition through repeated cyclical operations – an operation comparable to the process that the adept performs within himself with the support of the alchemical practice. The word *dan* (elixir) also denotes cinnabar, suggesting that the process begins and ends on two corresponding points along an ascensional spiral. This synonymy also shows the centrality of cinnabar in external alchemy, where this substance plays a role comparable to that of gold in the corresponding Western traditions. This role is taken by lead in internal alchemy. Both lead and gold, in their turn, are denoted by the word *jin*. The value of gold, and the word "gold" itself, is therefore mainly symbolic in China: the elixir, whether external or internal, and whatever its ingredients, is often defined as "gold," and Golden Elixir (*jindan*) is a name of the alchemical arts.

The extant *waidan* sources suggest that the two main methods outlined above acquired

progressive importance in the history of the discipline. In the ► [Huangdi jiuding shendan jing](#) (Book of the Nine Elixirs) and other texts dating from the first centuries AD, cinnabar is never the main ingredient of an elixir, and the lead-mercury compound – sometimes replaced by refined lead alone – is only used as a layer in the crucible together with other ingredients. In these methods, the substances undergo cycles of refining in a hermetically sealed crucible. This process consists of a backward reenactment of cosmogony that brings the ingredients to a state of *prima materia*. The elixir can be finally transmuted into alchemical gold projecting on it a minute quantity of the native metal. Important details on the early phase of Chinese alchemy are also found in portions of the *Baopu zi neipian*, written around AD 320 by ► [Ge Hong](#). Its descriptions of processes that can be compared with extant sources are, however, often abridged and sometimes inaccurate.

During the Tang dynasty, the *waidan* tradition reached one of its peaks with Chen Shaowei (beginning of the eighth century), whose work describes the preparation of an elixir obtained by the refining of cinnabar. Each cycle yields a “gold” that can be ingested, or used as an ingredient in the next cycle. In the second part of the process, the final product of the first part is used as an ingredient of a *huandan*. Among the representative texts of this period are several collections of recipes, one of the most important of which was compiled by ► [Sun Simo](#). The first half of the Tang dynasty also marked the climax of contacts between China and the Arabic world. These exchanges may be at the origin of the medieval word *alchymia*, one of whose suggested etymologies is from middle Chinese *kiem-yak* (the approximate pronunciation of the modern *jinye* or “Golden Liquor”) with the addition of the Arabic prefix *al-*.

While the Tang period is sometimes defined as the golden age of external alchemy, it also marked the stage of transition to internal alchemy. This shift, sometimes taken to be only due to the multiplication of cases of elixir poisoning, or to the influence of Buddhism, requires further study to be properly evaluated. The very

incidence and relevance of cases of accidental poisoning (which claimed their toll even among Emperors) suggest that external alchemy had lost, at least to some extent and in some contexts, its soteriological character, and that its practices had become known outside the legitimate transmission. Some masters may, therefore, have transmitted their doctrine modifying the supports used for the practice. In internal alchemy, the adept’s person itself performs the role which natural substances and instruments play in external alchemy. In doing so, this discipline avails itself – in ways and degrees that vary, and which require further study to be correctly understood – of traditional Chinese doctrines based on the analogies between macrocosm and microcosm, of earlier native contemplative and meditative disciplines, and of practices of Buddhist origin (apparently of Tantric character, through the possible medium of the Tiantai school).

Among the forerunners of internal alchemy is the Shangqing (Supreme Purity) tradition of Daoism, as practiced for example by ► [Tao Hongjing](#). Based on revelations of the late fourth century, this school attributed particular importance to meditation, but also included the compounding of elixirs among its practices. (Shangqing represents in fact the first example of close relations between alchemy and an established movement of “religious” Daoism.) The relevant sources exhibit the earliest traces of the interiorization of alchemy. Among the texts used in this school is the *Huangting jing* (Book of the Yellow Court), a meditation manual often quoted in *neidan* texts.

In Song and Yuan times, the history of *neidan* identifies itself with that of the lines of transmission known as Southern Lineage (*nanzong*) and Northern Lineage (*beizong*). The respective initiators were Zhang Boduan (eleventh century) and Wang Zhe (1112–1170). Both schools placed emphasis on the cultivation of *xing* and *ming*, which constitute two central notions of internal alchemy. *Xing* refers to one’s original nature, whose properties, transcending individuality, are identical to those of pure being and, even beyond, nonbeing. *Ming* denotes the “imprint,” as it is, that

each individual entity receives upon being generated, and which may or may not be actualized in life (the word also means “destiny” or “life,” but neither translation covers all the implications in a *neidan* context). The Northern and Southern lineages, and subtraditions within them, were distinguished by the relative emphasis given to either element. The textual foundation of both lineages was provided by the *Zhouyi cantong qi* of ► [Wei Boyang](#), and the *Wuzhen pian* (Awakening to Reality), a work in poetry by Zhang Boduan.

During the Ming and Qing dynasties the *neidan* tradition is known to have divided into several schools, but their history and doctrines are still barely appreciated. One of the last greatest known masters of this discipline was Liu Yiming (eighteenth century), who, in his works, propounded an entirely spiritual interpretation of the scriptural sources of his tradition.

See Also

- [Five Phases \(Wuxing\)](#)
- [Ge Hong](#)
- [Huangdi jiuding shendan jing](#)
- [Sun Simo](#)
- [Wei Boyang](#)
- [Yinyang](#)

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Alchemy in Islam

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Arabic alchemical writing and documentation emerges in approximately the second half of the eighth century (750–800 AD), a period that witnessed substantial growth in intellectual activity and methodological refinement for all the known sciences. With the rapid expansion of the Islamic empire, knowledge from civilizations such as the Greek, Persian and Indian was melded

and shared by means of the new lingua franca, Arabic. The unifying force of the Arabic language enabled scholars of diverse ethnic and disciplinary origins to exchange ideas, to transmit those ideas to their students, and to develop conceptual frameworks for exploring and expanding knowledge of the natural world. The Arabic term *al-kīmyā* appears morphologically to be non-Arabic in origin, most likely a borrowing from Syriac *kīmīyā*, which may derive from Greek *khemeia*, or *khymia*, prefixed with the definite article *al-* in Arabic (Ullman, 1965, p. 110; Wild, 1965, p. 4). This word has survived as the term for the entire pre-modern tradition of proto-chemistry. Nonetheless, this era within the Arabic/Islamic cultural tradition remains little explored and poorly understood within mainstream history of science.

Arabic alchemical writings show influences of Egyptian, Greek, Sabaeen, Syriac, Persian, and Indian cultures. Hermetic and gnostic influences are abundant, as many Arabic alchemical texts combine description and analysis of naturally occurring substances and chemical experiments with firm admonitions to adepts on the need for purity of heart, behavior and intent in order for transformation to occur (See Affifi (1949), Plessner (1954), and Corbin (1964, pp. 179–183) on hermeticism in Arabic sciences. For more on the Arabic *corpus hermeticum* see Klein-Franke (1973). On Islamic gnosis see Corbin (1975), and for Egyptian hermeticism in particular, see Fowden (1996)). The texts evidence not only cultural syncretism, but also interweave practices for psycho-spiritual transcendence with procedures to transform natural substances. The distinctive discourse of Arabic alchemical texts is variable in style. Sometimes it is descriptive, didactic, and straightforward, other times complex, highly abstract, mystical, and profoundly arcane.

That alchemy was well established as a branch of scientific study is attested by the fact that two tenth-century Arabic encyclopedia authors, al-Nadīm and ► *al-Khwārizmī*, each have extensive chapters on alchemy. Both chapters are available in English translation (Dodge, 1970; Ryding, 1994). Al-Nadīm focuses on the history,

personalities, and scholarly works of the alchemists, whereas al-Khwārizmī concentrates on the instruments, substances and procedures involved in alchemical operations.

The earliest Arab contributor to alchemical science is reputed to have been the Umayyad prince Khālīd ibn Yazīd ibn Mu‘āwiya ibn Abī Sufyān (ca. 665–704) (Nadīm, 1970, chapter on alchemy). Tradition says that he was instructed in alchemy by a Christian monk named Morienus/Marianus. A Latin manuscript entitled the *Booklet of Morienus Romanus, of old the Hermit of Jerusalem, on the Transfiguration of the Metals and the Whole of the Ancient Philosophers’ Occult Arts*, appeared in Paris in 1559 with the notation that the original translation from the Arabic was dated 1182. Stavenhagen (1974) has details on the manuscript as well as the English translation. Documentation of al-Khālīd’s alchemical interests is sketchy; no works of his on the topic have been discovered, and some scholars consider al-Khālīd’s reputation for alchemical scholarship unjustified (e.g., Ruska, 1924).

The central figure in Arabic alchemy is the semilegendary Jābir ibn Hayyān, who is said to have lived in Mesopotamia during the second half of the eighth century and died around 810–815 AD (Holmyard, 1923, p. 47). Nadīm gives Jābir’s full name as (Abū Mūsā ‘Āmī) Abū ‘Abdallāh ► *Jābir ibn hayyān* ibn ‘Abdallāh al-Kūfī, known as ► *al-Ṣūfī* (Nadīm, 1988, p. 420). Elsewhere his name is given as Abū Mūsā, and he is variously described as Tūsī, Tartūsī or Tarsūsī, Harranian and from Khorasān (Holmyard, 1923, p. 47). Major Arab biographers (including Nadīm, Qiftī, and al-Kutubī) consider him a genuine historical personage (Qiftī, 1903, p. 160–161; Al-Kutubī, 1973). Sarton considers him “the most famous alchemist of Islam,” calling the era 750–800, the Age of Jābir ibn hayyān” (Sarton, 1927, p. 521).

There has been debate as to the extent of Jābir’s authorship of what is referred to as the Jābirian corpus, with Kraus, Mieli, Ruska, and Plessner asserting that these works are largely attributable to an early Isma‘īlī sect in the late tenth century (Kraus 1986, also Plessner &

Kraus, 1968; Plessner, 1980), whereas Holmyard, Stapleton, and more recently, Corbin and Lory, give substantially more credence to the authorship of the historical Jābir (See especially Corbin (1986, pp. 68–69), where he discusses the work of Paul Kraus, “notre regretté collègue” who, he states, “fût entraîné sur sa lancée à un certain extrémisme.” (our sorely-missed colleague, who was drawn by his impulsiveness to a certain degree of extremism.) He goes on to state that “il se trouve que depuis trente ans la théorie traditionnelle a trouvé de vigoureux défenseurs, dont les recherches ont sérieusement ébranlé la thèse extrémiste de Paul Kraus.” (For 30 years the traditional theory has found vigorous defenders whose research has seriously weakened the extremist thesis of Paul Kraus.) See also Holmyard (1923), Corbin (1964: 184ff); Lory’s introduction to Corbin, 20ff; Stapleton (1936), and Sezgin (1971, pp. 132–269). Cf. Hachmi (1961), Macuch (1982), Mahmūd (1975), and Burnett (1992)). The Jābirian manuscript matrix may include later accretions from commentators and imitators, with a core of authentic older writings.

Whether or not the original Jābir is the source of all the manuscripts attributed to him in Arabic, and whether or not any of those writings constitute the source of the contributions of the European Geber has not yet been established, since the extant Arabic manuscripts have not been compared thoroughly or systematically with those in Latin of the European Geber. On this topic, see Holmyard’s introduction to Russell (1678, 1928), esp. pp. xvii–xxi and on the European Geber see Newman’s extensive 1991 analysis.

As Manfred Ullman states (1965, p. 112),

Arabic alchemy holds a key position in the development of chemical thinking as a whole. However, in glaring contrast to its importance, it has been regrettably neglected by research until now. Most of what historians of science have written on the Arabic alchemists is second-hand, based on obsolescent literature and disfigured by gross errors. A vast and fertile field lies here open to research; access to it, however, is not easy.

Ullman (1965, p. 113) cites three components of the theoretical foundations of Arabic alchemy

(1) The quicksilver-sulfur method for synthesizing gold, calculating the true proportions of quicksilver and sulfur in gold and endeavoring to reproduce those proportions; (2) The doctrine of “the relations of quantities” (used especially in the Jābirian texts). This took the form of speculation on the concept of balance, especially the “balance of letters”, a form of phonosymbolism wherein the letters of the Arabic alphabet are attributed certain weights (in dirhams) and qualities (dryness, moisture, heat, cold) that correspond proportionately to the contents of minerals and metals as they occur in the names of those metals (Kraus 1986, vol. 2, pp. 223–236). Thus the name of a particular metal such as lead (*usrub*) reflects exactly the essence of that metal; (3) Formulating the elixir (*al-ʿiksīr*) that, when added to base metals, has the power to transform them into gold or silver, or to grant everlasting life.

Other major contributors to the vast alchemical literature of Islam include Abū Bakr Muhammad ibn Zakariyā al-Rāzi (Rhazes) (ca. 864–925 or 935), whose work in alchemy “takes a new, more empirical and naturalistic approach than that of the Greeks of Djabir” (Goodman, 2001), Muhammad Ibn Umayl (ca. 900–960), and Aydamīr ibn Alī al-Jildakī (fourteenth century). Translations of all these texts, starting with Jābir, are sorely needed.

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Alcohol Fermentation in Australian Aboriginals

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Australia, it has been said, was the world's only "dry" continent, and its Indigenous peoples were one of the few societies in the world that had no traditional alcoholic beverages (Cleland, 1957, p. 159; Dingle, 1980, p. 228; Spencer, 1988). Australians commonly believe that prior to contact with outsiders in the eighteenth century, neither Aboriginal people nor Torres Strait Islanders (the two Indigenous peoples of the country) knew of the process of fermentation and thus how to make drinks containing alcohol. This is taken by some commentators to be the explanation for widespread alcohol abuse in later years. If people had no alcoholic drinks, it is argued, they lacked the traditions and rituals associated with alcohol consumption and had no need to develop the internal social controls that would contain any unwanted effects of intoxication.

These interpretations are only partly true for there are documented accounts suggesting that Aboriginal people in some regions did, in fact, know about fermentation and produced mild, low-alcohol drinks from the natural flora. The Torres Strait Islands (between Australia and Papua New Guinea) are a little different, with the residents of some islands learning how to ferment and distill an intoxicating drink (*tuba*), as a result of contact with outsiders from the East Indies or the Philippines. In this case, as a result of cultural diffusion, Islanders adopted and *made indigenous* a drink that originated from elsewhere.

Before European settlement, Aboriginal hunters and gatherers also harvested, prepared, and used a number of plant-based narcotics and stimulants. These were primarily chewed, nicotine-containing drugs, including the highly prized narcotic *pituri* (from the plant *Duboisia hopwoodii*), and numerous wild tobaccos of the

genus *Nicotiana*. All these plants required detailed knowledge of the landscape (the strongest *pituri* grew in a particular region of south-west Queensland and was traded from there), preparation techniques (drying and fragmenting the leaves), and methods of enhancing the drugs' effects by the addition of alkaline wood ash from particular trees. This increased the absorption of nicotine through the skin once the mixed quid was chewed or stored behind the ear (Clarke, 2007, pp. 105–109; Watson, 1983). Smoking was not practiced prior to contact with outsiders.

Way-a-linah: A Drink from the Tasmanian Cider Gum

In numerous regions of Australia, Aboriginal people made sweet, watery drinks by steeping nectar-bearing blossoms in water; these nonalcoholic drinks were consumed immediately rather than being left for natural fermentation to occur (Moore, 1978, p. 213; Petrie, 1904). But the sap of the Tasmanian "cider gum" is a well-documented example of a locally made drink that was allowed to ferment. In 2005, Tasmanian Aboriginal artist Mick Quilliam painted a canvas depicting this tree, around the base of which were grooves made by innumerable pairs of feet (Fig. 1). His painting commemorates the tree and its value to Aboriginal Tasmanians. The symbolic footprints were those of the many Aboriginal people who came from all directions to harvest *way-a-linah*, the Aboriginal name for a fermented drink made from the copious sweet sap of this high-altitude gum tree, *Eucalyptus gunnii* (Maiden, 1924, p. 119).

An early account of its use by Aboriginal people comes from George Augustus Robinson, a free settler in Tasmania who made several expeditions into the interior and who became known as the man who tried unsuccessfully to help the Tasmanians to survive the disastrous impact of European settlement that had commenced in 1803. His was the only detailed post-settlement record of Aboriginal life and languages there. In 1831 Robinson was traveling in the high country of Tasmania's north with several

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Fig. 1 Tasmanian artist Mick Quilliam's painting of the cider gum (2005) depicts the tree as a meeting place, with a trench worn around its base by the feet of the many Aboriginal people who came to harvest its sap (Natural ochers and pigment on canvas, reproduced with permission of the artist)



Aborigines, looking for any remaining Mairremmener people. His journal entry for 28 November 1831 shows that he was in the Lake Echo region when he first saw the cider tree:

The natives caught seven kangaroo this evening, but what interested me most were the numerous cider trees which skirted this extensive plain and which were the first I had seen. Most of those trees had been tapped by the natives. This they had effected by perforating a hole in the tree a short distance above the ground by means of sharp stones and then making a hole at the bottom of the tree into which the liquid is conveyed and from which they extract it, sometimes if the hole is small by sucking it through a reed or twisted bark. In some of these holes I observed upwards of a quart [one litre] of this juice and which my people greedily partook of. It is exceeding sweet and well flavoured and in this respect resembles the flavour of cider. Some that had been dried by the sun had an apple taste. . . . The natives are very fond of the juice and I am told it frequently makes them drunk. (Plomley, 1966, p. 534)

According to historian N. J. B. Plomley who edited Robinson's journals, Robinson made a point of recording plants used as foods by the Aborigines and provided useful information about the distribution of plant communities. Robinson was clearly intrigued by what he called the

"melliferous" cider gum, noting abundant stands of the tree whenever he encountered them and observing that the syrupy sap was attractive to ants, cockatoos, and animals as well as to the "natives." Some trees were huge, 12 ft in circumference, and produced what he described as "tolerable quantities" of the oozing liquid, which he thought was triggered by the warmth of the sun. A tree can yield half a liter of sap daily during the summer months. As it happened, Robinson's journey on this occasion in 1831 coincided with the time of year when the *Eucalyptus gunnii* sap flows most prolifically. Extracting the sap required local knowledge; the trees were and are found only in a limited area of the high country. At the proper season, during December and January (the quantity of sap lessens in February), Aboriginal people bored or cut into the trunk to release the sap which collected in a larger hole, a kind of holding tank made at the foot of the tree. Robinson witnessed Aborigines dipping their tin pannikins [cups] into these tanks at the base of the trees. Robinson (Plomley, 1966, p. 557) wrote,

Holes at the bottom of those trees had been made to receive the juice and which answered the purpose of a tank. Some of the liquor had dried and was white and resembled in appearance and taste a

bruised apple; some was brown. It was amusing to see the natives run from tree to tree to suck this juice, of which they are very fond.

Another nineteenth-century description from the naturalist Daniel Bunce provides further detail. He states that the Aborigines covered these collecting holes with a flat stone in order to stop birds and animals from drinking, which implies that the liquid rested there for some time. “When allowed to remain any length of time,” Bunce wrote, “it ferments and settles into a coarse sort of wine or cider, rather intoxicating if drank to excess” (Bunce, 1857, p. 47; Clarke, 2007, p. 105). Little is known about exactly how strong *way-a-linah* might have been: J. H. Maiden (the Government Botanist who wrote an 8-volume revision of the genus *Eucalyptus*) tested the fluid from a sample of sap and found that it contained sugar, acetic acid, water, and alcohol. Some non-Aboriginal people likened the juice to black beer or treacle, and Aboriginal people themselves used language terms which distinguished the unfermented “honey” (which was known as *wen.ner*) from the fermented “cider” (*way-a-linah*) (Plomley, 1976, p. 183). Early accounts by R. C. Gunn (after whom the eucalyptus species was named) mention that (European) shepherds and stockmen also cut the trees and harvested and consumed the sap. There were unsourced reports that at Christmastime 1826, the Aborigines of Lake Arthur indulged in a great eucalyptus cider orgy (MacPherson, 1921).

Sadly, in recent years large numbers of old *Eucalyptus gunnii* have been dying as a result of drought, and the trees are under threat from clearing, grazing, burning, and seed collection. The feet grooves can still be seen around the trunks of a few particular trees, along with old scars from the tapping process. Many present-day Aboriginal people have made and tasted the drink. Mick Quilliam, the painter, describes it as being sweet and tangy and about as alcoholic as a light beer.

***Mangaitch*: A Fermented Drink from Western Australia**

In 1992 an Aboriginal alcohol service in Perth, Western Australia, produced a series of radio

programs about alcohol and substance abuse. Aboriginal author Doris Pilkington was the narrator. The program began by questioning the argument that because alcohol was a recent introduction to Western Australia, Aboriginal people had not learned how to cope with it or develop tolerance. “Our people knew about fermentation and used alcohol on special occasions,” said the narrator,

We made it by soaking blossom of banksias and eucalyptus, and by dissolving the nectar and allowing it to stand. But the alcoholic content was slight and the use of these drinks was limited to special occasions and certain times of the year. In other words we exercised our own restraints. (Noongar Alcohol and Substance Abuse Service [NASAS], 1992)

Doris Pilkington was referring to a drink known to Aboriginal people in Western Australia as *mangaitch*. It was made from the flower-bearing cones of a species of banksia which produced a substance so sweet that it was known by Europeans as the honeysuckle tree (Moore, 1978, p. 136). The first detailed description of the drink was made by the physician and anthropologist W. E. Roth who described two species of banksia growing in the southwest of Western Australia. The banksia bore cones with pitcher-shaped flowers full of honey “especially visited by the black cockatoos.” Aboriginal people collected large numbers of cones and carried them alongside “swamps” where they dug troughs, lining them with boat-shaped containers or vats made of sheets of tea-tree bark.

The vat was next filled with these cones and water, in which they were left to soak. The cones were subsequently removed and replaced with others until such time as the liquid was strongly impregnated with honey, when it was allowed to ferment for several days. The effect of drinking this “mead” in quantity, was exhilarating, producing excessive volubility. The aboriginals called the cones and the fermented liquor produced therefrom both by the same name – the *mangaitch*. (Roth, 1904, p. 49)

Daisy Bates, an eccentric amateur anthropologist who worked in Western Australia, wrote that in the early 1900s there were annual feasts of *mangaitch*, with visitors from elsewhere hosted by the Aboriginal people of the South

Perth district. She also described how the “mungaitch honey-groves” were being razed to make way for flocks of sheep and herds of cattle (Bates, 1985, p. 241).

Kambuda: A Drink Made from the Spiral Pandanus

Another Indigenous fermented drink has been documented from the Borroloola region, near the Gulf of Carpentaria in the Northern Territory. It was made from the nuts of the spiral pandanus – a common pandanus in the Northern Territory from which Aboriginal people also harvest its leaves, which are stripped and rolled to make fiber for baskets. When ripe and red or orange in color, the nuts were roasted on the fire, then crushed. The crushed pulp was soaked in water for 2 days in a bark dish, making a mixture known as *wuthuwuthu* (in the Yanyuwa language). This made a fermented drink known as *kambuda*. It was said by Herbert Basedow that on ceremonial occasions the Aborigines drank more than usual and that the drink produced “merriment” (Basedow, 1918). One anthropologist recalled older Yanyuwa-speaking women were still making this drink in the 1980s (Brady, 2008).

All three drinks described here were undoubtedly low-alcohol drinks; however they did have mood-altering effects, and their existence indicates that Aboriginal people in these three widely separated regions of Australia knew of fermentation and how to achieve it. It was not until outsiders came to Australian shores that the Indigenous peoples tasted stronger alcohols for the first time: spirits such as rum and arrack and sweet and fortified wines. The English colonization of Australia began in 1788 in Sydney, New South Wales, but from the 1600s foreign ships had been making landfall on Australian coasts – either deliberately or unintentionally. The west coast of Australia in particular was peppered with shipwrecks, mostly of Dutch ships heading from the Cape of Good Hope to Batavia (now Jakarta, Indonesia); because of difficulties with the accurate measurement of

longitude, they failed to turn north in time. All ships carried wines and spirits and some shipwrecks left hundreds of men stranded in remote regions; it is possible that Aboriginal people tasted alcoholic beverages on these occasions. Dutch sailors visiting the west coast of the Cape York Peninsula in 1756 gave arrack (a strong distilled spirit made in Southeast Asia) to some Aborigines in an attempt to kidnap them (Heeres, 1899). The same drink was carried to northern Australia by fishermen from Makassar in Sulawesi from around 1700, giving Aboriginal people along the coast of what is now Arnhem Land in the Northern Territory their first taste of a distilled spirit (Fig. 2). The Makassan fleets sailed annually to collect the delicacy *bêche-de-mer* from shallow coastal waters, and their praus brought many desirable goods to share with the Aboriginal owners of the land, including rice, cloth, dugout canoes, iron knives, tobacco, and arrack (Clark & May, 2013; Macknight, 1976). Aboriginal people borrowed and incorporated the language terms for many of these items from the Makassar language, and these loan words are now part of the Yolngu and other languages of northern Australia (Evans, 1992).

The Makassans were, by all accounts, enthusiastic consumers of arrack, which was produced locally around the town of Makassar as well as being imported from Batavia in Java. Arrack can be made by distilling “toddy” (eighteenth-century Europeans often referred to this as “palm wine”), the fermented sweet juices exuding from the flowering buds of a number of palm trees, such as nipa, fan, areca, and coconut palm (Burkill, 1966; Clarke, 2007; Wallace, 1989). There is some evidence that visiting Makassans deliberately planted both areca and coconut palms on Australian soil in an effort to produce toddy and arrack during their regular months-long visits (cf. Clarke, 2007, p. 129; Ganter, 2006, p. 46); whether they succeeded, however, is unknown.

Making Tuba

It was in the islands of the Torres Strait (TSI), following contact with outsiders, that local people learned and adopted the techniques of both



Alcohol Fermentation in Australian Aboriginals, Fig. 2 Map to show the routes taken by Makassan *bêche-de-mer* fishermen to northern Australia c. 1700–1907

fermentation and distillation in order to produce what was, in effect, an “indigenous” alcoholic beverage known as *tuba* (Brady & McGrath, 2010). It was indigenous to the extent that the ingredients for making it were sourced and harvested locally from palm trees, its manufacture was incorporated into local knowledge systems, and its consumption became embedded in local Indigenous economic and social practice. It is difficult to say exactly when and by what means the technical knowledge of palm toddy fermentation and distillation arrived in the Torres

Strait which, by the nineteenth century, was a busy international maritime hub, part of the “polyethnic north” attracting pearl and trochus divers and lugger crews and laborers (Ganter, 2006, p. 198). Knowledge of *tuba* making could have arrived from several directions: from the Malay Archipelago to the west (including the Makassan and Bugis traders from Sulawesi), from the islands in the Pacific to the east, or from Singapore or the Philippines to the northwest. Peoples from all these regions at various times manufactured these drinks, but oral



Alcohol Fermentation in Australian Aboriginals, Fig. 3 Extraction of toddy (“palm wine”) on the Indian subcontinent (Lithograph, Louis van Houtte 1868–1888)

histories collected from Torres Strait Islanders, together with a Filipino origin for the term *tuba*, point to the Philippines and the “Manila men” (as they are known locally) as being the most likely source for this diffusion of technical knowledge.

Tuba is a Tagalog term from the Philippines, meaning “fermented coconut milk” (Schnukal, 2004), and in the Torres Strait, it describes the pale juice that seeps from a cut to the unopened fructifying bud of a coconut palm. Both written records and oral histories describe the production techniques for the drink – a process that remained remarkably unchanged over centuries. The toddy collector climbed the tree and hung a container under the cut bud to catch the juice: “You cut the point off and tie a rope down and bend it and chop it off, until the juice run out. We used a Sunshine milk tin,” a man from Murray Island said in 2004 (Fig. 3). This procedure was repeated every day, as Joseph Banks had pointed out in his journal of

the *Endeavour* voyage of 1770, while visiting the island of Savu (now in Indonesia), “people ... climb the trees for that purpose every morning and evening” (Beaglehole, 1963, p. 162). *Tuba* was made on the islands of the central and eastern groups in the Strait that could support coconut palms – indeed some residents planted large groves of trees for this purpose.

The juice could be drunk straight from the tree but the Islanders learned to leave their *tuba* to ferment in large bottles or clay-stoppered pots. In this form the drink was said to taste like vinegar or beer with an alcohol content around 4 %; some Islanders used this fermented mix as a raising agent for bread: “I got taste for that bread! I prefer my mother’s *tuba* bread to any in a bakery! The yeast is homemade” (Brady & McGrath, 2010, p. 318). The remaining *tuba* was distilled, using bamboo tubes and a metal drum to boil and steam the mixture, hence the local name “steamed *tuba*” for the resultant distilled drink. “He makes a big bamboo, at the end there’s a long thing for the drips and a big drum and he boils it up. Another bamboo goes up and steam goes through the bamboo and catches it. It’s very clear, like gin” (Brady & McGrath, p. 318; Fig. 4).

The distilled version was a strong “rough and ready job” as one Islander described it and virtually identical to the arrack that had been introduced to mainland Aboriginal groups by the Makassan *bêche-de-mer* fishers. Perhaps because it was so strong, it seems to have been drunk sparingly. With the advent of easily available commercial alcohols, licensed outlets and the end of race-based prohibitions on alcohol in the mid-twentieth century, *tuba* is now no longer consumed on the TSI, but in earlier years it had many uses. *Tuba* was explicitly made and consumed during the years of prohibition in the nineteenth and early twentieth centuries (supplies of liquor were banned to Aboriginal “natives and half-castes,” Aboriginal natives of the Pacific Islands or Polynesians born in Queensland), and thus it played a role in deliberately undermining the authority of the superintendent teachers who were responsible for local governance on the Islands. Offering *tuba* was a means for Islander

Alcohol Fermentation in Australian Aboriginals,

Fig. 4 Distillery for *tuba* (Guam, Mariana Is.). The stills on the Torres Strait Islands were similar to this (Lithograph, A. Pellion 1819)



families to show hospitality to their guests. It was sold to other Islanders for cash, and during World War II (when thousands of US and allied air force men passed through a northerly air base on Horn Island), several Island families “made a quid” by selling steamed *tuba* to the “Yanks.” It seems that relatively few health or social problems were associated with drinking *tuba* or steamed *tuba*, and in general Torres Strait Islanders have positive memories of the drink. This introduced but indigenized alcohol was harvested, manufactured, and distributed as part of an informal local economy and became embedded in the social and cultural life of the people of the islands on which it was made.

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Alcoholic Rice Beverages

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There are many "*aqua vitae*" – beverages made from millets, grapes, dates, palm, sugarcane, potato, and cereals including rice. Traditional foods provide a basic diet while alcoholic beverages supplement enhanced nutrition and palatability. People also drink alcoholic beverages to forget the aches of their daily toils. An abundant supply of rice in South East Asia has produced

a variety of spirits, wine, and beers. *Wong-tsiu* and *chaoxing* of China, *saman* of Malaysia, *chhang* of Tibet, and *sake* of Japan are some of the favorites.

In some religions, alcohol is a taboo. However, rice alcoholic beverages (RAB), like rice itself, have attained the status of sacred items in many Asian countries including the tribes of the central, East, Himalayan belt, and North Eastern states of India. RAB constitute an integral part of dietary culture due to the climatic conditions and have strong ritual importance among the ethnic people. In contrast to tribal people, peasant Hindus do not employ rice beer (or fermented grains in general) in rituals. This perhaps reflects an aesthetic aversion to the rotting and decay connotations of fermentation (Hancett, 1988).

RAB are home products in the tribal belt of India and are offered as a welcome drink in all households. Nagas do not know any other drink except rice beer; milk is used only in urban areas. Young and old, rich and poor, and men, women, and children relish it equally (Singh, 1995). In Europe Austrian beer and *tapuy* in the Philippines are products of rice brewing (Anonymous 1993). During pre-partition days, half of Indian rice exported was brewed into alcoholic drinks in Europe and the USA (Watt, 1901). At present about 7 % of rice production in the USA is used along with barley to make beer lighter and tastier for Americans (White, 1994). In the world of trade, broken rice used for brewing is called "brewers' rice." According to British records, the Ho tribe of Bihar were so fond of rice beer that they spent most of the year's rice storage preparing rice beer (Ahuja, Thakrar, Ahuja et al., 2001).

We have no written records of the initiation of the rice beverage drinking tradition, but there is no doubt among the people about its divine origin (Das, 1972). The Bodos of Assam credit Lord Mahadeva, the Karbi/Mikir to Chang Charpau (god of creation), the Mundas of Orissa to Singbonga, and the supreme God and the Konds of Orissa to Nirantalli – Supreme Mother Earth – for teaching the art of brewing. Most tribes consider the rice beer of divine origin; the

Bhuiyan of Orissa credit their hero Boram Burha (Ahuja et al., 2001).

Like the rice beer, the starter tablet is also considered as divine. The Kabris believe that God told Kabri women in her dream to make starter tablet using fecal matter of the Vokongching bird. The Adi and Mising people (Assam) consider that the starter tablet was created by the spilled milk of the fairy Miti Omum and was made into cakes by Engo Takar using plants grown on spilled milk and named it E'pop (Pegu et al., 2013).

In India fermenting drinks from rice is an age-old art. As early as 2000 BC, the Indus Valley civilization seems to have practiced alcoholic fermentation and distillation. In the later Vedic period, grain-derived products were *masara*, *kilala*, *kashaya*, *prasanna*, and *svetasura*. *Masara* may have been a pre-Aryan drink made from barley and later rice. *Prasanna* was fermented rice flour flavored with spices, bark, and fruits. In *svetasura* clarity was achieved by adding sugar to *prasanna*. Drinking was frowned upon in *Rgveda* and in the *Sūtras*. Kshatriyas were not permitted with grain-based liquors. The classic Indian medical authorities took a balanced view of drinking. Moderation was counseled as alcohol increases the mental principle *pitta* while decreasing both the physical and vitality principles *kapha* and *vata* (Achaya, 1998). Āyurvedic texts describe preparation of *sura* from fermenting rice flour which was hard to digest and caused constipation, increased fat, urine, and *kapha* and was used to treat gaseous abdominal swelling, dropsy, and reduced strength. *Varuni sura* was made by *punarava* and rice was easily digestible and cured flatulence (Sekar, 2007). *Bhagwat Puran* refers to distillation of liquor from wild rice. Aryans made *sura* from wild rice, flowers, and barley (Kumar, 1988).

Megasthenes, accompanying Alexander on his crusade to India, wrote in his memoirs (ca. 50 AD) that Indians avoided intoxicating drinks. However, for religious ceremonies, drinking of rice beer was permitted. The favorite drink Madhuka referred to in Kautilya's *Arthasāstra* was made of ten ingredients with fermented rice (Ahuja et al., 2001).

Ingredients

Rice in different forms is used as basic material for preparing beverages (beer, wine, or liquor) as paddy, boiled, raw, or germinated rice. Chinese and Japanese prepare drinks from ground rice powder; Filipinos prefer fried rice, while at other places boiled rice is used as the basic ingredient. Kodavas of Coorg in Karnataka use germinated rice for the preparation of a strong whisky called *Kachana Kallu* which is consumed lavishly during *Huttari*, the rice harvesting festival (Pai, 1994; Ponnappa, 1988). Tribal people in Silvassa, Maharashtra, prepare rice wine by using pounded paddy and potatoes. The paddy is pounded with the husk, placed in an earthen pot with a small quantity of yeast, and allowed to ferment for 6 days. It is then distilled over a slow fire into a crystal clear, potent drink.

Various tribes prepare rice beer at home by fermenting boiled rice soaked in water using a starter tablet (Jeyaram et al., 2008; Tamang et al., 2007) known by different names in various Indian states (Table 1). Regional specialization and the uniqueness of the process have been developed to such a fine level to give taste and color specific to each tribe (Deori et al. 2007; Saikia et al. 2007). The main point of modification is the herbs used in the starter tablets serving as a microbial culture for fermentation. The starter tablet is prepared by mixing rice flour with roots, leaves, bark, or seeds of the selected plants. The quality of the starter culture is said to be dependent on the variety of plant parts used and also on the maintenance of proper sanitary conditions. Every tribe has its distinct herbs used in their starter tablet (Table 1). The Deori tribe of Assam formerly used about 100 plants which have been reduced to 30–40. In Manipur there are two kinds of starter tablets. Normally a *chuwan* (starter) is a circular shape with an umbilical type of dimple in the center, but in male *chuwan*, there are three umbilical dimples instead of one.

The preference for rice variety used for fermentation differs from community to community. The Khasis of Meghalaya generally use

Alcoholic Rice Beverages, Table 1 Plants used in starter tablets of Alcoholic rice Beverages by Tribes of India

Tribe/state	Rice beer/distillate	Starter tablet	Tablet constituents
Oraons Orissa	<i>Jhara</i>	<i>Ranu dabai</i>	<i>Elephantopus scaber</i> roots, <i>Argyreia bella</i> stem, <i>Casearia graveolens</i> bark, <i>Symplocos racemosa</i>
Santhals Bihar, Bengal	<i>Harhia</i>	<i>Ranu dabai</i>	<i>Coccinia grandis</i> , <i>Clerodendrum viscosum</i> , <i>Vernonia cinerea</i> , <i>Plumbago zeylanica</i> , <i>Wattakaka volubilis</i>
Gonds, central India	<i>Handia</i>	<i>Ranu dabai</i> 25 plants	<i>Argyreia bella</i> , <i>Buchanania lanzan</i> , <i>Casearia graveolens</i> , <i>Cassine glauca</i> (Kumar & Rao, 2007)
Dimasa Naga,	Judima	Umhu	<i>Glycyrrhiza glabra</i> , <i>Acacia pennata</i>
Jeme Naga	Dekuijao, nduijao	Nduhi	<i>Glycyrrhiza glabra</i>
Angami	Zutho		
Derois	Sujen	Perok kushi	<i>Jasminum sambac</i> , <i>Zanthoxylum hamiltonianum</i> , <i>Lygodium flexuosum</i> , <i>Acanthus leucostachys</i> , <i>Cyclosorus exlensa</i> , <i>Alstonia scholaris</i> , <i>Alpinia malaccensis</i> , <i>Costus speciosus</i>
Adi Arunachal	Opo, ennog	Sityeh	<i>Clerodendrum viscosum</i> , <i>Veronica</i> sp.
Galo Arunachal	Poka	Apong kusure	<i>Clerodendrum viscosum</i> , <i>Debregeasia longifolia</i> , <i>Diplazium esculentum</i> , <i>Pilea</i> sp., <i>Urtica hirata</i> , <i>Solanum kurzii</i> (Bora et al., 2013)
Miris Assam	Apong	Apop pitha	<i>Scoparia dulcis</i> , <i>Cyclosorus</i> , <i>Costus speciosus</i> , <i>Adhatoda zeylanica</i> , <i>Zanthoxylum hamiltonianum</i> , <i>Naravelia zeylanica</i> , <i>Melothrea heterophylla</i>
Maities Manipur	Atingba, yu	Hamei	<i>Albizia myriophylla</i> , <i>Tectona grandis</i> L.f., <i>Ficus hispida</i> , <i>Alocasia indica</i>
Tripura	ChuwkBwtwk/chuwarak	Chuwan	Jack fruit leaves, Thakotor, Tokhiseleng
Tripura			Pineapple leaves, red chili
Bodos Assam	<i>Jou bishi</i>	Angkur	<i>Xanthium strumarium</i> , <i>Scoparia dulcis</i> , <i>Clerodendrum viscosum</i>
Rabha Assam	Choko/fortica	Bakhor, phap	<i>Ananas comosus</i> , <i>Artocarpus heterophyllus</i> , <i>Calotropis gigantea</i> , <i>Capsicum frutescens</i>
Ao, Nagaland	Zutho	Piazu	Germinated rice powder
Kabri(Assam)	HorAlang/hor arak	Thap	<i>Croton joufra</i> , <i>Artocarpus heterophyllus</i> , <i>Phlogacanthus thyrsiflorus</i> , <i>Solanum viarum</i> , <i>Acacia pennata</i>

(continued)

Alcoholic Rice Beverages, Table 1 (continued)

Tribe/state	Rice beer/distillate	Starter tablet	Tablet constituents
Ahoms	<i>Koloh pani</i>	<i>Vekur pitha</i>	<i>Oldenlandia corymbosa</i> , <i>Lygodium</i> sp.
Assam			<i>Hydrocotyle sibthorpioides</i> , <i>Centella asiatica</i> , <i>Cissampelos pareira</i> , <i>Piper nigrum</i>
Jaintias	<i>Sadhiar, kiad</i>	<i>Thiat</i>	<i>Khaw-iang/hawiang-iang</i> leaves
(Meghalaya)			
Tribals Lahaul- Spiti HP	<i>Chang/sra</i>	<i>Phab</i>	<i>Saccharomyces fermentati</i>

a red variety *kho-so* (Samati and Begum 2007), the Nagas use maize, Mundas of Chhattisgarh and Bihar use *karaini* or gora rice, Dimasis use *biron*, and the Rabhas of Assam prefer *sali aus* and boro rice. When boro rice is used, the beer obtained is reddish brown in color and has a shelf life of 6–12 months (Deka & Sarma, 2010).

The Adi and Nishis of Arunachal Pradesh prepare white *apong* and blackish *ennog*, respectively, from white and black rice (added with rice husks), and after fermentation, it is stored in bamboo vessels lined with *ekkam* (*Phryium capitulum* L) and *oko* (*Zingiberaceae* family) leaves, respectively (Tiwari & Mahanda, 2007). In Lahaul and Spiti, Himachal Pradesh *lugari* and *chhang* are prepared, respectively, from uncooked and cooked rice. *Lugari* is consumed only as a fermented product while *chhang* is used both as fermented and distilled (Kanwar et al., 2011).

Glutinous rice is preferred to non-glutinous rice, owing to the taste and alcohol content of the product. The Miris of Assam prepare whitish *noggin apong* from boiled and *poro apon* from glutinous rice to which ash of partially burned paddy husk and straw is added (Gogoi et al., 2013). The Bodos also prepare two types of beer called *maibra jou* from glutinous *bishi* and *matha jou bishi* from non-glutinous rice (Das et al., 2012).

In addition to the type and form of rice used, the Mundas of Orissa and central India add some plants to increase intoxication or to decrease the

period of fermentation while preparing *handia* (Kumar & Rao, 2007). They use *Elephantopus scaber* L. roots, *Argyrea bella* stems, and the bark of *Casearia graveolens* and *Symplocos racemosa*. The Kols of Madhya Pradesh use *Madhuca longifolia* flowers, rhizomes of *Imperata cylindrica*, and *Cissampelos pareira* with fruits of *Syzygium cumini* in fermenting rice beer (Mittre, 1991). The Apatani tribe of Arunachal Pradesh add ash extract of *Eleusino coracana* and *Saurauia roxburghii* to broth, the Ahoms of Assam add seeds of *Datura*, and the Adivasi of Assam add leaves of *Nicotiana tabacum* and *Polygonum hydropiper*. The Kabris and Deoris of Assam and Meities of Manipur add different types of fern leaves to give a strong aroma to rice beer. Half-burnt rice husk ash is added by the Adi, Kabris, and Miris (Chakrabarty et al., 2009; Gogoi et al., 2013; Tanti et al., 2010).

Some tribes distill the fermented product to obtain a strongly alcoholic distillate which has more shelf life (Table 1). The fermented and distilled products are of different ceremonial significance. The Kabris of Assam use the fermented *hor alank* in worship and marriages, while they use the distilled one during social occasions and death ceremony (Teron, 2006). The Rabhas of Assam believe that *fortica* has a curative effect on psychiatric patients (Deka & Sarma, 2010).

Among the various drinks from rice like beer, wine, and whisky, it is rice beer that is more

popular among tribal people. In fact rice beer is called the “national” intoxicating drink of the tribes. Rice beverages are used in various ceremonies in various Asian countries. Rice beer is widely used in rites of passage and agricultural festivals. In all events in life from births to funerals, sowing to harvesting crops, friendship to revenge, argument to settlement, abduction, and murder, and happiness to sorrow, rice beer is indispensable (Saikia et al. 2007). In the East and Northeast, rice beer is part of every household and is offered and served to guests like tea (Das, 1972; Pegu et al., 2013). The Kabris of Assam, during the marriage ceremony, fill a gourd shell with *hor lank* and give it to the bride’s father (Teron, 2006). Rice beer is used as money when it is paid as a court fee and bride price by a Lakher of Nagaland and as compensation for adultery in Orissa. In marriages, the number of *handia* to be given to the bride’s side is decided well in advance. They offer rice beer to all spirits.

The social, religious, cultural, and personal life of the Mising people of Assam offers a panoramic view of the use of rice beer, *apong*. In social life, it is consumed as refreshing drink by both men and women after a day’s hard work. It is served as a welcome drink to guests. It is customary to use *apong* during marriage, birth, and death events, rituals, festivals, and on the assembly of village chiefs. In the Miris of Assam, discussions on marriage proposals are initiated by offering *noggin apong* from the boy’s to the girl’s father and it is served only on the agreement of the proposal. No ritual is considered complete without offering *apong* to the concerned deity. The *po:ro apong* is indispensable during traditional harvesting festivals and in funeral ceremonies (Pegu et al., 2013). The ritual use of *apong* has its origin with the legend of the origin of *E’pob* (starter cakes). *Po:ro apong* is indispensable during traditional harvesting festivals *Ali-a:ye Li’gang* and *Po:rag* and in funeral ceremonies and also in *Urom apin*, *Dodgang*, and *Dobur ui* rituals. Both *noggin* and *Po:ro Apong* are used during *Tani siko* (ritual for deceased persons; Pegu et al., 2013).

Rice beer is relished equally by men, women, and children during social and agricultural ceremonies and festivals, and its use is a must in social ceremonies and rites (Ahuja et al., 2001). The Oraons and Mundas of Orissa make rice beer after sowing and at transplanting in hopes of a bumper harvest (Crooke, 1896; Kumar, 1988). They thresh the crop after Khariharn Puja with sacrifice of fowl and oblations of rice beer (Roy, 1928). The Deuris of Assam use *sujhen*, rice beer, in their household pujas and in elaborate rituals at the riverside to please the water deity, Jalki Dangoriya (Das, 1972). In Silvassa (Maharashtra), tribal people use rice wine in Vasant Utsav. The belief is that unless one is knocked out and fully drunk, he or she would not get the blessing of the Goddess Mahavidya (Pai, 1994). Rice wine is considered to be a favorite drink of deities such as Kameshwari in Assam, Kamakhya in South, and Durga in Bengal. Offerings of animal sacrifice and rice wine are a must (Bhattacharyya, 1978; Das, 1972; Das & Mahapatra, 1979).

Chhang is offered to deities and also exchanged as an important gift during weddings and other auspicious ceremonies by tribes of the Himalayan region. *Chhang* is an indispensable hospitality beverage among tribal people of Lahaul valley and is considered to provide protection against cold during winter months (Savitri & Bhalla, 2007).

RAB have their medicinal value too. The Bodos and the Rabhas use it for stomachache, urinary problems, insomnia, body ache, inflammation, diarrhea, expelling worms, and cholera (Deka & Sarma, 2010). The Maria tribes of Bastar take *handia* as a light tranquilizer. It is also given to treat fever, dysentery, diarrhea, and gynecological complaints (Kumar & Rao, 2007). The Gond tribe of Surguja district use *ranu* tablets in treating cholera (Ahuja et al., 2001). The people of Manipur use *yu* as a medicine, relaxant, and in the poor health condition of women due to irregular menstrual flow, infertility factors, obesity, loss of appetite, and low nourishment of foods (Singh & Singh, 2006). *Yu* is also used for treating fever, body ache, and

common cold and is smeared over the face and body parts as a beauty care product.

The residue after extraction of *yu* is given for fast and healthy growth of pigs. The Kabris use *horalank* to add aroma and flavor and to increase the shelf life of dried fish. Highly concentrated *hor acho* is used in dysentery and pharyngitis. The Mising believe that having two or three glasses (about 500 ml) of *po:ro apong* a day can prevent formation of kidney stones (Pegu et al., 2013). The Rabhas give rice beer to bulls to promote body strength and to cure swelling legs (Deka & Sarma, 2010).

Taboos and Safety Rite

The Santhals always keep one or a few dry chillies and a piece of charcoal, while the Rabhas place charcoal and *Ricinus communis* leaves on the raw materials and on products at different steps in order to keep all the evil forces away which may deteriorate the quality of *rice beer* (Deka & Sarma, 2010). The Miris and Deuris keep citrus fruits away from the vicinity during preparation of *E'pob* and *apong*, because they are said to make *apong* acidic or sour (Pegu et al., 2013). The Kabris believe consumption of *hor* before offering to God is a taboo. Preparation of *thap* (fermenter tablet) by women of the clan Bey and clan Hanjang is considered taboo by Kabris (Teron, 2006). Normally Miri women prepare *apong*, but during the ritual *dobur puja*, men extract *apong* because participation of women is a social taboo. In Manipur it is believed that a drop of sweat fallen into the production of beer will spoil the whole mass (Singh & Singh, 2006). During funeral ceremonies, the *handia* is not made in the deceased's house and relatives bring it. In Tripura women should not menstruate at time of preparation of *chuan*. She is also barred during a postnatal period of one month.

Originally rice beer was used as an antidote to fatigue and also as a prophylactic against sun stroke, snake bite, and other problems which tribal people usually faced during their work in the fields. Since it was produced at home, it was

not eligible for excise duty, so the British discouraged home-brewed drinks which led to a higher consumption of distilled liquors, disturbing the social order (Ray, 1993). The medicinal herbal mix which imparts such prophylactic properties to rice beer is not widely known now, and with the migration of young people to cities the knowledge is confined to a few elders.

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Al-Damiri

Emilia Calvo

Al-Damirī Muḥammad ibn Mūsā ibn ʿĪsā was born in Cairo, Egypt in AD 1341. Although he began work as a tailor, he soon decided to study with the leading teachers of the time such as Bahā' al-Dīn al-Subkī, Jamāl al-Dīn al-Asnāwī, Ibn ʿAqīl, and others. He became a professional theologian and taught in different centers such as al-Azhar University, achieving a great recognition for his preaching and his ascetic life. A very religious man, he made the pilgrimage to Mecca six times between AD 1361 and 1367 and died in Cairo in AD 1405.

The majority of al-Damirī's works are conventional commentaries and epitomes of earlier works such as the one on al-Nawawī's *Minhāj* (a manual of Islamic law). He also wrote sermons and treatises on canon law. Most of these works seem to be lost. His most famous work is *Hayāt al-ḥayawān* (Life of the Animals), a zoological dictionary which contains information on the animals mentioned in the *Qurʾān* and in the Arabic literature. It includes not only the zoological aspects, but also everything related to the animals mentioned.

The work contains 1,069 articles describing a lesser number of animals because the same animal is occasionally described twice using two different names. The animals are described in alphabetical order and usually contain seven

sections (1) grammatical and lexicographical peculiarities of the name, (2) a description of the animal according to the leading authorities, (3) Muslim traditions in which the animal is mentioned, (4) juridico-theological considerations regarding the animal, (5) proverbs about the animal, (6) the medicinal properties of the products derived from the animal, and (7) rules for the interpretation of dreams in which the animal appears.

There are three versions of this work: the large (*al-kubrā*), the medium (*al-wuṣṭā*), and the small (*al-ṣuḡrā*) and it has been republished several times and translated into Persian and Turkish.

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- The work still survives in Arabic under the following titles: *Jawāmiʿ ʿilm al-nujūm wa'l-ḥarakāt al-samāwiyya*, *Uṣūl ʿilm al-nujūm*, *ʿIlal al-aflāk*, and *Kitāb al-fuṣūl al-thalāthīn*. The *Jawāmiʿ* (sometimes translated as *Elements*) provided the medieval reader with a rather comprehensive account of Ptolemy's astronomy through a well-organized, accessible, and nonmathematical presentation. The work was translated into Latin at least twice in the twelfth century: by John of Spain (John of Seville) in 1135, and by Gerard of Cremona before 1175. The *Jawāmiʿ* was also translated into Hebrew during the thirteenth century by Jacob Anatoli. Copies of this translation exist today in Berlin, Munich, Vienna, and Oxford, among other places. In 1590, drawing from Anatoli's translation, Jacob Christmann published the third Latin version of the book in Frankfurt-am-Main. A later Latin translation of the text, along with al-Farghānī's original Arabic, was published in 1669 by Jacob Golius. Widely circulated in the West during the Middle Ages, the *Jawāmiʿ* was frequently referenced by medieval writers, and it is generally accredited today for having contributed considerably to the propagation of knowledge on the Ptolemaic system. In addition to the *Jawāmiʿ*, al-Farghānī wrote on the astrolabe. A number of his manuscripts on the subject survive under the following titles: *Fīṣanʿ at al-aṣṭurlāb*, *al-Kāmil fī'l-aṣṭurlāb*, and *Kitāb ʿamal al-aṣṭurlāb*.

Al-Farghānī

Ahmed Bouzid

Al-Farghānī, Abu-l-ʿAbbas Aḥmad ibn Muḥammad ibn Kathīr was born in Farghana, Transoxania and died in Egypt, ca. 850. He was a famous astronomer during the time of the ʿAbbasid caliph ► [al-Maʾmūn](#) and a contemporary of ► [al-Khwārizmī](#), al-Marwarudhī, ► [al-Jawharī](#), and Yaḥya ibn Abi-Manṣūr. He was well known in the Latin Middle Ages under the name of Alfraganus, thanks principally to his widely read book, *Compositio astronomica* (also called *Liber 30 differentiarum*, Book of the 30 Chapters), which is a summary of Ptolemy's *Almagest*.

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Astrolabe](#)

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Al-Fazārī

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Abū Ishāq Ibrāhīm ibn ḥabīb ibn Sulaymān ibn Samura ibn Jundab al-Fazārī (d. ca. 777) was a Muslim astronomer and the first Muslim constructor of astrolabes. He was the author of many scientific works whose manuscripts are not extant, but the Arabic historians Abū'l-Faraj Muḥammad ibn Nadīm al-Warrāq al-Baghdādī (d. 993) in his *Kitāb al-fihrist al-ʿulūm* (Bibliography of Sciences) and Jamāl al-Dīn ʿAlī ibn al-Qifṭī (1173–1248) in his *Taʾrīkh al-ḥukamā* (History of Sages) mention one mathematical and five astronomical works by al-Fazārī:

1. *Kitāb fī taṣṭīh al-kura* (Book on the Projection of a Sphere onto a Plane)
2. *al-Zīj ʿalā sinī al-ʿarab* (Astronomical Tables According to Arabic Years)
3. *Kitāb al-ʿamal bi'l-aṣṭurlāb al-musaṭṭah* (Book on the Use of the Plane Astrolabe)
4. *Kitāb al-ʿamal bi'l-as ṭurlābāt dhawāt al-ḥalaq* (Book on the Use of Astrolabes with Rings)
5. *Kitāb al-miqyās li'l-zawāl* (Book on the Gnomon for the Noon)
6. *Qaṣīda fī ʿilm al-nujūm* (Poem on the Science of Stars)

His son Muḥammad translated an astronomical work *Brāhma-sphuṭasiddhānta* by the sixth-century Indian astronomer and mathematician

Brahmagupta from Sanskrit into Arabic. The Arabic name of this work, *Sindhind*, came from the word *siddhānta*, astronomical texts, and the Arabic name for India, *Hind*. The extant fragments of *Sindhind* have been translated into English by David Pingree.

See Also

- [Astrolabe](#)
- [Brahmagupta](#)

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Alfonso X

Julio Samsó

Alfonso X, King of Castile (1252–1284) and a patron of literature and learning, made an important effort to recover Arabic and, very especially, Andalusian astronomical materials by translating them first into Spanish and later into Latin. His collaborators were one Muslim convert into Christianity, eight Christians (of whom four were Spaniards and another four Italians) and a very important group of five Jews. Alfonso failed in his attempt to integrate in his team a Muslim scientist of the importance of Muḥammad al-Riqūṭī but his interest for us here lies in the

fact that his translations preserve Andalusian astronomical works which would have been lost otherwise. This is the case, for example, of the *Libro de las Cruces* (Book of Crosses), a late Latin astrological handbook translated into Arabic in the early ninth century and revised, in the eleventh century, by a certain ‘Ubayd Allāh. Other works which are only known through his translations are the *Lapidario* (a book on the magical applications of stones) written by the otherwise unknown Abolays, the two books on the construction of equatoria written by Ibn al-Samḥ (d. 1035) and ► [Ibn al-Zarqāllu](#) (d 1100), ‘Ālībn Khalaf’s book on the use of the plate for all latitudes (*Lamina Universal*, Toledo, eleventh century) and Ibn al-Zarqāllu’s treatise on the construction of the armillary sphere. Other works which are, apparently, originals contributed to the European diffusion of Arabic astronomical ideas: the famous *Alfonsine Tables*, extremely popular between the fourteenth and the sixteenth centuries, were strongly influenced by the *Tables* of ► [al-Battānī](#) and marked a turning point in the development of late Medieval European astronomy.

See Also

► [Ibn al-Zarqāllu](#)

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Algebra in China

Lam Lay Yong

Arithmetic and geometry are the two oldest branches of mathematics. Algebra has its beginnings from both of them when attempts were made to generalize operations and relationships. Initially, such ideas were expressed in words; in the course of time, they were represented by some form of notation. The symbols facilitated the methods which in turn generated new concepts and methods. For instance, we are now able to solve with ease any arithmetical problem involving what we call a pair of linear equations in two unknowns through the use of the notational equations $ax + by = c$ and $dx + ey = f$. Around AD 825, Muḥammad ibn Mūsā ► [al-Khwārizmī](#) wrote a book expressing equations in words. In order to arrive at a solution, the two sides of an equation were manipulated through two main operations which he called *al-jabr* and *al-muqābala* – the name “algebra” was derived from the first word.

In ancient China, arithmetic developed through the use of the rod numeral system. Arithmetic was fully developed – not only were the methods of addition, subtraction, multiplication, and division known, but also the manipulations of the common fraction and the decimal fraction were commonplace, and methods such as those involving proportion and the Rule of Three were widely used. This article will describe very briefly how the mathematicians were able to generalize arithmetical operations and relationships which resulted in general methods of solution. The period covered will be from antiquity to the beginning of the fourteenth century. Traditional ► [mathematics in China](#) was at its height during the thirteenth and early fourteenth centuries; this was a time in Western Europe when the importance of the new arithmetic that evolved from the Hindu-Arabic numeral system was just beginning to be realized.

It might seem strange and improbable that the ancient Chinese were able to find general

methods of solving equations since they did not compute through a written system but through the use of rods. However, the rod numeral system was extremely sophisticated and flexible, and the positions where the numerals were placed usually represented certain mathematical concepts. For example, let us consider a set of linear equations in three unknowns which we now write in the following manner:

$$\begin{aligned}a_1x + b_1y + c_1z &= d_1, \\a_2x + b_2y + c_2z &= d_2, \\a_3x + b_3y + c_3z &= d_3.\end{aligned}$$

The ancient Chinese would notate such a mathematical concept by placing the numerical values of the as , bs , cs , and ds in rod numerals in the following matrix form:

$$\begin{array}{ccc}a_3 & a_2 & a_1 \\b_3 & b_2 & b_1 \\c_3 & c_2 & c_1 \\d_3 & d_2 & d_1\end{array}$$

The positions occupied by the rod numerals were important – the positions in the first row represented the first unknown, and those in the second and third rows represented the second and third unknowns, respectively.

The aim of the method was to obtain a group of zeros forming a triangle in the top left diagonal half of the matrix through a process of elimination with two columns at a time. Thus the elimination process would result in zeros for the positions which were occupied by a_3 , a_2 , and b_3 of the above matrix. After this was attained, the third unknown was derived from the third column from the right. This result would be able to derive the second unknown from the second column, and the solutions would in turn derive the first unknown from the remaining column.

The method is called *fang cheng* and can be found in the eighth chapter of *Jiu zhang suan shu* (Nine Chapters on the Mathematical Art). The whole chapter is devoted to the solutions of such equations which include a problem involving five equations in five unknowns and another involving five equations in six unknowns.

The matrix notation was derived through an evolution of a fundamental tradition that used positions occupied by rod numerals to represent concepts or things. Besides the placement of numerals involving the common fraction, problems related to proportion were solved by similar operations. The ancient Chinese were familiar with what is now called the Rule of False Position which, for them, originated from the solution of the concept of a pair of linear equations in two unknowns. The method is called *ying bu zu* and is the precursor of the *fang cheng* method.

The procedure for finding the square root of a number was derived from the geometrical division of a square into smaller areas. This was then arithmetized through the placement of rod numerals to become a general method. The offshoot of this method was the solution of what we call a quadratic equation of the form $x^2 + bx = c$, where b and c are positive. The ninth chapter of *Jiu zhang suan shu* has a problem involving an equation of this form. Besides the method of finding the square root, the book also gives the method of finding the cube root of a number. Knowledge of this method led to the solution of a cubic equation of the form $x^3 + ax^2 + bx = c$, where a , b , and c are positive. The seventh-century work *Jigu suanjing* (Continuation of Ancient Mathematics) by ► Wang Xiaotong has problems involving such equations.

The struggle to solve other types of quadratic equations besides the one mentioned above was depicted by the thirteenth-century mathematician ► Yang Hui, who quoted from the works of Liu Yi of the eleventh century – Liu Yi's works are now no longer extant. Though the concepts of the different types of quadratic equations were initially derived from a variety of geometrical considerations, the arithmetization of their operations through rod numerals revealed certain patterns and similarities which enabled the emergence of a general method of solution.

In his explanation of the development of the polynomial equation and its solution, Yang Hui quoted another eleventh-century mathematician, ► Jia Xian. He pointed out that Jia Xian was familiar with the triangular array of numbers

now known as the Pascal triangle and was the first to realize its close relationship with the procedure of root extraction. From here, Jia Xian laid the foundation for a ladder or algorithmic method of finding the root of a number of any degree. This eventually provided the breakthrough to finding a solution of any numerical polynomial equation.

It was Qin Jiushao's detailed and systematic methods of explaining the problems in his book, ► *Shushu jiuzhang* (Mathematical Treatise in Nine Sections), that established beyond doubt the competence of the Chinese mathematicians to solve numerical equations of higher degree. Among the problems in the book, there are three that are involved with equations of the fourth degree and one of the tenth degree. These equations are of the following form:

$$\begin{aligned} -x^4 + 763200x^2 - 40642560000 &= 0, \\ -x^4 + 15245x^2 - 6262506.25 &= 0, \\ -x^4 + 1534464x^2 - 526727577600 &= 0, \\ x^{10} + 15x^8 + 72x^6 - 864x^4 - 11664x^2 - 34992 &= 0. \end{aligned}$$

Yang Hui, Li Ye, and Zhu Shijie were the other thirteenth-century mathematicians who were also familiar with the algorithm method of solving a polynomial equation of any degree. This method is now generally accepted as similar to that put forward by Horner in 1819.

The Chinese were able to express the complex concept of a polynomial equation through the placement of rod numerals on the counting board. This notational representation was called *tian yuan shu* (Technique of the Celestial Element) in which an equation was formulated in terms of the unknown called *yuan*. An equation of the form

$$a_0x^n + a_1x^{n-1} + \cdots + a_{n-1}x + a_n = 0$$

was represented in rod numerals in a vertical line as follows:

$$\begin{array}{c} a_n \\ a_{n-1} \\ \vdots \\ a_1 \\ a_0 \end{array}$$

The positions occupied by the rod numerals had meanings – the first row signified that the rod numeral was a constant and the other rows in the downward direction signified that the numerals were the coefficients of the unknown in increasing power.

From here, Zhu Shijie in his *Siyuan yujian* (Precious Mirror of the Four Elements), written in 1303, proceeded to express polynomial equations in two, three, and four unknowns with rod numerals. For instance, the equation in two unknowns

$$(-x - 2)y^2 + (2x^2 + 2x)y + x^3 = 0$$

is expressed as follows:

𠄎	0	太
𠄎	𠄎	0
0	𠄎	0
0	0	

The slanting rod indicates that the numeral is negative. In the first column from the right, the character *tai* indicates the constant of the equation, which in the above case is zero. This column, which is similar to the notation of a polynomial in one unknown, represents $0 + 0x + 0x^2 + x^3$. The second column represents $0y + 2xy + 2x^2y + 0x^3y$, and the last column represents $-2y^2 - xy^2 + 0x^2y^2 + 0x^3y^2$.

Zhu Shijie gave examples to show how a set of simultaneous polynomial equations of varying degrees up to four unknowns could be reduced to an equation in one unknown, and thereby finding the solution. For example, he illustrated how the set of equations of the form

$$\begin{aligned} -2y + x + z &= 0, \\ -xy^2 + 4y - x^2 + 2x + xz + 4z &= 0, \\ y^2 + x^2 - z^2 &= 0, \\ 2y + 2x - u &= 0 \end{aligned}$$

was reduced to the following single equation in one unknown:

$$4u^2 - 7u - 686 = 0.$$

In *Siyuan yujian*, Zhu Shijie excelled in another area in algebra: he gave correct formulae for the sums of higher order equal difference series. They are of two types which may be described in the following manner.

First type:

$$\begin{aligned}
 1 + 2 + 3 + 4 + \cdots + n &= \frac{1}{2!}n(n+1), \\
 1 + 3 + 6 + 10 + \cdots + \frac{1}{2!}n(n+1) \\
 &= \frac{1}{3!}n(n+1)(n+2), \\
 1 + 4 + 10 + 20 + \cdots + \frac{1}{3!}n(n+1)(n+2) \\
 &= \frac{1}{4!}n(n+1)(n+2)(n+3), \\
 1 + 5 + 15 + 35 + \cdots + \frac{1}{4!}n(n+1)(n+2)(n+3) \\
 &= \frac{1}{5!}n(n+1)(n+2)(n+3)(n+4), \\
 1 + 6 + 21 + 56 + \cdots + \frac{1}{5!}n(n+1)(n+2)(n+3)(n+4) \\
 &= \frac{1}{6!}n(n+1)(n+2)(n+3)(n+4)(n+5).
 \end{aligned}$$

Second type:

$$\begin{aligned}
 1 \cdot 1 + 2 \cdot 2 + 3 \cdot 3 + \cdots + n \cdot n &= \frac{1}{3!}n(n+1)(2n+1), \\
 1 \cdot 1 + 2 \cdot 3 + 3 \cdot 6 + \cdots + n \cdot \frac{1}{2!}n(n+1) \\
 &= \frac{1}{4!}n(n+1)(n+2)(3n+1), \\
 1 \cdot 1 + 2 \cdot 4 + 3 \cdot 10 + \cdots + n \cdot \frac{1}{3!}n(n+1)(n+2) \\
 &= \frac{1}{5!}n(n+1)(n+2)(n+3)(4n+1).
 \end{aligned}$$

It was ► [Shen Guo](#) (1032–1095) who initiated the study of this type of series and he was followed by ► [Yang Hui](#) and Zhu Shijie – their basic technique was related to the piling of stacks.

The foundation of algebra, as we know it today, and its impetus for growth arose from the successful development of arithmetic based on the Hindu-Arabic numeral system. In the earlier civilizations, there were various beginnings of algebra which also depicted the struggle to find expressions for arithmetical operations and geometrical relationships. The development of algebra in China has proved to be unique and significant with its growth being maintained continuously until the Ming dynasty (1368–1644).

The essential ingredient that fostered the growth of algebra in traditional China was the rod numeral system. What was extraordinary about it was its notation: the position of each digit of a numeral represented the place value of that digit, such as units, tens, hundreds, and so forth. This notation of a number freed the mind of unnecessary work and enabled arithmetic to be developed to the fullest. The same kind of thinking in the use of the positions of rod numerals to represent concepts or things made possible the subsequent evolution of algebra.

Though the Chinese used rods to develop algebra, the results obtained manifested numerous similarities with our early algebra. In the solution of a set of simultaneous linear equations, the ancient Chinese invented the matrix notation and the *fang cheng* method of elimination. About 1,500 years later, ► [Seki Kowa](#) and Leibniz initiated the study of determinants – Seki Kowa knew of the *fang cheng* method.

In searching for a general solution of a polynomial equation, ► [Jia Xian](#) drew attention to a triangular array of numbers which we now call Pascal's triangle. The method that the Chinese used to solve the polynomial equation was rediscovered by Horner half a century later. The concise notation of expressing the concept of a polynomial equation led Zhu Shijie to invent a notation to express a set of polynomial equations up to four unknowns. He gave examples to show how to solve them. In eighteenth-century Europe, it was Étienne Bezout who initiated the study of solving a pair of polynomial equations in two unknowns. Zhu Shijie's formulae for the series of higher order equal difference series also showed that he was a few centuries ahead of his counterparts in Europe.

It is ironical that the use of rods, which enabled the expansion and sustenance of algebra in China for over one and a half millennia, was also the reason for its decline. The rods were used not only for the development of mathematics but also for computation. By the Song dynasty (960–1279), a faster-paced society could not tolerate the time required for manipulating the rods. The demand for quicker computation led to the invention of the ► [abacus](#). However, the abacus was only suitable for swift calculations and had

neither the potential to foster the growth of mathematics nor the capacity to allow for the conceptual retention of what had already been developed in mathematics. The replacement of the rods by the abacus signaled the demise of traditional mathematics.

Since ancient times, the Chinese mathematicians had been using a base ten place value numeral concept in the rod numerals, and so it would not have been difficult for them to adopt this concept in a written form. If they had made such an adoption during the switch to calculation with the abacus, there would have been a smooth transference of mathematical concepts from the rod medium to the written medium. However, such an adoption was only made when western mathematics entered China beginning with the arrival of Matteo Ricci in 1582. The consolation from this erroneous turn of events was that during the sixteenth and seventh centuries many Chinese were still knowledgeable in traditional mathematics, and they helped greatly to lighten what would have been a tremendous upheaval in the change to the new mathematics.

See Also

- [Abacus](#)
- [al-Khwārizmī](#)
- [Computation: Chinese Counting Rods](#)
- [Jia Xian](#)
- [Jiuzhang Suanshu](#)
- [Li Zhi \(Li Ye\)](#)
- [Qin Jiushao](#)
- [Seki Kowa](#)
- [Wang Xiaotong](#)
- [Yang Hui](#)
- [Zhu Shijie 朱世傑](#)

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Algebra in India: *Bījagaṇita*

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Bījagaṇita, which literally means “mathematics (*gaṇita*) by means of seeds (*bīja*),” is the name of one of the two main fields of medieval Indian mathematics, the other being *pāṭīgaṇita* or “mathematics by means of algorithms.” *Bījagaṇita* is so called because it employs algebraic equations (*samīkaraṇa*) which are compared to seeds (*bīja*) of plants since they have the potentiality to generate solutions to mathematical problems. *Bījagaṇita* deals with unknown numbers expressed by symbols. It is therefore also called *avyaktaṇita* or “mathematics of invisible (or unknown) [numbers].” Algebraic analyses are also employed for generating algorithms for many types of mathematical problems, and the algorithms obtained are

included in a book of *pāṭī*. *Bījagaṇita* therefore also means “mathematics as a seed [that generates *pāṭī* (algorithms)].”

Extant works in *bījagaṇita* include Chapter 18 (*kuṭṭaka* only) of Āryabhaṭa’s *Mahāsiddhānta* (ca. AD 950 or 1500), Chapter 14 (*avyaktaṅgaṇita*) of Śrīpati’s *Siddhāntaśekhara* (ca. AD 1050), Bhāskara’s *Bījagaṇita* (AD 1150), Nārāyaṇa’s *Bījagaṇitāvataṃsa* (before AD 1356, incomplete), and Jñānarāja’s *Bījādhyāya* (ca. AD 1500). Śrīdhara’s work (ca. AD 750), from which Bhāskara quotes a verse for the solution of quadratic equations, is lost. Chapter 18 (*kuṭṭaka*) of Brahmagupta’s *Brāhmasphuṭasiddhānta* (AD 628) has many topics in common with later works of *bījagaṇita*, but the arrangement of its contents is not so systematic as that of the later works, and an unusual stress is placed on *kuṭṭaka* as the title of the chapter suggests. *Kuṭṭaka* (lit. pulverizer) is a solution to the linear indeterminate equation: $y = (ax + c)/b$.

The symbols used for unknown numbers in *bījagaṇita* are the initial letters (syllables) of the word *yāvattāvat* (as much as) and of the color names such as *kālaka* (black), *nīlaka* (blue), *pīta* (yellow), etc. The use of the color names may be related to Āryabhaṭa’s *gulikā* (see below). Powers of an unknown number are expressed by combination of the initials of the words *varga* (square), *ghana* (cube), and *ghāta* (product). A coefficient is placed next (right) to the symbol(s) to be affected by it, and the two sides of an equation are placed one below the other. A dot (or a small circle) is placed above negative numbers. Thus, for example, our equation, $5x^5 - 4x^4 + 3x^3 - 2x^2 + x = x^2 + 1$, would be expressed as:

$$yāvaghaghā5yāvava4yāgha3yāva2yā1rū0,$$

$$yāvaghaghā0yāvava0yāgha0yāva1yā0rū1,$$

where *rū* is an abbreviation of *rūpa* meaning an integer or an absolute term. The product of two (or more) different unknowns is indicated by the initial letter of the word *bhāvita* (produced): e.g., *yākābhā* 3 for $3xy$.

These tools for algebra had been fully developed by the twelfth century, when Bhāskara wrote a book entitled *Bījagaṇita* (AD 1150), the main topics of which are “four seeds” (*bījacatuṣṭaya*), namely, (1) *ekavarṇa-samīkaraṇa* or equations with one color (i.e., in one unknown), (2) *madhyamāharaṇa* or elimination of the middle term (solution of quadratic equations), (3) *anekavarṇasamīkaraṇa* or equations with more than one color, and (4) *bhāvitaka-samīkaraṇa* or equations with “the product” (i.e., of the type $ax + by + c = dxy$).

At least part of this algebraic notation was known to Brahmagupta. He uses the words *avyakta* (invisible) and *varṇa* (color) for denoting unknown numbers, when he gives his rules concerning the same four seeds as Bhāskara’s, in Chapter 18 (*kuṭṭaka*) of his *Brāhmasphuṭasiddhānta*. The details of Brahmagupta’s algebraic notation are, however, not known to us.

Bhāskara, a contemporary of Brahmagupta, did know the word *yāvattāva*, meaning an unknown number, but it is not certain if he used it in equations, because he expresses the equation, $7x + 7 = 2x + 12$, without the symbol *yā* as:

7	7
2	12

in his commentary (AD 629) on the *Āryabhaṭīya*. In the same work, he refers to four seeds which are said to generate “mathematics of practical problems” (*vyavahāraṅgaṇita*) having eightfold of names beginning with “mixture,” but the kinds of seeds he mentioned by the names *yāvattāvat*, *vargāvarga* (square), *ghanāghana* (cube), and *viśama* (odd) are not exactly known. Similar terms (*yāvattāvat*, *varga*, *ghana*, and *vargavarga*) occur in a list of ten mathematical topics given in a Jaina canon, *Sthānāṅga* (Sūtra 747), which is ascribed to the third century BCE.

Āryabhaṭa used the term *gulikā* (a bead) for an unknown number when he gave his rule for linear equations of the type $ax + b = cx + d$

in his *Āryabhaṭīya* (AD 499). All the equations to which he gave solutions (including *kuṭṭaka*) are linear, although his rules for the interest and for the period of an arithmetical progression presuppose the solution of quadratic equations.

Brahmagupta gave many theorems for *vargaprakṛti* (lit. square nature), i.e., the indeterminate equation of the second degree: $Px^2 + t = y^2$, but it was Jayadeva (the eleventh century or before) who gave a complete solution for the case $t = 1$ (the so-called Pell's equation).

Bījagaṇita reached its culmination in the twelfth century, when Bhāskara gave solutions to various types of equations of quadratic and higher degrees by means of *kuṭṭaka* and *vargaprakṛti*. They include: $(ax + b)^2 = cy^2 + d$; $(ax + b)^2 = cy^2 + dy + e$; $(ax + b)^2 = cy^4 + dy^2$; $(ax + b)^2 = cy^6 + dy^4$; $(ax + b)^2 = cy^2 + dz^2 + e$; $(ax + b)^2 = cy^2 + dyz + ez^2$; $x + y + a = r^2$, $x - y + a = u^2$, $x^2 + y^2 + b = v^2$, $x^2 - y^2 + c = w^2$ (r, u, v , and w are not required); $ax + b = y^2$; $ax + b = y^3$; $(ax^n + c)/b = y$ ($n = 2$ or 3 ; x and y are integers). Bhāskara pointed out the infinity and invariability of the quantity called *kha-hara* ("zero-divisor"), that is, $a/0$ (a is an integer), and compared them to those of the god Viṣṇu. This assertion of the invariability was later criticized by Jñānarāja (ca. AD 1500), who claimed that the invariability of *kha-hara* does not hold true for the addition of fractions.

Kṛṣṇa (fl. ca. 1600) in his commentary on the *Bījagaṇita* gave detailed rationales (*upapatti/yukti*) of Bhāskara's rules. Kṛṣṇa also showed that the apparent change of *kha-hara* pointed out by Jñānarāja does not affect its infinity.

See Also

- [Arithmetic in India: *Pāṭīgaṇita*](#)
- [Āryabhaṭa](#)
- [Bhāskara I](#)
- [Brahmagupta](#)
- [Jayadeva](#)
- [Nārāyaṇa Paṇḍita](#)
- [Śrīdhara](#)
- [Śrīpati](#)

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Algebra in Islamic Mathematics

(with the collaboration of Osman Bakar and Kamel Arifin Mohd Atan)

Mat Rofa Bin Ismail

The word *algebra* is derived from the Arabic *al-jabr*, a term used by its founder, Muḥammad ibn Mūsā ► [al-Khwārizmī](#), in the title of his book written in the ninth century, *al-Jabr wa'l-muqābalaḥ* (The Science of Equations and Balancing). Algebra is also known as “the science of solving the unknowns in equations.”

The simplest equation with one unknown is of the form $ax = b$, with a and b as constants x here is called *al-jadhr* of the equation. Al-Khwārizmī enumerated six standard second-degree equations in his *al-Jabr wa'l-muqābalaḥ*:

$$\begin{array}{lll} ax^2 = bx, & ax^2 = b, & ax = b, \\ ax^2 + bx = c, & ax^2 + c = bx, & ax = bx + c. \end{array}$$

Also, he provided solutions to these equations using algebraic and geometrical justifications.

The main aim of al-Khwārizmī's algebra was to provide the Muslim community with the necessary arithmetical knowledge essential in their daily calculation needs, such as in matters pertaining to heritage and legacy, transaction, sharing and partnership, loss and profit, irrigation and land-acreage, and geometrical problems. Al-Khwārizmī devoted about half of his *al-Jabr wa 'l-muqābalaḥ* to such problems.

► [Abū Kāmil Shujā'](#) ibn Aslam of Egypt (AD 850–930) gave his treatise on algebra the name *al-Jabr wa 'l-muqābalaḥ*, the same title as al-Khwārizmī's. This treatise gives commentaries on al-Khwārizmī's six standard quadratic equations using Euclid's lemmas in geometry to justify the existence of two roots for a general quadratic equation. In the twelfth century, Abū'l-Fath 'Umar bin al-Khayyām listed 39 standard cubic equations in his *Risāla fi'l-barāhīn 'alā masā'il al-jabr wa 'l muqābalaḥ*, and solved them by intersecting suitable conic-sections (circle or semicircle, parabola, hyperbola, and ellipse) using Apollonius's theory of ► [conics](#). The solutions to the equations were represented by intersections of the curves, but he failed to identify the exact numerical solutions. Many attempts had been made toward finding the geometrical solutions of cubic equations before 'Umar al-Khayyām mentioned them in his book, such as those by ► [al-Māhāni](#) and Abu'l-Jūd.

Also in the twelfth century, Sharaf-al-Dīn al-Ṭūsī examined the cubic equation species classified by 'Umar al-Khayyām and provided their solutions through a systematic study of the minimum and maximum values of their associated functions. He gave the number of real solutions of a cubic equation in terms of its coefficients.

In the third portion of his *Kitāb fi 'l-al-jabr wa'l-muqābalaḥ*, Abū Kāmil discussed indeterminate problems (*mu 'ādalah siālah*) of the second degree. Some of these were of Greek origin and could be found in the *ṣinā 'ah al-jabr* by Diophantus, the translation of *Arithmetica* by ► [Qusṭā ibn Lūqā](#). The problems were then cited by Leonardo Fibonacci in his book *Liber*

abaci. Abū Kāmil concentrated on enumerating the possible solutions of simultaneous equations in his *tarāʾif al-ḥisāb*. They were based on the problem of determining the number of birds that could be purchased with 100 dirhams. Somebody is to buy 100 fowls, given that, for example, a rooster costs five units, a hen 3, and chicks are sold three for one unit. Problems of this type gave rise to a system of equations of the form:

$$\begin{aligned}x + y + z + u + v &= 100 \\ &= ax + bx + cz + du + ev.\end{aligned}$$

In the case of $a = 2$, $b = 1/2$, $c = 1/3$, $d = 1/4$, $e = 1$ Abū Kāmil gave 2,696 possible integer solutions. The analysis marks the birth of a field in algebra which is known today as linear algebra.

Extraction of square and cubic roots became an important subject of discussion in arithmetic and algebra books, or *ḥisāb al-Hindī* based on Indian Mathematics during the heyday of the Muslim mathematicians. The rule for the extraction of roots was then based on binomial expansion of the form $(a + b)^n$. Al-Ṭūsī listed the coefficients in the expansion of $(a + l)^n - a^n$ for some n , in his *Jawāmī* and arranged them in a triangular form which he called *manāzil al-ʿadad*. This triangular arrangement came to be known in the West as Pascal's triangle, after Blaise Pascal, the famous French mathematician who published his *Traité du triangle arithmétique* in 1665. Such an arrangement was also drawn up by ► [al-Karajī](#) in one of his books. This was further mentioned by Samuʿil (or Samau'al) ibn ʿAbbas, also called al-Maghribī (eleventh century), in his *al-Bāhir fi 'l-jabr*. ʿUmar al-Khayyām did write a book on the extraction of cubic and fourth roots, but the book is assumed to be lost. The extraction of the fifth root was carried out by al-Kāshī in the fifteenth century in his *Miftāḥ al-ḥisāb*. He gave a numerical example of extracting the fifth root of 44,240,899,506,197 (order of trillions).

In the expansion of an algebraic term raised to a certain power, the concept of the negative number is extremely important. Muslim mathematicians made a substantial contribution to the development of this concept. Abū'l-Wafā

al-Būzjānī in his *Ma Yaḥtaj ilayh al-kuttāb wa 'l-ʿummāl min ʿilm al-ḥisāb* considered debts as negative numbers. For example, the calculation for $35 + (-20) = 15$ was written as $35 + \text{dain } 20 = 15 - (\text{dain} = \text{debt})$. ► [Abū Kāmil](#), as a commentator on the *al-Jabr wa 'l-muqābalah* of ► [al-Khwārizmī](#), explained the application of positive and negative signs for the purpose of expanding the multiplication $(a \pm b)(c \pm d)$. This resulted in his rules:

$$(+)(+) = + = (-)(-), (+)(-) = (-)(+) = -.$$

These rules are embodied in his famous work *Kitāb al-jabr wa 'l-muqābalah*. Al-Karajī showed clearer examples illustrating operations with negative quantities in his *al-Fakhrī*. These rules are implicitly used throughout the book:

$$\begin{aligned}a - (-b) &= a + b, & (-a) + b &= -(a - b), \\ (-a) - (-b) &= -(a - b), & (-a) - b &= -(a + b).\end{aligned}$$

Samuʿil and Ibn al-Bannā' al-Marrākushi then made some finer rules about calculations involving negative numbers in their works, *al-Bāhir fi 'l-jabr* and *Kitāb al-jabr wa 'l-muqābalah*, respectively.

The art of proving became an important part of mathematical science. The direct and proof by contradiction methods are two important tools in proving mathematical statements. In some cases, however, they fail to work, especially in proving formulae containing integral terms. In this case, the method of *istiqrāʾ*, or proof by induction, is an appropriate one to use. Al-Karajī wrote an article by that name to explain this method. Samuʿil and Ibn al-Haytham used it to prove some formulae on infinite series. A good example of the employment of proof by contradiction was given by ► [Abū Jaʿfar al-Khāzin](#) to establish some properties of right-angled triangles. These can be found in the treatise *Risālah fi 'l-muthallathāt al-qāʾimat al-zawāyā* or in the *Tadhkirat al-aḥbāb fī bayān al-tuḥābb* of Kamāl al-Dīn al-Fārisī. The contradiction method based on the logical property “if (statement a is true) then it implies (statement b is true)” is equivalent to “if (statement b is not

true) then (statement a is not true).” The converse, however, is not always true. This type of reasoning is characteristic of discussions in *manṭiq* or logic.

To explain the method of *istiqrāʾ*, Samuʿīl proved the case $n = k$ through the assumption that the case $n = k - 1$ is true. For example, to prove $a^3 b^3 = (ab)^3$, Samuʿīl started with the assumption of $a^2 b^2 = (ab)^2$ (which had been proved before), then multiplied both sides by (ab) to obtain $(ab)(a^2 b^2) = (ab)(ab)^2 = (ab)^3$. Using the proposition mentioned earlier, i.e., $(ab)(cd) = (ac)(bd)$, he obtained $(ab)(a^2 b^2) = a^3 b^3$. Although in this demonstration, Samuʿīl used particular numbers instead of a general k , he successfully showed the method of *istiqrāʾ* correctly as we understand it today. Some writers, however, continue to attribute the method to Pascal or Bernoulli in the seventeenth century (Yadegari, 1978).

The inherent idea in the use of logarithm is to expedite the multiplication process by converting it into an addition one. This is done by employing the rules of exponent. Abūʿl-ḥasan al-Nasawī wrote a book on the idea in Persian which was later translated into Arabic with the title *al-Muqniʿ fi ʿl-ḥisāb al-Hindī*. Ibn Yūnus (eleventh century), a well-known Egyptian astronomer, discovered the role of the trigonometric relation

$$\cos(a) \cos(b) = \frac{1}{2} [\cos(a+b) + \cos(a-b)]$$

in transforming the process of multiplication into addition. For example, suppose one wishes to obtain the product of 35.84 and 54.46. Since $\cos(69^\circ) = 0.3584$ and $\cos(57^\circ) = 0.5446$, then $(35.84)(54.46) = 1951.5$ by using this identity. This formula had been proven earlier by Abūʿl-Wafā al-Būzjānī (d. 998) in his commentary on the *al-Majestī* (*Almagest*) of Ptolemy.

The expression of a fraction in the decimal form, based on an extant manuscript, goes back to *Kitāb al-fuṣūl fī al-ḥisāb al-Hindī* of Abūʿl-ḥasan Aḥmad ► [al-Uqlīdisī](#). It was written in the year 341H (AD 952). Uqlīdisī operated on the number 19 by consecutive halvings. First, he obtained (using his symbol) $9/5$ then $4/75$,

$2/375$, $1/11875$, and finally $0/59375$ (some commas indicating separations of hierarchy were dropped in the manuscript). Subsequently, Samuʿīl al-Maghribī gave a clearer idea of the notion of decimal fractions in his *al-Qiwāmi fi ʿl-ḥisāb al-Hindī*. This book was written in the year AD 1172. The quotient of 210 by 13 was expressed as follows:

The square root of 10 is expressed as 3.16227, a clear definition of a decimal fraction, as the number 16,227 is considered part of 1,000,000, with 3 as a whole number. More precisely, 3.16227 means:

Integer	Parts of 10	Parts of 100	Parts of 1,000	Parts of 10,000	Parts of 100,000
16	1	5	3	8	4

$$3 + \frac{1}{10} + \frac{6}{100} + \frac{2}{1,000} + \frac{7}{100,000}.$$

Jamshīd al-Kāshī (fourteenth century) expressed the decimal fraction in both al-Khwārizmī’s and the astronomers’ system in the article “*al-Risāla al-muḥīṭīyyah*.” He gave the value of 2π as 6.2831853071795865 (in al-Khwārizmī’s decimal system) or as 6-6, 16, 59, 28, 1, 34, 51, 46, 15, 50 (in the astronomers’ sexagesimal system).

The method of writing numbers as decimal fractions later appeared in the West in Stevin’s *de Theinde* or its French version, *La Disma*, in 1585. To indicate the integral and fractional portions of the number, Stevin employed a stroke to separate the two. He is considered the founder of the decimal fraction by some writers in the West.

Nicomachus in his *al-Madkhal ilā ʿilm al-ʿadad* (an Arabic translation of *Introduction*) gave the four first perfect numbers: 6, 28, 469, and 8,128. Ismail al-Māridīnī (twelfth century) added some others to the list of perfect numbers: 6, 28, 496, 8128, 1130816, (2096128), 33550336, 8589869056, 137438691328, (35184367894528). Actually, the two numbers in brackets are not perfect. This mistake is due to the difficulty in determining the primality of a number.

One can observe from al-Māridīnī’s list that it is hard to find an odd perfect number.

The numbers seem to be even, and the first digit (remember that Arabs write from the right) of a perfect number obtained by the formula is always 6 or 8. Indeed, the perfect numbers described by the formula $(2^{n-1} - 1)2^n$ are always even, since they are the product of even and odd numbers. However, many think that odd perfect numbers do exist. Euler, centuries later (1849), in his paper in *Tractus de numererum doctrina*, described a necessary condition for the existence of an odd perfect number, but it was not a sufficient condition.

Other types of numbers that became the subject of scrutiny of Muslim mathematicians are the deficient and abundant numbers. The mathematicians supplied some criteria to identify these numbers:

- Every odd number less than 945 is deficient.
- Every even-times-even number has factors less than itself.
- The first abundant number is 12, and the first odd one in this class is 945.
- If $2^n S$ is a perfect number, then $2^{n+1} S$ is an abundant number, and $2^{n-1} S$ is a deficient number.

Kamāl al-Dīn al-Fārisī (d. 1320) in his treatise, *Tadhkirah al-aḥbāb fi bayān al-tuḥābb* supplied the rule to find pairs of amicable numbers (*al-a'dād al-mutaḥābbah*) in a systematic way. Thābit ibn Qurra (836–901) developed the theory of amicable numbers and provided a technique to find such pairs in his *Risālah fi'l-a'dād al-mutaḥābbah*. Al-Fārisī reached the same conclusions through somewhat different paths. He based his new technique on the systematic knowledge of the divisors of a composite number and their sum. A pair of amicable numbers is defined as a pair of numbers (a, b) with the properties that the sum of all possible proper divisors of a is equal to b and the sum of all possible proper divisors of b is equal to a .

Ibn ṭāhir al-Baghdādī defined a new variety of numbers known as equivalent numbers or numbers of equal weight (*muta'adilan*) in his *al-Takmila fi'l-ḥisāb*. According to him:

If we have a given number and wish to find two numbers, the parts of which make up this number, we reduce it by one and split the result into two prime numbers, then two others, and so on, as many times as we can. The product of each pair is a number equivalent to the given number. Thus if we are given 57, we split 56 into (3,53), (13,43), etc. The products of 53 by 3 and 4 by 13 are numbers such that the sum of the parts of each is 57. (Saidan, 1977)

Equivalent numbers had not been studied by al-Baghdādī's contemporaries, nor by mathematicians for a few generations after him, until the time of Muḥammad Bāqir al-Yazdī (seventeenth century). Al-Yazdī, in his *Uyūn al-ḥisāb*, considered such numbers and chose evenly even numbers to be decomposed as al-Baghdādī had done. In this way it was convenient for him to establish some properties of equivalent numbers, such as: if p and q are prime numbers, then p and q are of equal weight. It was felt that numbers of this kind needed more attention and to be examined further as they exhibited interesting unique behaviors.

The problem of finding the sides (x, y, z) of a right-angle triangle was studied and addressed by many Muslim mathematicians, including Samu'īl (twelfth century) and ► [Abū Ja'far al-Khāzin](#) (tenth century). ► [Al-Khwārizmī](#) considered some basic problems related to a right-angled triangle. These problems became the source of his algebraic problems in his *Kitāb al-jabr wa 'l-muqābala*. Samu'īl in his *al-Bāhir fi 'l-ḥisāb* showed that any triple of the form

$$\left(a, \frac{(a^2 - b^2)}{2b}, \frac{(a^2 + b^2)}{2b} \right)$$

with a, b, c being appropriate positive integers, would describe right-angled triangles. Earlier, al-Khāzin had considered such problems in his *Risālah fi al-muthallathāt alqā 'imat al-zawāyā al-munṭaqaṭ al-aḍlā'*. He showed that it was not possible that any triple (x, y, z) , with x and y being odd (or evenly even) could be the sides of a right-angled triangle with z as an integer. Al-Khāzin then used the results to study the problems of the form $x^m + y^n = z^p$ with m, n , and p some small positive integers. He left out some cases,

however, such as $m = n = p = 3$ or 4 , for such problems have no solutions. Problems of these types were examined centuries later by de Fermat (1736).

The problem of splitting a cube into three other cubes, i.e., to find the solution of the equation with three unknowns, $x^3 + y^3 + z^3 = n^3$, was discussed by Ibn ṭāhir al-Baghdādī (tenth century) in *Takmila fi 'l-ḥisāb*. He gave the answer as

$$(x, y, z) = \left(\frac{n}{2}, \frac{2n}{3}, \frac{5n}{6} \right).$$

This problem then reappeared in the works of Barbaretta (1910).

See Also

- Abū Kāmil
- Abū 'l-Wafā'
- al-Karajī
- Al-Kāshī
- al-Khwārizmī
- al-Uqlīdisī
- Ibn al-Bannā'
- Ibn Yūnus
- Qusṭā ibn Lūqā
- Samū'īl ibn 'Abbās (Al-Maghribī)
- Sharaf al-Dīn al-Ṭūsī
- Thābit ibn Qurra
- Umar al-Khayyām

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Algebra in the Malay World: A Case Study of Islamic Mathematics

Mat Rofa Bin Ismail and Kamel Ariffin
Mohd Atan

The Malay World comprises countries which are now known as Malaysia, Indonesia, Brunei, Singapore, Thailand, Philippines, and Kampuchea.

This part of the world is also known as *Nusantara* or *Pascabima*. Ptolemy, the Egyptian geographer, visited the Malay world in the second century AD and called it “Golden Chersonese” (*Semenanjung Emas* in Malay – a beautiful golden peninsula) for its beauty and greenness. Indian travelers once referred to it as *Sunarvabumi*, which can be translated in the same way. The significance of this area in ancient history as a meeting place for sea travelers between ► east and west is due to its strategic location between India and China.

The region went through its own history under many religious influences such as Hinduism, Buddhism, and Islam. It is recorded that Islam came to this region in the very early period of the Umayyad caliphate when a Srivijayan king embraced Islam during the reign of Caliph Umar ibn al-Aziz (AD 717–720). Since then, Islam gradually became an important religion in the region. Religious matters, such as compulsory charity (*zakat*), inheritance problems (*farā’id*), and crescent sighting to mark a new month in the lunar calendar needed knowledge of systematic mathematical calculation. For these purposes, the works of ► al-Khwārizmī, Ibn al-Bannā’, al-Turtūsī, Ibn al-Hā’im, Ulugh Beg and ► Ibn al-Yāsamin in algebra, mathematics and astronomy were frequently cited by the Malay scholars.

Text books in algebra and arithmetic, such as *Khulasah al-ḥisab* (A Concise Treatise on Mathematics) by al-‘Amili, *Talqīh al-afkār* (Combining Ideas) and *al-Urjūyah al-Yāsamiyyah* (The Poem of al-Yasamin) by Ibn al-Yāsamin, *Tuḥfah al-a’dād li dhawī al-rushd wa al-rashād* (A Special Arithmetic for the Wise and the Rightly Guided) by Ibn Hamzah al-Maghribi, *Kashf al-asrār* (Unveiling of Secrets) by al-Qalsaldi, *Talkhīṣ al-ḥisab* (Purification of Mathematics/Understanding Mathematics?) by Ibn al-Bannā’ al-Marrakushi, and *Murshid al-ṭālib ila asna al-mutalib* (Student’s Guide to Excellence in the Pursuit of Knowledge) by Ibn al-Hā’im, were among frequent quoted references by Malay writers (see Zain, 2001).

The beginning of the history of Islamic mathematics can be traced to the late eighth century.

Among the earliest Muslim mathematicians was al-Khwārizmī (780–850 AD) who introduced a new system of numbering which greatly simplified the Roman one which had been widely used previously. The decimal system (*a’shariyyah*) provided simplification in carrying out basic arithmetical operations. In the Islamic tradition of knowledge, religious scholars who were experts in the field of theology were also conversant with and masters of other areas of knowledge. These included astronomy, medicine, the arts, logic, and rhetoric. Among those who fall into this category are ► al-Kindī (born 796 AD), ► al-Battānī (858–929), Ibn al-Haytham (965–1038), ► al-Bīrūnī (973–1048), and Ibn Sīnā (eleventh century). By the fourteenth century Islamic civilization was already very rich in its mathematical knowledge. Scholars moved to other fields besides basic mathematics.

The treatise by Ibn al Bannā’, entitled *Raf’u al-ḥijāb ‘an A’māl al-ḥisāb* (Unveil the Cover in the Arts of Mathematics) or *Khulasah al-ḥisab* by al-‘Amili, discussed the subject of basic arithmetic and algebra. For example, the discussion of permutations and combinations in the book of Ibn al-Bannā’ (fourteenth century) marks the first advance made by Islamic mathematics since the time of al-Khwārizmī. Islamic scholars continued to be active and productive in the field of mathematics until the seventeenth century, when their involvement waned due to backlash in the political arena during that period and subsequent to it. Until that time many outstanding treatises were produced and became references not only by contemporaneous scholars, but also by mathematicians in the subsequent centuries. They played an outstanding role in shaping and providing directions for the future development of mathematics in the world. Muslim works were brought into Europe by early scholars by translating Arabic treatises into Latin. Leonardo Fibonacci was among the pioneers in this pursuit. Centers of learning set up in places such as Cordova, Toledo, and other places in Spain became the focal point of convergence for western scholars to study Islamic mathematics.

Islamic mathematics came into the Malay world through the efforts of Malay religious

scholars who had gone to the Middle East to study Islamic theology. They mastered the mathematics of the day in its original form and in an integrated manner with branches of theology. Whatever was learnt in the Middle East was brought back and disseminated to students in traditional schools. Among the works collected and brought back were books on a variety of branches of mathematics which had been their references during their study, especially in Mecca, Medina, and the University of Al-Azhar. Some of the scholars became writers and produced mathematical works based on their learning experience. Many of the written works were in the form of leaflets, short notes, and letters, written in Malay using the Arabic script. These works came down to us through the descendants of these scholars. Though only a few manuscripts survived, they give us a glimpse of the serious efforts and quality of work of the early Malay scholars in mathematics.

The documentation of Islamic mathematics in the Malay World has to date not been completed. The earliest known record of a treatise in logic by a Malay writer, entitled *‘Ilm al-Manṭiq* (The Art of Logic), is dated 1593. However our search for such treatises in mathematics written in the region mainly concentrated on surviving documents that are dated later than the eighteenth century.

The records tell us about the existence of a number of Malay mathematicians for the period between the nineteenth and mid-twentieth century. They were mathematicians who were also scholars in religious studies. Our early survey (Ismail, 1995) showed that they originated mainly from Fatani/Patani (in southern Thailand), Sumatera Indonesia, and Kelantan Malaysia. Some were also of Riau and Kampuchean origin. They were highly respected by the Malay community then and now because of their knowledge in religion as well as in other scholarly areas. Syeikh Daud al-Fatani (b. 1720 AD), for example, was regarded as one of the great Malay scholars during that period. So were Syeikh Abdul Kadir al-Fatani (b. 1817 AD), Syeikh Muhammad Nur al-Fatani (b. 1873), Faqih Wan Musa al-Fatani (second

half of nineteenth century), and Syeikh Wan Ahmad Mohamad Zain al-Fatani (1856–1908). Another Malay scholar was Ahmad bin Abdul Latif al-Khatib al-Minangkabawi from Sumatra, Indonesia. He is regarded as the greatest Malay mathematician of the nineteenth century. Syeikh Tahir Jalaluddin (1867–1957), also of Sumatran origin, who later settled down in peninsular Malaysia, was regarded as a fine Malay astronomer towards the end of the nineteenth century. So was ‘Umar Nuruddin al-Kelantani.

Mathematical works by Ahmad bin Abdul Latif al-Khatib al-Minangkabawi entitled *‘Alam al-ḥussāb* (The Banner for Mathematicians) (1892) and *Rauḍat al-ḥussāb* (The Garden for Mathematicians) (1890) became the models for others to follow in the Malay world then. *‘Alam al-ḥussāb* was a Malay version of the Arabic *Rauḍat al-ḥussāb*. Al-Khatib was the first Malay *imam* (prayer leader), *khatib* (Friday prayer’s speaker) and religious teacher in Masjid al-Haram Mecca, appointed by The Holy Land’s authority. Many of his students came from the Malay region. In these two books were mathematical topics of the period found in the Muslim world, which included number theory, algebra, geometry, trigonometry, approximation theory, and discussions on daily problems especially those arising from Islamic practices (*fiqh*) and the like. The contents of these works reflected the discussions and debates that took place in the period that began in ninth century and ended in the seventeenth, especially on the works of Muhammad bin Musa ► [al-Khwārizmī](#) produced during the late eighth and early ninth centuries. Also included were those by Abu Kamil Shuja’ al-Aslam (tenth century), Abu Bakar al-Karaji (eleventh century), Ibn Yasamin (twelfth century), Ibn al-Bannā’ (fourteenth century), Ibn Hamzah al-Maghribi (sixteenth century), and Baha’uddin al-‘Amili (seventeenth century).

Umar Nurudin’s work on the distribution of properties left behind by deceased members of the family was entitled *Pelajaran Membahagi Pesaka* (Lessons in Distribution of Inheritance) (early nineteenth century). His other works include *Syams al-Fathiyyah fi A’amāl al Juyūb* (The Guiding Light to Success in the Art of

Trigonometry) or *al-Jaibiyah* (The Art of the (Trigonometrical) Sine) (1925), *Rubu' al-Mujayyab* (The Quadrant of the (Astronomical) Sine) (date unknown), and *Miftāḥ al-Ta'alīm* (The Key to Teaching and Learning) (1924). In the early twentieth century a scholar by the name of Muhamad Nur al-Ibrahimi, from Sumatra Indonesia, wrote a treatise on logic called '*Ilm Mantiq* (The Art of Logic) (1931). Sheikh Muhammad Nur Ibrahim of Kelantan wrote a book *Bantuan Ketika Bagi Orang yang Membahagi Pusaka* (A People's Guide to Inheritance Problems) (1936). Earlier, in 1932 he published a book entitled *Pilihan Mastika pada Menerangkan Qiblat dan Ketika* (Selected Gems in the Calculation of the Qibla Direction and (Prayer) Times), on the exact Qibla location in Mecca. Syeikh Tahir Jalaluddin, of Sumatran origin, wrote a book on the mathematical method of determining Muslim prayer times, entitled *Pati Kiraan pada Menentukan Waktu yang Lima dengan Logaritma* (The Essence of Calculations Related to the Five Prayer Times Using Logarithms) in 1938. He also authored two other books on astronomy and wealth distribution. His book on astronomy, *Risā'il fi'l-Falak* (Treatises on Astronomy), contained an article by Abdul Rahman Kelantan bin Muhamad al-Battul which was dated 1826. In our view, this may be the oldest extant treatise on astronomy ever found in the Malay language.

An arithmetic text written by Abd Qadir ibn 'Ali al-Sakhawi, known as *Matn al-Sakhawiyah* (The Shortened Version of Sakhawi), was rewritten by Sheikh Wan Ahmad bin Muhammad Zain of Patani with some significant commentaries and footnotes towards the end of the nineteenth century. This book was a standard text in arithmetic and algebra among new students in Islamic schools. The commentator mentioned the book by Ibn al-Ha'im as one of the references in his commentary.

The philosophy of learning mathematics in the Malay Islamic world is closely linked to the concept of the relationship between Allah, The Supreme Being and man, his servant. A Muslim is always conscious of this relationship and of the fact that whatever he has at his disposal must be

directed to the expression of his enslavement to Allah. Hence in the pursuit of knowledge he is always aware of his role and the roles of knowledge in glorifying the Supreme Being and the confines of his activities in this pursuit. Islam places high priority on the importance of learning. It is a religion whose understanding relies greatly on the grasp and the depth of one's knowledge of the physical and nonphysical world. Hence the learning of mathematics became necessary in a Muslim's life, as this subject is a tool in enhancing one's understanding of the world. If one is aware that the world is a creation of Allah, one's understanding of the greatness and infinite wisdom of Allah will be further heightened by grasping the mathematics principles that describe Allah's creations. Also the knowledge he has mastered will make him better able to contribute to the development of his society, which is also consonant with the teachings of the religion. Hence the positions of scholars and intellectuals rank high in an Islamic environment.

Among the daily activities in a Muslim society is the conducting of business transactions. Bartering, weighing, and using other means were characteristic activities in Muslim markets. All of these are closely connected to the ability to compute based on agreed principles. In his book '*Alam al-ḥussāb*, al-Khatib gave examples of the units of measures which were in use during that time. These include *sen*, *ringgit*, and *rupiah* as currency units, *pikul*, *kati*, *saga*, *kundi*, and *bungkal* as weights measures, *hasta* and *depa* for length units and *cupak*, and *gantang* for volume. Further discussions on the topic of measures according to al-Khatib can be found in his book in Arabic entitled *Sulh al-Jama'atain* (Conciliation of the Two Parties). Quizzes were also included in al-Khatib's books. They ranged from topics on multiplication and division to determinations of square roots based on real life problems. Among the topics covered in this book are *permulaan ḥisāb* (elementary arithmetic), *haqiqah bilangan* (on counting principles), *hitungan sahih* (on the integers), *kumpulan* (addition), *kurangan* (subtraction), *pukulan* (multiplication), *jenis-jenis pukulan* (types of multiplication), *bahagian* (division), *nisbah a-*

muttaṣilah ḥisābiyah (arithmetic progression), *al-muttaṣilah handasiyah* (geometric progression), *kaifiat mengetahui yang majhul* (systems of equations), *tabādul* (permutations), *kaifiat bilangan kali-kali mungkin* (combinations), *amal dua yang tersalah* (approximations method; golden rule), *al-jabr wa al-muqabbalah* or *amal dengan bertemper dan berkebetulan* (the term in Malay for the algebra of ► [al-Khwārizmī](#) and solutions to quadratic equations), *misāḥah* (plane geometry), and *al-mizan* (modular congruence). Most of the topics covered by this book are taught in modern day Malaysia. An interesting feature of this book, which was also admitted by the author, was the striking similarity between its content and that of the book *Khulāṣah al-ḥisāb* written by al-‘Amili (seventeenth century) which was one of the many links in the chain of Islamic mathematical tradition which had begun from the time of al-Khwārizmī. Al-Khatib’s approach in the teaching of mathematics was almost exclusively influenced by the traditional methods of teaching from the scholars of the early Muslim period which clung to the descriptive way of solving problems. Although symbolism was already introduced in the Islamic world as early as at the time of al-Khwārizmī and further popularized by Abu Kamil, al-Maghribi and later by al-Qalsaldi in Spain (fifteenth century) Malay Muslim mathematicians were not responsive to the idea of adopting the symbolism approach (Ismail, 2004). Descriptive representation of mathematical problems is the special feature of the curriculum in mathematics education outlined above, as demonstrated by the content of the book ‘*Alam al-ḥussāb fi ‘Ilm al-nisāb*’ by al-Khatib, a representative of works written in the Malay language in the nineteenth century.

The motivating factors in the teaching of mathematics in the Islamic system of education in the Malay archipelago are tied to the need to comprehend the basic teachings of the religion and efficient implementation of the administrative procedures as outlined by regulations stipulated by Islamic jurisprudence (*fiqh*) that governs everyday activities in the life of a Muslim. This was the dominant factor in the determination of mathematics education in the Islamic school

curriculum prior to the introduction of the secular school system brought by the British in the late nineteenth century.

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Algebra, Surveyors'

Jens Høyrup

Around 1930, a mathematical technique very close to later second-degree algebra was discovered in Babylonian cuneiform tablets, most of them dating from the early second and a few from the late first millennium B.C.E. (the “Old Babylonian” and “Seleucid” periods, respectively). Although the texts did not say so in any way, it was supposed that the technique was purely arithmetical, and that its “lengths,” “widths,” and “areas” were metaphors designating numerical unknowns and their products. The geometry of Euclid’s *Elements* II was then believed to represent a Greek geometrical reinterpretation of the arithmetical results of the Babylonians, necessitated by the discovery of irrationality.

A more sophisticated analysis of the Old Babylonian texts shows that the arithmetical interpretation does not hold water. For instance, the

texts distinguish sharply between two different concepts that had been understood as one and the same “addition”; two different “subtractions”; two different “halves”; and no less than four different “multiplications.” Instead, a nonmetaphorical interpretation as “naïve cut-and-paste geometry” imposes itself. A problem where the sum of the area and the side of a square is said to be $3/4$ is solved as in the illustration given later: The square itself represents the area. From one of its sides a “projection” 1 is drawn, which together with the unknown side contains a rectangle with an area equal to the side – the total area of the square itself and this rectangle is thus $3/4$. This projection is bisected, and the outer half is moved so that the two halves together contain a square of area equal to

$$\frac{1}{2}, \frac{1}{2} = \frac{1}{4}.$$

This small square completes the gnomon into which the original area $3/4$ is transformed as a larger square of area

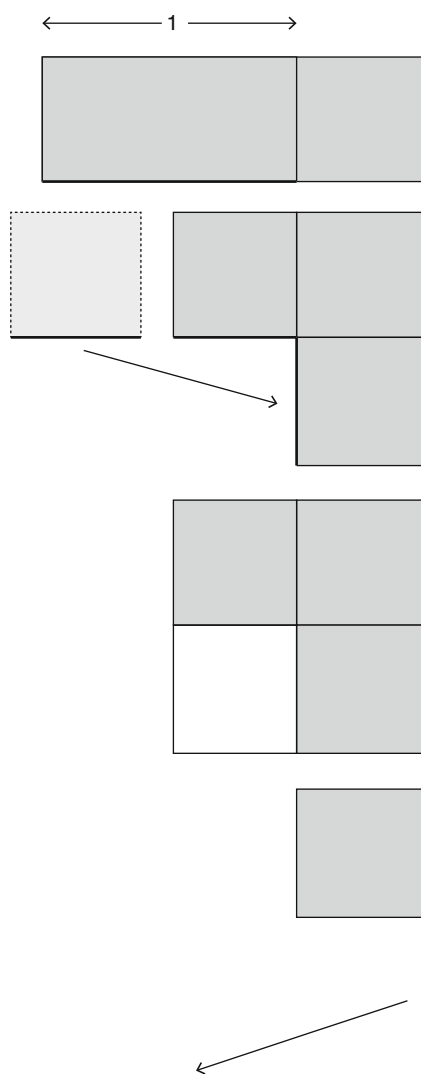
$$\frac{3}{4} + \frac{1}{4} = 1.$$

The side of this completed square will then be $\sqrt{1} = 1$ “Tearing out” that rectangular length $1/2$, which was moved around leaves

$$1 - \frac{1}{2} = \frac{1}{2}$$

for the side.

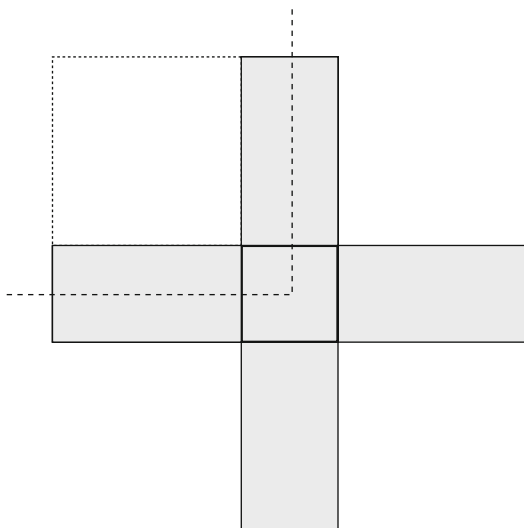
With this technique, the Babylonian scribe school teachers solved problems of much higher complexity than the present one – in non-normalized problems (e.g., if $2/3$ of the area plus $1/3$ of the side equals $1/3$) a change of scale is introduced, but apart from that everything goes by cutting and pasting – the approach is always “naïve” (as opposed to “critical”) in the sense that everything can be *seen* immediately to be true. No explicit argument proves that, for example, the two halves of the bisected rectangle really contain a square when arranged as in Fig. 1.



Algebra, Surveyors', Fig. 1 The sum of the area and the side of a square equals $3/4$

A few texts, apart from using the terms for “lengths,” “widths,” and “areas” of fields, hint in other ways at surveying practice. An important example is this problem: “Concerning a field: I have added the four fronts (sides) and the field (the area).” The formulation is unique in mentioning the sides before the area, and so is the solution, which refers to a configuration where a rectangle with length 1 is glued to each side of the field (Fig. 2).

Certain treatises from the Islamic Middle Ages reveal a close connection to this



Algebra, Surveyors', Fig. 2 The four fronts and the area. The dotted lines show the solution: one-fourth of the total area is taken and completed as a square

cut-and-paste tradition. The best known is al-Khwārizmī's *Algebra* (*Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa'l muqābalah* – The Book of Summary Concerning Calculating, restoration, and Equation) from the early ninth century A.D. The algebraic technique itself is arithmetical and at most obliquely if at all connected to the Babylonian tradition. However, in order to prove the correctness of his algorithms – first the one for “square and ten roots equal 39” – ► [al-Khwārizmī](#) makes use precisely of the diagrams of the figures shown, the second with completion in all four corners instead of quadrisection.

Less widely discussed is a *Book on Mensuration*, written by an otherwise unidentified Abū Bakr. The text is known from a meticulous Latin translation made in the twelfth century by Gerard of Cremona, and contains in its first half a large number of problems similar to those known from the Babylonian texts, both in mathematical substance and method and in the very characteristic grammatical format. However, the differences that are also present and systematic reveal that the Babylonian scribe school “algebra” is not the source. Instead, both the scribe school and Abū Bakr appear to have

drawn on a surveyors' tradition, which had been present at least in Central Iraq, and probably in a wider region, from the early second millennium B.C.E. onward.

This tradition nurtured and transmitted a stock of recreational problems with appurtenant techniques for their solution. Those that can be determined with some certainty were of the same quasialgebraic nature as the Babylonian problems cited earlier.

If we designate by Q a square area and by s its side, by A a rectangular area and by l , w , and d its sides and the diagonal, we may be fairly sure (from what is common to the scribe school and Abū Bakr together with other medieval sources) that the following problems were present (Greek letters stand for given numbers, which cannot be safely determined because the Babylonian and the Medieval tradition give different values – question marks indicate doubtful presence):

$$\begin{aligned} s + Q &= 110; \quad Q - s = 90, \\ 4s - Q &= \alpha(?); \quad A + (l \pm w) = \alpha, \quad l \pm w = \beta, \\ 4s + Q &= 140; \quad Q - 4s = 60(?), \\ A &= \alpha, l \pm w = \beta; \quad A = \alpha, d = \beta. \end{aligned}$$

For two squares Q_1 and Q_2 , one of which was probably thought of as located concentrically within the other, the four problems $Q_1 + Q_2 = \alpha$, $s_1 \pm s_2 = \beta$ and $Q_1 - Q_2 = \alpha$, $s_1 \pm s_2 = \beta$ were dealt with. All problems are of the second degree (although $Q_1 - Q_2 = \alpha$, $s_1 \pm s_2 = \beta$ reduce trivially to the first degree, since $Q_1 - Q_2$ is easily seen in a diagram to equal $[s_1 + s_2] \times [s_1 - s_2]$).

Since Abū Bakr's treatise contains the problem $d - s = 4$, we may guess that the subscientific tradition solved this problem by equating the diagonal of the 10×10 square with 14. Abū Bakr gives the exact solution $s = 4 + \sqrt{32}$ whereas the Babylonians (who always worked backward from known solutions in their “algebra”) eliminated this “unscientific” problem in the same process as they transformed the restricted stock of surveyors' riddles into a genuine, systematic discipline and into something that can legitimately be regarded as an *algebra*.

The Seleucid cuneiform “algebra” texts have traditionally been understood as faithful continuations of the Old Babylonian tradition. Close scrutiny of the texts shows even this to be a half truth. Indeed, the Old Babylonian mathematical tradition lost its higher, algebraic level when the scribe school system collapsed around 1600 B.C.E., and only the directly applicable level survived in an environment whose professional pride was based on other aspects of its practice. The surveyors’ tradition, however, survived, and appears to have supplied the material for an algebraic revival in the later first millennium at the level of scholar scribes. In the meantime, the surveyors had developed more sophisticated methods – e.g., calculating the heights of triangles and using this for area determination instead of restricting themselves to practically right triangles laid out in the terrain. The most important Seleucid algebraic text also reads as a catalog of new problems and methods for the treatment of rectangles, some of them quite refined (e.g., determining the sides from $l + d$ and $w + d$ or from A and $l + w + d$).

The surveyors’ tradition influenced not only Late Babylonian scribal mathematics and Medieval Islamic mensuration but also ancient Greek geometry and arithmetic. What is reflected in *Elements* II is, indeed, not Babylonian “algebra” in general but very precisely *that part of Old Babylonian algebra which it shared with the surveyors’ tradition* – whence one may conclude that the real inspiration was *not* Old Babylonian scribal mathematics – long since forgotten – but the still living stock of surveyors’ riddles. Proposition 1, it turns out, justifies the geometrical addition of rectangles which have one side in common, whereas propositions 2 and 3 concern the special cases where sides are subtracted from or added to square areas. Propositions 4 and 7 are used, e.g., in two different but equivalent solutions to the problem of finding the sides of a rectangle from the area and the diagonal. Proposition 6 explains the solution of all problems $Q \pm \alpha s = \beta$ (including “the four sides and the area”) and $A = \alpha, l - w = \beta$, while proposition 5 has a similar relation to rectangular problems

$A = \alpha, l + w = \beta$ and to $\alpha s - Q = \beta$. Proposition 8, which is used nowhere else in the *Elements*, is associated with the concentric inscription of one square into another, and propositions 9 and 10 are connected to the solution of the problems $Q_1 + Q_2 = \alpha, s_1 \pm s_2 = \beta$.

What the Greek text does is not merely repeat the traditional solutions – in fact, it presents us with theorems, not with problems to be solved. But the theorems are *critiques* of the traditional “naïve” procedures, showing that what is immediately “seen” is indeed correct and can be proved within the axiomatic framework. The proofs fall into two parts, the first of which establishes the equality of areas and that the quadrangles which are believed to be squares are indeed so. Then on firm ground, the second part goes through the traditional cut-and-paste procedure.

Propositions 11–13 are connected to matters found in Abū Bakr’s treatise, and the textual evidence suggests that at least propositions 12 and 13 (the generalized Pythagorean theorem) were originally developed independently of the Greek theoreticians, as part of the “new” stage of the surveyors’ geometry. Propositions 1–10, on the other hand, are completely untouched by the innovations. This critique thus seems to go back to a moment when the “new” development had not yet taken place, or not yet reached the ears of Greek geometers (we may point to the late fifth century B.C.E., the epoch of Hippocrates of Chios and of Theodoros).

Book I of Diophantos’ *Arithmetic*, which also contains undressed versions of favorite arithmetical recreational problems, embraces a few problems of the second degree – as it turns out, arithmeticized versions of $A = \alpha, l \pm w = \beta$ and $Q_1 + Q_2 = \alpha s_1 \pm s_2 = \beta$ (all four belonging to the original surveyors’ stock). As can be seen from certain passages in Plato, Diophantos’ work builds at least in its terminology upon a tradition reaching back to Greek calculators of the fifth century B.C.E. or earlier. The present simple problems can be assumed to belong to the early ingredients of this tradition, which then agrees with the chronological conclusions that could be drawn from *Elements* II.

A single Greco-Egyptian papyrus (probably second century A.D.) shows that the “new” diagonal-centered group of surveyors’ problems circulated among the mathematical practitioners of the Greco-Roman orbit at this later moment, without being adopted into the corpus of scientific mathematics. In China, on the other hand, they appear to turn up in the *Jiuzhang suanshu* (Nine Chapters on Arithmetic) (one of them in a dress which with high probability points back to Babylonia and thus shows the Chinese problems to be borrowed). In the later Chinese tradition, however, this interest disappears again.

“Naïve” geometry is also to be found in the Indian *Śulbasūtra* geometry (mid-first millennium B.C.E.), and a few commentaries to later Indian algebraic works might suggest a fundament in something similar to our surveyors’ tradition. The evidence, however, is too shaky to allow any conclusion, except in the case of the ninth century Jaina mathematician ► [Mahāvīra](#), whose *Gaṇita-sāra-saṅgraha* contains indubitable borrowings from it, and even treats material stemming from the Bronze Age phase, the preseleucid Late Babylonian phase and the Seleucid phase in separate sections of its geometry chapter. Apart from that and from its role for the emergence of Babylonian “algebra” and for that of Greek metric geometry as found in *Elements* II, the only literate mathematical culture where the anonymous surveyors gained real influence is thus that of medieval Islam. Its reflection in al-Khwārizmī was already mentioned, to which it may be added that al-Khwārizmī’s borrowed geometric proofs were taken over by numerous algebraic authors until the mid-sixteenth century – one step in Cardano’s solution of the third-degree equation makes use of a three-dimensional generalization of this diagram, another of the solution of the rectangle problem $A = \alpha, l + w = \beta$. Within the mensuration tradition, the twelfth-century ► [Abraham bar ḥiyya](#) ([Savasorda](#)) betrays familiarity with the surveyors’ quasialgebraic riddles, in a version which shows him to be independent of Abū Bakr); so does Jean de Murs’ fourteenth century *De arte mensurandi*.

As the technique was taken over by scientific mathematicians, the reason to uphold a distinct naïve-geometric tradition disappeared. Abū Bakr had already solved many of the problems in two ways, first by naïve geometry and then by *al-jabr* – the originally subscientific discipline committed to writing and made famous by al-Khwārizmī. Abraham bar ḥiyya, for his part, refers to *Elements* II in his solutions. Nonetheless, the riddles themselves continued to be attractive. They are important in Leonardo Fibonacci’s *Pratica geometrie* (1220), which draws on Abraham bar ḥiyya, on Gerard of Cremona’s translation of Abū Bakr, and on at least one other work belonging to the tradition. And they turn up again in Luca Pacioli’s *Summa de arithmetica geometria Proportioni: et proportionalita* (1494), which still asks for the side when “the four sides and the area” equals 140, with the same anomalous order of the members as in the Bronze Age. The last shimmering of the tradition is in Pedro Nunez’ *Libro de Algebra en Arithmetica y Geometria* (1567), after which every trace disappears, together with the knowledge that such a tradition had ever existed.

From the beginning some 4,000 years ago, the surveyors’ riddles were algebraic in the sense that the solutions follow steps that correspond to those of a modern solution by means of symbolic algebra. They were also algebraic in the sense that their method was *analytic*: the unknown side of the square is treated as if it were known, and submitted to such operations that at the end it is isolated and thus known – precisely as a modern x .

However, the surveyors’ technique lacked two essential characteristics of modern equation-algebra (characteristics which, by the way, modern equation-algebra shares with the Old Babylonian scribe school “algebra”). First, it was no general method for finding unknown quantities; the measurable lines and areas which it manipulated were never used as representatives of something else. It was, and remained until it was taken over and reshaped by the written traditions, a collection of sophisticated riddles with no practical purpose beyond itself. Second,

it always dealt with the entities which are naturally present in the geometrical configurations of which it spoke: *the area, the side or the four sides*, etc. It is never, as we may find it even in those of the Old Babylonian scribal texts which otherwise come closest to the background tradition, “one half of the length and one third of the width” of a rectangle. This is also the reason that its problems are – with one very late and thus dubious exception – always normalized, and a supplementary reason that it did not develop into an all-purpose algebra. We may therefore, legitimately, speak of a surveyors’ “algebra” – but not of a surveyors’ algebra without quotes.

See Also

- ▶ Abraham Bar Ḥiyya (Savasorda)
- ▶ Al-Khwārizmī
- ▶ Mathematics
- ▶ Mathematics Practical and Recreational
- ▶ Surveying

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Al-Ḥajjāj

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Al-Ḥajjāj ibn Yūsuf ibn Maṭar was one of the earliest translators of Greek mathematical and astronomical texts into Arabic. Few details of his life are known. According to a report of the biobibliographer Ibn al-Nadīm, he prepared an Arabic version of Euclid’s *Elements* under the sponsorship of the ‘Abbāsīd caliph, Hārūn al-Rashīd (170–193 AH/AD 786–809). Later, under caliph al-Ma’mūn (198–218 AH/AD 813–833), he prepared a second (and improved) version version (Brentjes, 1994). There are some hints that the mathematician Thābit ibn Qurra (died 288 AH/AD 901) may have helped to revise the latter version.

Neither version is extant (De Young, 1991, 2002–2003, 2005; Lévy, 2005). Quotations from what purports to be the second version serve as the basis for a commentary by al-Nayrīzī (d. early fifth century AH/AD tenth century). These quotations seem, however, to have been edited by the commentator on the basis of the later translation of Ishāq ibn Ḥunayn (215–298 AH/AD 830–910). There appear to be other traces of the transmission of al-Ḥajjāj in commentaries by Aḥmed al-Karābīsī and in the epitome of the Euclidean *Elements* in Ibn Sīnā’s *Kitāb al-Shifā’* (The Cure [of Ignorance]). Probably this transmission tradition also served as the basis for the Latin translation of Adelard of Bath and the nearly contemporaneous Latin version of Hermann of Carinthia (Brentjes, 2000).

Al-Ḥajjāj is also credited with production of an Arabic version of Ptolemy’s *Almagest*, perhaps by way of a Syriac intermediary. The relation of this transmission to that of Ishāq ibn Ḥunayn has not yet been fully established (Kunizsch, 1974). In this case, both traditions are extant, allowing a more careful scrutiny of philological characteristics and translation techniques. Attempts to apply what we learn from a study of the *Almagest* transmissions to Euclid remain incomplete.

See Also

- *Almagest: Its Reception and Transmission in the Islamic World*
- *Al-Ma'mūn*
- *Al-Nayrīzī*
- *Thābit Ibn Qurra*

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Al-Hamdānī

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Abū Muḥammad al-ḥasan ibn Aḥmad ibn Ya'qūb al-Hamdānī, with the honorific name Lisān al-Yaman ("The Tongue, i.e., the Mouthpiece of the Yaman"), was born into a turbulent time in a turbulent world and was not called to make his time and world less turbulent. He did create not only turbulence, but also a scholarly monument which has remained the pride of his Yamanite compatriots and an enduring contribution to the culture of mankind.

Background and Life

When al-Hamdānī was born, in Ṣan'ā', perhaps on ṣafar 19th, 280 AH (May 10th, 893 AD), the Muslim expansion had created a wide common market and an equally wide uncommonly cultured world, both without frontiers. The common market and the peace of the caliphate had given rise to huge fortunes which had financed numerous cultural and scholarly activities inspired by the new religion Islam, carried by its versatile language, Arabic, on a foundation laid by Hellenistic culture. Members of different religions, Muslims, Christians, and Jews, with different languages, Arabic, Greek, Aramaic and Persian, had collaborated in transforming the Hellenistic heritage into the Islamic culture of Arabic language. It was possible to travel in search of profit, *faḍl* Allāh, or of knowledge, from the River Indus in the East to Spain in the West without being hindered by frontiers, customs, wars, language difficulties, or different currencies.

Knowledge and profit supported each other. New technology, new industries, new goods and new money were spread; palaces, universities and schools were built. Gardens were made for the study of plants; books were written and manuscripts were collected, copied and translated and libraries founded. Scholars and artists met in the

houses of patrons, and in spite of intense discussions there reigned a liberal atmosphere. Never in the Middle Ages had there been such a width and liberty in research and teaching.

Nevertheless, there were sectarian conflicts, e.g. with the Khārijites and Shī'ites, which had dynastic and political aspects, and there were nationalistic conflicts, e.g. with the Shu'ūbiya, a movement of mainly Persians who opposed Arab supremacy. There were nationalistic conflicts also among the Arabs themselves when South and North Arabians brought their rivalry as far as Spain. And there were local conflicts where the control of the central power was weak, as in the Yaman, so that local chiefs were able to oust the representative of the caliph. Al-Hamdānī was one of the most energetic champions of South Arabian nationalism, and yet his nationalism prompted him to scholarly and literary works of high value while it also rendered him open to persecution and maybe, as has been said, brought him a premature death in prison.

As his name shows, al-Hamdānī was a descendant of the powerful tribe Hamdān which had already played an important role in the Yaman to the north of Ṣan'ā' in pre-Islamic time. He was born in Ṣan'ā', in the neighbourhood in which his family had lived for four generations. He was surnamed Ibn al-ḥā'ik, after an ancestor who was a famous poet, and al-Hamdānī was to take up this family tradition.

A few decades before al-Hamdānī's birth the head of a local dynasty from Shibām, Yu'fir b. 'Abdarraḥmān al-ḥiwālī, defeated the governor of the 'Abbāsid caliphate and later transferred his power to his son Muḥammad who in his turn relinquished it to his son Ibrāhīm. When al-Hamdānī was born, Yu'fir had recently ordered his grandson Ibrāhīm to murder his father which led to a revolution and the destruction of the silver mine in al-Jawf. In this revolution Ibrāhīm's house was plundered and he himself murdered, and the 'Abbāsid governor reinstated the power of the caliph. But when al-Hamdānī was a small child the governor was called back to Baghdad and his Turkish soldiers were left to ravage Ṣan'ā'. The first Zaydī *imām*, al-Hādī ilā l-ḥaqq, was called in to restore order. The

following years witnessed repeated battles between al-Hādī and the Yu'firids. When a Fāṭimid *dā'i* entered the scene, however, the Yu'firids under As'ad b. Ibrāhīm and al-Hādī became allied.

These events did not leave al-Hamdānī unaffected: his own tribe Bakīl of Hamdān won a victory over the Fāṭimid army, and he was imprisoned by As'ad's nephew, because he was opposed to the foreign element among the followers of the Yu'firid's ally. Al-Hamdānī's satirical verses gave rise to a revolt against al-Hādī's son an-Nāṣir, which culminated in the battle of Katafā and the death of an-Nāṣir and his brother ḥasan. Al-Hamdānī escaped from prison to Hamdān's *sayyid* in Rayda and praised the leaders of the revolt in poems. It is thus doubtful that he died in prison in Ṣan'ā' in 334/946 as had been said by ṣā'id b. ṣā'id al-Andalusī on the authority of the Andalusian caliph al-Mustanṣir; others maintain that he did not die until about 350.

The Geographer

As a scholar, al-Hamdānī had an excellent education and did much travelling. One result of his travels is his geography of Arabia, particularly South Arabia, *Ṣifat jazīrat al-'arab*, the only systematic monograph of the Arabian Peninsula from the Middle Ages, which has been preserved in its entirety.

The first part of the work is a general geographical-astronomical introduction which follows Ptolemy. In this introduction al-Hamdānī showed his knowledge of Greek learning (he also quoted Hermes Trismegistos and Dioscorides). He was also familiar with the Indian astronomical work *Sindhind* and its Arabian translator al-Fazārī, as well as Ṣan'ā's own astronomers.

The next part is a work on the physical, political and economical geography of the Arabian Peninsula. Starting with the Yaman, al-Hamdānī describes the different parts of Arabia with their mountains, valleys and wādīs, their vegetation and animal life, their tribes, habitations, villages, towns and castles, the number of inhabitants, the

ownership and cultivation and irrigation of land, the pilgrim's roads and the dominions of sultans and governors. One of the themes is meteorology, as has repeatedly been observed, a theme that recurs in al-Hamdānī's medical work *Kitāb al-Quwā* (see below), as he mentions himself in his *Kitāb al-Jawharatayn* (see below).

The geographical description is interspersed with historical, genealogical, ethnographical and psychological notes, and he quotes Islamic and pre-Islamic poetry. In one of the concluding chapters, Hamdānī deals with weather conditions, food, prices, domestic animals and deposits of precious stones.

The Poet

Also as a poet and a collector of poetry al-Hamdānī shows his national and political fervour. His *Qaṣīda aḍ-ḍāmigha fī faḍl al-Qaḥṭān* is an answer to Kumayt b. Zayd al-Asadī's satirical attack on the South Arabian tribes 200 years earlier. To this poem – of its 590 verses rhyming *in-i/una* 476 are preserved – al-Hamdānī is said to have written a detailed commentary in a big volume. Another poem, *Qaṣīdat al-Jār*, deals with politics contemporary with the author, blaming the Yu 'firid ruler for having put him in prison. *Al-Iklīl* also contains many specimens of South Arabic poetry, including al-Hamdānī's own. His *Diwān*, with the commentary of Ibn Khālawayh, is said to have comprised six volumes, but has not come down to us.

The Philologist

As a philologist, al-Hamdānī is interested in words for things, e.g., in his *ṣifa* it is the names of the flowers rather than the flowers themselves which are the object of his interest. In his *K. al-Jawharatayn* he discusses different words for gold and silver and for gold and silver coins and their sides and parts with their etymologies. In this context he explains the South Arabian mīmation and the formation of words of four radicals with *-m* as the fourth radical as

originating in the *mā l-ibhāmīya*. In his *ṣifa* he treats the spoken language of 113 different parts of the Arab peninsula and whether their language is correct or not or even ununderstandable. The best Arabic is spoken by, i.a., the Hamdān and by the nomads in the ḥijāz and Najd as far as Syria, whereas in 'Adan the common people not only speak bad but are even stupid, and the Mahra are as foreigners, impossible to understand (actually, the South Arabic Mahrī dialect is also today not understood by those speaking a North Arabic dialect). Al-Hamdānī also illustrates his verdicts by examples, e.g. when he says that the Sarw ḥimyar say *ya bna m-* 'amm instead of *ya bna l-'amm* and *sima* instead of *isma* – also other tribes have a definite article with *-m* instead of *-l*. Some tribes are said to speak ḥimyarite. Al-Hamdānī gives in *al-Iklīl* some further examples to illustrate the ḥimyarite language and even some text samples.

Quotations from book 9 of *al-Iklīl* in a later work (the commentary on Nashwān's ḥimyaritic *qaṣīda*) show that al-Hamdānī had a certain knowledge of the South Arabic script, which he reproduces in a table in book 8 with the (North) Arabic equivalents, but that he did not understand the inscriptions.

Al-Hamdānī's own language, by the way, does not seem quite to have followed the rules of the classical grammar. Al-Qifṭī tells us that *lamma dakhala l-ḥusayn b. Khālawayh al-Hamadhānī an-Naḥwī ilā l-Yaman wa'-aqāma bi-hā bi-Dhamār, jama'a diwān shi 'rihi* (ya 'ni shi 'r al-Hamdānī) *wa- 'arrabahu wa-a 'rabahu* ("When ḥ. b. Kh. al-H. the Grammarian came to Dh., he collected his (sc. al-Hamdānī's) poetry and made it into correct and clear Arabic"). And at least his *Kitāb al-Jawharatayn* shows in fact deviations from the classical norm and traces of the author's spoken language.

The Faqīh

Al-Hamdānī was also interested in law. In a work that has not been preserved but has been mentioned by al-Qifṭī, *Kitāb al-Ya 'sūb*, he is said to have written about the legal rules concerning

hunting. The legal chapter in the *Kitāb al-Jawharatayn* has been omitted in the manuscript with the exception of the title, *bāb hukūmat al-‘iyār wa-fiqhihi wa-mā’ashbahahu*. Only short comments on gold and silver in the Hadith, on the prohibition of interest and of two purchases in one or the selling of gold for gold and silver for silver, and on the question of whether it is allowed to change God’s creation are found in other chapters of the *Kitāb al-Jawharatayn*. The idea that gold as God’s creation should be worked as it is without being refined is refuted by al-Hamdānī who compares it with wheat and sugar-cane which are also of God’s creation but are worked and used in different ways.

The Historian

Al-Hamdānī’s geography is supplemented by his historical work, *al-Iklīl*. This work was written in 332/944 while its author was living as the guest of Sayyid Hamdān, Abū Ja’far ad-Dahhāk, in the castle of Tayfum in Rayda. It consisted of ten books: books 1, 2 and 10 deal with the beginning of genealogy and present genealogies of South Arabian tribes, and book 8 describes the old castles of pre-Islamic South Arabia. These books are extant today. Of those not preserved, book 3 is said to deal with the merits of the South Arabian tribes, books 4–6 with the history of South Arabia before Islam, book 7 contained a critique of false traditions, and book 9 South Arabian inscriptions. Al-Hamdānī’s sources were Abū Naṣr Muḥammad b. ‘Abdallāh b. Sa’īd al-Yaharī al-ḥanbaṣī, the learned lord of the castle ḥanbaṣ, the archives (*siḥill*) of the Banū Khawlān in ṣa’dā and oral popular tradition and written information from different sides, e.g. from the legendary ‘Ubayd b. Sharya al-Jurhumī, the collector of legends Wahb b. Munabbih and the famous genealogist Hishām b. Muḥammad al-Kalbī. *Al-Iklīl* (The Crown) is quoted in al-Bakrī’s *Mu’jam maṣṭa’jam*. Another historical work of al-Hamdānī, *Kitāb al-Ayyām*, to which he refers in his *ṣifa*, has not been recovered. That so many of al-Hamdānī’s historical writings were lost is, according to al-Qifṭī, because members of tribes

not favourably mentioned had destroyed all the copies they could find.

The Philosopher

The two works, *Ṣifat Jazīrat al-‘Arab* and *al-Iklīl* have made al-Hamdānī known as a geographer and a historian. But that he was also said to be one of only two famous Arab philosophers – the other was ► [al-Kindī](#) – is difficult to understand. Al-Kindī is well known as a famous philosopher, but why al-Hamdānī? After two other works by al-Hamdānī have become known, however, it is easier to understand the appreciation of the philosopher al-Hamdānī. As a philosopher, al-Hamdānī was interested, in his book on gold and silver, *Kitāb al-Jawharatayn al-‘atīqatayn* (see below), in the generation and corruption of matter, in the transmutation of one element into another and in the influence of the heavenly bodies upon the earth. He was a follower of the Greek philosophers, and he quotes the works of Aristotle concerning the generation of heat. But in his astronomical work *Sarā’ir al-ḥikma* (see below) he opposes Aristotle, maintaining that each part of the celestial sphere is connected with a corresponding part of the earth.

The celestial sphere is divided according to the signs of the Zodiac, and this division also governs that of the seasons. In his *Kitāb al-Jawharatayn* al-Hamdānī gives a survey of the seasons with the qualities (warm, cold, dry and moist), elements (fire, water, earth and air) and cardinal humours (blood, phlegm, black and yellow bile) belonging to each season, and he also tells us which substances are related to which planet or sign of the Zodiac: lead, e.g. belongs to Saturn and to Capricorn. The influence of the planets on their substances varies according to their positions and the season of the year. The influence occurs also according to similarity: fire can influence only what already contains fire.

When al-Hamdānī compares the earth as round and globular and situated in the middle of the likewise round and globular sphere with the centre in the circle, he is repeating a comparison already to be found in a quotation by Archimedes

from Aristarchos. Also in his historical work, ancient conceptions of the world as being eternal or created are said to be discussed. Some influence from the theory of atoms seems to be found in expressions such as *ijtimāʿ* for having a three-dimensional body, properly signifying the fusion of atoms into a body, and the repeated use of the word *ajzāʿ*, particles, atoms.

The Aristotelian theory of the generation of substances from the four elements under the influence of the heavenly bodies forms the basis of alchemy. The theory is that the different matters consist of a mixture of the four elements. According to their purity and proportions and the influence of the planets the metals arise in the earth. Of the metals, gold is the most pure, containing the elements in ideal proportions. Thus it ought to be possible to imitate the processes of nature by artificial means, removing the impurities and restoring the ideal proportions and thereby to obtain gold.

The alchemists used sulphur, being hot and dry, and mercury, being cold and moist, as representing the elements. It appeared, however, that no mixing of sulphur and mercury results in gold. The alchemists then presumed ideal forms of sulphur and mercury, not existing in the natural world. In order to accelerate the transformation which happens very slowly in nature, they used an elixir, having the same effect as yeast, and to produce this elixir the alchemists used a lot of methods, such as distillation and sublimation, boiling and calcination, amalgamation, etc. by means of crucibles, retorts and distilling-apparatuses, thus laying the foundations of chemistry. Later alchemists made this procedure into a ritual with an allegorical meaning, and a secret art.

The Muslim scholars had different opinions about alchemy. The great physician ► [al-Rāzī](#) (d. 313 or 323 H) tried to transmute metals, and he classified the matters he used according to their natures and properties. The great scientists ► [al-Bīrūnī](#) and Ibn Sīna (both fifth century H) believed in the generation of matter and in the sulphur-mercury theory, but they were opposed to alchemy because they were of the opinion that art was not able to imitate nature.

The Astronomer

In Greek and Islamic tradition you cannot separate the philosopher, the scientist and the doctor, and the views which I have mentioned are closely related to astronomy and astrology, chemistry and medicine, subjects on which al-Hamdānī was also productive.

Al-Hamdānī is also said to have compiled astronomical tables, *az-Zīj* – he mentions *Tanbīh az-Zīj* – and a book on horoscopes and the projection of rays (*Kitāb at-tālīʿ wal-maʿāriʿ*). In a medicinal work, *al-Quwā*, which is lost, he showed the influence of the planets upon the temperature of the earth. It is also said that pieces on astronomy and physics are scattered through his historical work.

Of his astronomical work, *Sarāʿ ir al-ḥikma fi ʿilm an-nujūm*, al-Qifṭī says, quoting ṣāʿid al-Andalusī, that its aim is *at-taʾrīf bi-jumal hayʾat al-aflāk wa-maqādīr ḥarakāt al-kawākib watabyīn ʿilm aḥkām an-nujūm wa-stifaʾ ḍurūbihi* “the definition of the total form of the celestial bodies, the extent of the movements of the stars, the exposition of astronomy, and the exhaustive treatment of its kinds”. It is also quoted by Abū Marwān al-Istijī, according to ṣāʿid one of the best astrologers in al-Andalus. However, only the tenth chapter of this work has been recovered in two manuscripts in al-Yaman. In this work several Greek scholars are cited – Dorotheos of Sidon, Ptolemy, Valens, Hipparchos and the mythical Hermes Trismegistos – as also the Indian astronomical work *Sindhind* as well as its Arabic translator al-Fazārī and Persian astronomical works but also Islamic scholars, such as Māshāʿallāh, Abū Maʿshar, Abū Muḥammad b. Nawbakht, Sulaymān b. ʿIṣma.

The Economist

We have seen that al-Hamdānī's historical and geographical works were intended to be complementary to each other. In the same way his book on gold and silver, *Kitāb al-Jawharatayn al-ʿatīqatayn min aṣ-ṣafrāʾ wal-bayḍāʾ*, belonged to a trilogy on South Arabic economy, the parts of

which were also complementary. Part 1 dealt with agriculture, part 2 with camel breeding and part 3 with gold and silver, i.e. the three kinds of property: landed property, cattle and precious metals. Only the part dealing with gold and silver has been preserved. Here gold and silver are mentioned as a form of investment, and its advantages in this respect are praised, above all that it is easy to take along.

The Metallurgist

In the *Kitāb al-Jawharatayn* the *Qurʾān* and the *Tradition* are quoted but so are popular traditions. An abundance of Persian expressions for substances and tools show that al-Hamdānī also had inherited an Iranian tradition with which he had personal contact. He says that Persian tribes, which had immigrated into al-Yaman already before Islam, were working the mines in South Arabia. They were called *furs al-maʿdīn* and enjoyed a good position and property in Ṣanʿāʾ.

Al-Hamdānī also learnt about metallurgy and minting from specialists among his compatriots. The art of forging is very old in al-Yaman. It perhaps has its origin in the connections of al-Yaman with India – the Indian steel and the Indian swords made from it are often mentioned in Arabic poetry and by al-Hamdānī. The art of forging swords and armours is traced back by tradition to the Tubbaʿ, the kings of ḥimyar, and the swords of al-Yaman are famous in Arabic poetry. Another important source of his knowledge was the master of the mints in Ṣanʿāʾ and ṣaʿda and his sons, one of whom was to succeed him in the office.

Al-Hamdānī's *Kitāb al-Jawharatayn* is the oldest and most comprehensive of the four Arabic works on gold, silver and minting known to us (the other three are *Kashf al-asrār* by Ibn Baʿra, a manual of the Egyptian mint of the seventh century H, *ad-Dawḥa al-mushtabika fī dawābiḥ dār as-sikka* by ʿAlī b. Yūsuf al-ḥakīm, a manual of the mint in Fās of the eighth century H, and a manual of the mint in Marrākush from the 990s H). It abounds in technical and chemical information which extends from the extraction of ore

from the mines to the minting of coins. It also contains valuable information about gold and silver mines in Arabia, Africa and Iran. It also mentions the use of gold and silver for gilding and silvering and for ornaments and of gold leaf for decorating pages of the *Qurʾān*. It describes glass and methods of counterfeiting. Also the use of other metals such as iron and mercury and the sickness caused by some substances and their use are dealt with. The main subject of the book is, however, the fabrication of coins.

The fabrication of coins can be divided into three stages: the fabrication of the dies, the fabrication of the flans and the stamping of the flans. According to al-Hamdānī the die was made from hardened steel, its surface filed and the inscription engraved with an iron stylus. The die was pegged and holed in order to hold its two halves in a fixed position and to achieve a fixed relationship between the coin's obverse and reverse.

The flans were made after the gold and silver had been purified. The impurities in the gold ore were separated from the gold by means of sulphur, and the gold left in the separated impurities was collected by amalgamation with mercury. Silver was also extracted by amalgamation and otherwise purified by heating while supplying air at the same time, so that the lead in the silver ore combined with the oxygen in the air and was separated as lead oxide. Al-Hamdānī describes three methods to fabricate the flans. One was lamination: the cutting of flans from moulded bars. A second method consisted of casting the flans in moulds of clay. The third method consisted of pouring molten silver or gold into water. Thus small round pieces of metal were obtained which were hammered flat and used as flans, in spite of their different size.

The Physician

Al-Qiftī calls al-Hamdānī *aṭ-ṭabīb* (physician), and one of his books, *al-Quwā*, is said to be a medical work, but we do not know its content. That al-Hamdānī was interested in medicine is, however, clear also from *Kitāb al-Jawharatayn*, which contains some medical information.

The pain of burns is mitigated by means of gold. Rash is treated with water containing gold. Chips of gold and silver are ingredients in important remedies. The oculists use dross of gold and silver. Silver slag removes the stink of the sweating of the axillae and is used in salves to close wounds. Verdigris, made from copper and wine vinegar, is used in many remedies and in colours. Antimony heals wounds and stops haemorrhage from the cerebral membranes, and mixed with fat it is used for burns. Mercury is used against colic but can also increase colic, causing constipation and death. There are also some general remarks on the influence of compound drugs on the body and the difference between medicine for internal and external application. Some of the information is borrowed from Dioscorides' *materia medica*.

Al-Hamdānī also mentions damages caused by different substances. The mercury vapour produced by gilding and amalgamating causes hemiplegia and convulsions. Since mercury is moist and cold the remedy ought to be something warm, such as wine. The fumes of lead, which evaporate when silver is purified, affect the brain, and the vapours of the substances used for purifying the gold dry out the nose and saliva, cause cutaneous fissures and affect the brain. Therefore, a wall is put between the furnace and the workers, or the workers cover their noses – early examples of safety precautions for workers. Fumes from lead and copper injure the teeth, weaken the bladder and cause a pain in the waist. The fume from the manure used when silver amalgam is heated causes headaches, and other fumes from the furnace give rise to jaundice, disturbed vision, attacks of sickness, abdominal pains, and headaches.

The Man

Intellectually, al-Hamdānī was a man of independent thought. We have seen that he did not simply reproduce the learning of others. As a geographer he relied mainly on his own observations, travelling extensively over the country he was going to describe. He had his own opinion about the

colour of the skin of the peoples in the tropical countries, which was contrary to that of Ptolemy. He had his own division of the world with more climata than the usual seven. He contrasted the opinion of the Greeks concerning the extension of the inhabited world with that of the Indians and the Chinese and exposed in detail the differences between the Greek, Indians and Arabs concerning latitude and longitude. He also contrasted two theories concerning the seasons, their qualities and the cause of these qualities.

Morally, al-Hamdānī was a man of courage and strong passions. Although a Muslim, he dared to attack the tribe of the Prophet, and his strong stand for the Yaman can also be seen in the absence of descriptions of Makka and al-Madīna from his *ṣifa*. He was not afraid of taking part in the political turmoil of his days, and prison did not frighten him and did not break him down. Nothing in his writings, however, gives the impression that he was but a pious Muslim, well versed in the *Qurʾān* and the Hadīth.

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Al-Hāshimī

F. Jamil Ragep

‘Alī ibn Sulaymān al-Hāshimī flourished some time in the second half of the ninth century, probably somewhere in the central lands of Islam. Virtually nothing is known about him other than the fact that he wrote a rather uncritical work on *zīj*es (astronomical handbooks) that nevertheless preserves a great deal of otherwise unknown or little known information. This book, *Kitāb fi ‘ilal al-zījāt* (Explanation of Zījes), was written at a time before Ptolemaic astronomy had become the dominant astronomical tradition in Eastern Islam. As such, it contains considerable material about the Indian and Persian astronomical traditions, at least insofar as they were received and preserved during this early period of Islamic science.

Hāshimī mentions some 16 *zīj*es, of which 2 are Greek (Ptolemy’s *Almagest* and Theon’s *Canon*, which is based upon it); 7 are Indian or derived mainly from Indian sources (the *Arjabhar*, the ► *Zīj al-Arkand*, the *Zīj al-Jāmi‘*, the *Zīj al-Hazūr*, the *Zīj al-Sindhind* of al-Fazārī [eighth century] as well as a second *zīj* by him, and the *Zīj* of Ya‘qub ibn ṭariq [eighth century]); 2 are Persian but mainly Indian in inspiration (the *Zīj al-Shāh* of Khuro Anūshirwān and the *Zīj al-Shāh* of Yazdigird III); and 5 are from the ninth century and use material from these three traditions in varying degrees (the *Zīj al-Sindhind* of ► *al-Khwārizmī*, the *Zīj al-Mumtaḥan* of ► *Yaḥyā ibn abī Maṣṣūr*, the first Arabic *zīj* that was principally Ptolemaic, two *zīj*es of Ḥabash, one mainly Indian, the other mainly Ptolemaic, and the *Zīj al-Hazārāt* of Abū Ma‘shar).

Besides its importance as a historical resource, Hāshimī’s work provides some valuable clues about the state of Islamic science during this early period. It is clear that the impressive number of astronomical works

floating about made a work explaining them desirable, giving evidence for the vitality of science during this period. The influx of “foreign” knowledge had its detractors, though, and Hāshimī felt compelled, in a passing comment, to affirm that the cycles of Indian astronomy were not from their prophets, whatever might be claimed; nor were they for the purpose of “soothsaying”, something he knows would be unIslamic. Rather he asserts that they are mathematically derivable and as such safe, an interesting and not atypical way of handling religious opposition to astronomy in Islam.

This makes the subsequent history of Islamic astronomy all the more remarkable. Indian astronomy with its cycles and computational tradition, but lacking a full-blown cosmology would, at first glance, seem to be a much more congenial tradition for Islam, which had its own religious cosmology and metaphysics. In fact Hāshimī implies as much in introducing the *Sindhind*; he also reports that Shāh Anūshirwān (sixth century) preferred Indian to Ptolemaic astronomy. So the subsequent predominance and triumph in Islam of Ptolemaic astronomy, based ultimately on Aristotelian physical principles and cosmology, was a remarkable occurrence indeed.

See Also

- *Abū Ma‘shar*
- *al-Khwārizmī*
- *Almagest: Its Reception and Transmission in the Islamic World*
- *Yaḥyā ibn abī Maṣṣūr*
- *Zīj*

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Al-Idrīsī

Sayyid Maqbul Ahmad

Abū ‘Abd Allāh Muḥammad ibn Muḥammad ibn ‘Abd Allāh ibn Idrīs, known as al-Sharīf al-Idrīsī, was one of the great Arab geographers of medieval Islam. He was born in Ceuta (Morocco) in AH 493/AD 1100 and died there in AH 560/AD 1166. Al-Idrīsī belonged to a ruling family, the Alavī Idrīsīs, who were claimants to the caliphate and had ruled in the region around Ceuta from AD 789 to 985. His ancestors were the nobles of Malaga, Spain who, unable to maintain their authority there, migrated to Ceuta in the eleventh century. Al-Idrīsī was educated in Cordoba and began traveling at a very early age. At the age of 16, he visited Asia Minor and then traveled in southern France, England, Spain, and Morocco.

This was a period of the growing power of the Normans in Europe and the Mediterranean region. It is said that Roger II (1097–1154), the Norman ruler, invited al-Idrīsī to come and stay with him in Palermo (Sicily), saying he would be safe from Muslim kings who were trying to murder him. Al-Idrīsī accepted the king’s invitation and went to Palermo sometime in AD 1138 and stayed there until after the death of Roger in AD 1154. Then he returned to Ceuta.

Sicily at this time was an important center, where Arab-Islamic and Western European cultures intermingled. Roger himself was very interested in the promotion of arts and sciences, and we learn from al-Idrīsī that he was also interested in geography and astronomy. Roger gave al-Idrīsī an important task, probably from political motives, which was to construct a world map. Roger was still engaged in expanding his empire in North Africa, and thought al-Idrīsī would be a suitable person for this task. Although he was well traveled in North Africa and Europe, al-Idrīsī was not a geographer in the true sense of the word at this stage. But he began constructing the map under the patronage and supervision of Roger. Finding that the courtiers

at his palace did not possess sufficient knowledge of the geography of the world, Roger sent envoys to different regions to collect fresh data. After the information was acquired, al-Idrīsī utilized only such data on which there was unanimity; the rest was discarded. He also used the Arabic geographical works which were available to him, such as the Arabic version of Claudius Ptolemy’s (ca. AD 90–186) *Geography* (Arabic *Jughrāfiya*), *Kitāb ṣūrat al-Ard* (Book on Routes and Kingdoms) by Ibn Hawqal, *Al-Masālik wa’l Mamālik* by ► [Ibn Khurdādhbih](#) (AH 232/AD 846), and the lost work of al-Jayhānī entitled *Kitāb al-Masālik wa’l Mamālik*. Thus it seems that al-Idrīsī had a vast amount of geographical material on the known world at his disposal.

He worked on the map for 15 years, basing it primarily on Ptolemy’s map, with some modifications. When it was completed, Roger asked him to have it carved on a round silver disc, which al-Idrīsī did with great skill with the help of artisans. The silver map had all the physical features and names of places drawn on it. Roger was so pleased with al-Idrīsī’s performance that he asked him to write a book on world geography. He produced the voluminous compendium *Nuzhat al-Muṣṭāq fi ikhtirāq al-ʿAfāq*, the full Arabic text of which has now been published as *Opus Geographicum* under the auspices of the Italian Institute of the Middle and Far East in Rome and the Institute of Oriental Studies at Naples University. Although the silver map has not survived, the original world map has. The *Nuzhat* is supposed to be a description of this world map. Al-Idrīsī divided the known world into seven climes (*iqḷīm*) running parallel to the equator up to 64°N latitude and divided each of the climes into ten longitudinal sections. Thus there are 70 odd sectional maps, and the arrangement of the book follows the 70 divisions. In many cases, there is more information in the book than is depicted on the maps. Al-Idrīsī’s world map is the most detailed and largest map drawn by any Muslim cartographer. His book is indeed a mine of information on physical, topographical, human, cultural, and political geography. From the world map and the book, one can see that his knowledge of Europe, North Africa,

and West and Central Asia was much deeper and more correct and extensive than it was of South Asia or the Far East.

Al-Idrīsī had a mathematical basis for his map, but he did not provide latitudes or longitudes as al-Maghribī did, who followed the pattern of al-Idrīsī. As he tried to include all the information at his disposal, some distortions were bound to take place, especially in the northern and southern regions. For example, the shapes and positions of the islands in the Indian Ocean were distorted. Even with these errors, his book is an encyclopedia of geographical knowledge of medieval times, and was an important geographical textbook for a long time.

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al-Jabartī

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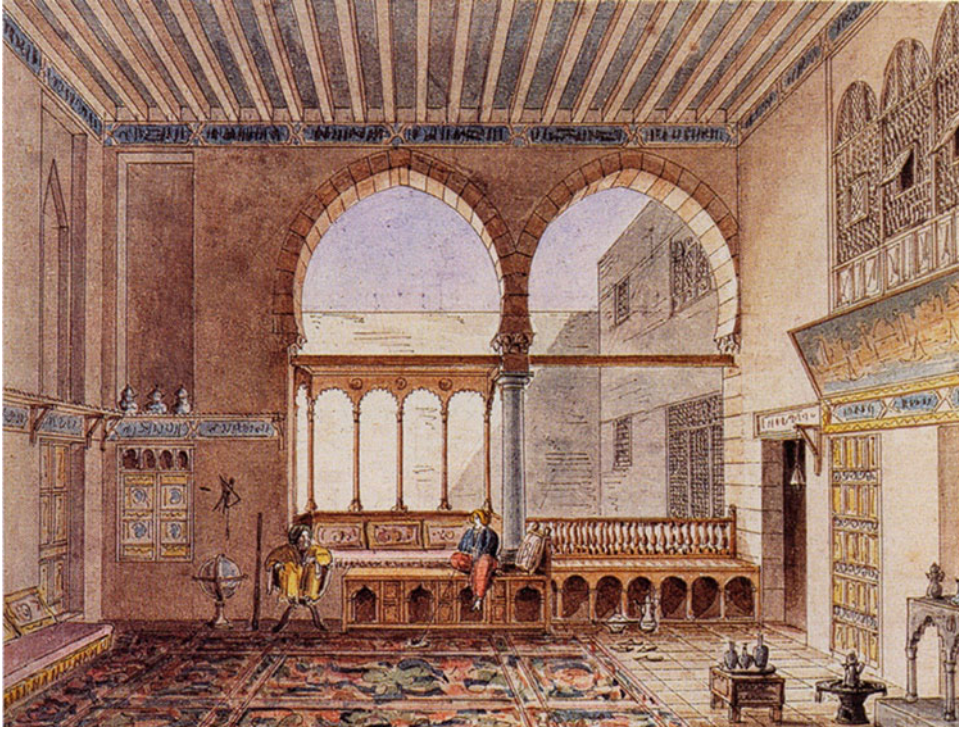
Abd al-Raḥmān al-Jabartī (1753–1825 CE) was born and died in Cairo. He was a prominent member of the Islamic religious scholarly class

(the *ulamā'*) and witness to both Bonaparte's invasion and the short-lived French occupation of Egypt (1798–1801). He also experienced the rise to power in Egypt of the Albanian military commander, Mehmet Ali Pasha (1769–1849), who would ultimately declare himself Khedive of Egypt as Ottoman forces reestablished themselves in the years following the negotiated French withdrawal (Fig. 1).

Al-Jabartī is widely cited in modern scholarship because of three works, written in his native Arabic, that addressed eighteenth and early nineteenth-century Egypt and the dramatic figures of Bonaparte and Mehmet Ali. We have extant copies of both of al-Jabartī's accounts of the French occupation, one written 7 months into the occupation and another version penned following French withdrawal. His major work, and by far the lengthiest manuscript, chronicled Egypt from the start of the twelfth century *Hijrī* (the Islamic calendric system, corresponding to 1688 CE) and continued, with the author circulating updates, to the end of al-Jabartī's life. Despite the ostensible breadth of the chronicle, spanning more than 130 years, the vast majority of the text dealt with the period of al-Jabartī's lifetime. Whether completely accurate or not, al-Jabartī claimed that “most of the events [in the four volumes] are tribulations which we have experienced and matters which we have witnessed.” This work interwove accounts of events in Cairo and its environs, organized chronologically, with biographies of important figures who had died in the same year. He entitled his major work, *'Ajā'ib al-āthār fīl-tarājīm wal-akhbār* (*Marvels of Evidence Concerning Lives and Events*), although it is known in English as al-Jabartī's *History of Egypt*.

Historians of Arab and Ottoman society have long turned to al-Jabartī's texts for evidence concerning many aspects of daily life in an Arab-Ottoman city over the eighteenth and early nineteenth centuries. Despite such reliance on his work, however, al-Jabartī himself remains little studied, and the first critical edition of his major work has just been published by Shmuel Moreh.

Al-Jabartī's biographies followed many of the conventions of Islamic biographical dictionaries,



A

al-Jabarti, Fig. 1 There is much we do not know about al-Jabartī's family and life; however, by his own account, he grew up in the prosperity of a family that owned three houses in and around Cairo and many male and female

slaves. Al-Jabartī reported he was the only one of his father's forty children to survive past adolescence. *Interior view of Cairene home believed to be that of al-Jabartī seated on the left. Watercolor, Pascal Coste*

giving information about the texts studied and written, the teachers and students, of various members of the religious scholarly class and high-ranking members of the military and government classes. In the course of these accounts of lives and events, al-Jabartī provided more than 600 biographies. Many biographies recounted students and scholars of what he called the "well-known sciences" of Islamic jurisprudence and theology. However, al-Jabartī's text provided sustained attention to patrons and students pursuing what he and others from the period called "the less common sciences," investigations including branches of mathematics, weights and measures, astronomy, astrology, timekeeping, medicine, and various forms of divination. These practitioners made up more than one in eight of his biographies and were often the subject of detailed and effusive praise. While al-Jabartī's text did not exclusively focus on such figures, they formed a

significant element of his chronicle of Egypt and have begun to attract the attention of historians of science (Fig. 2).

Al-Jabartī's views on French science had already attracted the attention of an earlier generation of historians. Because al-Jabartī chronicled the French occupation of Egypt, leaving to posterity a rare account of European occupation from the receiving end, scholars have used his work to understand European and Islamic encounters quite broadly. Bonaparte self-consciously sought to bring European sciences to Egypt – or rather, since he and others believed that many of the sciences had their origins in Pharaonic Egypt, they spoke of "returning" the sciences to their homeland – and the French staged a number of marvels and popular scientific demonstrations in Cairo during their occupation. Al-Jabartī's responses have been used to gauge Muslim attitudes to European science quite broadly (Fig. 3).

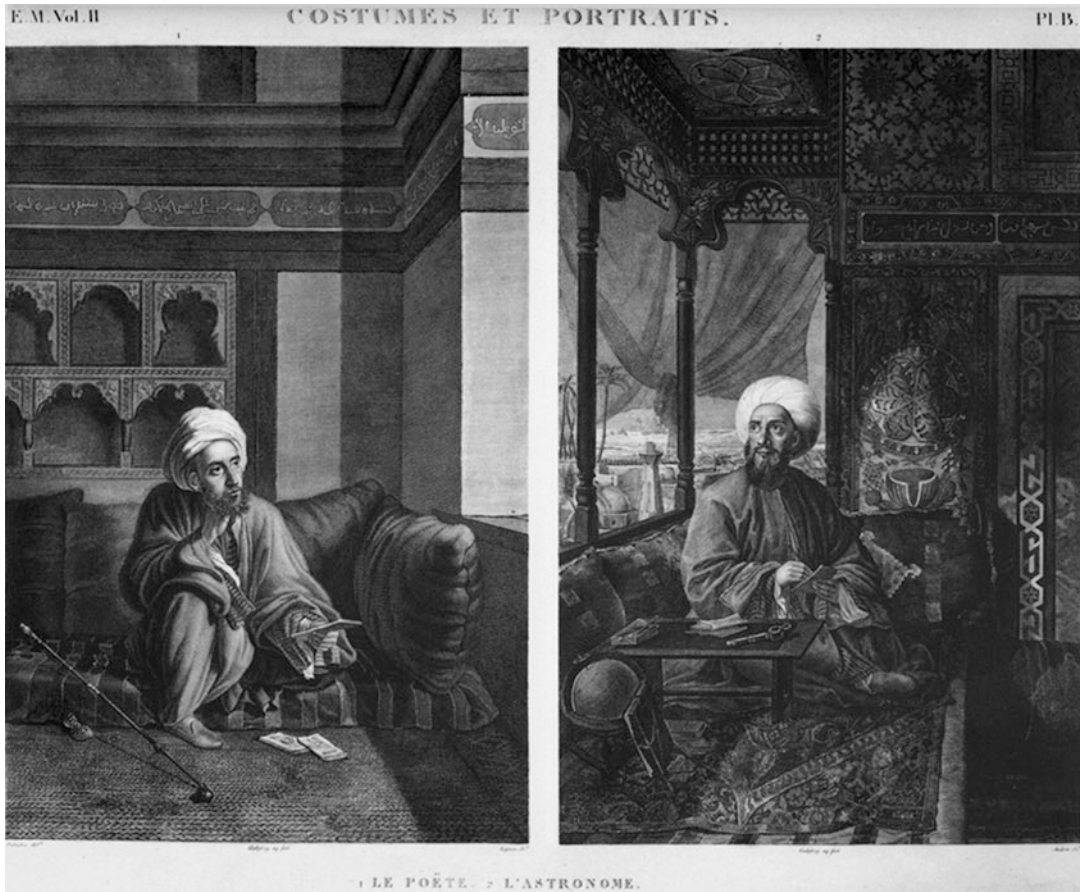


al-Jabarti, Fig. 2 (a) and (b) Commissioned instruments from the eighteenth century: a sundial produced for Cairo by a scholar noted by al-Jabarti. (Marble sundial, 1188 A. H./1774 C.E., Cairo Museum of Islamic Art, no. 12630). A luxury illuminated box describing the proper direction

of prayer for cities under Ottoman control. (Round wooden box with illustration of the Ka'ba, a map of the Islamic world and a compass, 1152 A.H./1739 C.E., Cairo, Museum of Islamic Art, no. 3348)

Bonaparte made scientific expertise central to his plans for turning Egypt into a French colony. He enlisted 120 scholars and engineers to accompany his troops in the invasion and tasked them with establishing a scientific institute in Cairo, which they did almost immediately. French *savants*, as they were called at that time, also staged scientific demonstrations and marvels of the kind that were sweeping towns and cities across eighteenth-century Europe and beyond. Electricity and “new” chemistry engaged audiences around the world, from Philadelphia to Edo. From Bonaparte’s memoirs, it appears he envisioned the cumulative force of these displays alongside his military strength leading the Cairene elite to willingly become Frenchmen. In this, Bonaparte did not prove prescient (Fig. 4).

Al-Jabarti’s French contemporaries voiced frustration at the difficulties they faced in their occupation, from continued uprisings in Cairo to disappointing responses to marvels like the *montgolfière* balloon. Edmé François Jomard was present at the first balloon’s launch, and his assessment is often quoted to show the lack of curiosity or even antagonism toward science among the local population: “The Africans, uneasy to show emotion and well-guarded against the arts of the Europeans,” were seen walking along al-Azbakiya square “not even deigning to lift their heads.” However, al-Jabarti’s report was quite different. He claimed that, “The people, as usual, raised a great din about [the announced balloon launch]. On the afternoon of this day the people and many



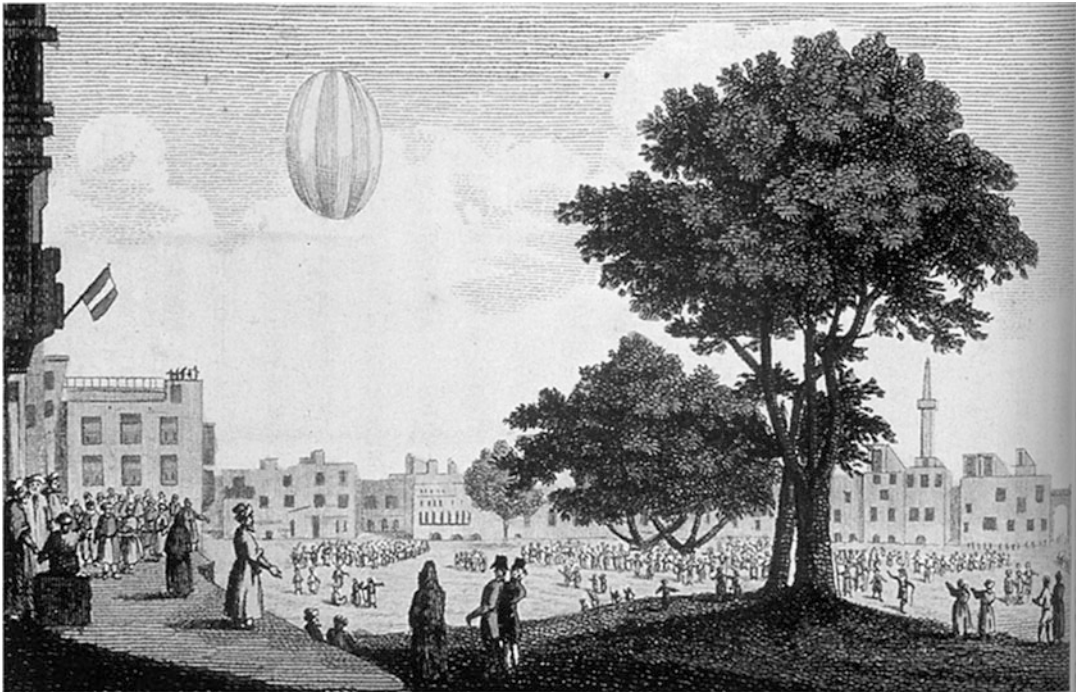
al-Jabarti, Fig. 3 Andre Raymond suggested that al-Jabartī was the model for the astronomer in this French engraving that circulated in Europe as part of the massive *Description of Egypt*

Frenchmen assembled to observe this marvel.” Al-Jabartī was present and took evident pleasure in describing the shortcomings of the balloon that soon tipped over and crashed to the ground. “The French were embarrassed at its fall. Their claim that this apparatus is like a vessel in which people sit and travel to other countries in order to discover news and other falsifications did not appear to be true. On the contrary, it turned out that it is like kites which household servants build for festivals and happy occasions.”

The scientific marvels put on by Berthollet, Conte, and others have been examined in terms of al-Jabartī’s reaction to, in the words of one modern scholar, “European science and technology [which] had developed to an extent that the Islamic world could not imagine” after the

“atrophy of the military power and the culture of Islam.” Another modern scholar has concluded that “[t]heir apparent indifference is without doubt a sort of self-protection, as if this imported science threatened their identity.”

Recent scholarship challenging the picture of European science as so easily disentangled from European colonialism has questioned the claim that al-Jabartī’s opposition to French colonization or his criticism of some French displays should be equated with hostility toward scientific enterprises in general or even everything that the French shared with him. Al-Jabartī described the French astronomical instruments, for example, in glowing detail. Moreover, scholars have begun to pay attention to al-Jabartī’s own study of medicine and astronomy and the extensive network of patrons,



Envol d'une montgolfière au Caire, d'après J. B. Breton.

al-Jabartī, Fig. 4 One French public marvel was a hot air balloon launched in a fashionable district of Cairo. Al-Jabartī also recorded circle shocks demonstrating the

Leyden jar's effects and Berthollet's chemical transformations of various liquids and powders into colored smoke and solids

scholars, and teachers of the sciences that are recorded in his writings. Manuscript catalogs show that al-Jabartī was not alone in these interests. We have thousands of extant manuscripts in astronomy, astrology, mathematical topics, divination, and medicine from eighteenth-century Cairo alone.

In fact, there are so many manuscripts of this sort in multiple libraries that they have not all been cataloged, much less studied. Ultimately, we will reach a clearer understanding of al-Jabartī, and why certain practices and practitioners garnered his praise or disdain when a sharper image of the wide range of Arabo-Ottoman scientific study emerges from these manuscripts.

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Al-Jawharī

Sonja Brentjes

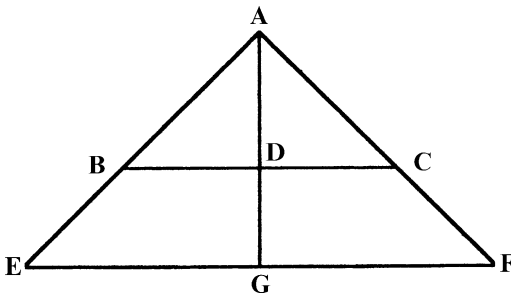
Probably of Iranian origin, al-ʿAbbās Ibn Saʿīd al-Jawharī was one of the court astronomers/astrologers of Caliph [al-Maʾmūn](#) (r. 813–833) in charge of the construction of astronomical instruments. He participated in astronomical observations carried out in Baghdad in 829–830 and in Damascus in 832–833. He is said to have composed an astronomical handbook ([► Zīj](#)), which is lost, except for indirect references (Sezgin, 1973). In his house in Baghdad, meetings were held at which the participants discussed Ptolemy's *Almagest*, Euclid's *Elements*, and problems derived from the two books. A not yet studied manuscript, *Kalām fī maʿrifat buʿd al-shams ʿan markaz al-arḍ* (Speech about the Knowledge of the Distance between the Sun and the Center of the Earth), might be an extract of his *Zīj* or an independent astronomical treatise. In astrology, he was considered an expert at horoscopes determining an individual's length of life.

His main achievements in the mathematical sciences are in geometry. He edited or commented on the *Elements*. Extracts of this work are preserved as independent manuscripts containing fragments of his *Ziyādāt fī'l-maqāla al-khāmisa min kitāb Uqlīdis* (Additions to Book V of Euclid's Book) and as quotations of his attempted proof of the parallel postulate (Book I) in Naṣīr al-Dīn al-Ṭūsī's *al-Risāla al-shāfiya ʿān al-shakk fī'l-khuṭūṭ al-mutawāziya* (The Healing Treatise on the Doubt Concerning Parallel Lines). In this treatise, al-Ṭūsī also cites one of al-Jawharī's additions to Book I, namely that the angles contained by three lines drawn from one point in different directions equal four right angles.

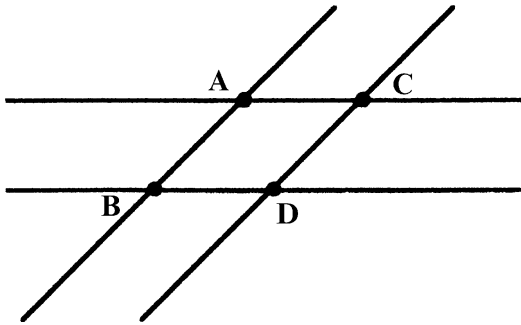
Al-Jawharī's attempted proof of the postulate was contained in the same edition of the *Elements* as the aforementioned additional proposition. It evidently was inspired by the proofs of Simplicios (sixth century) and Aghānīs/Aghānyūs (Agapios?, fl. ca. 511), since he used the same variant of the so-called Eudoxos-Archimedes axiom as Aghānīs and at least two propositions attributed by ʿAlam al-Dīn Qayṣar (d. 1251) to Simplicios. Since both proofs were contained in Simplicios' commentary on the definitions, postulates, and axioms, its Arabic translation obviously was made in the first half of the ninth century.

The theorem upon which al-Jawharī's proof is built states principally that if a triangle ABC is divided by a line AD and this line and the two sides AB and AC are extended and cut by a line EF such that $AB = BE$ and $AC = CF$, then $AD = DG$ with G being the point of intersection between line EF and the extension of line AD (see Fig. 1).

The proof of this proposition and consequently the proof of the postulate ultimately depend upon two propositions possibly introduced by al-Jawharī himself. The problem of the whole proof lies in the incomplete proof of the second part of the first of the two theorems, which al-Ṭūsī had already discovered. This second part states principally that the distance between one point of a line and its "corresponding" point on a second, parallel line always equals the distance between a second point on the first line and its "corresponding" point on the second line,



Al-Jawhārī, Fig. 1 Jawhārī's theorem



Al-Jawhārī, Fig. 2 The distance between one point of a line and its corresponding point on a second, parallel line always equals the distance between a second point on the first line and its corresponding point on the second

$AC = BD$ (Fig. 2). Al-Jawhārī's proof of this part not only treats a special case, but also fails to prove the equality of the two joining lines.

The fragment of al-Jawhārī's additions to Book V contains three propositions which try to prove Euclid's definitions V, 5 (identity of ratios), V, 7 (one ratio $>$ a second ratio), and the negation of definition V, 5. This illustrates how difficult those definitions were. Usually, a definition is not proven, since it was regarded as an evident assumption or a statement agreed upon between scholars. Al-Jawhārī's explanations dressed as formal proofs do not really clarify those definitions, since all he did was simply to repeat them for special objects, namely, natural numbers.

Al-Jawhārī is also credited with the translation from Persian into Arabic of a book about poison

of supposed Indian origin, the so-called *Kitāb al-Shānāk* (The Book of Shānāk), for ► [al-Ma'mūn](#).

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [al-Ma'mūn](#)
- [Astronomical Instruments in the Islamic World](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Zīj](#)

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Al-Jazarī

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Al-Jazarī, Badī' al-Zamān Abū'l-'Izz Isma'īl ibn Al-Razzāz, was an engineer who worked in al-Jazira during the latter part of the twelfth century. His reputation rests upon his book, *Kitāb fī ma'rifat al-ḥiyal alhan-dasiyya* (The Book of Knowledge of Ingenious Mechanical Devices), which he composed in 1206 on the orders of his master Nāsir al-Dīn Maḥmūd, a prince of the Artuqid dynasty of Diyar Bakr. All that we know of his life is what he tells us in the introduction to his book, namely that at the time of writing he had been in the service of the ruling family for 25 years. The book is divided into six categories (*naw'*). Each of the first four contains ten chapters (*shakl*), and the last two consist of only five each. The categories are as follows:

1. Water clocks and candle clocks
2. Vessels and pitchers for use in carousals or celebrations
3. Vessels and basins for hand washing and phlebotomy
4. Fountains and musical automata
5. Water lifting machines
6. Miscellaneous

There are many illustrations, both of general arrangements and detailed drawings, and these are of considerable assistance in understanding the text, which contains many technical expressions that have since fallen into disuse. Some 13 manuscript copies, made between the thirteenth and the eighteenth centuries, are extant to bear witness to the widespread appreciation of the book in the Islamic world.

There are, however, no references to al-Jazarī in the standard Arabic biographical works of the Middle Ages, and there is no known translation

into a European language before the twentieth century.

Only one of the complete machines, a twin cylinder pump driven by a paddle-wheel, can be said to have direct relevance to the development of mechanical technology. Many of the devices, however, embody techniques and mechanisms that are of great significance, since a number of them entered the general vocabulary of European engineering at various times from the thirteenth century onward. Some of these ideas may have been received directly from al-Jazarī's work, but evidence is lacking. Indeed, it seems probable that a large part of the Islamic mechanical tradition – especially water clocks and their associated mechanisms and automata – had been transmitted to Europe before al-Jazarī's book was composed. Even leaving aside the question of direct transmission, we still have a document of the greatest historical importance. First, it confirms the existence of a tradition of mechanical engineering in the Eastern Mediterranean and the Middle East from Hellenistic times up to the thirteenth century. Al-Jazarī was well aware that he was continuing this tradition and was scrupulous in acknowledging the work of his predecessors, including Apollonius of Byzantium, the Pseudo-Archimedes, the ► [Banū Mūsā](#) (ninth century), Hibat Allah ibn al-ḥusayn (d. 1139–1140), and a certain Yūnus al-Aṣṭurlābī.

Other writings and constructions, whose originators were unknown to al-Jazarī, are also mentioned.

Second, his use of and improvement upon the earlier works, together with his meticulous descriptions of the construction and operation of each device, enables us to make an accurate assessment of mechanical technology by the close of the twelfth century.

See Also

- [Banū Mūsā](#)
- [Engineering](#)
- [Technology in the Islamic World](#)

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Al-Jurjānī

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Abū'l-Fadā'il Ismā'īl ibn al-ḥusayn al-Jurjānī, Zayn al-Dīn, sometimes called Sayyid Ismā'īl, was the most eminent Persian physician after ► [Ibn Sīnā \(Avicenna\)](#), and the author of the first great medical compilation written in Persian. Born at Jurjan, 50-mile east of modern Gorgan, east of the Caspian, he was a pupil of Ibn Abī šādiq (d. 1066–1077), who had himself been a pupil of Ibn Sīnā. In 1110 al-Jurjānī entered the service of the ruler of Khwarizm (modern Khiva), the Khwārizmshāh Quṭb al-Dīn Muhammad (d. 1127) and his son Atsiz; later he moved to Marw (Merv) and served the rival sultan Sanjar. Al-Jurjānī died at Marw in about 1136 (AH 531).

Al-Jurjānī's great work is entitled *Dhakhīra-i-Khwārazmshāhī* (The Thesaurus of the King of Kharazm). Comparable in size and scope to Avicenna's *Canon*, the *Thesaurus* is a compendium of medical knowledge and clinical practice. It rapidly became a classic and established the medical and scientific vocabulary in Persian; its influence was extensive and long-lasting. It was translated into Hebrew, Urdu, and Turkish, and remained in use until the nineteenth century.

There are many manuscripts, both complete and fragmentary, but no available modern edition (although Keshavarz records an Indian edition of 1865–1866, and one produced in Tehran in 1965).

In addition to the *Thesaurus*, al-Jurjānī composed other works in Persian which appear to be, in the main, abridgements of it. Chief among these is the condensed version called *Mukhtaṣar-i Khuffī-i 'Alā'ī* (Abridgement for the Boots of Alā') in two long volumes for Shah Atsiz to carry in his tall riding boots. This work was printed in Agra (1852) and Cawnpore (1891), but neither edition is readily available. There are several manuscripts in Turkey, one in the British Library, and an Arabic translation in Paris and at the University of California.

The *al-Agrād al-ṭibbīya* (Aims of Medicine), composed for the vizier of Atsiz, is partly another abridgement of the *Thesaurus* combined with an account of the symptoms and treatment of local diseases. The *Yadgar i-ṭibb* (or Remembrancer) is largely on pharmacology.

Al-Jurjānī's works have not been much studied, and the relationships between the various texts and translations have not been worked out. A work in Arabic, *Zubdat al-ṭibb* (Essence of Medicine), is frequently assigned to him; this is presumably a translation of one of the Persian treatises mentioned above, but it is not clear which one. Some of the other manuscript works ascribed to al-Jurjānī are probably excerpts from his lengthy books.

See Also

► [Ibn Sīnā \(Avicenna\)](#)

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Al-Karajī

Jacques Sesiano

Al-Karajī Abū Bakr Muḥammad was a Persian mathematician and engineer. He held (ca. 1010–1015) an official position in Baghdad during which time he wrote his three main works.

1. His *al-Fakhrīfī’l-jabr wa ‘l-muqābala* (Glorious on Algebra) contains an exposition of algebra and auxiliary topics (e.g. summing series of integers). The next and larger part is a collection of problems: some are commercial and recreational, but for the most part they belong to indeterminate algebra. All of the latter sorts are taken from Diophantus or ► [Abū Kāmil](#).
2. The *Badī‘ fī’l-ḥisāb* (Wonderful on Calculation) is more original. After restating many of Euclid’s theorems, al-Karajī shows how to calculate with square, cubic, and biquadratic roots and with their sums, then how to extract the root of a polynomial in x (this is the earliest known mention of the procedure). A second part contains problems on indeterminate algebra. Here, al-Karajī has taken the basic methods used by Diophantus in his problems and classified them, the result being a useful introduction to Diophantus’s algebra.
3. The composition of the *Kāfī fī’l-ḥisāb* (Sufficient on Calculation) belongs to the usual duty of a mathematician holding an official position: to write a simple textbook in a way accessible to civil servants and

containing the elements of arithmetic with integers and fractions (common and sexagesimal), the extraction of square roots, the determination of areas and volumes, and elementary algebra. All this is illustrated by numerous examples.

4. The *‘Ilal al-jabr wa’l-muqābala* (Grounds of Algebra) is a small compendium on basic algebra (reckoning with roots, solving the basic six forms of the equations of the first two degrees), without resort to any geometrical demonstrations.
5. The *Inbāt al-miyāh al-khaṭīyah* (Locating Hidden Waters) was written after al-Karajī’s return to Persia. It is concerned with finding subterranean water, extracting it, and transporting it in accordance with the soil’s configuration.

Other, lost works of al-Karajī’s are known to have dealt with indeterminate algebra, arithmetic, inheritance algebra, and the construction of buildings. Another contained the first known explanation of the arithmetical (Pascal’s) triangle; the passage in question survived through al-Sama’wal’s *Bāhir* (twelfth century), which heavily drew from the *Badī‘*.

Although much of his work was taken from others’ writings, there is no doubt that al-Karajī was quite an able and influential mathematician. However, the quality of his writings is uneven, as he seems to have worked hastily sometimes.

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Al-Kāshī

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Al-Kāshī, or al-Kāshānī (Ghiyāth al-Dīn Jamshīd ibn Mas'ūd al-Kāshī (al-Kāshānī)), was a Persian mathematician and astronomer. He was born in Kāshān in northern Iran and worked at first in Herat (now in Afghanistan) at the court of *khāqān* ("khān of khāns" Shāhrukh, the son of Tīmūr). In 1417 he was invited by Ulugh Beg, the son of Shāhrukh, the ruler of Samarqand (now in Uzbekistan), to become the director of his astronomical observatory. His scientific treatises were mostly written in Arabic and partly in Persian. Al-Kāshī died in Samarqand in about 1430.

Al-Kāshī's main mathematical work is *Miftāḥ al-ḥisāb* (Key of Arithmetic). This work, written in the tradition of Arabic mathematical texts, contains five books: (1) Arithmetic of Integers, (2) Arithmetic of Fractions, (3) Arithmetic of Astronomers, (4) Geometry, and (5) Algebra.

In book 1, al-Kāshī considers duplication (multiplication by 2), mediation (division into 2), addition, subtraction, multiplication, and division. As Naṣīr al-Dīn al-Ṭūsī (1201–1274) did in his arithmetic treatise, he also considers extraction of roots of arbitrary integer powers by means of what we now call the Ruffini-Horner method and expresses the approximate value of the root by means of "Newton's binomial formula" for $(a + b)^n$. In book 2, al-Kāshī introduces decimal fractions and calls the digits of these fractions "decimal minutes," "decimal seconds," "decimal thirds," etc. The arithmetic of astronomers considered in book 3 is the arithmetic of sexagesimal fractions borrowed by Islamic astronomers from Ptolemy, who in turn had borrowed them from Babylonian astronomers. Islamic astronomers designated figures from 1 to 59 by means of letters and zero by $\bar{o}$.

Like the ancient Babylonians, al-Kāshī extended the sexagesimal system onto integers and called the sexagesimal digits "raised," "twice raised," "three times raised," etc. In book 4, the rules of mensuration of many plane and solid figures, including buildings, cupolas, and stalactite surfaces, are formulated. In book 5, besides explaining the algebraic solution of quadratic equations and equations reducible to them, al-Kāshī discusses the solutions of equations by means of the rule of two errors, actions with roots, algebraic identities, and Thābit ibn Qurra's rule for the determination of amicable numbers. Al-Kāshī claims that he wrote an algebraic treatise with the classification of equations of the fourth degree and that for every type he proposed the solution by means of the intersection of conics more general than the conics by means of which 'Umar al-Khayyām solved cubic equations. This algebraic treatise is not extant and since the number of these equations does not coincide with those mentioned by al-Kāshī, this treatise was not finished.

The *al-Risāla al-muḥīṭiyya* (Treatise on Circumference) is devoted to the calculation of the ratio of circumferences of circles to their radii (now this ratio is designated by 2π). Al-Kāshī calculates the perimeters of regular inscribed and circumscribed polygons with $3 \cdot 2^{28}$ sides. The number of sides is chosen on the condition that the difference between these polygons for the great circle of the sphere of fixed stars must be less than the "width of a horse hair." The result is expressed in sexagesimal and decimal fractions.

In the *Risāla al-watar wa'l-jayb* (Treatise on Chord and Sine), al-Kāshī calculates the $\sin 1^\circ$ according to the known $\sin 3^\circ$. This problem was necessary for the composition of the tables of sines with five sexagesimal digits in Ulugh Beg's *Zīj-i Ulugh Beg* (Ulugh Beg's *Astronomical Tables*). This problem was reduced to the cubic equation $4x^3 + q = 3x$ ($x = \sin 1^\circ$, $q = \sin 3^\circ$) and was solved by the method of successive approximations:

$$x_1 = \frac{q}{3}, \quad x_2 = \left(\frac{q + 4x_1^3}{3} \right), \dots$$

In the field of astronomy, al-Kāshī was the author of *Zīj-i Khāqānī* (Khāqān Astronomical Tables) written in 1413–1414 in Herat. He also composed a treatise on astronomical instruments written in 1416 dedicated to the ruler of Iṣf āhān Iskandar, who was the nephew of Shāhrukh, and was one of the authors of Ulugh Beg's *Astronomical Tables*. He was also the translator of the last tables from Persian into Arabic. In the treatise *Nuzha al-ḥadāiq* (Delight of Gardens), al-Kāshī describes an instrument for the representation of the movements of planets which he invented. He was also the author of numerous other astronomical treatises.

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Al-Khalili

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Al-Khalīlī, Shams al-Dīn Abū 'Abdallāh Muḥammad ibn Muḥammad, lived in Damascus, ca. 1365. He was an astronomer associated with the Umayyad Mosque in the center of Damascus. A colleague of the astronomer Ibn al-Shāṭir, he was also a *muwaqqit* – that is, an astronomer concerned with *ilm al-mīqāt*, the science of time-keeping by the sun and stars and regulating the astronomically defined times of Muslim prayer. Al-Khalīlī's major work, which represents the culmination of the medieval Islamic achievement in the mathematical solution of the problems of spherical astronomy, was a set of tables for astronomical timekeeping. Some of these tables were used in Damascus until the nineteenth century, and they were also used in Cairo and Istanbul for several centuries. The main sets of tables survive in numerous manuscripts, but they were not investigated until the 1970s.

Al-Khalīlī's tables can be categorized as follows:

- Tables for reckoning time by the sun, for the latitude of Damascus
- Tables for regulating the times of Muslim prayer, for the latitude of Damascus
- Tables of auxiliary mathematical functions for timekeeping by the sun for all latitudes
- Tables of auxiliary mathematical functions for solving the problems of spherical astronomy for all latitudes

- A table displaying the *qibla*, that is, the direction of Mecca, as a function of terrestrial latitude and longitude
- Tables for converting lunar ecliptic coordinates to equatorial coordinates

The first two sets of tables correspond to those in the large corpus of spherical astronomical tables computed for Cairo that are generally attributed to the tenth-century Egyptian astronomer Ibn Yūnus.

Al-Khalīlī's fourth set of tables was designed to solve all the standard problems of spherical astronomy, and they are particularly useful for those problems that, in modern terms, involve the use of the cosine rule for spherical triangles. Al-Khalīlī tabulated three functions and gave detailed instructions for their application. The functions are as follows:

$$f_{\phi}(\theta) = \frac{\sin \theta}{\cos \phi} \text{ and } g_{\phi}(\theta) = \sin \theta \tan \phi,$$

$$K(x, y) = \arccos \left(\frac{x}{R \cos y} \right),$$

computed for appropriate domains. The entries in these tables, which number over 13,000, were computed to two sexagesimal digits and are invariably accurate. An example of the use of these functions is the rule outlined by al-Khalīlī for finding the hour-angle t for given solar or stellar altitude h , declination δ , and terrestrial latitude ϕ . This may be represented as:

$$t(h, \delta, \phi) = K \left\{ \left(f_{\phi}(h) - g_{\phi}(\delta) \right), \delta \right\},$$

and it is not difficult to show the equivalence of al-Khalīlī's rule to the modern formula

$$t = \arccos \left(\frac{\sin h - \sin \delta \sin \phi}{\cos \delta \cos \phi} \right).$$

These auxiliary tables were used for several centuries in Damascus, Cairo, and Istanbul, the three main centers of astronomical timekeeping in the Muslim world.

Al-Khalīlī's computational ability is best revealed by his *qibla* table. The determination of the *qibla* for a given locality is one of the most complicated problems of medieval Islamic trigonometry. If (L, φ) and (L_M, φ_M) represent the longitude and latitude of a given locality and of Mecca, respectively, and $\Delta L = |L - L_M|$, then the modern formula for $q(L, \varphi)$, the direction of Mecca for the locality, measured from the south, is

$$q = \arccos \left(\frac{\sin \phi \cos \Delta L - \cos \phi \tan \phi_M}{\sin \Delta L} \right).$$

Al-Khalīlī computed $q(\varphi, L)$ to two sexagesimal digits for the domains $\varphi = 10^\circ, 11^\circ, \dots, 56^\circ$ and $\Delta L = 1^\circ, 2^\circ, \dots, 60^\circ$; the vast majority of the 2,880 entries are either accurately computed or in error by $\pm 1'$ or $\pm 2'$. Several other *qibla* tables based on approximate formulas are known from the medieval period. Al-Khalīlī's splendid *qibla* table does not appear to have been widely used by later Muslim astronomers.

See Also

- [Ibn al-Shāṭir](#)
- [Ibn Yūnus](#)
- [Qibla and Islamic Prayer Times](#)
- [Sexagesimal System](#)

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Al-Kharaqī

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Abū Muḥammad ‘Abd al-Jabbār ibn ‘Abd al-Jabbār al-Kharaqī was a Persian astronomer, mathematician, and geographer. He was born at Kharāq near Marw and worked at Marw at the court of Saljuq Sultan Sanjar (1118–1157). Al-Kharaqī wrote in Arabic.

His main work was *Muntahā al-idrāk fī taqāsīm al-aflāk* (The Highest Understanding of the Divisions of Celestial Spheres). The work consists of three books: astronomical, geographical, and chronological. It is written in the tradition of Arabic astronomical textbooks initiated by al-Farghānī, continued by Ibn al-Haytham, and widely spread after al-Kharaqī in the form of Arabic and Persian books on the science of cosmography (‘ilm al-hay‘a). In these books, the planets are considered not as supported by imaginary circles according to Ptolemy's *Almagest* but

as supported by massive material spheres in which they move in tubes.

His *Kitāb al-tabṣira fī ‘ilm al-hay‘a* (Introduction to the Science of Cosmography), written in the same tradition, is the shortened version of the first work and contains two separate books, “On the Heavens” and “On the Earth.”

Al-Kharaqī was also the author of two lost mathematical treatises, *al-Risala al-shāmila* (Comprehensive Treatise), devoted to arithmetic, and *al-Risala al-maghribiyya* (The North African Treatise), on the “calculus of dirham and dinar.”

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Hay’a](#)
- [Ibn Al-Haytham \(Alhazen\)](#)

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al-Khayyām

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Ghiyāth al-Dīn Abū’l-Faṭḥ ‘Umar ibn Ibrāhīm al-Khayyāmī (Khayyām) al-Naysābūrī (Nīshāpūrī)

was a Persian mathematician, astronomer, poet, and philosopher who remained faithful to Aristotle in his scientific and philosophical works. He was born ca. 1048 CE in Nīshāpūr, now in north-eastern Iran, and he spent his early years in Balkh. He then moved to Bukhārā where he remained until about 1070. There, he wrote three works on music and mathematics. The *al-Qāwī ‘alā ajnās allatī bi’l-arba‘a* (*Reasoning on kinds [formed] by fourths*) treats ratios in music. In the lost *Mushkilāt al-ḥisāb* (*Problems in arithmetic*), al-Khayyām proved rules for extracting square, cube, and higher roots with Indian numerals. The proofs were based in the number theory books in Euclid’s *Elements*, and the rules for higher roots were of his own invention.

Al-Khayyām’s most important work from this period is the *Risāla fī taqṣīm rub‘ al-dā‘ira* (*Treatise on the division of a quadrant of a circle*). In it, he poses the problem of dividing a quadrant of a circle in such a way that a certain ratio is satisfied. He reduces this to a problem about a right triangle which he solves by algebra. By making one line ten and another “a thing” (like our x), he sets up a quartic equation that simplifies to the cubic equation $x^3 + 200x = 20x^2 + 2000$. Following traditional Arabic algebra, this is expressed in words as “a cube and 200 things equals 20 *māls* and 2000 in number.” (The Arabic word *māl* commonly means “sum of money” or “possession.” In algebra, it was the name given to the second power of the unknown.) Using the “numbers” (coefficients) of the terms, he constructs a semicircle and a hyperbola, and the solution to the equation is a line extending to their intersection.

Al-Khayyām would mention in his later book on algebra that Abū Ja‘far al-Khāzin and other mathematicians had also applied algebra to problems in geometry in which the resulting cubic equation was solved by intersecting conic sections. Seeing that any equation of degree three or less simplifies to one of only 25 types, he pauses in the middle of the solution of his triangle problem to outline his future project of providing each of these equations with a solution. There are 25 equations rather than our single $ax^3 + bx^2 + cx + d = 0$ because the solutions utilize the

“numbers” of the terms, and these must be positive. For example, the equations $x^3 + ax = b$ and $x^3 = ax + b$ were regarded as being different types.

It was about 1070 that al-Khayyām reached Samarkand. There, under the patronage of the judge Abū Ṭāhir, he realized this algebraic project with his now famous *Risāla fī’l-barāhīn ‘ala masā’il al-jabr wa’l-muqābala* (*Treatise on proofs of the problems of algebra*). In it, he presents the 25 equations with solutions and proofs. He gives geometrical solutions to each equation in the form of a constructed line. And while he had previously maintained that algebra belongs purely to geometry, he now also gives arithmetical solutions where possible (arithmetical solutions to irreducible cubic equations were first found in sixteenth-century Italy). These are worked out by the same kind of algorithm already common in practical algebra.

Al-Khayyām worked within the framework of Aristotle’s division of the genus of “quantity” into discrete and continuous. Numbers are discrete and consist only of positive integers, while geometrical magnitudes are continuous. This might have posed an obstacle to applying algebra to geometry, since traditional Arabic algebra is a numerical problem-solving technique in which the numbers can be any quantity that arise in calculation, including fractions and irrational roots. Al-Khayyām solved this incongruity by positing a unit line and regarding the numbers of the algebraists as the dimensionless measures of continuous magnitudes. So a “number” like $3\frac{1}{2}$ or $\sqrt{2}$ could be the length of a line, the area of a plane figure, or the volume of a solid. This foundational shift had no effect on the practice of algebra since it merely justified the calculations that were already being performed. Al-Khayyām’s idea of “continuous numbers” resurfaced later in the third part of his commentary on Euclid’s *Elements* (see below). His fidelity to Aristotle meant of course that his arithmetical solutions were restricted to positive integers (Oaks 2011).

Al-Khayyām’s book gave algebra the proper foundation and the necessary rules to make it a legitimate and practical tool for

problem-solving in the mathematics of the Greek tradition. Faced with a problem in geometry or arithmetic, one names an unknown magnitude or number “a thing” or some other algebraic term. The conditions of the problem are then applied to set up an equation, which is simplified to one of the 25 types. One then looks up the equation type in al-Khayyām’s book. If the original problem is in geometry, then the construction is followed. If the original problem is in arithmetic, then one follows the numerical algorithm. Throughout the algebraic solution, the powers of the unknown (“thing,” *māl*, “cube,” *māl māl*, etc.) are al-Khayyām’s dimensionless “continuous numbers,” and the geometric solutions utilize only the “coefficients” of the equation. It is only in the proofs of the geometric constructions that the first three powers are represented as geometric magnitudes of dimension 1, 2, and 3.

In 1074, al-Khayyām and other scientists were invited to the court of the Saljūq sultan Jalāl al-Dīn Malik Shāh in the newly founded capital of Isfahan (now in central Iran). There, they were charged with the construction and operation of an observatory. The *Zīj Mālikshāhī* (*Mālik Shāh astronomical tables*), of which only a fragment survives, was likely based on their observations. Another work probably related to the observations is al-Khayyām’s calendar, known to us only through later secondhand reports. This “Malikī” or “Jalālī” calendar was named for its patron and was completed by 1079. It was a solar calendar in which the new year is placed at start of Aries. Leap days were usually added every fourth year, but sometimes at the end of a 5-year cycle. We lack enough details to understand precisely how this calendar functioned, but it was perhaps more accurate than our Gregorian calendar. It was never put into use.

In 1077, al-Khayyām completed his commentary on Euclid’s *Elements*. The *Sharḥ ma ashkala min muṣādarāt kitāb Uqlīdis* (*Commentary on difficulties with foundations in Euclid’s book*) addresses three problems: Euclid’s fifth postulate, the definition of proportional ratios in Book V, and the compounding (i.e., multiplication) of ratios.

In the first part, al-Khayyām criticizes on philosophical grounds Ibn al-Haytham’s use of motion to produce a line. For his own solution to the problem, he replaces Euclid’s fifth postulate with a postulate that converging lines must intersect and that they cannot diverge in the direction of convergence. He then states and proves a sequence of eight propositions which are intended to replace Euclid’s proposition I.29.

In the second part of his commentary, al-Khayyām proposes to replace Eudoxus’ definition of proportional ratios, which is based on equimultiples, with a definition based on anthyphairesis. In this scheme, two ratios are said to be equal if repeated subtractions yield the same sequence of numbers. Al-Māhānī (9th c.) and al-Nayrīzī (early 10th c.) had made similar proposals before.

The last part of the commentary addresses the compounding of ratios. Just as in his work on algebra, al-Khayyām posits a unit measure for continuous magnitudes which allows him to work with his concept of continuous number. His proofs rely on the dimensionless character of these numbers, so that any proportion $a : b : c : d$ can be converted into the equality of the products $ad = bc$ and that the product of the unit by any number results in that very number (in magnitudes, this would increase the dimension). Contrary to what some historians have suggested, al-Khayyām’s continuous numbers were not grounded in ratios. It just happens that in this book they appear in connection with ratios. Further, while these numbers may resemble our modern real numbers, their ontological foundation was entirely different.

Court politics shifted with the death of the sultan in 1092. The observatory was closed and al-Khayyām found himself out of favor. He remained in Isfahan, though, and in this period he composed his history of Persian solar calendar reforms, the *Naurūz-nāma*.

Sometime after 1118, al-Khayyām left Isfahan for Merv, the capital of the Seljuk sultan Sanjar, where he probably wrote his two works on mechanics, *Mizān al-ḥikam* (*Balance of wisdoms*) and *Fī’l-quṣṭas al-mustaqīm* (*On correct*

portions). Both are reproduced in the *Book of the Balance of Wisdom* of his student al-Khāzinī in 1121. In the first of these works, al-Khayyām solves the problem of determining the portion of gold in an alloy of gold and silver by both geometry and algebra. In the algebraic solution he calls the weight of the portion of gold in air “a thing,” then sets up and solves the linear equation $10\frac{3}{4} - 1\frac{1}{10}x = 10\frac{1}{2} - 1\frac{1}{20}x$ (all expressed in words, of course).

Poetry and Philosophy

Al-Khayyām initiated a kind of literary tradition when he authored a collection of quatrains (*rubāʿiyyāt*) in Persian. Over the generations the collection assumed a degree of fluidity, with many quatrains being added by various (usually anonymous) hands. Religious authorities found evidence in al-Khayyām’s poetry to accuse him of “freethinking,” and we are told by al-Qifī (13th c.) that in his later years, al-Khayyām was compelled to make a pilgrimage to Mecca to appease them.

Al-Khayyām also authored five works on philosophy, beginning with his *Risāla al-kawn waʾl-taklīf* (*Treatise on being and duty*) in 1080. These works, which are not very original, show him to be a follower of Ibn Sīnā’s brand of Aristotelianism. Al-Khayyām died in his birthtown of Nīshāpūr, probably in 1131. Biographical details of al-Khayyām are taken largely from (Youschkevitch & Rosenfeld, 1973). Editions and French translations of his mathematical works are found in (Rashed & Vahabzadeh, 1999).

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Al-Khāzinī

Julio Samsó

Abūʾl-Faṭḥ (or Abū Maṣṣūr) ʿAbd al-Raḥmān (also called in some sources ʿAbd al-Raḥmān Maṣṣūr) was an astronomer and expert in mechanics and scientific instruments. He lived in Marw (Khurāsān) ca. 1115–ca. 1131. A slave (and later a freedman) of Byzantine origin, he was bought by a treasurer (*khāzin*) of the Seljuk court at Marw, called Abūʾl-ḥusayn (or Abūʾl-ḥasan) ʿAlī ibn Muḥammad al-Khāzin al-Marwāzī, who gave him a good scientific education.

As an astronomer his main work is his *al-Zīj al-Sanjārī*, an astronomical handbook with tables, compiled between ca. 1118 and ca. 1131 and dedicated to the Seljuk Sultan Sanjar ibn Malikshāh (1118–1157). This ► [zīj](#) seems to be influenced by the work of Thābit ibn Qurra, ► [al-Battānī](#) and ► [al-Bīrūnī](#), but parts of it seem to have been checked against a limited number of his own observations (planetary, solar, and lunar in moments of conjunctions and eclipses) made in Marw. He is credited with a careful determination of the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), but he adopts the Battanian value of 23°35′ and concludes (against al-Battānī and most of the successive Islamic astronomical tradition) that this parameter is a constant. His *zīj* includes a rich chronological section and a lot of materials related to the theory of Indian cycles. It also contains very important developments on the theory of planetary visibility as well as a very elaborate set of eclipse tables. He seems to have been interested by the problem of *qibla* determination (attempting to figure out the direction to Mecca) and the canons of his *zīj* mention a double entry *qibla* table computed for each integer degree of difference in latitude (from 1° to 30°) and in longitude (from 1° to 60°) between Mecca and other localities. This *qibla* table seems to be lost and the one ascribed to al-Khāzinī by the

fourteenth century author al-Mustawfi does not seem to have anything to do with our author. Al-Khāzinī's *Zīj* was used in Byzantium by Georges Chrysococcos (fl. ca. 1335–1346) and Theodore Meliteniotes (fl. ca. 1360–1388).

Among his minor astronomical works we find his treatise on instruments (*Risāla fī-l-ālāt*) which deals with observational instruments as well as with analog computers and simple helps for the naked eye. Furthermore, his short treatise on “the sphere that rotates by itself with a motion equal to the motion of the celestial sphere” (*Maqāla li'l-Khāzinī fīittiḥād kura tadūru bi-dhātihā bi-ḥaraka musāwiya li-ḥarakat al-falak wa ma'rifat al-ʿamal bihā sākina wa mutaharrika*) –probably the earliest of all his extant works – shows the link between his interest both in astronomy and in applied mechanics. It describes a solid sphere, marked with the stars and the standard celestial circles and half sunk in a box, the rotation of which is propelled by a weight falling in a leaking reservoir of sand. Similar devices were known and built in Classical Antiquity.

The most important of al-Khāzinī's works is probably his *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom), a treatise on the physical principles that underlie the hydrostatic balance as well as the construction and use of the instrument. This work was written in 1121–1122 and dedicated to Sultan Sanjar: the instrument it describes was meant for Sanjar's treasure, for its main application was to discriminate accurately between pure and adulterated metals as well as between real gems and fakes. A similar balance, also called *mīzān al-ḥikma*, had been built by al-Khāzinī's predecessor al-Asfīzārī also for Sanjar, but its scales had been destroyed. Al-Khāzinī's book is a long work, divided into 8 books and 80 chapters, and its quotations bear witness to the Classical sources on pure and applied mechanics that reached the Islamic lands (Aristotle and the pseudo-Aristotelian treatise on mechanical problems, Euclid, Archimedes, Menelaus) as well as to the development of the discipline in Islamic civilization (Muḥammad ibn Zakariyyā ► [al-Rāzī](#), ► [al-Bīrūnī](#), Ibn al-Haytham, Abū Sahl al-Qūhī,

ʿUmar al-Khayyām). There is nothing specifically new in al-Khāzinī's physical ideas which derive mainly from Aristotle and Archimedes, but his treatise has the obvious interest of its very careful description of a highly precise instrument with which he has been able to calculate tables of the specific gravities of many substances, both metallic, and nonmetallic, attaining, in some cases, results which are correct to within 1 %.

See Also

- [Thābit ibn Qurra](#)
- [Zīj](#)

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Al-Khujandī

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Abū Maḥmūd ḥāmid ibn al-Khiḍr al Khujandī (ca. 990) was a mathematician and astronomer who lived and worked under the patronage of the Buwayhid ruler, Fakhr al-Dawla (978–997).

In mathematics he worked on equations of the third degree and tried to show, although in an imperfect manner, that the sum of two cubed numbers cannot be another cube $a^3 + b^3 \neq c^3$. His name is included among others such as Abū'l-Wafā al-Buzjanī (940–997), Abū Naṣr Maṣṣūr ibn 'Alī ibn Irāq (ca. 1000), and ► **Naṣīr al-Dīn al-Ṭūsī** (1201–1274) to whom the discovery of the sine law is attributed. The sine law says that if ABC is any triangle, then $\frac{c}{b} = \frac{\sin C}{\sin B}$.

Although we do not have any reliable information on whether al-Khujandī founded an observatory on Jabal Tabrūk, in the vicinity of Rayy, he tells us that he made observations on planets for Fakhr al-Dawla with armillary spheres and other instruments and prepared a ► **zīj** (astronomical handbook with tables) entitled *al-Fakhrī* based on these observations. According to E. S. Kennedy an incomplete copy of a *zīj* in the Library of the Iranian Parliament (Tehran Ms. 181) may be attributed to al-Khujandī.

His fame depends on an important instrument constructed for the measurement of the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). This instrument surpassed all previous ones in size. Al-Khujandī praises his instrument and says that it is of his own invention. It is a 60° of meridian arc and is called *al-suds al-Fakhrī*, after Fakhr al-Dawla. Although *suds* means the sixth part of a circle (i.e., to say sextant), in reality it is constructed in place of a mural quadrant. As the distance between the summer solstice and the winter solstice is about 47°, a 60° of meridian arc is enough for observations of the sun. It has a radius of about 20 m, and each degree was subdivided into 360 equal parts. Therefore each 10 s portion was distinguished on the scale, and with it the limit of precision had been pushed to seconds.

This arc was constructed between two walls erected on the meridian. On the arched ceiling there was a hole through which the sun's rays passed and there were projections on the divisions of the arc. ► **Al-Bīrūnī** tells us that the aperture sank by about a span, and caused a slight displacement of the center of the arc.

In 384 H (AD 994), al-Khujandī observed the summer solstice in the presence of a group of scientists. They gave their written testimony concerning the observations. Although the cloudy weather prevented his observing the winter solstice, he calculated the position of the sun from the observations made preceding the solstice. The result was 23°32'19". According to al-Bīrūnī, displacement of the center of the arc also affected the result. By comparing this result to the Indian astronomers' and Ptolemy's he deduced that the obliquity of the ecliptic was decreasing. He also fixed the latitude of Rayy (35°34'39").

He describes a kind of astrolabe which is called *shāmīla* (universal instrument) in his *Risāla fī A'māl al-'amma* (Treatise on the Construction of the Universal Instrument). The astrolabe, which carried a stereographic projection of the heavens on a circular plate, is a portable instrument. As we know from existing specimens, they ranged in size from 2 in. to 2 ft in diameter. They were used to measure the altitudes of the sun and to show the places of the stars in certain latitudes. Khujandī's *shāmīla* could be used over a larger territory than former ones. He also provides methods of projection concerning intersections of circles of the azimuth by the equator and *muqantarāt*. Abū Naṣr Maṣṣūr mentions al-Khujandī's two methods on this topic. Al-Bīrūnī, in his *Tahdīd Nihāyāt al-Amākin* (Limit of Ends of Places), states that al-Khujandī was unique in his age for his constructions of astrolabes and other astronomical instruments.

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Al-Khwārizmī

Jacques Sesiano

Al-Khwārizmī, Muḥammad ibn Mūsā, is the earliest Islamic mathematician and astronomer of fame, and his works had considerable influence in the medieval world. His name suggests that he was of Persian origin, but his treatises were written in Baghdād during the caliphate of ► [al-Ma'mūn](#) (813-833).

The *Algebra* (possibly *al-Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa'l muqābala*), al-Khwārizmī's best known work, consists of four parts of very unequal length. The first part explains the fundamentals of algebra: the resolution of the six basic types of equations of first and second degree (with positive coefficients and at least one positive solution), then basic algebraic reckoning (with expressions involving an unknown or square roots); then, six examples of problems each ending with one of the six equations, and lastly various other problems of the same kind. This structure as well as some characteristic features (no symbolism, numbers written in words, illustrations of algebraic rules by geometrical figures) remained customary in early textbooks on algebra. The second part contains a few considerations on the application of the rule of three to commercial transactions. Part 3 covered surfaces and volumes of elementary plane and solid figures, mostly without any use of algebra. The lengthy part 4 is devoted to the application of

algebraic methods (or simple arithmetic) to the sharing out of estates in accordance with wills and Islamic legal requirements regarding the parts due to heirs.

Several Latin translations of parts 1 and 2 were made in the Middle Ages.

The *Arithmetic* (possibly *Kitāb al-ḥisāb al-hindī*) exposes the newly introduced Indian positional system of numerals and its use in arithmetical operations and (square) root extraction, for integers and fractions, both common and sexagesimal. This work is lost in Arabic, but has survived in two Latin translations.

The ► [Zīj al-sindhī](#) (*Astronomical Tables*), al-Khwārizmī's best known work in astronomy, is a set of tables based mainly on Indian material. Instructions on the use of the various tables are provided; with their help, one can determine the mean motion of the seven known celestial bodies, also daily motions, sizes, and eclipses of the sun and moon; calendric and trigonometrical tables are included. We do not know the original text, since only a Latin translation of a later reworking has come down to us.

The *Kitāb ṣūrat al-arḍ* (*Geography*) is a list of longitudes and latitudes of cities, mountains (geographical points along), sea coasts, islands, center points of regions and countries, and detailed courses of rivers. The information is drawn from Ptolemy's *Geography*, but improvements are found, mostly, of course, for the regions under Islamic rule or traveled through by Arabian merchants.

The *Istikhrāj ta'rikh al-yahūd* (*Calendar of the Jews*) is the oldest extant description of the modern Jewish calendar. After reporting that God inspired it to Moses (its Mesopotamian origin was unknown to al-Khwārizmī), we are told about the year and the intercalation of seven intercalary months within the 19 year (Metonic) cycle and how to determine on which day *rosh ha-shana* falls. Next we are given the positions of the celestial bodies at the beginning of three eras (Adam, Temple of Jerusalem, and Alexander). Finally, we are taught how to determine the mean positions of the sun and moon for any given date and the time elapsed since their last conjunction.

The *Kitāb al-ʿamal bi'l-asturlāb* (On the Use of the Astrolabe) contains short instructions, but perhaps not in their original form. We are taught how to find altitudes of celestial bodies, and how to determine time or latitudes from celestial observations.

The purpose of another minor work, *Kitāb al-rukhāma* (On the Sundial), is to explain the construction of a plane sundial; the appended tables are given for various latitudes besides that of Baghdād.

A *Kitāb al-taʿrīkh* (Chronicle) is known by quotations from other historians; it reported purely historical events and covered at least the years 632–826.

As to lost works, a short treatise *Kitāb ʿamal al-aṣṭur-lāb* (On the Construction of the Astrolabe) is attributed by Arabian bibliographers to al-Khwārizmī (it may be extant as an anonymous work). At the end of his *Algebra*, ► [Abū Kāmil](#) explains a short way for calculating the result of the duplication on the chess-board's cells ($1 + 2 + 2^2 + \dots + 2^{63} = 2^{64} - 1$), which he attributes to al-Khwārizmī but which appears in no known work of his. Another lost work was concerned with the rule of false position.

Al-Khwārizmī has enjoyed a great reputation, particularly as the first algebraist. Although he seems not to have made a great number of original contributions, he was a learned man of great versatility and didactical ability. His role was primarily that of a disseminator of science in early Islamic times. As some of his works were studied in eleventh century Spain, he played the same role for the Christian world through Latin translations. The latinization of his misread Arabic name as *algorismus*, later misread as *algoritmus*, later misinterpreted as *algorithmus*, has kept his name if not his fame alive until the present time.

See Also

- [Algebra in China](#)
- [Astrolabe](#)
- [Sundials in Islam](#)

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Al-Kindī

George N. Atiyeh

Al-Kindī, Abū Yūsuf Yaʿqūb ibn Ishāq, was born ca. 801 in Kūfah and died ca. 866 in Baghdad.

Often called the Philosopher of the Arabs, little is known with certainty about the life of this early Muslim philosopher and scientist. He flourished in Baghdad, then capital of the Abbasid Empire and center of its intellectual life. Greek, Persian, and Indian works were being translated into Arabic and a multitude of religious and other thinkers were developing new and sophisticated schools of thought and literature. The *Mutakallimūn*, Islamic theologians, were actively engaged in controversies over God's attributes and freedom of the will as well as over the methodology of knowledge. During the life of al-Kindī, Baghdad experienced the political ascendancy and fall of the dialectical theological movement of the *Muʿtazilah*, a movement that used a rationalistic approach to defend the religious dogmas of Islam. Al-Kindī sympathized with some ideas of this movement such as the uniqueness of God, his justice, and the use

of a rational approach in the defense of Islam against its opponents. Also like *al-Muʿtazilah*, al-Kindī looked at God as the ultimate source of all being, yet believed his creations were independent in their daily function.

Most of the works of al-Kindī have, unfortunately, disappeared. Ibn al-Nadīm (d. ca. 987), one of the earliest bibliographers of Islam, lists 242 works, mostly essays and epistles, dealing with a wide range of sciences: logic, metaphysics, mathematics, spherics, music, astronomy, geometry, medicine, astrology, theology, psychology, politics, meteorology, prognostics, and alchemy.

The scientific works of al-Kindī are by far the most numerous. In fact there are among the early Arabic authors many who considered him a mere scientist and not a philosopher. Z. al-Bayhaqī (d. 1169), who is often cited, referred to him as an engineer, and ► **Ibn Khaldūn** (d. 1406) did not list him among the philosophers. Whatever the case may be, one can find in al-Kindī's presently known works the outline of a philosophical system. Based on his treatise *Fī al-Falsafah al-ula* (On First Philosophy), al-Kindī defined philosophy as the "knowledge of the realities of things according to human capacity." He stressed the cumulative character of philosophy and the duty to receive the truth gratefully from whatever source it comes. He distinguished between philosophy and theology proper as two different disciplines, both pursuing and reaching the same goal, which is truth. The first pursues it through arduous research and effort, the second through prophetic knowledge which is granted to certain individuals immediately and without any effort. He established the various divisions of philosophy on the basis of the different channels of human knowledge, the sense experience of material entities and that of rational cognition of immaterial ones. First philosophy or metaphysics is concerned with the First Principle, the True One, the Necessary and Uncaused Being who is eternal and infinite. Probably drawing upon the ideas of the pre-Islamic John Philoponus who championed the concept of creation ex nihilo, he opposed the Aristotelian theory of the eternity of the universe. The chief attribute of God, argued al-Kindī, is unity. God is the only real

agent or cause in the world. Unlike the Muslim theologians, he did not ignore the role of secondary agents in the process of nature. He established the premise that the causes of generation and corruption are the heavenly bodies, which are superior to the physical bodies and possess intelligence.

The writing of al-Kindī on the soul and the intellect are neither numerous nor comprehensive. Besides his important short treatise *Risālah fī māʿiyat al-ʿaql* (On the Intellect), he wrote *Kalām fī al-naḥs mukhtaṣar wajīz* (A Discourse on the Soul Abridged and Concise) where he explains the nature of the union between the soul and the body as different from the union between the elements. Inspired by Aristotelian, Platonic, and Pythagorean sources, he considered the soul as the principle of life and only accidentally related to the body, being nobler in nature. In his *On the Intellect*, al-Kindī presents a Platonic interpretation of Aristotle's noetics. He defines the intellect as "a simple essence cognizant of things in their true realities." There are four intellects, the first of which is separate and seems to be construed in the image of Aristotle's active intellect. It exists outside the human soul and is the cause of "all intelligible thoughts and secondary intellects." The four intellects – the active, the potential, the habitual, and the manifest or acquired – played an important role in the history of medieval discussions on the nature of the intellect. In his *Risālah fī daḥḍ al-aḥzān* (On the Means to Drive Away Sadness), al-Kindī offers practical advice to overcome sorrow based on the principle that true riches are not material by nature. What causes sadness is the loss of externals and the failure to attain what we highly cherish. By despising external things and educating our souls to seek what is spiritual, we avoid the miseries of sorrow.

With many of his scientific works not available, it is difficult to offer a systematic exposition of al-Kindī's scientific works and contributions. They covered almost all fields of the physical sciences and went beyond the mere transmission of Hellenic scientific data by adding to it through observations of his own and some rudimentary experimentation. Al-Kindī took over the Greek

scientific heritage which was available in translations or which he had helped to translate, and tried to assimilate, summarize, and at times develop it and experiment with it. In his classification of the sciences, he starts from the idea of a hierarchy of beings according to which the lower sciences deal with sensible beings and higher sciences with the nobler and intelligible beings. There is a close relationship, however, between science and philosophy, especially mathematics, which he considers preparatory and essential to the study of philosophy. He uses mathematical concepts and arguments when discussing infinity and plurality in proving his theory of the unity of God.

Al-Kindī was not satisfied with the role of the transmitter and commentator. In many of his scientific works we feel the surge of an investigative spirit. In works on optics, pharmacology, and music, for example, he provided new data and approaches, thus enhancing our knowledge of these subjects, among many others. At times, he sought to verify some statements through experimentation, as when he shot an arrow in the air to verify Aristotle's statement that substances expand when heated. In his work *Risālah fī ikhtilāf al-manaṣīr* (*De Aspectus*), which is based on Euclid and Heron of Alexandria's optics, he rejected the Euclidean theory of the emission of light, and using geometrical arguments, he offered amendments so it conformed with observable data. Furthermore, al-Kindī gave an original interpretation independent from that of Aristotle of the azure blue we see in the sky. He argued that the color we actually see is the reflection of light from vapors and particles of dense bodies carried up into the atmosphere.

Likewise, al-Kindī, in his medical and pharmaceutical works, was a contributor of new ideas trying to improve upon the knowledge of antiquity. In his work on pharmacology *Risālah fī ma'rifat qūwah al-adwīyah al-murakkabah* (translated into Latin as *De medicinarum compositorum grabidus investigandis libellus*), he applied the principles of posology [the study of dosages]. He based the efficacy (*qūwah*) of compound medicine upon geometrical progression. He linked the degree of intensity with the

numerical changes in the qualitative forces that produce them. The efficacy corresponds to the proportion of the sensible qualities: warm, cold, dry, and humid. If a compound medicine was to be warm in the first degree, it had to possess double the equable mixture. If it was to be warm in the second degree, it had to possess four times as much, etc.

The same tendency to improve on the ancient sciences is seen in his works on music. For example, he used the letters of the alphabet to designate the notes of the scale. Al-Kindī's musical works in Arabic on the theory of music paved the way for the *Kitāb al-musiḳi al-kabir* (Great Book on Music) by al-Fārabī.

Al-Kindī's influence in medieval Europe might not be as great as the other Arabic philosophers such as Ibn Sīnā and Ibn Rushd; he was nevertheless a courageous intellectual and scientist. Whether he was the first philosopher in Islam is still not ascertainable in the absence of many of his philosophical works. There is no doubt, however, that he was the first in Islam to bridge the gap between philosophy and the Islamic dogma, thus establishing the conceptual framework that became characteristic of philosophy in Islam.

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Almagest: Its Reception and Transmission in the Islamic World

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Around AD 150, Ptolemy wrote his great handbook of astronomy called *Mathematike Syntaxis* (The Mathematical Composition) in the original Greek. Because of its importance, it soon received wide attention throughout the Hellenistic world. Its fame seems to have radiated into the Middle East, because there are hints that the work was known, and perhaps even translated partially or completely, into Middle Persian (Pahlavi) under the Sassanian ruler Shāhpur I (reigned AD 241–272). A second period of intensive contact of the Persians with Greek science was in the

middle of the sixth century, after the closing of the Academy in Athens (AD 529), when several Greek scholars sought refuge in Persia. At this point, Ptolemy's work may again have been brought to the attention of Persian scholars. However, this was the first knowledge of the Arabs (who conquered the Middle East and established the Islamic empire of the caliphs around the middle of the seventh century) about Ptolemy and his work betrays Persian influence. The Arabs first knew Ptolemy's astronomical handbook under the title *Kitāb al-majāsī* (The Book Almagest), which evidently derives from a Greek superlative (*Megiste* [scil. *Syntaxis*], The Greatest Composition). Under this title, the book was already known in Arabic-Islamic circles before the translations proper. It would seem that the Arabic spelling *al-majāsī* is derived from a Middle Persian form rather than from the Greek directly – a Middle Persian spelling *mgstyk* is documented, and a form like this may have led to the Arabic spelling *al-majāsī*. Later, in twelfth-century Spain, the Europeans translated Arabic scientific works into Latin and converted the Arabic *al-majāsī* into Latin *almagesti*, and henceforth Ptolemy's work has been known in the West under this short title, Latinized from an Arabized Greek word. It may be added that in the direct transmission, in Greek, the title *Megiste Syntaxis* has not yet been found – here we have only the forms *Mathematike Syntaxis* or *Megale Syntaxis* (The Great Composition).

Direct knowledge of the text of the *Almagest* in Arabic-Islamic science developed through a series of translations from Greek into Arabic. Before the Arabic translations, a translation was made into Syriac, the language common among Christian monks and scholars who later played the main role in the translation of Greek scientific works into Arabic. It is not known when and by whom this Syriac translation was made, but it is probable that the first translators of the work into Arabic knew and used the Syriac version. Still, in the twelfth century, Ibn al-Ṣalāḥ had the Syriac version to hand. A first Arabic translation of the *Almagest* was made some time around AD 800 – its text is now lost, but it was often cited by Arabic-Islamic astronomers and bibliographers as “the

first” or “the old” or “the mamūnian” translation, after the caliph al-Ma’mūn, who patronized translations and scientific work in general. Traces of it are found in the astronomical work of al-Battānī (d. 929) and in Ibn al-Ṣalāḥ. A second translation was made in 827–828 by al-ḥajjāj ibn Yūsuf ibn Maṭar in cooperation with a Christian, Sergius the son of Elias. Of it, two manuscripts have survived until our times, one complete and the other fragmentary. About 50–60 years later, a third translation was made by Ishāq ibn Ḥunayn (830–910). It was soon afterward revised by Thābit ibn Qurra (836–901) – of this revised version, ten manuscripts are still extant today.

The two versions of al-ḥajjāj and of Ishāq revised by Thābit were received in Muslim Spain – they were both used by Gerard of Cremona for his translation of the *Almagest* into Latin (Toledo, ca. 1150–1180). Gerard’s Arabo-Latin version then remained the standard version of the *Almagest* in Europe until Renaissance times.

In the following centuries, Arabic-Islamic astronomers not only studied the *Almagest* as their main source in astronomy, but they also wrote commentaries on the entire book or on problems of detail. Fuat Sezgin lists more than 30 commentaries, several of which were afterward commented upon themselves. Among the numerous commentators, two shall be named here. Ibn al-Ṣalāḥ (d. 1154) is important, because he had to hand five versions of the *Almagest* (the Syriac version, the “old” version, the version of al-ḥajjāj, the original of Ishāq’s version, and Ishāq’s version as revised by Thābit) from all of which he tried – by comparing the texts and by observing the stars – to establish the best values in longitude and latitude for a selected number of stars from the star catalog in the *Almagest*. Another famous commentator was Naṣīr al-Dīn al-Ṭūsī (1201–1274) who wrote revisions of many translated Greek mathematical and astronomical texts, which included the *Almagest* – his *Tahrīr* (based on the version of Ishāq as revised by Thābit) survives in numerous manuscripts, but is still unedited.

The last Oriental translation of the *Almagest*, from al-Ṭūsī’s *Tahrīr* into Sanskrit, was

made in 1732, in Jaipur, India, by order of Maharaja Jai Singh II.

The title *al-majasī/Almagest* became so famous that other authors freely used the name for their own works, both in the East and in Europe, e.g., the *Kitāb al-majasī* (The Book *Almagest*) of the mathematician Abu’l-Wafā’ al-Būzjānī (940–987 or 998), the *Almagestum novum* of the astronomer Giovanni Riccioli (1651), or even the *Almagestum Botanicum* of Leonard Plukenet (1696).

See Also

- [Abū’l-Wafā’](#)
- [al-Battānī](#)
- [al-Ma’mūn](#)
- [Ishāq ibn Ḥunayn](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Thābit ibn Qurra](#)

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Al-Māhānī

Yvonne Dold-Samplonius

Al-Māhānī, Abū 'Abd Allāh Muḥammad ibn 'Īsā, was born in Māhān, Kerman, Iran. He lived in Baghdad, ca. 860 and died ca. 880.

Little is known about al-Māhānī's life, and few of his works are extant. In the *ḥākimate Tables* Ibn Yūnus cites observations of conjunctions and lunar and solar eclipses made by al-Māhānī between 853 and 866. In the only extant astronomical work, *Maqāla fī Ma'rifaṭ as-samt li-aiy sā'a aradta wa-fī aiy mauḍi' aradta* (On the Determination of the Azimuth for an Arbitrary Time and an Arbitrary Place), al-Māhānī added arithmetical solutions to two of the graphic ones. His method corresponds to the cosine formula in spherical trigonometry, and is later applied by ► [al-Battānī](#).

Al-Māhānī worked on the fundamental problems of mathematics of his time and is especially known for his commentaries to Euclid's *Elements*, to Archimedes' *De Sphaera et Cylindro* (On Spheres and Cylinders), and to the *Sphaerica* by Menelaus. In the last treatise, now lost, he inserted explanatory remarks, modernized the language, especially the technical terms, and remodeled or replaced obscure proofs. It was revised and finished by Aḥmad ibn Abī Sa'īd al-Harawī in the tenth century. Al-Tūsī considered al-Māhānī's and al-Harawī's improvements valueless and used the edition by Abū Naṣr Maṣṣūr ibn 'Irāq. This redaction, the most widely known Arabic edition, is included in the collection of the *Intermediate Books*. These were the

books read between Euclid's *Elements* and Ptolemy's *Almagest*.

Of the commentaries to the *Elements* only those to Book V and to Book X are extant. In the former al-Māhānī compared magnitudes by comparing their expansion in continued fractions, referring to Thābit ibn Qurra. Ratio is defined as "the mutual behavior of two magnitudes when compared with one another by means of the Euclidian process of finding the greatest common measure." Two pairs of magnitudes were for him proportional when "the two series of quotients appearing in that process are identical." Essentially the same theory was worked out later by ► [al-Nayrīzī](#). Neither established a connection with Euclid's definition, which was first done by Ibn al-Haytham. In the commentary to Book X al-Māhānī examined and classified not only quadratic irrationalities, but also those of the third order. In contrast with Euclid, for whom magnitudes were only lines, he considered integers and fractions alike as rational magnitudes, while regarding square and cube roots as irrational ones. Al-Māhānī then explicated the contents of Book X using rational and irrational numbers instead of geometric magnitudes.

According to al-Khayyāmī, al-Māhānī was the first to attempt an algebraic solution of the Archimedean problem of dividing a sphere by a plane into segments, the volumes of which are in a given ratio (*De Sphaera et Cylindro* II, 4). He expressed this problem in a cubic equation of the form $x^3 + a = cx^2$, but he could not proceed further. Al-Khayyāmī relates that the problem was thought unsolvable until al-Khāzin succeeded by using conic sections.

See Also

- [al-Battānī](#)
- [Al-Nayrīzī](#)
- [Elements: Reception of Euclid's *Elements* in the Islamic World](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn Yūnus](#)
- [Thābit ibn Qurra](#)
- [Umar al-Khayyām](#)

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Al-Majrīṭī

Emilia Calvo

Al-Majrīṭī Abū-l āsim Maslama ibn Aḥmad al-Faraḍī was born in Madrid, Spain in the second half of the tenth century and died in Cordoba ca. AD 1007. He settled early in Cordoba where he studied with Abū Ayyūb ibn ʿAbd al-Gāfir ibn Muḥammad and Abū Bakr ibn Abī ʿĪsā. He was engaged in making astronomical observations in about AD 979; he may have served as court astrologer.

He had a number of disciples who made his work known throughout the provinces of Spain. Among them were al-Kirmānī (d. AD 1066); Abū-l-Qāsim Aṣḥbagh, known as Ibn al-Samḥ (d. AD 1035) who is the author of a treatise on the construction and use of the astrolabe in 130 chapters and of the *Book of the Plates of the Seven Planets*, of which the original Arabic version is lost. [However, it was translated into Spanish and included in the *Libros del Saber de Astronomía*;] Abū-l-Qāsim Aḥmad known as Ibn al-ṣaffār (d. AD 1034), who is the author of a treatise on the astrolabe attributed in its Latin version to al-Majrīṭī; Ibn al-Khayyāt; al-Zahrāwī; and Abū Muslim ► *ibn Khaldūn* of Seville.

Maslama's most important work is the adaptation of al-Khwārizmī's astronomical tables

(► *zīj*) which were elaborated ca. 830. This adaptation is not preserved in his original Arabic form but in a Latin translation made by Adelard of Bath (fl. 1116–1142) and revised by Robert of Chester. The work done by Maslama in this adaptation illustrated his high degree of astronomical and mathematical knowledge.

Another work is an Arabic commentary on Ptolemy's *Planisphaerium*, entitled *Taṣṭīḥ baṣīṭ al-kura* (Projecting the Sphere onto a Plane), which deals with the stereographic projection on which the conventional astrolabe is based. This adaptation is only preserved in a Latin version by Hermann of Dalmatia (1143) and in a Hebrew abridgement. This work was the point of departure of a long series of Andalusian treatises on this topic. Maslama also knew the *Almagest* as well as al-Battānī's tables.

Maslama also wrote a treatise on *muʿāmalāt* (commercial arithmetic) which probably dealt with sales, cadastre (an official record of property ownership and value), and taxes using arithmetical, geometrical, and algebraic operations.

Some other works are attributed to him, such as *Rutbat al-ḥakīm* (The Rank of the Sage), composed after AD 1009, and *Ghāyat al-ḥakīm* (The Aim of the Sage), translated into Spanish in AD 1256 by order of Alfonso el Sabio and distributed throughout Europe under the name of *Picatrix*.

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Al-Ma'mūn

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Al-Ma'mūn, Abul'-Abbās 'Abdallāh ibn Hārūn, was born in 786 in Baghdad, and died in 833 near Tarsus, in a campaign against the Byzantines.

Al-Ma'mūn was not himself a scientist. He was the seventh caliph of the dynasty of the Abbassids, son and second successor of the famous caliph Hārūn al-Rashīd (well known from the tales of the Arabian Nights). He ruled the Islamic empire from 813 to 833, at first from Marw (in the Eastern province of Khurāsān, where he was based before his accession), and from 819 from the capital of Baghdad (founded in 762 by the caliph al-Manṣūr). In the intellectual history of the Islamic world and in the history of science, al-Ma'mūn played an important role as an instigator and patron of many important activities. He was a firm adherent of the Mu'tazila, a rational school of Islamic theology which was strongly influenced by Greek philosophy; in 827 he declared Mu'tazilism the official doctrine for the whole empire. His interest in philosophy and the sciences manifested itself in many ways. He initiated and patronized the translation of scientific works, mostly from Greek, but also from Persian and Syriac, into Arabic. One translation (of several successive versions) of Ptolemy's *Almagest*, and two translations (also of several successive versions) of Euclid's *Elements* were distinctly called, after him, "the Ma'mūnian version(s)." In the *Elements*, the theorem I, 15 was given, after him, the nickname *al-ma'mūnī*, "the Ma'mūnian [theorem]." Later, in the medieval Latin translation, this degenerated into *elnefea*, *id est fuga* and,

more contracted, *eleufuga* or *elefuga*. In 832 he founded the Bayt al-ḥikma (House of Wisdom, in continuation of a similar institution established earlier by his father Hārūn), which was established for collecting scientific texts, translation, and teaching. Further, on his order, astronomers carried out new measurements of many of the astronomical parameters transmitted in Greek texts, such as precession of the equinoxes, inclination of the ecliptic, length of the year, length of a degree of geographical latitude, geographical coordinates, etc. For many of these data, they arrived at remarkably better values. The results of the observations made by al-Ma'mūn's astronomers were laid down in a work called *al-Zīj al-mumtaḥan* (The Revised Tables, dated 829–830; in medieval Latin, *Tabulae probatae*); it is only preserved in a reworked form. These values were afterwards widely quoted and used by other Islamic and also medieval Western astronomers. From quotations in the *Elementa astronomica* of ► [al-Farghānī](#) (ninth century), al-Ma'mūn's name entered the West in the forms Almeon (Johannes Hispalensis's Latin translation of al-Farghānī's *Elementa*) and Maimon (Gerard of Cremona's translation of the same). On Riccioli's map of the moon (1651) a crater was called Almaeon (i.e., the aforementioned Almeon); as Almanon the name survives on modern charts, in permanent memory of this remarkable Eastern ruler.

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Elements: Reception of Euclid's Elements in the Islamic World](#)
- [Precession of the Equinoxes](#)

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Al-Māridīnī, Jamāl al-Dīn, and Badr al-Dīn

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Jamāl al-Dīn al-Māridīnī was a competent astronomer who lived in Damascus or Cairo ca. 1400. He authored numerous short treatises, mainly dealing with instruments. One of the most remarkable of these instruments is a universal quadrant, the only known example of which is from Spain ca. 1580, made by a craftsman in the Louvain tradition (now in the Adler Planetarium, Chicago). His name indicates that he or his family came from Mardin, now in southern Turkey, but biographical information is lacking; indeed it is not even clear where he worked. He is often confused with his grandson, Sibṭ al-Māridīnī.

Badr al-Dīn al-Māridīnī, known as Sibṭ al-Māridīnī, lived in Cairo, ca. 1460. He was a grandson (Arabic *sibṭ*) of Jamāl al-Māridīnī and was one of the leading astronomers in Cairo. He compiled a large number of treatises, including many short works on the standard instruments of his time, the trigonometric and astrolabic quadrant and sundials. These treatises

became extremely popular and exist in hundreds of copies. In fact they were studied by everyone in Egypt who was interested in astronomy in the succeeding centuries. As a result of this, more significant works were forgotten and the level of astronomy declined.

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Al-Mas'ūdī (Abu' 'l ḥasan 'Alī Ibn al-ḥusayn al-Mas'ūdī)

Mushtaqur Rahman

In the tenth century A.D. Muslims were arguably the leaders of world sciences, including geography. Many Muslim geographers, including al-Mas'ūdī, established the principles of science and research in geography. Al-Mas'ūdī's geographic curiosity took him as far as China and Madagascar. His conceptual orientation, which

combined geography and history to explain cultural history, made him an outstanding scholar.

Not much is known about al-Mas'ūdī's early life and education, except that he was born in Baghdad in A.D. 893 and died in Old Cairo, Egypt, in A.D. 956. His two surviving books, *Murūj al-dhahab wa-Ma'ādin al-Jawhar* (Meadows of Gold) and *Kitāb al-tanbīh wa'l-Ishraf* (Book of Indication and Revision) provide no biographical information. Presumably, his early education was with historians, philosophers, scientists, *ḥadīth* specialists (those who study the words of the Prophet Muḥammad), grammarians, and literary critics. He began his travels at the age of 23 to seek geographic knowledge and ended them when he was 56 years old. He lived and traveled during a period of Islamic Renaissance in many fields including geography.

In his book, al-Mas'ūdī described the shape of the earth, seas and their depths, islands, mountains and rivers, mines, marshes, and lakes. He also provided information on inhabited areas and explained why land and sea changed their forms.

As a historian and geographer, al-Mas'ūdī broadened the concept of geography by including all the known branches of geography in his discussions. In doing so he benefited equally from the scholarly works of both Muslims and non-Muslims. He quoted quite extensively from Greek, Persian, and Indian sources. Al-Mas'ūdī also studied people within their own habitats. To him, "nature" (*ṭabī'ā*) meant the processes of the external physical world. He related those processes to humans in the universe, the activity of God in history, and the growth and development of societies.

An aspect of the development of Arabic geographic literature of his period was the production of maritime literature and travel accounts. Al-Mas'ūdī also made important contributions to the field of oceanography, but his reputation as a scholar and scientist is based on his two surviving books on history and natural history.

Al-Mas'ūdī had a universal outlook. He focused on a wide range of topics dealing with

Islamic and non-Islamic cultural histories and provided elaborate cultural, historical, geographical, ethnological, climatic, and maritime descriptions of the known world of his time. He was a cultural geographer of the first order, and far ahead of his time.

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Al-Muqaddasī

Mushtaqur Rahman

Born at Al-Bayt al-Muqaddas (Jerusalem) in A.D. 946, al-Muqaddasī (Shams ad-Dīn Abū 'Abdallāh Muḥammad ibn Aḥmad ibn Abī Bakr al-Bannā'), also called al-Maqdisī, made important contributions in regional geography. In his early days he studied Muslim history, especially its political and cultural aspects, civilization, religion, and jurisprudence. To seek knowledge he visited distinguished scholars, met the men of science, and studied in royal libraries at a fairly young age.

Among other Arab geographers of the time, al-Muqaddasī's definition of a region was probably the most original and produced one of the most valuable treatises in Arabic literature, *Kitāb aḥsan-al taqāsim fī ma'rifat al-aqālim* (The Best Divisions for the Classification of Regions). Though al-Muqaddasī belonged to the Balkhī school, he was critical of it and felt that they disregarded real geography. He argued that scientific geography must be based on observation. He critically examined the information presented by Al-Jayhānī, al-Balkhī, Ibn al-Faqīh, al-Jahiz, and others and questioned their methods of acquiring information, their objectives, and their misrepresentations and selectivity of information. Then al-Muqaddasī stated:

I have endeavored not to repeat anything other writers have written, nor narrated any particulars they narrated, except where it was necessary, in order neither to deny their right nor myself to be guilty of plagiarism, for in any case those alone will be able to appreciate my book who examine the works of those authors or who have travelled through the country, and are men of education and intelligence.

Al-Muqaddasī claimed that no one who had treated geography before him adopted his method or provided the information he did. In order to achieve his objective, he traveled through the Muslim world, with the exception of Spain and Sindh, conversed with scholars, and waited on princes. He discussed matters with judges, studied under doctors of law, frequented the society of men of letters, and associated with people of all classes until he attained what he wanted.

In his book, *Aḥsan al-taqāsim*, al-Muqaddasī divided the Muslim empire into 14 divisions, and treated the Arab world separately from the non-Arab world. Then he described the districts in each division, identifying their capitals and principal cities and giving their towns and villages in due order. Information which did not fit into either the Arab or non-Arab context was treated separately. While treating the regions in their entirety, Al-Muqaddasī provided a regional framework, and can rightly be called the father of regional geography.

See Also

- [Balkhī School of Arab Geographers](#)
- [Geography in the Islamic World](#)

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Al-Mu'taman ibn Hūd

Jan P. Hogendijk

Yūsuf Al-Mu'taman ibn Hūd was the king of the kingdom of Zaragoza in Northern Spain from 1081 until his death in 1085. He lived in the Aljafería palace in Zaragoza, which was built by his father Aḥmad al-Muqtadir ibn Hūd (r. 1041–1081), and which is now the site of the Parliament of Aragon. Al-Mu'taman was interested in mathematics, optics, and philosophy. He wrote a very long mathematical work, the *Kitāb al-Istikmāl* (Book of Perfection), of which large parts have recently been identified in four anonymous Arabic manuscripts in Copenhagen, Leiden, Cairo, and Damascus. A revised version of the whole *Istikmāl* was recently discovered.

In the *Book of Perfection*, al-Mu'taman divides most of pure mathematics according to a philosophical classification in five “species” (*anwā'*). Species 1 deals with arithmetic and the theory of numbers. Al-Mu'taman summarizes the arithmetical books of Euclid's *Elements*, and he proves Thābit ibn Qurra's rule for amicable numbers. The remaining species 2–5 deal with

geometry. Al-Mu'taman summarizes the works of Greek authors such as the *Elements* and *Data* of Euclid (300 BCE), *On the Sphere and Cylinder* of Archimedes (250 BCE), and the ► [Conics](#) of Apollonius (200 BCE). He does the same for Arabic authors as well, such as the *Quadrature of the Parabola* (Miṣāḥat al-qaṭ' al-mukāfi) by ► [Ibrāhīm ibn Sinān](#) (909–946) and the *Optics* (Kitāb al-Manāẓir), *On Analysis and Synthesis* (Fī'l-tahlīl wa'l-tarkīb), and *On Given Things* (Fī'l-ma'lūmāt) by Ibn al-Haytham (965–ca. 1041). The summaries in the *Book of Perfection* show that al-Mu'taman really understood these works. Often he was able to shorten and generalize their contents quite drastically.

Al-Mu'taman does not mention his sources, and he does not tell us what his own contributions are. The *Book of Perfection* probably includes some original contributions, such as a construction of two mean proportionals between two given lines by means of a circle and a parabola. A few geometrical theorems occur in the *Book of Perfection* for the first time in history, such as the theorem of Ceva (hitherto named after Giovanni Ceva, who independently discovered it in 1678), and the general proof of the invariance of crossratios under a perspectivity (a special case was proved by Pappus of Alexandria in late antiquity). It seems that al-Mu'taman intended to add to the *Book of Perfection* a second part on astronomy and optics, but he probably did not have the time to do so.

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Al-Nayrizī

Sonja Brentjes

Born in Persia, al-Nayrizī spent most of his life in Baghdad. He was a court astronomer/astrologer of caliph al-Mu'taḍid (r. 892–902), to whom he dedicated several treatises, among them *Al-Risāla fī aḥdāth al-jaww* (Treatise on Meteorological Phenomena) or *Al-Risāla fī ma'rifaṭ ālāt yu'lamu bihā ab'ād al-ashyā' al-shākhiṣa fī l-hawā' wal-latī 'alā basīṭ al-arḍ wa-aghwār al-audīya wa'l-abār wa-urūḍ al-anhār* (Treatise on the Knowledge of Instruments through which Distances between Distinct Things in the Air or Set up on the Ground and the Depth of Valleys and Wells, and the Widths of Rivers Can be Known). He wrote commentaries on Ptolemy's (fl. ca. 127–167) *Almagest* and his astrological work *Tetrabiblos* and an astronomical handbook (*Zīj*), a longer and a shorter version. And he commented on Euclid's (fl. ca. 300 BCE) *Elements* and his astronomical work *Phainomena* and wrote independent works on the determination of the *qibla*, the direction of Mecca, the spherical astrolabe, methods for solving particular astronomical problems, and astrological subjects.

The longer version of his *Zīj* is said to have been based upon Indian astronomical tradition (*Sindhind*) and used data from the *Zīj* prepared for ► [al-Ma'mūn](#) (r. 813–833). This was criticized by Ibn Yūnus (d. 1009), who pointed out further differences in opinion, especially with respect to the theory of Mercury, the eclipse of the moon, and the parallax. His commentary on the *Almagest*, lost as are his handbooks and his commentary on the *Tetrabiblos*, was quoted by later authors like ► [al-Bīrūnī](#) or Ibn al-Haytham and even occasionally called the best work of this type.

His extant works on the *qibla* and the spherical astrolabe built on the works of earlier scholars are some of the very best summaries on the subject still available. Others of his extant works on

astronomy, astrology, geodesy, and meteorology have not yet been seriously studied.

Al-Nayrīzī's commentary on the *Elements* translated by Gerard of Cremona (d. 1187) into Latin includes extracts of the lost Greek commentaries by Heron (second century?) and Simplicios (sixth century) and of Arabic treatises like Thābit Ibn Qurra's alternative proof of the Pythagorean theorem. He omitted Simplicios' own proof of the parallels postulate in favor of that by Aghānīs/Aghānyūs (Agapios?, fl. ca. 511), which is also preserved in his independently transmitted *Al-Risāla al-m u šādara al-mashhūra* (Treatise on the Proof of the Well-Known Postulate).

In Book V, al-Nayrīzī follows a theory of proportion adopted before him by ► [al-Māhānī](#) (d. ca. 880) and, perhaps, Thābit ibn Qurra, a theory based on definitions of ratio and proportion which compared the expansion of magnitudes in continued fractions.

The text of the *Elements* contained in the Arabic manuscripts of al-Nayrīzī's commentary was viewed for a long time as the second version made by al-ḥajjāj ibn Yūsuf ibn Maṭar. Although it is derived from a text of the ḥajjāj tradition, al-Nayrīzī evidently edited it using a text of the Iṣḥāq/Thābit tradition. He changed its language, didactical features, and even letter symbols used for diagrams. He incorporated references to earlier Euclidean theorems, definitions, postulates, or axioms as well as to propositions stated by the Greek commentators. In a similar manner, he edited those texts he added as comments.

See Also

- [al-Bīrūnī](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [al-Māhānī](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn Yūnus](#)
- [Qibla and Islamic Prayer Times](#)
- [Thābit ibn Qurra](#)
- [Zīj](#)

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Alphabet

Sema'am I Salem

As far as we know, literacy goes back to about 3500 BCE. The earliest people to have left written symbols are the Sumerians, followed by the Egyptians. The earliest clay tablets unearthed in Mesopotamia are picture writings which have not yet been deciphered, but those written after 3200 BCE are clearly Sumerian and their content is well known. Their subject matter includes groups of words, accounts of deeds of sale, and some fragments of early literature.

The Sumerians wrote primarily on clay tablets, producing wedge-shaped characters, which became known as cuneiform script, from the Latin *cunus* (wedge). It is quite probable that the idea of writing was introduced into Egypt from Mesopotamia. Soon after the Sumerians invented their script, the Egyptians formulated their own system, which consists of picture word-signs, and which they called *m-d-w-n-t-r* (speech of the gods), and which is now known by its Greek name, hieroglyphs (sacred, carved letters). The Egyptians then produced a simplified version, which is known as Hieratic (sacred). When the common Egyptians, not only the priests, learned to write, they used a highly simplified form known by the Greek name demotic (popular). Several scholars consider the demotic script a first step toward alphabetic writing.

By about 2000 BCE other forms of writing began to appear in various parts of the Middle East. The Hittites, who lived in modern-day Turkey, introduced a new form of hieroglyphs, consisting of some 70 signs, each of which stood for a simple syllable, and about 100 word-signs. Similar forms of hieroglyphs, consisting of word-signs and syllable-signs, were also used in Crete, Cyprus, Lebanon, Palestine, and Syria. The early script uncovered in Crete is in the form of pictograms and was probably introduced into Crete from Egypt. Although it has not been completely deciphered, it is known that it contains the names

of certain gods such as Zeus, Athena, and Poseidon.

All the word-sign methods of writing are complex and difficult to learn, and only professional scribes were able to read and write. To write a letter, keep an account, check a legal document, or read a will, an ordinary person had to rely on the services of trained scribes.

This monopoly on reading and writing persisted until the advent of the alphabet, whose invention is one of the most important and useful inventions of all time. The transformation from word or syllable writing to an alphabetic script is immense – it simplified the process of reading and writing to a degree that enabled a common person to master the art, thus freeing him from the need for professional scribes. Its value lies in its elegance and its simplicity, and in its ability to express all the vocal sounds needed in any language in about 2-dozen symbols.

There has always been speculation as to the origin of the alphabet, beginning with the early Greek and Latin authors, who credited the invention of the alphabet to practically every near-eastern country. Diodorus Sciculus states, "The Syrians are the discoverers of the letters, and the Phoenicians having learned them from the Syrians and then passed them to the Greeks." Pliny, on the one hand, claims that: "the invention of the letter is a Phoenician feat," and speaks also of a Mesopotamian origin. Tacitus maintains that the alphabet is of Egyptian origin, and adds, "The Phoenicians took all the credit for what they received before passing it on to others." The various views of the classical authors are mere speculations that demonstrate their awareness of the problem and their cognizance of the importance of the discovery.

Opinions as to the origin of the alphabet are still voiced. There are those who still believe that the alphabet is of Mesopotamian origin – they base their opinion on the Ugaritic script which dates back to about 1400 and which consists of 30 symbols representing 30 consonant letters written in cuneiform script.

The existence of an alphabet in a cuneiform script does not imply, in any way, that the idea of an alphabet originated in Mesopotamia, where

there is no evidence that it ever existed. Of the half a million or so cuneiform tablets and fragments of tablets uncovered in Mesopotamia, there is not one that bears a sign of an alphabet.

By about 2000 BCE the Mesopotamian cuneiform system of writing was used throughout the Near East and particularly in Canaan, where the rulers were using it in their correspondence even with the pharaohs of Egypt. When the Ugaritic scribes were writing their alphabet using the wedge-shaped cuneiform signs, the Mesopotamians were still content with their word-symbols.

There are also contemporary scholars who believe that the alphabet is of Egyptian origin; they base their views on the yet undeciphered Sinaitic inscriptions uncovered in 1906 in the Sinai Desert by Sir William Flinders Petrie and which date back to about 1500 BCE. The discovery was hailed by many as the missing link between the alphabet and the Egyptian demotic writing, and led to the belief that the Canaanites learned their method of writing from their contacts with the Egyptians. A recent discovery in the land of Canaan showed that the so-called Proto-Sinaitic inscriptions were used by Semitic people as early as 1700 BCE, and they are purely a Semitic script. The Canaanites, who were working the Egyptian turquoise mines in southwestern Sinai, left symbols scribbled on rocks and stones, and some scholars believe that the Canaanite workers learned their signs from their Egyptian lords. The Sinaitic pseudo-hieroglyphic and proto-Canaanitic scripts may at best be considered a first attempt at the complex process that led to the alphabetic script.

The champions of an Egyptian origin support their claims by the presence of simple symbols in the Egyptian hieroglyphs that goes back to about 2000 BCE. Egyptian scribes, like many others, were introducing symbols, which stood for simple sounds or syllables and to a certain degree resemble the symbols of the alphabet. This pseudo-hieroglyph has so many signs that it is considered more syllabic than alphabetic, and instead of simplifying the Egyptian way of writing, it added to its complexity. The Egyptians priests could not relinquish their complex picture

word-signs, and kept using them until about AD 500.

The uncovering of Minoan hieroglyphs and other Minoan pictograms in the beginning of this century suggested to the archeologist Sir Arthur Evans that the Phoenician alphabet was itself derived from Crete. On the basis of Evans' statement, and in spite of the fact that the excavations on the island revealed no alphabetic signs, Glasgow wrote, "We now know, for instance, that the art of writing came from Crete, Phoenicia being the medium."

Many of the supporters of non-Phoenician origins point out that some of the sounds assigned to the signs that make up the alphabet do not correspond to the Canaanite names represented by the signs. As a matter of fact a few of the signs, only two, do not correspond to any known objects, but as we shall see, all the rest do. The variations may be attributed to the whim of a scribe or scribes, who forsook fidelity in favor of beauty or simplicity. The alphabet evolved for several centuries before reaching its known Phoenician form.

The most probable origin of the invention of the alphabet is the land of Canaan. It seems that a scribe in Canaan conceived of the idea that a language might be written without the numerous signs used in Babylonian cuneiform or Egyptian hieroglyphs. It took a great deal of effort and insight to realize that complex words may be broken down into simple sounds, and that it does not take many of these simple sounds to write an entire language. This is tantamount to saying that the large number of words that forms a language are made up of various combinations of a relatively small number of simple sounds.

Each one of the simple sounds was represented by the picture of a familiar object, whose Canaanite name corresponds to the sound. Thus *beit* (house) stood for the *b* sound and *daleth* (door) stood for the *d* sound – the pictures stood for the simple sounds only and not for the word-sign. In a similar fashion all the consonants that form the language were represented. For reasons yet unknown, the vowels were not considered important enough to play a role in this scheme. This is why it is rather difficult to read

modern-day Arabic and Hebrew scripts, where only the consonants are written.

In addition to the script uncovered in the Sinai desert, there are those unearthed in Byblos (Jbayl) and ascribed to the middle of the second millennium BCE. Other proto-Canaanite inscriptions were found in various parts of the Near East, such as Beit Shamesh, Gezer, Lakish, etc. The Gezer calendar is relatively recent – it dates to ca. 950 BCE. The alphabetic signs found in various localities are different – they do not resemble one another. This leads to the speculation that once the often-competing Canaanite clans knew of the magnificent invention, each group began to formulate its own symbols. Thus began the early stages of the alphabet of which several examples have been recovered, but many aspects of its early development are lost.

Except for the Ugaritic alphabet, which was written on clay tablets, the few early alphabetic signs found in the land of Canaan were scratched on stones or rocks. Toward the middle of the second millennium BCE Canaan was under the influence of Egypt, and the Canaanite scribes were writing on Egyptian papyrus. Unfortunately, in the relatively damp soil of Canaan, papyrus did not prove to be a durable material, and the early development of the alphabet written on it is lost; the real origins may never be known.

The earliest known pure “alphabetic” signs are the proto-Canaanitic scripts, and they may be considered as first attempts in a long process that led to what we call the Phoenician alphabet. However, on the whole, they do not suggest true alphabetic designations as a large number of the Sinaitic signs are syllabic rather than alphabetic. Although there are a few similarities between the Sinaitic and the Phoenician signs, many are very different, indicating that radical changes had taken place.

The Ugaritic alphabet may be considered a new way of writing the Canaanite script. The Ugaritic literature, written on clay tablets, is the earliest, most comprehensive alphabetic script that has survived. Furthermore, the order of the letters of the alphabet, at least the first few signs, support this possibility – the head of the

𐎀	'a	𐎁	m
𐎂	'b	𐎃	n
𐎄	'h	𐎅	s
𐎆	b	𐎇𐎇	j
𐎈	g	𐎉	'
𐎊	d	𐎋	g
𐎌	b	𐎍	p
𐎎	w	𐎏	t
𐎐	z	𐎑	z
𐎒	b	𐎓	q
𐎔	b	𐎕	r
𐎖	s	𐎗	j
𐎘	y	𐎙	z
𐎚	k	𐎛	t
𐎜	l	𐎝	z

The thirty symbols that constitute the Ugaritic alphabet and their pronunciations. (For further clarification, see Bull. American School of Oriental Research, May 1986. No. 262. p.3).

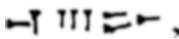
Alphabet, Fig. 1 The Ugaritic alphabet

Canaanite pantheon is El, whose epithet is *thor* (bull). It is most appropriate to put the head of the pantheon at the head of the alphabet, hence the first letter, *aleph*, meaning bull or ox. In the Canaanite mythology, the great gods dwell in large houses, and one often reads about the house of god, and the adobe of El is frequently mentioned. Thus the second letter of the alphabet, b, is represented by *beit* (house); and what is a house without a *daleth* (door), thus d is the fourth letter of the alphabet, followed by *hah* (window). There are several other such conjugate pairs in the Phoenician alphabet: *yad* and *kaff* (hand and palm), *mem* and *nahir* (water and river), and *rosh* and *shin* (head and tooth) (Fig. 1).

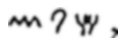
The earliest proto-Canaanitic symbols found in Phoenicia belong to the fourteenth century, and the first inscriptions of the Phoenician alphabet, which were left on arrowheads in Jbayl, belong to the twelfth century BCE. It is quite probable that the roots of the Phoenician alphabet go back to the Sinaitic proto-Canaanitic scripts. This hypothesis is strengthened by the few similarities between the Sinaitic and the early Phoenician signs and by the fact that they are listed in somewhat corresponding orders. Thus one may deduce that the formulation of the alphabet was a lengthy process culminated by the Phoenicians easy-to-reproduce form, which replaced the Sinaitic almost syllabic and the Ugaritic cumbersome cuneiform, with simple signs. There are indications that the scribes of Ugaritic, in their later writings, wrote from right to left and dropped a few of their consonants symbols. The Phoenicians continued the process of converging sounds to accommodate sound variations in their standard language, reducing the total number from 30 characters to 22.

Most recent authors attribute the origin of the alphabet to Phoenicia and more precisely to Jbayl. This is a definite possibility; the invention of the forms of the letters may have taken place in Jbayl. To compare the three scripts, let us reproduce the word “MLK” meaning king and written without vowels:

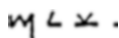
- Ugaritic



- Proto-Canaanitic



- Phoenician



Note the similarity between the Phoenician and the Latin letters. The simplicity of the Phoenician signs rendered them more accessible than all others, and by the end of the second millennium, the Phoenician alphabet became firmly established in the entire land of Canaan.

If doubt persists as to the origin of the invention of the alphabet, it is absolutely clear that the Phoenicians taught the letters to the Greeks and then to the rest of the known world. Some authors recognize the importance of this step and do not speak so much about the invention as about the diffusion of the alphabet. Herodotus is one such author and in one often quoted passage, he wrote, “These Phoenicians who came with Cadmus...among other kinds of learning, brought into Hellas the alphabet, which had hitherto been unknown, as I think, to the Greeks.”

The vowels, sometimes erroneously referred to as a Greek contribution, were arrived at either by sheer misunderstanding or because some of the Phoenician consonants were not needed in the Greek language, and the Greeks themselves were having difficulty pronouncing them. Thus the Phoenician aspirate “hah” became a short “e” or *epsilon* in Greek, the aspirate “heth” became a long “e” or *eta*, the semiconsonantal “yad” or “yod” became an “i” or *iota*, and the throaty “ayn” became an “o” or *omicron* (Fig. 2).

The similarities between the old Phoenician and Greek alphabets are apparent; the order to the letters are basically the same and the names assigned to most symbols, which have no significance in Greek, are taken from Phoenician words. In the fifth century BCE the Greek scribes altered the shape of their letters by changing them into their mirror images. In general, minor changes took place whenever the alphabet was adapted to a new language.

The early Greeks expressed their gratitude to their benefactors by referring to their letters as *phoinikeia* (Phoenician objects). An inscription unearthed in Crete contains the verb *poiniazēn* (to write) and the title *poinikastas* (scribe).

This alphabet soon spread into the Mediterranean region, or wherever Phoenician and later Greek trading posts were established. This helped in keeping records of commercial transactions and simplified the work of the Phoenicians, the sea traders of the ancient world. While the Phoenicians carried their alphabet with their goods and deposited both all over the Mediterranean world, Western Europe, and Northwest Africa, their cousins, the Arameans, moved with it

Alphabet, Fig. 2 The development of the alphabet

Caananitic (ca. 1500 BC)	Phoenician (ca. 1200 BC)	Picture represents	Meaning	Greek character	Greek name
		aleph	ox	α	alpha
		beit	house	β	beta
		gamma'	sickle	γ	gamma
		daleth	door	δ	delta
		hah	window	ε	epsilon
		waw	hook	ζ	zeta
		Zayn	—	η	eta
		heth	—	θ	theta
		teh	—	ι	iota
		yad	hand	κ	kappa
		kaff	palm	λ	lambda
		lamed	staff	μ	mu
		myi or mem	water	ν	nu
		nahir	river	ξ	xi
		samkeh	fish	ο	omicron
		'ayn	eye	π	pi
		feh or peh	—	ρ	rho
		sad	—	σ	sigma
		quof	—	τ	tau
		rosh	head	υ	upsilon
		shin	tooth	φ	phi
		tā	cross	χ	chi
				ψ	psi
				ω	omega

eastward, where it displaced most of the cunei-form script down the Euphrates and into Persia, then penetrated the western frontiers of India, furnishing the Indians with their Sanskrit alphabet.

The diffusion of the Phoenician alphabet, first into the Greek, then into the Roman cultures, provided the proper tool that fueled one of the greatest cultural explosions the world has ever known.

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Al-Qalaşādi

Ahmed Djebbar

In the Islamic world of the fifteenth century there was a general halt in research and a lowering of the level of instruction. In mathematics this tendency resulted in a repetitive scientific

production made up of poems or commentaries directed at an increasingly narrow public: teachers, *muwaqqits* (astronomers) charged with determining the hours of daily prayers, judicial functionaries, government bookkeepers, etc.

It is in light of this tendency that we can appreciate both the intellectual journey and the scientific contribution of al-Qalaṣādī, one of the last scholars of Andalusian origin who dedicated a large part of his life to disseminating – to the central Maghreb, to Ifriqiya, and to Egypt – what he knew of the Arab mathematical tradition of the preceding centuries.

‘Alī ibn Muḥammad al-Qalaṣādī was born around 1412 in the Andalusian village of Basta. This small village, which is in the northeastern part of Grenada, was already prosperous in the time of the geographer ► [al-Idrīsī](#) (d. 1153) and continued to be so for two centuries.

We know nothing of al-Qalaṣādī’s childhood except that he grew up in his birthplace where he learned the *Qu’rān* from his teacher Ibn ‘Azīz and where he received his first lessons in Arabic and probably also in mathematics. In the course of his adolescence he continued these studies and was taught grammar and mathematics from the arithmetic texts of Ibn al-Bannā’ (d. 1321), as well as law, the science of inheritance, and calculation.

In 1436, at the age of 24, al-Qalaṣādī left his native village and began his first educational voyage, heading to Tlemcen, the first stop of a long journey to scientific centers in the Maghreb, al-Andalus, and Egypt. The educational voyage (*riḥla* in Arabic) was a medieval tradition, one of whose goals was to allow students to complete their education in various places, taking classes from famous professors.

Al-Qalaṣādī’s stay in Tlemcen lasted 8 years. His most serious study of mathematics was with az-Zaydūrī (d. 1441). He himself says that az-Zaydūrī taught him the contents of two important texts of Ibn al-Bannā’: the *Kitāb al-Uṣūl wa l-muqaddimāt fī l-jabr wa l-muqābala* (Book on the Foundations and Preliminaries in Algebra and Restauration) and the *Raf‘ al-ḥijāb ‘an wujūh a‘māl al-ḥisāb* (Lifting of Veil on the Science of Calculus Operations).

It also appears that the first scientific works of al-Qalaṣādī were written in Tlemcen, between 1436 and 1444. There were three commentaries on writings on the science of inheritance and a mathematics book entitled *al-Tabṣira* (The Book which Makes Things Intelligible).

In 1444, al-Qalaṣādī left Tlemcen for Tunis, which was at that time one of the most dynamic intellectual centers in the Maghreb. In the *madrasas* (colleges) where he studied, al-Qalaṣādī took courses in Malikite law, the Arabic language, grammar, and the rational sciences. At the same time, he devoted time to his own writing. He published three books on calculation: the *Kashf al-jilbāb ‘an ‘ilm al-ḥisāb* (Unfolding the Secrets of the Science of Calculation) in 1445, the *Qānūn fī al-ḥisāb* (Canon of Mathematics), and his commentary entitled *Inkishāf al-jilbāb ‘an qānūn al-ḥisāb* (Explaining the Canon of Mathematics). He also published two works on traditional sciences, *al-Kulliyyāt fī al-farā’id* (Collection on Successional Division), and a commentary on it. At the end of his stay in Tunis, in 1447, it appears that he wrote his epistle on irrational numbers entitled *Risāla fī dhawāt al-asmā’ wa l-munfaṣilāt* (Epistle on Binomials and Apothems).

On 30 May 1447, al-Qalaṣādī left Tunis and headed to Cairo and then to Mecca, where he wrote a commentary on the *Farā’id* (Book on Successional Division) of Ibn al-ḥājib on traditional science. Returning from the pilgrimage, he again stayed in Cairo, teaching and taking classes from several professors, notably Shams al-Dīn al-Samarqandī in rational sciences.

In April 1449, al-Qalaṣādī left Cairo and returned to al-Andalus. In 1451 he returned to his native village of Basta, and then went to Grenada, where he stayed for 30 years. There he studied with eminent professors like the astronomer Ibrāhīm Ibn Futūḥ, who specialized in the study of astrolabes.

A deterioration of the political climate of the interior of the kingdom of Grenada and increasingly worrisome menaces from outside forced al-Qalaṣādī to leave the Andalus once and for all in 1483. He settled finally in Béja in Ifriqiya where he died in 1486, just 6 years before the fall of Grenada.

Mathematical Works of al-Qalaṣādī

Like some of his contemporaries in al-Andalus and the Maghreb, al-Qalaṣādī wrote on many different subjects. In almost all disciplines he also, again like many of his contemporaries, published numerous commentaries on classical texts. But he is, to my knowledge, the only scholar of his era to have written so many works on mathematics.

The mathematical development of al-Qalaṣādī seems to have been centered basically on the science of calculation, on the processes of arithmetic and algebraic calculation and their application in the solving of abstract exercises and practical problems – e.g., problems of commercial transaction, monetary conversions, or the division of inheritances.

In algebra, he wrote chapters included in the arithmetical works already noted. In these chapters he treats algebraic operations and the resolution of the canonical equations of ► [al-Khwārizmī](#). To that we must add his commentary on the algebraic poem of ► [Ibn al-Yāsamīn](#).

In these texts one finds a peculiarity of the Maghrebian mathematical tradition, the utilization of a certain symbolism to express objects or algebraic concepts such as an unknown, different powers, or equality in equations. For a long time the invention of this symbolism was attributed to al-Qalaṣādī. But the results of recent research now permit us to affirm that this same algebraic symbolism was already in existence in this twelfth century, particularly in the work of Ibn al-Yāsamīn entitled *Talqīḥ al-af kār* (Fertilization of Thoughts), and that it was widely in use in the fourteenth century, in particular by ► [Ibn Qunfudh](#) (d. 1407). The work of al-Qalaṣādī bears witness to the persistence of these symbols and of their widespread use throughout the Maghreb.

In arithmetic, his writings deal essentially with the four arithmetic operations (applied to whole numbers, fractions, and irrational quadratics), with the extraction of the exact or approximate square root of a number, with the rule of three, with the method of false positives, and with other

arithmetical procedures such as the breakdown of a number into prime factors and the calculation of the sums of series of natural numbers from their squares and cubes. Again, it is important to note that the techniques used by al-Qalaṣādī in these books are related to techniques already used in the works of al-ḥaṣṣār (twelfth century) and of Ibn al-Bannāʾ.

The fact that these themes are present in the works of al-Qalaṣādī and his method of treating them leads to the conclusion that in the fifteenth century, the mathematical traditions of al-Andalus and of the Maghreb were unified by being based upon each other. Moreover, if one compares the work of al-Qalaṣādī with that of Ibn al-Bannāʾ, one notices a certain continuity both in form and content. Because of this, one can argue that al-Qalaṣādī is more Maghrebian than Andalusian. This stamp of the Maghreb on the education and work of a scholar from al-Andalus of the importance of al-Qalaṣādī offers proof, moreover, of the decline of scientific activity in al-Andalus in the fourteenth and fifteenth centuries.

On the other hand, when one compares his different works in mathematics, one does not see a noticeable evolution from one book to another, but rather different formulations of classic themes and techniques. Al-Qalaṣādī himself claimed that some of his books were only developments or summaries of previously published works. It is important to note that this process, which was not unique to al-Qalaṣādī and which was already in evidence at the end of the fourteenth century both in the Maghreb and in Egypt, only reflects the continuation in the fifteenth century of the slow decline of scientific activity in the Islamic city. In this difficult context the scientific aptitude of al-Qalaṣādī was not really able to flourish fully, and it is greatly to his credit that he contributed to maintaining the level of scientific activity of that of the fourteenth century in the Andalus and the Maghreb.

See Also

- [al-Idrīsī](#)
- [Ibn al-Bannāʾ](#)

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Al-Qūhī (or Al-Kūhī)

Yvonne Dold-Samplonius

Abū Sahl Wayjan ibn Rustam al-Qūhī (or al-Kūhī) probably originated from the village of Quh in the Iranian province of Tabaristan. He worked in Baghdad under the Buwayhid Caliphs 'Aḍud al-Dawla and his son and successor Sharaf al-Dawla. In 969/970 al-Qūhī assisted at the observations of the solstices in Shiraz. These observations, ordered by 'Aḍud al-Dawla, were directed by Abū'l-ḥusayn 'Abd al-Raḥmān ibn 'Umar ► [al-Ṣūfī](#). In 988 al-Qūhī supervised astronomical observations in the garden of the palace of Sharaf al-Dawla in Baghdad in the company of several magistrates and respected scientists.

Some of al-Qūhī's contemporaries considered him to be the best geometer of his time; al-Khayyāmī held him in high esteem. In the geometrical writings known to us he mainly

solved problems that would have led to equations of higher than the second degree. A note by al-Qūhī is added to Naṣīr al-Dīn al-Ṭūsī's redaction of Archimedes' *Sphere and Cylinder* in the Leiden manuscript, on how to construct a sphere segment equal in volume to a given sphere segment, and equal in surface area to a second sphere segment. This problem is similar to but more difficult than the constructions solved by Archimedes in *Sphere and Cylinder* II,6 and II,7. Al-Qūhī constructed the two unknowns, i.e., the radius of the sphere and the height of the segment, by intersecting an equilateral hyperbola with a parabola and rigorously discussed the conditions under which the problem is solvable.

Conic sections provided the tools for several problems, as in the classical problem of trisecting an angle. In the small treatise *Risāla fī qismat al-zāwiya* (On the Trisection of the Angle) al-Qūhī gave a purely Islamic solution by means of an orthogonal hyperbola. This solution was taken over by ► [al-Sijzī](#). In *Risāla fī istikhrāj ḍil'al-musabba'al-mutasāwi'l-aḍlā'* (On the Construction of the Regular Heptagon) the precise construction is more complete than the one attributed to Archimedes. Al-Qūhī's solution is based on finding a triangle with an angle ratio of 1:2:4. He constructed the ratio of the sides by intersecting a parabola and a hyperbola, with all parameters equal. Al-Sijzī, who claimed to follow the method of his contemporary Abū Sa'ied al-'Alā ► [ibn Sahl](#), used the same principle. A second, different solution by al-Qūhī also exists. One of the most interesting examples of late tenth-century solutions is al-Qūhī's construction of an equilateral pentagon in a given square in *Risāla fī 'amal mukhammas mutasāwi l-aḍlā' fī murabba'mā'lūm* (On the Construction of an Equilateral Pentagon in a Known Square). This solution is based on Books I–VI of Euclid's *Elements*, Euclid's *Data*, and parts of Books I–III of Apollonius' ► [Conics](#). The construction is remarkable, because it contains a proof of the focus-directrix property of a hyperbola with eccentricity $\varepsilon = 2$. It is reasonable to assume that al-Qūhī independently discovered and

proved this property, thus going a step further than Apollonius.

In *Risāla fī istikhraj misāhat al-mujassam al-mukāfi* (On Measuring the Parabolic Body) al-Qūhī gave a somewhat simpler and clearer solution than Archimedes had done. He said that he knew only Thābit ibn Qurra's treatise on this subject, and in three propositions showed a shorter and more elegant method. Neither computed the paraboloids originating from the rotation of the parabola around an ordinate. That was first done by Ibn al-Haytham, who was inspired by Thābit's and al-Qūhī's writings. Although he found al-Qūhī's treatment incomplete, Ibn al-Haytham was nevertheless influenced by his thinking. Maybe the two met in Basra, where al-Qūhī wrote his correspondence to Abū Ishāq al-ṣābī and four books on centers of gravity. Analyzing the equation $x^3 + a = cx^2$, al-Qūhī concluded that it had a (positive) root if $a \leq 4c^3/27$. This result, already known to Archimedes, was not known to al-Khayyāmī, whose analysis is less accurate.

Al-Qūhī was the first to describe the so-called perfect compass, a compass with one leg of variable length for drawing conic sections. In this clear and rather general work, *Risāla fī l birkar al-tāmm* (On the Perfect Compass), he first described the method of constructing straight lines, circles, and conic sections with this compass and then treated the theory. He concluded that one could now easily construct astrolabes, sundials, and similar instruments. In his *Kitāb ṣan'at al-aṣṭurlāb* (On the Manufacture of the Astrolabe) al-Qūhī used an original method for drawing azimuth circles, based on an analemma, a procedure for reducing problems in three dimensions to two dimensions. A commentary on this work was written by Abū Sa'd al-'Alā ibn Sahl. Al-Qūhī's proofs for this construction were reproduced in an inferior form by Abū Naṣr Maṣnūr ibn 'Irāq, who highly esteemed al-Qūhī, in *Risāla fī dawā'ir as-sumūt fī al-aṣṭurlāb* (Azimuth Circles on the Astrolabe).

The correspondence between al-Qūhī and Abū Ishāq al-ṣābī contains discussions of the

possibility of curvilinear figures being equal to rectilinear figures, the meaning of "known ratio," and whether one can square a parabolic segment by exhausting it with triangles. The first letter especially gives impressive evidence for al-Qūhī's creativity in two theorems on centers of gravity of circular sectors and arcs. In the same correspondence he deducted a value of 28/9 for the ratio of the circumference of a circle to its diameter (π). This result was attacked by Abū Ishāq and then, almost 150 years later, by Abū'l-Futūḥ Aḥmad ibn Muḥammad ibn al-Sarī. The latter thought that al-Qūhī got swept away by enthusiasm about his result. Also the 27 propositions in *Hādhā mā wujida min ziyādat Abī Sahl 'alā al-maqālah al-thānīyah min kitāb Uqlidis fī al-uṣūl* (Abū Sahl's Additions to Book II of Euclid's Elements) are rather weak and not very clearly stated. Probably, however, those additions, if they were even written by al-Qūhī, were originally only marginal notes in his copy of Euclid's *Elements*.

See Also

- [Abū'l-Wafā'](#)
- [Al-Ṣāghānī](#)
- [al-Šūfī](#)
- [Astrolabe](#)
- [Conics](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn Sahl](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Samū'īl ibn 'Abbās \(Al-Maghribī\)](#)
- [Thābit ibn Qurra](#)
- [Umar al-Khayyām](#)

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Al-Rāzī

Albert Z. Iskandar

Abū Bakr Muḥammad Ibn Zakariyyā al Rāzī (Rhazes), the most original physician philosopher of his time, was born in al-Rayy (hence the name, al-Rāzī), now ruins near modern Teheran. Medieval historians wrote more on his copious bibliography than on his life.

► **Al-Bīrūnī** (d. AD 1048 or 1050) writes in his *Risāla fī Fihrist Kutub Muḥammad Ibn Zakariyyā al-Rāzī* (Missive on the Index of Books of Muḥammad Ibn Zakariyyā al-Rāzī) that he was asked by a learned man to compile a bibliography of al-Rāzī. To accomplish this task, he examined many manuscripts, and recorded only those works in which he found al-Rāzī's name mentioned as author in the text. Al-Bīrūnī's method of research undoubtedly resulted in his failure to record some of al-Rāzī's genuine works.

Al-Rāzī advised doctors to practice in densely populated cities, where they could benefit from the experience of many skillful physicians and have the chance to examine many patients. He himself moved from al-Rayy to Baghdad where, in his youth, he studied and practiced the art of healing at its hospital (*bīmāristān*). Later, he returned to al-Rayy, at the invitation of its ruler, Manṣūr ibn Ishāq, to assume responsibility as Hospital Director. To this ruler, al-Rāzī dedicated two books, *al-Almṣūrī fī'l ṭibb* (al-Manṣūrī on Medicine) and *al-ṭibb al-Rūī ḥ ānī* (The Spiritual Physic). These were intended to unite the study of diseases of the body with those of the soul.

Having achieved fame in al-Rayy, al-Rāzī returned to Baghdad to become Head of its newly founded hospital, named after its founder the Abbasid caliph al-Mu'taḍid (d. AD 902). The last years of his life were spent in al-Rayy, where he suffered from glaucoma (*al-mā' al-azraq*), and died in AD 932 or 925.

Al-Rāzī's book *Fī'l Shukūk 'alā Jālīnūs* (Doubts about Galen), so far unpublished, is devoted to the criticism of 28 of Galen's books, beginning with the *al-Burhān* (Demonstration) and ending with *Fī'l Nabḍ* (On the Pulse).

Before embarking on the criticism of Galen, he writes an apology in which he acknowledges his debt to his master, but says that "the art of physic is a philosophy which does not tolerate submission to any authority, nor does it accept any views, or yield to any dogmas without proper investigation." He says Galen himself supported this view. In the closing passage of his introduction, al-Rāzī affirms the validity

of his book, saying that none of Galen's predecessors had escaped Galen's own scathing criticism.

To al-Rāzī, progress in scientific knowledge is inevitable. In his treatise *Fī Miḥnat al-ṭabīb wa Ta'yīnih*, he says "He who studies the works of the Ancients gains the experience of their labour as if he himself had lived thousands of years spent on investigation."

Al-Rāzī also mentions *al-Jāmi' al-Kabīr* four times in his book *al-Murshid aw al-Fuṣūl* (The Guide or Aphorisms), which was written to serve as an introduction to medicine. *Al-Jāmi' al-Kabī* consists of 12 sections (*aqṣām*), of which only 2 have been recently discovered in manuscripts: *ṣaydalat al-ṭibb* (Pharmacology in Medicine) and *Fī Istinbāṭ al-Asmā' wa'l-Awzān wa'l-Makāyīl* (On Finding the Meaning of Unfamiliar Terms, Weights, and Measures).

His medical prescriptions took into account the patients' social status. For the rich, princes, and rulers, the effective drugs had to be mixed with sweet vehicles, as explained in *al-ṭibb al-Mulūkī* (The Royal Medicine). For the poor, he wrote a book of recipes entitled *Man lā Yaḥḍuruh al-ṭabīb* (Who has no Physician to Attend Him) also known by the title *ṭibb al-Fuqarā'* (Medicine for the Poor).

Al-Rāzī argued that the medicinal properties attributed to various parts of animals, vegetables, and minerals should be recorded in books, which he did in his *Khawāṣṣ al-Ashyā'* (The Properties of Things). Such properties should neither be accepted nor discarded, unless experience (*al-tajriba*) proves them to be true or false. Physicians should not accept any property as authentic, unless it has been examined and tried.

In theory, al-Rāzī followed Galen, yet he found it necessary to correct him, and in practice, he revived the Hippocratic art of clinical observation. Having read the Hippocratic book *Abīdhīmā* (Epidemics), he decided to write his own case histories, where he carefully recorded the name, age, sex, and profession of each patient. He also gave an early example of a clinical trial, when he divided his patients suffering from meningitis (*al-sirsām*) into two groups.

He treated one group with bloodletting and intentionally, as a control, refrained from applying venesection to the other group.

All these detailed case histories are extant in his private notes which became known after al-Rāzī's death as the *al-ḥawī fi'l ṭibb* (Continens on Medicine). It should be considered a private library of a well read and highly educated physician-philosopher, not a book meant for publication. It is interesting to remark that illnesses which affected al-Rāzī himself are recorded in *al-ḥawī fi'l ṭibb*. In a note, preceded with "Lī (mine)," he mentions how he cured an inflammation of his own uvula by gargling with strong vinegar; in another, he jots down the fact that he recovered from a swelling in the right testicle by taking emetics (*muqayyi'āt*) for a long time.

Al-Rāzī's medical works had great influence on medical education in the Latin West. *Al-ḥawī fi'l ṭibb* was rendered into Latin (*Liber Continens*) by a Sicilian Jew, Faraj Ibn Sālim (Farrajut) in AD 1279. It was printed five times between AD 1488 and 1542. His *Liber ad almansorem*, consisting of ten books, and his *Liber Regius* were very popular among medieval European practitioners. The seventh book of *Liber ad Almansorem* (On Surgery) and the ninth entitled *Nonus Almansoris* (A General Book on Therapy) constituted a part of the medical curriculum in Western universities.

Al-Rāzī established an accurate differential diagnosis, based on clinical observations, between smallpox (*al-jadarī*) and measles (*al-ḥaṣba*). His book *Smallpox and Measles* was translated into Latin (*De variolis et morbillis*), and into other occidental languages and was printed about 40 times between AD 1498 and 1866.

The subject matter in this book is quite original. First, al-Rāzī asserts that Galen knew of smallpox, yet failed to indicate its etiology and to prescribe any satisfactory therapy. Secondly, he lays down his own differential diagnosis by his vivid description of the pustules of smallpox and the rash of measles. In his prognosis of the course of smallpox, he recommends close attention to the heart, the pulse, respiration, and excreta. He outlines his own method of

protecting the patient's eyes and elaborates on how to avoid deep facial scarring.

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Al-Ṣāghānī

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Abū ḥāmid Aḥmad ibn Muḥammad al-Ṣāghānī al-Aṣṭurlābī was an Arabic astronomer and mathematician. He was born in Chagaian (Central Asia) and worked in Baghdad.

His main work was the *Kitāb fī'l-tasṭīh al-tāmm* (Book of the Perfect Projection on to a Plane) which is extant in two manuscripts. The treatise is devoted to a generalization of the stereographic projection of a sphere onto a plane, usually used in the making of astrolabes. This concerns the projection from a pole of the sphere onto the equatorial plane or a plane parallel to it. Under this projection, circles on the sphere are imaged onto the plane as circles or straight lines. The “perfect projection” invented by al-Ṣāghānī is the projection of the sphere from any point of its axis onto a plane orthogonal to the axis. Under this projection, circles on the sphere are imaged on the plane as conic sections (ellipses, hyperbolas, and parabolas) or straight lines. These descriptions of methods for conics construction are important for geometry. In the treatise, al-Ṣāghānī considers the construction methods for images of different circles of the celestial sphere, such as the celestial equator and its parallels and the horizon and its almaccantars, verticals, and one ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The contents of the treatise are explained in detail by al-Bīrūnī (973–1048) in his *Astrolabes*.

Al-Ṣāghānī was also the author of two mathematical treatises, on the construction of a regular heptagon inscribed in a circle and on the trisection of an angle. He also wrote three astronomical treatises. *Kitāb qawānīn 'ilm al-hay'a* (Book on Rules of the Science of Astronomy) is not extant, but al-Bīrūnī in his *Geodesy*

Boris A. Rosenfeld: deceased

mentioned measuring the value of the angle between the ecliptic and the celestial equator found by al-Ṣāghānī in Baghdad. The second, *Maqāla fī'l ab'ād wa'l-ajrām* (Article on Distances and Volumes), dealt with the distances and volumes of planets and stars. The third work was *Fī'l sālāt al-ma'mūla 'alā ṣafā'ih al-aṣṭurlāb* (On Horary Lines Produced on the Tympanums of Astrolabes).

See Also

► [Astrolabe](#)

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Al-Samarqandī

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Shams al-Dīn al-Samarqandī, as his name implies, was from Samarqand, in what is now Uzbekistan. We know few of his biographical details with any certainty. He is believed to have been active during the second half of the seventh AH/AD thirteenth century, since he

composed a star calendar for 675 AH/AD 1276–1277 to accompany his *Al-Tadhkira fī'l-Hay'a* (Synopsis of Mathematical Cosmography or Hay'a). A manuscript (Istanbul, Laleli Library, 2432), probably written by one of his pupils, reports that he died in 701 AH/AD 1302. Although Naṣīr al-Dīn al-Ṭūsī had gathered many leading intellectuals together at the Marāgha observatory, al-Samarqandī is never mentioned among their number.

Al-Samarqandī's earliest contributions were in the field of logic, but he is best known to historians of science for his brief tract, *Kitāb Ashkāl al-Ta'sīs* (*Book of Fundamental Theorems*), a collection of 35 propositions from Euclid's *Elements* (mostly from books I and II, although proposition VI, 1 was also included), with abbreviated demonstrations [De Young, 2001]. The title has often caused confusion because the theorems chosen for inclusion do not always seem to be fundamental in the sense of providing a mathematical underpinning for the *Elements*. But the term *shakl* (plural: *ashkāl*), which often is translated as “proposition,” also has a wider meaning in philosophy and logic as “form” or “image.” Moreover, the term *ta'sīs* may also carry wider connotations than merely something fundamental or basic. It can mean, in a more general context, an organization or foundation and hence could be interpreted to mean “that which exists.” Read in this way, the title implies that the work is not just a collection of geometrical theorems but an investigation into the geometrical forms that formed the basis of and gave rise to the world of the existent, thus revealing an underlying Platonism that gives primacy to mathematics and especially geometry [Fazlhoğlu, 2008].

The treatise is very concise and is historically better known through the commentary composed by Qāḍīzāde al-Rūmī (died 840 AH/AD 1436). Of special interest has been the “proof” of Euclid's parallels postulate (the fifth postulate of book I) which al-Samarqandī included. The argument is more philosophical than mathematical: if two lines are not parallel – always equidistant from one another – then they must be approaching, getting closer together, on one side

or the other. And if they are continually getting closer together, they must eventually meet one another. Most historical discussion of parallel lines in the *Ashkāl al-Ta'sīs* has focused on the “demonstration” quoted in the comments of Qāḍīzāde al-Rūmī but more correctly ascribed to Athīr al-Dīn al-Abharī (died 663 AH/AD 1265) [Dilgan, 1960; Souissi, 1982; Jouiche, 1986].

See Also

- Hay'a
- Qāḍīzāde al-Rūmī

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- physician and ophthalmologist at the newly established MuZaffarī hospital. As a child he was the apprentice of his father, who died when Shīrāzī was 14. Having assumed his father's position at the hospital, he continued his studies with several other local teachers of medicine and the rational and religious sciences. At this time he began the study of the first book, *al-Kullīyāt* (On General Principles) of Ibn Sīnā's *Qānūn fī 'l-ṭibb* (Canon of Medicine), the leading medical textbook of the Middle Ages. His father had also initiated him into the Suhrawardī order of Sufis (Islamic mystics).
- By the time he reached adulthood, he was in need of advanced medical instruction that could not be provided by the teachers of a provincial city like Shiraz. It would have been normal for him to have gone off earlier to one of the major Islamic cities for advanced studies, but in 1253 the Mongols had invaded the Islamic lands of Central and Southwestern Asia, sacking Baghdad in 1258, so Shīrāzī was confined to his home city until peace was reestablished.
- In 1259 Hulegu, the Mongol ruler of Iran, gave a large grant to the famous scientist ► [Naṣīr al-Dīn al-Ṭūsī](#) (1201–1274) to pay for the preparation of a new set of astronomical tables (► [zīj](#)) for use in astrological calculations. Ṭūsī established an observatory in the town of Marāgha, at that time the Mongol capital, and brought together a brilliant team of scientists and scholars. Shīrāzī came to the observatory as a student soon after it was founded. While he was disappointed by Ṭūsī's lack of knowledge about medical theory, he learned a great deal of mathematics, astronomy, and philosophy from him and his faculty, and he soon became the most important student at the observatory. Ṭūsī took him along on his travels and introduced him at court. Shīrāzī also apparently spent some time studying in Qazvīn, Khorasan, and Baghdad with various teachers.

Al-Shīrāzī

John Walbridge

Quṭb al-Dīn Maḥmūd ibn Mas'ūd al-Shīrāzī (1236–1311) was a Persian scientist and philosopher. He was born into a medical family in Shiraz in central Iran. His father was a staff

Around 1270 he left the observatory and went to Konya in Anatolia, where he met the famous Sufi poet Rūmī and studied *ḥadīth* (the sayings of Muḥammad) with ṣadr al-Dīn Qūnawī, the leading disciple of the mystical philosopher Ibn

‘Arabī. Soon after he was appointed *qāḍī* (religious judge) of the Anatolian cities of Sivas and Malatya. This was evidently a sinecure to allow him to pursue his scientific work, for his first major work, *Nihāyat al-Idrāk fī Dirāyat al-Aflāk* (The Highest Attainment in the Knowledge of the Spheres), a technical work on mathematical astronomy, was published in Sivas in 1281 and was dedicated to the vizier of the Mongol ruler. Other works on astronomy and mathematics soon followed.

In 1282 he was appointed to a diplomatic mission to Egypt. Though the mission failed in its political objectives, Shīrāzī found three complete commentaries on the first book of Ibn Sīnā’s *Qānūn*, along with glosses and other sources. With this new material in hand, he was finally able to achieve his youthful goal of mastering the intricacies of this work. Shortly after his return to Anatolia he published a large commentary on the *Qānūn*. He published second and third editions in 1294 and in 1310, a few months before his death.

Of his personality we are told that he had a sharp wit, and indeed he was a stock character in a certain genre of joke for several centuries thereafter. He was expert in chess and prestidigitation and was a lively conversationalist and lecturer. He was an authority on musical theory, which in the Middle Ages was considered a branch of mathematics, and was a fine player of the *ribāb*, a forerunner of the violin. He seems to have grown more concerned with religious matters as he grew older, although he was a Sufi all his life.

He eventually settled – interrupted by several exiles – in Tabriz, at that time the capital of Mongol Iran. He was an intimate of the court. The funds that supported his scientific work came from a series of viziers and petty rulers. In addition to his works on astronomy and medicine, he wrote on mathematics, philosophy, and the Islamic religious sciences. In his last years he spent less time on the rational sciences and more on religious subjects. He died in relative poverty, having given almost everything he had to charity and to his students and not yet having received the large payment promised for the

third edition of his commentary on Ibn Sīnā’s *Qānūn*. He was given a lavish funeral by a wealthy student.

Shīrāzī was typical in most respects of Islamic scientists. He was a polymath, interested not only in the corpus of science inherited from the Greeks but also in the religious sciences of Islam. Of the rational sciences it was astronomy and medicine that found the most ready market – astronomy as the handmaid of astrology or for timekeeping in the mosques. The other rational sciences, particularly mathematics, and philosophy, were supported by their more practical subordinate sciences. Sophisticated practitioners of the rational sciences generally drifted to the royal courts, the only reliable sources of funding for such subjects, and became involved in the life and politics of the court – and in its perils.

See Also

- [Al-‘Urḍī](#)
- [Astronomy](#)
- [Ibn Al-‘Arabī](#)
- [Ibn Sīnā \(Avicenna\)](#)
- [Marāgha](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Optics in the Islamic World](#)
- [Zīj](#)

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Al-Sijzī

Yvonne Dold-Samplonius

Al-Sijzī, Abū Saʿīd Aḥmad ibn Muḥammad ibn ʿAbd al-Jalīl, was born in Persia, ca. 945 and died ca. 1020. The name al-Sijzī indicates that he was a native of Sijistān in southeastern Iran and southwestern Afghanistan. This is confirmed, for example, when al-Sijzī refers in his *al-Mudkhal ilā ʿilm al-handasa* (Introduction to Geometry) to a planetarium which he had constructed in Sijistān. Al-Sijzī was already active in 963, when he copied a manuscript of Pappus' *Introduction to Mechanics* (Book VIII of the Collection), and still active in 998, when he completed a treatise on the proof of the plane transversal theorem.

Al-Sijzī's father, Abū'l-ḥusayn Muḥammad ibn Abd al-Jalīl, was also interested in geometry and astronomy, and al-Sijzī addressed some of his works to him, e.g., *Risālat fī Khawāṣṣ al-qubba az-zāʿida wa-l-mukāfiya* (On Parabolic and Hyperbolic Cupolas), completed in 972. Around 969 al-Sijzī spent some time at the Buwayhid court in Shirāz and assisted in 969/970 at the observations of the solstices conducted by Abd al-Raḥmān ibn ʿUmar al-ṣūfī. There he met a number of important geometers and astronomers, including Abū'l Wafāʾ, Abū Sahl al-Qūhī, and Naẓīf ibn Yumn (d. ca. 990).

Al-Sijzī was active in astrology and had a vast knowledge of the literature. He usually compiled and tabulated, adding his own critical commentary, as with three works by ► **Abū Maʿshar** and the second of the five books ascribed to Zoroaster. He used Sassanid material and sources from the time of Hārūn al-Rashīd and from the late Umayyad period for a book on general astrology and its history. In his work on horoscopes he gives tables based on Hermes, Ptolemy, Dorotheus, and "the Moderns." Al-Sijzī's tables, together with those of Ptolemy, are quoted by Ḥītiyāzu' l-Dīn Muḥammad in his *Judicial*

Astrology. The treatise *Kitāb fī Qawānīn mizājāt al-aṣṭurlāb al-shimālī maʿa l-janūbī* (On the Astrolabe) deals with the different kinds of astrolabe retes (a circular plate with many holes used on the astrolabe to indicate the positions of the principal fixed stars) with which al-Sijzī was familiar. This treatise is used by ► **al-Bīrūnī** in his *Istīʿab al-wujūh al-mumkina fī ṣanʿat al-aṣṭurlāb* (Book on the Possible Methods for Constructing the Astrolabe).

Al-Sijzī wrote at least 45 geometrical treatises, of which some 35 are extant, and about 14 astronomical treatises. He was well-read and had many contacts with his contemporaries. A number of his works are therefore of unusual historical interest. In *Risālat fī Qismat az-zāwiya al-mustaqīmat al-khaṭṭain bi-ṭalāṭat aqsām mutasāwiya* (On the Division of the Angle into Three Equal Parts) al-Sijzī describes a number of problems, to which various other writers had reduced the problem of the trisection of the angle. The method of "the Ancients" by means of a neusis was not considered a legitimate construction by al-Sijzī. His own construction, by intersecting a circle and a hyperbola, is a variation of the solution by al-Qūhī. The treatise ends with five problems of al-Bīrūnī. Regarding al-Sijzī's construction of the heptagon, this is, according to Jan Hogendijk, to a great extent the history of a dispute between two young geometers, al-Sijzī and Abū'l-Jūd, who were both engaged in plagiarism. In the meantime al-Qūhī solved the problem in an elegant manner.

For the *Geometrical Annotations* (*Kitāb fī l-masāʾili l-mukhtārati llātī jarat baynahu wa-bayna muhandisī Shīrāz wa-Khurāsān wa-taʿlīqātihi*, Book on the Selected Problems Which Were Currently Being Discussed by Him and the Geometers of Shirāz and Khorāsān, and His (Own) Annotations) al-Sijzī had the example of Ibrāhīm ibn Sinān's *al-Masāʾil al-mukhtāra* (Selected Problems) in mind. A number of the problems and solutions are clearly influenced by or adapted from the *Selected Problems*, but al-Sijzī's treatise is on the whole on a lower level.

The *Misāḥat al-ukar bi-l-ukar* (Book of the Measurement of Spheres by Spheres) is about a surrounding sphere which contains in its interior

up to three mutually tangent spheres. Al-Sijzī determines the volume of the solid which results when one deletes from the surrounding sphere all points that belong to the spheres in its interior. He expresses this volume as the volume of a new sphere, and he determines the radius of this new sphere in terms of the radii of the spheres used in the definition of the solid. Al-Sijzī's proofs are trivial consequences of identities for line segments, proved geometrically. The treatise contains 12 propositions, of which proposition 11 and its proof are false for (three-dimensional) spheres. The proposition holds in dimension four. Perhaps al-Sijzī had four-dimensional spheres in mind, although he does not use them elsewhere in the treatise; perhaps he made a mistake.

His small treatise *Risālat fī Kaif īyat taṣawwur al-khaṭṭain alladhain yaqrubān wa-lā yaltaqiyān* (On the Asymptote, or How to Conceive Two Lines Which Approach Each Other But Do Not Meet, If One Extends Them All the Way to Infinity) is devoted to Apollonius II,14. Some cases, he says, can be solved as explained in his *Kitāb fī tashīl as-subul li-stikhrāj al-ashkāl al-handasiya* (On Facilitating the Roads to the Geometrical Propositions); for others a philosophical method is needed, as Proclus has shown in the definitions of his *Elements of Physics*. The treatise ends with the case where the two asymptotes are two hyperbolas. In *Risālat fī anna 'l-ashkāl kullahā min al-dā 'ira* (On [the Fact] that All Figures Are Derived from the Circle), a treatise until recently attributed to Naṣir ibn 'Abdallāh, al-Sijzī describes one of the few instruments that finds the *qibla* (the direction of Mecca) geometrically. He also wrote an original treatise on the construction of a conic compass.

In the introduction to *Risālat fī l-shakl al-qat'ā'* (The Transversal Figure), written before 969, al-Sijzī says that he wrote the work having seen neither Thābit ibn Qurra's *Kitāb fī l-shakl al-mulaqqab bi-l-qat'ā'* (Book of the Transversal) nor any other work on the topic, except Ptolemy's *Almagest*. The treatise begins with enunciations and proofs of two lemmas, which also appear, in different terms, in the *Almagest*.

Following the two lemmas al-Sijzī enunciates and proves his 12 propositions. Aware of the astronomical applications of the theorem he evidently saw the need to provide a complete mathematical basis for these uses. The details of the proofs of all 12 theorems are carried out according to a uniform procedure. This makes the treatise a step toward recognizing the mathematical discipline of trigonometry.

See Also

- [Abū Ma'shar](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Al-Qūhī \(or Al-Kūhī\)](#)
- [Astrolabe](#)
- [Astrology in Islam](#)
- [Ibrāhīm ibn Sinān](#)
- [Qibla and Islamic Prayer Times](#)

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Al-Šūfi

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Al-Šūfi, Abu'l-ḥusayn ʿAbd al-Raḥmān ibn ʿUmar, was born in 903 in Rayy, near modern Tehran, and died in 986.

Al-Šūfi was an astronomer in the Arabic-Islamic area. He was of Persian origin, but wrote in Arabic, the language of all science in that time. He was best renowned, and became most influential, through his *Kitāb ṣuwar al-kawākib al-thābita* (Book on the Constellations), written around 964. Knowledge of the fixed stars in Greek-based Arabic-Islamic astronomy was mainly derived from Ptolemy's catalog of 1,025 stars arranged in 48 constellations contained in his *Almagest* (ca. AD 150). Al-Šūfi reexamined Ptolemy's values of the star coordinates and magnitudes. In his book, he described all the stars catalogued by Ptolemy, adding his criticism in each individual case. However, in the tables added to his book he nevertheless faithfully rendered Ptolemy's traditional values, adding a constant of $12^\circ 42'$, for precession, to Ptolemy's longitudes. Only the magnitudes were given according to al-Šūfi's own observation. For each constellation he added two drawings, one showing the figure as seen in the sky, the other as seen on the celestial globe. His book and his drawings served as models for work on the fixed stars in the Arabic-Islamic world for many centuries, and became known even in medieval Europe, where his constellation drawings were imitated in a series of Latin astronomical

manuscripts (though no veritable Latin translation of his book was made). Apart from this book, al-Šūfi left treatises on the use of the astrolabe and the celestial globe, an introduction to astrology, and a short geometrical treatise. His name lives on, Latinized as Azophi, as a name for a crater on the Moon.

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Al-Suyūṭī

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Al-Suyūṭī (1445–1505) wrote on just about every discipline that had been recognized, in his time, as having its own method and subject matter. What is most noteworthy is that *hay'a* (cosmology, cosmography, but also astronomy) was among them. The author was in his own estimation an authority in the traditional Arabic and Islamic sciences (*al-ʿulūm al-naqliyyah*, transmitted sciences), especially in grammar, jurisprudence, and in tradition (*ḥadīth*, the

Sayings of the Prophet), but in no way in those “Sciences of the Ancients” (*al-‘ulūm al-‘aqliyyah*), which had entered the libraries of Islamic culture through numerous translations from Greek, Syriac, Middle Persian, etc. He even expressed his special hatred for philosophy and logic. The title of his treatise, *al-Hay’a al-sanīya fī l-hay’a al-sunnīya*, already reveals the challenge he had in mind: his was to be *the* Islamic cosmology, based on authentic Islamic traditions, the *Sunna*, which so conveniently rhymed with *sanīya* (brilliant, magnificent, glorious). The choice of the technical term *al-hay’a* in the title implies that the author is offering an alternative to those cosmologies based on the principles and methods of pre-Islamic astronomers. As such it is a parallel of his book *al-ṭibb al-nabawī* (Prophetic Medicine). As the author says himself, it was his goal “that those with intelligence might rejoice, and those with eyes take heed.” Actually, the great number of extant manuscripts in our libraries proves that as-Suyūṭī’s *Hay’a* attracted more attention than most other contemporary books on the cosmos.

This work is a collection of fragmentary descriptions and explanations of such natural phenomena as the sun, moon, and stars in their celestial spheres, lands and seas, winds and clouds, etc. The distinctive feature is, however, that all these fragments are authenticated in the traditional manner with chains of trustworthy authorities which connect them with Quranic revelation or Prophetic wisdom. As a result, some of the earliest theories about cosmological entities and natural phenomena have been preserved that may elucidate the worldviews prevalent among the young Muslim community before they were developed under the impact of the translations from pre-Islamic cultures. It remains doubtful whether even in the Middle Ages a mythical theory about the winds, because of the traditional authorities, would have been accepted with the same truth claim as a modern one. But the fact that the authorities were already interested in the phenomena of nature and cosmos may have opened rather than closed the eyes of the student.

See Also

► [Hay’a](#)

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Al-Ṭabarī

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Abū’l-ḥasan ‘Alī ► [ibn Sahl](#) Rabbān al-Ṭabarī was born in the environs of the city of Marw, in the province of Khurasān in Persia (presently Mary, in Turkmenistan), about AD 783, before the reign of the Abbasid Caliph Hārūn al-Rashīd (786–809). His father Sahl was a prominent citizen of great learning and a highly placed state official. As a religious leader in the Syriac-speaking community, he was reverently called *Rabbān* (from the Aramaic for teacher), and had far-reaching knowledge in theology, philosophy, and medicine.

Sahl took a special interest in his son’s upbringing, providing him with the best available educational opportunities. ‘Alī read the best Syriac books and excelled in learning. When he was 14, he turned to medicine. He concentrated there, because he realized he could help the sick and the needy.

From the Marw region, he moved to Tabaristān (Māzandarān, south of the Caspian Sea). Thus he became known as al-Ṭabarī. He was appointed counselor-secretary-scribe to the

Prince-Sultan Māzyār ibn Qārīn. When the latter rebelled against the Abbasid's authority in open revolt, Caliph al-Mu'taṣim sent a powerful army that crushed the mutiny and killed Māzyār in AD 839.

Al-Ṭabarī spoke of it later on as "a tragic episode" which left deep scars that remained until late in his life. Meanwhile, he was summoned to the Caliph's court at the new capital, Sāmarrā'. Under the Caliph's influence, al-Ṭabarī renounced his Christian faith and embraced Islam. He continued as a physician during the remaining part of al-Mu'taṣim's life, and remained there under his successor, his brother al-Wāthiq (843–847).

His good fortune came with the rise of Caliph al-Mutawakkil (AD 847–861). He was promoted to the position of physician-in-ordinary, and also became the Caliph's counselor and trusted companion (*nadīm*). In appreciation, al-Ṭabarī dedicated his best and largest medical compendium, *Firdaws al-ḥikmah* (Paradise of Wisdom) to his patron in AD 850. This was the first and most comprehensive medical encyclopedia of its kind in Islam. It took him 20 years to complete. In the introduction, the author stated that the work was to be useful to his medical students as well as to practitioners. He listed five points concerning the importance of the art of medicine:

1. It brings relief and healing to the sick, and consolation to the weary.
2. It successfully diagnoses and skillfully treats ailments, even unseen diseases not easy to discover or observe.
3. It is needed by all, regardless of age, gender, or wealth.
4. It is among the noblest of all callings.
5. The words *ṭibb*, *ṭibābah*, *mu'āssāh*, and *usāt* all relate to medicine and its healing processes.

Al-Ṭabarī then mentioned four virtues that all physicians had to possess in order to be successful and esteemed: *al-rifq* (leniency and kindness), *raḥmah* (mercy and compassion), *qanā'ah* (contentedness and gratification), and *'afāf* (chastity with simplicity).

Firdaws was divided into 7 sections in 30 treatises, composed of 360 chapters in all. They ranged from cosmogony, the nature of man, embryology, and anatomy, to materia medica, psychotherapy, pathology, and surgery. Other topics included theoretical and practical medicine in the Greek and Indian traditions, and rules of conduct with insistence on strict adherence to the highest ethical standards.

Another noteworthy literary contribution was his book *al-Dīn wā'l-Dawlah* (Religion and the State). It represents a defense as well as an exposition of the religion of Islam, the Holy Qur'ān, and the Holy Prophet Muḥammad. It seems temperate, rational, and objective in style and tone, and appears free from misgivings or barren argumentation. It also abounds with quotations from the Bible (in the Syriac version).

In these two works, al-Ṭabarī shed much light on the development and progress of the religious, philosophical, and medical advancements during the first two quarters of the ninth century AD. He died in Sāmarrā' ca. 858.

The Kitāb al-Dīn was soon eclipsed during the Islamic Middle Ages, because of a lack of interest in such studies as comparative religion. Only in the twentieth century was the book edited more than once. *Firdaws*, however, has continued to enjoy a good reputation, with a wide circulation throughout the Islamic world. Both works can now be considered classical literary works.

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Altars in China

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Altar: A Definition

An altar, or *tán* (坛) in Chinese, is “a sacrificing place” as defined by *Shuowen jiezi*, the oldest surviving Chinese dictionary dating to 100 AD. The main structure of an altar is a round or rectangular mound (known as the sacrificial platform, or the altar itself) made by rammed earth and sometimes covered with a layer of white plaster, bricks, or stones (Fig. 1). The sacrificial platform is often encircled by one or more circles of walls and accompanied by a group of buildings and constructions (Fig. 2).

There are different types of sacrificing places in ancient China, among which altars and temples are most common. Altars and temples are different in form and content. Generally speaking, temples are roofed, while altars are open to the sky. Besides Buddhist and Taoist temples, temples are also for deified humans such as ancestors, sages, and heroes, while altars are for natural gods, or, in rare cases, for legendary human figures (Liu, 2000, pp. 3–5).

Altar and Confucian Rituals

The ancient Chinese believed that gods (or spirits) had exclusive power to control nature and human fates. Until the early twentieth century, such beliefs were only rarely questioned. There are two sources of gods. One is derived from natural elements (such as Heaven, Earth, the sun, the moon, stars, mountains, and rivers) and phenomena (such as thunder, droughts, or floods). The other comes from humans (such as ancestors, historical, or legendary figures). The worship of nature and ancestors has a history almost as long as Chinese civilization. The earliest material evidence for ritualistic practice in China can be traced back to the period between 7000 and 5700 BC, when Neolithic humans at the lower region of the Yellow River were already able to produce wine, music, and scripts for ritual purposes (Zhang et al., 1999, p. 368).

During Confucius' life (551–479 BC), his ideology encouraged development of elaborate theories and practices on rituals. Confucius regulated and interpreted ancient rituals. After his death, his thoughts were collected and recorded by his disciples in the *Liji* (Book of Rites), a collection of Confucius' discourses on the rules of propriety or ritual ceremonies. In the *Liji*, rituals were divided into five categories, known as the rituals of sacrifice, wedding, funeral, archery, and visiting. Among them the most important rituals are the imperial sacrifices to the Gods of Heaven, Earth, Land, and Grain. These sacrifices must be held not in temples, but at altars, because “the Son of Heaven (that is, the emperor) was open to receive the hoarfrost, dew, wind, and rain, and thus to fully experience the influences of Heaven and Earth” (Legge, 1885, p. 425).

From the Han dynasty (206 BC–220 AD), Confucianism was authorized as the state ideology and remained largely dominant until the Qing dynasty (1644–1911 AD). It was especially after the twelfth century that Neo-Confucianism, a form of Confucianism that adopted ideas from Daoism and Buddhism, became the dominant philosophy influencing everything from the

Altars in China, Fig. 1 A bird's-eye view of the archaeological excavation of the main part of the Round Altar (Altar of Heaven) in Chang'an (former name of Xi'an) dates back to Sui and Tang times (581–907 AD). The height of the round mound is about 8 m and the diameter 53 m. It has four layers of platforms and 12 sets of stairways, indicating four seasons of the year and 12 divisions (each division is 2 h) of the day (An et al., 2000)



Altars in China, Fig. 2 The aerial view of the Altar of Heaven in Beijing, built in Ming and Qing times (1368–1911 AD) (Luo, 2002, p. 258)



culture of politics to daily social etiquette. In Neo-Confucianism, the abstract concept of the “Law of Heaven” (*tianli* 天理) is seen as the starting principle; all beings on Earth are bound to follow this law. It denotes balance (i.e., *yin* and *yang*) and movement (i.e., following the natural sequence). Therefore, all beings are connected and reflect each other. Rituals provide the practical guidelines and direction with which the law should be followed.

There is a distinct hierarchy of sacrifice. Different people practice different rituals. Sacrifice to Heaven, Earth, the Sun, and the Moon can only be carried out by emperors, while the sacrifice to Soil and Grain (symbolizing territory and food, which are thought to be two of the most important issues for a government) is practiced by people within different social levels, each of whom has respective altars for sacrifice (Chen, 1985, pp. 23–24; Legge, 1885, pp. 207–209).

The emperor pays his sacrifices at the imperial Altar of Soil and Grain, the local governmental officials at local Altars of Soil and Grain, while additionally every 100 homes have their own Altar of Soil and Grain. The Altar of the God of Agriculture, traditionally used solely by emperors, is also sanctified to receive sacrifice from various levels of society. This serves to teach local officials the importance of husbandry.

Altar sacrifice is the most important of the five types of rituals, and sacrifice to Heaven and Earth by the emperor is considered the most supreme. By practicing this ritual, the emperor sets an example to the state and thus his subjects follow suit. Within this context altar sacrifice represents the core values of Chinese culture. By sacrificing to Heaven, the emperor presents himself to the whole nation as the model of observance and reverence to his ruler – the God of Heaven. As a consequence, all his subjects learned to be observant and reverent to the emperor (Legge, 1885, p. 367). Apart from the purpose of regulating government, imperial sacrifice served as the means to beg for a good harvest, which is vital to agriculture and therefore the nation. The gains from agriculture largely depended on climate, particularly on water and sun, so praying for good weather to various Nature gods was always seen as essential. This is another responsibility for the sovereign who had to pay great reverence to the deities. For example, in order to pray for rain during droughts, the emperor was to fast for three days followed by walking to the Altar of Rain (located at the Altar of Heaven compound) himself, rather than being carried there.

Imperial Altars in Beijing

In 1420, the Ming emperor Yongle (1360–1424, r. 1403–1424) built three altars in Beijing when he moved the capital from Nanjing to Beijing, namely, the Altar of Soil and Grain, the Altar of Heaven and Earth, and the Altar of Mountain and River. In 1530, considering contemporary altars not “authentic,” the Ming emperor Jiajing (1507–1567, r. 1522–1566) claimed to restore

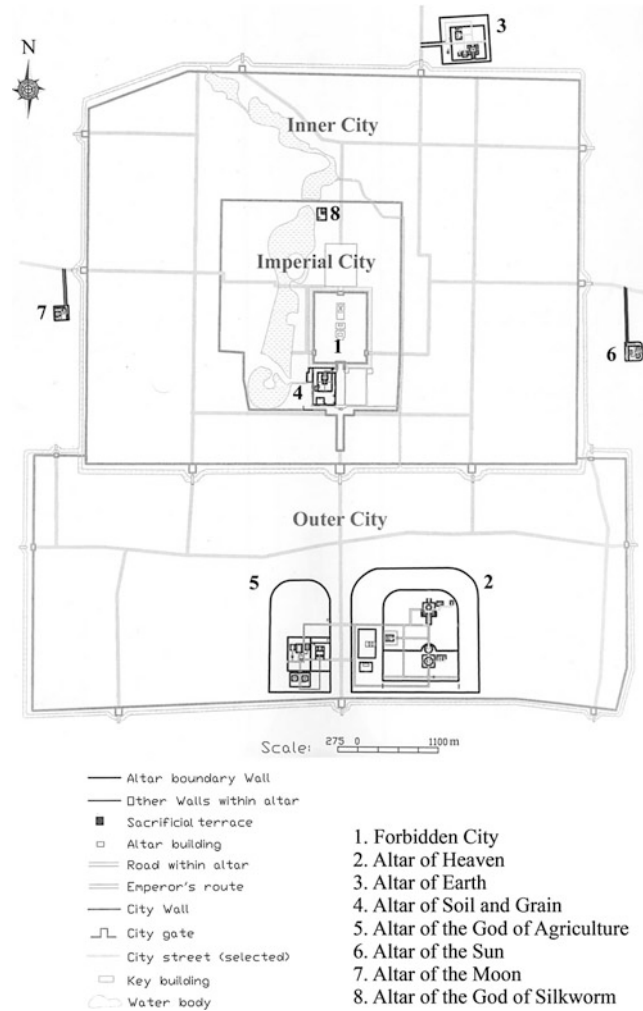
the ancient ritual system and altered the imperial altars. The number of altars increased to seven, with the Altar of Heaven and Earth being separated into two altars, the Altar of Heaven and the Altar of Earth, and three altars were added: the Altar of the Sun, the Altar of the Moon, and the Altar of the God of Silkworms. The Altar of Mountain and River was incorporated into the Altar of the God of Agriculture. This arrangement was retained afterwards and accepted by subsequent Ming and Qing emperors.

The altars were incorporated within the formal layout of Beijing, the center of which was formed by the Forbidden City. This was surrounded by the Imperial City Wall, which was then encircled by the Inner City Wall and the Outer City Wall (which, though only half finished, was connected to the southern side of the Inner City Wall). A straight north–south axis through the Forbidden City divided the city and its walls symmetrically into two. The emperor’s administration hall and hall of residence were located in the middle, with a straight avenue emerging from it, connecting the Forbidden City with the southern gate of the Outer City Wall. The Altar of Heaven and the Altar of the God of Agriculture were located on either side to east and west of the southern gate. The Altar of Soil and Grain, located immediately south of the Forbidden City, was on the west side of this axis. The Altars of the Sun and the Moon were outside the Inner City to the east and west on a cross axis. The Altar of the God of Silkworms was centrally to the north inside the Imperial City, with the Altar of Earth to the north of the Inner City (Figs. 3 and 4).

The location and orientation of these altars, as well as the individual layout and designs of structures, were all determined by Confucian rituals, thus reflecting a worldview which integrated human society and Nature gods. The layout of the altars was formal. Walls and pavements were arranged orthogonally, buildings and terraces were connected to each other, and evergreen trees were planted in regular delineations. All these characteristics provided an air of solemnity, while the fact that they were only open to the emperor and his entourage provided an element of mystique.

Altars in China,

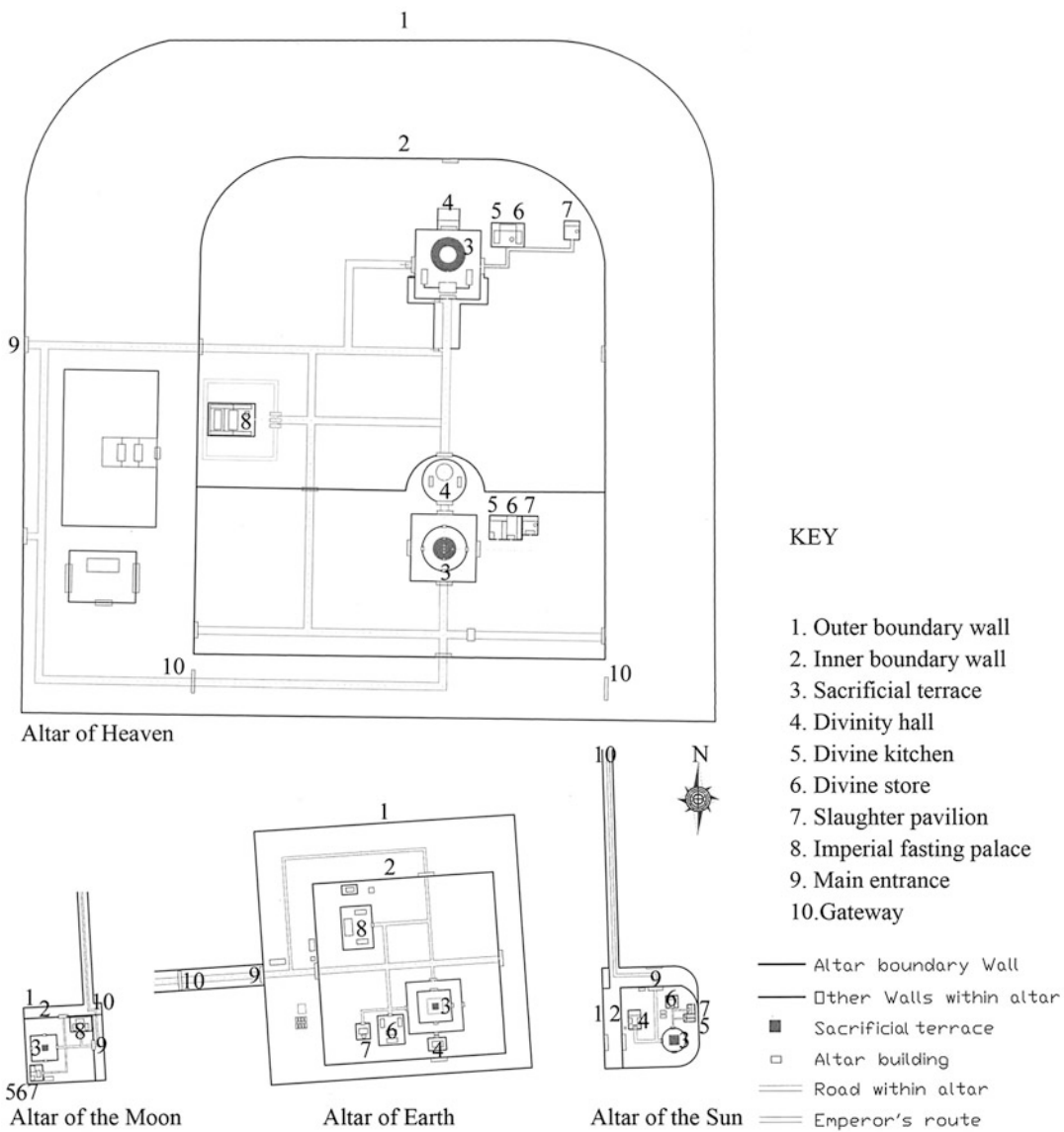
Fig. 3 Location of imperial altars in Qing dynasty City of Beijing (Gao & Woudtra 2011)



Despite the fact that the layouts were originally defined by rituals, the altars were changed over time in response to the needs and ideas of various emperors. Originally, the Book of Rites regulated both the Altar of Heaven and the Altar of Earth, when they were two separate altars, located at either side of the city. But in the Ming dynasty, the emperor Yongle thought it improper to separate the Gods of Heaven and Earth, since “the God of Heaven and the God of Earth, like father and mother, should stay together.” As a result in 1420, he ordered the Altar of Heaven and Earth to be built and decreed this arrangement to remain forever (Editorial Board of Beijing Chronicles, 2006, pp. 2–3). However, in 1530, Emperor Jiajing believed this order distorted the authorized rituals

and needed to be rectified. Therefore, he built the Altar of Earth to the north of the city and renamed the Altar of Heaven and Earth to the Altar of Heaven. In accommodating this to its sole purpose, a new sacrificial terrace was added to the south dedicated to the God of Heaven. The existing rectangular-shaped Divine Hall was demolished and rebuilt in a circular shape to represent Heaven (the Chinese believed Heaven to be round and the Earth square). A decade later, the Altar of Heaven was expanded towards the west and an extra boundary wall added, which provided the arrangement which can still be appreciated today (Fig. 5).

The Altars of Heaven, Earth, the Sun, and the Moon were places for sacrificing to Nature gods on specific days of the year. On the day of the



Altars in China, Fig. 4 Plans of four imperial altars in Beijing, drawn to the same scale and orientation, reveal a similarity in physical arrangement including positioning

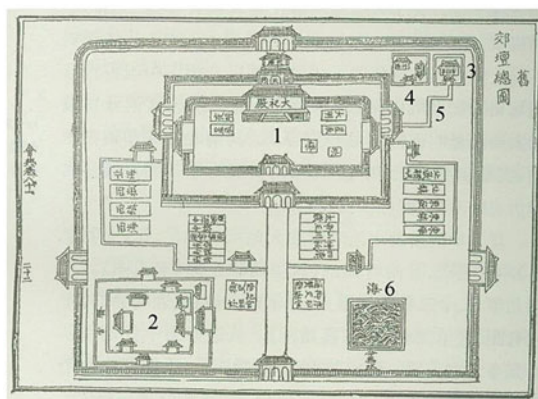
of altar features and symbolism. The variation in size reflects the relative significance of the respective gods to whom they are dedicated (Gao & Woudtra 2011)

winter solstices, the sacrifice to Heaven was held at the Altar of Heaven. And the sacrifice to Earth was held on the day of the summer solstices at the Altar of Earth. The sacrifice to the sun is held on the spring equinox and the sacrifice to the moon on the autumnal equinox.

In the Book of Rites, it is said that the temple for ancestors should be located to the east of the king's palace and the Altar of Soil and Grain to

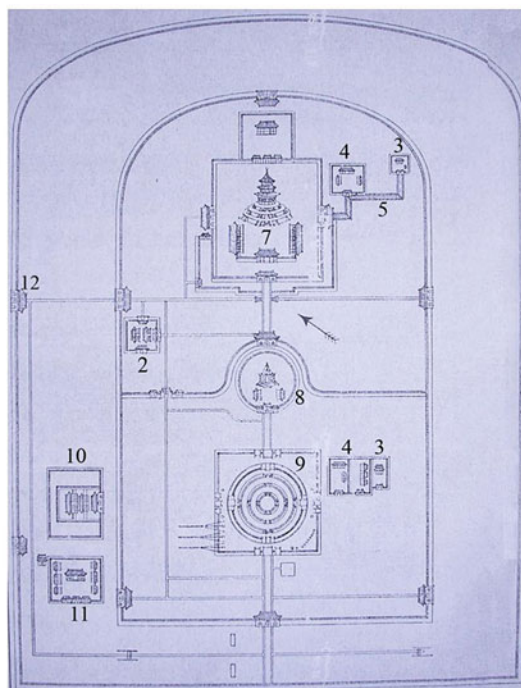
the west. This rule has been kept with few questions. The Altar of Soil and Grain in Beijing is located next to the Forbidden City, at the its west front.

The Altar of the God of Agriculture and the Altar of the God of Silkworms were for agricultural ancestors (as well as for legendary gods). Emperors took responsibility for agriculture and empresses for feeding silkworms and making



KEY

- 1 Great Sacrificial Palace for the Gods of Heaven and Earth
- 2 Imperial fasting palace
- 3 Slaughter pavilion
- 4 Divine kitchen and store
- 5 Covered passage way
- 6 Pond
- 7 The Hall of Prayers for Good Harvests
- 8 The Hall of Heavenly Emperors
- 9 Sacrificial terrace for the God of Heaven
- 10 Hall for musicians
- 11 Stables for sacrificial animals
- 12 Main entrance of the Altar



Altars in China, Fig. 5 Historical situation of the Altar of Heaven during the Ming dynasty (*left*) and Qing dynasty (*right*). While the plan on the left does not represent the correct proportions, and neither of these plans are at the correct scale, they show the general shape of individual buildings and features, as well as their relationships. The major changes from the earlier period include

the new construction of the Hall of Prayers for Good Harvest (*right plan*) on the site of the Great Sacrificial Palace for the Gods of Heaven and Earth (*left plan*) and the addition of the Sacrificial Terrace for the God of Heaven (*right plan*) to the south requiring further amendments to the original site (Casson, 1955, p. 400; Fu, 2004, p. 342)

clothes, making their respective sacrifices. In consideration of the *yin-yang* theory and practical considerations, the Altar of the God of Agriculture was arranged to face south mirroring the Altar of Heaven on the other side of the central north-south axis, thus providing a balanced composition. Before becoming the Altar of the God of Agriculture, it was referred to as the Altar of Mountains and Rivers. After the revision of sacrificial tradition in 1530, the Mountain and River gods were moved to the Altar of Earth as associated gods. The Altar of the God of Silkworms, located outside the city wall during the sixteenth century, was relocated inside the imperial “Western Gardens,” immediately alongside the Forbidden City. In this way the empress and her attendants could pay sacrifice without having to face the public – something much frowned upon at this time.

Due to the very complicated rules and processes and extreme significance of the imperial sacrifices, a special branch of government known as the Ministry of Rites was set up to administer ritual issues, including selecting sites, constructing altars and temples, inviting people to attend, as well as approaches to sacrifices. The most significant event was the annual sacrifice to the God of Heaven, which took place at the winter solstice. The second most significant was the sacrifice to the God of Earth on the summer solstice; the spring and autumn equinoxes were for the God of the Sun and the God of the Moon, respectively. The sacrifice to the God of Soil and Grain was taken on a special day of each spring and autumn (known as the day of Soil), and the first day of the spring plowing was the time for sacrificing to the God of Agriculture. It was the same for the empress sacrificing to the God of

Silkworms. Such arrangements were considered as following the order of nature.

Ritual ceremonies at imperial altars played a significant role in consolidating spiritual beliefs, but they also served as a reminder of political control, therefore being consolidated by various imperial dynasties. Qing emperors, although not Han Chinese in origin, took ritual ceremonies more seriously than previous Ming emperors, who sometimes sent princes or ministers to perform the rituals. With the exception of the sacrifices to the Sun and Moon gods, which ceased in 1813, the imperial sacrifices at the other altars continued until the end of the Empire in 1911. The practice of ritual ceremonies at imperial altars had dual meanings. On the one hand, it instilled a sense of fear in the emperors' and officials' minds and reminded them of their subordinate status towards a world beyond their dominance; on the other hand, by performing at imperial altars, the emperor sanctified his ruling status and stabilized the hierarchy of society. The imperial altars served as a stage for such ceremonial performances, which reinforced the meanings and values of these physical landscapes.

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Al-Uqlidīsī

Jacques Sesiano

Al-Uqlidīsī, Abū'l-ḥasan Aḥmad ibn Ibrāhīm, wrote an Arithmetic (*Kitāb al-Fuṣūl fī'l-ḥisāb al-hindī*) in Damascus in 952–953. This is a sizable compendium and remarkable as the earliest arithmetic extant in Arabic.

The first part explains the place-value system, the four arithmetical operations (addition, subtraction, multiplication, division), and the extraction of square roots for integers and fractions, both common and sexagesimal. Numerous examples are given. This part is supposed to be accessible to a large audience. The second part develops the earlier topics and adds curiosities or different methods. The third part would seem to be the result of the author's experience in teaching; it consists of explanations and questions with their answers concerning some difficulties the reader might have met in the first two parts. The fourth part contains some digressions about the changes Indian arithmetic undergoes when one uses ink and paper (since Indian computations were made on the dust abacus). In this part al-Uqlidīsī also explains (according to him, better than his predecessors) how to extract cube roots.

Al-Uqlidīsī was concerned with the applicability of arithmetic. How original his work was we do not know. He often claims originality or at least superiority of his teaching, but so do his contemporaries. He does not claim originality,

however, for the most important feature of his *Arithmetic*, the first occurrence of decimal fractions (besides the usual common and sexagesimal ones). He uses a mark placed over the last integral unit in order to indicate the separation from the subsequent, decimal part.

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Al-ʿUrdī

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Muʾayyad al-Dīn ibn Barmak al-ʿUrdī al-Dimashqī (thirteenth century) was an astronomer, architect, and engineer. He was born in Damascus and first worked in Syria. He did some hydraulic engineering in Damascus and constructed an astronomical instrument for the ruler of Hims (Emessa), al-Manṣūr Ibrāhīm (1239–1245). He also taught *handasa* (architecture or geometry).

In or soon after 1259, he was in Maragha, the capital of the Mongol conqueror Hulagu Khan, the grandson of Genghis Khan. He was one of the four astronomers who worked with Naṣīr al-Dīn al-ṭūsī, the founder of the Maragha observatory. He participated in the organization, building, and construction of the instruments of this observatory and in the building of a mosque and a palace in Maragha.

The best known al-ʿUrdī's work is *Risāla fī kayfiyya al-arṣād wa mā yukhtāj ilā ʿilmihī wa*

ʿamalihi min al-ṭuruq al-muwaddiya ilā maʿrifa ʿawḍāt al-kawākib (Modes of Astronomical Observations and the Theoretical and Practical Knowledge Needed to Make Them, and the Methods Leading to Understanding the Regularities of the Stars). Manuscripts of this treatise are extant in Istanbul, Paris, and Teheran. The treatise contains the description of 11 of the most important astronomical instruments of the Maragha observatory which he himself mainly constructed: (1) mural quadrant, (2) armillary sphere, (3) solstitial armilla, (4) equinoctial armilla, (5) Hipparchus' diopter (alidade), (6) instrument with two quadrants, (7) instrument with two limbs, (8) instruments to determine sines and azimuths, (9) instruments to determine sines and versed sines, (10) "the perfect instrument" built by him in Syria, and (11) parallactic ruler (after Ptolemy).

Al-ʿUrdī was also the author of three astronomical treatises: *Kitāb al-hayaposa* (Book on Astronomy) on the motion of planets, *Risāla fī ʿamal al-kura al-kāmila* (Treatise on Construction of the Perfect Sphere), and *Risāla fī l-taʿrīf al-buʿd bayna markaz al-shams waʾl-awj* (Treatise on the Determination of the Distance between the Center of the Sun and the Apogee).

Al-ʿUrdī's sons Shams al-Dīn and Muḥammad also worked in the Maragha observatory. Muḥammad (ca. 1280) constructed a celestial globe 150 mm in diameter, which is extant in the Mathematical Salon in Dresden.

See Also

- [Marāgha](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Observatories in the Islamic World](#)

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Anatomy in Ancient India

Lakshmi Rajgopal

In India I found a race of mortals living upon the earth but not adhering to it; inhabiting cities but not being fixed to them; possessing everything yet possessed by nothing. Apollonius Tyanaeus (Greek thinker and traveller, first century AD).

The history of India is both fascinating and daunting. The geographical terrain of Bharat (Hindustan), as India was known then, extended far beyond the boundaries of India as they exist now. It is this region that cradled a civilisation in the Indus valley about 5,000 years ago, evidence of which is amply found in Harappa, Mohenjo-daro, Lothal (Gujarat) and other places. There is evidence that ancient Hindus practiced science, especially medical science; they were adept in practical anatomy and knew how to apply anatomical knowledge to the practice of surgery.

Prehistoric Period

The history of medicine in India can be divided into two broad periods. The prehistoric period ranges from the Stone Age to the beginning of written history. This period can again be subdivided into the early prehistoric period (40000–2500 BCE) and the protohistoric period (2500–1500 BCE). Prehistoric people were wanderers, hunters and worshippers of supernatural phenomena (Subba Reddy, 1971). Any anatomical knowledge these men might have possessed was only to use it for hunting and not as a basis for diagnosis and surgical treatment of diseases. There is evidence, in the form of cave paintings (Fig. 1a, b) discovered in Bhimbetaka, near Bhopal in Central India, that superficial anatomical knowledge was used to hunt animals.

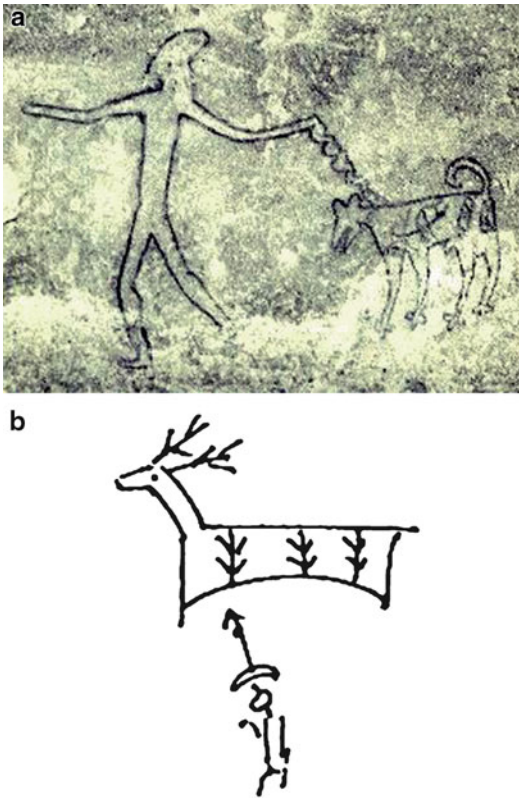
These are similar to the Pindal elephant pierced by arrows near its heart and the Niaux bison portrayed with weapons directed at its vital centres; they show that prehistoric man had some knowledge of gross anatomy (Gordon, 1949).

Protohistoric Period

The Protohistoric period is the time when the Indus Valley civilisation flourished in northwest India. The people of this civilisation were architects and built planned cities. They were also public health experts, as is evidenced by the wells and bathrooms in the houses and a closed system of drains that have been excavated in Harappa, Mohenjo-daro and other sites. They were also healers, although the practice of healing was more magico-religious, based on rites and rituals (Kutumbiah, 1962).

Historic Period

The historic period of ancient Hindu medicine started with the invasion of the Indus valley by Indo-European tribes such as the Aryans around 1500 BCE. The Vedic period extended from 1500 to 800 BCE. This was followed by the Brahmanic period or the Buddhic period, from 800 BCE to



Anatomy in Ancient India, Fig. 1 (a, b) Cave paintings at Bhimbetaka (Reproduced from K. L. Kamath. Prehistoric Paintings, URL: <http://www.kamat.com/kalranga/rockpain/betaka.htm> accessed on 23 Sept. 05)

1000 AD. This was followed by the Mongol period or the Moghul period from 1000 AD onwards (Major, 1954).

Vedic Period

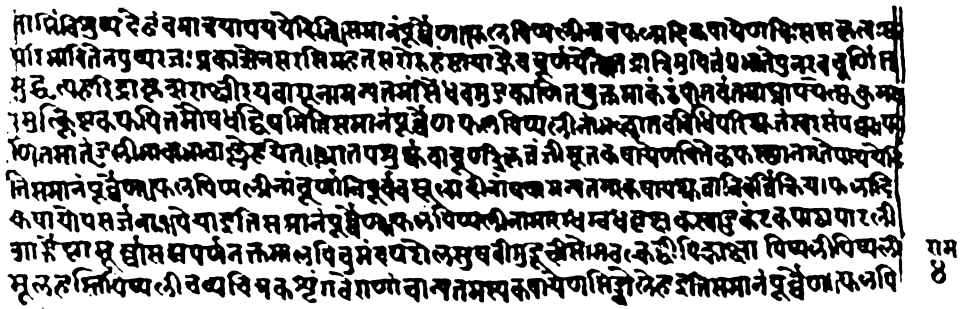
The word “Veda” means knowledge – *ṛgveda* is knowledge of hymns of praise; *Yajurveda* is knowledge of sacrificial formulae; *Sāmaveda* is knowledge of melodies and *Atharvaveda* is knowledge of magic formulae (Major, 1954). The Vedas speak about the structure of the body. In the *ṛgvedic* hymns mention is made of the lungs, the heart, the stomach, the intestines, the kidneys and other viscera (Kutumbiah, 1962). Atharvavedic medicine is an amalgam of magico-religious elements consisting of chants and charms and empirico-rational elements which used drugs to cure disease. The

Atharvaveda gives an impression of the coarser anatomy of the body. There is a hymn in the tenth book which mentions the creation of man describing the articulation of bones (Lanman, 1905). *Atharvaveda* also refers to the heart as a “lotus with nine gates”. The comparison of the heart with a lotus is very common in Sanskrit literature. When we compare it with present day knowledge, we see that there are indeed three venous openings in the right atrium, four pulmonary veins opening in the left atrium and the pulmonary artery and the aorta leaving the right and the left ventricles, making nine openings in all. The heart, if held upside down, does resemble a lotus bud (Rajgopal, Hoskeri, Bhuiyan, & Shyamkishore, 2002). *Atharvaveda* also describes childbirth in some detail.

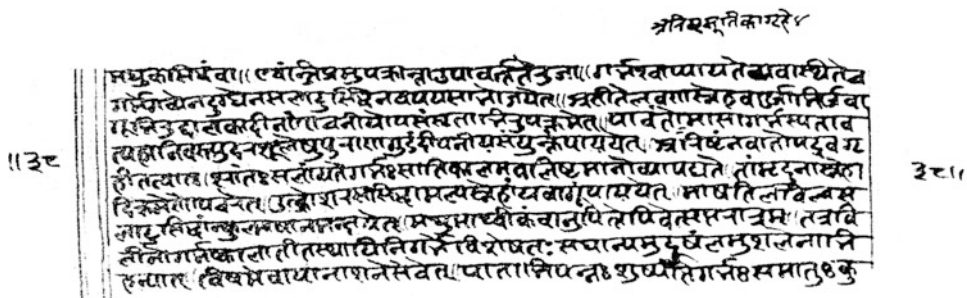
Brahmanic Period

Vedic books such as *saṃhitās* contained hymns. It was difficult for common people to follow them. So the post-Vedic period saw a lot of literary work which described the Vedic work in simpler language. Thus were born the *Brāhmaṇas* which described and explained the Vedic rites and stories. These were followed by *Aranyakas* which were the continuation of the *Brāhmaṇas* but were meant for people who have entered the third ashram of *Vanaprasta* in life. *Aranyaka* is derived from *arni* meaning wooden sticks, the rubbing of which results in the production of the sacrificial fire. The fire thus produced was used by the *Vanaprastis* for their day-to-day living (Bodas, 1908). *Aranyakas* were followed by *Upaniṣads*. In fact *Upaniṣads* are part of *Aranyakas* which treat the higher doctrine of the soul (*Upaniṣad* = secret knowledge/esoteric lore). Upanishadic knowledge is obtained by the disciples by sitting around a teacher and listening to him in the ‘Guru-Shishya’ tradition (Udwadia, 2000).

Hindu scriptures had a peculiar way of comparing the structure of human body with things that are metaphysical. In *Satapatha Brāhmaṇa*, Yajnavalkya, who flourished in the court of King Janaka, mentions that the total number of bones in the body is 360 and compares it to 360 days of the year (Hoernle, 1907). It is during this period



Anatomy in Ancient India, Fig. 2 A leaf from *Suśrutasaṃhitā* (Reproduced from Indian System of Medicine by O. P. Jaggi. New Delhi: Atmaram & Sons)



Anatomy in Ancient India, Fig. 3 A leaf from *Carakasamhitā* (Reproduced from Indian System of Medicine by O. P. Jaggi. New Delhi: Atmaram & Sons)

that the science of “Āyurveda” came into being, roughly between 800 and 600 BCE. Āyurveda, or the science of life, was expounded by Brahma and given to the Ashwinikumars; they then taught Indra, who transmitted his knowledge to other priests (Jaggi, 1972). This period was the “Golden Period” in the history of Indian medicine.

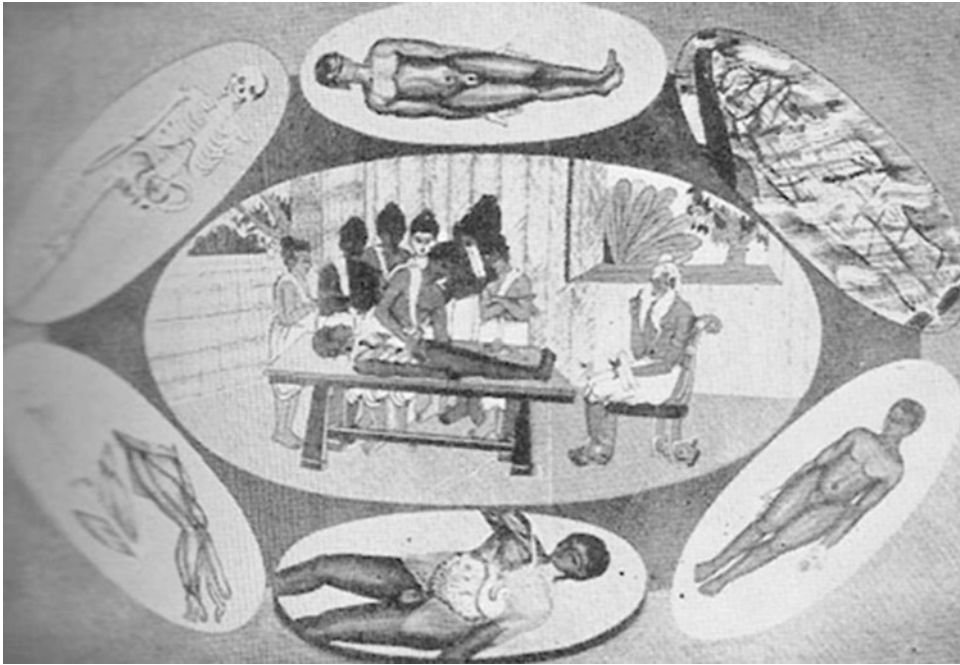
The Golden Period

According to the Indian medical tradition, the knowledge of medicine had two origins. On the one hand, it was delivered by the God Indra to the sage Bharadwaja and the latter then handed it over to Punarvasu ► [Ātreya](#). On the other hand, it descended from Indra to Dhanvantri (also called Divodasa or Kasiraja) and from him to ► [Suśruta](#). This tradition gives medicine a mythical origin and when traced further leads to historical facts. In the age of Buddha, two great universities existed in India where all forms of

science including medical science were taught. They were Benares or Kasi in the East and Takshila or Taxila in the West on the river Jhelum (Hoernle, 1907). The leading professor of Medicine in Takshila was Ātreya and the famous teacher of surgery at Benares was Suśruta. They were two stalwarts of Āyurveda and their teachings were compiled in the form of texts. Suśruta's teachings were compiled as *Suśrutasaṃhitā* (Fig. 2).

Ātreya had Agniveśa as one of his disciples, and ► **Caraka** was in turn his student. Caraka revised *Agniveśatantra* and it came to be known as *Carakasamhitā*. Caraka was the court physician of the celebrated Indo-Scythian king Kanishka and that puts the period of Caraka as 125–150 AD (Bhandarkar, 1906) (Fig. 3).

Suśrutasaṃhitā is a great storehouse of Aryan surgery. Though Garrison claims that Indian medicine was weak in anatomy which he attributes to fanciful enumerations (Garrison, 1924),



Anatomy in Ancient India, Fig. 4 Preparation of a dead body for dissection (Reproduced from the museum guide of the Institute of History of Medicine, Hyderabad)

it is a fact that to practise the art of surgical healing, one must have sound knowledge of anatomy. Suśruta could not have achieved such mastery over surgery without a thorough knowledge of anatomy. It is precisely for this reason Suśruta insisted that his disciples practice dissection, even though their religion prohibited it. Suśruta had devised his own method of overcoming religious cutting open the dead body prohibition by placing the dead body in a cage covered with hemp and then keeping it in a secluded spot in the riverbed which would allow the body to decompose slowly in water. Later the observer gently scraped off the layers of the skin using *kusa* grass and could see both the external and internal aspects (Clendening, 1942; Dampier, 1942; Jaggi, 1972; Kutumbiah, 1962) (Fig. 4).

Both Suśruta and Caraka devoted an entire chapter to anatomy, *Sarira Sthana*, in their *Samhitās*. Osteology (the study of bones), myology (the study of muscles) and splanchnology (study of the viscera and its organs) are some

divisions of anatomy in which these ancient authors excelled. Suśruta noted 300 bones and 210 joints in the body. He also classified joints into eight different types, e.g. *kora* (hinge joint) at the ankles and elbows, and *samudga* or *ulukhala* (ball and socket joint) as in the hip and shoulder. Caraka's anatomy is mainly that of external observation. Caraka described 360 bones and 200 joints. The reason for the discrepancy is that many cartilages, nails and protuberances were counted as separate bones. ► Suśruta gave the total number of muscles as 500 and specified their distribution as 400 in 4 extremities, 66 in the trunk and 34 in the head and neck regions. Caraka's description of muscles is quite rudimentary. Besides muscles, both Suśruta and Caraka described 900 *snayus* (ligaments; Kutumbiah, 1962).

Suśruta had more thorough and critical knowledge of the internal viscera as is evidenced by his description of the heart and the vessels. He referred to the heart as a lotus bud hanging with its apex downward and also



A

Anatomy in Ancient India, Fig. 5 Preparation of clay models by students of anatomy (Reproduced from the museum guide of the Institute of History of Medicine, Hyderabad)

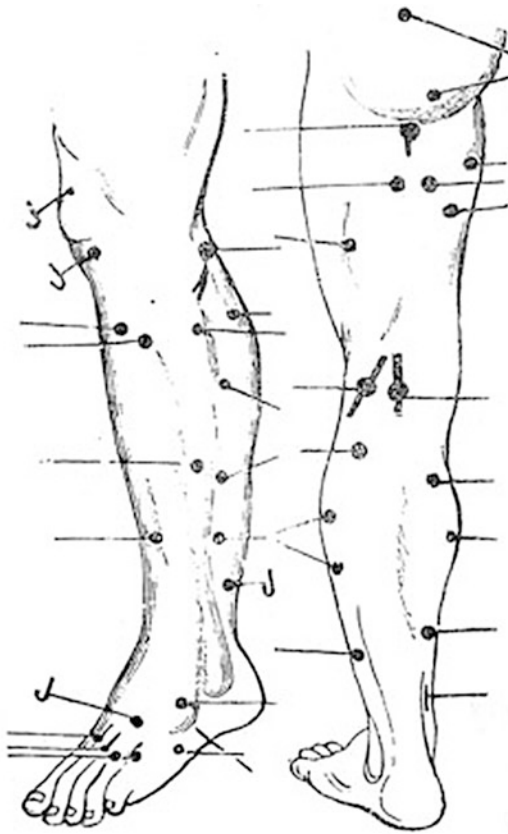
noted 24 *dhamanis*, 700 *siras* and 22 *srotas*. *Dhamanis* are thick-walled tubes and *siras* are thin-walled tubes equivalent to present-day arteries and veins. *Srotas* probably referred to lymphatics. Suśruta observed that all the *dhamanis* and *siras* arose from the umbilicus and there were 40 important ducts in the body. Caraka said that the heart was the root of ten *dhamanis* which run to different parts of the body. Nerves were also classified as ducts and included in the count of vessels.

Suśruta does not state anything of importance concerning the brain but considers the head as the centre of all senses. Both Suśruta and Caraka mention various viscera in the abdomen. The stomach is referred to as *amasaya*; the intestine is called *pakvasaya* and the rectum *gudam*. The uterus is known as *garbhasaya* and the gallbladder as *pitthasaya* (Kutumbiah, 1962).

According to Suśruta, apart from dissecting, a student of anatomy should learn the subject and obtain mastery over it by preparing clay

models (Fig. 5). Suśruta implored his students of surgery to be careful about 107 vital spots or *marmas* in the body. *Marmas* are the meeting place of any two or more of the five elements of the body: vessels, muscles, ligaments, bones and joints. The *marmas* are then classified into five groups (1) *Mamsa marmas* (fleshy); (2) *Sira marmas* (of the vessels); (3) *Snayu marmas* (of the ligaments); (4) *Asthī marmas* (of the bones) and (5) *Sandhi marmas* (of the joints). According to Suśruta, some of them when injured will result in instantaneous death and some others when injured will cause pain and paralysis (Bhishagratna, 1991; Clendening, 1942; Dampier, 1942; Jaggi, 1972) (Figs. 6 and 7).

Apart from gross anatomical findings, embryology, the study of the development of the foetus, also achieved a high level in ancient India. Structures such as amniotic membranes are mentioned in the Bhagavad Gītā (Needham, 1934). Indian anatomists were of the opinion that union



Anatomy in Ancient India, Fig. 6 Vital spots or *marmas* in the limbs according to Suśruta (Reproduced from *The Suśruta Saṃhitā* – English translation by K. K. Bhishagratna. Varanasi: B. Chowkhamba Sanskrit Series Office)

of the blood of the mother, called *sonita* and the semen of the father, called *sukra* was responsible for the production of the foetus. They were aware that the mechanism of sex determination took place at the time of fertilisation (Kutumbiah, 1962). Moore and Persaud (1999) quote *Garbhoniṣad* (sixth century BCE) which describes the stages of development of the foetus. A 1-day-old embryo is jelly-like and called *kalala*. After seven nights, it becomes vesicular (*Budbuda*) which indeed is the case, as we know now. We call this a blastocyst. After a month it becomes a firm mass and the head is formed after 2 months.

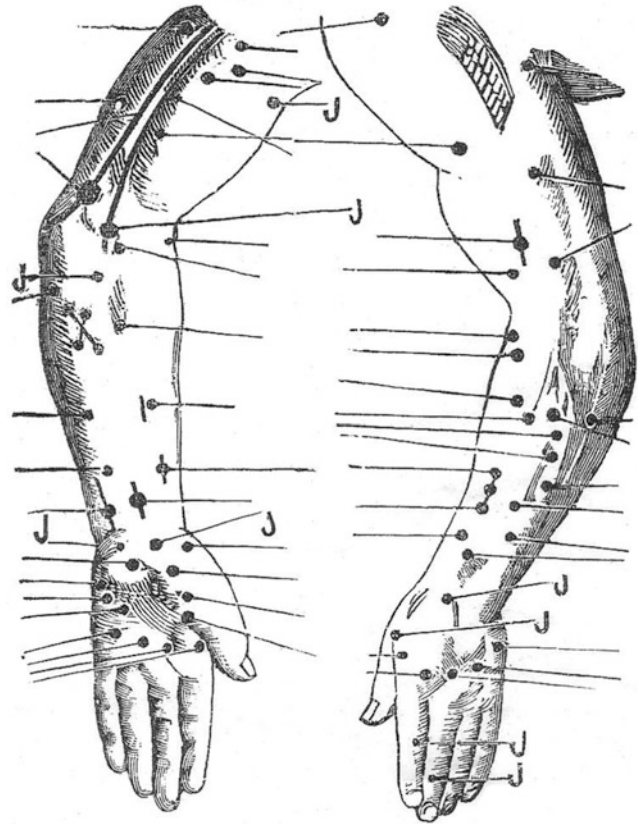
In the third month legs and arms appear distinctively. In the sixth month hair, nail, bones

and veins develop. In the eighth month there is drawing of the vital force (*ojas*) from the mother. Indian anatomists believed that the growth of the embryo occurs by a process of layering where at least seven strata are superimposed one upon the other. The seven layers are *avabhasini*, *lohita*, *sveta*, *tamra*, *vedini*, *rohini* and *mamsadhara* (Kutumbiah, 1962). They also believed that softer parts of the foetus, such as skin, blood, flesh, fat, navel, heart, lungs, liver and marrow, are derived from the mother and the harder parts, such as the head, nails, teeth, bones and nerves, are derived from the father (Jaggi, 1972; Zimmer, 1948). The formation of the embryo is also compared with the formation of creamy layers of milk; this similar comparison to the clotting of milk to form cheese has also been used by Aristotle (Needham, 1934).

It is possible that Indian thought influenced the schools of Asia Minor and through them those of Greece (Dampier, 1942). There is evidence that Indian medical practices spread all over Asia including Indonesia, Tibet and Japan. The translation of Ayurvedic literature into Arabic and Persian in the eighth to eleventh century AD led to its further spread (Lyon & Petrucelli, 1987). *Carakasamhitā* was translated from Sanskrit into Arabic in the eighth century AD and *Sharaka indianus* appears in the Latin translation of Avicenna, Rhazes and Serapion. *Suśrutasaṃhitā* was translated into Arabic before the end of the eighth century AD as ‘Kitab-i-shawshoon–Al-Hindī’ and also mentioned as ‘Kitab-i-Susrud’ by Ibn Abillsaibal. Rhazes often quotes ‘Sarad’ as an authority in Surgery (Mukhopadhyaya, 1913).

The ancient Indian medical doctors can be credited with the inquisitiveness to learn about the structure of the human body and a systematic study of the same. They practised human dissection despite religious restrictions. They also had an appreciation of the relation of anatomy to the practice of medicine. Even if the enumerative method of various parts of the body may minimise their significance, what cannot be denied is that they used their knowledge of anatomy to master surgery and practised medicine in a more scientific way.

Anatomy in Ancient India, Fig. 7 Vital spots or *marmas* in the limbs according to Suśruta (Reproduced from *The Suśruta Saṃhitā* – English translation by K. K. Bhishagratna. Varanasi: B. Chowkhamba Sanskrit Series Office)



A

See Also

► [Surgery in Ancient India](#)

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- *Papyrus Hearst*, ca. 1550 BCE, a less systematically organized collection of remedies that duplicates many of those in the Ebers Papyrus
- *Papyrus Berlin 3038*, ca. 1350–1200 BCE, another collection of drug recipes, with another version of the *Secret Book*
- *Papyrus Chester Beatty*, ca. 1250–1150 BCE, a fragment of an earlier monograph on diseases of the anus
- *Magical Papyrus of London and Leiden*, ca. third century AD, containing many examples of spells used in healing rites

From the beginning, magic dominated Egyptian concepts of illness and its treatment. Empiric observations eventually entered therapeutic thinking, but magic was seldom far removed from it. The Egyptians attributed healing powers to a number of their local gods, while Thoth, scribe of the major gods and inventor of the arts and sciences, became a part-time god of medicine. Not until he was deified sometime after 525 BCE did Imhotep, who had been the chief minister of the pharaoh Zoser (reigned 2630–2611 BCE), and the inventor of the pyramid, assume the role of chief god of Egyptian medicine.

Throughout most of the three millennia of pharaonic history, three kinds of healers treated the sick. Two of them, magicians and priests, relied chiefly on magical or religious rituals. The third group, the lay physicians called *swnw* (pronounced something like “sounou”), relied chiefly on surgery and drugs, techniques that were also used by healing priests. How they learned their professional skills is not known, but most probably they learned from their fathers, and all were literate. Interestingly, not all were men: an inscription from the Old Kingdom period (2575–2134 BCE) describes a woman named Peseshet as the Lady Director of the Lady Physicians.

Swnws usually accompanied armies into the field, and were employed at public works sites such as temples, pyramids, and quarries. The oldest known doctor’s bill lists payments to a *swnw* who worked at the village of the workmen who built the tombs and temples of Thebes, in

Ancient Egypt

J. Worth Estes

Humanity was concerned with sickness and death long before the Egyptians appeared along the banks of the Nile. But only from the beginning of pharaonic civilization, about 2900 BCE, do we have evidence of how sickness and trauma were treated in the ancient world. It comes primarily from several monographs, or collations of sections of earlier monographs, written on papyrus. The major medical papyri are, in their probable chronological order:

- *Veterinary Papyrus of Kahun*, ca. 1900 BCE, on the treatment of animals
- *Gynecological Papyrus of Kahun*, ca. 1900 BCE, a fragment of a monograph on the diseases of women
- *Papyrus Edwin Smith*, ca. 1550 BCE, part of a monograph on wounds that also includes a fragment of a work on the heart and vessels called the *Secret Book of the Physician* that was probably composed ca. 3000 BCE
- *Papyrus Ebers*, ca. 1550 BCE, a collection of remedies for several kinds of ailments that contains a longer version of the *Secret Book*

about 1165 BCE. Although physicians were paid only about a third as much as construction workers, *swnw*s sometimes achieved very high rank at court, and were rewarded accordingly.

The average age at marriage was 12–13 for women, and 15–20 for men. The fertility rate, at least among the few queens for whom we have data, was lower than might have been expected, about 3.5 births per woman, in part because children were not weaned until they were 3-years old. The average life expectancy at birth was probably about 30 years in the early Old Kingdom, and might have increased to as much as 36 years over the next 2,500 years. Evidence of very old age is scarce among mummies simply because most Egyptians died in their 30s, before the diseases that are typical of old age could have developed. A few kings and priests lived into their 90s, but fewer than 10 % of Egyptians lived longer than 40 years. By contrast, about 94 % of modern Americans die after age 40, and their life expectancy is about 76. As in most preindustrial cultures, both the population and the average life expectancy rose (and the death rate fell) when the food supply increased, as farmers increased their ability to exploit the Nile with improved irrigation systems.

Egyptians well understood the biological relationships among the testes, penis, semen, and pregnancy. However, because much of their anatomical knowledge came from cattle, they thought that semen was produced in the bone marrow, even if they also knew that removing the testes – castration – prevented any possibility of fatherhood. On the other hand, they knew nothing about the ovaries, and thought that women's role in reproduction was simply to nourish the fully formed seed that the father planted in the fertile uterus. Although the *swnw* did not attend births, he did treat women's medical problems. He attributed menstrual abnormalities to malpositions of the uterus, which meant that many "gynecological" treatments were designed to restore it to its proper position.

It has been difficult to learn much about the actual causes of death in ancient Egypt, despite the hundreds of mummies in the world's museums. Several have been studied

nondestructively, using X-rays and CAT scans. Such noninvasive techniques can easily reveal diagnoses such as fractures, dislocations, calcified arteries, and gall stones, but such conditions need not be fatal per se. X-rays of 26 royal mummies from the New Kingdom (1550–1070 BCE) period have revealed more about their age at death, their teeth, and about mummification techniques, than about their illnesses, and even less about the causes of their deaths. The few mummies that have been dissected have provided surprisingly little specific pathological information, partly because most Egyptians probably died of infections that left few anatomical traces, and partly because mummification usually destroyed potentially diagnostic tissues. On the other hand, Egyptians may have been so thinly scattered along the river that many infectious diseases could not easily have propagated themselves. Nevertheless, in some places at least, the population may have finally become sufficiently dense over the centuries to facilitate the spread of such diseases.

Not all evidence of illness in ancient Egypt has come from human remains. A few statuettes show spinal distortions characteristic of tuberculosis of the spine, as do several mummies. Similarly, both a funeral monument and a mummified leg show the dropped foot deformity typical of poliomyelitis (although it could also have been a club foot). Identifiable illnesses are not found in the detailed pictures of everyday life that adorn tombs, since sickness had no useful role in the next life.

In addition to tuberculosis, Egyptians had many of the diseases we have, although in different proportions of the population, plus several protozoal and worm infestations that are still found along the banks of the Nile, such as trachoma and schistosomiasis. Most of the nontraumatic illnesses that occurred in ancient Egypt have not been identified in modern terms, but the Ebers Papyrus shows that the *swnw* classified them by their anatomic location, such as the skin, hair, abdomen, limbs, genitalia, and so on.

The Edwin Smith Surgical Papyrus contains several "firsts" in the history of medicine,

including the first written descriptions of any surgical procedures, and the earliest examples of inductive scientific reasoning. The 48 cases described in the monograph are organized anatomically, from the top of the head down through the neck to the upper arm and chest; the scribe stopped transcribing the text when he reached the section on the upper spine. Because many injuries described in the Smith Papyrus were probably battle wounds, its prognostic predictions can also be taken as early examples of systematic battlefield triage.

The original author of this surgical text classified injuries by their extent and severity, and by their localization in bone or flesh, and established a systematic procedure for dealing with each kind of problem. Each chapter is devoted to a different injury, beginning with clinically important phenomena that could be seen or palpated, followed by a diagnosis based on facts elicited during the examination, and concluding with a prognosis. The prognoses are in three standard forms: injuries that are treatable, those of uncertain outcome that the *swnw* will try to treat anyway, and those that are unlikely to respond to any treatment, such as depressed skull fractures and compound fractures. The latter prognosis usually leads to the recommendation that nature be allowed to take its course.

Ancient Egyptian surgery provided simple, practical solutions to a number of self-evident problems. Today, most of it would be called “minor surgery,” such as incising and draining abscesses, removing superficial wens, tumors, and so on. Circumcision was practiced on adolescent boys, but by priests, not physicians. The *swnw* did not perform major operations such as amputations, although he did try to reduce simple fractures and dislocations. Penetrating wounds were drained and cleaned. The *swnw* used adhesive plasters, not sutures, to hold wound edges together.

He differentiated between “diseased,” or infected, wounds, and “nondiseased” wounds, which we would call “clean.” The Smith Papyrus recommends daily inspections so that dressings can be changed when necessary. Many wound ointments were made with honey or the green

copper ore malachite. Recent experiments have shown that both substances could have been effective against the kinds of bacteria most often found in contaminated wounds, permitting them to begin healing of their own accord.

When it came to what we now call internal medicine, magicians and healing priests relied largely on spells and incantations to cure their patients, and on amulets, written spells, and repulsive materials like animal feces to drive away or prevent illness. Sometimes they relied on healing statues standing in sacred ponds, so that patients who bathed in the same water would be cured by the god to whom the statue was dedicated. Late in pharaonic history, a patient might be instructed to sleep in a temple, expecting that its god would send him a dream that would reveal his cure, a procedure called “incubation.”

The *swnw* might not have understood the underlying pathology of nonsurgical illness, but he had a logical, even if speculative, theory of disease. According to the medical historian Henry Sigerist, “Physiology began when man tried to correlate the action of food, air, and blood.” The Egyptians saw the heart as the focal point of that correlation. It was the body’s most important organ, and the seat of intelligence and emotion.

The *swnw*, who knew that air is vital to life, thought that it passed through the trachea to both the heart and the lungs. From the heart it traveled, in blood and along with other fluids, to other organs in primary afferent ducts called *metu*. From those organs a series of secondary *metu*, or efferent ducts, led to the surface of the body. The body’s secretions and excretions, including phlegm, tears, semen, urine, and even a little blood, escaped through that second set of *metu*. This concept permitted the *swnw* to exploit a fairly plausible theory of disease. He could accept the *metu* as fact chiefly because Egyptians could not differentiate arteries, veins, nerves, and tendons anatomically. They thought that all of them were hollow *metu* that transported disease, in the form of a foul substance called *ukhedu*, to various organs, depending on how many *metu*, and which ones, were involved.

Because decay and foul odor characterize both normal feces and death, the potentially fatal *ukhedu* was thought to originate in the feces as the residue of incompletely digested food. Indeed, postmortem putrefaction is most noticeable in the intestines. Thus, if any *ukhedu* were allowed to accumulate to overflowing within the intestines, the excess would overflow up into the *metu* that normally carry blood from the heart to the intestines, so that the excess traveled backward to the heart. From there it could then enter other primary or secondary *metu* and be carried to other organs. Once it had entered a given *metu*, the *ukhedu* in that vessel could destroy the blood in it, producing pus. When it reached other organs, the pus would settle in and produce disease in them. Thus, the appearance of pus on the surface of a wound was a favorable prognostic sign, inasmuch as it signified that it was escaping and not accumulating within the body. Many treatments were designed to help *ukhedu* escape from the body. For instance, because boils were obviously filled with pus, they were opened so that the dangerous *ukhedu* could escape. Similarly, the standard wound ointments made with malachite or honey would counteract *ukhedu* that surfaced in a wound.

Egyptian drugs included many animal parts. Almost no clinical selectivity was associated with any of them, although ostrich eggs were used somewhat selectively in diarrhea remedies. Most of the animal products used in drugs, such as fat and grease, were used principally as emollients in wound ointments. In addition, the blood of several species was thought to be modestly selective for hair problems and eye trauma. But most animal parts used in drugs were included chiefly because of their magical associations. For instance, since ravens are black, their blood was used to treat the Egyptians' black hair; stallion semen was used to restore sexual drive; and fish skulls appear in headache remedies.

By contrast, the majority of drugs recommended in the Ebers Papyrus was aimed at disorders of the gastrointestinal tract, followed by remedies for the eyes, limbs, and skin. The *swnw* classified accumulations of *ukhedu* in the

metu-ducts as gastrointestinal disorders, because the *ukhedu* originated in the alimentary canal. Thus, cathartics were usually prescribed to help flush *ukhedu* out of the rectum before it could accumulate to dangerous levels. Although some remedies for disturbances within the *metu* or the intestines do promote bowel movements, many laxative or cathartic drugs were used to treat nonintestinal symptoms. For instance, the mild laxative aloe was sometimes prescribed for eye disease, and the strong laxative colocynth for respiratory ailments. Thus, it seems likely that the *swnw* thought that all cathartics were at least somewhat selective for removing *ukhedu* from both the rectum and the *metu* which distributed it in the body.

Constipation implied that accumulated *ukhedu* could not escape by its usual route through the anus. Indeed, an Egyptian might take strong laxatives 3 days a month just to prevent *ukhedu* from filling up, and overflowing from, his rectum into his *metu*, whence it might reach his heart. Although diarrhea was a frequent complaint, sometimes it was not treated at all, because plentiful stools implied that the bowels were being adequately emptied of the dangerous *ukhedu*.

Honey, the most popular of all drug ingredients mentioned in the papyri, was used not only in wound ointments, but also in both laxatives and antidiarrheals, and in many other remedies. Since it was not used for any one kind of clinical problem more often than another, we can infer that honey was not used very selectively for symptoms associated with any particular organ system. Honey was probably regarded as selective for the *ukhedu*, especially when it appeared in wounds as pus.

The next most frequently used drug was called *djaret*. The word has not yet been convincingly translated, but it was clearly a plant product. Because it appears in about half of all prescriptions for diarrhea, *djaret* was probably thought to have some selectivity for that problem. In addition, it was included in a third of the prescriptions for eye diseases, and may have been thought to be at least modestly selective for them. However, whatever it was, *djaret* was also prescribed for

many other disorders, so it must have been regarded as a multipurpose drug, even if as not as a panacea. Frankincense, too, was often prescribed for many illnesses, but it was aimed most selectively at pains of the head and limbs, and less often at intestinal problems. Like the mysterious *djaret*, an antimony ore was applied to eye problems.

The next most frequently used ingredients were applied fairly nonselectively, although some were often used in both laxative and antidiarrheal mixtures. The pulp of the colocynth gourd is a very powerful cathartic that was also used for the latter purpose. Figs were used for abdominal pains and urinary disorders. Malachite was aimed at eye problems; it could not be taken internally because copper salts cause vomiting. It probably first entered medical usage as a topical ointment after long usage as an eye cosmetic. The author of the Ebers Papyrus knew about the laxative property of castor oil, but he included it in only a very few recipes for cathartics; he thought it was better suited for making women's hair grow. Like many other Egyptian remedies, it, too, survived in Western medical usage until well into this century, but as a cathartic, not as a hair restorer. However, most of the 328 different drug ingredients mentioned in the Ebers Papyrus were used for almost any illness.

Although Egyptian physicians prescribed a wide variety of remedies, they appear merely to have dispensed predetermined remedies to patients with similar ailments; the *swnw* seems not to have treated each patient as an individual. That concept would not be introduced until Greek medicine began to flourish in the fifth century BCE. There is no evidence that any of the *swnw*'s remedies, save for malachite and honey, when applied topically, had any truly beneficial effect on the outcome of ancient patients' illnesses, nor is there any modern reason to think so. Although they may not have known it, ancient physicians were able to rely on their drugs, and even on their magical spells, because of the body's impressive ability to use mechanisms such as the immune and inflammatory responses to heal itself of most ordinary ailments. By contrast, Egyptian surgery

probably did provide reasonably effective treatments for many traumatic injuries.

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Ancient Indian Square Roots

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Introduction

Our modern system of positional decimal notation with zero, together with efficient algorithms for computation, which were discovered in India some time prior to 500 CE, certainly must rank among the most significant achievements of all time. And it was not easy. As Pierre-Simon Laplace (1923) explained, “the difficulty of inventing it will be better appreciated if we consider that it escaped the genius of Archimedes and Apollonius, two of the greatest men of antiquity” (pp. 222–223).

The Mayans came close, with a system that featured positional notation with zero. However, in their system successive positions represented the mixed sequence (1, 20, 360, 7,200, 144,000, ...), rather than the purely base-20 sequence (1, 20, 400, 8,000, 160,000, ...), which precluded any possibility that their numerals could be used as part of a highly efficient arithmetic system (Ifrah, 2000, p. 311).

What is more, mathematicians in ancient India developed remarkably advanced schemes, at a very early era, for computing square roots. This entry summarizes these schemes. It is based on an earlier study by the present authors, to which readers are referred for additional details (2012).

The Discovery of Positional Arithmetic

The original discovery of positional decimal arithmetic is, sadly, unknown. The earliest known physical evidence, using single-character Brahmi numerals (which are the ancestors of our modern digits), is an inscription of the date 346 on a copper plate, which corresponds to

595 CE (Chrisomalis, 2010, p. 196). But there are numerous passages of more ancient texts that suggest that both the concept and the practice of positional decimal numeration were known much earlier (Plofker, 2009, p. 122).

For example, a fifth-century text includes the passage “Just as a line in the hundreds place [means] a hundred, in the tens place ten, and one in the ones place, so one and the same woman is called mother, daughter, and sister [by different people]” (Plofker, 2009, p. 46). Similarly, in 499 CE the Indian mathematician Āryabhaṭa wrote, “The numbers one, ten, hundred, thousand, ten thousand, hundred thousand, million, ten million, hundred million, and billion are from place to place each ten times the preceding” (Clark, 1930, p. 21).

These early texts did not use Brahmi numerals, but instead used the Sanskrit words for the digits one through nine and zero, or, when needed to match the meter of the verse, used one of a set of literary words (known as “word-symbols”) associated with digits. For example, the medieval Indian manuscript *Sūryasiddhānta* included the verse, “The apsids of the moon in a cosmic cycle are: fire; vacuum; horsemen; vast; serpent; ocean.” Here the last six words are word-symbols for 3, 0, 2, 8, 8, 4, respectively (meaning the decimal number 488,203, since the order is reversed) (Ifrah, 2000, p. 411).

The most ancient Indian documents are more recent copies, so that we cannot be absolutely certain of their ancient authenticity. But one manuscript whose ancient authenticity cannot be denied is the *Lokavibhāga* (“Parts of the Universe”). This has numerous large numbers in positional decimal notation (using Sanskrit names or word-symbols for the digits) and detailed calculations (Siddhanta-Shastri, 1962, pp. 70, 79, 131). Near the end of the *Lokavibhāga*, the author provides some astronomical observations that enable modern scholars to determine, in two independent ways, that this text was written on 25 August 458 CE (Julian calendar). The text also mentions that it was written in the 22nd year of the reign of Simhavarman, which also confirms the 458 CE date (Ifrah, 2000, p. 417).

One even earlier source of positional word-symbols is the mid-third-century CE text *Yavanajātaka*, whose final verse reads, “There was a wise king named Sphujidhvaja who made this [work] with four thousand [verses] in the Indravajra meter, appearing in the year Visnu; hook-sign; moon.” The three word-symbols, “Visnu,” “hook sign,” and “moon,” mean 1, 9, and 1, signifying year 191 of the Saka era, which corresponds to 270 CE (Plofker, 2009, p. 47).

The earliest record of zero may be in the *Chandaśśūtra*, dated to the second or third century BCE. Here we see the solution to a mathematical problem relating to the set of all possible meters for multi-syllable verse, which involves the expression of integers using a form of binary notation (Plofker, 2009, p. 55). The very earliest origin of the notion of positional decimal notation and arithmetic, however, is still obscure; it may be connected to the ancient Chinese “rod calculus” (Plofker, p. 48).

Ārayabhaṭa’s Square Root and Cube Root

One person who deserves at least some credit for the proliferation of decimal arithmetic calculation is the Indian mathematician Ārayabhaṭa, mentioned above (see Fig. 1). He devised ingenious digit-by-digit algorithms for computing square roots and cube roots, as given (tersely) in his 499 CE work *Āryabhaṭīya* (Clark, 1930, pp. 24–26). These schemes were used, with only minor variations, by Indian mathematicians such as Siddhasena Gani (~550 CE), Bhāskara I (~600 CE), Śrīdhara (~750 CE), and Bhāskara II (~1,150 CE), as well as by numerous later Arabic and European mathematicians (Datta & Singh, 1962, I, pp. 170–175).

The Bakhshālī Manuscript

Another ancient source that clearly exhibits considerable familiarity with decimal arithmetic in general and square roots in particular is the Bakhshālī manuscript. This ancient mathematical



Ancient Indian Square Roots, Fig. 1 Statue of Ārayabhaṭa on the grounds of IUCAA, Pune, India (no one knows what Ārayabhaṭa actually looked like) (Courtesy of Wikimedia)

treatise was found in 1881 in the village of Bakhshālī, approximately 80 km northeast of Peshawar. Among the topics covered in this document, at least in the fragments that have been recovered, are solutions of systems of linear equations, indeterminate (Diophantine) equations of the second degree, arithmetic progressions of various types, and rational approximations of square roots. The manuscript appears to be a commentary on an even earlier work (Hayashi, 1995, pp. 86, 148).

Ever since its discovery in 1881, scholars have debated its age. Some, like British scholar G. R. Kaye, assigned the manuscript to the twelfth century, in part because he believed that its mathematical content was derivative from Greek sources. Others, such as Rudolf Hoernle, assigned the underlying manuscript to the “3rd or 4th century CE” (Hoernle, 1887, p. 9). In the most recent analysis, Takao Hayashi assigned the

commentary to the seventh century, with the underlying original not much older (1995, p. 149).

The Bakhshālī Square Root

One particularly intriguing item in the Bakhshālī manuscript is the following algorithm for computing square roots:

[1:] In the case of a non-square [number], subtract the nearest square number; divide the remainder by twice [the root of that number]. [2:] Half the square of that [that is, the fraction just obtained] is divided by the sum of the root and the fraction and subtract [from the sum]. [3:] [The non-square number is] less [than the square of the approximation] by the square [of the last term]. (Translation is due to Datta (1929), except last sentence is due to Hayashi (1995, p. 431).)

The Bakhshālī Square Root in Modern Notation

In modern notation, this algorithm is as follows. To obtain the square root of a number q , start with an approximation x_0 and then calculate, for $n \geq 0$:

$$a_n = \frac{q - x_n^2}{2x_n} \quad (\text{sentence \#1 above})$$

$$x_{n+1} = x_n + a_n - \frac{a_n^2}{2(x_n + a_n)} \quad (\text{sentence \#2 above})$$

$$q = x_{n+1}^2 - \left[\frac{a_n^2}{2(x_n + a_n)} \right]^2. \quad (\text{sentence \#3 above})$$

The last line is merely a check; it is not an essential part of the calculation. In the examples presented in the Bakhshālī manuscript, this algorithm is used to obtain rational approximations to square roots only for integer arguments q , only for integer-valued starting values x_0 , and is only applied once in each case (i.e., it is not iterated). But from a modern perspective, the scheme clearly can be repeated and in fact converges very rapidly to $\sqrt{q}$, as we shall see in the next section.

Here is one application in the Bakhshālī manuscript (Hayashi, 1995, pp. 232–233).

Problem 1 Find an accurate rational approximation to the solution of

$$3x^2/4 + 3x/4 = 7,000 \quad (1)$$

(which arises from the manuscript's analysis of some additive series).

Answer $x = (\sqrt{336,009} - 3)/6$. To calculate an accurate value for $\sqrt{336,009}$, start with the approximation $x_0 = 579$. Note that $q = 336,009 = 579^2 + 768$. Then calculate as follows (using modern notation):

$$\begin{aligned} a_0 &= \frac{q - x_0^2}{2x_0} = \frac{768}{1,158}, \\ x_0 + a_0 &= 579 + \frac{768}{1,158}, \\ \frac{a_0^2}{2(x_0 + a_0)} &= \frac{294,912}{777,307,500}. \end{aligned} \quad (2)$$

Thus, we obtain the refined root

$$\begin{aligned} x_1 &= x_0 + a_0 - \frac{a_0^2}{2(x_0 + a_0)} \\ &= 579 + \frac{515,225,088}{777,307,500} \\ &= \frac{450,576,267,588}{777,307,500} \end{aligned} \quad (3)$$

(Note: This is $579.66283303325903841\dots$, which agrees with $\sqrt{336,009} = 579.66283303313487498\dots$ to 12-significant-digit accuracy). The manuscript then performs a calculation to check that the original quadratic equation is satisfied. It obtains, for the left-hand side of Eq. 1,

$$\frac{50,753,383,762,746,743,271,936}{7,250,483,394,675,000,000}, \quad (4)$$

which, after subtracting the correction

$$\frac{21,743,271,936}{7,250,483,394,675,000,000}, \quad (5)$$

Ancient Indian Square Roots, Fig. 2 Fragment of Bakhshālī manuscript with a portion of the square root calculation mentioned in Problem 1. For example, the large right-middle section corresponds to the fraction $\frac{50,753,383,762,746,743,271,936}{7,250,483,394,675,000,000}$ in Formula (4) (Graphic from Hayashi, 1995, p. 574)



gives,

$$\frac{50,753,383,762,725,000,000,000}{7,250,483,394,675,000,000} = 7,000. \quad (6)$$

Each of the integers and fractions shown in the above calculation (except the denominator of Eq. 5, which is implied) actually appears in the Bakhshālī manuscript, although some of the individual digits are missing at the edges – see Fig. 2. The digits are written left to right, and fractions are written as one integer directly over another (although there is no division bar). Zeroes are denoted by large dots. Other digits may be recognized by those familiar with ancient Indian languages.

Convergence of the Bakhshālī Square Root

Note, in the above example, that starting with the 3-digit approximation 579, one obtains, after a single application of the algorithm, a value for $\sqrt{336,009}$ that is correct to 12 significant digits. From a modern perspective, this happens because the Bakhshālī square root algorithm is *quartically convergent* – each iteration approximately quadruples the number of correct digits in the result, provided that sufficiently accurate arithmetic is used (although there is no

indication of the algorithm being iterated more than once in the manuscript itself) (Bailey & Borwein, 2012).

An Even More Ancient Square Root

There are instances of highly accurate square roots in Indian sources that are even more ancient than the Bakhshālī manuscript. For example, Srinivasiengar noted that the ancient Jain work *Jambūdvīpa-prajñapti* (~300 BCE), after erroneously assuming that $\pi = \sqrt{10}$, asserts that the “circumference” of a circle of diameter 100,000 *yōjana* is 316,227 *yōjana* + 3 *gavyūti* + 128 *dhanu* + 13½ *angula*, “and a little over” (1967, pp. 21–22). Datta added that this statement is also seen in the *Jībāhigama-sūtra* (~200 BCE) (1929, p. 43), while Joseph noted that it seen in the *Anuyoga-dvāra-sūtra* (~0 CE) and the *Triloko-sara* (~0 CE) (2010, p. 356).

According to one commonly used ancient convention, these units are 1 *yōjana* = 14 km (approximately); 4 *gavyūti* = 1 *yōjana*; 2000 *dhanu* = 1 *gavyūti*; and 96 *angula* = 1 *dhanu* (Joseph, 2010, p. 356). Converting these units to *yōjana*, we conclude that the “circumference” is 316227.766017578125... *yōjana*. This agrees with $100,000\sqrt{10} = 316227.766016837933...$ to 12-significant-digit accuracy!

What algorithm did these ancient scholars employ to compute square roots? The present

authors conclude, based on a detailed analysis, that the most reasonable conclusion is that the Indian mathematician(s) who published the above did some preliminary computation to obtain the approximation 316,227; then used one Heron iteration (i. e., $x_{n+1} = (x_n + q/x_n)/2$), which was known in ancient times in Greece and elsewhere to compute an approximate fractional value; and then converted the final result to the length units above (2012). Evidently the Bakhshālī formula had not yet been developed.

Note that just to perform one Heron iteration, with starting value 316,227, one would need to perform at least the following rather demanding calculation:

$$\begin{aligned}
 x_1 &= \frac{1}{2} \left(x_0 + \frac{q}{x_0} \right) \\
 &= \frac{1}{2} \left(316,227 + \frac{100,000,000,000}{316,227} \right) \\
 &= \frac{1}{2} \left(\frac{316,227^2 + 100,000,000,000}{316,227} \right) \\
 &= \frac{99,999,515,529 + 100,000,000,000}{2 \times 316,227} \\
 &= \frac{199,999,515,529}{632,454} \\
 &= 316,227 + \frac{484,471}{632,454},
 \end{aligned} \tag{7}$$

followed by several additional steps to convert the result to the given units. By any reasonable standard, this is a rather impressive computation for such an ancient vintage (200–300 BCE). Numerous other examples of prodigious computations in various ancient Indian sources are mentioned by Datta and Singh (1962), Joseph (2010), Plofker (2009), and Srinivasiengar (1967). Although some impressive calculations are also seen in ancient Mesopotamia, Greece, and China, as far as we are aware, there are more of these prodigious calculations in ancient Indian literature than in other ancient sources.

In any event, it is clear that ancient Indian mathematicians, roughly contemporaneous with Greeks such as Euclid and Archimedes, had

command of a rather powerful system of arithmetic, possibly some variation of the Chinese “rod calculus” or perhaps even some primitive version of decimal arithmetic.

Controversies

In spite of these discoveries, we should caution that there is a tendency among some ethnomathematicians to optimistically ascribe independent or prior discovery to various Indian sources, such as the Vedas (a collection pre-Christian-Era texts) and the Kerala school (a group of mathematicians writing from the fourteenth to sixteenth centuries). For example, while Kerala mathematicians appear to have found the Gregory series for the arctangent and computed π to 12-digit accuracy, nonetheless they did not formulate any systematic theory of calculus, nor is there any evidence that they transmitted their findings outside the school (Plofker, 2009, p. 253).

Conclusion

The discovery of positional decimal arithmetic with zero, together with efficient algorithms for computation, by unknown Indian mathematicians, certainly by 500 CE and probably several centuries earlier, is a mathematical development of the first magnitude. And the schemes they developed for computing square roots are also quite remarkable for this era.

It should be noted that these ancient Indian mathematicians missed some key points. For one thing, the notion of decimal fraction notation eluded them and everyone else until the tenth century, when a rudimentary form was seen in the writings of the Arabic mathematician al-Uqlidisi, and in the twelfth century, when al-Samaw’al illustrated its use in division and root extraction (Joseph, 2010, p. 468). Also, as mentioned above, there is no indication that Indian mathematicians iterated algorithms for finding roots.

Aside from historical interest, does any of this matter? As historian Kim Plofker notes, in

ancient Indian mathematics, “True perception, reasoning, and authority were expected to harmonize with one another, and each had a part in supporting the truth of mathematics” (Plofker, 2009, p. 12). As she neatly puts it, mathematics was not “an epistemologically privileged subject.” Similarly, mathematical historian George G. Joseph writes, “A Eurocentric approach to the history of mathematics is intimately connected with the dominant view of mathematics ... as a deductive system.” In contrast, as Joseph continues, “[s]ome of the most impressive work in Indian and Chinese mathematics ... involve computations and visual demonstrations that were not formulated with reference to any formal deductive system” (Joseph, 2010, p. xiii).

In short, the Greek heritage that underlies much of Western mathematics may have unduly predisposed many of us against experimental approaches that are now facilitated by the availability of powerful computer technology. Thus, a renewed exposure to non-Western traditions may lead to new insights and results and may clarify the age-old issue of the relationship between mathematics as a language of science and technology and mathematics as a supreme human intellectual discipline.

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Ancient Jewelry in Turkey

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Early Evidence (ca. 40,000–10,000 BCE)

The skillful manufacture of jewelry items using a huge variety of different materials has a long and eventful history in Ancient Turkey, making it a fascinating arena for studying ancient craftsmanship at large. Shell beads dated as early as the beginning of the Upper Paleolithic (ca. 40,000 BP) are reported from the Üçağızlı Cave (Kuhn, Stiner, Reese, & Erksin, 2001, p. 7641); marine shell beads used as ornaments are likewise known from funeral contexts at the Epipaleolithic site of Pınarbaşı in Central Anatolia (Baird, 2012; Fig. 1). The presence of maritime shell specimens in inland sites further testifies to trade and exchange contacts established with communities residing along the Mediterranean littoral (Baysal, 2013).

Neolithic Advances (ca. 10,000–5,000 BCE)

With the beginning of the Holocene about 12,000 years ago, the first sedentary communities



Ancient Jewelry in Turkey, Fig. 1 Dentalia and shell beads from Pınarbaşı, Central Turkey (After Baird, 2012)

appear, struggling to succeed in this radical new lifestyle and the risky demands of agriculture and animal husbandry. The southeast of Turkey as the northern extent of the Fertile Crescent becomes a dynamic catchment for the versatile application of different raw materials and jewelry-making techniques: stone, bone, shell, and malachite beads are proficiently manufactured in huge numbers and a considerable variety of shapes in the Aceramic Neolithic (tenth to eighth millennium BCE) (Erim-Özdoğan, 2011; Fig. 2). Of particular importance is the combination of different working materials, such as Mediterranean shells with traces of inlaid Malachite from the Pre-pottery Neolithic levels of Çayönü, and more especially the utilization of cold-hammered and annealed (heated, but not smelted) copper as a new working material for bead and pendant making (Fig. 3). Larger jewelry objects include rather coarse limestone fragments allegedly used as rings or bracelets (e.g., from Akarçay Tepe, Şanlıurfa, and Southeast Turkey) (Özbaşaran & Duru, 2011, p. 176; Fig. 4) but also beautifully

polished, flawlessly shaped marble bracelets from Cafer Höyük (Malatya, Southeast Turkey) (Cauvin, Aurenche, Cauvin, & Balkan-Atlı, 2011, p. 12; Fig. 5).

The pioneering use of cold- and hot-worked copper can also be observed at the Central Anatolian Aceramic site of Aşıklı Höyük (ca. 8,500–7,400 BCE): several tubular and biconical copper beads, predominantly retrieved from intramural burials, were not necessarily exclusive funeral gifts but rather personal ornaments of individuals (Fig. 6). Noteworthy in terms of applied working techniques are two different ways of making copper jewelry at the site: beads were either made from thin sheets of copper, which was rolled or twisted to finalize the desired shape, or hammered from a lump of solid copper and then pierced with a hot awl-type instrument (Özbaşaran, 2012, p. 142). Copper aside, red limestone and different types of chalcedony count among the most prominent raw materials for jewelry making (Fig. 7).

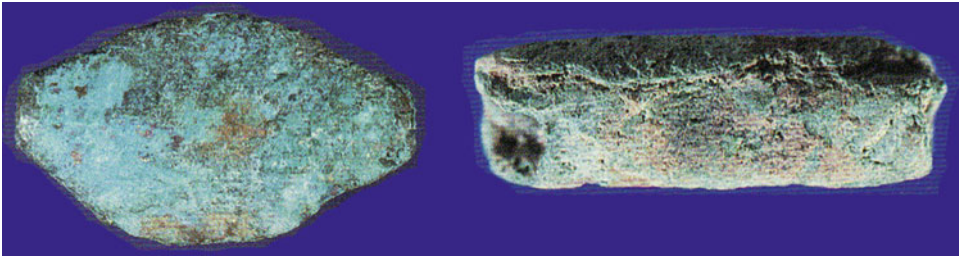
Unabated creativity and further specialization in shaping and combining different working materials such as stone, bone, and copper for making beads and pendants are plainly visible also in the succeeding centuries, when pottery started to be produced on a regular scale. Excavations at the internationally famous site of Çatalhöyük in the Konya plain (Southern Central Anatolia) have produced a huge variety in ornaments produced and consumed there (recently Bains (2012)). More exciting in this regard is Köşk Höyük (Niğde, Central Anatolia, ca. 6,500–5,500 BCE) from whence comes the inventory of a jewelry workshop with beads in different shapes and sizes and various bone tools for scraping, cutting, and drilling (Öztan, 2012, pp. 34–35; Fig. 8).

Technological Breakthroughs (Chalcolithic and Early Bronze Age, ca. 5,000–2,000 BCE)

An epoch-making technological breakthrough that occurred about 5,000 BCE (Middle Chalcolithic) in Ancient Turkey finally paved



Ancient Jewelry in Turkey, Fig. 2 Stone beads from Çayönü, Southeast Turkey (After Erim-Özdoğan, 2011)



Ancient Jewelry in Turkey, Fig. 3 Copper beads from Çayönü, Southeast Turkey (After Erim-Özdoğan, 2011)



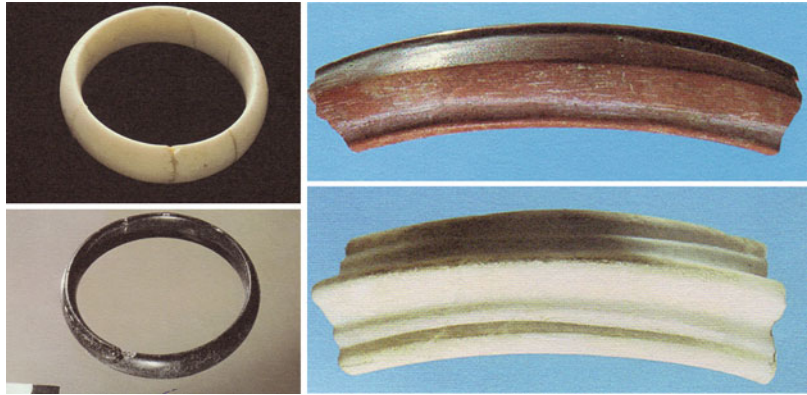
Ancient Jewelry in Turkey, Fig. 4 Fragments of probably limestone bracelets from Akarçay Tepe, Southeast Turkey (After Özbaşaran & Duru, 2011). Photo by T. Ülgür

the way for a new chapter in ancient craftsmanship. Extractive metallurgy, smelting copper from the ore, first successfully performed at the site of Mersin-Yumuktepe, allows for an entirely

new treatment of copper and other metals, which can now be liquefied, poured, cast and recycled, reshaped, and redesigned. This technological leap impacts on jewelry making at large, since raw copper (and later also other non-precious and precious metals) is no longer worked like stone (i.e., simply hammered and sometimes heated to shape it more easily), but as a material with different physical qualities. With the advent of real metalworking, previously unseen groups of jewelry objects, first and foremost pins as dress fasteners now occur in the relevant archaeological assemblages (Fig. 9).

However, a real boost in metal production and consumption on a larger scale does not occur in Ancient Turkey before the end of the fourth millennium BCE. The rich inventory of a cist grave found in Arslantepe, Malatya (Eastern Turkey) contained beneath weapons and metal vessels and also pins, bracelets, and a large diadem with hallmarked wavy line decoration. The rather exotic alloy of evenly balanced copper and silver used for some of the items might testify to a new

Ancient Jewelry in Turkey, Fig. 5 Marble bracelets from Cafer Höyük, Southeast Turkey (After Cauvin et al., 2011)



Ancient Jewelry in Turkey, Fig. 6 Copper beads and pierced deer teeth from burial context at Aşıklı Höyük, Central Turkey (After Özbaşaran, 2012)

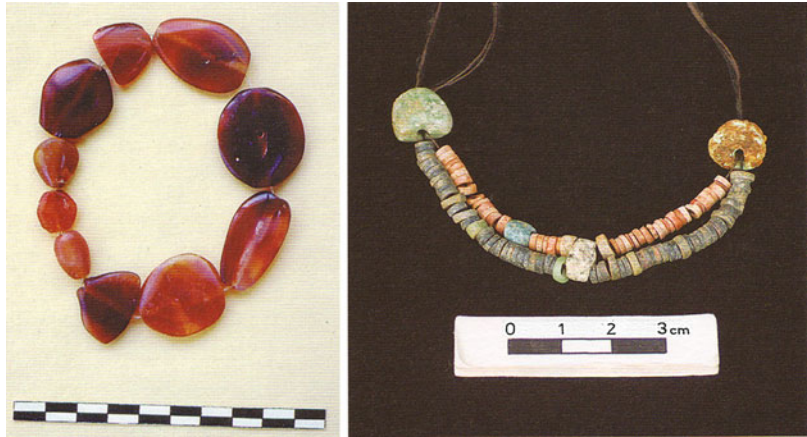
(Trans)caucasian jigsaw piece within the cultural mosaic of Late Chalcolithic (Eastern) Anatolia (Frangipane, 2001) (Fig. 10).

The next apogee in crafting ornaments occurs towards the mid-third millennium BCE (Early Bronze Age II–III). This is also the time when early jewelry making had one of its finest periods – best reflected in the prominent treasure finds from the Troia citadel (Çanakkale, NW Turkey). These treasure complexes – the largest

one coined “Priam’s treasure” in a pseudo-historic fashion by Heinrich Schliemann – are, despite their obscure and much debated history of retrieval, considered genuine by most archaeologists (Easton, 1984; Easton, 1994; Sazcı, 2007; *contra* Traill, 1984, 2000). These assemblages, some of them probably unnoticed grave gifts, are composed of a breathtaking variety of objects and materials, ranging from lapis lazuli axes and large bronze omphalos plates to tiny beads, chain links, and metalsmith’s equipment, including magnifying lenses and prefabricated gold ingots (Fig. 11). Outstanding are especially the earrings and head ornaments that combine different advanced gold-working techniques, for example, granulation and loop-in-loop fabrication of chains (Fig. 12), a group of material well known and perpetuated by the iconic image of Schliemann’s second wife Sophia Engastromenos, wearing Troian jewelry with a weary facial expression (Fig. 13). Since no potential forerunners for such exquisite jewelry are attested in the region, the hypothesis of highly skilled itinerant artisans, presumably trained in Mesopotamia and hired by the thriving local elites, has gained widespread academic consensus (Tolstikov & Trejster, 1996; Treister, 2002; Figs. 14 and 15). Equally skillfully crafted jewelry is also known from other early centers as at Alaca Höyük (as burial gifts) (Fig. 16) and Eskiypar (as one of the very few secure hoards in pre-Classical Anatolia) (Fig. 17). However, smaller rural settlements have also produced evidence for beautifully manufactured ornaments and where even the custom of combining silver

Ancient Jewelry in Turkey,

Fig. 7 Chalcedony and red limestone beads from Aşıklı Höyük, Central Turkey (After Özbaşaran, 2012)

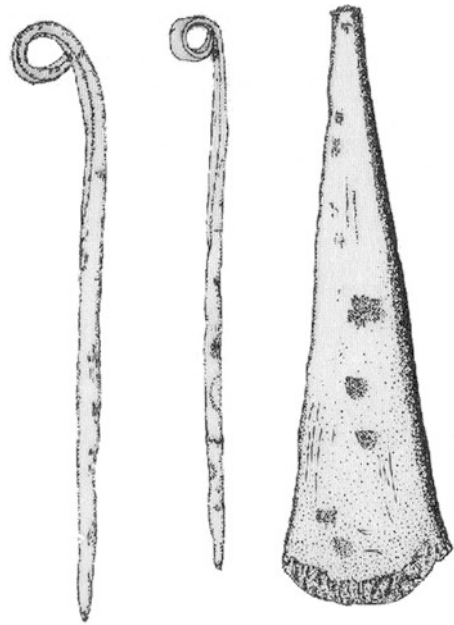


Ancient Jewelry in Turkey, Fig. 8 Stone beads and stonework tools from jewelry workshop at Köşk Höyük, Central Anatolia (After Öztan, 2012)

and copper attested much earlier at the end of the fourth/beginning of the third millennium BCE (cf. supra) resounds in selected inventories (Fig. 18).

The Historical Periods (Middle Bronze to Iron Age, ca. 2,000/1,950–547 BCE)

The beginning of the second millennium BCE marks the advent of history in Ancient Turkey. Assyrian merchants, traversing the Taurus mountain ridge to establish trading posts (*karums*) in Anatolia, bring not only clothing and other much



Ancient Jewelry in Turkey, Fig. 9 Earliest cast metal items (flat ax or chisel and pin) from Mersin-Yumuktepe, Southeast Turkey, layer 16 (ca. 5,000 BCE) (After Yalçın, 2008)

demanding luxury goods but also literacy with them. Many thousands of cuneiform tablets, most of them retrieved from the major Assyrian trade center known as the Karum Kanesh at Kültepe/Nesha (Kayseri, Central Anatolia), give an unprecedented idea of a flourishing economy, based on the trade of metals and garments, being of mutual benefit for the Old Assyrian traders and



Ancient Jewelry in Turkey, Fig. 10 Copper-silver bracelets, rings, and quadruple spiral headed pins from Arslantepe, Eastern Turkey (After Frangipane, 2001). Photos by R. Ceccaci, Arslantepe Archive, Sapienza University of Rome

the indigenous Anatolian populations alike. The production and consumption of exquisite jewelry, now also mentioned in written texts to complement the sparse archaeological evidence, was most certainly enough an indispensable facet of Middle Bronze Age life in Anatolian towns, villages, and trade hubs. Known from both philological and archaeological contexts are traditional dress fasteners such as pins with varying head shapes but also a great variety of elaborate golden jewelry items, for example, granulated earrings with lapis lazuli or carnelian decoration (Özgüç, 2004, pp. 222–233; Dercksen, 2011, p. 113; Fig. 19).

From 1,650 BCE onward, the Hittites, once merely one of the many Anatolian ethnicities the Assyrians did business with, become the new masters of Anatolia, forging together an ever-growing, tightly organized empire, a politically powerful and equal rival to the Assyrian, Egyptian, and Mycenaean realms. However, much of the magnificent artwork of Hittite times,



Ancient Jewelry in Turkey, Fig. 11 Treasure “F” from Troia, Northwest Turkey, with prefabricated gold rods (possibly ingots) (After Sazci, 2007)

including jewelry, is frequently represented not by stratified examples from regular excavations, but as finds without proper context from private or museum collections (exceptions like the pendant published in Bell (1986) or the lotus flower ornament from Ortaköy/Shapinuwa (Süel & Süel, 2008, p. 185) confirm the rule). On the other hand, cuneiform inventory lists occasionally shed some further light on Hittite types of jewelry and the materials used (Maxwell-Hyslop, 1980; Siegelova, 2008). Here it is important to note that iron was regularly used not only for weapons and tools but also jewelry production and was probably valued very highly as a material that was difficult to retrieve and even more difficult to work with. The known range of jewelry, worn by men and women alike, comprises earrings, pendants, and bracelets but also larger items as with diadems or pendants (Fig. 20).

The collapse and disintegration of the Hittite empire towards the end of the second millennium BCE in the wake of the Mediterranean and Near Eastern crisis years around 1,200 BCE followed a phase of political restructuring that reshaped Anatolia for the centuries to come. In the East, the Urartians became the new masters of the Eastern Anatolian highlands, while the Phrygians reigned in Central Anatolia, with the Lydian kingdom controlling larger parts of what is

Ancient Jewelry in Turkey, Fig. 12 Golden headdress from Troia, Northwest Turkey, Treasure “A”, showing loop-in-loop fabrication of chains (After Tolstikov & Trejster, 1996)



Ancient Jewelry in Turkey, Fig. 13 Schliemann's wife Sophia Engastromenos wearing Troian jewelry (After Tolstikov & Trejster, 1996)

nowadays Western Turkey. But as with the corpus of Hittite metalwork, much of the jewelry produced by these three major ruling entities of first millennium Iron Age Anatolia is known in the form of looted material on display in international museum collections, lacking any proper archaeological context. Urartian metal jewelry objects, however, betray another supreme level



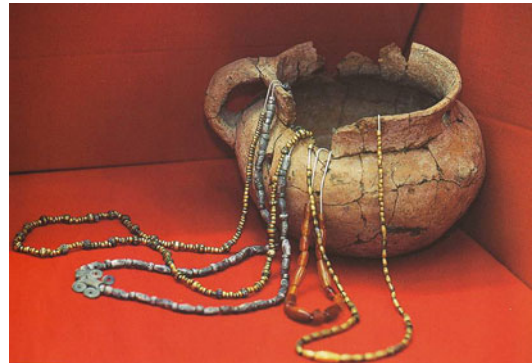
Ancient Jewelry in Turkey, Fig. 14 Examples for Trojan goldwork from Treasure “A” (After Tolstikov & Trejster, 1996)

in crafting jewelry objects: brass as an alloy of copper and zinc is now manufactured also on a regular basis, as is iron for larger jewelry items (Figs. 21 and 22). Further to the west, with Sardis as its capital, the Lydian kingdom marks not only an influential political center for Post-Bronze Age Anatolia but also another focus of excellence in using silver-rich gold (electrum) washed out of the river Pactolus (modern Sart Çayı). This is best illustrated with the so-called Lydian treasure, a huge assemblage of goldwork and silverwork dug

Ancient Jewelry in Turkey, Fig. 15 Pins and earrings from Troia, Treasures “A” and “O” (After Tolstikov & Trejster, 1996)



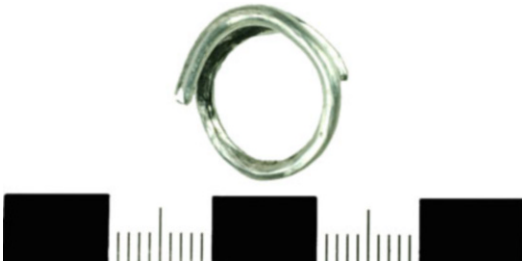
Ancient Jewelry in Turkey, Fig. 16 Selected jewelry from the Alaca Höyük, Central Turkey “royal” burials (Museum of Anatolian Civilizations, Ankara)



Ancient Jewelry in Turkey, Fig. 17 Jewelry from the Eskiypar hoard, Northeastern Central Turkey (Museum of Anatolian Civilizations, Ankara)

up illegally from several sites and trafficked abroad, which could be studied and published in detail only after its retrieval and return to Turkey (Özgen & Öztürk, 1996). Some of the masterfully executed jewelry pieces might testify to an amalgamation of Persian/Achaemenid and Eastern Greek styles, but the majority retains a genuine Lydian fashion which then became so utterly influential in Greek art (Fig. 23). As for Central

Anatolia, this was under Phrygian rule, with Gordion as its capital. The so-called Midas tumulus (probably the burial place of his father Gordios) contained a splendidly furnished burial chamber, equipped with wooden furniture, banqueting equipment and especially large numbers of the characteristic bronze Phrygian fibulae, the diagnostic dress fastener of the Iron Age (Fig. 24).



Ancient Jewelry in Turkey, Fig. 18 Silver-copper-gold ring from an Early Bronze Age burial at Resuloğlu, Çorum, Central Turkey (After Zimmermann, Yıldırım, Özen, & Zararsız, 2009)



Ancient Jewelry in Turkey, Fig. 21 Pins and beads from the Early Iron Age cemetery at Karagündüz, Eastern Turkey (After Sevin & Kavaklı, 1996)



Ancient Jewelry in Turkey, Fig. 19 Gold rings with lapis lazuli and obsidian inlays from Kültepe-Karum layer Ib, Central Turkey (After Özgüç, 2004)



Ancient Jewelry in Turkey, Fig. 20 Lotus flower ornament from the Hittite city of Shapinuwa/Ortaköy, Central Turkey (After Süel & Süel, 2008)



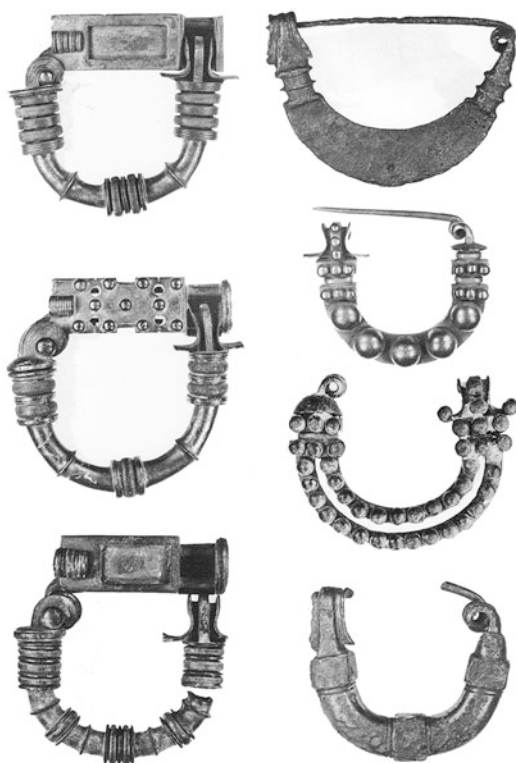
Ancient Jewelry in Turkey, Fig. 22 Iron bracelets from the Early Iron Age cemetery at Karagündüz, Eastern Turkey (After Sevin & Kavaklı, 1996)

The Persian conquest of Anatolia, with the capture of Sardis in 547 BCE, brought an end to the political rule of the indigenous Western Asiatic cultures and was in turn replaced by

Hellenistic rule after the fourth century BCE, before gradually coming under Roman domination, a process that started in 129 BC. When these Western empires culturally superseded Ancient Turkey and made Anatolia part of the



Ancient Jewelry in Turkey, Fig. 23 Gold necklace and bracelet with glass inlays from the “Lydian treasure” complex, Western Turkey (After Özgen & Öztürk, 1996)



Ancient Jewelry in Turkey, Fig. 24 Selection of typical Phrygian bronze fibulae from Central Turkey (After Caner, 1983)

Greek-speaking world, they could draw from a deep well of marvelous technological accomplishments and excellence in workmanship, accumulated and made perfect over many millennia.

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Ancient Urban Water System Construction of China

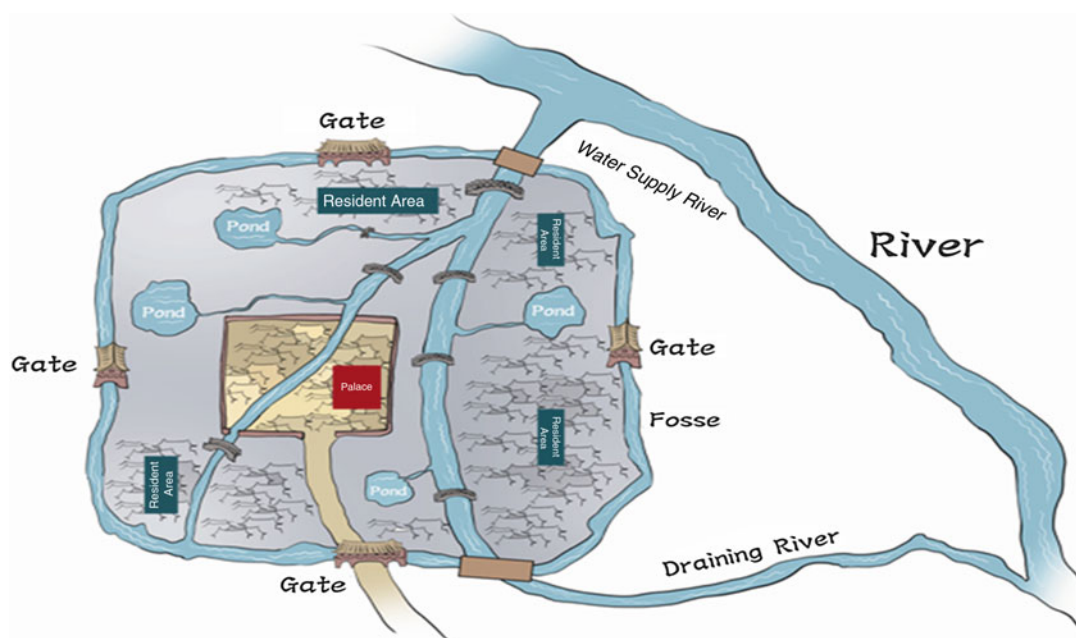
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Introduction

China is an agricultural-based country, but the documented urban history was dated back to more 4,000 years. The early civilizations began in the middle and lower basin of Yellow River (Cai, 2012). Accordingly, in the early age of the Chinese cities, the major river nearby places were strongly considered as the site for building the city, especially rivers like Yellow River basin and Yangtze River basin. However, all the influential ancient cities in China were built close to the major rivers. They include a series of the most influential ancient capital cities such as Anyang, Chang'an, Luoyang, Kaifeng, Nanjing, Hangzhou, Beijing, etc. For example, Anyang, the oldest capital city of China, was built crossed the riversides of the old Heng Shui (洹水) river. Chang'an, today's Xi'an City, was built close to eight rivers likes Wei(渭), Jin(泾), Lao(滌), Feng(泃), etc and became the capital city for 1,700 years by 13 dynasties. Kaifeng City was located between the Yellow River and Huai River. Nanjing city was located at the south riverside of Yangtze River (Jin, 2005). Being situated near rivers, the city had convenient water supply and irrigation system, which later also made transportation convenient. At the same time, it also faced high flooding risk from the rivers; accordingly, the ancient founders and governors of the cities always paid strongly attention to combat urban flood. Even later, many cities were built near the major canals, for example, the Grand Canal Jinghan. However, the situation did not change (Tang, Wang, Li, & Deng, 2012).

Basically, the early Chinese civilization was developed in the Yellow River basin. Accordingly, the major cities also developed in the



Ancient Urban Water System Construction of China, Fig. 1 The urban water system of ancient China in general

Yellow River basin before Nan-Bai Dynasties (420—589 AD), but after Nan-Bai Dynasties, the major cities along the Yangtze River were developed. This outnumbered the Yellow River basin hundreds of years later, along with the economic development of the basin (Dong, 2004). Accordingly, the design and construction of urban water system of ancient Chinese cities were based on the condition of the urban site which mainly located near the rivers, after a model of urban water system was formed at the Han dynasty; not just major cities but also smaller cities also followed the model to design and construct their urban water system in subsequent years (Zheng, 2014).

The Urban Water System Design

Although the ancient cities had a complex design to adapt to the local water environment especially the rivers, the tracks of regular pattern of urban water system can still be followed. Usually, the model of water system in ancient Chinese city was usually combined with (1) water supply river, (2) urban rivers, (3) Internal Draining

System, (4) ponds and lakes, (5) city moats (fosse), and (6) draining river (Fig. 1). However, these parts formed an urban water system in a city. Usually, each part performs its function, but they are connected to each other to perform the integrated functions in a city.

The Water Supply System

The water supply system is a canal or river that directs water into the city for water supply. According to the regulation of city site, a major city is usually located close to the river. However, if the river was not suitable to be used for water supply directly due to unexpected flood risk by the river drop, the city founders have to build a canal to lead water into the city. But the fact is that many cities were built very close or crossed the river to make the river as the urban water supply source. For instance, the East Capital of North Song Dynasty (A.D. 960—1127), today's Kaifeng City, was built near the Yellow River. Hence, there were four rivers, Bian river (汴河), Jingshui river (金水河), Cai river (蔡河), and Wuzhang river (五丈河), which crossed flow the city and perform the functions of water supply and transportation. Also, many cities were built

close to the Grand Canal Jinghan. The canal and its branch rivers usually cross the urban areas of the city and became the water supply rivers directly due to lower flood risk. Also, if the flood risk was not high, the city built close to the river in the urban area would always be in a favourable situation.

The Urban River

The urban river is the rivers or canals that flow inside the city as a water-cycling system. During the ancient ages, the urban rivers were very important to perform the functions of water use and drainage. Sometimes, they include the natural rivers inside the city when the city was built. Other times, canals were built as the urban river. For example, in Shuzhou City, there are many rivers inside the city. Consequently, there are seven major rivers flow in the city, but at same time, many other smaller rivers flow inside the city. For example, in every one street in some district, one river flows through. In the Han Chang'an City, not just the natural rivers in the city were present, but some canals were also built; for example, a very famous canal "The Open Ditch" was built to introduce water into the palaces. Urban river performs the functions of water supply, drainage and transportation, waterscape, etc. Furthermore, the residents especially use water from the rivers (Chinese usually did not drink from river, but from wells especially in major cities) according to the Chinese tradition. Thus, urban rivers were convenient for residents to get daily water, wash foods and clothes, etc. Urban river is also a function of the urban drainage, and most rainwater and wastewater were drained by the urban rivers. In another way, urban river also plays an important role in transportation, especially in many cities in Yangtze River basin. Along with the Grand Canal Jinghan, river transportation is not just busy inside the city, but is also important for the trade outside, for example, the cities of Jaingsu province like Suzhou, Yangzhou, Huaiyin, etc.

Ponds and Lakes

Ponds and lakes are usually natural or are built in a city. Thus, it is very popular to find ponds and

lakes inside the old cities. Ponds and lakes are very important part of the city's natural water system, but many of them were built for multipurpose use, e.g., for storage and sluice of water and also as the city waterscapes. For example, in the ancient Chang'an City, 10 big ponds were built for rainwater sluice and water storage in summer, but water supply in winter. At same time, many cities also included the natural lakes inside the city. The ponds and lakes were usually linked with the urban rivers during the dry season and were used for water storage. Also, this ponds and lakes were important for sluice of rainstorm water during summer. At same time, the waterscape made the city more beautiful.

The Draining System

The drainage system for rainwater and wastewater was strongly considered during the construction of a city. Usually, it was designed and built with a city's original construction plan. The archeological discovery showed that early sewer in China was dated back to 4,000 years ago (Zheng, 2013). In major cities, the network of draining channel was built in palace and residential areas. However, some were underground channel, while some were surface channel for draining waste water and rainwater into the urban rivers and, later, into the drainage rivers. The draining system usually constitutes of four parts. They include: (1) The small sewers from the houses. (2) The street sewers and channels receive water from the house sewers. In many cities, there were open ditches or underground sewers along the street, which is a very popular way of building sewer along the streets, which is then covered with flagstones. (3) The urban rivers receive water from the street sewers. (4) The draining river to drain water to the outside the city. In addition, an urban draining system also includes other parts of the water system such as ponds, lakes, and moat.

Moat (Fosse)

The ancient city was usually built with the town walls. Also, a canal was built outside the walls which surrounded the town. Basically, the moats were built for the urban defense, but it was also

linked with the city's water system for drainage. When the city meets rainstorm, it will perform the function of sluice from the town to reduce the risk of flood. Accordingly, the function of moat was often used for drainage purpose than its original purpose, which is for defense.

Draining River

Draining river is the river or canal that passed the city which leads water into the lower basin of the river or to other places.

The Logic of the Urban Water System Design

The rivers nearby were strongly considered in the building of cities by Chinese ancestor due to its convenient water supply. Accordingly, most Chinese early cities were built along the major rivers basins, especially the Yellow River basin and Yangtze River basin. Nevertheless, there are high flood risks when a city is built near a river for the purpose of convenient water supply. Therefore, it had a major impact on the cities at any period because flood was the major disaster to ancient cities. Consequently, the logic of design and construction of the urban water system was to build a water-cycling system in the city and ensure water cycling which flows in and out of the city. Hence, a perfect situation was the seasonal balance of water storage and drainage in the city. Therefore, when a city was built with water supply through river or canal, the drainage river and sluice system inside the city will be built simultaneously. After water was introduced into the city and cycled inside the city for use, it will be channeled out of the city into that same river source or other rivers. Through this water-cycling system, the city met the demands of water supply and reduces the risk of flood. Notwithstanding, not all risk was saved but was effectively achieved at this point which had been evidenced through centuries. Accordingly, the design and construction of urban water-cycling system was one of the most important wisdom of the ancient urban water management of China.

Through the above systemic design and construction of a water system, water was introduced from the nearby river to supply the city. Water cycling in the urban water system includes the urban rivers, channels, ponds, and moats, which then flows into the lower basin of the rivers or the farmlands outside the city. If rainstorm comes, the urban rivers, ponds, and towns surrounding moats would serve as sluice for the storm water to reduce the risk of flooding. Therefore, if a city was built with such a logical water system, a water-cycling system from the nearby river then returns the water to the river again. This puts the city in a superposition with its natural environment especially the water sources. In such cases, not just the citizen can use and enjoy the water conveniently but would also make the city flourish. Consequently, some cities even faced high flood risk, but the towns were still built close to the river or include the river as an urban river. For example, the Kaifeng City in Song Dynasty was built near the Yellow River. Also, the Bian river (汴河) inside the town, before the city was destroyed by flood, was from the Yellow River. The Bian riversides had become a very flourishing area of the city.

The Paradigm of the Urban Water System Construction

From Han Dynasty (202 B.C. ~ A.D. 220), the urban construction of China was going into a new age. Taking more than 400 years construction and development, Han had become one of the flourished tops of the dynasties in Chinese history. Also, many major cities were built with complex urban water system.

The founder of Han Dynasty founded its capital Chang'an City near today's Xi'an City, Shanxi province. According to the historical documents, this city was developed to be a very large city quickly after it was founded. It has also existed as the capital city for 15 dynasties until A.D. 907. Chang'an city was 35 km² in size at that time with a population of 500,000 (Yang, 1989). The archeological discovery showed a complex water system which was built in the

city and which combines the functions of water supply, drainage, storage of water, and ship transportation. However, the main constructions of the water system are described below.

Water Supply: The water supply of the city was from the river naturally. The city was found at the south side of Wei Shui (渭水) River, but the water supply was from the Jue Shui (泾水) River because the location of the town was higher than the Wei Shui River. Jue Shui River flows from the south of the city and flows to the north into the town. It flows across the palaces and the city (this part was called Ming river, meaning open ditch, 9 km of length), and then out of the town into the Wei Shui river. Furthermore, other branch of Jue Shui River also flows across part of the town, and then into the Wei Shui river. However, for the purpose of improving water supply, a big pond was built to receive water from Jao Shui River (交水). This pond is a very famous pond called “Kunming Pond.” After this pond was built, an aqueduct was built to introduce water into the town for urban water supply.

Urban Rivers: There are many rivers or canals inside the town which serves as water-cycling system. For example, the main water supply source, Jue Shui River, flows into the town directly. Firstly, it passes through the palaces for water supply, and then, it separates into two ways to the residential areas and finally into other rivers. As mentioned above, there are also aqueducts built from Kunming Pond or other sources to introduce water into the town. Hence, the aqueduct from the Kunming Pond was called “Kunming Aqueduct,” which is the important water supply canal to the city. In addition, the urban river cycling inside the town to supply water to the town also performs the function of drainage.

The Ponds: There are 10 big ponds which are built for rainwater sluice in summer and water storage supply in winter. According to the documentary, the ponds was also use for training water war for the army, but fortunately, it became the waterscapes of the city mainly and gave adequate space for the citizens to enjoy water most periods.

The Drainage System: Drainage systems were built inside the town. They include the



Ancient Urban Water System Construction of China, Fig. 2 The brick structured sewer of Han

sewers, open ditches, channels, ponds and moats, and draining rivers. There are many earthen pipes and underground sewers which have been found. However, by archeological discovery shown, a sewer system was built in the palaces, and the residential areas then were linked to the urban rivers (Li, 1981). In 2008, a major sewer was found in the old Chang'an City. It was built with bricks of 2 m wide and 40 m length, Hence, we can see how large a sewer system was built in Han City (Figs. 2 and 3) (Feng, 2008).

The water systems are connected to each other through water supply rivers, ponds, drainage sluiceways, moat, and drainage rivers. However, not only wastewater can be drained, but also rainstorm water could be sluiced.

The Town Moat: Outside the town, a moat (length of 26 km) was built around the town. It was connected with the main urban river, Ming River, and also performs the function of rainwater sluice from the town (Wu, 2009).

Additionally, the water system include parts of the water supply rivers or aqueducts, urban rivers and channels, ponds, sewers, moat, and draining rivers, which combines to form a perfect urban water system. An important point was that the water system in Chang'an City also created a model of urban water system which influenced many Chinese cities subsequently. Consequently, Chang'an City was not just a flourishing city



Ancient Urban Water System Construction of China,
Fig. 3 Part of the sewer of Han

historically but also a very important stage in the history of urban construction of water system in China (Zheng, 2013).

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Animal Domestication

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A

Animal domestication is the process by which humans exert direct or indirect, partial or total, conscious or unconscious influence over the reproduction and evolution of animals that they own or otherwise manage (Rodrigue, 1987, p. 1). There is quite an extensive continuum between wild species utilized as resources by humans and fully domesticated species (Russell, 2002; Terrell et al., 2003; Marshall et al., 2014). The question of “origins” depends on a choice of where to draw the line between “wild” and “domesticated” along this continuum, and that choice is often the basis of arguments about the earliest domestication of many species.

A fully domesticated animal exhibits significant genotypic and phenotypic differences in both appearance and behavior from its nearest wild relatives due to its evolution under conditions dominated by humans. The domestication of animals and plants is one of the most significant impacts that humans have had on their natural environments, ultimately the root of the contemporary global economic system and its marvels and tragedies. Indeed, the increases in carbon dioxide and methane accompanying the diffusion of agriculture and animal husbandry into forest lands may well have sustained Holocene climate warming against orbital forcings that could have cooled climate (Ruddiman, 2003; Salinger, 2007). For most of our species' existence, however, human impacts were less thoroughgoing. People did not tend crops and maintain animals, living instead as seasonally migratory gatherers, hunters, and fishers of wild food sources.

The Geography of Domestication

The archeological record of settlements, bones, pollen, and artifacts indicates that settled

societies based on plant cultivation and/or animal husbandry emerged roughly 10,000–11,500 years in certain areas of the world. Archeological research into the earliest domestications has tended to focus largely on the Near East. For example, suggestions of goat (*Capra hircus*) domestication reach back about 10,000 years in western Iran (Zeder & Hesse, 2000) and earlier than 10,400 years in Cyprus (Vigne et al., 2011). Sheep (*Ovis aries*) domestication goes back some 10,500 years in northernmost Iraq (Perkins, 1964; Zeder, 2011) and 10,200 years ago in central Turkey (Stiner et al., 2014), while pig (*Sus scrofa*) domestication developed possibly as early as 11,000 years ago in southeastern Turkey (Pringle, 1998a; Rosenberg, Nesbitt, & Peasnell, 1998) and some time before 10,400 years ago in Cyprus (Vigne et al., 2011).

The early domestication of barley (*Hordeum vulgare*) is evidenced in the Zagros foothills of the eastern Fertile Crescent and the northern Levant some 10,200 years ago (Fuller, Willcox, & Allaby, 2012; Zeder, 2011), while einkorn (*Triticum monococcum*) and emmer (*T. dicoccoides*) wheats trace back to southeastern Turkey and northern Syria (Lev-Yadun, Gopher, & Abbo, 2000; Özkan et al., 2002) and the southern Levant (Fuller et al., 2012) nearly 11,000 years ago. The cultivation and possibly the domestication of rye (*Secale cereale*) may arguably go back nearly 13,000 years in the northern Levant (Fuller et al. 2012; Pringle, 1998b; Zeder, 2011). Legumes evidence ancient domestication in the Near East as well, with peas (*Pisum sativum*) and lentils (*Lens culinaris*) going back nearly 11,000 years in the southern Levant and chickpeas (*Cicer arietinum*) going back 10,400 years in the northern Levant (Fuller et al., 2012). Within roughly a millennium, plant and animal domesticates were joined together in agriculture and husbandry complexes, which quickly spread throughout the ancient Near East and beyond.

Other parts of the world, however, saw similar, apparently independent domestications and assemblages of crop and animal complexes. Some of these include New Guinea with taro (*Colocasia esculenta*) going back 10,000 years

and banana (*Musa* spp.) going back nearly 7,000 years (Denham et al., 2003; Denham, 2011); eastern China, with rice (*Oryza sativa*) cultivation going back at least 11,000 years (Mannion, 1999), with domestication solidified by 6,500 years ago (Gross & Zhao, 2014), and chicken (*Gallus gallus*) keeping tracing back nearly 8,000 years (West & Zhou, 1988); and Southeast Asia, with still controversial signs of cultivated cucumbers (*Cucurbita* spp.), water chestnuts (*Trapa natans*), peppers (*Piper* spp.), almonds (*Prunus dulcis*), and betel nuts (*Piper betel*) dating back 11,000–9,000 years and possible chicken domestication before 8,000 years ago (Gorman, 1969; Fumihito et al., 1996; Yen, 1977). Africa domesticated cattle (*Bos taurus*), donkeys (*Equus asinus*), African rice (*Oryza glaberrima*), pearl (*Pennisetum glaucum*) and finger millets (*Eleusine coracana*), sorghum (*Sorghum bicolor*), teff cereal (*Eragrostis tef*), yam (*Dioscorea* spp.), cowpea (*Vigna unguiculata*), okra (*Abelmoschus esculentus*), oil palm (*Elaeis guineensis*), cola (*Cola* spp.), and coffee (*Coffea canaphora*) variously going back 10,000 before the present (cattle) to 2,000 BP, with several distinct centers of domestication: northeast Africa, west Africa, and the Ethiopian highlands (Hanotte et al., 2002; Harlan, 1971).

In the New World, northwestern South America and highland Mexico began the domestication of gourds and squashes (*Cucurbita* spp.) 10,000–12,000 years ago (Piperno & Stothert, 2003), while maize (*Zea mays*) domestication has been traced over 8,700 years before the present in Mexico (Piperno et al., 2009). Potatoes (*Solanum tuberosum*) go back about 8,000 years ago near Lake Titicaca in the Andes (Roach, 2002). Other crops domesticated in the New World include tomato (*Lycopersicon esculentum*), peppers (*Capsicum* spp.), tobacco (*Nicotiana tabacum*), and cacao (*Theobroma cacao*) (Sauer, 1969). The New World domesticated few animals, however. Alpaca (*Lama pacos*) and llama (*L. glama*) domestication goes back 6,000–7,000 BP in Peru (Wheeler, 2003), as does guinea pig (*Cavia porcellus*) domestication there (Sandweiss & Wing, 1997). Turkey

(*Meleagris gallopavo*) is a much later domesticate in the New World, going back 500–2,200 years ago in the Pueblo cultures of the American Southwest and in Mesoamerica (Pinkley, 1965; Speller et al., 2010), as is the muscovy duck (*Cairina moschata*), which goes back 2,600 years ago in the lowlands of Ecuador (Hesse, 1980). A particularly intriguing plant domesticate is the bottle gourd (*Lagenaria siceraria*) that may have entered domestication near its wild home in Zimbabwe very early on and then accompanied African emigrants in the peopling of the rest of the Old World. Evidence for domesticated bottle gourds goes back to the ninth millennium BP in China and Japan and 10,000 years ago in Peru, implying that the domesticated plant, along with the dog, accompanied early Asian settlers of the New World during the Pleistocene–Holocene transition (Erickson et al., 2005; Zeder et al., 2006)!

Sequencing of Animal Species Entering Domestication

The dog (*Canis lupus familiaris*) is widely considered the first domesticate. The oldest tentative identification of domestic dog remains through traditional archeological methods goes back about 13,000–17,000 years in western Russia (Sablin & Khlopachev, 2002).

DNA analysis has transformed the archeology of domestication, most dramatically in its application to a large sample of living dogs of a variety of breeds, in order to determine how far back the domesticated breeds began to diverge from their common ancestor (Vilà et al., 1997). This approach yielded the startling and still contested figure of 135,000 BP, while analysis of patterns of variation in mitochondrial DNA suggests a concentration of genetic diversity (indicative of an ancestral population) in East Asia with divergence from wolf populations there roughly 15,000 BP (Savolainen et al., 2002). New World dogs were probably brought there by Paleoindian migrants from Asia, as their DNA resembles that of Asian wolves, rather than North American wolves (Wayne, Leonard, & Vilà, 2006).

All dogs are now known to be domesticated Old World wolves (hence the Latin species name changes from *Canis familiaris* to *C. lupus*). The earliest dogs may have been pets, self-domesticating scavengers, and convenient sources of meat, evolving into hunting partners as their commensalist relationship with humans deepened.

Several animal species entered domestication in a second, nearly simultaneous development from 11,000 to 8,000 years ago: cattle, pigs, sheep, and goats, as discussed above, and possibly cats (*Felis sylvestris catus*) and pigeons (*Columba livia*) as well. Domesticated cattle are evidenced in south central Turkey some 10,400 years ago (Grigson, 1989; Perkins, 1969), but there is DNA evidence that a line of cattle was independently domesticated in northeast Africa about 10,000 BP (Hanotte et al., 2002) or that Near Eastern cattle may have been introduced into northeast Africa, but pastoralists there used wild indigenous bulls to improve their herds (Stock & Gifford-Gonzalez, 2013). Chickens appear in archeological sites throughout East Asia and Southeast Asia before 8,000 years ago (Fumihito et al. 1996; West & Zhou, 1988), and mtDNA studies imply they may have been domesticated as long ago as 10,000 BP in northern China (Xiang et al., 2014). Cats may have been domesticated as early as 10,300 years ago, judging from work in Cyprus (Vigne et al., 2011). Pigeons are first evidenced in Mesopotamian fertility shrine effigies about 6,500 years ago, but analysis of their staggering domesticated breed diversity suggests they may well be the first birds domesticated, perhaps as long ago as 10,000 BP (Johnston & Janiga, 1995; Price, 2002).

A third wave of animal domestications occurred roughly 7,000–4,000 years ago, this time involving the New World, too. The species involved included South American camels – llama and alpaca – in Peru approximately 6,000–7,000 years ago (Wheeler, 2003); the horse (*Equus caballus*) in the Ukraine, southernmost Russia, and westernmost Kazakhstan, about 6,000 years ago (Vilà et al., 2001; Warmuth et al., 2012); the donkey in northeast Africa about

5,000 years ago (Beja-Pereira et al., 2004; Kimura et al., 2011; Shackelford, Marshall, & Peters, 2013); the Bactrian camel (*Camelus bactrianus*) perhaps 4,000–5,000 years ago in Turkmenia and eastern Iran (Marshall et al., 2014; Zeder et al., 2006); the dromedary (*C. dromedarius*) in the Arabian Peninsula near the Persian Gulf about 4,000 years ago (Rosen & Saidel, 2010); water buffalo (*Bubalus bubalis*) in South Asia and Southeast Asia about 5,000–6,000 years ago (Yang et al., 2008); yak (*Bos grunniens*) in Tibet around 4,000–5,000 years ago (Rhode et al., 2007); and the silkworm (*Bombyx mori*) in China about 5,000 years ago (Yamauchi et al., 2000, p. 17). The honeybee (*Apis mellifera*) has been kept in hives, if arguably domesticated, over 7,000 years in Europe (Oldroyd, 2012).

A number of other domestications have taken place from that time to this, such as the turkey (*Meleagris gallopavo*), rabbit (*Oryctolagus cuniculus*), guinea fowl (*Numida meleagris*), ferret (*Mustela putorius*), cormorant (*Phalacrocorax carbo*), Pekin duck (*Anas platyrhynchos*), muscovy duck (*Cairina moschata*), goose (*Anser anser*), carp and koi (*Cyprinus carpio*), and goldfish (*Carrasius auratus*). Domestications continue at the present, including parakeets (*Melopsittacus undulatus*), canaries (*Serinus canaria*), diamond doves (*Geopelia cuneata*), mink (*Mustela vison*), laboratory rats (*Rattus norvegicus*), foxes (*Vulpes fulvus*), hamsters (*Mesocricetus auratus*), aquarium fish, and ongoing experiments with promising livestock species, such as eland (*Taurotragus oryx*) and fallow deer (*Dama dama*) (National Research Council Board on Science and Technology for International Development, 1991).

Why Domesticate Animals?

Why did people give up the hunting of animals for the work entailed in domesticating them? The factors involved differ by species and human circumstance. The simple human tendency to pet keeping may have played a role, though utilitarian use of pets is a difficult obstacle to cross

(Serpell, 1989), and animals imprinted on humans are commonly unable to breed (Rodrigue, 1987, p. 163).

Nomadic hunters–gatherers could have domesticated certain herd animals (Ingold, 1980). Such peoples as the reindeer-herding Saami of northernmost Europe sometimes follow the migratory herd species (*Rangifer tarandus*) all year and influence the direction and spatial cohesion of the animals through driving and herding. They selectively cull the animals, which amounts to the evolutionary pressure associated with domestication. The reindeer nomads may have been exploiting reindeer for as long as 20,000 years (NRC Board on Science and Technology for International Development, 1991, p. 285). It is not clear, however, whether migratory herding hunters in the past actually undertook independent domestications of the animals they hunted or adopted the idea later from nearby agriculturalists and associated pastoral nomads.

Settled cultivators may have had a variety of reasons to undertake the control and maintenance of animal populations. Their crops, food stores, and even their salty latrine areas attracted animals, inviting reciprocal exploitation and eventual domestication through a commensalism pathway (Zeder, 2012; Zeuner, 1963). Wolves would steal scraps of food and may have been tolerated as a garbage disposal system. Fields, grain stores, and latrine areas would attract bovine species. The granivorous and cliff-nesting pigeons would descend on early cereal fields and roost in nearby buildings (Johnston & Janiga, 1995; Woldow, 1972). Indeed, many of the smaller animals drawn to raid human crops and food stores would themselves attract still other animals to prey on them (e.g., cats), which would become inadvertent partners and sometimes eventual domesticates. The opportunities for coevolutionary interactions between people and animals increased once people settled and especially once they took up crop cultivation and food storage (Rindos, 1984).

Certain scholars have argued that settled cultivators had no particular economic or ecological need for animals, and animal management does

entail work and can prove dangerous. They feel that the earliest animal domestications provided sacrifices for rituals or amusement for gamblers (e.g., Isaac, 1970). This argument has not done well in archeological testing (Rodrigue, 1992), but the argument cannot be dismissed (Fumihito et al. 1996, p. 6795). Of particular interest are recent discoveries of monumental architecture at a handful of very early Holocene sites (11,600 BP to 11,000 BP) in the early Pre-Pottery Neolithic A of both the northern and southern Levant, e.g., Göbekli Tepe to the north and Wadi Faynan 16 Structure O75 to the south (Dietrich et al., 2012; Mithen et al., 2011, respectively). Göbekli Tepe offers spectacular suggestions of feasting, alcohol consumption, dancing, and cultic symbols, with no evidence of animal husbandry or plant cultivation.

Other scholars have worked out coevolutionary ecological contexts for animal domestications (Rindos, 1984) and economic arguments relating to relative time costs and resource yields of hunting and husbandry in different contexts (Alvard & Kuznar, 2001; Layton, Foley, & Williams, 1991; Rhode et al., 2007).

In some cases, people may have at least partially domesticated an animal species and later abandoned it. Gazelles (*Gazella gazella*), for example, may have been in the process of domestication in the ancient Levant around 11,000 years ago, later being replaced by goats and sheep (Bar-Oz et al., 2004; Legge, 1972; Moore, Hillman, & Legge, 2000; Zeder, 2012). These latter imports may have had some sort of advantage over indigenous domesticates. Of relevance to this process of shifting focus is renewed attention to the concept of “domesticability,” with attempts to identify “domestication genes” or genetic traits that responded more amenable to human selection (Zeder et al., 2006). Perhaps, it was less a question of domesticability and more an artifact of military displacement and conquest of one culture by another that could have replaced one constellation of animal domesticates with another. The development of religious taboos has caused species to be dropped from husbandry in given areas (e.g., pigs in areas of Jewish or Muslim religion).

Conclusion

To resolve these different issues and disputes over their interpretation will take considerable work. Much of the world has never had adequate coverage of its archeological heritage. Archeological funding has been biased toward those areas regarded rightly or wrongly by Westerners as somehow connected with their own culture histories, such as the Biblical Levant and Mesopotamia, Egypt, ancient Greece and Rome, Europe, and even Mesoamerica and Peru (due to Mormon religious interest in the region). There are many tantalizing indications that archeological work in other areas in the non-Western world, applying the many new techniques and technologies available, will transform our present perceptions of the origins of domestication.

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Animal Mummies

Salima Ikram

Although it is commonly known that the ancient Egyptians mummified humans, it is a less well-known fact that they also mummified animals. Animals were mummified for the same reason as humans: to preserve their bodies so that they could live forever. This suggests that a belief in animal souls was a part of Egyptian religion.

Mummification is the preservation of a body through artificial means. In terms of animal mummies it varied somewhat depending on the time period and the type of mummy that was being created. The basic principle, however, remained the same: to desiccate the body using natron (a naturally occurring compound of salt and soda found in the Wadi Natron in Egypt) or even salt. Once the corpse was desiccated, it was anointed with oils and resins and wrapped in

linen bandages. There are four types of animal mummies: food offerings, pets, sacred animals, and votive offerings. Pets and sacred animals seem to be the most carefully mummified, while votive offerings are the most carelessly prepared. The preparation of food offerings varies.

Food or victual mummies consist of mummified foods for humans, such as beef ribs, steaks, joints of meat, ducks, and geese that were placed in tombs so the tomb owner could feast for eternity. The meat and poultry was prepared for consumption, so joints are cut, and the poultry is cleaned, ready for roasting. This mummy type was especially common in the New Kingdom (1549–1060 BCE) and the twenty-first Dynasty (1060–940 BCE).

Pet mummies were of animals beloved of their owners and therefore preserved so that they and their owners could enjoy eternity together. These appear throughout Egyptian history, though the better-known examples come from the New Kingdom and the twenty-first Dynasty, with the gazelle of Queen Isetemkheb D being an example from the latter period.

Sacred animals were animals that were worshipped during their lifetime as the spirit or *ba* of the god entered them, and upon their deaths mummified as were kings, and buried in sarcophagi which were interred in single or catacomb-like sepulchers. Whilst alive these animals would provide oracular advice. The Apis Bull, a manifestation of Ptah, and the Ram of Elephantine, the manifestation of Khnum are particularly well-known animal incarnations. Although the Apis is known from Dynasty I, the Serapeum at Saqqara where the mummies of these animals were kept dates to the eighteenth Dynasty (1549–1298 BCE) and later.

Votive offerings consisted of mummified animals that were dedicated to specific deities. Gods had specific animals that were their totems or symbols: cats were sacred to the goddess Bastet, goddess of pleasure, ibises and baboons to the god Thoth, god of learning, etc. These mummified animals were purchased and offered by pilgrims at shrines dedicated to these gods,



Animal Mummies, Fig. 1 A mummified cat in a sycamore wood coffin, CG 29783 from the Egyptian Museum, Cairo (Photo by Anna-Marie Kellen)



Animal Mummies, Fig. 2 CG 51098 food mummy from the Egyptian Museum, Cairo (Photo by Anna-Marie Kellen)

and finally buried in deep catacombs. The mummified animals would present the prayers of the pilgrim to the god throughout eternity, much in the way votive candles are purchased and burned in churches. This type of mummy was common from the seventh century BCE until the fourth century AD (Fig. 1).

Not all mummy packages contain animals. A group of “fake” mummies, generally found amongst the votive offerings, have come to light during scholarly investigations. These consist of packages that are wrapped to look like real creatures, but either contain fragments of real animals, or rags and bits of mud or wood. In the case of the former the idea is that a part signifies the whole, while in the latter case, one might suggest that the appearance of the package and the identification of the bundle as a certain creature turns it into that animal. Thus, when there was a paucity of actual animals to mummify the embalmers made these substitutions. On a more cynical note, these could be ways of defrauding unsuspecting pilgrims.

In the early days of archaeology most animal mummies were ignored and often discarded, or else taken away as casual souvenirs that illustrated the oddity of the Egyptians; they were never seriously considered as artefacts that could elucidate any relevant aspect of ancient Egypt. However, in more modern times scholars have realized that a study of these mummies can provide information about the fauna of the

country and, indirectly, its climate, as well as animal domestication, veterinary practices, human nutrition, mummification itself, and the religious practices of the ancient Egyptians. Examining their wrappings can also inform us about chronological and geographical variations in production practices.

These mummies are currently studied in a variety of ways, all of which tend to be non-destructive. Visual examinations and radiography are most common. Sometimes CT-scans are employed. Destructive studies include tests on the wrappings and the flesh itself in order to determine the types of resins and other embalming materials used.

All sorts of animals were mummified, including: dogs, cats, ibises, raptors, shrews, crocodiles, snakes, cattle, rams, fish, and even scarab beetles. The practice of animal mummification reached its heyday in the Late and Graeco-Roman periods (700 BCE–AD 395), when sacred and votive animal mummies became increasingly popular. The many millions of ibis, cat, and dog mummies that have been found all date to these periods. The majority of animal mummies created in earlier periods belonged to the pet, food, and to some extent, sacred animal genres. Animal mummification ceased in the fourth century AD with the advent of Christianity (Fig. 2).

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Approximation Formulae in Chinese Mathematics

Jean-Claude Martzloff

Approximation formulae may be used for various reasons. In some cases, certain computations (such as for example, the extraction of roots digit by digit) are by nature inexact. It may also be that exact solutions of certain problems are unknown or else that such solutions are theoretically known but deemed too complex, so that users prefer elaborating alternative solutions more or less accurate with respect to a certain context of utilization. The history of Chinese mathematics illustrates well these two aspects of the question.

Remarkably, many Chinese approximation formulae are also attested in Babylonian, Greek, Roman, Indian, and Mediaeval European mathematics. For example, the so-called “Hero’s iteration formula” for the approximation of square roots converges quadratically to x is also found in the ► *Jiuzhang suanshu* (Computational Prescriptions in Nine Chapters, also translated as Nine Chapters on the Mathematical Arts) from the Han dynasty (206 BCE–AD 220).

Hero’s iteration formula:

Let $x = \sqrt{n}$. Then, the sequence

$$x_k = x_k = \frac{1}{2} \left(x_{k-1} + \frac{n}{x_{k-1}} \right)$$

The approximation formula for the computation of the area of a quadrilateral by taking the product of the half sum of its opposite sides appears not only in the *Wucaosuanjing* (Computational Canon of the Five Administrative Services), and the ► *Xiahou Yang suanjing* (Xiahou Yang’s Computational Canon) (fourth century AD) but also in the Babylonian mathematical corpus (More precisely in YBC 4675 (Neugebauer & Sachs, 1945, pp. 44–47)), in the writings of the Roman agrimensors (surveyors) (References are given in Martzloff, 1997, p. 325), in Alcuin’s

Propositiones ad acuendos iuvenes (Propositions to Sharpen the Minds of the Youth) (The *Propositiones* have been translated into German by M. Folkerts and H. Gericke, “Die Alkuin Zugeschrieben Propositiones ad Acuendos Iuvenes (Aufgaben für Schärfung des Geistes der Jugend)” *Science in Western and Eastern Civilization in Carolingian Times*. Eds. L. Butzer and D. Lohrman. Bale: Birkhäuser Verlag, 1993. 288) and numerous other places. The same remark also applies to the *false* formula for the computation of the area of a segment of a circle:

$$A = \frac{h(b+h)}{2}.$$

In the *Jiuzhang suanshu*. Such examples are much more numerous than historians of mathematics formerly imagined.

This striking phenomenon is an indicator of the strong unity of ancient mathematics. Recent research unceasingly confirms that ancient mathematics were not so much “Chinese” than “written in Chinese,” “Indian” than “written in Sanskrit” and so on, even though, by any standard, the cultural imprint they bear is certainly very strong in each case. Nevertheless, this unavoidable conclusion has opened the way to controversial issues, especially when the famous mathematician and historian of mathematics van der Waerden deduced from this that all ancient mathematics have a common Indo-European origin (van der Waerden, 1983). This new theory has gained little acceptance and it is a fact that it surpasses by far the data on which it is based.

However, Chinese mathematics also contains examples of approximation formulae apparently not attested anywhere else. These all occur in Chinese astronomy and concern astronomical problems such as that of the determination of gnomon shadows or questions of conversions between the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) and equatorial coordinates.

The monograph on mathematical astronomy of the Song Dynasty, the *Songshi* (Song History), an official text compiled between 1343 and 1345,

for example, reports that between AD 1102 and 1106, Chinese imperial astronomers devised a new theoretical algorithm for the determination of the length of the shadow of the sun cast by a standard gnomon 8 *chi* (feet) long, each day, at noon, during a whole year. If t = the number of days elapsed since the last winter solstice and

$$s_1(t) = 12.83 - \frac{20,000t_2}{100\left(100,617 + 100t + \frac{10,000t_2}{725}\right)},$$

$$s_2(t) = 1.56 + \frac{4t^2}{7,923 + 9t},$$

$$s_3(t) = 1.56 + \frac{7,700t^2}{13,584,271.78 + 44,718t - 100t^2},$$

at Kaifeng, the Song imperial capital whose latitude is $34^\circ 48' 45''$, the length of the shadow of the gnomon is computed as follows (the original text is formulated in words, with no symbols, but its interpretation is straightforward):

if $t < 662.2$	$l(t) = s_1(t)$
if $62.2 < t < 91.31$	$l(t) = s_3(182.62 - t)$
if $91.31 < 182.62$	$l(t) = s_2(182.62 - t)$
if $182.62 < t < 273.93$	$l(t) = s_2(t - 182.62)$
if $273.93 < t < 303.04$	$l(t) = s_3(t - 182.62)$
if $303.04 < t < 365.24$	$l(t) = s_1(365.24 - t)$

The various numerical coefficients appearing in these formulae all depend on the lengths of the seasons.)

Chen Meidong, a contemporary historian of Chinese astronomy from the Academia Sinica in Beijing, has compared the results provided by these approximate formulae and those of actual observations (simulated for the years 1102–1106 by using the modern astronomical theory of the sun backward). He has concluded that the error never exceeds 0.02 *chi*, that is much less than a centimeter! Yet Song astronomers were still not satisfied with their approximation and sought

new formulae; some of these have reached us. Incidentally, these formulae are vaguely reminiscent of the Indian approximation formula for the sine, cosine, and other trigonometric functions cited in (Gupta, 1972). In both cases the approximations use rational fractions.

Another interesting approximation formula occurs in the *Yuanshi* (Yuan History), an official compilation written about AD 1370 but reporting on Guo Shoujing's astronomical reform undertaken one century earlier. (Guo Shoujing (1231–1316) was a specialist on canal draining and astronomy.) Without going into too much detail, we note that Guo's technique was devised to compute certain segments corresponding to given arcs of circles similar to those which arise when converting ecliptic coordinates into equatorial coordinates. For us the question is solved in a relatively simple way by means of spherical trigonometry. But plane and spherical trigonometry were both unknown in China at the time, so that the mathematical techniques of Chinese astronomy had necessarily to rely on approximation formulae. In particular, Guo's technique relied on the three following formulae:

1. $p = \sqrt{r^2 - q^2} = \sqrt{(2r - v)v}$,
2. $x = p + \frac{v^2}{2r}$,
3. $v^4 + (4r^2 - 4rx)v^2 - 8r^3v + 4r^2x^2 = 0$,

where r represents the radius of the “trigonometric” circle, and p , q , and v the sine, cosine, and versed sine of the arc x , respectively.

Formula (1) is exact; (2) and (3) are approximate. The polynomial of the fourth degree in v , (3), is the consequence of the elimination of the half chord p between the second part of (1) and (2); (3) serves to compute v given the arc x by finding a root (in fact the smallest positive one) of (3) by means of a technique similar to that which is usually known as “Horner's method” (from a method attributed to the British mathematician William George Horner (1786–1837) who lived five centuries after Guo Shoujing). Lastly we also observe that Guo Shoujing divides the length of the circumference into as many degrees as there are days in a year (365.25°) and computes the radius of the corresponding circle by dividing the

circumference by 3 (i.e., by taking $\pi = 3$). A priori, the reliance on such a value of π would indicate a severe mathematical deficiency. However, when Guo Shoujing devised his techniques, better values of π , such as Zu Chongzhi's (429–500) celebrated approximation $\pi = 355/113$, were currently available in China. In fact, according to Toshio Sugimoto, a mathematical analysis of the above formulae shows that when (1), (2), and (3) are computed using approximations of π better than 3, worse results are obtained! The recourse to approximations disturbs the impeccable logic which would hold if exact representations were used.

These various examples show that approximation formulae are well represented everywhere but that some of them are attested only in China. As recent works by historians of Chinese astronomy indicate, the recourse to such formulae seems typical of Chinese astronomy (see the articles in the journal *Ziran Kexue shi yanjiu*, 1982–1994). Are Chinese approximation formulae really original or are they also found elsewhere? Further historical researches not limited to Chinese mathematics will perhaps shed some light on a question which has never really been studied in depth.

See Also

- [Guo Shoujing](#)
- [Jiuzhang Suanshu](#)
- [Mathematics](#)
- [Pi in Chinese Mathematics](#)
- [Zu Chongzhi](#)

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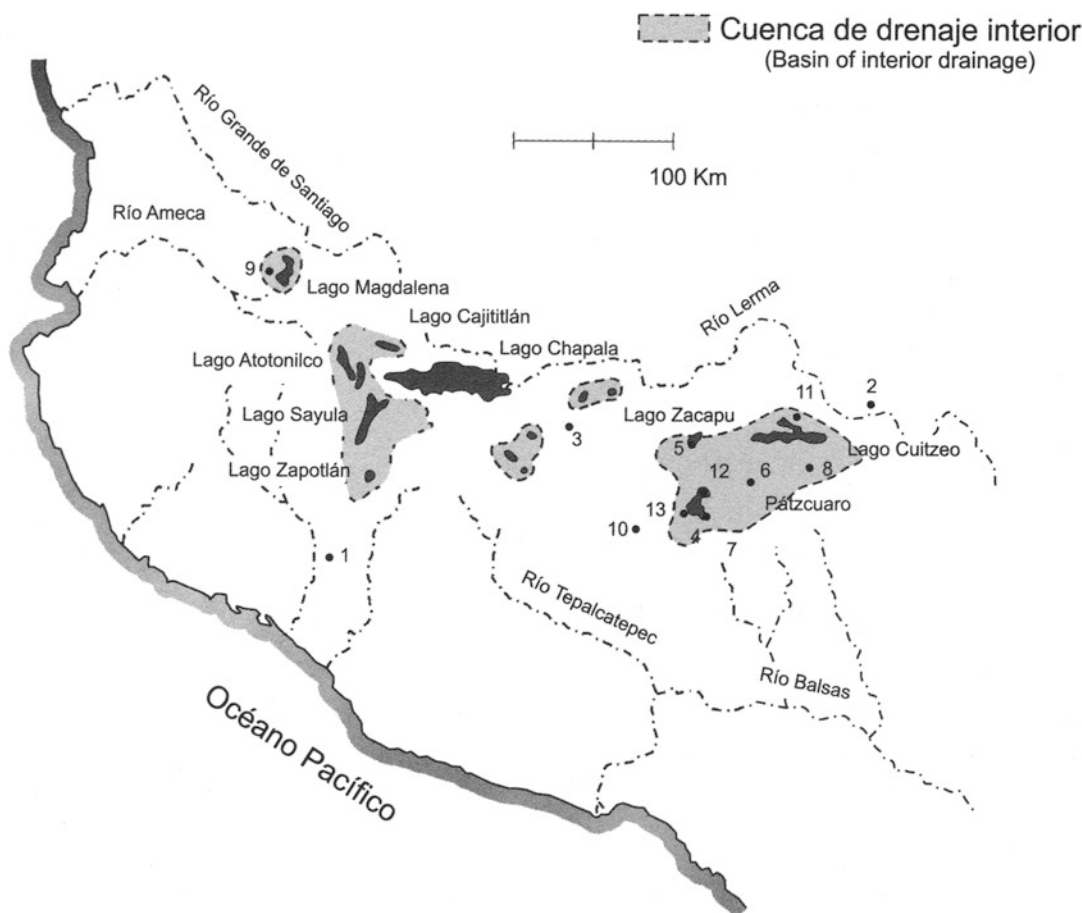
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Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities

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Pre-Hispanic Mesoamerica was the only civilization in the ancient world which flourished without access to major domesticated animals such as horses, cattle, pigs, and sheep (Diamond, 1999). Therefore, fishing, hunting, and gathering had to provide all the nutritional complement to agriculture (Parsons, 2006, 2010, 2011; Rojas, 1998), and aquatic environments were by far the most productive landscapes in Mesoamerica (Parsons, 2010, 2011). Ethnohistorical and ethnographic research has allowed us to characterize the Mesoamerican aquatic lifeway by means of three basic subsistence activities: (a) fishing, which included many edible water species besides fish; (b) hunting, including aquatic species such as waterfowl, reptiles, amphibians, and many others, as well as terrestrial species from the lake basin and the nearby hills; and (c) gathering of plants obtained for nutritional, medicinal, and many other purposes, such as building material and basket weaving, and finally



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 1 Main lakes and rivers of Western Mexico. *Shaded areas indicate interior drainage basins including the major archaeological sites: (1) Capacha, (2) Chupícuaro, (3) El Opeño, (4)*

Ihuatzio, (5) Loma Alta, (6) Loma Santa María, (7) Pátzcuaro, (8) Queréndaro, (9) Teuchitlan/Etztatlán, (10) Tinganio, (11) Tres Cerritos, (12) Tzintzuntzan, and, (13) Urichu (Base map adapted from Tamayo & West, 1964, Fig. 4)

insects and their eggs, which were an important source of protein (García Sánchez, 2004, p. 27; Parsons, 2006; Williams, 2009a, 2009b, 2014a, 2014b). To these three activities, we should add the manufacture of many implements, features, and artifacts which were indispensable for the survival and reproduction of social groups.

Subsistence Activities in Aquatic Environments

What follows is a brief discussion of fishing, hunting, gathering, and manufacture using wild

aquatic species in several areas of Mesoamerica during ancient and modern times, from the perspective of ethnography, ethnohistory, and archaeology. This is a study of pre-Hispanic technology, highlighting material culture and many examples of its survival from ancient times into the twenty-first century. The areas under discussion are the Cuitzeo and Pátzcuaro lakes in Michoacán and Lake Texcoco in the Basin of Mexico (Fig. 1).

Fishing

In pre-Hispanic times, Mesoamerica's lakes, marshes, and rivers had a great abundance of



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 2 The *corral* is a fish trap made of *carrizo* reeds, used in Lake Cuitzeo

fish, reptiles, and many other animal species which contributed to human subsistence. Several fishing techniques are still used in Lake Cuitzeo, such as nets, fishhooks, and traps known as *corrales*, which are made of reeds (Fig. 2). Many kinds of fish are caught in these traps, as well as animals such as frogs and ducks. As much as 5 kg of fish are caught in the corral in 1 day, and in the dry season, when the level of the lake is lower, the daily catch can be 10 kg. A single fisherman can have 20 or 30 *corrales*, although in some cases the number can be as high as 50, and tending them is a full-time occupation.

At present, some fishermen still make their own fine-mesh nets fixed on a round circular frame with a long handle, both made of *pirul* wood or willow twigs, which are notably flexible (Fig. 3). Several other kinds of nets that were used around Lake Cuitzeo in the early twentieth century are no longer seen, but the *chinchorro*, or seine net (Fig. 4), and the *atarraya* (Fig. 5) are still important at both Lake Cuitzeo and Lake Pátzcuaro.

Another fishing technique, known as *tumbo* in lake Cuitzeo, involves a long, narrow gill net held in a vertical position by floaters (today plastic bottles have replaced the traditional pieces of reed stalks) and reed posts (Fig. 6a). The *tumbo* is 40–50 cm high and may be up to 100 m long. Each fisher has his own nets and uses personal marks, such as distinctive knots, to distinguish them from others. On average, 10 kg of fish are caught daily in each *tumbo* and then sold in



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 3 The *red de aro* (ring net) was used for fishing in Lake Cuitzeo until recent times



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 4 At Lake Pátzcuaro, the *chinchorro* is handled mostly by men. In this case, however, a fisher from the town of Tareiro is helped by his two daughters

lakeside towns. A similar gill net is called *cheré mekua* at Lake Pátzcuaro (Fig. 6b).

The *nasa* is a fish trap that was used until some 50 years ago in the Lake Cuitzeo Basin, which



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 5 The *atarraya* is a small throw net used in Lake Cuitzeo (this specimen) and Lake Pátzcuaro

was made by weaving willow twigs (Fig. 7) in a process very similar to that of making a basket. Making *nasas* as a craft has died out in the Lake Cuitzeo Basin, but they are still manufactured in Lake Chapala by a single family of artisans.

Hunting

Many animal species were hunted in the Lake Cuitzeo Basin in the past. In pre-Hispanic times, hunting wildfowl may have been an important activity in this area, as it was in the late sixteenth century, according to the extant historical sources (see Williams, 2009a for a discussion of the ethnohistorical information). The Lake Cuitzeo and Pátzcuaro basins are relatively rich in wildlife, although most wild animals have decreased in number in recent years.

Hunting has decreased in importance for local subsistence and the economy of Lake Pátzcuaro, as well as at Lake Cuitzeo. Though duck hunting has virtually disappeared from many lakeside communities, up to just a few decades ago, this activity was still quite important. The number of ducks that visit Lake Pátzcuaro has declined sharply, but duck hunting is still regarded as a distinctive feature of the Tarascan (or Purépecha) Indians of Lake Pátzcuaro. Every year around the end of October, there is



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 6 The gill net is called *tumbo* in Lake Cuitzeo (a) and *cherémekua* in Lake Pátzcuaro (b). This net is still used to catch many species of fish



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 7 The *nasa* is a trap once used to catch fish in Lake Cuitzeo but still in use at Lake Chapala, where this specimen was found

a communal duck hunt known as *kuirisi atakua* – an ancestral tradition that renews contacts and social bonds among several Indian communities (Toledo et al., 1980).

Many species of aquatic birds are hunted in Lake Pátzcuaro, including those known as *gallaretas*, and several duck species, all of which arrive at the lake from North America around September. According to one of the fishers from this lake, “Birds used to arrive here by the millions.” In Jarácuaro, fishers used to hunt ducks seasonally for food (from early November to late December) using the *fisga* (a harpoon-like weapon made of *carrizo* reed; see Fig. 8), thrown with an *atlatl* (spear thrower) called *tzipaki* in Tarascan (Figs. 9 and 10). According to the same informant quoted above, “Ducks no longer come here; it used to be they’d start to arrive in October and on October 31st we used to go hunting.” The hunters would go out in their canoes from eight in the morning to three in the afternoon to look for ducks on the lake. On one trip, they might catch as many as 140 birds. According to our informants, this took place between 1945 and 1950, but as late as 1960 wild ducks still formed part of the diet in Jarácuaro (in the Lake Pátzcuaro Basin), while some were taken to Pátzcuaro for sale.

The *Florentine Codex* is one of the best sources of information about ancient Mesoamerican subsistence activities (Sahagún, 2012). This book is dedicated to documenting the civilization

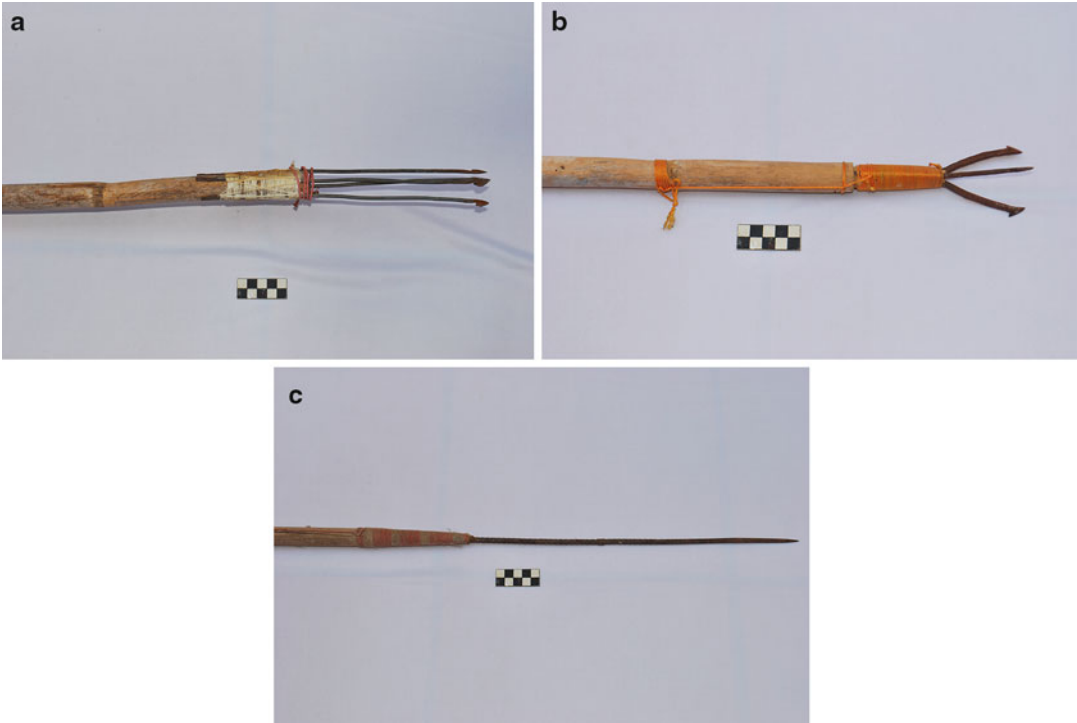
of the Aztecs of the Basin of Mexico, and its value for archaeologists resides in its faithful and detailed portrayal of material culture. Figure 11, taken from the *Florentine Codex*, shows a net used by Aztec fishers and hunters to catch wild ducks in the shallow waters and marshes of the Basin of Mexico. This hunting technique was also used until recent years in the lakes and marshes of the Upper Lerma River Basin (Albores, 1995).

Gathering and Manufacture

The Lake Cuitzeo Basin has an abundance of wild plants, which have been used for food and medicine since early times, according to the extant sources from the sixteenth century. The *Relación de Cuiseo de la Laguna*, for example, mentions several medicinal plants: “There is a weed called *andumucua* [tobacco, *Nicotiana* sp.] ... which is greatly esteemed by the natives. . . and. . . it gives them so much heat and strength. . . There is likewise a tree the natives call *chupirini*, which they use for the bubonic illness: they cut a branch and milk comes out. . . and. . . they take it with a little chicken soup. . .” (Acuña, 1987, p. 87).

Several wild plants are still used for food and medicine in the Lake Cuitzeo Basin. An edible tuber known as *Nymphaea gracilis* is similar to the potato in taste and manner of cooking, although it has become scarce in recent years. Another edible wild plant is called *Berula erecta*, which is also good for making infusions used in stomach and kidney ailments. Lastly, the local people also eat the *berro* (*Rorippa nasturtium-aquaticum*) (Rojas & Novelo, 1995, p. 14).

Among Lake Cuitzeo’s aquatic plants, two *tule* species are the most important: *Typha latifolia* and *T. dominguensis* (Ávila, 1999, p. 186), as well as *carrizo* (*Arundo donax*). Reeds and rushes have been very important for the local economy since ancient times, and they still are, although less so now than before. *Tule* and *carrizo* are still used for building houses, which are quite fresh, but people have to be careful, since these plants are quite flammable when dry. Most houses were made of *tule* and *carrizo* (or *carrizo* covered with mud) in the



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 8 The *fisga* is a *carrizo* spear around 3 m in length with metal prongs.

It is used for hunting frogs and fishing in Lake Cuitzeo (a), while in Lake Pátzcuaro, it is used to hunt waterfowl (b) and for fishing (c)



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 9 This *atlatl*, called *tzipaki* in Tarascan, was used to hunt waterfowl in Lake Pátzcuaro. This item comes from Tareiro, Lake Pátzcuaro Basin



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 10 A fisher from Tareiro showing how the *tzipaki* was used to hunt ducks in Lake Pátzcuaro

villages and towns around the lake until about 50 years ago, but this type of “vernacular architecture” is becoming scarce to the point of virtual extinction. Tule is cut from the plant using a scythe-like tool called *hoz* in Spanish (Fig. 12); in ancient times, sawlike chert implements may have been used to cut reeds (Fig. 13).

Fishermen in a lakeside town called Mariano Escobedo catch insects known as *mosco de agua* or *nizpo* (*Corisella texcocana* and *Ephydra* sp.), which are used as bird feed. Four varieties of



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 11 Nets were used to hunt ducks and other aquatic birds at Lake Texcoco in ancient times, as recorded by Father Bernardino de Sahagún in the *Florentine Codex* (Adapted from Sahagún, 2012, Figure 187)



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 12 The sickle is used to cut *tule* and *carrizo* in both Lake Cuitzeo and Lake Pátzcuaro

nizpo are known here (*picalón*, *barrilito*, *paloma*, and *de sangre*), and they all lay eggs which may also have been exploited in ancient times. The season for gathering *mosco* is during the months of August, September, and October, when the lake level is low. According to the fishermen, in

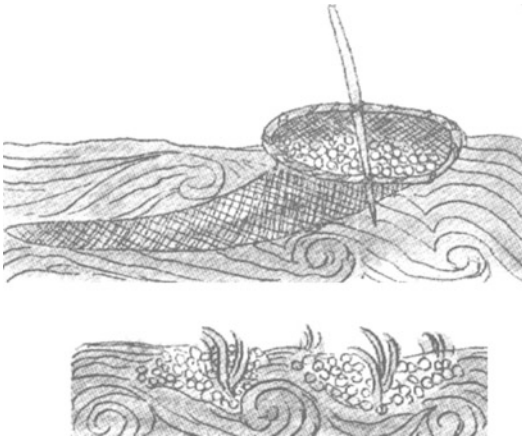


Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 13 The ancient aquatic lifeway included activities, like cutting *tule* and *carrizo*, that might be characterized by items like this sawlike (serrated) cutting tool found in Lake Texcoco, Basin of Mexico (Courtesy of Jeffrey Parsons)

shallow areas of the lake (with a depth of 8–20 cm), murky water is ideal for gathering the insects. The net used for this activity is called *red mosquera*. It is of finer mesh than the one used for fishing; it is 4 m wide by 180 m long and is dragged by four men in order to capture the insects that are on the water surface. In a good season, as much as 50–60 kg of *mosco* is taken in 1 day, although this is a diminishing resource.

A method used for harvesting *mosco* eggs is known as *costalera*, which consists of several sacks tied to wooden stakes sunk in the bottom of the lake. Once the insects lay their eggs, the sacks are taken out of the water and dried under the sun during 3 or 4 days. After this, the sacks are shaken and the eggs are collected in plastic bags (Argueta et al., 1986, p. 142).

Fishers at Lake Texcoco still gathered insect eggs until recent years using a special kind of net (Parsons, 2006). This was an important source of protein in ancient times, and together with algae collecting, fishing and hunting, aquatic insects and their eggs contributed to a complete and balanced diet (Parsons, 2011; Rojas, 1998). Father Sahagún recorded the techniques used for gathering aquatic insects at Lake Texcoco in the sixteenth century (Fig. 14).



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 14 In Aztec times, many aquatic insects were caught in nets (*top*), and their eggs were laid among aquatic plants in shallow lake areas, where they were gathered by fishers (*bottom*) (according to the *Florentine Codex*; adapted from Sahagún, 2012, Figures 224 and 225)

Lake Cuitzeo was once well known for the *petates*, or reed mats, made with tule from the lake. Petate weaving is still important for the domestic economy in the Lake Cuitzeo Basin, although it has been in decline since the 1950s. After cutting and drying the reed stalks, they have to be slightly moistened in order to weave a petate. The weaver uses a stone known as *piedra petatera* or *petatura* which is 7–10 cm in diameter and 3–4 cm thick; its shape is well adapted to the hand of the artisan who uses it to flatten the tule fibers as he or she weaves the petate. These stones sometimes are found when people dig canals, ditches, or even tombs in the local graveyard, so they may be quite old. Each *petatero* (tule weaver) (Fig. 15) has his or her own stone (Fig. 16), which may be passed down from generation to generation. In some towns around the lake, there are specialists who manufacture these stones. The only other tool used for tule weaving is a metal knife to cut the fibers and finish the reed mat.

The *carrizo* reed is no less important than tule for the local economy. Carrizo needs to be mature in order to be worked. Once the plant is cut and taken to the workshop, the artisan spends 3 days a week cutting the reeds in order to have the fibers



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 15 An artisan weaving a reed mat or *petate* in Coro, a town in the Lake Cuitzeo Basin. The only tools used in this activity are a stone called *piedra petatera* and a metal knife



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 16 The tool kit linked to *petate* weaving is quite simple, consisting of a stone (*piedra petatera*) and a metal knife. In the background of this figure is a *guangoche*, or sack made of *ixtle* (maguey) fiber, still used in the Lake Cuitzeo Basin

used in making a basket (Fig. 17). Two days a week are dedicated to weaving the bottom of the basket and 2 days in weaving the rest of the basket. The tools used to make a carrizo basket in several towns such as Colonia Guadalupe (see map, Williams, 2014a, Fig. 2) are the stone hammer and anvil (called *piedras de majar*, see Fig. 18) and several metal knives.

Some fishermen still weave their own nets of cotton or synthetic thread, which has replaced the *maguey* (*Agave* sp.) fiber still used in the first half of the twentieth century. Weaving is carried out using wooden tools called *malacate*, *astilla*, and *aguja plana* (Fig. 19). Don Fidencio, a fisherman



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 17 Artisan in Ihuatzio (Lake Pátzcuaro Basin) trimming *carrizo* reed with a steel knife used in basket-making



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 18 Hammer and anvil stones used for making *carrizo* reed baskets in the domestic workshop shown in Fig. 17

in Estación Queréndaro, showed us how these artifacts are made. The wood he uses comes from the *zapotillo* tree, which has to be green. A machete and several knives of different sizes are used for making these wooden artifacts. Don Fidencio told us that many years ago, he used to make needles for weaving fishnets out of cattle bone. He agreed to make some for us, which are shown in Fig. 20. Similar pre-Hispanic artifacts have been found at Lake Sayula, Jalisco (Fig. 21); they may have been used for weaving baskets or making nets.



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 19 Wooden tools used for weaving a net. From top to bottom: *malacate* (two shown, one with cotton thread), *aguja plana*, and *astilla* (Estación Queréndaro, Lake Cuitzeo Basin)



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 20 A fisher from Estación Queréndaro (Lake Cuitzeo Basin) made *malacates* and needles from cow bone that were similar to pre-Hispanic artifacts. In ancient times, such items might have been made of animal bone or deer antler

Conclusions

The ethnographic, archaeological, and ethnohistorical data discussed in this entry help shed light on the cultural processes and the resulting archaeological correlates (i.e., artifacts and features)



Aquatic Environments in Mesoamerica: Pre-Hispanic Subsistence Activities, Fig. 21 These pre-Hispanic artifacts were found at Lake Sayula, Jalisco; they may have been used as awls for weaving baskets or as needles for making nets (Photo courtesy of Ericka Blanco)

linked to aquatic subsistence in Michoacán and other areas of Mesoamerica. This information is vital for interpreting the archaeological record in all those regions of Mesoamerica where lakes, rivers, marshes, and streams offered their natural bounty for human exploitation (Williams, 2009a, 2009b, 2014a, 2014b).

In the last 60 years or so, many traditional activities and manufactures have all but vanished from the Mexican lake basins discussed here, such as maguey fiber processing and *pulque* (i.e., an alcoholic drink made from maguey sap) making. Because of the serious problems affecting most aquatic environments in Mexico, such as pollution, deforestation, and desiccation, the present generation of researchers may well be the last one to document a traditional aquatic lifeway reminiscent of the pre-Hispanic past.

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Archaeoastronomy of North Africa

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In this entry, I review data on orientations of pre-Islamic funerary and religious monuments in North Africa, including Sahara and the Maghreb and excluding Egypt, which has been extensively discussed elsewhere. The time span of the monuments discussed is extremely wide, from the Neolithic up to the Arabic invasion. The main conclusion is that there were enduring patterns in the orientations, very likely related to the ritual or symbolic importance of the rising sun. The overwhelming evidence confirms the strong solar aspects of the North African religion that the ancient writers indicated.

The prehistoric drystone funerary monuments of the Sahara are called *idebnan* (in plural) and *idebni* (in singular) by the present-day Tuareg. There are several different architectural types, and they are distributed in a very extended geographical area. Early European visitors realized that a large proportion of these monuments tend to be orientated with their main distinctive elements towards the east. The earliest type of *idebnan* is called “keyhole monument.” Paris (1996) obtained radiocarbon dates for some of these monuments in Niger (Emi Lulu) finding that they date from 3600 to 220 BCE. This kind

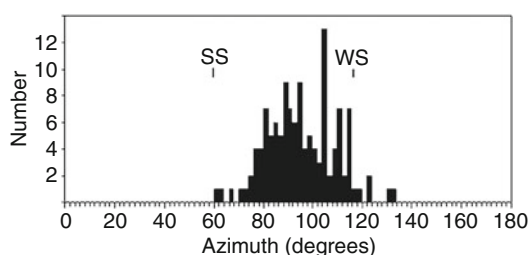
of monument is found even more densely at Tassili (Algeria). Savary (1966) obtained that the orientations of 158 keyhole monuments in Fadnoun (Algeria) lie in the azimuth range where the sunrise (or moonrise) takes place and can be described as a clear case of sunrising (SR) custom following Michael Hoskin’s definitions (Hoskin, 2001, pp. 19–20). Gauthier and Gauthier (2006) collect information about the orientation of 205 of these monuments in different geographical areas, finding a rather Gaussian distribution centered on an azimuth of about 98° without any local variation.

Another relevant type of Saharan drystone prehistoric burial is the so-called V-shaped monument which consists of a tumulus and two lines or arms of stones – also called antennae – that could be about some tens of meters or even up to 200 m long (see Fig. 1). These monuments are more concentrated in the Messak Settafet in the Fezzan region of Libya. The earliest monuments of this kind are dated about 3200–2900 BCE (Cremaschi & di Lernia, 1998). Hachid (2000) has compiled data for many *idebnan* in Tassili indicating that the antennae of most of the V-shaped monuments of this zone are oriented to the east. Some of them are located in the middle of wonderful landscapes, facing the borders of the impressive mountain ranges of Tassili. Recent statistical studies of the orientations of 49 and 31 V-shaped monuments of the Messak plateau (Fezzan, Libya) and Immidir Mountains (Algeria) by Gauthier and Gauthier (1999, 2003; see Fig. 1) show that the bisectors of the antennae show a narrow range of orientations also consistent with an SR custom. Other kinds of drystone monuments as the “platforms cairns with an arm” (Gauthier & Gauthier, 1999) and “L-shaped monuments” (Gauthier & Gauthier, 2001–2002) of Fezzan, as well as the “goulets” (narrow parts) of Immidir (Gauthier & Gauthier, 2003), show exactly the same orientation pattern (Fig. 2).

Later types of Saharan stone burials such as “crater tumulus” and “monuments with an alignment,” which are dated from 1900 BCE down to the start of Islamic culture locally, also have their structural elements as well as the head or faces of their skeletons oriented to the east (Hachid, 2000).

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Fig. 1 Example of a typical Saharan V-shaped drystone monument, located 30 km to the southeast of Al Awaynat (Fezzan, Libya) (Photo by Yves Gauthier (February 2006). Used with his permission)



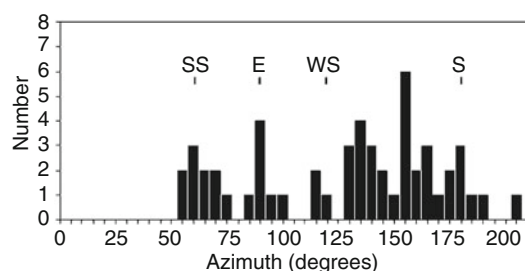
Archaeoastronomy of North Africa, Fig. 2 Number histogram of orientations of 132 V-shaped monuments, “goulets,” and “platform cairns with an arm running eastwards” of Immidir (Algeria) and Fezzan (Libya). Data are binned in 2° intervals. SS and WS indicate the azimuths of the rising sun at summer and winter solstices, respectively (Diagram adapted from Gauthier and Gauthier (2003)). This is an example of a sun-rising (SR) custom of orientations

Gauthier and Gauthier (2008), based on a large number of orientation measurements of “monuments with an alignment,” estimated from Google Earth satellite images found possible relation with the rising moon and rather clear regional variations. Other Saharan stone monuments – not necessarily related to tombs – as the so-called “horseshoe” structures with a straight line of little towers or altars are usually also oriented to the east, although with a much wider azimuthal distribution. These monuments are also known as “tents of Fatima” and are supposedly rural shrines. However, some kinds of monuments such as the single or triple crescents of the Messak Settafet, some crescents of south Algeria, and the bazina/tumulus with small auxiliary towers of Morocco and

Algeria do not follow the typical Saharan orientation customs (Gauthier & Gauthier, 2002, 2003, 2005). In fact, the orientations of the last group of monuments could be oriented towards the rising or setting moon. It would be interesting to reassess the orientation data of Saharan monuments considering the correction due to the real (non-flat) horizon where the monuments are actually facing, a kind of analysis that has not yet been carried out in the area.

Earlier possible evidence of astronomical observances by the Neolithic Saharan people has been found at Nabta Playa in Egypt, on the border of the Libyan Desert (McKim Malville et al., 1998). Here a group of megalithic circles and stone rows dating from some time earlier than 4500 BCE are oriented to the summer solstice or zenith passage of the sun.

Burial monuments of coastal and pre-desert zones of North Africa from the first millennium BCE up to the Islamic conquest are extremely diverse. One can find simple and monumental dolmens, tumuli of very different typology, rock-cut tombs (*hawanat*), hypogaea (the subterraneous portions of a building or subterranean galleries, such as the catacombs), and the later great mausolea. In his magnificent book about protohistoric funerary monuments of North Africa, Camps (1961) admits that the orientation of the main entrances, façades, and corridors of those burial monuments is in most cases consistent with a general east–west arrangement. This fact makes one wonder if the protohistoric



Archaeoastronomy of North Africa, Fig. 3 Number histogram of orientations of 53 dolmens at Elles (Tunisia). Data are binned in 5° intervals. SS and WS indicate the azimuths of the rising sun at summer and winter solstices, respectively; E and S indicate east and south, respectively (Data taken from Belmonte et al. (1998)). This is an example of a sun-rising/sun-climbing (SR/SC) custom of orientations

orientation pattern is related to the ancient Neolithic Saharan traditions discussed above.

Savary (1969) analyzed the precise orientations of 13 North African dolmens at Beni Messous (Algeria). He found that the orientation pattern could be classified as a sun-rising/sun-climbing (SR/SC) custom following Hoskin's scheme (Hoskin, 2001, pp. 19–20); this definition covers a range of azimuths from about 60° to due south or thereabouts. This range includes the sunrise and the position of the sun while it is climbing in the sky or around culmination. Belmonte, Esteban, and Jiménez González (1998) have measured dolmens in different necropolises of Northern Tunisia. These authors find a clear SR/SC pattern for the orientations of megalithic monuments of the necropolis of Elles (see Fig. 3). An SC and an SR/SC orientation pattern seems applicable to the dolmenic necropolis of Thugga and the complex megalithic tombs of Mactar (see Fig. 4), respectively. On the other hand, the very rough and simple dolmens of Bulla Regia show a highly unusual westerly orientation. Hoskin and Foderà Serio (private communication) and Hoskin (2001) consider that the reason for the orientation of the dolmens in the Tunisian necropolises of Elles, Henchir Midad, and some others around the town of Mactar is simply topographical: they are facing downhill. However, the orientations of Henchir Midad have been further discussed by Belmonte et al. (2003)

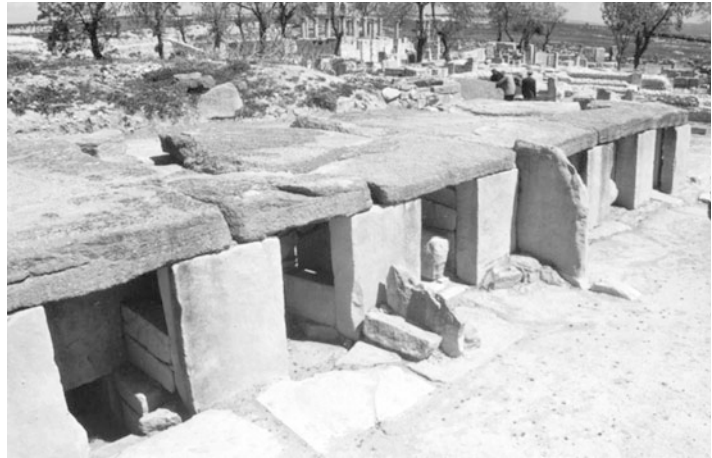
stressing their astronomical significance. They have studied the several groups of Numidian dolmens of Northern Tunisia, finding a general SR/SC orientation pattern. Finally, it is remarkable that several groups of rock-cut tombs (*hawanat*) of Northern Tunisia analyzed by Belmonte et al. (1998, 2003) also show orientations following the typical SR/SC scheme (see Fig. 5).

It is mostly accepted that the North African dolmens were earlier than the Roman conquest, perhaps prior to the Phoenician expansion, and clearly after the Neolithic (Camps, 1961, pp. 146–148). The distribution of the North African dolmens along the Maghreb suggests that their origin is not autochthonous and should be the Iberian Peninsula for the monuments of the north of Morocco and Sardinia, Corsica, Italy, and/or Malta for the Algerian–Tunisian group (Camps, 1961, pp. 149–152, 1995a, pp. 2508–2509). In this context, Camps remarks on the important role that Sardinia could play in this transmission. He notes that Diodorus Siculus (Diodorus V, 8) and later Pausanias affirmed the Libyan origin of the Sards. In fact, Hoskin (2001, pp. 175–192) has found that the 97.7 % of around 200 Sardinian dolmens, *corridoi dolmenici* and *tombe di giganti*, show the same orientation custom as the North African dolmenic and *hawanat* necropolises. Therefore, taking into account the differences with respect to the most common ancient Saharan pattern of orientations – which is clearly SR – the data are consistent with an alien origin of the North African dolmens and *hawanat*.

Information about the orientations of the most common protohistoric North African burial monuments – stone and earth tumulus and *bazinas* – is rather scarce, mostly because of the impossibility of defining an axis of symmetry in most of them. However, we have information about some groups of stone monuments: chapel tumuli, niche monuments, and the great Algerian mausolea. In the case of the chapel tumuli, there are detailed studies of two necropolises of the Tafilat: the chapel tumuli of Taouz (see Fig. 6) show an apparent SR custom in their orientation (Belmonte et al., 1999; Castellani, 1995), while

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Fig. 4 Complex megalithic tomb of Mactar (Tunisia) with six chambers



Archaeoastronomy of North Africa, Fig. 5 Group of rock-carved tombs (*hawana*) at Chauach (Tunisia)

the monuments at Hassi Beraber seem to be oriented somewhat more southerly, consistent with an SC custom (Castellani, 1995). Camps (1961) reviews data for the chapel tumuli of the necropolises of Bouia (Tafilat) and Negrine, pointing out that all the monuments are oriented with their entrances facing east. From published plans of the chapel-tumuli of Djorf Torba, Belmonte et al. (1999) find two predominant orientations, to nearly due east and to southeast. Southeast and east seem also to be the orientation of a sample of circular niche monuments at d'El-Esnam and Kef Sidi Attalah, respectively. Belmonte et al. (1999) also study 34 skylight-tumuli in the necropolis of Fom al Rjam in the Saharan Morocco, finding a clear SR/SC custom in their orientation.

The most evolved and impressive pre-Islamic burial monuments of North Africa – the Algerian great mausolea (Medracen, Blad el-Guitoun, Tombeau de la Chrétienne, Djedar), which show clear Punic architectural and stylistic influences – have their ceremonial corridors and external platforms oriented towards the east (Camps, 1961, pp. 199–205). In particular, the Djedar of north Algeria are especially interesting because of their late chronology, which is as late as the fifth and sixth century AD, just before the Arabic conquest (Camps, 1995b, pp. 2419–2422). They represent the end-point of the genuine pre-Islamic North African funerary traditions.

Elements of the proto-Berber culture survived in the Canary Islands until its conquest by the Castilians in the fifteenth century. Belmonte et al. (1997) obtained orientation diagrams of the burial chambers of several important tumular necropolises in the islands of Gran Canaria and Fuerteventura, finding an SR (or sunset) custom in the necropolis at Tirba Mountain (Fuerteventura) and for the drystone tumuli of Maípez (Gran Canaria). Perhaps as a reflection of the mixed trends found in the continent, an SC custom is found for the tumuli of Arteara (Gran Canaria).

In the land of the Garamantes (Fezzan, Lybia), one finds burials of very different typology perhaps associated with the different cultural contacts experienced by this warrior people.

Archaeoastronomy of North Africa, Fig. 6 East-facing chapel tumulus of Taouz (Morocco) (Photograph reproduced from Belmonte et al. (2002))



Archaeoastronomy of North Africa, Fig. 7 Field of Garamantian pyramidal tombs at El Hatir (Fezzan, Libya)



The extensive excavations carried out by Daniels (1989) point out that the Garamantian tombs are mainly dated from Roman times. Belmonte et al. (2002b) have studied the orientation of funerary monuments in some of the most representative Garamantian necropolises as the pyramidal tombs of Charaig and El Hatir (see Fig. 7), the mud-brick tombs of Saniat ben Howedi, and the mastaba-like royal tombs at Germa. The pyramidal tombs are arranged with their four sides oriented approximately to the cardinal points. Many of the tombs of Saniat ben Howedi have stone offering tables and are facing near due east or due west. The most clear orientation pattern is shown by the mastaba-like and circular tumulus (with a stèle showing the relevant direction) of the royal necropolis of Germa; all the tombs measured are oriented to the east, following a clear SR custom. Although the formal similarity to the Egyptian monuments is evident and even the presence

of obelisks or stelae in their proximity could suggest a direct Nilotic influence, this is not entirely clear. Camps (1961, pp. 165–166) indicates that the Garamantian monuments are not very different to the pre-Islamic rectangular *bazinas* of late chronology that can be found elsewhere in North Africa, whose geographic distribution cannot be explained by a gradual diffusion from Egypt. Moreover, their orientation pattern is also consistent with the typical customs of the rest of the contemporary North African funerary monuments and especially with the much older and autochthonous *idebnan* of the Fezzan.

It is generally accepted that the impact of the Punic culture was profound and enduring on the Libyan or proto-Berber culture and especially on their religion (Bénabou, 1975, pp. 377–380; Picard, 1954). There are interesting facts about the orientations of Punic funerary monuments. Belmonte et al. (1998) find a clear SR custom in

the early Punic necropolis of Utica and a doubled-peaked distribution centered on the sunrise at the equinoxes and the winter solstice in Menzel Temine and the early Phoenician necropolis of Villaricos in the southern Mediterranean coast of the Iberian Peninsula (Belmonte, 1999; his Fig. 5.5). A general east–west orientation is also found for the Punic necropolises of Tipasa in Algeria (Baradez, 1969) and of Aïn Dalia Lekbira in north Morocco (Alaoni, 2000). González García et al. (2006) have measured a large number of tombs in the Punic necropolises of Sardinia and Ibiza, finding a general tendency of orientations towards the solstices and equinoxes. However, there is not a regular orientation in all Phoenician/Punic necropolises studied. In Byrsa (Carthage), Belmonte et al. (1998) have found a rather unusual south–west distribution. In Dermech (Carthage), the orientations show an azimuth preference between 120° and 160°. Finally, the Maltese shaft tombs and burial chambers studied by Ventura (2000) show a clear preference for the approximate north–south direction. It is also interesting to remark that the general planning of the Punic sacred areas or tofets in Sicily and Sardinia is usually arranged along the cardinal axes (Ribichini & Xella, 1994). Finally, an additional interesting archaeological indication was obtained by Carton, who found that in an open sacred area in Thuburnica (Sidi-Ali-Bel-Kassem, Tunisia), all Neo-Punic stelae were orientated to the east (see Leglay, 1961, p. 276). In summary, there is not a regular pattern in the orientations of the Punic tombs, although many necropolises and funerary areas show an east–west custom. This has also been observed in the Phoenician–Punic necropolises of south Spain, where the archaic tombs (eighth–seventh centuries BCE) tend to be oriented to the east and the later ones do not follow that rule so strictly (Ramos Sainz, 1986, pp. 32–33).

The Roman custom of building mausolea or monumental tombs was also common in North Africa, especially from western Algeria to Tripolitania. Belmonte et al. (2002) compiled data on some different monuments of Roman epoch, and most of them were oriented following an SR custom. However, the largest concentration of

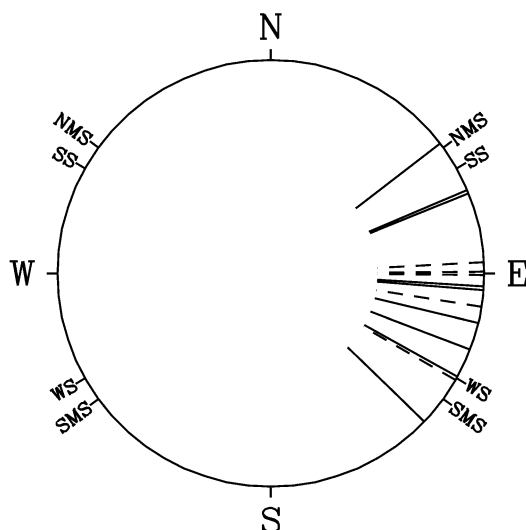
mausolea from the late Roman epoch is in the settlement of Ghirza, in the Libyan pre-desert. The plans published by Brogan and Smith (1984) show that the doorways or the ornamental false doors of the tombs of the northern group show a clear SR custom, while the tombs of the northern complex are oriented towards the north (Esteban, 2003).

Perhaps the earliest known constructions that can be considered sanctuaries or temples in North Africa to the east of the Nile Valley are of Punic origin. The importance of the orientation in the Punic ritual is documented in a stone inscription found in the zone of Salamambo in Carthage. This stone was an offering placed in a sanctuary dedicated to Baal Hammon. The text indicates explicitly that the stone was orientated with its front side to the sunset and its back side to the sunrise (Xella, 1991, p. 48).

Esteban (2002) reports that the *Decumanus Maximus* of Roman Carthage – as well as the layout of the Roman and the Punic city and acropolis – is oriented towards the winter solstice sunrise. This author also compiled the orientations of five Punic and Neo-Punic temples and sanctuaries from published plans and measurements, finding that the temples were orientated towards a fairly narrow zone of the horizon, from 90° to 127°. It is remarkable that three of them are also oriented to or near the winter solstice sunrise.

Esteban et al. (2001) have carried out an extensive survey of the orientations of a large number of Roman and pre-Roman temples of Morocco, Tunisia, and Libya. Belmonte et al. (2006) measured additional temples of Northern Tunisia. Esteban et al. (2001) found that the complete sample of temples built in Roman times show a definite random distribution of orientations. Moreover, there is no correlation between the dedication of the temples and their orientation, except for those dedicated to Saturn. Most of the religious buildings dedicated to this deity are oriented following an SR custom (see Fig. 8).

Saturn was the most important deity worshipped in Northwest Africa in Roman times (Bénabou 1975, pp. 370–375; Leglay, 1966; Picard, 1954, pp. 100–129) from ancient Numidia



Archaeoastronomy of North Africa, Fig. 8 Orientations of temples dedicated to Saturn from Roman North Africa. Continuous lines: direct measurements by Esteban et al. (2001) and Belmonte et al. (2006); dashed lines: orientations obtained from published plans. SS and WS indicate the azimuths of the rising/setting sun at summer and winter solstices, respectively. NMS and SMS indicate the points where the rising/setting of the moon takes place at northern and southern major standstills, respectively

to Mauretania (present-day Tunisia to Morocco). Its cult had strong pre-Roman roots and was the inheritor of the ancient cult of the Punic Baal Hammon, who was the most important god of both the rural and Punicised Libyan population, probably because of the strong similarities of the Carthaginian deity with a former ancient supreme Libyan god (Leglay, 1966, pp. 417–447).

The cult to Saturn is almost completely absent in the deeply Punicised Tripolitania (Brouquier-Reddé, 1992, pp. 255–265; Leglay, 1966, pp. 267–268). In this region Jupiter Hammon was an adaptation of the great god of the Eastern Libyans, the ram-headed Ammon (see Bénabou 1975, pp. 335–338; Mattingly, 1994, pp. 167–168). The spread of the cult of Ammon is demonstrated by the many rural (mostly indigeneous) temples or *ammonia* for which we have evidence in Tripolitania and among the Garamantes and the Libyan Desert oases of Siwa and Augila (Mattingly, 1994, pp. 36, 168). Esteban (2003) has collected published data for

rural shrines built in Roman times in Tripolitania (Brouquier-Reddé, 1992, Esteban et al., 2001, and references therein) and for the Garamantian ashlar masonry temple at Germa (Esteban et al., 2001). It is remarkable that the range of orientations of many of the rural sanctuaries of Tripolitania show an orientation similar to those dedicated to Saturn in the rest of the Maghreb, a fact that could be related to the common pre-Roman substrate in the popular religion in both territories.

Among the Tripolitanian rural shrines, the one of Ghirza (Brogan & Smith, 1984, pp. 80–92) is especially interesting due to its strong Punic elements; these make it a unique monument in Tripolitania. Brogan and Smith (1984, p. 88) suggest that the building was perhaps devoted to the cult of Baal-Saturn in his role of earthly fecundity, but Brouquier-Reddé (1992, p. 146) proposes that the sanctuary was dedicated to the Libyan bull-headed god Gurzil, son of Ammon. From the plans published by Brogan and Smith (1984; their Figs. 25 and 26), Esteban (2003) finds that the orientation of the building is towards the east, very similar to that of Germa (Esteban et al., 2001) and also consistent with the SR range.

Finally, Esteban et al. (2001) have also measured the orientation of some temples built in the epoch of the Numidian and Mauretanian kingdoms, prior to the Roman annexation of all North African provinces. These kingdoms were autochthonous but deeply Punicised in their culture, especially in religion (Camps, 1979). All these monuments show orientations consistent with the patterns found for the temples of Saturn and the rural temples of Tripolitania.

The possible astronomical motivation of the orientation patterns of the North African funerary and religious monuments discussed above has further support in some remarkable astronomical markers that have been found in important archaeological sites of the area, from Libya to Morocco.

Belmonte et al. (2002a) report the discovery of an impressive solstitial marker over a distant foresight from the east edge of the top of Zinchecra, the capital city of the Garamantes of the Fezzan (Libya) and inhabited since the ninth



Archaeoastronomy of North Africa, Fig. 9 Carved cupmarks at the eastern border of the cliff of Zinchecra, the hilltop fortified capital of the ancient Garamantes of the Fezzan (Libya). The *arrow* indicates the place where the sun rises at the summer solstice, just on the intersection of the escarpment of the black plateau of the Messak and the sand sea of Ubari. That zone of the escarpment corresponds to the long-lasting sacred area known as Al-Fugar

century BCE. The sun at summer solstice rises just on the most conspicuous distant topographical element of the skyline: the intersection of the flat escarpments of the Messak and the southern border of the sand sea of Ubari (see Fig. 9). This precise zone of the escarpment is called Al-Fugar and contains a major Garamantian and a later marabout cemetery. It is a sacred area used from prehistoric times until recently and continues to be today a place for pilgrimage and prayer (Barnett & Mattingly, 2003). The discovery of a striking astronomical marker in the first known political center of the Garamantes gives further support to the importance and continuity of the

astral elements of the genuine Libyan funerary and religious world, just before the contacts with the Phoenicians and Greeks.

Esteban et al. (2001) found another possible pre-Roman solstitial marker at the Numidian city of Simithus (Tunisia). From the Roman forum, which is located above the preceding Numidian tombs dated from the fourth to the first centuries BCE, it is possible to see the Numidian sanctuary (dedicated to Saturn in Roman times) just on the top of the Sacred Hill of Simithus. Esteban et al. find that the line of sight of the sanctuary as seen from the Numidian tombs at the forum coincides with the summer solstice sunrise. Moreover, a large Numidian monumental tomb is oriented precisely to the hill summit.

The group above found another spectacular astronomical marker in the temple of Apollo of Mactar (Tunisia). The Numidian-Punic traditions were very strong in this city and survived for several centuries after the Roman conquest (M'Charek, 1982, p. 12). The temple is located outside the city; it is oriented east–west and built over a previous Punic or Libyan sanctuary (Picard, 1984). The temple faces a small natural cut in a mountain (Fig. 10) which is exactly where the sunrise takes place at the midday in time between solstices, very close to the equinox (see definition in Esteban, 2003). Although the Punic Baal Hammon was conflated with Saturn in most of the Roman province of Africa, there is some controversy that this could be not the case in the region of Mactar (see the discussion by M'Charek & Ghaki, 1991 and references therein). Bisi (1978) suggests that in Mactar, the ancient cult of Baal Hammon was assimilated to Apollo, the sun-god of the Romans. If this hypothesis is true, the presence of an equinoctial marker at the temple of Apollo would provide proof of the transmission of the solar elements from the ancient Punic–Libyan religion to the Romanized local cults.

Another possible relation with the equinoxes or a date close to it has been found at the temple B of Volubilis (Morocco) that shows all the characteristics of the temples of Saturn but lacks a direct confirmation of its dedication. It has a very precise orientation towards the sunrise



Archaeoastronomy of North Africa, Fig. 10 Remains of the Temple of Apollon in Mactar and its eastern horizon. The arrow indicates the place where the sunrise takes place at the equinoxes. The upper left box shows an enlargement of the horizon, and the white circle indicates the size of the solar disk (Figure reproduced from Esteban et al., 2001 and Esteban, 2003). The cutting in the mountain at the left of the arrow coincides with the point where the sunrise takes place at the midday in time between solstices (see Esteban, 2003)

around the equinoxes (Esteban et al., 2001; Morestin, 1980, pp. 56–57) that takes place over the nearby mountain Zerhoun, the most famous holy mountain of Muslim Morocco (see Morestin, 1980, p. 135). The actual Roman building was built over a previous *tofet*, the westernmost Punic funerary sacred area known in Africa.

A last possible equinoctial marker could be at the temple of Saturn at Thugga (Tunisia). As in the case of the temple B of Volubilis, the Roman temple was built over a previous Punic *tofet*. The temple is oriented inside the range of the sunrises but not related to the solstices or equinoxes (Esteban et al., 2001). Esteban (2003) found that the peak of Zaghouan (the highest peak of Tunisia and the most important water source of

ancient Carthage) seems to be located in the general direction of the horizon where the sunrise takes place around the equinoxes.

As we can see, there are possible equinoctial markers – or markers towards the midday in time between the solstices – in three sacred areas or *tofets* of important cities of Libyan–Punic origin (Mactar, Volubilis, and Thugga). In the three cases, the sanctuaries were reutilized in Roman times and were dedicated to Saturn (the great North African deity) or to the Roman sun-god Apollo. It is interesting to note that several equinoctial markers (analogous to the one found at Mactar) have been found in sanctuaries belonging to the Iberian culture in the southeast of Spain (Esteban, 2003, 2013) which was also influenced by the Punic civilization in many aspects and especially in its religion. Finally, the discovery of striking equinoctial markers in important pre-Hispanic sanctuaries of the Canary Islands also suggests that this element was important in the ritual of the proto-Berber peoples of the archipelago (see Esteban & Delgado, 2005). In the light of the results gathered, it seems very probable that the ancient settlers from the continent imported this astronomical tradition. This original population was culturally Punicised to some degree.

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Architectural Decoration in Islam: History and Techniques

Ruba Kana'an

Architectural decoration has been one of the most resilient of the Islamic arts. The partial and more often overall decoration of buildings has been a characteristic feature of Islamic architecture from the eighth century onwards. Religious monuments as well as secular complexes have been decorated with an array of styles and techniques that reflected the multiplicity of Muslim societies and their cultural expressions. The importance given to decorating one's built environment has also been applied to temporary settlements such as tented encampments.

Up until the eleventh century, most decorative techniques such as the use of decorative brickwork or moulded stucco in the Muslim east, and mosaics, *ablaq* and carved stone in the central Muslim world were inherited from pre-Islamic cultures and societies. Muslim artisans transferred these skills into their respective contexts and adapted them to their architectural needs. It was only in the eleventh to thirteenth centuries that the use of repetitive patterns and intricate designs of geometric, calligraphic, and abstract vegetal motifs became the dominant decorative repertoire (Jones, 1978). These elements permeated architectural decoration throughout the Muslim world resulting in a new and distinct decorative language (Fig. 1).

Decorative elements such as the use of arabesque, geometric interlace (*girih*) and *muqarnas* or stalactite vaults became widely spread. Common among these decorative elements are notions of modularity, geometry and rhythm. Arguably, these forms are manifestations of a geometric pattern that is based on the subdivision of space, form or surface and the infinite repetition of the structural modules and motifs. Division and repetition, for example, applied to abstract forms of vegetation that are subjected to the rules of

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Fig. 1 Dome of the Al-Ashrafiyyah Madrasa in Ta'izz, Yemen. 1398–1400. Showing painted decorations and carved stucco



geometry and then extended indefinitely in all directions, formed the arabesque. Geometric interlace patterns (*girih*) also follow the same structural principle; these decorative compositions are based on the folding and repetition of regular shapes using circles, triangles and squares. The resulting patterns are purely mathematical and their artistic value lies in the choice of what aspect of the geometric pattern to highlight and which colours to use. (See “The nature of Islamic art”, MET timeline http://www.metmuseum.org/toah/hd/orna/hd_orna.htm.)

Subtle mixtures of geometry and rhythm also characterized the *muqarnas* or stalactite vault which is distinctive to Islamic architecture and decoration. The *muqarnas* is both a structural element filling zones of transition between walls and domes and a decorative element that follows the same structural composition (Fig. 2). *Muqarnas* domes, vaults, niches and decorative friezes are found in different construction materials including brick, stone, wood and stucco all over the Muslim world. (See a good survey of *muqarnas* types and their geographical distribution <http://www.tamabi.ac.jp/idd/shiro/muqarnas/>.) In its simplest form the *muqarnas* can be described as layers of superimposed



Architectural Decoration in Islam: History and Techniques, Fig. 2 Mihrab of the mausoleum of Haseki Hürrem wife of Süleyman the Magnificent, Istanbul, Turkey. 1550–1557

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Fig. 3 Mihrab of the mausoleum of Gur-i Emir, Samarqand, Uzbekistan. 1404. Decorated with painted and gilded arabesque designs and *square* Kufic inscriptions



A

niches that link or decorate two surfaces. The earliest surviving mathematical treatise on *muqarnas* was written during the fifteenth century by the mathematician Ghiyāth al-Dīn Mas'ūd al-Kāshī (d. 1429). The treatise was used to inform the simulation of a model of a *muqarnas* in Necipoğlu's book on a Timurid period scroll found in the Topkapi Saray Museum in Istanbul (Asad, 1995). The earliest surviving drawing of a *muqarnas*, however, was found in the Takht-i Sulaiman excavations in the northwest of Iran. The plaster panel of (50 × 50 cm) inscribed with a design of a *muqarnas* dating to ca. 1270 currently housed in the archaeological museum of Berlin was drawn into an exact plan (Harb, 1978) and later studied and analysed by a numerical geometry group at the University of Heidelberg in Germany. (See the numerical geometry study group <http://www.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/> and the Takht-I Sulaiman muqarnas drawing http://www2.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/Img/suleyman_plate.jpg).

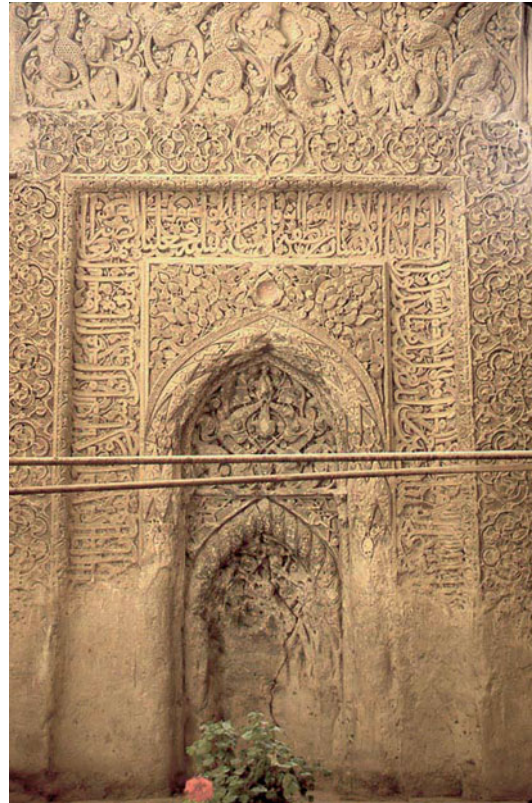
The use of calligraphy in architectural decoration pre-dates Islam. However, after the birth of Islam words and calligraphic compositions became a primary component of a collective aesthetic. Notably, decorative inscriptions were not often applied in isolation as calligraphy was most commonly used as part of an overall

composition that at times overlapped with other decorative techniques such as arabesque. Like other decorative forms, calligraphic compositions are based on a modular principle where letters, words, or full sentences are subject to geometric rendition and repetition. The purpose, form, content and location of inscriptions on buildings varied according to time and place (Blair, 1998). A large percentage of surviving inscriptions are Qur'anic or religious in nature but inscriptions with historical information providing the name of the building's patron, its date of construction and at times the name of a builder are also common (Fig. 3). Whereas Arabic served as the main language for monumental inscriptions, Persian, Ottoman Turkish and in a few cases Pahlavi and Swahili were also used. The location of calligraphy on a building followed stylistic developments and regional variations. Most commonly, calligraphic friezes tend to delineate structural zones in a building such as between walls and zones of transition, the bases of domes, entrances and on the voussoirs (wedge-shaped stone building blocks used in constructing an arch or vault) or tympana (the triangular area in a pediment) of arches. Calligraphy was also used as a form of overall decoration such as the large buff and turquoise brick inscriptions in the *hazārbāf* technique (see below) that adorned

walls and minarets of monuments during the Timurid period. (See the Islamic Art and Architecture Organization <http://www.islamicart.com/main/calligraphy/index.html>).

The application of different decorative elements on a building was wide-spread in Muslim architecture. Nevertheless, the form of decoration and its location followed regional preferences and local traditions. For example while monuments of Fatimid and Mamluk Egypt were decorated with carved inscriptions, *ablaq* stonework, and architectonic features, the facades of monuments in Khurasan and Transoxiana were decorated with overall brick patterning, blind arches, glazed and moulded tiles, terracotta inlays, stucco and ornamental inscriptions. Even in buildings where the exteriors were left almost totally unadorned such as the Ilkhanid period mosques of Iran and Iraq (1256–1353), interiors and particularly the mihrab niche was the focus of sumptuous stucco decoration (Fig. 4). So too is the case in fourteenth century North Africa and Spain as for example in the courtyard arcades of the Nasirid palace in Granada or the complex decoration of the Marinid ‘Aṭṭārīn Madrasa in Fez built between 1323 and 1325.

Decorative elements applied to architecture were used singularly or in combinations. Of particular significance was the use of overlapping patterns in two or more dimensions. An example is the tile mosaic design on the dome of the Shah Mosque in Isfahan, Iran (1611–1638), with its ochre lattice screen pattern and white and blue arabesque. Another example with a similar overlapping composition yet a different effect is the stone dome of the Sultan Qaytbay mausoleum in Cairo (1472–1474) with its geometric interlace design and flowering arabesque (Fig. 5). Whereas the former is two-dimensional, the Cairo example has a sculptural effect as both elements are carved in a precise bas-relief. The use of complex and overlapping decorative patterns was also subject to stylistic changes. The pre-Mongol arabesque based on twining vine tendrils and acanthus or palm leaves gave way from the turn of the fourteenth century to lotus scrolls with peony sprays and serrated leaves (*hata’i*). This aesthetic



Architectural Decoration in Islam: History and Techniques, Fig. 4 The mihrab of the Shrine of Pir-i Bakran in Linjan, Iran. 1299–1312

became popular in Iran and was later adopted in the early sixteenth century Iznik ceramic tiles produced by the Ottomans.

The Meaning, Purpose and Transmission of Architectural Decoration: Problems of Interpretation

Because of the perennial emphasis on geometric patterns and abstract vegetal motifs, the decorative language of Islamic architecture is commonly perceived to reflect a Muslim ethos that is aniconic and unchanging. (When referring to a deity image, aniconic denotes a symbol which does not attempt an anthropomorphic (humanlike) or representational likeness.) This perception is at the heart of a number of debates in the study of Islamic art and culture including: was the use of



Architectural Decoration in Islam: History and Techniques, Fig. 5 Dome of the mausoleum of Sultan Qaytbay, Cairo, Egypt. 1472–1474



Architectural Decoration in Islam: History and Techniques, Fig. 6 Muqarnas dome of the mausoleum of Nūr al-Dīn in the al-Nūriyya Madrasa, Damascus, Syria. 1168

A

geometry and arabesque patterns a reflection of Islam's antipathy to images? Was it a reflection of the special status of mathematics and geometry in Muslim cosmology? Or was it, perhaps, a reflection of a cultural process with its social, political and religious ramifications? These debates represent the two main current schools of thought on the meaning and purpose of architectural ornament: the "iconological" and the "cosmological".

In the iconological approach all works of art, including architectural decoration, are interpreted as visual signifiers of the cultural context which they embody. As such, a work of art has a meaning that is culturally constructed and related to a specific time, place and context of production. It is read and considered as evidence or representation of its context on par with other historical, political, social or literary documents. Such an approach is at the heart of Tabbaa's analysis of the transformation of architectural decoration in the central Muslim lands between the middle of the eleventh and the middle of the thirteenth centuries (2001). He argues that the evolution of an artistic language which is characterized by the use of arabesque, geometric interlace, *muqarnas*

vaulting, and monumental calligraphy was largely brought on by a Sunni revival that strived to standardize religious norms in a period of political and sectarian upheaval (Tabbaa, 2001, p. 6). The evolution of the gravity-defying and ever changing effect of the *muqarnas* domes, for example, is interpreted in his study as an embodiment (or abstraction) of the Ash'arite Sunni theology which is based on an occasionalistic cosmology (133). As such, the evolution of the *muqarnas* dome, as well as the other decorative techniques, is explained within a precise political and religious context within which it would have had a symbolic meaning (Fig. 6).

For the proponents of the cosmological approach, geometric and decorative patterns are interpreted as manifestations of underlying principles of faith that are regarded as both universal and timeless. This approach attributes a functional role to ornament that is first and foremost a reminder of the principle of Tawhīd: the Oneness and Transcendence of the Divine (Al-Faruqi Isma'il & al-Faruqi, 1986, pp. 163–169). Islamic art and geometric patterns used in architectural decoration are thus seen as means to reconcile

multiplicity with Unity. They depict a physical mathematical pattern which reflects a sacred cosmology. Islamic art is thus regarded as an aniconic art where the spiritual world is reflected through geometry, rhythm, arabesque and calligraphy. For example, the circle is read as symbol for the origin and the end, an archetypal form from which the three primary shapes (triangle, hexagon and square) emerge (Critchlow, 1976). The same ideas are expressed by Burckhardt (1976, p. 63) who sees geometric interlace as a direct expression of the idea of Divine Unity. Thus unlike the iconological approach, the cosmological approach does not take into account the socio-political context of a decorative programme or the vicissitudes of artistic influences.

These two approaches often regard each other as incompatible. The iconological school sees the attempt to interpret style through faith too speculative and at best normative. Whereas for those who consider Islamic art as an expression of Muslim faith and Divine Unity in particular, the temporal contextual analysis of decorative patterns misses the point. What the two approaches agree on, however, is the need for intermediaries to translate these complex mathematical and philosophical ideas into patterns that could be understood and applied by craftsmen. For example, Nasr explains geometric patterns as being the “results of the vision of the archetypal world by seers and contemplatives who then taught craftsmen to draw them upon the surfaces of tiles or alabaster” (1987, p. 49). Tabbaa (2001, p. 100) and Necipoğlu (1995, p. 123), on the other hand, propose that one of the reasons for the development of these complex and geometrically based decorative techniques is that geometric treatises were increasingly available for artisans. This presumed relationship between the artisan and the mathematician in medieval Islam, however, was dismissed by George Saliba, Professor of Arabic and Islamic science at Columbia University. Saliba argued that based on the available evidence from the few surviving mathematical treatises the assumption is hard to entertain, let alone prove (1999, p. 641). He also provides textual evidence for the difference in the technical language used by mathematicians and artisans, and

the need therefore to avoid the assumption that the presence of mathematical treatises means that they are used or understood by artisans. Theoretical mathematicians, according to Saliba, “rarely taught artisans directly, and seldom wrote for them specifically” (643).

Another important issue that arises in debates about architectural decoration is the manner in which architectural or decorative designs were transmitted. Jonathan Bloom (1993, p. 25) argues that the form and general characteristics of early mosques were transmitted mostly by example. That is, the general features of one building were copied by another in the same region. Bloom also argues that such buildings could have been described orally or in geographical works, and thus what was transmitted was a notional idea of a building or a decorative detail. These suggestions remain to be fully proven. It is worth noting that there are also a few historical accounts which mention the involvement of patrons in drawing designs of a desired monument, but no material evidence survives before the fourteenth century (O’Kane, 1987, p. 34). In this connection, the presence of a notational convention used by craftsmen based on drawings and models is only attested to from the thirteenth century with the 1270s stucco panel with a *muqarnas* plan (discussed above) as the earliest surviving example. Early drawings on paper survive from the sixteenth and seventeenth century in Tashkent, and the fifteenth and sixteenth century in Istanbul (Necipoğlu, 1995). Finally, one of the important ways of transmitting knowledge about decorative techniques and practices was through the movement of craftsmen who brought with them new traditions and technical know-how.

Architectural Decoration by Media

Studies on the building crafts in Muslim societies are sparse and mostly regional or media specific. The best example is Hans Wulff’s book on Iran (1966) which provides an invaluable detailed study of building and decorative traditions concentrating on local practices and

techniques. Iran's craft industry during the nineteenth and the early twentieth centuries and its encounter with Western technical development are also documented (Floor, 2003). For Syria and Egypt dictionaries of traditional crafts (al-Qasimi, 1988) and architectural terms (Amin & Ibrahim, 1990) provide glimpses into local technical practices. IRCICA, the Research Centre for Islamic History, Art and Culture based in Istanbul has had since 1990 a programme for the study and development of crafts in Muslim societies. The programme hosted conferences and seminars in different regions and recently published some of their proceedings (see www.ircica.org). What follows is a summary of the history and techniques of stone, brick, tile and stucco decoration.

Stone

Stone was used as a decorative medium in Syria, Anatolia, Egypt after the eleventh century, Spain, and India (Fig. 7). North Syria, especially the area around Aleppo during the period between the twelfth and fifteenth centuries, seems to have been a source of technical innovation for stereotomic stone techniques that are based on the precise cutting and assemblage of stone blocks (Clévenot & Degeorge, 2000, p. 68). (Stereotomy is the science or art of cutting solids into certain figures or sections, as arches; the art of stonemasonry.) The decorative use of stone exploited the natural variety of stone colours to produce polychrome compositions for the interior and exterior of buildings. Some techniques such as alternating the colours of stone courses (*ablaq*) or interlocking the stones of arches (joggled voussoirs) were used in pre-Islamic monuments but became more sophisticated and more widely used after the spread of Muslim culture. Stone mosaic designs of *opus sectile* (pavement or wall decoration made of shaped tiles of coloured marble) and its stone paste derivatives were used only for decorative purposes (Fig. 8). In most cases, however, structural and decorative techniques overlapped. The most common decorative stonework techniques were:



Architectural Decoration in Islam: History and Techniques, Fig. 7 Portal of the Ayyubid palace. Aleppo Citadel, Syria. ca. 1210

Stone Mosaic

This is a technique that was inherited from the Byzantines in Syria and Palestine. It was used for land covering and paving during the Umayyad periods in Syria and Spain.

Abraq

This is a simple technique of alternating different colours of stone courses in order to achieve a colouristic impact. The most commonly used colours were light sand or limestone alternating with dark basalt and in some cases a third layer of reddish stone. This technique spread from Syria to Egypt under the Mamluks and Turkey under the Rum Saljuqs and the Ottomans.

Joggled or Interlocking Stones

This is a technique in which stone blocks with precisely cut scallops, zigzags and complex carved

Architectural Decoration in Islam: History and Techniques, Fig. 8 The Faḥiyyah Madrasa, Damascus, Syria. 1743



profiles were fitted together without the use of mortar. Single or multiple coloured stones were used to create a beautiful effect. Interlocking stones, however, were technically challenging as the desired shape was cut into a regular block that was bonded into the masonry. They decorated horizontal decorative bands on facades or had a structural function in lintels and arch voussoirs.

Muqarnas Vaulting Over Portals

These vaults consist of three or more tiers of staggered *muqarnas* cells usually surmounted by a scalloped or centrifugal half-dome. Muqarnas became the main decorative feature of monumental portals between the thirteenth and the fifteenth century. It seems to have developed in Aleppo in Northern Syria and spread from there south to the rest of Syria and Egypt and north to Anatolia and Turkey.

Monochrome and Polychrome Geometric Interlace

Stone geometric interlace was introduced during the twelfth century and used mostly in the spandrels above arched gates and prayer niches (mihrabs). Technically, the geometric interlaces are different from surface cladding as each component of the geometric interlace is cut on the face of a regular block that is built within the structure of the arch spandrel, and as such, fully bonded to the masonry (Tabbaa, 2001, p. 156).

Stone Cladding and Inlay

This technique included the decorative use of marble panelling which was common in Syria, Palestine and Egypt. Stone inlay in *opus sectile* and marble intarsia reached its apogee under the Mughals of India (Fig. 9). Inlay in hard stones and semi-precious stones (*pietra dura*) where lapis, onyx, jasper, topaz, cornelian and agate were inlaid in marble made its first major appearance in the Tomb of Iltimād al-Dawla in Agra (1622–1668).

Stone Sculpture

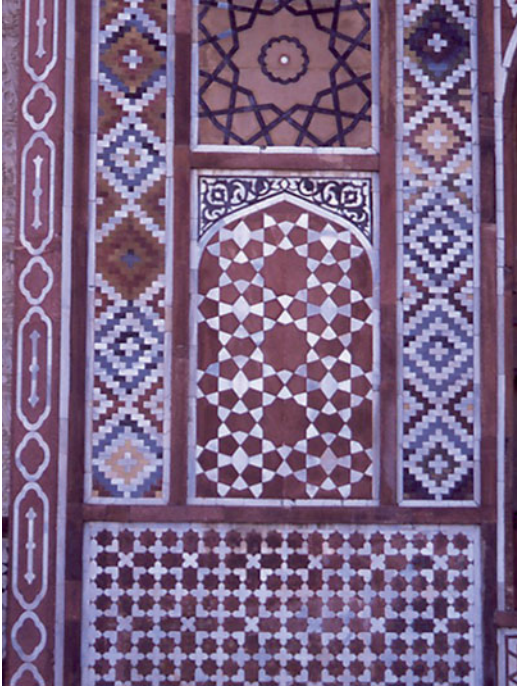
The most common form of stone sculpture was relief carved inscriptions and decorative patterns. Dense patterns created through carving out or hollowing the stone surface is also demonstrable in the façade of the Mushatta palace in Jordan (ca. 740) currently in the museum of Islamic Art in Berlin. The surface is carved in the form of triangles housing rosettes that are surrounded by dense foliage at times inhabited by birds and mythical creatures. An exceptional example of a more plastic modelling in stone sculpture comes from the portals of the Great Mosque of Devriği in Anatolia built in 1228–1229 (Fig. 10).

Bricks

Decorative brickwork was used to articulate the structural walls of monuments built over a vast

area including Iraq, Iran, Afghanistan and central Asia. Brick was readily used as a medium of structure and decoration as it was cheap to make and fast to build. The alluvial plains of the various rivers in the region provided rich sources of

clay that were used for manufacturing rammed-earth (*pisé*), mud brick, baked brick and terra cotta in addition to clay pipes and tiling roofs (Wulff, 1966, pp. 108–113). Although the size of the brick differed from one region to the other, the overall visual effect of plainly built brick walls was similar. The indigenous builder was able to develop various decorative uses for brick construction based on simple alternate layering of bricks in horizontal and vertical rows creating patterns in the otherwise plain facades. Bricklayers also used half-bricks, quarter-bricks, and moulded bricks along with the full size bricks to create more dynamic decorative patterns (Fig. 11). The ability to design a small composition based on a simple brick pattern and multiply the design vertically and horizontally meant that the bricklayers were able to maximize the effect of the pattern and minimize the human effort.



Architectural Decoration in Islam: History and Techniques, Fig. 9 Tomb of Akbar. Sikandra, India. 1614

Hazārbāf and Bannā'ī

In addition to the basic technique of forming decorative patterns in brick walls through varying the orientation of bricks, builders used the contrast between light and shadow that resulted from alternating flush and protruding bricks to create intricate decorative patterns. The most widely spread technique of ornamental brickwork is known as *hazārbāf*, from Persian, meaning a thousand twisting or a 1,000 weaving, accentuating the structural similarities between creating continuous brick patterns and weaving a textile.

Architectural Decoration in Islam: History and Techniques, Fig. 10 The northern gate of the Great Mosque of Devriği, Turkey. 1228–1229



Architectural Decoration in Islam: History and Techniques,

Fig. 11 Mausoleum of the Samanids. Bukhara, Uzbekistan. 914/43



This technique is also known as the *bannā'ī* or the 'builder's art', as the decorative patterns are part of the structure of the building and not an afterthought or a later cladding. Carved brick plugs and carved and moulded plaster joints were developed to enhance the overall effect.

The earliest surviving example of decorative brickwork comes from Abbasid Iraq and dates to the eighth century in (the city gate in Raqqa ca. 772). In the Ukhaydir Palace south of Baghdad (possibly begun around 762) the south wall of the courtyard has an *iwān* with *hazārbāf* decorative patterns using one-third, two-third, and full size bricks. (An *iwān* is a large, vaulted chamber with a monumental arched opening on one side.) Early examples from Iran and Central Asia are later than those in Iraq but more complex. The decorative use of bricks in the tomb of the Samanid ruler Ismā'īl in Bukhara, Uzbekistan (913–943), for example, created a weaving effect by highlighting the contrast between recessed and protruding bricks in an overall decorative design. This play between shadow and light in brick construction continued to be a dominant decorative medium for building exteriors such as the twelfth century Gunbad-i 'Alawiyān in Hamadan (Iran) where bricks were used to create a 'key' and 'swastika' patterns (Shani, 1996, p. 61) or the

minaret of Mas'ūd of Ghazna in Afghanistan where the builder used brick layering, brick mosaic, sculpted bricks and brick inscriptions in a sumptuous decorative composition.

Glazed Bricks

Glazed bricks were also a pre-Islamic tradition inherited from Babylonian and Achaemenid times. The earliest examples in the eastern Muslim provinces date back to the early twelfth century when moulded tiles or 'end plugs' were used as a contrast to the natural buff colour of bricks. During the twelfth century glazed tiles were used in inscription bands such as the Tower of Jam, Afghanistan (late twelfth century), or the minaret of the Kalayān mosque in Bukhara (1127) (Fig. 12). One might argue that colour was introduced in brick architecture to render the complex decorative and inscription friezes more legible from the distance. Under the Ilkhans (1256–1353) the use of glazed bricks became a prominent feature of monumental architecture as domes and large surfaces were covered in decorative compositions of glazed bricks and tiles. The Timurid opulence of Tamerlane's mausoleum in Samarqand, the Gur-i Emir, (ca. 1400–1404), or the royal necropolis of Shah-i Zand demonstrate the skilful



Architectural Decoration in Islam: History and Techniques, Fig. 12 Minaret of the Kalayan Mosque. Bukhara, Uzbekistan. 1127

combinations of plain bricks, glazed bricks and glazed tiles that were used to maximize the decorative effect (Fig. 13).

To create glazed bricks, brickmakers used glazes or filmy glass layers that were fired and fused over the porous clay body of the brick for functional and aesthetic reasons. Glazes were added to the brick in a powder format that coated the body and melted in the kiln. The colour and opacity of the glazes were determined by their chemical composition. The most commonly used colours in Iran and the Muslim east were turquoise and blue. These colours were achieved by using an alkaline fluxing agent composed of powdered pebbles and potash for copper oxide and cobalt, respectively (Al-Hassan & Hill, 1986).

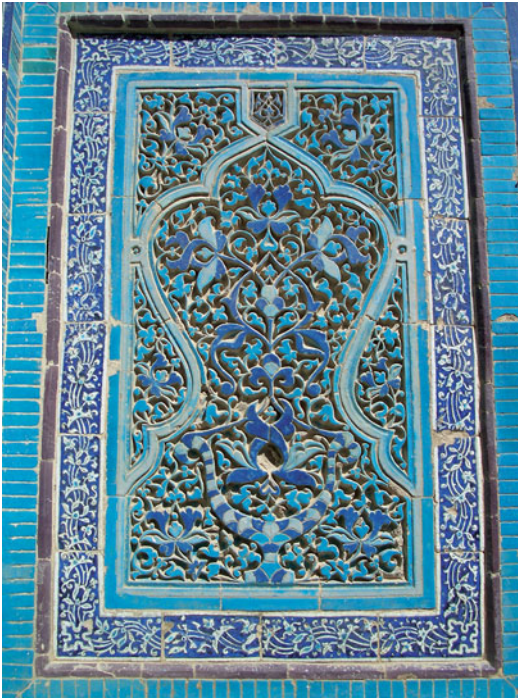
Glazed Tiles

Decorative tiles comprise glazed slabs made out of clay or frit (stone paste) that were used in a variety of forms and shapes to create impervious surfaces with stunning visual impacts. The surface of the tile can be left plain before glazing but it can also be carved, incised or moulded for

Architectural Decoration in Islam: History and Techniques,

Fig. 13 Façade of the Shir Dor Madrasa. Samarqand, Uzbekistan. 1619–1636





Architectural Decoration in Islam: History and Techniques, Fig. 14 Details of carved and glazed tiles from the Shah-i Zinda necropolis. Samarqand, Uzbekistan. End of fourteenth or beginning of the fifteenth century

additional effect. Glazed tiles were used to cover different parts of a building including walls, domes and zones of transition. The technical know-how and desired final decorative effect dictated the development of the glazed tiles tradition in different regions of the Muslim world. A good, yet incomplete, starting point for the study of Islamic ceramics including glazed tiles is the teaching website developed by the Ashmolean museum in Oxford, UK (see <http://islamicceramics.ashmol.ox.ac.uk/>). Tiles are covered with a layer of glaze and fired in a kiln in the same manner as glazed brick (Fig. 14).

Many decorative techniques were used with glazed tiles including painting in the glaze, under the glaze and over the glaze. Glazes are either transparent or opaque depending on their chemical compositions. They are found in different

colours and at times colour combinations. The most commonly used metals by Muslim potters were cobalt for blue, manganese for purple, iron for green, and copper for turquoise. Changing the chemical agent used for fluxing the glaze produced different colours. Copper, for example, turned into green if fluxed with a lead glaze, and turquoise-blue if fluxed with an alkaline glaze. Cobalt turned sapphire-blue in an alkaline glaze, and turquoise in lead glaze (Al-Hassan & Hill, 1986).

Lustre Tiles

The best-documented tradition of lustre tile production is the city of Kashan in Iran where there is evidence of continuous production between the twelfth and the early fourteenth centuries. Lustre production (for vessels and tiles) requires special materials, double firing and a special kiln. The metal oxides added to the tile after the first firing form a metallic deposit upon firing in a reducing kiln at a much lower temperature. The recipe and the process of making lustre vessels and tiles were described in a 1301 treatise [<http://islamicceramics.ashmol.ox.ac.uk/Glossary/abulqasim.htm>] (Allan, 1973). Abu al-Qāsim's treatise suggests that that vessels and tiles were covered with an alkaline glaze and fired for 12 h. They would then have six and a half days of cooling in the kiln before the lustre design was applied. The recipe for lustre glaze comprised a mixture of red and yellow arsenic, gold and silver marcasite, yellow vitriol, copper, and silver ground with sulphur dissolved in grape juice or vinegar. The second firing takes place in a low-temperature reducing kiln which allows the metal oxides to fuse with the alkaline glaze and create the lustrous sheen. Star-and-Cross tile patterns with figural and vegetal motifs, at times moulded in bas relief, as well as moulded and painted inscription friezes were the most common patterns of decoration. The buff-and-blue aesthetic that characterises the early use of glazed bricks on the exterior of buildings was also predominant in the decoration of interiors with lustre tiles. Cobalt blue was used to highlight relief-moulded inscriptions on lustre tiles



Architectural Decoration in Islam: History and Techniques, Fig. 15 Detail of a floral tile mosaic from the Gur-i Amir Mausoleum. Samarqand, Uzbekistan. 1404

as is clear from the *mihrab* tile now in the Los Angeles County Museum of Art (see http://www.lacma.org/islamic_art/figures/fig_a31.htm).

The earliest surviving lustre tiles known to have decorated Muslim monuments are the tiles that adorned the *qibla* wall of the Great mosque of Qayrawan in Tunisia (ca. 862). According to the historian Ibn Nāḥī (d. 1433), who cites al-Tujībī (d. 1031), some of those tiles were sent from Baghdad but an Iraqi craftsman who knew the lustre technique manufactured some locally. There is also evidence for the use of lustre in Egypt and Syria before the technical know-how was transmitted to the potteries of Kashan in Iran.

Cut Tiles or Tile Mosaic

The earliest examples surviving in this technique are from twelfth century Iran and thirteenth

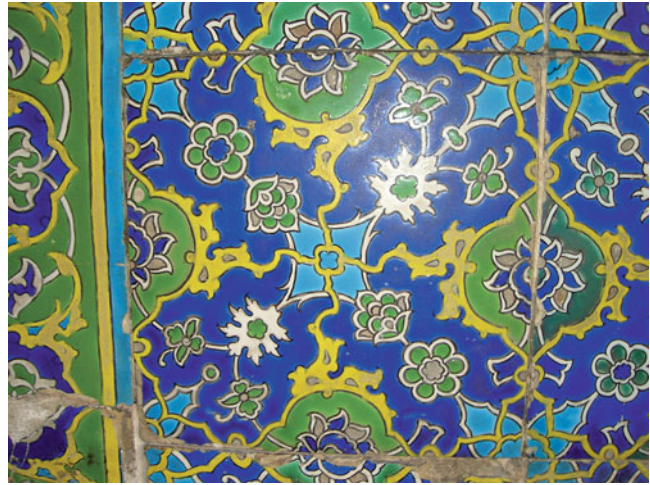
century Anatolia. Technically, tiles are glazed and fired separately and then cut according to the desired design or pattern. They are placed face down and a layer of plaster is applied to the back of the pattern which, once dried, turns into a panel that can be easily fitted onto a wall. The same technique is used for the application of tile mosaics on concave or convex curved surfaces. The heyday of the tile-mosaic technique was under the Timurids when designs became increasingly complex with overlapping layers of arabesque and geometric patterns on flat or curved surfaces (Fig. 15). See also the fourteenth century *mihrab* from Isfahan, Iran currently in the Metropolitan Museum of Art, New York. http://www.metmuseum.org/Works_of_Art/viewOne.asp?dep=14&viewmode=0&item=39.20.

Cut tile mosaic has the advantage of maintaining the brilliance of the colour of each tile. The different coloured tiles are fired separately according to the specific temperature needed by the chemical component that gives the colour of the glaze (Wulff, 1986, p. 120). In North Africa, there was a phase of experimentation in cutting the *zillīj* components from a clay panel after the first firing and then glazing each piece separately. The result, however, was less precise patterns (shrinkage), and less smooth surfaces, as the glaze would bulge around the sides (Hedgcock & Damluji, 1992). This technique, however, is still practiced in some workshops in Titwan in Morocco.

Tile mosaic technique was the predominant form of tile decoration in North Africa. Known as *zillīj*, the ceramic cut tiles are put together in a complex geometric design. Each component of the *zillīj* is monochromatic but the final design is a polychrome matrix. Glazed tiles first appear in North Africa in the archaeological context of tenth century Qal'at Banū ḥammād, possibly inspired by the Aghlabids, who in turn were copying Abbasid models. During the twelfth and thirteenth centuries glazed tiles were nailed to or embedded in minarets and towers. The *zillīj* tradition in North Africa, however, reached a stunning maturity under the Marinids who ruled

Architectural Decoration in Islam: History and Techniques,

Fig. 16 Detail of *cuerda seca* tiles currently embedded in a re-constructed wall in the Topkapi Palace, Istanbul, Turkey. Late fifteenth century



from Fez between 1244 and 1465. In Spain *zillīj* became common only during the late thirteenth and early fourteenth centuries. There are some differences in the colour palette between Spain and North Africa as Spanish tiles made more use of various shades of blue using cobalt as a colouring agent. The colour palette also used ochre yellow, copper for green and manganese for purple, brown and black.

The Cuerda Seca (Dry Thread) Tiles

This is a method of painting with different colour glazes on a single tile in order to achieve the overall colouring effect that cut tile techniques provide in a less expensive and less time consuming manner. Tiles were painted with different colours of glazes that were separated by a greasy or wax material that leaves a black matt line between the different glazes when fired. The waxy material stops the colours from running into each other in the kiln and acts as a pencil line or drawing line that defines the different components of a pattern. The tiles, however, were fired at a preset temperature and as a result, the glazes were not fired to their ultimate brilliance (as in the case of separate firings for the different colours). The colours achieved were

less brilliant but the method was much faster and cheaper than tile mosaic. This technique started to replace tile mosaic in popularity during the reign of Shah Abbas in Isfahan.

The colour palette of this technique is necessarily limited to the chemicals that melted or fluxed at reasonably close temperatures. The predominant colours used in the *cuerda seca* technique are known as the *hafrang* or seven colours. This range of colours was used in Iran and central Asia from the late eleventh century and reached its apogee in the late fourteenth and early fifteenth centuries. To create overall patterns for large areas square tiles are put side by side and the overall design is transferred on to them. The colour glazes were then added and each tile fired separately (Fig. 16).

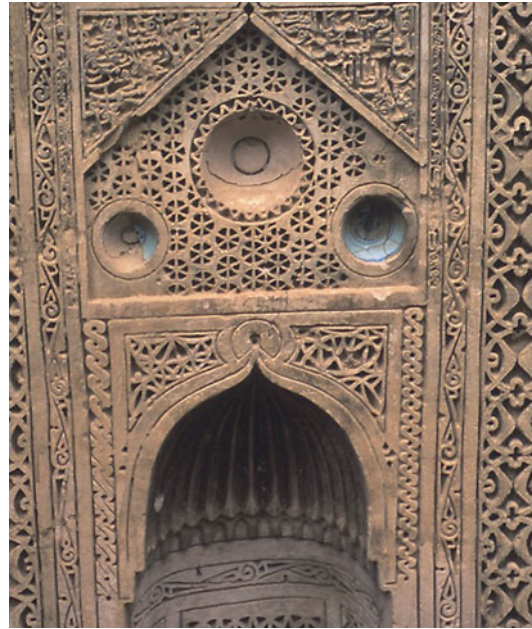
Underglaze Painting: Ottoman Tiles and the Iznik Tradition

Blue-and-white underglaze painted tiles evolved in Central Asia and Anatolia during the thirteenth and fourteenth centuries. Their popularity under the Ottomans is linked to a group of Iranian craftsmen known as the 'Masters of Tabriz' who are responsible for the decoration of the Yeşil Mosque in Bursa (1419–1424). The full



Architectural Decoration in Islam: History and Techniques, Fig. 17 Underglaze painted tile, circumcision room, Topkapi Palace. Istanbul, Turkey. ca. 1520

repertoire of their work included *cuerda seca* tiles, monochrome glazed tiles, and underglaze painted blue-and-white tiles. Tile production in Ottoman Turkey went through various phases of development that became linked to the court workshops from the early sixteenth century (1525–1550 blue and white from the Freer Gallery <http://www.asia.si.edu/collections/singleObject.cfm?ObjectId=25488>). One of the most stunning examples of early Ottoman underglaze painted tiles is a group of large tiles dated to the 1520s now decorating the exterior of the Circumcision Room in the Topkapi Saray (Fig. 17). The tiles are painted in the *sāz* style featuring serrated leaves, lotus blossoms and rosettes inhabited with birds and mythical creatures in a blue and turquoise palette on a white background. This painting style is associated with Shahkulu who served as the court designer



Architectural Decoration in Islam: History and Techniques, Fig. 18 Evidence of the use of stencils to copy stucco patterns, the mihrab of the Mosque of al-Uwaynah. Wādī Banī Khālid, Oman. ca. 1540

between 1526 and 1556. This period of experimentation led to the development of a more natural floral repertoire that featured tulips, carnations, roses and hyacinth, the hallmarks of the exuberant floral style that distinguishes Ottoman decorative language.

The colour palette of the underglaze painted tiles also went through changes in the early part of the sixteenth century. In addition to blue, turquoise and green, purple was introduced in the late 1540s. It was only in the 1550s when the well known architect Sinan became in charge of the royal workshops of Iznik producing ceramics and tiles that tile sizes became standardized allowing for vast pictorial compositions and monumental calligraphy. It was also under Sinan in 1557 that the colour red was introduced into the palette of Iznik tiles (Fig. 2 above) (1575 typical Iznik with red Freer <http://www.asia.si.edu/collections/singleObject.cfm?ObjectId=37077>).

Architectural Decoration in Islam: History and Techniques,

Fig. 19 Detail of the mihrab of Oljeitu, Friday mosque of Isfahan. Iran. 1310



Stucco

Stucco is a plaster-based decorative medium that was used throughout the Muslim world as a decorative finish as it was cheap and created a considerable effect in a relatively short time. It was perhaps the most common form of decorating building interiors until some of its role was taken over by tile revetments from the thirteenth century. Stucco can be applied to all sorts of surfaces rendering the basic rammed-earth structures (*pisé*) into buildings with sumptuous decoration (Milwright, 2001).

Stucco is commonly made out of gypsum, but lime stucco is also used especially for exterior decoration and for rendering exteriors and special features impervious. A watertight variety of stucco made out of lime and wood ashes bonded with goat hair is used for water channels and for decorating buildings in Oman (known as *ṣārūj*) and in Yemen (known as *Qudād*) (Al-Radi, 1994). In some regions certain substances are rubbed onto the surface of the final pattern to provide a shiny patina. Colour or gold leaf could then be added to the surface.

Stucco is prepared by the calcinations of gypsum or lime through mixing the sifted powder

with water while continuously stirring in order to slow down the process of crystallization (Clévenot & Degeorge, 2000, p. 84). It is usually applied in several layers then smoothened. A pattern is then traced either through the use of dry point, ruler and compass or stencil paper which is blotted with charcoal powder. The pattern can be cut out or carved and some of the components further articulated through hatching, perforating and quilting (Fig. 18). Decorative patterns could also be moulded onto the wet stucco by pressing a pre-carved mould (probably hardwood) into the last layer of gypsum – each being allowed to set separately providing a faster way of achieving decorative patterns. For stucco grills which were common all over the Muslim world designs were knife cut in semi-set gypsum boards.

The different techniques for cutting and shaping stucco followed regional and historical patterns. In Samarra, the Abbasid capital of the ninth century, three styles of stucco were excavated. Stucco styles developed from hollowed out background creating patterns of vine leaves and grapes to one where the design is abstract and cut in a bevelled style. Stucco panels with the bevelled style were excavated in a house

in Nishapur (Iran) and are now in the Metropolitan Museum of art in NY (http://www.metmuseum.org/toah/hd/nish/ho_gallery_view.htm). The major change to the stucco tradition, however, took place under the Ilkhans (1256–1353) who decorated the *mihrab*s of their mosques with stucco compositions of arabesque, calligraphy and geometric interlace modelled in plastic compositions in tiers and on different planes. One of the most famous examples is the mihrab built in the winter prayer hall of the Friday mosque of Isfahan during the reign of Oljeitu in 1310 (Fig. 19).

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Architecture and Landscape in India

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Architecture and landscape are connected on many levels in India. The meanings imbued in the architectural forms create diverse conceptual landscapes overlain on the same geographical area. Architecture defines the landscape, and the presence of different architectural traditions helps create these multiple landscapes. Architecture is used to highlight the landscape's association with the cosmos, with mythological events, and with historical and current events and is also the frame for where people live and work (Mack, 2004).

Evidence for humans symbolically imbuing the natural landscape with additional meaning through the built environment dates to the Neolithic in South India. Ashmounds, large stratified deposits constructed between 3000 and 1200 BC, were loci of social relationships placed with regard to the surrounding landscape (Johansen, 2004).

The connection between the earthly landscape and the celestial landscape has been apparent in India for thousands of years. There is evidence at Dholavira and other Harappan sites that the cities were planned with axial orientations, apparently following the placement of sky-based features (Bisht, 2000). Danino (2008) has noted that this demarcation of space is a key factor in cultural definition. In other words, it is the space, more so than the buildings that inhabit it, that is the focus of attention and energy.

Celestial orientations become more apparent in cities and towns built based on the sixth-century architectural manuals known as the *vāstuśāstras*, which mandate a grid plan based on the maṇḍala form (Deva, 2000). The maṇḍala can take many forms but is essentially a series of concentric geometric figures which represent the structure of the universe. The figures of circle,

square, and triangle can be interpreted as representing the elements of light, water, and wind, respectively. They can also represent the four directions, the nine planets, and the three mythic realms (Singh, 2000). Maṇḍala-inspired architectural arrangements reflect the cosmological structure in the earthbound landscape, thus connecting the two.

The maṇḍala is frequently represented in Hindu temple complexes and the surrounding towns. This structure is most apparent at sacred sites which serve as pilgrimage centers. The maṇḍala is first reflected at the level of the individual structure of the temple. The temple is ideally situated on a north-south axis, with enclosure walls and circumambulatory paths creating a series of concentric squares. The *vāstuśāstras* even dictate a formal ritual for measuring and laying out the shrine. Temple towns are frequently laid out to continue the maṇḍala plan, with the temple complex at the center of the town and streets running around the walls and leading out from the gateways in the cardinal directions (Michell, 1993). At Srirangam, the temple is enclosed by seven sets of walls, creating a clear maṇḍala form radiating outward and encompassing part of the town (Fig. 1). Likewise, Madurai and Chidambaram have multiple enclosures around the central temple, with main streets running parallel and perpendicular to the complexes. Some temple towns, such as Kanchipuram and Kumbakonam, house multiple temples, and the spatial arrangement in the town reflects this. Each temple is the center of its own district, and each district has a distinct geometric form. Roadways in these towns tend to link these distinct neighborhoods, forming a unifying whole in that way. The geometry of the built environment spreads out into the landscape, thus imposing a structure on the landscape through architecture.

While the built environment can structure the landscape, the physical features of the landscape determine the placement of architecture and influence the nature of the geometric forms of the towns. Vijayanagara is set in a landscape of bouldery granite outcrops, leaving the valleys between as prime construction areas (Fig. 2).



Architecture and Landscape in India, Fig. 1 A view from a gateway into one of the interior courtyards of the Ranganatha temple at Srirangam shows how the complex is a series of embedded rectangles

While the landscape strongly influenced the placement of structures, the city shows an axial layout and cosmological affinities (Malville, 1994; Fritz and Michell, 1987).

Circumambulation reinforces the connection of the natural and built environment and draws connections to the celestial world, since circulatory paths in India are often represented by the *maṇḍala*. Physically moving through the geometric pattern symbolizes a cosmic journey. The *panchakroshi* route at Varanasi moves pilgrims through 108 shrines spaced in a mathematical pattern which embeds the geography of the site into the psyche of the pilgrim. The 108 shrines also represent a cosmic circuit based on 12 zodiac signs and the nine planets of Hindu mythology (Singh & Fukunaga, 2010).

While the *maṇḍala* is an ideal form, influencing architectural constructions, the landscape itself is a key determinant in the location of these structures. Landscape features have sacred qualities, but the built environment is fundamental to imbuing the land with meaning. Landscape and architecture thus are intertwined physically and conceptually. The *vāstuśāstras* prescribe the placement of settlements near water sources, such as river confluences. Rivers represent confluences of sacred and profane and provide homes for deities. Therefore rivers become

Architecture and Landscape in India, Fig. 2 The Vithala temple complex at Vijayanagara is set in a valley below granite outcrops, near the Tungabhadra River



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Fig. 3 A shrine on the top of Malyavanta Hill at Vijayanagara blends with the rocks



magnets for settlements and sacred sites, though a nearby water source is essential for sustaining a population, irrespective of the holiness of the site. Most of the ancient towns in India are found on the banks of sacred rivers, such as the Ganga and Yamuna. The seven cities (*Saptāpurī*) of Varanasi, Mathura, Ayodhya, Ujjain, Dvarka, Kanchipuram, and Hardvar are all located on peninsulas, surrounded on three sides by water.

Hills and mountains are also an important landscape element in the Hindu tradition, and like water these features provide domiciles for gods (Fig. 3). The mountain of Tirumala is the home of the god Sri Venkateswara, and the temple there draws the largest number of pilgrims of any Hindu temple. The town of Tirupati at the base of the mountain developed in support of this holy site (Nag & Reddy, 1994). The hill at Tiruvannamalai symbolizes the column of fire from which Shiva emerged and serves as the basis for the conceptual spatial organization for the town. Patterns of movement also serve to connect buildings with the natural landscape. Circumambulatory routes and ritual paths extend far beyond the temple complex, connecting multiple shrines, in cases such as Varanasi, or encompassing the landscape itself, such as the circumambulation of the sacred mountain at Tiruvannamalai, which also includes a journey through the town itself (L'Hernault, 1993). These routes blur the line between the built and natural environments.

Beyond the water and hills, entire landscapes are often imbued with symbolic and mythological

meaning. Landscapes associated with the Ramayana legend are key examples of this phenomenon, as seen at sites such as Ayodhya, Chitrakut, and Vijayanagara (Sinha, 2010). The pilgrimage circuit at Ayodhya, the site of Rama's birth, takes worshippers to shrines along the banks of the Saryu River, which encircles the town. The river, ghats, and shrines combine to form the total landscape. At Chitrakut, the physical landscape is dominated by the Mandakini and Payasvini rivers and enhanced by the specific sites associated with Rama and Sita. The area around Vijayanagara is associated with Kishkinda, the monkey kingdom. The Tungabhadra River cuts through the landscape, through the hills, to form the most significant natural features, and many are associated with the Ramayana – Hanuman is said to have been born on Anjenadri Hill, and Rama and Lakshmana waited out the monsoon on Malyavanta Hill. These hills have been adorned with temples commemorating these events, intertwining the man-made and the natural.

The importance of place on the creation of these spaces is further emphasized by the willingness of people to renovate shrines, often entirely rebuilding *vimanas* and even migrating deities from subsidiary to central and vice versa. Branfoot (2013) attributes this to the fact that it is the sites themselves – the landscape – that is sacred.

Architectural associations with important events and personages are seen at a variety of sites in India. Stupas, which themselves represent

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Fig. 4 Humayun's tomb in Delhi sits in man-made landscape, where the tanks, gardens, and walkways follow a grid pattern



A

the body of the Buddha, house relics, though in these cases the relics have been brought to the site and were not necessarily an inherent part of the landscape before construction of the stupa. Nonetheless, there is evidence that the stupas themselves were built with a mind toward celestial import. Rao (1992) has posited that the stupas of Sanchi have an axial alignment that orients them toward moonrise and sunset on Buddha Purnima.

Elaborate tombs built by Muslim rulers include tanks, gardens, and well-defined paths, creating their own landscape (Fig. 4). Muslim dargahs [Sufi Islamic shrines built over the grave of a revered religious figure] often attract pilgrims who honor the holy men entombed within and mark the importance of a specific place on the landscape. Religious claims on the landscape are not necessarily exclusive; multiple religious shrines from different traditions share the landscape at sites such as Ellora and Mathura (Ray, 2004).

This historic and mythological significance of the landscape and the associated religious architecture was also used by rulers to lend credence to their claims to power. Basu has argued that the Buddhist Kushan rulers at Mathura built structures specifically to associate themselves with the site's existing sacred geography (2010). Early in the development of the Garhat states of Orissa,

forts and settlements were placed on the landscape with defense and supplies from nearby villages. Forts were protected by hills and jungles. However, rulers maintained their link with the villages by associations with local deities, who were worshipped within the walls (Kulke, 1993). This legitimation through the ritual landscape grew in scale as the towns grew. The Ramachandra temple at Vijayanagara was used by the kings to enhance their legitimacy, by associating themselves with the god-king who spent time in the surrounding area. They used the architecture and specifically the placement of the buildings to build those associations. The temple was built in the heart of the Royal Center, amid palaces and the kings' seat of power. Fritz has argued that the city was planned such that the Ramachandra temple lays at the center of routes of circumambulation and was on an important north-south axis in the city, so that the overall structure of the city was planned to draw associations between the rulers and Rama (Fritz, 1986). In this case, the mythic associations of the site were manipulated by Vijayanagara rulers to enhance their own power and to legitimate their rule in the eyes of local chiefs and other high-ranking citizens. However, the sheer act of construction was also used for legitimation, with or without mythic associations. Medieval temples

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Fig. 5 Children playing and grinding food on a side street near the Banashankari temple, occupying the “quotidian landscape”



with towering gateways were, and in many cases still are, the most dominant landscape features and were directly associated with rulers whose funds aided their construction.

While research into the importance of cosmology, mythology, and legitimation has dominated landscape studies in India, the most common usage of the landscape has been for day-to-day residential and subsistence activities. Most importantly, these activities occur in the midst of all the other happenings. For instance, while axial layouts and cosmological orientations are applied to temples and surrounding towns in order to maintain a ritual integrity, these neighborhoods are also the centers of everyday life. At Srirangam, which was mentioned earlier as an archetypal maṇḍala shape, boys play cricket in the streets on the outer circuits of the walls. A few steps from the primary circumambulatory routes in any temple town lead to residential areas, local shops, and mundane activities – a quotidian landscape (Fig. 5). This overlay of secular and religious use of the same landscape is seen throughout India, at sites sacred to all religious traditions.

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Architecture in Africa, with Special Reference to Indigenous Akan Building Construction

Tarikhu Farrar

The hall itself was the chief object that attracted my attention. It was at least a 100 ft in length, 40 ft high, and 50 broad. It had been quite recently completed, and the fresh bright look of the materials gave it an enlivening aspect, the natural brown polish of the wood-work looking as though it were gleaming with the lustre of new varnish. Close by was a second and more spacious hall, which in height was only surpassed by the loftiest of the surrounding oil palms; but this, although it had only been erected 5 years previously, had already begun to show symptoms of decay... Considering the part of Africa in which these halls were found, one might truly be justified in calling them wonders of the world; I hardly know with all our building resources what material we could have employed, except it were whalebone, of sufficient lightness and durability to erect structures like these royal halls of Munza, capable of withstanding the tropical storms and hurricanes. The bold arch of the vaulted roof was supported on three long rows of pillars formed from perfectly straight tree stems; the countless spars and rafters as well as the other parts of the building being composed entirely of the leaf-stalks of the wine-palm

(Raphia vinifera). The floor was covered with a dark red clay plaster, as firm and smooth as asphalt. The sides were enclosed by a low breastwork, and the space between this and the arching roof, which at the sides sloped nearly to the ground, allowed light and air to pass into the building. (Schweinfurth, 1874, Vol. II, pp. 42–3)

Famed nineteenth century botanist, Dr. Georg Schweinfurth, here writes of one of tropical Africa's most remarkable achievements in indigenous architecture and building technology, what he calls the "royal halls" of the Mangbetu kingdom. In the last years of the 1860s, Schweinfurth, traveling with Sudanese merchants, made his way southward along the Nile corridor toward the African interior. Ultimately, he reached the northeast quadrant of central Africa.

Schweinfurth would go on to write voluminously about this central African world. He also produced illustrations in quantity and of considerable quality. From his writings and illustrations we can gain some appreciation of the technological prowess of this region's cultures in the late precolonial era. The grandeur and elegance of the "royal halls" certainly captured Schweinfurth's imagination. So too did the considerable building skills embodied in their construction.

The "royal halls" were merely the grandest expression of the architectural and building skills of the peoples of this part of Africa. Of the more ordinary buildings, dwellings, storage structures, etc., we can also learn something from Schweinfurth's writings and illustrations. He was encountering traditions of architecture and building technology that were indigenous to tropical Africa. Nor should we imagine that the Mangbetu, in this instance, represent some sort of unusual or atypical culture.

The building materials identified by Schweinfurth are familiar from elsewhere in tropical/sub-Saharan Africa. These include types of clay, particularly those deriving from forest and savanna ochrosols and oxysols, and tropical black earths. Also included are various hardwood tree species. Of great importance is the raphia palm. Virtually every part of this useful tree was employed in the building process.

The trunk provided posts; the fronds, laths and rafters; and the leaves, roofing or thatch. Rope and twine for binding purposes (binding laths to posts, for example) were also made from the woven fibers of the leaves. These materials were readily available, abundant, and admirably suited to the task of building. As elsewhere in tropical Africa, the peoples of this region mastered their use. This is evident in the way that the materials were processed, in the techniques of building developed in conjunction with their use, and in the final product of the building process. Here, as elsewhere in tropical/sub-Saharan Africa, people constructed houses that were durable, comfortable, and, in today's jargon, "ecologically sound."

The study of African architecture, at least in an academic setting, did not truly develop until the second half of the twentieth century. A small, but determined and dedicated body of scholars, not a few of them from Africa, had taken up the challenge to the orthodoxy. Africa (i.e., sub-Saharan/tropical, or Black Africa), they insisted, was indeed a part of the *historical* world and worthy of study as such. Within this group was body of architects, folklorists, a few historians, and others who began to pay serious attention to indigenous African architecture, or what was termed "African traditional architecture." (See, for example, Denyer 1978; Dmochowski 1988 [1958–1965]; Gardi 1973; Gluck 1973 (1956); Hull 1976; Oliver 1971; Prussin 1969).

Their work, in conjunction with the written accounts of earlier travelers to Africa like Schweinfurth, provides us with a solid foundation on which to continue to piece together something of a coherent picture of the technologies of building developed by the peoples of tropical Africa at earlier periods in their histories. Also useful are recent ethnoarchaeological/material culture studies of "traditional" building where and to the degree that it continues to be practiced. The writer conducted this type of research in southern Ghana, primarily in the Akan region, in the mid-1980s. The information yielded by this research is useful in developing a broader understanding of indigenous building technologies in tropical Africa based on the use of clay, wood, and other plant materials.

The Akan peoples inhabit roughly the southern half of the modern country of Ghana, and spill over into the eastern borderlands of Cote d'Ivoire. They constitute almost half of the population of Ghana, and in terms of history and culture are among the better known of West Africa's peoples. While the so-called "traditional" architecture of the Asante has been studied and is reasonably well known, that of other Akan groups has not received comparable attention, in some cases none at all. The study of Asante architecture has, in general, focused on the products of the building process rather than the raw materials and the building process itself. Considerable attention has been paid to the esthetics of architectural forms, and the uses and meanings that the various forms of enclosed space (e.g., shrine houses, palaces, etc.) were and continue to be imbued with. The focus here is different. Consideration will be given to the materials used in building construction.

In the mid-twentieth century, the Akan peoples were practicing a number of different building technologies, as were Ghanaians generally. Of these, only two can be described as being "indigenous." The two are *timber frame construction* and *coursed clay construction*. Both types, by the way, were observed by Schweinfurth in the Upper Nile region and northern central Africa, and are widespread throughout tropical Africa. The Akan and other Ghanaian peoples recognize these building technologies as being of considerable antiquity, long predating the colonial era. They have an existence in local oral history, as the writer was to discover to his surprise. Moreover, historical documents (i.e., written documents from the period of early European contact, or ca. 1500–1750) and archaeological evidence firmly support the idea of great antiquity.

Coursed clay construction is related technologically to the building methods known in other parts of the world as pise, tapia, rammed earth, and tauf. The product of this method is a structure with freestanding, solid clay walls. *Timber frame construction* is historically the more widely practiced of the two by the Akan peoples. It starts with a timber framework, which may then be closed in

with a panelling of palm-fronds (this is the case with the Mangbetu “royal halls”) or ► **bamboo**, or with a structure of clay and wood. The two techniques and resulting built forms are distinguished in local terminology. Timber frame construction finished with clay and wood is often referred to by the archaic “wattle and daub” by English speakers, although some more accurately call it “frame and plaster.” In southern Africa it is known as “pole and daga.”

Of the range of building materials employed in indigenous building construction, plant materials constitute the most varied group. These include a staggering number of hard and soft wood species, including several species of palm, and other woody plants, notably shrubs and lianes. Many of the tree species, especially the palms, provide not only useful timber, but leaves and bark. The leaves are used for thatch and in the manufacture of binding material. Sometimes, fibers, also used in the manufacture of binding material, are derived from the bark. Also included in this group are various species of grass, particularly bamboo and elephant grass.

Earthen materials consist primarily of clays. Most of the soil types of southern Ghana are characterized by strata classified as light to medium clays. These strata lie immediately beneath a layer of sandy to silty topsoil at depths of 20–2 m (Brammer, 1962, pp. 101–20). Light to medium clays are locally described as being “soft.” What this means is that they are easily workable. With little difficulty, they can be trodden or mixed with a hoe into the proper consistency for building. The only thing required is the addition of water.

By contrast, those clays that are described as being “hard” are the types that are more suitable for pottery manufacture. Unlike some of the neighboring peoples, notably the Anlo Ewe and the Se (Shai) Dangme who occasionally use such clays for wall construction, the Akan have never used them for this purpose. Kaolin, *hyire* in the Akan language, is a “hard” clay that was used extensively by the Akan, but for the manufacture of white, yellow, or gray wall finish or plaster. At the time of the earliest European contact (the late fifteenth century), such plasters were a nearly universal feature of buildings in Akan towns.

As mentioned above, the earthen material used in wall construction is found nearly everywhere in the region inhabited by the Akan, lying just beneath the topsoil. The predominant soil types in southern Ghana are savanna and forest ochrosols, and to a lesser extent, oxysols. Tropical black earths are found, but are of limited distribution. From the point of view of agricultural potential, these differences in soil type have significance. In terms of use as building material, they do not. All contain light to medium clay strata.

Color is the primary characteristic by which the Akan distinguish soil types, but always in combination with other characteristics, for example, viscosity. *Notia/dotia*, or *netia/detia* is the generic term for soil. The different soil types are *notia tumtum*, *notia koko*, and *ntwuma*. *Ntwuma* is a sub-type of *notia koko*. *Notia tumtum*, literally, “black soil,” refers to two different types of soil, both black in color. No terminological distinction between the two is made, although people are quite clear on the differences in terms of physical properties in general, and specifically with reference to use for building purposes.

One type of *notia tumtum* derives from the predominant soil type, *notia koko* (savanna/forest ochrosols). This type results from the decomposition of organic matter, in particular “kitchen” refuse, into the upper strata of *notia koko*. Thus, it is typical of the soil found under and around middens and other places of refuse deposit, and is also found near habitations. This type of soil is not at all suitable for building purposes, although excellent for kitchen gardens.

The principal type of *notia tumtum* is a tropical black earth. It is characterized by light to medium clay strata immediately below the topsoil and is thus appropriate for any type of construction. It has never been widely used by the Akan simply because its distribution in those parts of Ghana where they live is limited. In Ghana, tropical black earths are found principally in the coastal savanna (Brammer, 1962, pp. 116–117). They do constitute a good part of the soils of the Accra Plains where they are known as *Akuse clays*. There, they are extensively used for building by the Ga and Se Dangme peoples.

Notia koko, literally, “red soil,” is the predominant soil type and the most widely used earthen building material. It is used in both timber and clay (wooden frame with clay plaster) construction, and in coursed clay (free-standing, solid clay wall) construction. It is used for walls, floors, courtyards, and hearths.

Ntwuma is described as a distinct type of notia koko. “Ntwuma” has been translated as “hematite” because it is used as a source of red ochre. The quality that makes ntwuma the building material par excellence for construction of solid, free-standing clay walls is its near ideal balance between clay, sand, and silt. It is widely distributed and is often found beneath the more ubiquitous notia koko by digging down to a depth of about a meter where the red earth matrix begins to reveal traces of yellow clay. The type of ntwuma used for plastering floors, courtyards, hearths, and wall bases, on the other hand, is of more limited distribution. It is quarried from special sites. It is distinguished by its deeper red color, presumably reflective of a higher iron content.

As mentioned above, the number of different species of plants that constitute building materials is extensive. F. R. Irvine (1962), in his *Woody Plants of Ghana*, lists 124 species of trees, shrubs, and lianes used throughout Ghana for building purposes, and this is not likely to be a complete listing.

Through several interviews conducted in the Brong-Ahafo region of Ghana, in the settlements of the Nkoransa Traditional Area and in the town of Nkoransa itself during the dry season of 1986–1987, the writer was able to compile a list of nearly 50 plant species used in building construction. Some 35 of these are species of trees and shrubs used to provide timber. An additional 13 species of trees, shrubs, and vines are used in the manufacture of binding material (rope, twine, etc.), plaster, and thatch. The trees that were identified as the main sources for the timber framework were mostly hardwood species. Some softwoods can be used for elements of the framework that do not come into contact with the ground, for example, thatch poles and rafters. But posts and studs require decay and insect resistant

hardwoods (For a complete listing of plant species used in building construction along with their scientific names, see Appendix).

Each tree, shrub, vine, and cane was thoroughly described in terms of its physical properties and its uses. Trees, for example, had the color and texture of their bark, sapwood, and heartwood described, whether or not the wood was soft, medium, or hard, and how resistant to insect attack and to decay. Discussions always went beyond uses in building construction to include information about uses in woodworking, of medicinal properties of bark, roots, fruits, etc., and uses for food, if any. Some species were said to have specific useful “spiritual” (for lack of a more accurate term) properties, and these, too, were described (For a detailed description of the collection and processing of building materials see Farrar, 1996, pp. 95–154.).

This vast range of building materials, earthen and plant, is the stuff of indigenous Akan building. In the past, the materials constituted the universe of Akan building materials and were used in the construction of two timber frame architectural forms and one of coursed clay. Of the two timber frame building types, one, the *mpapa-dan* structure, is built entirely of plant materials. The other, the *tare-dan* structure, consists of a timber framework with an infilling and final plastering of clay. The former is normally a type of temporary dwelling, while the latter is designed to have much greater longevity, or at least was so in the past.

The considerable skill that once characterized indigenous building construction was the product of centuries of technological growth. This process involved the acquisition of a profound knowledge of the environment and the multitude of resources therein, and the result was the evolution of architectural forms that were attractive, comfortable, and reasonably durable. The materials used in this type of building construction were widely available and easily accessible to most people. The tools used in their collection and processing were widely possessed. The skills associated with indigenous building were virtually universal, although some builders attained a level of building skill that earned them the status

of “masters” in a way that separated them from others. And finally, the pressures placed on precious resources were minimal. These architectural/building traditions of tropical Africa thus represent an intelligent, rational, and efficient use of the local environment. They are yet another reminder of a largely ignored indigenous African technological ingenuity.

Appendix: Timber Used in Building Construction

Unless otherwise stated, the below-listed trees were described by Akan builders as having hard wood. Finer distinctions between hardwoods were made with respect to degree of hardness, resistance to insects and decay, etc., but are not indicated below because of limited space. Some of the characterizations of the hardness of the wood of various species are at variance with those of F. R. Irvine. The writer, in those cases, has stuck with the descriptions given by builders.

Abisiwa – *Vitex Doniana*.

Adobe – *Raphia* spp. The part of the tree that is used in the framework is the midrib of the frond. The leaves are used for thatch and in the making of a strong but soft fiber.

Asesea – *Trema Guineensis*. A fiber is also produced from the bark.

Atoaa – *Spondias Monbin*. A softwood timber that is not resistant to insects or decay. It is nevertheless occasionally used in the Bono region by “a lazy man who cannot find a hardwood tree,” in the words of one Bono builder.

Babadua – *Thalia Geniculata*.

Dodowa – *Sterculia Tragacantha*.

Dwini – *Baphia Nitida*.

Fihankra – *Tetrorchidium Didymostemon*. F. R. Irvine claims that the wood is “soft and perishable,” but Bono and Asante builders maintain that the wood is hard and insect resistant.

Kane – *Anogeissus Leiocarpus*.

Kokoaa – Identification uncertain. Possibly *Parinari Robusta*.

Kokobata – *Pileostigma Thonningii*.

Kranku – *Butyrospermum Parkii*. This is the well-known Shea butter tree.

Krayie – *Pterocarpus Erinaceus*.

Kwabedua – *Dacryodes Klaineana*.

Kyiribente – *Lophira Alata*.

Mmaa Kube – *Borassus Aethiopum*.
Borassus palm.

Moto – *Neuropeltis Acuminata*.

Mpampuro/mkanpuro – *Oxythenantera Abyssinica*. Savanna ► bamboo. Although technically a grass, bamboo is used like timber in the construction of a house framework.

Mpapa – *Elaeis Guineensis*. Mpapa are the oil palm-frond midribs. The tree is called Abe.

Ngo ne nkyene – *Cleistopholis Patens*.

Nwoo – Identification uncertain. Possibly *Terminalia Glaucescens*.

Nyame Dua – *Alstonia Congensis*.

Odum – *Chlorophora Excelsa*. The leaves are also used for sandpaper.

Odwuma – *Musanga Cercopiodes*. A softwood timber used only for rafters.

Ofram – *Terminalia Superba*. A timber of moderate hardness, but not resistant to insects or decay. Used extensively for building purposes in the areas of dense forest.

Opesiakwa – *Morinda Lucida*.

Pam – *Trichilia Heudelotii*.

Pampani – *Albizia Adianthifolia*.

Pepaa/mpepea – *Antidesma venosum*.

Pinimu – Unable to identify.

Potorodom – *Sterculia Rhinopetala*.

Prekese – *Tetrapleura Tetrapleura*; also, *Prosopis Africana*.

Sisi – Identification uncertain. Possibly *Erythrophleum Africanum*.

Wama/awama – *Vitex Mesozygia*.

Fiber/Rope/Cordage Sources

Asense – *Urera* spp. A vine. Fiber is derived from the fibrous, woody interior.

Batatwene – Unable to identify. A vine. Cut and used as is.

Firaye – Unable to identify. A shrub. An extremely soft fiber is derived from the leaves.

Mfun/mfo – *Triumfetta Cordifolia*. A shrub. Fiber is derived from the stems.

Muto – *Neostachyanthus Occidentalis*. A vine. Cut and used as is.

Nem – *Ancistrophyllum Opacum* and *Calumas Deeratus*. The rattan palms. Fiber is derived from the split stems.

Notuo – *Hippocratea Africana*. A vine. Fiber is derived from the fibrous, woody interior.

Ntwea – *Hippocratea Rowlandii*. A vine. Cut and used as is.

Sibre – *Corchorus Aestuans*. A grass. Fiber is derived from the outer skin of the cane.

Sofa – *Christiana Africana*. A tree. Fiber is derived from the bark.

Toa-ntini – *Paullinia Pinnata*. A vine. Cut and used as is.

Sources of Thatch, Plaster, etc

Asakoo – *Cissus Populnea*. A liane. The root – bark and stems are used in the manufacture of plaster.

Awuromo – Unable to identify. A shrub. The leaves are used for thatch.

Etoo – *Pennisetum Purpureum*. Elephant grass. The blades are used as thatch. The stalks, “hyiridie” (the Akan term), resemble small bamboo stalks and are used to build doors, gates, fences, “bamboo curtains,” etc.

Sapotoro – *Grewia Mollis*. A tree. The bark is used in the manufacture of plaster.

Identifications were made with the aid of F. R. Irvine’s *Woody Plants of Ghana*.

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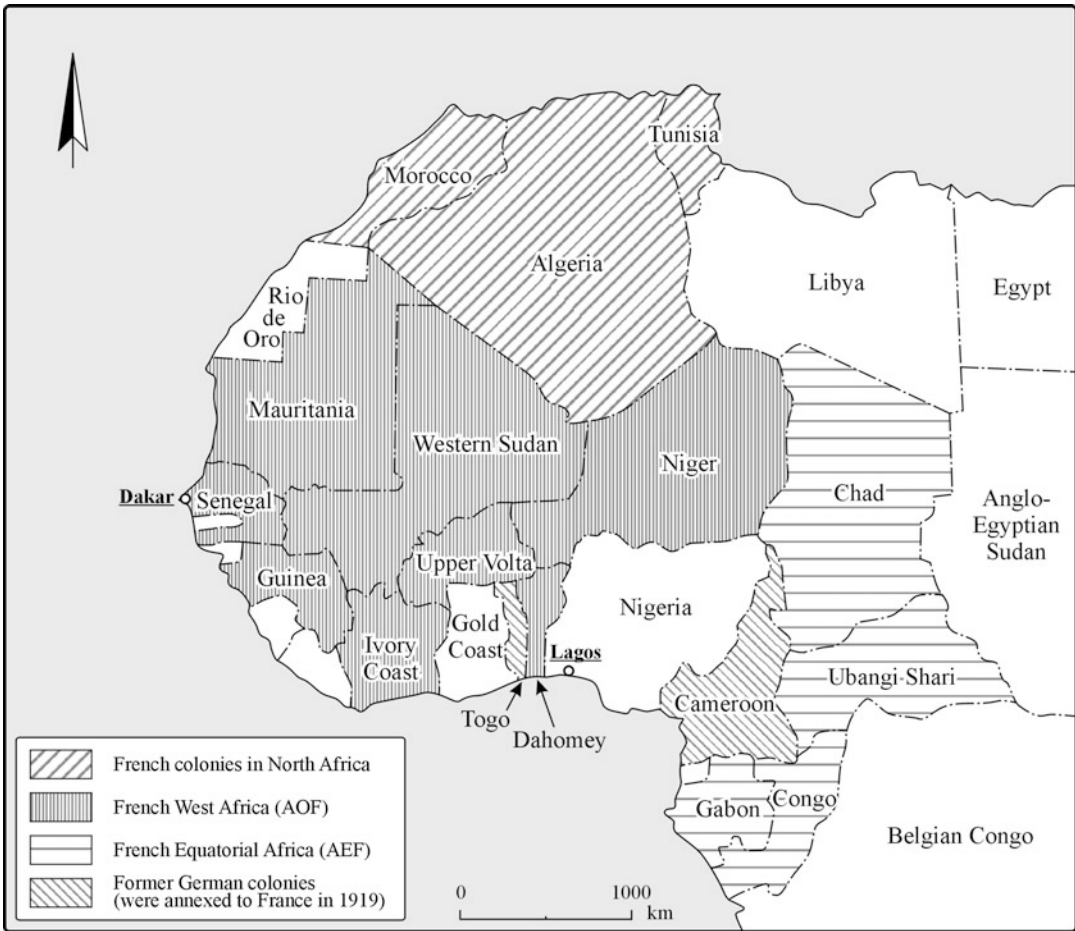
Architecture in French West Africa

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The great variety of architecture in question – mainly indigenous, European, and in-between creations in terms of structure and form – is limited in space and time due to our use of the term “French West Africa.” As an invented politico-administrative unit, French West Africa (AOF for *Afrique Occidentale Française*) was a federation established by the Ministry of the Colonies in Paris (1895–1956). Created alongside the neighboring federation of French Equatorial Africa (AEF, 1910–1956), the aim of the AOF was to facilitate the centralist decision-making process in the home country and the economic exploitation of this vast territory. It consisted of 4,633, 985 km² with the government general’s headquarters, from 1902, in Dakar. The federation included eight colonies: Senegal, French Sudan (today’s Mali), French Guinea, Ivory Coast, Dahomey (Benin), Upper Volta (Burkina Faso), Niger, and Mauritania (Conklin, 1997; Suret-Canale, 1971) (see Fig. 1).

There is little space here to expand on the architecture that accompanied the French expatriate community – the white civil and private sectors stood, in the so-called golden age of the interwar period, at only 4,200 persons spread over a territory 14 times larger than France



Architecture in French West Africa, Fig. 1 Colonial West Africa (Map drawn by the author)

(Brunschwig, 1986). Nor is there enough space to depict the medieval roots of the architectural vernacular traditions, i.e., of the Berbers, the Tuaregs, the Fulani (Fulbe or Peuls), Wolof (Oulouf), Serer, Tukolor (Toucouleur), Malinke (Mandingue), Soninke, Bambara, Dyula (Diola or Juula), Songhay, Hausa, Bobo, Senufo, Mossi, Kpelle, Loma, Kissi, Agni, Baule, Fon, Adja, Yoruba, and Bariba – all of whom, among others, fell within the physical borders of the AOF (Elleh, 1996; Oliver, 1997).

Moreover, some of the colonial-cum-indigenous architectural traditions stretched far beyond the physical space and time-span delimited by the AOF. We would rather treat this subject through a few selected examples of certain reciprocal influences between colonial

and indigenous architectures, representing the two main sides of the colonial equation. This is because the colonial situation, encapsulated in the term French West Africa, could be primarily characterized as a moment of encounter. The classic definition of the colonial situation by the French sociologist Georges Balandier supports this point of view, especially when translated from the sociopolitical realm to the spatio-aesthetic one. According to Balandier (1966), this situation can be understood as the overall influences of the foreign regime on the local (African) societies, the expatriate communities, and other involved groups, in most aspects of life – political, economic, social, religious, institutional, and psychological – from individual everyday lives to the public level.

Our focus on the formalistic correspondence in the built form between the colonizer and the colonized and vice versa is also valuable in bringing together their two architectural historiographies, each of which is normally considered separately. Moreover, it is valuable in transforming the orientation of each historiography, admittedly Eurocentric. That is, African architecture has been classified until recently as technologically unsophisticated material culture, no more than a temporary shelter (Oliver, 1971; Skinner, 1973). While some of its monumental expressions, such as the Sudanese style in West Africa, were the subject of scholastic attention, these were always assigned to exogenous inspirational models: an Egyptian heritage, Andalusian, or Moroccan (Prussin, 1986). Contemporary Sufi urban design in West Africa, nurtured on regional historical precedents in terms of configuration and semiosis, has even been attributed to Haussmann's Paris (Ross, 2006).

Colonial architecture suffers from a bad image: putting aside its ambivalent associations from the subaltern point of view, from a metropolitan perspective, it is associated with standardization, formalistic unity, and bureaucratic planning (King, 1992; Soulillou, 1993). Colonial architecture has been regarded as a simplistic reproduction of its occidental counterpart, provincial at best; until recently, the way western models spread in the colonial setting – adapted to the tropical climate and the interests of the ruling powers – was hardly treated (see, for instance, Bigon & Katz, 2014; Njoh, 2007).

Among the earliest indigenous examples that provided prototypes for colonial style in the AOF-to-be is the distinctive architecture of the Luso-Africans, or Portuguese as they identified themselves. Established in coastal trading centers from the Petite Côte in Senegal south to Sierra Leone from the sixteenth to the early nineteenth century, these Portuguese emigrants – some of them Jews who escaped from the Inquisition – married local African women. Their rectangular houses had a vestibule at the

entrance or were surrounded by a porch or veranda, and their outside walls were whitewashed with lime. Suited to both the climate and the owner's occupation, the latter could negotiate with other traveling merchants in the vestibule. These elements spread among the neighboring populations and gradually became the contemporary vernacular (Mark, 2002). The veranda was prevalent in West Africa in the precolonial period and also, since the mid-nineteenth century, became a symbol of European colonial architecture in the tropics. Research is ambiguous as to the history of this architectural element in this part of the continent.

The old French settlements in Senegal, particular testimony to the European presence in this part of the continent as early as the mid-seventeenth century, featured similar elements made of more permanent materials, such as stone. First in Saint-Louis and Gorée and then in Rufisque and Dakar, the houses of the *métis* community (descendants of a French merchant forefather and an African *signara*) inspired both the indigenous and later colonial building styles. Their rectangular units were built around an internal courtyard, usually with a second floor used for living quarters, enhanced with an internal colonnade and external terrace, and a ground floor which served for storage and business negotiations. Their distinctive features, known as the Saint-Louisian style, also introduced a rich imagery of social prestige, status, and stratification among the autochthonous population, based on built form and materials (Sinou, 1993; see also Sinou, 1995; Sinou & Oludé, 1988) (see Figs. 2 and 3). This sociopolitical stratification was backed by AOF legislation, which, particularly from the early twentieth century, promoted residential segregation on a racial basis between locals and expatriates, based on similar criteria of building materials and forms (Bigon, 2009).

The second half of the nineteenth century was marked by military occupation of the vast hinterland, launched by the French from along the Senegal River, where a series of fortified posts was erected by the Engineering Corps to house

Architecture in French West Africa, Fig. 2 Saint-Louis, Senegal. An old renovated façade of an eighteenth-century house of a European merchant/*métis*, its form adapted to the climate and original function (Author's photo)



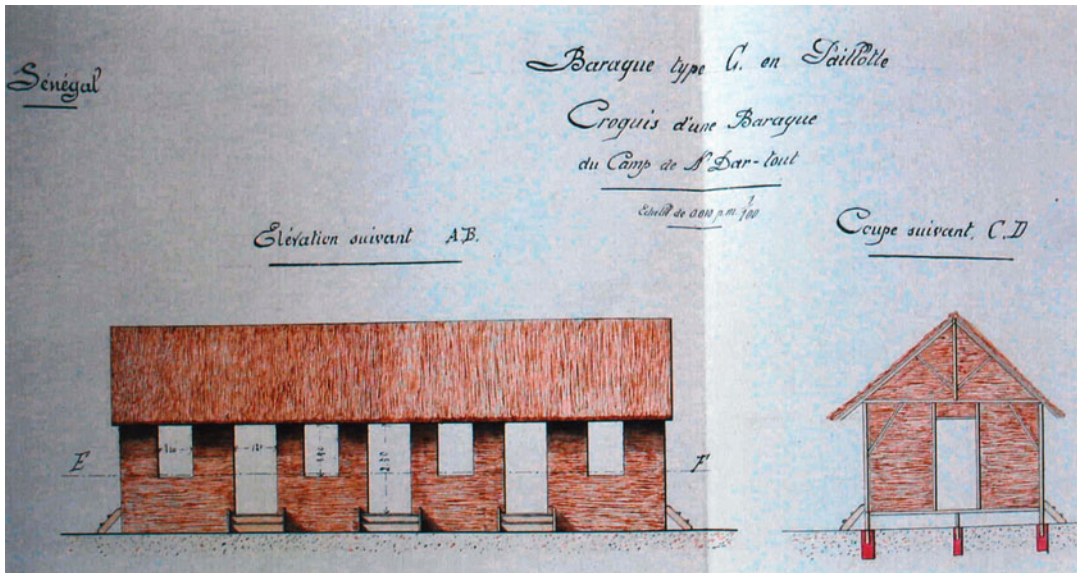
Architecture in French West Africa, Fig. 3 Dakar, Senegal. The old commercial city center. An inside view from the courtyard of a Saint-Louisian style house dated to the late nineteenth century (Author's photo)

the garrison. These posts, such as those of Podor, Médine, Bakel, Kayes, and Kita, were configured as a square, rectangle, or star, usually surrounded by a ditch. Due to the practical hardships in transporting permanent materials such as stone from the coast inland or the cost of their import from Europe, the use of local building materials was maximized by the Corps. The use of sun-dried mud bricks – already familiar to these engineers from the French conquest of North Africa – evokes some similarity with the Sudanese fortified complexes, employing this technique for at least several hundred years. In both cases a monumental building is involved, well defined by thick walls and surrounded by ditches. Moreover, because of the employment of local natural building materials by the Corps in the western Sudan and in spite of the contemporary image of the colonial army as an island of civility inside a barbaric sphere, some barracks in certain military outposts actually resembled the African straw huts! The latter were generally condemned by colonial civil servants, seeing them as precarious, unsophisticated, and primitive structures (see Figs. 4 and 5).

There is abundant literature about the vernacular mud building of the western Sudan and the Islamic medieval towns of Timbuktu,

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Fig. 4 French Guinea. Indigenous rectangular huts made of mud bricks and mortar and roofed with palm tree thatch (Postcard, private collection)



Architecture in French West Africa, Fig. 5 Drawing of the façade of one of the straw barracks erected in the military camp of N'Dar Tout, Saint-Louis (Courtesy of the Archives Nationales du Sénégal)

Djenné, and Gao, which are considered its archetypal models (Brunet-Jailly, 1999; Maas & Mommersteeg, 1992; Prussin, 1986; Takezawa & Cisse, 2012). Often labeled as *style Sudanese*, its formal features include a base that gradually becomes narrower towards the upper part of the structure, blind columns with rocket-shaped heads, a few small openings,

and projecting wood beams that are decorative but over which the builders also climb after the short wet season in order to renew the mud patina (see Figs. 6 and 7). Indeed, most of the research literature has been preoccupied almost exclusively with residential buildings and mosques. A reason for this might be because a great portion of the fortified complexes was



Architecture in French West Africa, Fig. 6 Mali (French Sudan). Residential house in Djenné, exemplifying the Sudanese architectural style (Photo taken in the 1960s, courtesy of Marli Shamir)

completely destroyed by the *pax colonial* and the following pacification process; and the rest is in ruinous state. The study of the *tata* – the historical fortified mud-brick complexes of the Sudan, can teach us about the extent of indigenous spatial control, political and military command until the early colonial period (Bah, 1985).

In the country of Senegal, for instance, there are only a few examples of the *style Sudanese*, most especially in the northern region of Futa Toro. These examples of monumental mud mosques with thick semi-fortress walls are assigned by local oral traditions to the mid-nineteenth century, with the return of Hajj Omar from the pilgrimage to Mecca. Other traditions assign them to the Toucouleur warriors during their withdrawal to Futa Toro at the end of the



Architecture in French West Africa, Fig. 7 Mali (French Sudan). Friday Mosque, Mopti (Photo taken in the 1960s, courtesy of Marli Shamir)

same century, following the destruction of Omar's empire by the French (Boulègue, 1972). It is possible that these traditions are not contradictory but complementary. However, in the Senegalese coastal strip of Cayor, one of the four districts of the Wolof precolonial kingdom, the plain ground, consisting of dunes of moving sands, made *tata* building impossible. This point is particularly ironic as in the interwar period, colonial Dakar which is situated in the Cayor region was the preferred location by the French for the realization of their neo-Sudanese architectural style. The latter invented colonial style had been inspired by the indigenous forms of the *tata* and the *style Sudanese*.

More than any other architectural style in West Africa, the *style Sudanese* became a French national symbol for the whole colonial endeavor in the AOF in the interwar years. The adherence to this style was both transnational and

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Fig. 8 Dakar, Senegal. The neo-Sudanese façade of the Polyclinique of the Médina, built in 1932 (Author's photo)



multilateral in its character from a very early stage of the French colonial occupation. Against the background of the exoticist and romanticist literature in France at the end of the nineteenth century, the visual documentation that accompanied the French explorative missions into Africa's hinterland contributed to the fossilization of the vernacular vocabulary in the metropolitan mind. This in turn influenced the visual representation of the AOF's pavilions at a series of Universal and Colonial Exhibitions held in France (and in Europe) from 1855 to 1937 – an imaginative construct that argued for a fictive authenticity. Through these exhibitions, the metropolitan archetypes found their way back to the Sudan, where several French reconstructions were created. Examples include *La Residence* at Ségou in 1893 – this renewed version of the original Palace of Ahmadu was now symmetrically arranged into a three-part, neoclassical composition in the Beaux-Arts style – or the 1911 renewal of the mosque at Djenné, carried out with the support of French administration funds and military advice (Morton, 2000; Prussin, 1985).

Moreover, the latter reconstruction became a prototype for a neo-Sudanese style. That is, a selective choice, designated for a series of colonial public buildings from the regional

formalistic repertoire, is to be executed in concrete, ochre color, and Art Deco style. Ideologically, this *style AOF* was in line with the French colonial doctrine of *association*, which displayed a seemingly softened approach towards the autochthonous societies by comparison to the previous one of *assimilation* (Betts, 1961, 1985; Johnson, 1971). In the French colonial empire up to the early twentieth century, assimilation was identified with transplanting the neoclassical style into the colonized regions, hence known as the conqueror style (Çelik, 1997; Wright, 1991). Situated in a variety of AOF capitals, the neo-Sudanese works were, however, few and somewhat uncrystallized – this rather temporary style faded out after the interwar period (Bigon & Sinou, 2013) (see Fig. 8).

With the developmental impulse of the post-Second World War order, accompanied by winds of decolonization, such historicist architectural approaches were replaced by less exclusive and less segregationist urban vocabularies. During the 1940s until the 1960s, International Modernism could be noticed in certain commercial and administrative complexes of urban centers such as Dakar and Abidjan, as well as in other Francophone and Anglophone contexts such as Kinshasa, Douala, and Lagos (see Figs. 9 and 10).



Architecture in French West Africa, Fig. 9 Dakar, Senegal. The governmental *building administratif*, the 1950s (Author's photo)

This architectural optimist wave for the future of the newly independent states was followed by the brutality of the 1970s, stressing public services and facilities, as well as by more eclectic and varied trends in built forms. However, these styles and built projects, whether backed by internal governmental or other external bodies, were always increasingly limited in terms of actual space and target population. Moving at this point from French West Africa into postcolonial French-speaking Africa and West Africa in general, it is more and more difficult to speak about architecture per se in this subregion. With a total population of 312.2 million in 2011, of whom 44.9 % lived in urban areas, it is projected that an urban majority of 65.7 % will be reached by 2050 in one of the world's poorest regions (UN-Habitat, 2014). This massive population growth in the face of widespread poverty produces a complexity of threats, vulnerabilities, and risks to the African populations and their habitats (see Fig. 11). The emerging urban spatial and aesthetic configurations call for the development of creative ways of thinking and analyzing West African architectural trajectories and imagined futures, together with a reexamination of western paradigms.

Architecture in French West Africa, Fig. 10 Douala, Cameroon. Residential building in the old commercial center, a melange of Bauhaus and Art Deco (Author's photo)



Architecture in French West Africa,

Fig. 11 Limbé, Cameroon. Houses made all of corrugated iron, built on a cement platform (Author's photo)



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Useful Website Links

- ArchiAfrika Foundation/Accra. <http://www.archiafrika.org/>
- EU COST Action IS0904: Architecture beyond. <http://www.architecturebeyond.eu/>
- Institut de Recherche pour le développement (IRD), France. <http://www.orstom.fr/>
- The Tombouctou Manuscripts Project. <http://www.tombouctoumanuscripts.org/>
- UN-Habitat for a better urban future. <http://mirror.unhabitat.org/categories.asp?catid=9>

Architecture in Hanoi

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Historical Context

Architecture in Hanoi is influenced by the city's dynamic transformation as a result of more than 1,000 years of Chinese occupation, almost

100 years of French colonization, and several decades of post-independence with support and assistance from the former Soviet Union. Almost 30 years of *Doi Moi* (economic reform) and opening up to global markets have led to rapid transformation of the built environments yet bring another architectural coating to Hanoi.

The street names in Hanoi represent the city's turbulent history. Several of Hanoi's main streets were named after local heroes, such as Ngo Quyen and Tran Hung Dao, who led the city against Chinese and Mongolian invaders in the tenth and thirteenth centuries respectively. To mark the end of French colonization in Hanoi, one of the most important streets is named Dien Bien Phu, after the place in northern Vietnam where French troops officially withdrew from the country in 1954. The main road to southern Vietnam is named Giai Phong (liberation), to celebrate the North–South reunification at the end of the war against America in 1975. Street names are also significant in Hanoi's Ancient Quarter, since they reveal the street's specializations and traditions. Hang Bac (silver) Street, for example, is where tin products are made and sold by silversmiths who came from the same village and craft guild near Hanoi.

In recent decades, Hanoi has changed a lot due to globalization. This has weakened the cohesiveness of the craft guild system in Hanoi's Ancient Quarter. One can buy not only local silver products on Hang Bac Street, but also Italian-style clothes, for example. Young people now love to sit in global fast food and coffee shops, such as KFC, or in universal-style food courts in shopping malls that are mushrooming in the city. Hanoi's layered history and recent changes provide some context for the following discussions about the city's architecture and urbanism.

Village Architecture

Hanoi can be seen as the city of villages (Phuong 2010). The establishment of Hanoi was connected to village settlement, which resulted in the city having some important elements of Vietnamese village culture, including village



Architecture in Hanoi, Fig. 1 Communal house in Bat Trang village

architecture in its inner-city villages. Village culture, including the village sense of community, is represented by traditional public buildings, such as the *dinh* (communal house), *chua* (village pagodas), *den* (village temple), and village gates. Village domestic life is represented by village houses, local craft production with the *phuong* or guild system, building rites and customs, and everyday activities within the houses.

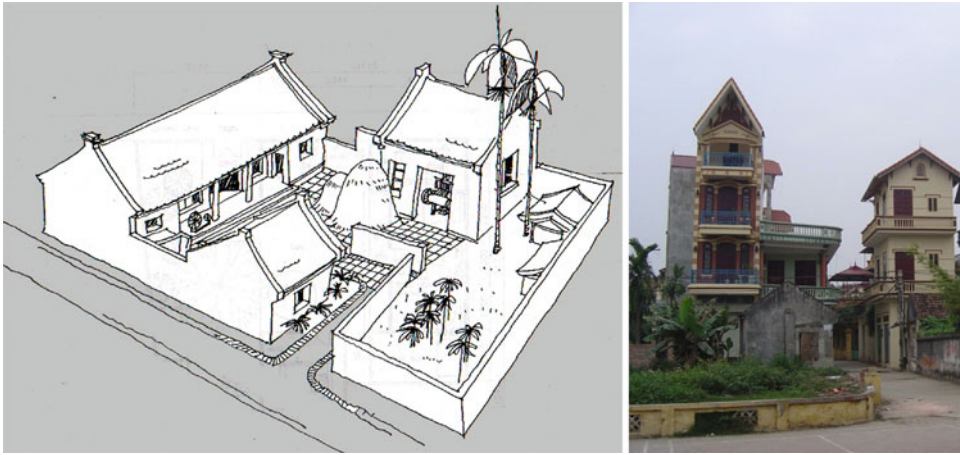
For example, Bat Trang is a ceramic village in Long Bien District in Hanoi, where there are a number of public buildings constructed and maintained by villagers. The most important building is the *dinh*, an open structure for public use. What makes the *dinh* important is not only its impressive structure, but also its essential social and cultural values to the community. The main functions of the *dinh* are administrative, cultural, and religious, demonstrating some patterns of life including village festivals and local ceremonial activities. Despite many changes, the *dinh* is always the place for keeping and developing the village traditional values (Fig. 1).

Along with the *dinh*, the *chua*, the village pagoda, has been an important building that enhances the village's built form as well as the village's social and spiritual life. Each village often has a pagoda that villagers regard as a Buddhist ground, which provides them with spiritual support during the course of daily life. While the traditional role and use of the *chua* were disregarded during the war effort, the economic reform that started in 1986 has resulted in the need for a better cultural and spiritual life,

which encourages people to renovate and recover the *chua* and its social position in the village.

From the village center, the village roads lead to the village houses, which share similar features created by building styles and techniques, rites, and folk beliefs. There are L-shape, U-shape, and H-shape house layouts in plans that reflected the owners' economic condition, social ranking, and feudal government rules. A typical village house has a main building and one or two side buildings for kitchen, storage, and craft production. The house construction and related customs are crucial for guaranteeing the inhabitants' spiritual comfort, which sometimes is more important to consider than physical convenience. Despite many common characteristics, the village dwellings are varied. Craft production has an impact on the use of space in a village house. The force of the market economy, urbanization, and tourism increases the demand for craft products that transform the spatial arrangement in the house compound. The changes of production techniques and increase in population also lead to spatial transformations inside the houses (Fig. 2).

Shophouses, an urban housing typology, have also been built in the village in the last few decades. The new market economy results in major shifts in the house layout, and attracting tourists and customers seems to be the key driving force that transforms the shophouse's compositions and façades. The uses of new architectural elements such as front yards in Bat Trang, as well as the imitation of the so-called French-style architecture, indicate people's perception of



A

Architecture in Hanoi, Fig. 2 Left, a village house in Van Phuc village; right, new tall houses in Phu Thu village, Hanoi

architectural changes. Tourist tastes and commercial activities also bring more abstract styles of house designs and result in the exploitation of the traditional features in new shophouse designs.

Most aspects of village culture were maintained almost at the same time as when village craftsmen migrated to the central of Hanoi in the fifteenth century (Le Van Lan, 1977, p. 196). People from the same village often lived and worked in a street, where they set up craft guilds and built communal houses to worship the village gods, who often were the founders of their professions. Since then, Hanoi's Ancient Quarter has been known as the area of 36 streets and guilds, which, up to now, are characterized by rows of shophouses.

Hanoi's Ancient Quarters and Shophouses

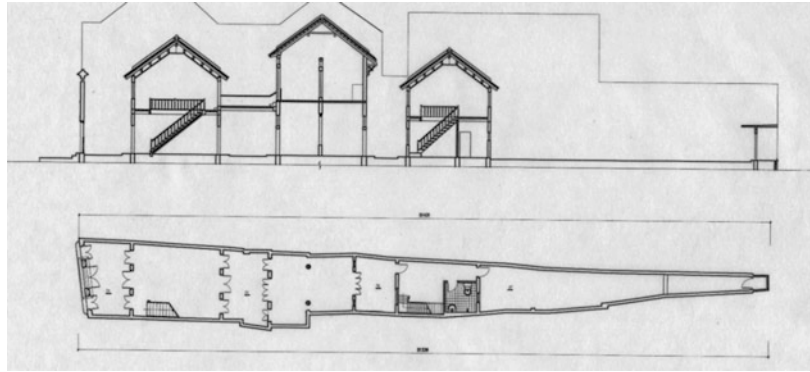
Hanoi's Ancient Quarter has been a shopping area since it was founded almost 1,000 years ago (Nguyen Vinh Phuc, 1994; Logan, 2000). The streets of the area are characterized by *phuong* or guilds, a village system of trade and production, so that each street is named after a particular product which was once locally made and merchandized in that street. The practice remains today even though many streets have changed their specializations.

The streets' identity is strongly influenced by *nha ong* (tube houses) or shophouses which normally have front shops or workshops with narrow façades and prolonged and deep living quarters behind. Rows of narrow shophouses that maximize the use of shop fronts for retail are the key feature of Hanoi's Ancient Quarter. This area has experienced significant changes spatially, socially, and physically as a result of its adaptation to the influences from external forces, including recent globalization.

The formation and development of the area were not the result of formal planning strategies but were directly linked to the (re)settlement of villages. Local historians, such as Nguyen Van Uan (1995), also suggested that streets in this area were first established by rows of market stalls built by craftsmen, and traders came from nearby villages. Living rooms were added to the back of each stall as the village craftsmen decided to stay and work in the area. Narrow streets with rows of market stalls on two sides were established. As the population grew the stall owners kept adding living rooms and space to the back of their properties until the empty spaces, including the small lakes, in the center of the blocks were closed. The village craftsmen then built permanent shophouses on the land they occupied. As a result, most blocks are fully occupied by long and narrow shophouses, which are 3–4 m in width

Architecture in Hanoi,

Fig. 3 Section and floor plan of 38 Hang Dao (silk) Street



Architecture in Hanoi,

Fig. 4 Left, old shophouse; right, new tall shophouses in Hanoi



and 30–60 m in length. Some houses can be as narrow as 2 m and as long as 100 m (Fig. 3).

There are several types of shophouses in Hanoi's Ancient Quarter. The first one is *nha chong diem* or shophouses with a *chong diem* style roof generally dating from the nineteenth century (Dang Thai Hoang, 1999, p. 19). The upper level, which is set back, has a double roof, while the first level has a single roof. The upper level of the house looks approximately half the height of the lower level, and therefore the shophouse is seen to have one and a half levels. The second levels have small windows. At present, *nha chong diem* remain in several streets in Hanoi's Ancient Quarter, such as Hang Bac Street, Hang Bo (basket) Street, and Hang Duong (sugar) Street.

The second type of shophouse, which is normally taller than *nha chong diem*, were popular at the beginning of the French colonial period in the early twentieth century (Dang Thai Hoang, 1999, p. 28). Wealthy shop owners often renovated their *nha chong diem* to be bigger and taller, altering the second levels to make them similar in height to those of the first levels. The building façades were also renovated by adding some French-style elements, such as louver windows opening on to the balconies. This type of shophouse, therefore, presented a mixed style of architecture created by the earlier *nha chong diem* and the latter larger building with French architectural elements (Fig. 4).

Hanoi's Ancient Quarter is significantly marked by private housing constructions, which

flourished after *Doi Moi* since the late 1980s. Having the right to run private businesses and to own private property has enabled Hanoi's residents to improve their lives and change the area. Consequently, many people have become wealthier and spent their money buying property and building houses, in particular the tall shophouses that perhaps best represent the characteristics of Hanoi's everyday architecture and streetscape in post *Doi Moi*. The shift of property ownership from government to private has significantly changed Hanoi's street blocks. Many old timber shophouses, which were previously owned by the government, were sold to wealthy businessmen. The old shophouses were replaced by much taller ones with five or six levels to be used as shops, small budget hotels, bars, and offices for the increasing number of both Vietnamese and foreign tourists coming to Hanoi. Architecturally, many of these new shophouses present French-style facades, which represent a revival of the French colonial experience in Hanoi.

French-Style Architecture

With almost a hundred years of colonizing Vietnam (1858–1954), the French strongly influenced Hanoi's architecture and urban characteristics. After establishing Hanoi as the capital of northern Vietnam and the larger region of Indochina, the French built new French-style buildings and a new French-style urban quarter, popularly called *khu pho Phap*. Alfred de Pouvourville described the area in 1888 as “now featuring broad, well-cut boulevards, and the execution of recent projects by the municipality which makes this, without doubt, the most beautiful city of the Far East.” This urban vision for Hanoi also showed the power of French culture and a significant link to the prestige of Paris (Wright, 1991).

One of the earliest and most significant French influences on the city was probably the establishment of a commercial and cultural axis on Paul Bert Street during the 1880s. This street, which now consists of Trang Tien Street and Hang Khay

Street, was widened by demolishing all of the thatched houses built by the Vietnamese. Andre Masson (1929, p. 130) added that Paul Bert Street was characterized by an increasing number of French-style coffee shops, such as *Café de Paris* and *Café de Beira*, which were popular places for many French traders, officials, and soldiers. Also located in the street were a number of important buildings, such as Hanoi's central department store *Grands Magasins Reunis* and the cinema *Cinema Palace*.

In 1911, an opera house called *Nha Hat Lon* was erected at one end of Paul Bert Street marking another French influence on Hanoi's architecture. According to William Logan, “it was characteristically French both in its architecture and its siting. It seems to have been inspired by Charles Garnier's opera house in Paris. . . It was sited in baroque town planning fashion on Foch Square at the convergence of important roads and closing off a key vista along fashionable Rue Paul Bert” (Logan, 2000, pp. 93–94) (Fig. 5).

There were a number of other public buildings and hotels designed and built by French colonial experts in Hanoi including the Indochinese Bank, Hotel Metropole Hanoi, Hanoi University, and the Presidential Palace. Many of these buildings were designed by Ernest Hebrard, the head of the Hanoi Town Planning and Architecture Service, who was also famous for his unique Indochinese style that integrates French architectural elements and local tradition as shown in the design of Hanoi Historical Museum and Hanoi University (Fig. 6).

Together with other aspects of French influences, the French colonial villas represented the modernized lifestyle in Hanoi for both local residents and French migrants. During the late 1880s and early 1890s, the French Quarter was developed to the south of Hanoi's Ancient Quarter. Similar to those in Paris, the boulevards in Hanoi had wide tree-lined pavements. French-style villas were gradually built to provide homes for an increasing number of French newcomers. Most villas were detached houses; each was built on a large lot of land ranging from 300 m² to 1,000 m². Tramlines and a number of Paris-style sidewalk cafés were established in

Architecture in Hanoi,

Fig. 5 Hanoi Opera House marks the end of formerly Paul Bert Street, Hanoi



Architecture in Hanoi,

Fig. 6 Front façade and doorway of Hanoi University, Hanoi



the quarter. The development of the French Quarter with different style villas in Hanoi represented Indochina's French urban image, which provided nostalgic feelings for the French living in the city.

French villas built between 1880s and 1940s in Hanoi are diverse in style. Local architects, such as Tran Quoc Bao (2009), categorize them into several main styles: neoclassical villas, regional French villas, art-deco villas, villas with Indochinese styles, and French-Chinese villas. Older villas were often built and owned by the first French colonial officials, and businessmen worked in Hanoi. According to Dang Thai Hoang (1999), with solemn and highly decorative looks, these villas represented the wealth

and pride of their owners who were successful in business and politics while settling in the new colony. With simplified architectural details and flat roofs, Hanoi's art-deco villas were most preferred by Vietnamese middle class families who wanted to express their appreciation of modern living and the status as a modernized and civilized population. A villa often has three levels: level one includes a garage, a kitchen, storage, and rooms for servants. Level two provides rooms for a foyer leading to a guest room and sitting rooms and a dining room. Level three includes bedrooms with toilets and bathrooms, balconies, and open space for plants and drying clothes (Fig. 7).



Architecture in Hanoi, Fig. 7 French colonial villas, Hanoi

Another style of colonial villa is a “regional style villa,” because villas of this style resembled those from different regions in France. They were erected in Hanoi between the end of the nineteenth century and early twentieth century. These villas were built and owned by colonial officials, military officials, and businessmen who came to reside in Hanoi from different regions in France. As a nostalgic expression, they wanted their villas to have similar architecture to those in their hometowns in northern, central, and southern France. As a result, old villas in Hanoi are diverse in style, which present similar architectural feature to their French counterparts. For example, to represent architectural characteristics of villas in northern or northwestern France, some villas in Hanoi have steeper roofs compared to those that resemble the southern French villas. While steeper roofs would help draining winter snow in northern France, they do not have this role in Hanoi because there is no snow in the city.

Due to economic and political changes after the end of colonialism in 1945, Hanoi’s French architecture has been changed together with a shift to socialist-style architecture under the post-colonial government.

Soviet-Style Architecture

Several decades of support and assistance from the former Soviet Union had an impact on

Hanoi’s built environment. While South Vietnam had American support, the North followed the socialist ideology, popularly practiced in the countries of the Soviet bloc. During the American/Vietnam War, and after the 1975 reunification of the country, Hanoi received great economic and technological aid from the Soviet Union. This also applied to the field of architecture and urban planning. Architects and urban planners from Russia were sent to Hanoi, while many Vietnamese were sent to universities in Soviet bloc countries to study architecture and construction (Fig. 8).

The influence of the Soviet Union and socialist ideology on Hanoi’s architecture was probably most recognizable in the area of housing. After 1954, the government strictly controlled houses and land. Private ownership of property was illegal. In Hanoi, the government implemented subsidized public housing developments called *khu tap the* (KTT), which were modeled after the Soviet housing architecture called “microrayon” by Bater (1980, p. 102). This housing scheme was implemented in Hanoi by leading Russian experts, such as S.I. Sokolov (Hung & Thong, 1995, pp. 144–145; Logan, 2000, p. 206). Each KTT was a self-contained residential community that consisted of a number of four- or five-level apartment blocks with attached basic services, such as medical centers, schools, and kindergartens. Each apartment block had standard units for different-sized families with shared bathrooms and kitchens. They were often



Architecture in Hanoi, Fig. 8 Plan of KTT Nguyen Cong Tru and a typical floor plan of an apartment block

managed by a government company to provide homes for its employees and staff.

The impact of the Soviet Union on Hanoi's architecture can also be seen through the design and construction of many of its major public buildings and monuments, such as the Ho Chi Minh Museum and Mausoleum Complex and the Cultural Palace of Labour (formerly called the Soviet-Vietnamese Friendship Cultural Palace). Even though most of the projects attempted to reflect the traditional architectural character of Vietnam, they also "made use of architectural models established previously in the Soviet Union" (Logan, 2000, p. 196). The Cultural Palace of Labour is possibly the best example to illustrate this point. The building was given by the Soviet's Central Union of Labour to its Vietnamese counterpart, the General Vietnamese Union of Labour, under a friendship agreement (Nguyen Vinh Phuc, 2000, p.304). It was designed by a Soviet-funded architectural team

led by G. Isakovitch (Dang Thai Hoang, 1999, p. 113) and consisted of a number of theaters, cinemas, lecture halls, conference rooms, and exhibition spaces, which provided decent facilities for cultural and social events in Hanoi. It is a reinforced concrete structure with solid pillars tiled with white marble panels (Fig. 9).

Like many cities in the Soviet Union, Hanoi wanted to have a statue of Lenin to symbolize its socialist ideology and fellowship with other Soviet bloc countries. The Lenin Statue, which was jointly designed by G. Isakovitch and the Russian sculptor A. Tyurenkov, was built in 1985 on a site formerly occupied by a French statue opposite Hanoi's historical flag tower (Nguyen Vinh Phuc, 2000, pp. 277–278; Logan, 2000, p. 198). While most Lenin statues around the world were removed after the collapse of the Soviet Union in 1991, Hanoi's still remains as a reminder of Vietnam's socialist links despite the fast changing city under *Doi Moi*.



Architecture in Hanoi, Fig. 9 *Left, Ho Chi Minh Museum; right, the Cultural Palace of Labour, Hanoi*



Architecture in Hanoi, Fig. 10 *Left, New Hanoi Museum; right, National Convention Centre by GMP*

New Architecture under *Doi Moi*

In 1986, *Doi Moi*, an economic reform program, which encouraged Vietnam to establish a market economy and global integration, was officially launched. Hanoi has changed significantly since this reform, and this is particularly true of its architectural practices.

Hanoi's urban and architectural changes under globalization might be most obvious in the construction of a number of high rises and new residential areas designed and planned by international consultants since the late 1990s. Buildings, such as the Hanoi Nikko Hotel on Tran Nhan Tong Street, built by the Japanese

hotel group Nikko, present an international appearance and standard interior designs that can also be experienced in many other places around the world. The development of several new residential areas, such as Ciputra Hanoi International City by Ciputra, an Indonesian group of developers, which is like a "gated community," has been developed in western countries for several decades and more recently in South-east Asia (Fig. 10).

The impact of global integration on Hanoi's built environment is more significant in recent years as more urban and architectural projects at a national level have been entrusted to foreign consultants and experts, especially those from



Architecture in Hanoi, Fig. 11 Times City Development by Vingroup

western countries. The design competitions and subsequent construction of the country's major projects, such as the new Parliament House Complex, the National Conference Centre, and the National Museum of History, have attracted well-known international architectural firms, including Von Gerkan, Marg and Partners (GMP) from Germany, Denton Corker Marshall (DCM) from Australia, Renzo Piano Building Workshop, and Norman Foster Associates, as evidence that after decades of wars and isolation from the West, Hanoi's architecture is more open to international participation and subsequent influences.

Moreover, Hanoi's People Committee and its Korean partner from Seoul recently launched an urban planning and design scheme to build a new city center, called Hanoi Red River North, along the northern side of the Red River in Hanoi. The new city together with the old city center, which has been developed to the south of the Red River, will create a new Hanoi city region with Seoul as a model for urban development. According to the authorities, the two cities have similarities: for example, the Han River in Seoul and the Red River in Hanoi share natural and geographical characteristics; therefore, the development of Seoul along the Han River is a good model for Hanoi (Trang An Nguyen, 2007).

Local developers, such as Vingroup, one of the Vietnamese largest private corporations, are

also active in residential and commercial developments in Hanoi. Vingroup recently opened two of its ambitious inner-city developments called Royal City and Times City built on large areas of land, which formerly were state-owned factories. Both estates show global characteristics architecturally and functionally. Each contains a number of apartment towers and shopping and entertainment complexes with international-style food courts, global brands, and cinema and amusement facilities. The estates also contain some school and hospital buildings that provide educational and health-care services claimed to be at international standard. Most buildings present global design features, which include several underground and aboveground levels for retails, services, and entertainments following up by towers of apartments. Such global characteristics make them hard to differentiate from new developments in any other cities such as Singapore or Shanghai (Fig. 11).

Hanoi's built environment is increasingly dependent on global designs and international planning standards. Many parts of the city have been homogenized so that it is now not easy to differentiate them from other places in Vietnam or elsewhere. Perhaps globalization is inevitable, but it is still important for place makers to search for Hanoi's distinctive characteristics and to integrate them into the new developments so that some aspects of the city's unique architecture will be maintained.

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Architecture in Java

Gunawan Tjahjono

This article focuses mainly on the architectural objects of the Javanese people whose worldviews are closely related to the court society of Central Java, Jogjakarta and Surakarta. As architecture

concerns ideas of making meaningful space, this article will discuss the spread of ideas represented by various building types.

Throughout their cultural history, the Javanese interacted with five major religions and cultures: Hinduism, Buddhism, and Islam, China and the West (Europe). The most significant influences are from Hinduism and Buddhism, followed by Islam. Chinese carpentry affected East Java and some parts of Central Java. Western culture introduced modern town planning and new building types.

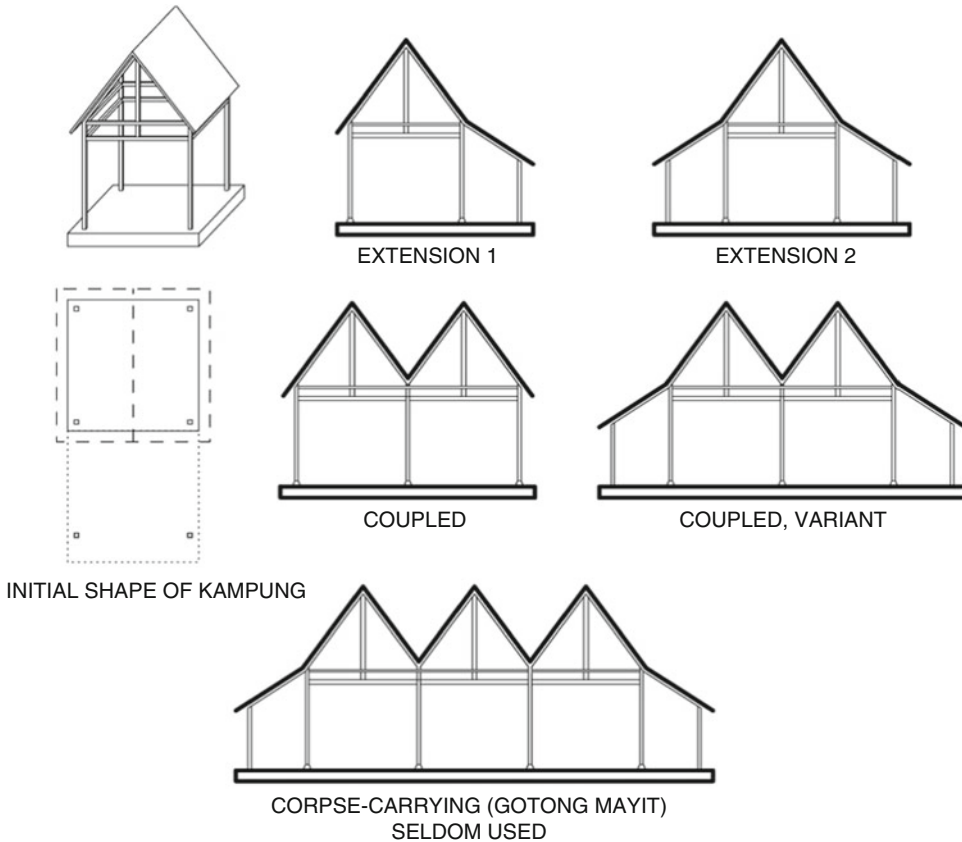
The Javanese House: An Architectural Type

The house is perhaps the first structure human beings constructed to seek shelter. The inherent ideas in a house can thus serve as the architectural basis for other building types, such as temples, cemeteries, and cities. Although there are no remains of ancient houses, as they were constructed with perishable materials, one can trace the tradition of building houses from such remains as palaces and well maintained houses in two Javanese cultural cores around Jogjakarta and Surakarta; and also from the bas-reliefs of temples.

The temples' bas-reliefs illustrate the probable built environment of the Javanese past when stone and wood were the major building materials. Stone appeared in sacred structures, while wood appeared in residential structures. Buildings depicted there are on stilts. Tall pile structures as shown on the bas-reliefs of Central Java's temples can seldom be found in Java now. Low pile structures, as shown on the bas-reliefs of East Java's temples, can still be found in Bali. Thus people in Java probably lived on stilts.

Javanese houses differ in roof shapes but agree in plans. Roof shapes were connected to the social and economic status of the owners. There are three major roof shapes for houses; *Kampung*, *Limasan*, and *Joglo*.

- *Kampung*, also known as *Serotong*, is the simplest shape and is used by the common people.



Architecture in Java, Fig. 1 The Kampung (Schematic drawing. Illustrator: Paulus)

It consists of four main posts braced by a double ring of beams. Two upper posts stand at the middle of one pairs of beams, usually those parallel to the north-south direction, to support the roof ridge beam. Two roof sheets meet at this line and fall away on either side of the beam. The roof can extend in one or two directions at different angles (Figs. 1 and 2).

- *Limasan* is a more elaborate *kampung*. It requires more materials and effort to build and is associated with a higher socioeconomic status. It contains eight posts to support its trapezoidal roof. Two transitional posts rise at the middle of the beams that span the interior space between the middle posts. The main roof extends evenly to four sides (Figs. 3 and 4).
- *Joglo* looks like a more developed *limasan*. It is more difficult to construct and was the most favorable shape for the nobility.

It embodies several distinct features. These include a steeper main roof which resembles a pyramid that comes to two points and four main posts hold layers of wooden blocks which step back in several directions. The outer layer of these blocks holds the roof, while the inner, *Tumpang Sari*, the “essential piling up,” divides the ceiling into two inverted pyramids (Figs. 5 and 6).

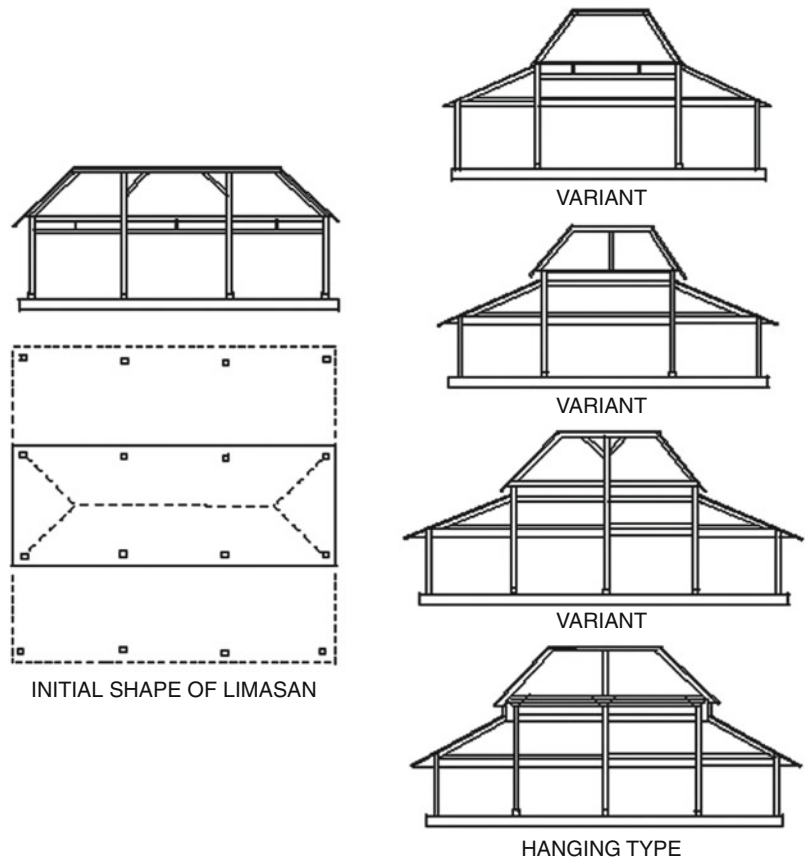
A house consists of at least a basic unit containing essential spatial patterns that all social strata share. All houses have a sanctuary and two storerooms, a clear boundary between the inner and outer domain, and are patterned according to the hierarchy of sacredness of place. The house plan is independent of the roof shape, especially for *kampung* and *limasan*, and to some extent, for *joglo* which has a more elaborate spatial division.

Architecture in Java,
Fig. 2 (Photograph:
author's collection)

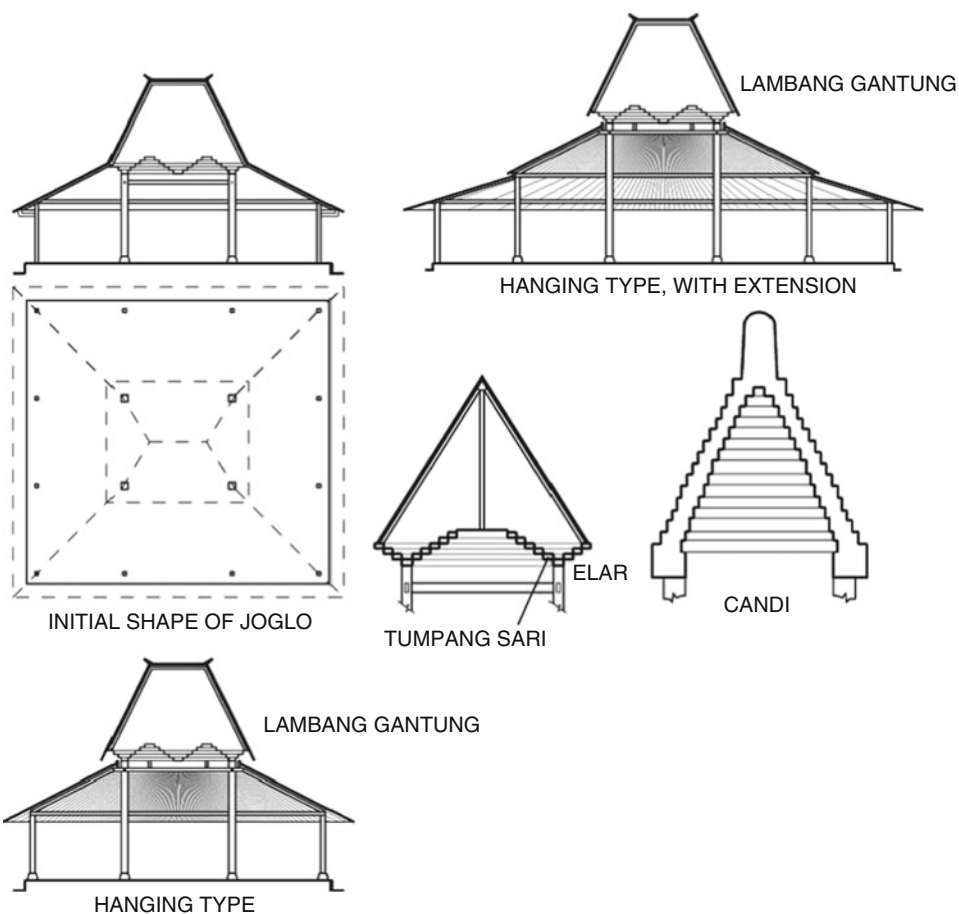


A

Architecture in Java,
Fig. 3 Limasan
(Schematic drawing.
Illustrator: Ary Dananjaya
Cahyono)



Architecture in Java,
Fig. 4 Photo image of a
 limasan roof (Author's
 collection)



Architecture in Java, Fig. 5 Joglo (Schematic drawing. Illustrator: Paulus)



Architecture in Java, Fig. 6 Photo image of Joglo (Author's collection)

The basic unit of a house is *omah*, which employs a rectangular plan emphasized by a raised floor. It encompasses an inner and an outer domain defined by wall panels. The outer, *emperan* or porch, is about 2 m wide to accommodate the family's more public activities. There is a wide bamboo bench for sitting, lying or sleeping. A wide door at the middle of the front wall connects this domain to the inner part.

The inner, *dalem*, is an enclosed structure which is subdivided into either two: front-rear, or three: front-middle-rear sections along a north-south axis. Each section suggests three spatial domains along the east-west axis. A two-section *dalem* applies usually to a *kampung* or a *limasan* roof, while a three-section one is for a *joglo*.

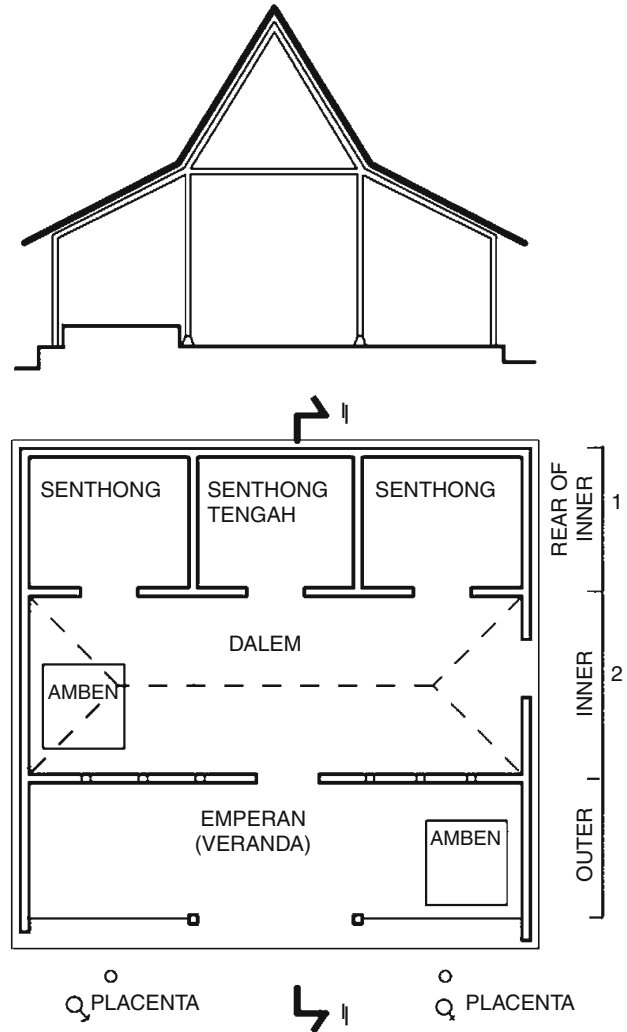
The middle section, if any, which is defined by four main posts at its center, has no exact usage. The central part was where the incense was burned once a week in honor of the rice goddess Sri, who occupied a permanent place in the house at the center of the rear section.

The rear section encompasses three enclosed rooms called *senthong*. The west *senthong* stored agricultural products. The east one stored other equipment or was sometimes empty. The middle *senthong* was the most lavishly decorated but the least used part of the house. It was the sanctuary of the rice goddess Sri and thus took the form of a

fully equipped bed. The function of this room would be fully revealed during the most celebrated ritual, the wedding ceremony. In this ritual the bride and bridegroom sit at the front of the *senthong tengah*, underneath the house ridge. Now many Central Javanese have transformed the once sacred *senthong tengah* for prayer. Many new houses now do not follow concepts from the recent past but from examples of new models in the big cities (Fig. 7).

An ideal house should have at least two, and if possible, three main structures: an *omah*, a *pendapa*, and a *peringgitan*. *Pendapa* is a roofed open hall located at the front yard of an *omah*. Its shape, size and position of posts are often akin to those of the *omah*. It displays a different spatial quality from that of an *omah*. It is open, accessible and lighted, while *omah* is opaque, forbidden and dark. *Pendapa* is the public domain of a house, a place for gathering and ritual performance and informal entertainment. *Peringgitan*, which employs a *kampung* or a *limasan* shape, connects *pendapa* to *omah*. It is a place for the performance of the shadow puppet play *wayang*, the ritual in Javanese culture that predicted life cycles, harvest, and higher rank career promotions.

The kitchen stays outside an *omah*, separately built near the well. A well should be the first to be

Architecture in Java,**Fig. 7** Plan of a two section Omah (Illustrator: Paulus)

dug out prior to the construction of any erected structure. The well also serves a later developed lavatory which has its own structure at the left and the back of a house compound. As the number of families and income grew, new structures expanded first to the east or to the north, then to the south for pendapa, and next, as needed, to the west to complete the symmetry. In an expanded house, the family lived in the wings and the omah became a real sanctuary.

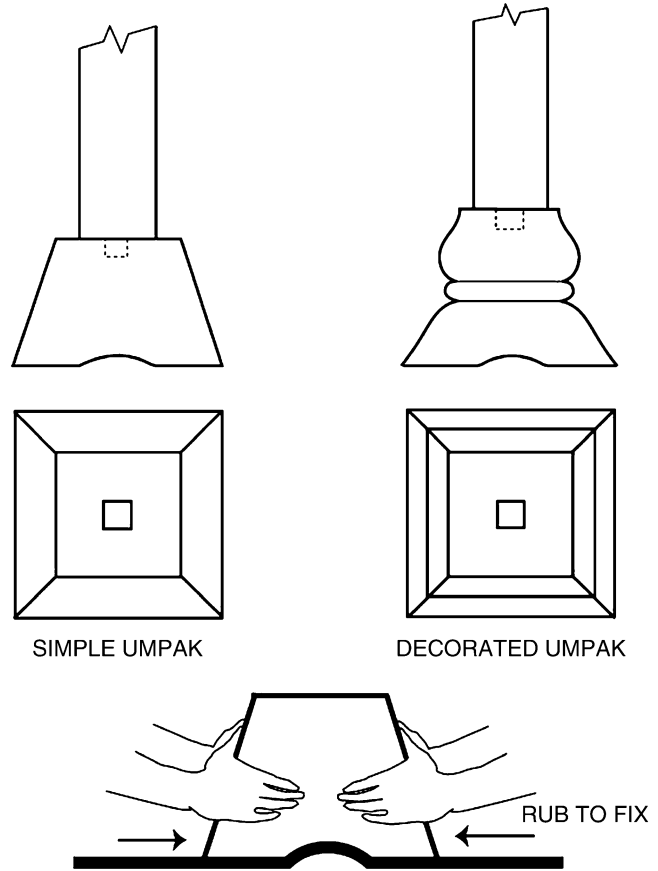
Most houses in Central Java whose entries were facing south have front, sides, or back yards within a clear boundary marked by a brick wall or low fence. The enclosed wall often has a roofed or unroofed gate, which connects the inner

world of family to the outer universe of community. After selecting and purifying a site and after digging out a well, the next step is to determine the location of the omah, as it should always be built first. After setting the omah's position, the team of community volunteers led by a carpenter starts the construction. The basic house plan is a matter of measurement and house shape of affordability. The carpenter will adjust the dimensions derived from the dweller's body to determine the size of the house.

The construction follows this sequence:

1. Dig the well
2. Erect the omah

Architecture in Java,
Fig. 8



3. Build the east *gandok* or kitchen
4. Construct the pendapa
5. Finally set up the west *gandok*
6. Fencing is the last, if needed, to be done

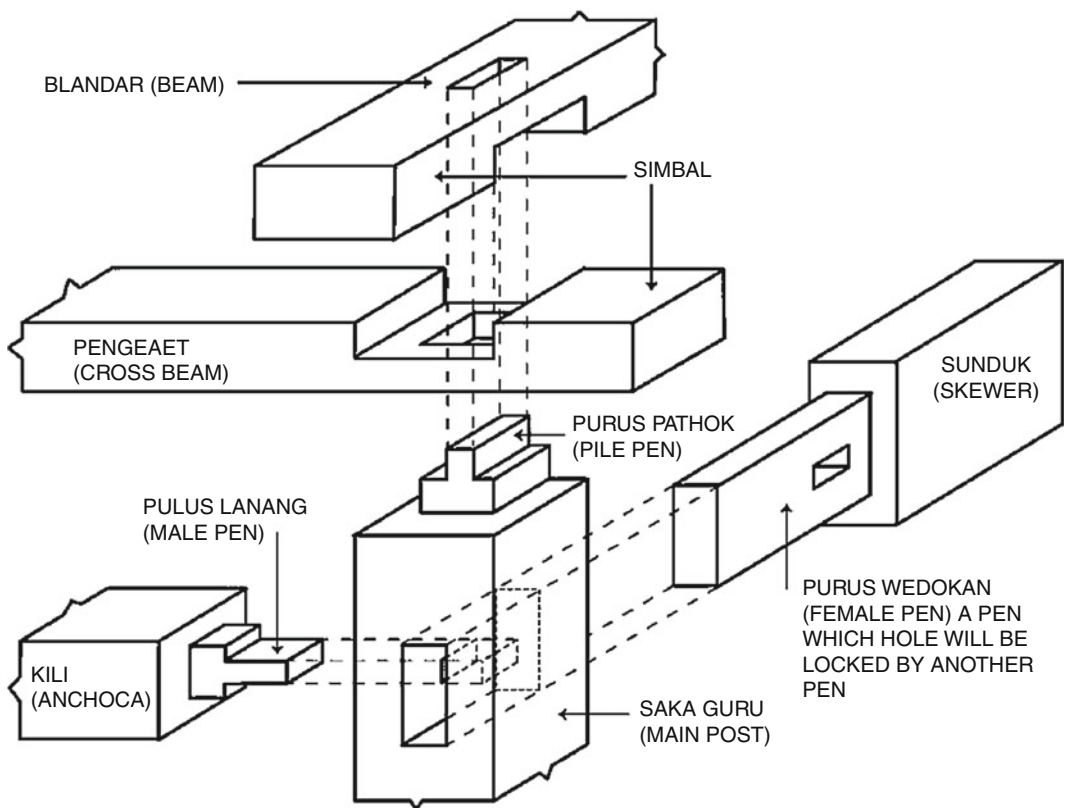
Construction proceeds by leveling the site and improving the strength of the soil by piling ► **bamboo** or stones around the edge of the main building. Its floor is often elevated to help drainage. The main posts are usually on *umpaks*, the three dimensional trapezoidal stones which act as transitions between the posts and foundations. The size of the umpak varies, from $20 \times 20 \text{ cm}^2$ to more than a square meter, dependent upon the dimension of the post, which commonly ranges between 12×12 and $40 \times 40 \text{ cm}^2$. Umpak is a structural device which reduces horizontal forces caused by earthquakes. It prevents the posts from the infiltration of

ground water. The wooden posts always stand according to the direction of tree growth (Fig. 8).

Two or three parallel beams join the post at its top. The posts may directly support roof trusses or roof beams. In the case of joglo, the main posts are usually topped by two sets of inward stepped wooden piles, *tumpang sari*, and outward stepped piles, *elar*. The number of *tumpang sari* steps reveals the status of the owner. The roof sheet is framed by wood blocks or bamboo sticks (split in half); the smaller blocks or sticks are laid parallel in a horizontal position with some distance between each other. All blocks are in a horizontal position rather than upright which, as seen individually, is more appropriate to the law of force of material (Fig. 9).

The post has pins at both ends; the lower fixes the umpak and the upper plugs in the hole

Architecture in Java,
Fig. 9 Tumpang Sari
(Author's collection)



Architecture in Java, Fig. 10 Construction join (Illustrator: Paulus)

of the main beam, which represents females. At the upper position of the main post, a hole is cut out to be filled by the pen of a secondary beam which acts as a stabilizer, as opposed to the beam

above it. The basic structure is stable upon the completion of all plug-in procedures. The term for pen is *purus* meaning the male sex organ (Fig. 10).

Modular Coordination and Mobility

The Javanese book of carpenter Kawruh Kalang mentions the basic measurement unit *dim* which is determined by either the length of a foot or the width of a fist. The length of beams and the interval between posts apply the formula $5 \times n \times \text{dim} + m$. The m should be within one to three because four or five *dim* is considered an inauspicious number for the initial structure, and n is any number defined by a special event such as a wedding. In it a fourfold modular grid based on serving devices is applied. Under such a practice, the interval between the main posts averages 2.5 m, being approximately the width of two floor mats. Plug-in construction join and the application of modular coordination have the flexibility to mobilize the house. A house can be moved after it has been torn down into construction parts and refabricated at other preferable places.

Although there is no concrete proof about the origin of Javanese houses, they can be traced back to agricultural tradition. Buildings for worship or commemoration altered as religion changed. However, the ideas that generate a house remain the source for the spatial arrangement of other buildings.

Buildings for Worship: The Hindu-Buddhist Legacy in Javanese Architecture

Hinduism and Buddhism, whose imprints in Java can be traced back to the fifth century, affected most forms of cultural expression, such as religion, art, (a certain degree of) social organization, technology, language, and statecraft. The intensive ceremonial life filled the interior Javanese landscape with *candis* (temples). Remains of habitats in the forms of foundation stones that spread around various *candi* complexes indicate that social organization was centered on religious ceremony at the state and, to some extent, the village level.

In prehistoric Java, mountains were the places where the ancestral spirit could be contacted for

protection and prevented from their wrath by offerings. *Lingga*, an upright stone and *yoni*, a flat stone plate, were possibly the first erected effigies to consecrate the center of the universe symbolizing creation and fertility. Later on, Hindu Javanese *candis* were designed to replicate mountains at the high places where spirits of the gods could be induced to go down into a *lingga* in a cave-like hall. *Candis* were enclosed by walls to divide the sacred inner from the profane outer. In the inner zone the priests presented offerings, performed prayers, and contacted the gods when they descended to earth. Thus temples were not for holding large numbers of peoples.

As religious buildings, *candis* were built to last in stone or brick. Archaeologist Jacques Dumarçay observed that the Central Javanese stone *candis* developed the techniques of interlocking stones articulated with perspective effect to cast expected results. They cut the stones into several modular blocks and created stone courses by joining stones placing one on top of the other without mortar.

The early eighth century Hindu Javanese *candi* compound is located at the Dieng Plateau. The four major *candis* known as Arjuna group face west. *Candi Arjuna* comprises a square room constructed over a pit containing a foundation deposit for ritual. The stone blocks interlocked through tongue-and-groove connections by having cut a section out of each stone in horizontal and vertical directions. The eighth century Buddhist temple compound *Candi Sewu*'s stone wedges were driven between the stone blocks, pushing adjacent sides outward toward the corner of building, strengthening the course and reducing the gap between joints. The ninth century's *Candi Loro Jonggrang* of central Java exemplifies the greater stone technology achievement in Hindu Javanese *candis*. Here, according to Dumarçay, the technique of double-leaf walls was adopted by establishing a pair of parallel walls, then filling the gap between them with rubble or unshaped stones by using mud or lime.

The Buddhist legacy Borobudur of the ninth century exemplified such techniques with an adjusted ten-layer *mandala* (Mandalas are geometric designs intended to symbolize the

Architecture in Java,**Fig. 11** Lorojonggrang of Prambanan (Author's collection)

universe) plan. The 113 m side long square plan base tells the story of a worldly sinful life through carved bas-relief. Ascending from the base are three layers of stepped enclosed roofless corridors with each wall relief describing the world of daily life. Up another three layers one finds on one side a slightly opened corridor which depicts the world of form as the intermediate experience of the last three layers. The last three layers represent the formless world without enclosure so one can also look out against the blank wall. At the top layer, whose center is a stupa, you could watch your surroundings as if the whole universe were under your eyes. To experience Borobudur, one ascends nine peripheries of adjusted squares whose size decreases gradually to the top. It brings visitors through a spiral labyrinth route to find nirvana.

Candi Loro Jonggrang exemplified the highest achievement of the Central Javanese Hindu legacy. Consecrated in 856, it was a complex dedicated to Siva and was possibly related

to a town of the same size. It consists of three walled courtyards on ascending terraces. The inner two courtyards are concentric and facing east, while the outermost is aligned another way. The terraces are made of heaped-up earth. Eight major sanctuaries fill the upper terrace. Three cruciform plan structures are devoted to the trinity of Hinduism, Siva, Vishnu, and Brahma. Facing each is a smaller structure for vehicles or mounts of the god. Two accompanying candis stand at the south and north entrances of the complex. Two hundred and twenty-four smaller structures fill the four lower terraces of the middle courtyard; those at the corners have two doors and the rest have one door. Such an arrangement recalls the image of mandala (Fig. 11).

Dumarçay concluded from his research on the stone construction of temples in Southeast Asia that Borobudur and Loro Jonggrang applied a perspective principle to create special visual effects in their construction, so that visitors



Architecture in Java, Fig. 12 The Great Mosque of Jogjakarta (Author's collection)

could experience the glory of their existence from various angles. For Borobudur it is at its base that this effect was applied so that its upper terraces would be visible. In Loro Jonggrang it is through the manipulation of the form which enhances the feeling of height.

Buildings for Worship: The Islamic Legacy in Javanese Architecture

Islam spread gradually from the twelfth century on. It began with trade around the ports and then infiltrated the interior of Java. The earlier Islamic buildings retained references from Hindu architectural elements such as ceremonial gateways, split portals and multilayered roofs.

The concept of early mosques in the interior cultural core of Central Java around the sixteenth century resembled that of a house. Dutch scholar de Graaf identified seven distinctive features of these mosques as (1) a square plan, (2) a raised solid floor, (3) a multilevel roof that peaks to one point, (4) a roofed veranda called *serambi* at the front, (5) a *mihrab* – an annex or niche on its western or northwestern edge to indicate the direction of Mecca, (6) encircling by water, which in turn is surrounded by open spaces, and (7) a wall that encloses the whole complex. In addition to those features, the door of early

Javanese mosques faced east, with the prayer direction oriented toward the west rather than Mecca.

Of these features, the square plan, raised floor, and walled enclosure can be found in the structure of the remaining Hindu Javanese temples, while the one-point multilevel roof is a common element of the Balinese Meru that existed in East Java before the domination of Islamic culture. The niche, *mihrab*, is a common element in mosques elsewhere in the world; perhaps each regional culture incorporates it differently. The encircling water is an adaptation of a moat appropriated to Javanese cosmology which can be found in old Javanese palaces. *Serambi* is a typical Javanese creation. Separating the sacred domain from other domains is parallel to the division of activity zones in a house. An ideal complete house exemplified such an idea by separating other daily activities from omah, especially the *senthong tengah*. The spatial quality of a sacred domain, which was usually governed by darkness, as in the main mosque and in the dalem, appeared to dominate Javanese thought (Fig. 12).

The great mosque of Demak of Central Java exemplified all the principles and became the model for the subsequent mosque around coastal Java. Its influence continues, as can be seen by the reproduction of its basic shape in the mosques

built around Indonesia sponsored by former President Suharto. The four main posts that support the upper roof were originally made by tying pieces of timbers with iron strips.

The additional element in many recently built mosques is the crown, which is now in the shape of a small dome, a result of native adaptation of an outside idea. The onion shaped dome has been associated with Islamic architecture in many parts of the world. However, such a dome has seldom become the main body of the roof in the Javanese mosques. A dome reduced in size is employed as a crown to top the roof. It is interesting to note that any new mosque, whose construction is funded by a special presidential grant, must follow the traditional Javanese two-layer *tajug* roof shape.

The House Extended: Settlement, Palace and City

Settlement patterns in the cultural center of central Java follow the north-south axis. Almost all traditional houses located in this district face south. Some coastal settlements are linearly aligned facing east for the north coast of East Java. The linear arrangement appears in many coastal zones. This is the most practical arrangement considering coastal conditions. Rural houses seldom have pendapa. Housing in the Cilacap, southern Central Java coastal area, has a common hall as a collective pendapa. This instance raises questions as to when the pendapa became the exclusive property of the urban elite.

A concentric settlement called *mager sari*, or fencing the essence, applies in urban Central Java. In it the houses of the wealthy were enclosed by the servants' houses. It is a reflection of a feudal society which illustrates the master-servant relation. The master is the center and the servants are represented by the fence. The palace or *kraton* compound exemplifies these relations.

Kraton refers to the seat of a ruler at a level of king or prince. The term is widely used in many Indonesian Islands such as Sumatra, Java, Kalimantan, Sumbawa, Sulawesi, and Maluku;

it is applied not only to an Islamic kingdom, but also a pre-Islamic one. Kraton was a dynasty's center of power, and usually generated an urban environment around it. In Java, e.g., it was the kraton, rather than the territory that identified a kingdom's geographical image.

Most kratons are located on a plain served by a river and its tributaries. In Java, the seat of a kraton was usually backed by a single coned sacred mountain. The Javanese kratons manifest these relations even stronger through axial positioning of the building complex toward the sacred mountain. A kraton comprises several buildings within a clear boundary. Descriptions of such boundaries of older kratons have not been supported by archaeological findings; possibly the materials for the palisades could not survive the tropical climate. The fence can be easily found in more recent kratons. Large kratons, such as those at Banten in West Java, Cirebon in Central Java, Jogjakarta, and Surakarta, had stone-walled boundaries. The wall was a defense device as well as a representation of hierarchical segregation based on status or sacredness.

As an ideal center, the alignment of a kraton reflects the ruler's views on the universe. The kratons of both Jogjakarta and Surakarta expose these images through a series of courtyards and gates lined up on a north-south axis. The axis replicates the directions of the mountain and sea and of cardinal points in Hindu cosmology. The Sultan's residence contains the royal pleasure garden which is located on the outskirts of the inner wall. The main pendapa, where the Sultan held audience, is the only building that faces east. This pendapa created a new east-west axis.

The main pendapa exemplified the most refined construction of a joglo. Timber blocks and rafts frame its roof sheet. The rafts are laid parallel in a horizontal position with some distance between each one. They are tied onto the layers of larger blocks and are arranged in a sun ray or centrally organized pattern. All the blocks are horizontal rather than upright. Dutch architect Maclaine Pont suggested that the Javanese treated their roof as an entity rather than the sum of individual elements (Fig. 13).

Architecture in Java,
Fig. 13 The Great
 Pendopo of Jogjakarta
 Kraton (Author's
 collection)



A

The *alun-alun* or town square is related to the seat of power. Two banyan trees stand at the alun-alun's center to symbolize harmony. The alun-alun was the meeting place of the Sultan and his people. It held major state rituals, festivals, games, and in the past was a place for punishment. The north alun-alun of Jogjakarta still hosts major cultural events today. It is encircled by several important buildings – the state mosque at its west, the main market and a prison at its north, with some other buildings around. The mosque was usually followed by a compound of the *kaum* – the religious experts who initiated religious rites and ceremonies – called the *Kauman*.

The kraton determined the conceptual layout of the city associated with it. From the toponyms one can trace this order in such old towns as Kuta Gede near Jogjakarta and Banten. According to sociologist Selo Soemardjan, the city of Jogjakarta exemplifies the social strata through several rings, which started with the Sultan at the center, with his family around him, and other nobility within the walled compound. Around the wall is the ring of town community surrounded by the rural community. The town community comprises those who have frequent contact with the ruler such as the smiths, the slaughterers, the carpenters, the *kaum*, and the merchants. The rural community is in charge of cultivating agricultural land.

The layout of both Jogjakarta and Surakarta suggests a Javadvipa, the central continent of the whole cosmos which consists of seven rings of continents separated by seven rings of ocean. Javadvipa contains seven mountains and six plains along a north-south axis, and four mountains and plains along the east-west axis. At the center is the *Mahameru*, the sacred mountain. Both kratons have six courtyards and seven gates with the seat of the sultan at the center to represent this inner cosmos.

This pattern, to some extent, can also be found in a coastal Javanese kraton and its cities. Since the coastal areas had many foreign traders, the ruler also provided a special zone for foreigners which served the same function as a *kampung*.

Kraton, square, state mosque, and market are the basic features for most Javanese towns. Their appearance set guidelines for building shapes around them. The other governmental centers followed such patterns during the period of Dutch control. The square accommodates recreational activity for the citizen. The mosque also serves as a religious court. The markets have peak activity once a week. There are coastal markets, littoral markets and agrarian town markets. Their location defines the character of the town economy. Such patterns also appeared in other towns, with the office of the ruler at the center and a town square which connected the mosque, marketplace and prison.

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Architecture in Mesoamerica

Phil C. Weigand

The Mesoamerican world system was composed of a number of closely connected and related but distinct civilizations. The peripheries of the system extended from the southwestern United States of America, in the north, to the borders of Nicaragua, in the south. Each of these component civilizations, while sharing with the larger whole series of cosmological and iconographic concerns, had an unambiguously regional architectural style. The distinct civilizations usually considered, from south to north, are the highland Mayan area (Guatemala), the lowland Maya (the Petén of Guatemala and the Mexican states of Yucatán, Quintana Roo, and Campeche), the Gulf Coast lowlands (Veracruz and Tabasco), southern Pacific coast (Chiapas and Guerrero), Oaxaca, Central Mexico (the states of Puebla, Tlaxcala, México, and Hidalgo), the Huasteca (northern Veracruz and southern Tamaulipas), western Mexico (Jalisco, Michoacán, Nayarit, Colima, and Sinaloa), and northern Mexico (Zacatecas, Durango, Chihuahua, and Sonora, with extensions into New Mexico and Arizona). The architectural styles represented within each region were original and innovative traditions

which in some cases lasted for centuries with only cosmetic changes. To speak simply of the existence of pyramids in Mesoamerica is to miss the point: while pyramids of one type or another indeed were pan-Mesoamerican, accompanying them was a remarkable diversity of other building forms, representing styles that still remain difficult to classify. Some areas, such as western Mexico, had a number of radically different architectural traditions through time, while other zones, such as Central Mexico, displayed much more conservatism. Of course, anything approaching a comprehensive survey is not possible in this summary. Important sites, even regions, have been omitted.

Reference and Bibliographical Considerations

There have been many descriptive architectural studies within Mesoamerica. Over the last century of research this orientation has produced a wealth of detail that has never been completely synthesized. The study by Marquina (1951) is a classic of the descriptive school, though there are major area omissions in his text and very little in terms of comparative or integrative commentary. Never-the-less, his text remains the most useful and encyclopedic source available in the Spanish language. In English, other overviews, though also limited in area coverage, have been published by Kubler (1975) and Gendrop and Heyden (1993). Useful general summaries concerning architecture within specific regions of Mesoamerica are in the *Handbook of Middle American Indians* (Wauchope, various dates). In the *Handbook*, surveys on regional architectural traditions include Smith (1965) on the Guatemalan highlands, Acosta (1965) on Oaxaca, and Margain (1971) on Central Mexico.

One of the best sources for specific site details is the journal, *Cuadernos de Arquitectura Mesoamericana*, published by the Facultad de Arquitectura of the Universidad Nacional Autónoma de México. Early numbers of the journal basically followed the Marquina descriptive tradition, though in recent years interest has

broadened to include spatial relationships, cultural symbolism, and astronomical considerations. Excellent and more specialized books and monographs on those topics also exist. As examples, for spatial relationships: Mangino Tazar (1990); for cultural symbolism: Kowalski (1999); and for ancient astronomy as viewed through architecture: Aveni (1977). A useful dictionary for architectural terms and terminology pertaining to Mesoamerica has been compiled by Gendrop (1997).

A number of site studies, emphasizing spatial relationships, describe architectural specifics in addition to the character of community settlements patterns. Three representative studies are Millon (1973) on Teotihuacan in Central Mexico, Blanton (1978) on Monte Albán in Oaxaca, and Folan et al. (1983) on Cobá in the lowland Mayan area. Researchers in the lowland Mayan area have produced some of the most detailed descriptive studies. This is no doubt due to the spectacular nature of the soft limestone building tradition in that region, wherein architectural ornamentation and elaboration, often baroque in character, reached a peak of development unequalled in any other area of Mesoamerica. An example is the study of the Río Bec, Chenes and Puuc styles, by Gendrop et al. (1998). In western Mexico, due to the highly geometric character of the early monumental architecture (Weigand, 1996), the approach of Chippindale (1986) and Stiny (1976) has been utilized to determine the rules of formal design employed there.

Architectural Types

The typology employed *infra* is far from complete, but represents a sampling of building types found throughout pre-Hispanic Mesoamerica.

Pyramids

Urban precincts, as spaces, and the buildings within, are almost universally well organized and formal. Within them are found the most monumental buildings in Mesoamerica, usually pyramids which are often of considerable size.

Among the earliest monumental pyramids is the structure found at La Venta, Tabasco. Located in a tropical rain forest and made from earth, it is badly eroded. Hence, its original shape has generated controversy. Its original shape may have been like a fluted cone, with ten alternating ridges and valleys at regular intervals around the oval base (Heizer, 1968). Its original height cannot be determined, but it towered over the flat flood plain that surrounds the site. Apparently, there existed no access ramp or stairway. This structure dates to around 900–400 BCE.

For the Classic period (AD 150–700), while the Pyramid of the Sun at Teotihuacan is the best known, it is not the largest. That distinction belongs to great pyramid at Cholula (Puebla), considered by some to be the largest single structure (by volume) in the Americas. While the pyramid is the greatest single building of the Mesoamerica architectural tradition, it is poorly preserved and understood. This structure eventually covered over 16 ha of surface, and was 55 m high. Some of the 16 ha represent poorly preserved platforms attached to the main body of the pyramid. The basic form is shared with the monumental pyramids at Teotihuacan: square to rectangular and terraced, culminating in a flat surface atop of which was placed a rather small temple (Marquina, 1951, pp. 115–125; Fig. 1). The pyramid at Cholula was constructed over a very long period of time, apparently in constant use from around AD 100 to the Spanish conquest in the early sixteenth century. As such, it represents one of the monumental buildings in longest continuous use within the overall area. The material used in construction varied from well-prepared adobe brick to rock and clay fill. The decorative finish, usually described as variations on the *talud-tablero* technique, was painted and highly sophisticated. The *talud-tablero* technique is usually ascribed to influence from Teotihuacan, but in most cases throughout Mesoamerica, including Cholula, this is doubtful. This architectural decorative technique was pan-Mesoamerican, though, very prominent at Teotihuacan.

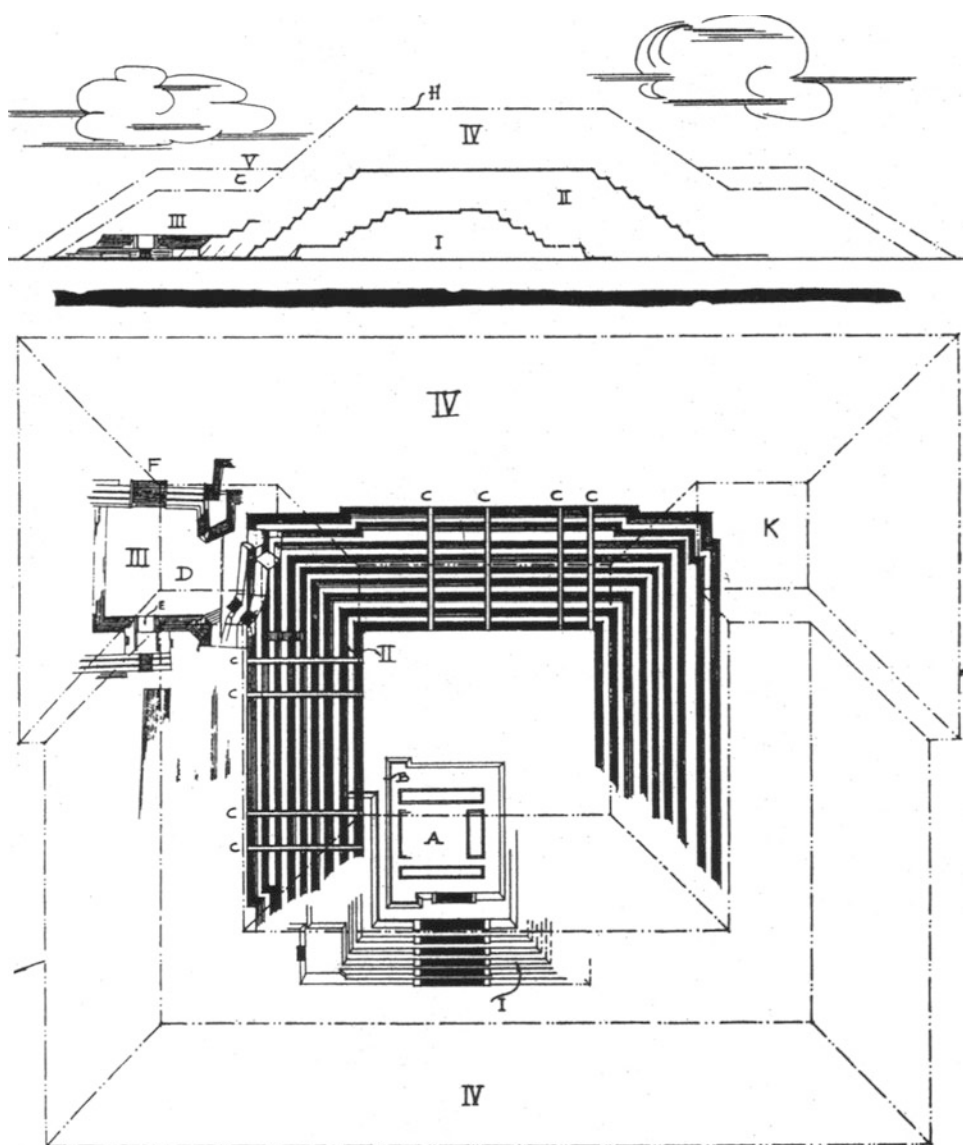
The pyramids at Teotihuacan, dating from the Classic period (AD 100–850), as well as

adjoining and neighboring structures, have been extensively studied for over a century. The site, while huge (22.5 km² – Millon, 1973), is still the focus of intensive research. George Cowgill's ongoing project at the Pyramid of the Moon has shown an extremely complex construction history, including prestige burials with sacrifices for this structure, thus supplying documentation equivalent at Teotihuacan for Cholula. The Pyramid of the Sun covered just under 5 ha of surface, and is 61 m high. The restoration of this structure, begun over a century ago, is controversial (Fig. 2). A natural, but improved, cave underneath this pyramid may represent the famed *chicomostoc*, or emergence tunnel through which people of this world originated. A tunnel dug through the Pyramid shows what may be a much earlier structure, perhaps representing a tomb (Millon & Drewitt, 1961).

Perhaps one of the best examples of baroque architecture in Mesoamerica is the Pyramid of the Niches at Tajín, Veracruz. While the substructure as such is comparable to pyramids elsewhere, it is the decorative elements that set it aside (García Payón, 1957). Its fine decorative masonry is unique in the non-Mayan regions of Mesoamerica. The niches, 365 in number, set into the ornamental *talud-tablero* facing, probably housed figurines (Fig. 3).

The double pyramid at Tenochitlan, destroyed by the Spanish after they conquered the city in 1521, is the most famous of this architectural type. The building has been extensively excavated and restored, and its history and utilization is fairly well understood (Matos Moctezuma, 2003). The pyramid was associated with a multiplicity of rooms and adjoining shrines, containing painted murals, rich offerings, and statuary. The “double” term refers to the peak of the pyramid. There, twin temples, each reached by a separate stairway, sat atop a common base. In architectural models and illustrations, this structure is often portrayed as being far more monumental than it actually is. This is apparently due to the centrality given to the Aztecs in the official histories of the Republic.

The small pyramid complex at Tula, Hidalgo, while not impressive if viewed as isolated



A

Architecture in Mesoamerica, Fig. 1 Map of the Cholula pyramid, Puebla, showing plan and profile (Taken from Marquina, 1951, p. 119)

structures, had extremely complex sculpture and appended buildings. The “atlantean” statues, originally placed atop one of the main pyramids, and the Halls of Columns adjoining that same structure, are unique in Central Mexico (Mastache et al., 2002; Fig. 4).

Pyramids in the Mayan area are unusual for their steepness and height in relation to their bases. The Temple of the Giant Jaguar (also called Temple #1) at Tikal, in the Petén district

of Guatemala, is one of the best examples. It had nine terraces, and three rooms at the summit. The rooms’ vaults were supported by beams from the sapodilla tree. A large vaulted tomb was excavated in the plaza before this pyramid was finished. On the upper terrace of the pyramid is a limestone temple which has a two-level roof comb. This comb, while adding a decorative element to the building, also increased significantly its overall height. This structure was finished



Architecture in Mesoamerica, Fig. 2 The Pyramid of the Sun, Teotihuacan, State of México (Taken from Millon, 1973, Plate 24a)



Architecture in Mesoamerica, Fig. 3 Pyramid of the Niches, Tajín, Veracruz (Taken from Porter-Weaver, 1981, p. 244)

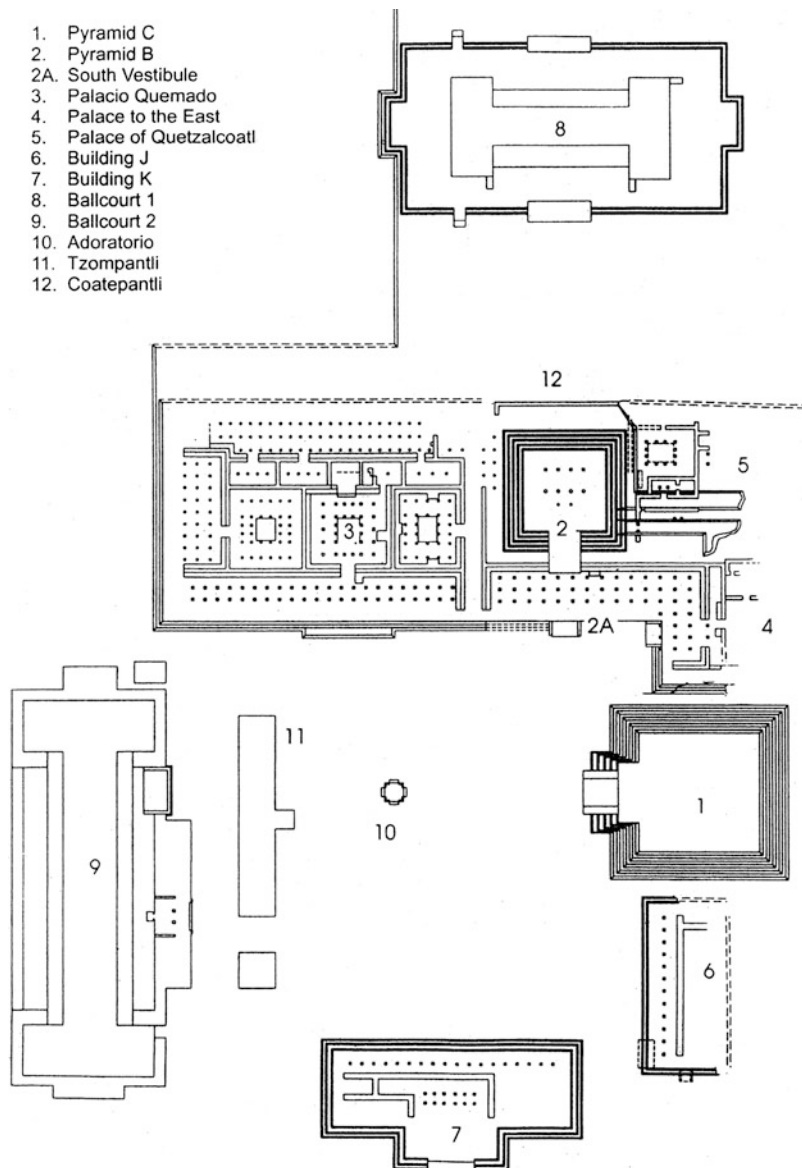
around AD 700 (Coe, 1967). Other pyramidal buildings of note are found at Piedras Negras (Houston et al., 2000); Palenque, and its great subpyramid tomb of King Pacál (Ruz Lhuillier, 1963); Chichén Itzá (Ruppert, 1952); as well as those mentioned in Gendrop et al. (1998). Aside from the decorative sculptures and friezes, some Mayan buildings had elaborate wall murals. The

best preserved of these are at the Temple of the Paintings at Bonampác, Chiapas (Ruppert et al., 1955).

In western Mexico, three sites deserve special note. The Guachimontón precinct, at Teuchitlán, Jalisco, has ten concentric circular structures, each having central circular pyramids, surrounded by elevated circular patios, which in

Architecture in Mesoamerica,

Fig. 4 Plan of the Halls of Columns, and associated buildings, Tula, Hidalgo (Taken from Mastache et al., 2002, p. 92)

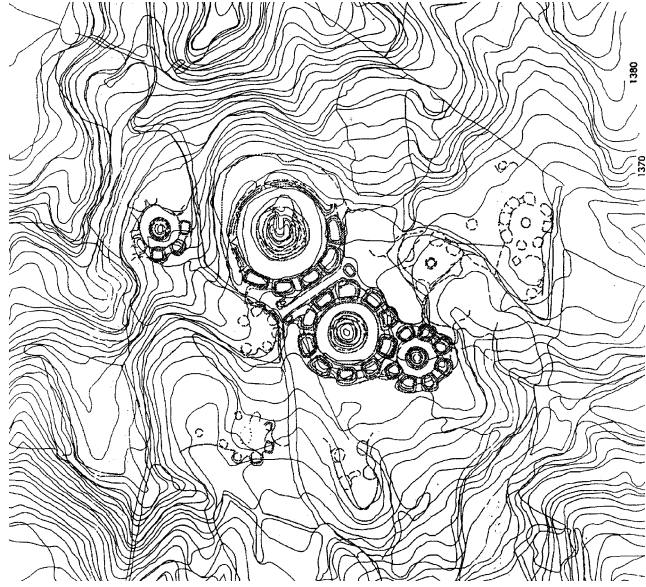


turn are surrounded by circular banquettes. While some 400 of these precincts have been located to date, this type of architecture morphology is unique in the world repertoire. The largest circle is 128 m in diameter, and 405 m in circumference. The precinct covers 19 ha. The pyramids in these complexes are only attributes of the overall structure. The highest one is 20 m. The outer banquette served as the base for between 8 and 16 platforms, atop of which were large temples. Beneath the platforms are the shaft-tombs, which

are full of the figurines that have given the region its fame in the antiquities market. The deepest shaft-tombs are 14–20 m, with between three and five large rooms. These structures date from the late Formative and early Classic period (350 BCE–AD 450; Weigand, 1996, 2005; Fig. 5).

Ihuatzio and Tzintzuntzan, Michoacán, are both sites associated with the Tarascan empire of the late post-Classic period (1300–Spanish conquest). Ihuatzio is the earlier site. It has a

Architecture in Mesoamerica, Fig. 5 The Guachimontón precinct at Teuchitlán, Jalisco (Taken from Weigand, 1996, p. 95)



large double pyramid complex which is partially surrounded by huge walls that clearly limited access to them. The *yácata* style building is also present. *Yácatas* are another unique building form found only in western Mesoamerica. They are large circular altars appended to rectangular platforms. Stairways are at the rear of the structures. The site with the most impressive array of *yácatas* is Tzintzuntzan. Five *yácatas* are lined up atop a huge rectangular platform (Cabrera Castro, 1987; Pollard, 1993; Fig. 6). Clearly, the *yácatas* and their base platform form a single structure, one of the most monumental of Mesoamerica.

Palaces

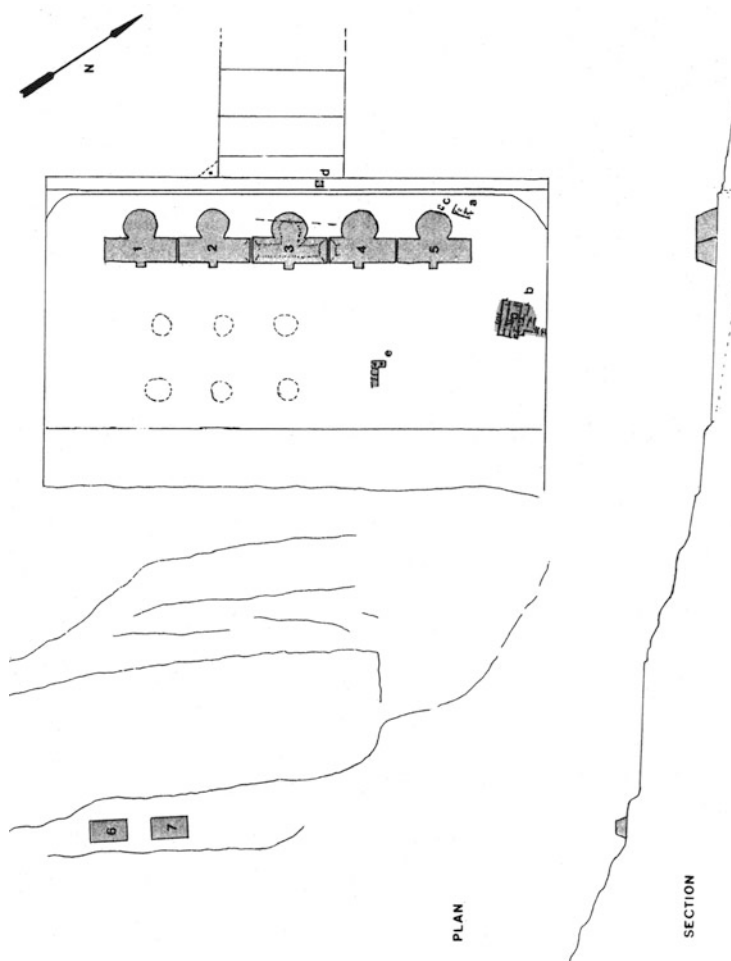
These structures, commonly called *tecpan*, abound within the complex sites of Mesoamerica. Although the identification is not certain, the Ciudadela at Teotihuacan is often identified as a *tecpan* (Millon, 1973). It is a huge, square structure measuring 400 m to a side. Its interior plaza is a large open space facing a small pyramid complex with complex serpent and rain god heads protruding from its surface (Drucker, 1974). It was probably completed around AD 300, if not earlier. Also at Teotihuacan, many sunken patio structures aligning the Street of the Dead have been identified as palaces, or at least

as residences of the elite elements that ran the urban complex. Many of these buildings were elaborately decorated with murals and low relief carvings. The Quetzalpapatl Palace is one of the best examples of this type of building (Acosta, 1964). It is a stunning example of a highly complex structure which apparently combined public administrative functions with residential quarters. A magnificent courtyard is bordered by porches. This type of structure is commonly called a *patio hundido*, or a sunken plazuela complex. The palace apparently dates to around AD 500.

The studies by Evans (1998, 2001) constitute the most comprehensive comparative research concerning palace structures in Central Mexico. Since so many of the late palaces in Central Mexico are covered by Colonial and contemporary buildings, including that of the last Aztec emperor, Moctezuma II, in Tenochtitlan, she has made ample use of ethnohistorical descriptions. In general, the Central Mexican *tecpan* is defined as an open court surrounded by a high banquette on at least three sides and open on one side to community plazas. The Codice of Quinatzín, portraying a Texcoco palace (State of México) clearly shows this type of structure (Fig. 7). Moctezuma's palace is said to have been 200 m

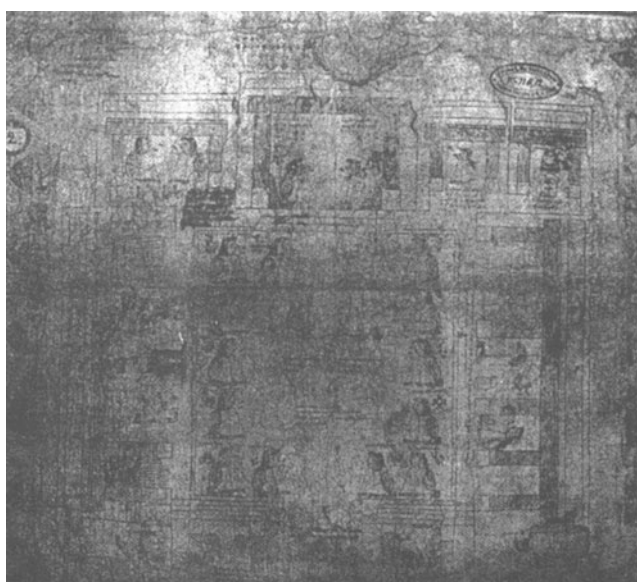
Architecture in Mesoamerica,

Fig. 6 Map of the *yácatas* at Tzintzuntzan, Michoacan (Taken from Pollard, 1993, p. 48)



A

Architecture in Mesoamerica, Fig. 7 The *tecpan* represented in the Codice of Quinatín (Taken from Weigand & García, 1996, p. 183)



to a side, though this structure, buried beneath Mexico City, is no longer visible. The average, however, is considerably smaller: between 60 and 80 m to a side.

Several structures at Monte Albán have been identified as possible palaces (Winter, 1974). These structures face the large, rectangular plaza that forms the central feature of the citadel. While they somewhat resemble palace structures at Teotihuacan, and date to approximately the same period, they are much more compact, and with fewer decorative elements. The plazuelas are quite small. Tombs, most probably lineage crypts, are often associated with these structures, and open directly onto the plaza.

At Yagúl, in Oaxaca, a different type of palace structure has been identified. Apparently, six side-by-side structures existed, built during the post-Classic period. Each is characterized by a series of fairly small rectangular patios surrounded by long, narrow rooms. The overall effect is cramped and crowded. The core of these buildings was rough stone and earth, but the exterior decorations were careful and sophisticated, usually plaster or cut stone. Facades and door frames were decorated with small cut stones formed into geometric mosaic patterns (Bernal, 1965). This decorative appliqué is similar to that found at Mitla, though the functions of the structures there have not been identified with certainty.

Buildings identified as palaces abound in the Mayan area. Perhaps the best known of these is the Tower Palace at Palenque. This square, four story structure was constructed from finely cut limestone blocks. The floors were supported by wooden beams, instead of corbelled arches so often employed in other palaces and temples throughout the zone. While attached to a palace-like structure, the tower is unusual for its height. A variety of functions have been suggested for the tower per se (Carlson, 1976).

From the post-Classic period, the largest visible *tecpan* is found within the village of Oconahua, Jalisco. At 125 m to a side, it conforms rather exactly to the arrangement set out in the aforementioned Codice of Quinatán. An internal plazuela is surrounded by high platforms, the northern one of which is out-sized at 125 ×

50 m. Outside this building is an external plaza measuring 180 × 55 m. Within this plaza were small platforms which served as bases for large stelae. The core of the structure is clay and earth, with some rock. It was finished with cut stone slabs, almost all of which have been looted (Weigand et al., 2005).

Market Places

These spaces were frequent features within Mesoamerican urban spaces. Often, they are hard to identify, and frequently are labeled as just plazas. One of the largest and earliest such spaces has been identified at Teotihuacan (Millon, 1973). Across the Street of the Dead from the aforementioned Ciudadela, this open space measures approximately 125 × 250 m. It is surrounded by streets and buildings, some of which are directly associated with the market. Stalls, some of which dealt in obsidian artifacts, were arranged within the plaza of the market. Unfortunately, this space was chosen to house the site museum and a restaurant, and is therefore difficult to appreciate today.

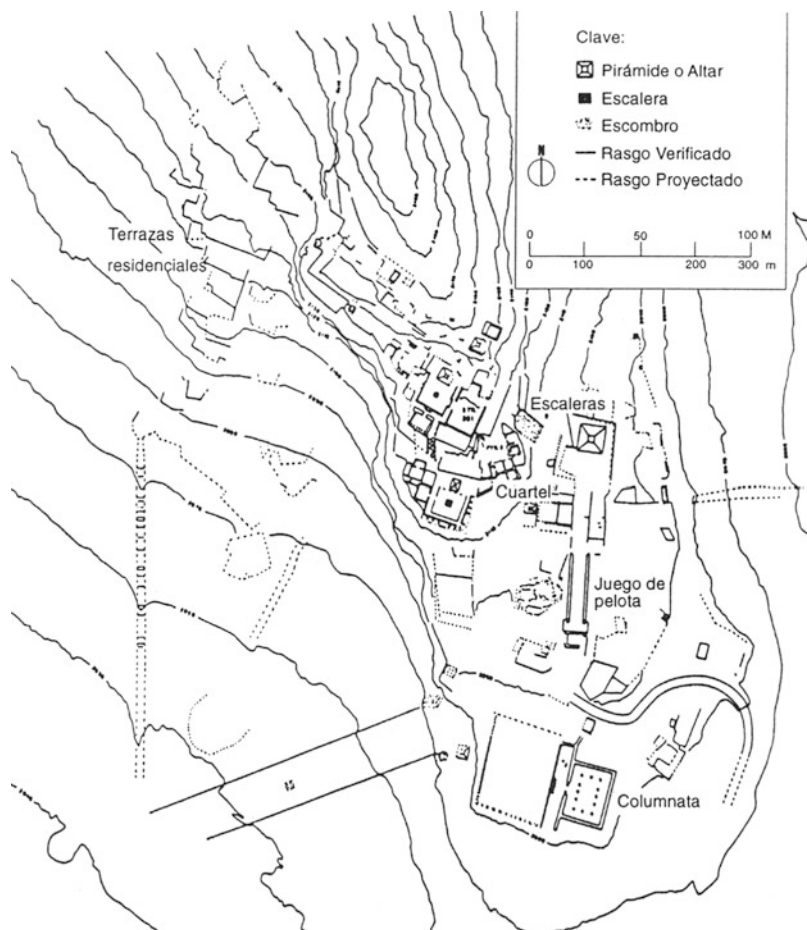
Places identified as markets have been located in the Oaxaca valley, as well, such as at Xaachila. The best information, though, comes from the Spanish sources from the conquest period. These attest to great markets at Cholula and Tlatelolco, in addition to other sites.

Ball-Courts

Fortunately, for this type of structure, excellent comparative studies are available. The studies by Taladoire (1981, 1998) are unparalleled in detail, classification, and chronological considerations. A few more recent studies from western Mexico have added detail to his overview (Weigand & García, 2005). Taladoire associates the architecture of ball-courts in different areas quite logically with the types of games performed there. Basically, two types of games dominated the Mesoamerican ball-court traditions. One type was the game played off the forearm (*antebrazo*), which required a court that had a hoop and a tall banquette. This is the type of game played at the monumental court at Chichén Itzá, for example. At 135 m in overall length, this

Architecture in

Mesoamerica, Fig. 8 The fortified citadel at La Quemada, Zacatecas (Taken from Weigand & García, 1996, p. 170)



court is one of the largest within all of Mesoamerica. The site of Tajín has perhaps the largest quantity of ball-courts, and the decorative elaboration of several is unsurpassed anywhere else. Elsewhere, the game played is called the *cadera*, or hip game. No hoop is required and thus the lateral banquettes are lower than in the *antebrazo* variety. The earliest monumental ball-courts of this type are found in Jalisco, where five buildings have been located and studied. The one at Santa Quitería is 135 m long, and the other four average 110–115 m in total length. The court at the Guachimontones has been restored, and dates to 150 BCE–AD 150 (Weigand & García, 2005).

Fortifications

Fortified or defensible sites abound within Mesoamerica. Three strongly fortified sites

stand out as excellent examples of military architecture: Tepexi el Viejo in Puebla (Gorenstein, 1973), Oztuma in Guerrero (Armillas, 1944), and La Quemada in Zacatecas (Armillas, 1948; Fig. 8). All three forts share several basic features: located on high, difficult terrain, they are terraced with walls and *revetments*? to make access almost impossible. All have specialized buildings and apparent gateway areas. Ceremonial architecture, while present, is modest and rather inconspicuous. La Quemada is the earliest of these three examples, dating to the AD 600–1100 period, while the other two belong to the Aztec polity. Smaller, but still impressive and earlier forts, can be found at the Peñol de Santa Rosalía, Jalisco (Weigand, 1996). Some areas, such as the Caxcan zone of southern Zacatecas, have fortified sites literally on every hill top.

Architectural diversity characterizes the many traditions of ancient Mesoamerica. This diversity is both temporal and spatial in nature. Some types have not been considered in this survey: specialized shrine sites, such as Malinalco in the State of México; mining complexes, such as those at the Sierra de Navajas in Hidalgo, and Chalchihuites in Zacatecas; ports of trade, such as Xicalanco, between Tabasco and Campeche; elegant burial chambers, such as the monumental shaft-tombs of Jalisco; and the great agricultural field systems such as the chinampas of Jalisco and Central Mexico.

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Architecture in Palestine

Shadi Sami Ghadban

When talking about traditional architecture in this area of the Middle East, it is more correct to identify this architecture by the term “Palestinian

Architecture” rather than by “Architecture in Palestine.” The second term refers to all architectural styles found in Palestine throughout the different historical periods, from Hellenic, Roman, Byzantine, Umayyad, Abbasid, Fatimid, Crusades, Mamluk, Ottoman, and the British Mandate until today. These architectural styles were mainly popular in major cities like Jerusalem, Jaffa, Acre, and Nablus. In addition, these styles were commonly related to the architecture of the economic and political elite and the urban notables.

On the other hand, the first term “Palestinian Architecture” reflects what is known as “architecture without architects,” which has flourished for several centuries in urban and rural areas. It maintained its characteristics until World War I because of the social, economic, and religious factors that reflected the needs and living habits of a particular time, and it directly reflects the interaction between human beings and their environment (Fig. 1).

Prior to the year 1839 (when Ottoman land reforms were applied), land in Palestine was the main source of livelihood and status, with very limited transactions with the regional or world market. The Palestinian community retained a system of agricultural subsistence, employing simple agricultural technology. The community as a whole was considered the unit of taxation by the state, and there were patriarchal households, where the extended family acted as the main unit of production and consumption, and labor was divided along clear gender lines.

The year of 1832 marked a critical turning point in the history of the region, when Mohammad ‘Ali, the Governor of Egypt from 1805 to 1848, occupied Great Syria, including the Palestinian territories, and implemented several land, administrative and economic reforms (Manna’, 1999, p. 161). He gained the support of the European superpowers for his military campaign when he said that he would take into consideration their vital interests in the area, treat the non-Moslem minorities in a better way than the Ottoman Authorities had, and even try to give them equal rights with the Moslems (Scholch, 1988, pp. 130–145). This Occupation brought



Samhan palace, village of Ras Karkar, Ramallah district.



Talamas house, Bethlehem city



Agha Tuqan house, Nablus city



Two-storey house with shops at the street level, Nablus city



Village courtyard house, Ramallah district



Two-storey house, Al-Bireh city

Architecture in Palestine, Fig. 1 Houses of the economic and political elite at different districts of the Palestinian territories during the eighteenth and nineteenth

centuries (Photos are student works from the course "Local Architecture in Palestine", Birzeit University, 1998–2001)



Partial view of the old city of Ramallah, where the old fabric is scattered by the modern buildings constructed in the area.



Partial view of the old city of Nablus, surrounded by the new modern urban structure

A

Architecture in Palestine, Fig. 2 Images demonstrating the rapid construction growth outside and within the historical fabrics in Urban Areas (Photos by the author)

about several developments accompanied by the implementation of several administrative and economic reforms, but they were obstructed by different uprisings and disobediences that occurred in the area (Manna', 1999, pp. 137–138). The Egyptian policy in the Palestinian territories led to increasing European influence in these territories, mainly in Jerusalem. The activities of different missionary groups concentrated on constructing new churches and providing educational, social, and health services to the local population. The first European British Consulate in Jerusalem was inaugurated in this period, which was followed by other consulates during the period 1841–1858 (Spyridon, 1938).

In 1839, the Ottoman Sultan Abdul-Majeed came back to power in Great Syria, and this included the Palestinian territories. He was supported by the European coalition established by Great Britain, Russia, Austria, and Prussia (Scholch, 1988, pp. 458–475). In his decree, known as *Khat Golkhanah*, issued in November 1839, he expressed his readiness to apply new reforms that were known later as *Tanzimat Khairiah* (Davidson, 1973). In addition, the increasing European influence led to an economic amalgamation of the Palestinian territories with the world capital market, and produced an active involvement of the Palestinian local leadership in the continuously changing political

circumstances. All these factors shaped the new socioeconomical interactions within Palestinian society.

By the end of the nineteenth century a new eclectic architecture with mixed styles witnessed the western influence that came through the activities of different missionary groups. This development was accelerated during the last three decades of the nineteenth century and continued intensely during the first two decades of the British Mandate (1920s and 1930s) when a rapid construction growth sprawled in both rural and urban areas (Fig. 2). Therefore, by the end of the 1930s, a new architectural fabric began to emerge which greatly affected Palestinian society since the middle of the nineteenth century.

The Tanzimat period represented one historical period of the Ottoman Empire, but for Palestine and other Arabic areas in the eastern coast of the Mediterranean, this period consisted of three major stages:

- *First stage (1840–1856 AC)*. The Crimean war ended and a decree called *Khat Sharif Hamaion* was issued on 18th February 1856. This decree contained several reforms that Sultan Abdul-Majeed addressed to get the support of the European countries for his war against Russia. In this stage the Ottoman Authorities performed reforms similar to

those applied by the Egyptian Government (1832–1840). However, the local leadership, mainly in the countryside, rejected them, arguing that they were contradicting with their interests (Izz-Elddine, 1928, pp. 95–96).

- *Second stage (1858–1878 AC)*. The Ottoman land reforms (Tanzimat) started in 1858, which aimed to change the communal ownership of land to private ownership. This period, mainly in 1878, evidenced the first parliamentary experience during Sultan Abdul-Hameed the Second's rule. New fundamental changes affected not only the relations between the state and the Palestinian local leadership, but also had an extensive effect on the socioeconomical, cultural, and living conditions of the Palestinian local society.
- *Third stage (1878–1919 AC)*. During this stage the integration of the local economy into the world trade market and acceleration of the European influence in the area continued. However, there was a growing trend toward improving the infrastructure, mainly in the fields of transportation, communication, education, and governmental administration. It was also around this time that Palestinian immigration to both Americas increased and the immigrants started sending back money to their families in Palestine to build their future houses. In addition, this period included the expansion of Jewish emigration and construction of new settlements with imported architectural styles.

The 1840s was a decade rich with events assumed by several historians as indicators for the beginning of a new history in the Palestinian territories. As a result, new architectural systems, i.e., new building styles and forms, use of new materials and methods of construction were imported and implemented, but within the framework of the local knowledge in the area (Fig. 3).

Factors Influencing Palestinian Traditional Architecture

Several factors bear upon the development of Palestinian traditional architecture.

Geography

A distinguishing part of Palestine is its geographical location along the eastern Mediterranean coast. It has a key location between Asia and Africa, and has a specific character as a Holy Place for Judaism, Christianity, and Islam. Altitudes, which range from 394 m below sea level to 1,400 m on the mountainous chain parallel to the coast, allow the existence of a diverse landscape. The mountains shape the nature of the Palestinian territories and control climate and rainfall.

Many influences affected the Palestinian land, and large-scale architectural activities took place during the rule of foreign powers such as the Romans, Crusaders, Mamluks, or Ottomans. Despite the fact that these activities reveal strong local characteristics, they are of foreign origin. Therefore, independent Palestinian architecture was limited to housing structures and modest religious and public buildings. The influence of geography can be observed in the adoption of certain types of construction, architectural forms, orientation, and the arrangement of buildings. The articulation of plan, elevations, simplicity of masses, and the habit of one or two-story constructions are largely caused by the predominant conditions in the three main geographical zones of the country: the coastal area, the highlands and the Jordan valley (Fig. 4).

Natural Building Materials

Palestinian territories have an unusual geology because of their location between Great Syria and the Sinai Peninsula, where different geological formations produced a unique topography, diverse both in form and structure.

The mountainous area consists of hills, valleys, and gorges, where the geological strata are easily accessible. These strata usually consist of sandstone between limestone, and are cut up by various clefts, mainly in the Hebron, Bethlehem, and Nablus areas.

The abundance of stone in the country offers the opportunity for good masonry construction. The continuous use of stone has produced stonemason's families who passed on their accumulated skills from generation to generation, evolving a mastery and tradition of design in



House in El-Bireh City.



House in Jerusalem City.



Bisan Company Office in Ramallah City.



Sakakini Cultural Center in Ramallah City.



Three-Storey Building in Jerusalem City.



Two-Storey House, Bethlehem City.

Architecture in Palestine, Fig. 3 Houses and buildings with new architectural types, forms, new materials and methods of construction (Photos are student works from

the course "Local Architecture in Palestine", Birzeit University, August 2000)

stone that is largely responsible for the homogeneous character of Palestinian architecture (Figs. 1 and 3).

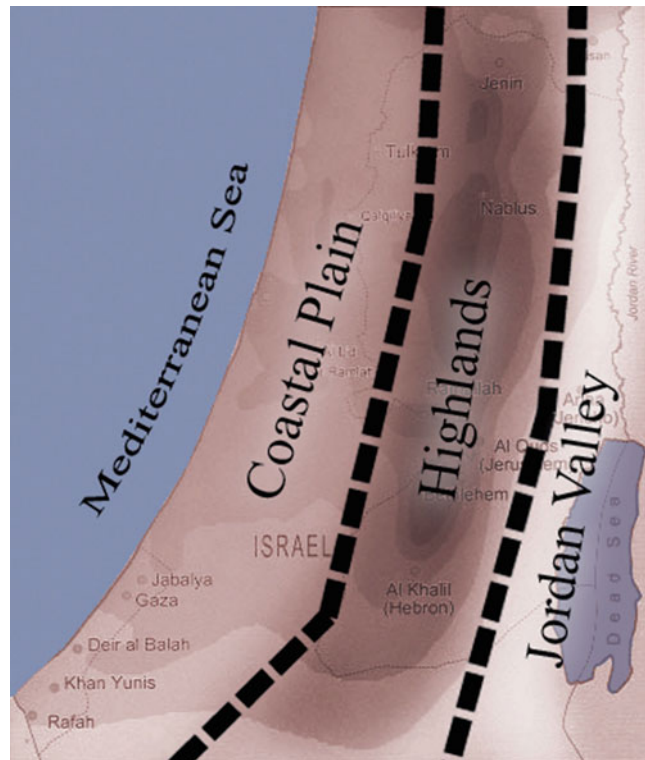
Mud is limited to the Jordan valley and some coastal areas, mainly Gaza, because of their

geological conditions. The fairly dry climate in these areas allows the application of mud brick (adobe) structures.

For many centuries, the use of wood for construction was limited to some kinds available in

Architecture in

Palestine, Fig. 4 An illustration demonstrating the three geographical zones in historical Palestine (Adapted by the author, using as a base a map distributed by Applied Research Institute (ARIJ), <http://www.arij.org>)



the area, such as one-palm trees and olive trees and rarely poplar, willow, walnut, and maple. Wood is mainly used for doors, windows, some furniture, and for roof construction.

The Climate

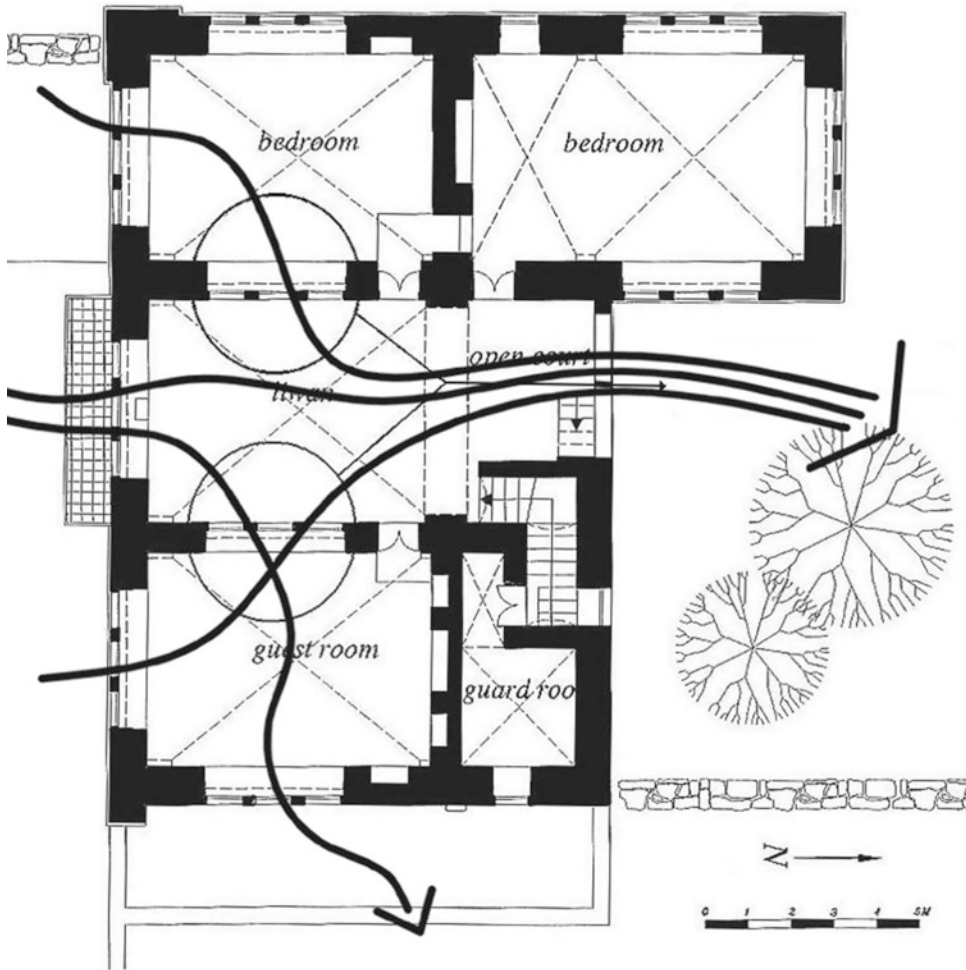
There are four climatic zones in the Palestinian area: the coast area, the western slopes of the mountainous area, the eastern slopes and the Jordan valley and the desert. The annual climatic cycle of the country consists of four hot dry summer months, a mild autumn with little rainfall, a rainy winter with snow down to 700 m and an early spring with the last rainfall in April.

The architecture of Palestine is a synthesis between local environmental conditions and the formulas of the philosophy of life, art and design prevailing in the entire Mediterranean region. The massive construction in stone or mud-brick in terms of a wall's thickness, height, texture, and verticality, satisfies to a large extent the

exigencies of the climate. The roof structure, either flat surfaced from mud, wood, and straw or vaulted mainly from stone, guarantees appropriate temperature insulation and reduces the heat transfer process. Crossventilation is facilitated by openings placed high in the single-spaced structures or by internal windows between rooms and the central space, which is assumed to be the coolest space during the hot daytime (Fig. 5). The open ends of the central space are turned either to the north or to the south in order to avoid deep penetration of the sun's rays. Fortunately, the placement of the house parallel to the contour lines of the slope toward the valley makes its face toward the prevailing wind direction and ensures the desired ventilation.

Socioeconomic Factors

Palestinian traditional architecture has been the result of an experience between human beings and their environment. This dialog has two forms: action and reaction. The action of the



A

Architecture in Palestine, Fig. 5 A house plan showing the crossventilation system imposed by the central hall system used for functional organization of the internal

spaces. A student work from the course "Local Architecture in Palestine", Birzeit University (1998–2001)

human being always produces a reaction in the environment, and vice versa. In both cases, the reaction has two levels: an unconscious reaction and a conscious reaction that needs to be reinforced and enhanced.

Palestinian traditional architecture has been very resonant in functional, constructional, and artistic approaches during the last 120 years. When the changeable living conditions of the Ottoman Reforms and the English Mandate caused some elements of traditions and values to lose their initial meaning, they had to be replaced by new ones with a function closer to

the new requirements that still responded to certain sociohistorical conditions.

In this regard, there is a substantial importance to specific Palestinian local forms of production, religious customs, beliefs, traditions, mental adaptation, self-confidence, and spirit of people, because all of them are determined by local physical, geographical, and climatic conditions.

The religious affiliation of the Palestinian family did not affect the distribution of house types in Palestine. The conditions of living either in the mountains, valley, or in the coast areas were essentially the same for all religious



General view of Al-Lubban village, Nablus district.



General view of Ras Karkar village, Ramallah district

Architecture in Palestine, Fig. 6 Images demonstrating the panoramic form and dimensional connection with the existing environment in rural areas (Photos by the author)

communities, and all families adhered to a strong paternalistic structure. Great class discrepancies were unknown and the social structure was egalitarian.

On the other hand, the Islamic influence has been very strong in artistic and architectural forms and details, but there is very little Islamic influence in the planning of the houses. They were simple and straightforward, and that includes the lack of specialized spaces as well as a lack of privacy for the individual.

The House

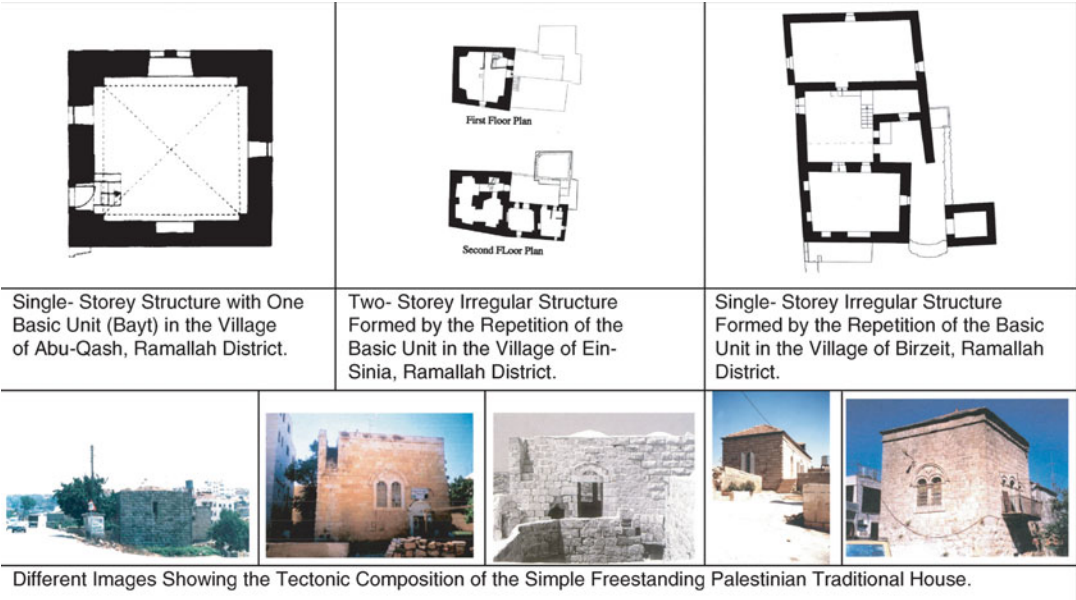
Prior to the Ottoman Reforms (Tanzimat), land in Palestinian Territories was the main source of livelihood and status, and the Palestinian community employed simple agricultural technology. A system of agricultural subsistence was retained, with very limited transactions with the regional or world market. The village as a whole and not the individual was considered the unit of taxation by the state. The community had patriarchal households, the extended family acting as the main unit of production and consumption, and labor was divided along clear gender lines (A'miry & Tamari, 1989, pp. 11–15).

The Palestinian village has had an outstanding harmonic panoramic form and a dimensional connection with the existing environment where

the built up area grew together with the land, but revealed its own main image (Fig. 6). This local rural process could be described as a classical expression of organizing the habitation process by spontaneity, intuition, and a connection with site topography. The socioeconomic organization of the built environment before 1832 evoked the implementation of one of two main systems:

- The single-storey freestanding structure, which consists of a square or rectangular space (*bayt*) with a low entrance (*bab*), ventilation opening below the roof (*taqat*), and one or a pair of two small windows (*mijwiz*) (Fig. 7).
- The clustered and concentric patterns of spatial organization, where houses and other structures have formed the traditional clustered fabric. The pattern was produced by repetition of the single-storey structure, as each house unit was adjacent to other house units at least from two sides, as the back of the structures formed a part of the periphery protecting the inner courtyard (Fig. 8).

Both systems were built either from natural stone and roofed by traditional crossvaults or with mud mixed with straw and roofed by a wooden flat structure. The free grounds between the structures mainly were used for agriculture, livestock, and/or for future expansion.



Architecture in Palestine, Fig. 7 Single and multi storey freestanding structures, consisting of a Square or Rectangular Space (Bayt), and a Pair of Two Small

Windows (Mijwiz) (Student works within the Course “Local Architecture in Palestine”, Birzeit University, 1999–2000)



Master Plan of the Old Quarter In the Top View of the Old Quarter In the City Village of Ein-Senia, Ramallah of Bethlehem, Bethlehem District.

Architecture in Palestine, Fig. 8 Two images showing the Clustered and Concentric Pattern of the Spatial Organization at the Urban and Rural Palestinian Areas. Student

Works within the Course “Local Architecture in Palestine”, Birzeit University, 1999–2000



Initial Forms of the Traditional House

Today, there are still some examples that demonstrate the initial forms of the Palestinian vernacular house before 1850, but most of them have

been extensively restored that they can no longer belong to any specific period. Three original forms of this architecture are still used as spaces for living, agricultural, and stockbreeding

activities. Mostly, they are located in the hilly areas, villages or within the large historical cities. The general characteristics of these forms are as follows:

- *Caves*: they are considered the first habitation structure used by Palestinians for living purposes. Mostly, they are located at the eastern slopes of the Jordan Valley (winter pastures) and at the western mountains of the Palestinian territories (summer pastures). These caves are either natural, or have been rehabilitated to meet new living requirements (Fig. 9a). Each cave consists of one open space articulated into different zones by means of harmony between the various social, functional and aesthetic elements. Furthermore, some of these caves continue to host several living activities as a major element in the further extension of the living environment.
- *Watching Towers (Mantarah)*: a freestanding stone structure that imitates tectonically the vernacular typical house, but with different function and details. Usually, they are located outside the rural or urban fabrics, on the top of hills between fig and olive trees and pastures. These structures had multifunctional purposes as places for watching and cultivating land, summer vacations, storage places and bases for winter agricultural activities. Each watching tower is divided vertically into two or three levels. It consists of a ground floor for livestock and storage, a first floor for living and a second floor in the form of an open terrace used for multipurpose activities. This structure exists in both rectangular and circular plans (Fig. 9b) and all levels are accessible by an internal staircase.
- *Shepherd's House*: this model represents the most popular form of the Palestinian vernacular house with a simple single-storey square structure, built from the limestone rock abundant in the surrounding areas, and has only one low arched entrance (Fig. 9c). Walls are massive, sometimes 1 m thick, in order to support the heavy stone crossvault of the roof. The elevations are free of any window

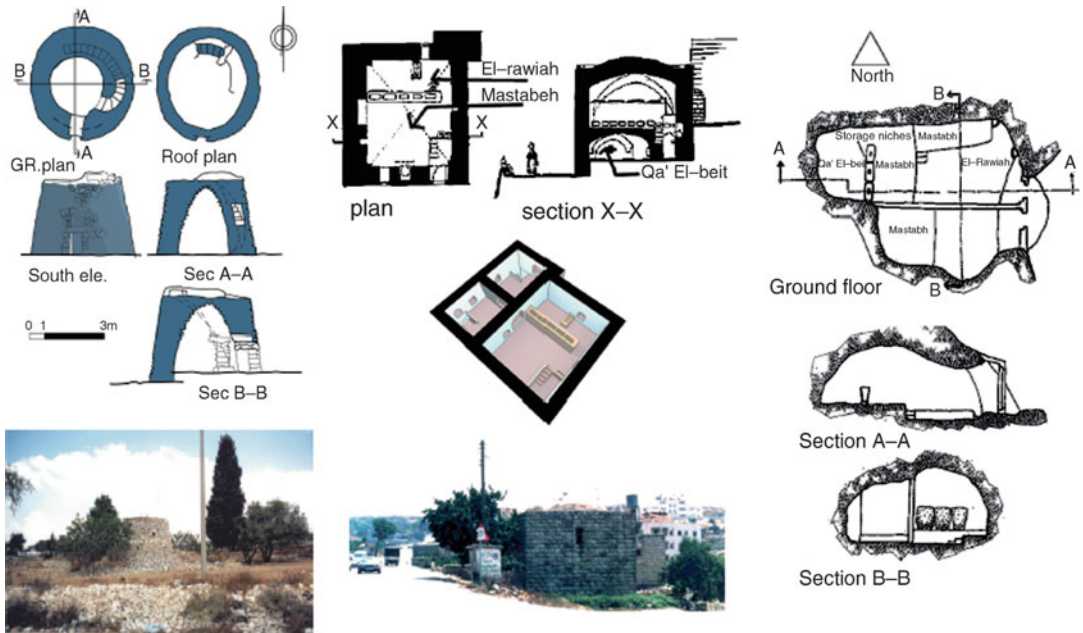
openings apart from small ventilation holes. The three-dimensional development of the shepherd's house produced three well-defined and integrated domains (A'miry & Tamari, 1989; Hamdan, 1996): (a) the multipurpose space for living (*Mastabeh*), (b) the animals' space (*Qa' El-beit*), and (c) the food storage space (*El-rawieh*).

These three domains were available at all three forms, with certain discrepancies according with physical and environmental needs.

New Forms of Palestinian Traditional Architecture

Palestinian traditional architecture is a product of the cultural development of the East Coast of the Mediterranean basin. Historical events caused a great dislocation of ethnic groups and populations with different public systems, specific customs, and intertwined cultural traditions. Appropriate conditions for mutual influence were established during the formation, development and enrichment of traditions and values. Several new forms of the Palestinian traditional house were created. They reflect the sociopolitical changes, which took place after the Tanzimat (reforms) period in 1842 and brought about essential transformations in the traditional structural of the Palestinian society:

- Creation of modern state institutions, mainly in the large cities, that led to immigration toward the new urban centers. This phenomenon led to major growth in the population inside the boundaries of the Old City. As a result, the existing structure became incapable of assimilating the augmenting needs of the population, and people started moving outside the Old City, creating new urban centers that were in the beginning juxtaposed to the frontiers of the Old City.
- Decline in the power of the village sheikh (Ruler).
- Changes in land tenure due to the Ottoman land reforms (Tanzimat), and privatizations of the main means of production: the land. The new ownership policies allowed foreign



Architecture in Palestine, Fig. 9 Original initial forms of the Palestinian vernacular house (Photos and drawings by the author)

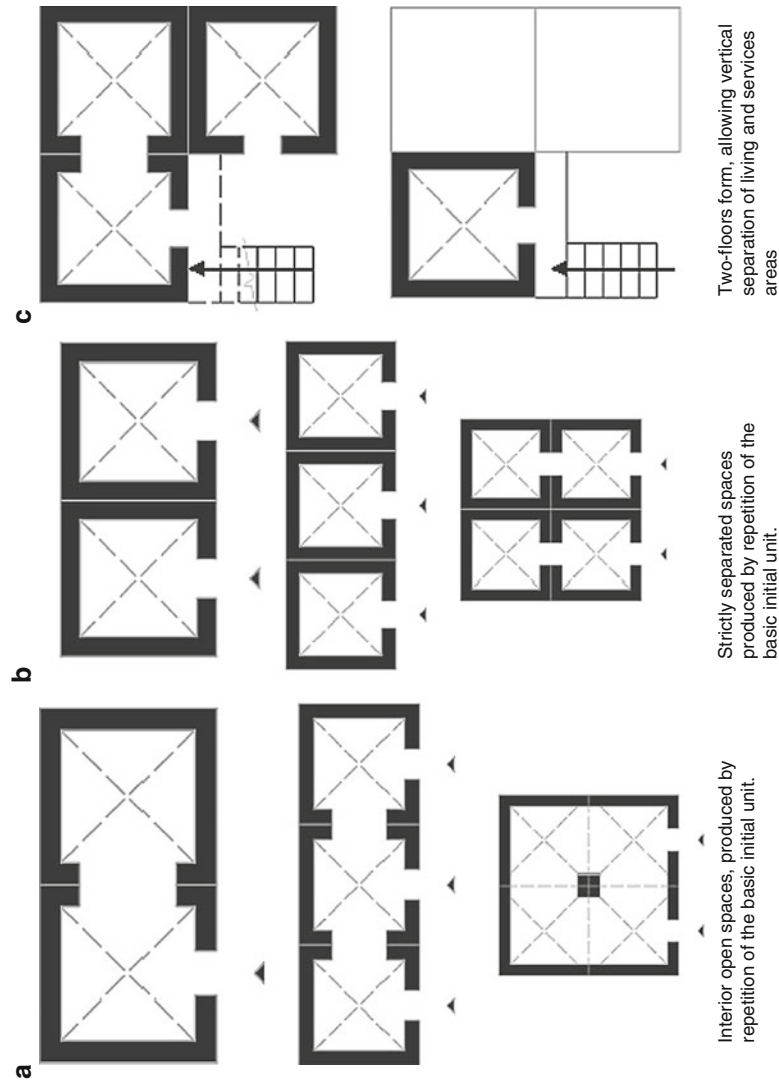
citizens to buy and register lands in their names. Foreign religious missions, relief agencies and consulates started their activities and gradually built up their religious, educational, health, and residential compounds.

- Growing integration of the local economy in the world trade market. This had an effect over all agricultural, trade and investment structures in Palestinian society.
- Formation and dissemination of a new culture in addition to the prevailing Islamic one.
- Changes in the occupational structure of the local population.
- Aggravation of social contradictions.
- Active emigration among the young Palestinian generation toward the American continent and Europe, in order to avoid the obligatory military service forced by the Ottoman authorities. Most of the immigrants started sending back their savings to invest them in Palestine by building mansions that reflected the new lifestyle of an affluent social class that was in formation in most Palestinian urban sites around that time.

Rectangular House with Repetitive Initial Units

The term “Repetitive Initial Units” is used here to express the way this type of traditional house was produced. It consists of a repetitive arrangement of the rectangular or square initial model in a horizontal or vertical direction producing a composite structure (Fig. 10). Further development of this system initiated other more advanced forms of this architecture:

- Enlarging the space by means of one or more interior supports producing large open spaces with an internal system of pillars or vaulted roofs and enclosed by bearing walls (Fig. 10a). Mud and stone were both used.
- Strict separated spaces with sharp rectangular corners and increased rigidity of forms. In this way the organic unity of the interior space is reduced (Fig. 10b). Roofing was implemented by barrel vault or crossvault structure, and both invited the addition of an upper floor. This form was mainly produced by stone material.



Architecture in Palestine, Fig. 10 Basic schemas of the rectangular traditional house. For existing examples refer to Figs. 7 and 9 (Drawings by the author)

- Adaptation of a two-floor form of stone construction, which was very significant since it allowed the vertical separation of the living and service areas. This system ended the cohabitation of people and animals, symbolizing their emancipation from unremitting toil (Fig. 10c). The connection between floors was always external.

The Court House

The court denotes an open space delimited by wings and connected to the surroundings or the main alley by a main door or gate. This schema was predominantly applied in the main villages and towns, because of the clustered character of the construction fabric (Fig. 11). In this case building units are arranged in an L or U shape and rarely in a closed square or rectangular shape.

The house built around a courtyard is fairly extensive and contains well-oriented wings that offer privacy and safety and form a reception space and daily activities area for the family. The courtyard was enriched by the addition of a covered terrace on one side called *Liwan*, which served as an extension toward a significant orientation like a valley, seashore or another nice view.

The Gallery House

The gallery (*Riwaq*) indicates a covered space, which opens to the outside through a series of supports such as colonnades or arcades. In the Mediterranean two forms of the gallery are popular. The first is a gallery that exists as an addition of a covered open space, mainly produced by ornamental plants or grapevines and therefore called a passive gallery. The second one is the active version of the gallery and is designed as an open corridor that functions as a traffic or transitional area linking different components of the building (Fig. 12). As a rule the gallery is greater in length than in depth. In general the gallery is reached either directly from the surroundings, if the terrain slope allows that, or by a courtyard in front. In contrast with the closed rectangular type the gallery building expresses three major trends (Ragette, 1974, p. 44): (a) appreciation of the gentle climate and the natural beauty of the region; (b) a feeling of confidence to the

inhabitants, and (c) an increasing emphasis on life within the family.

In the majority of cases the gallery building has two floors, the lower of which is vaulted and the upper is flat-roofed or with tiled pitched roofs (imported from Europe in the nineteenth century). In its formal expression the gallery building presents the greatest possible contrast to the closed rectangular type. The continuous arcade or colonnade provides the feeling of openness and expresses the superior social standing of the building's owners.

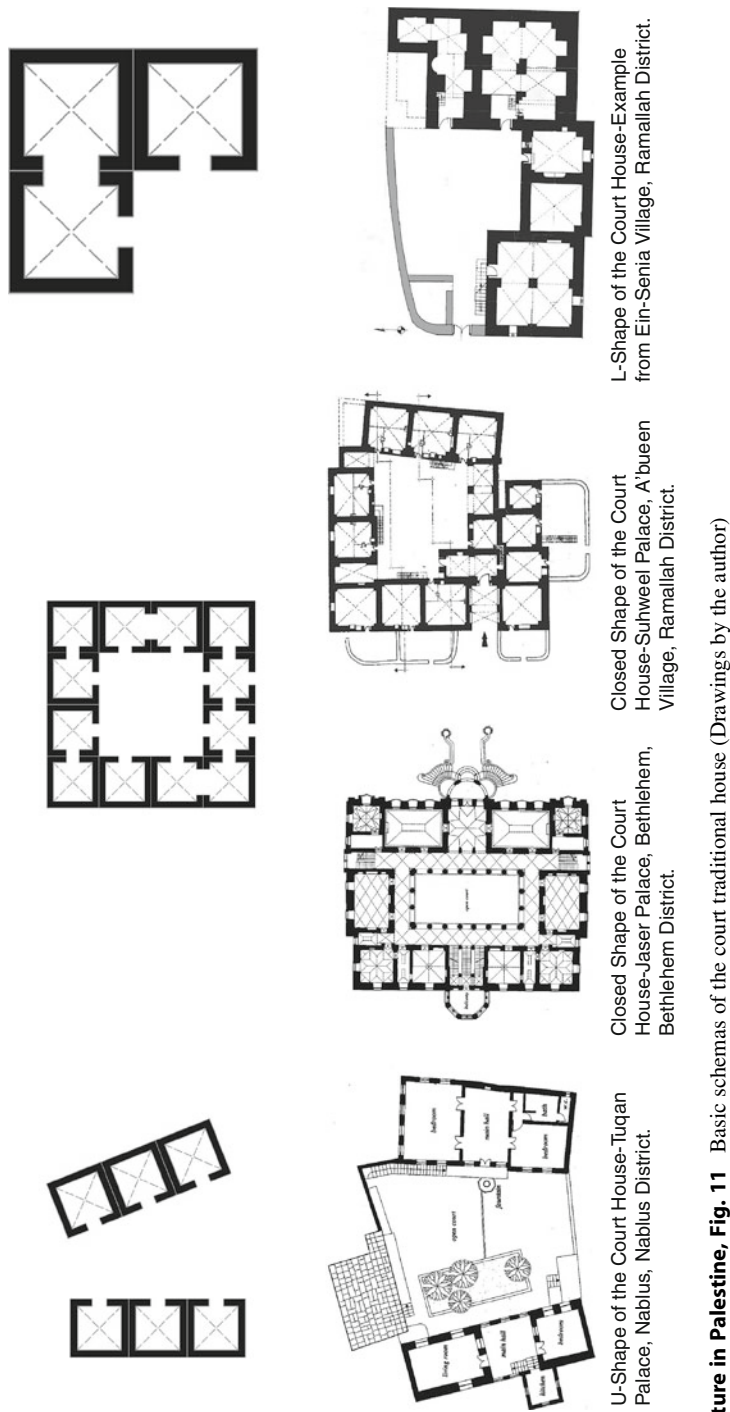
The Central Hall House

Although this type appears in Palestine at a later date than the other mentioned types, it became the most popular form of traditional house by the second half of the nineteenth century (Fig. 13). It has one, two, or three floors, and one or more entrances. In addition the central hall has a full depth, subdivided or surrounded by rooms from three sides. A symmetrical composition prevails when the entrance leads directly to the central hall, while the corridor to the central hall disturbs the symmetry when the entrance is lateral.

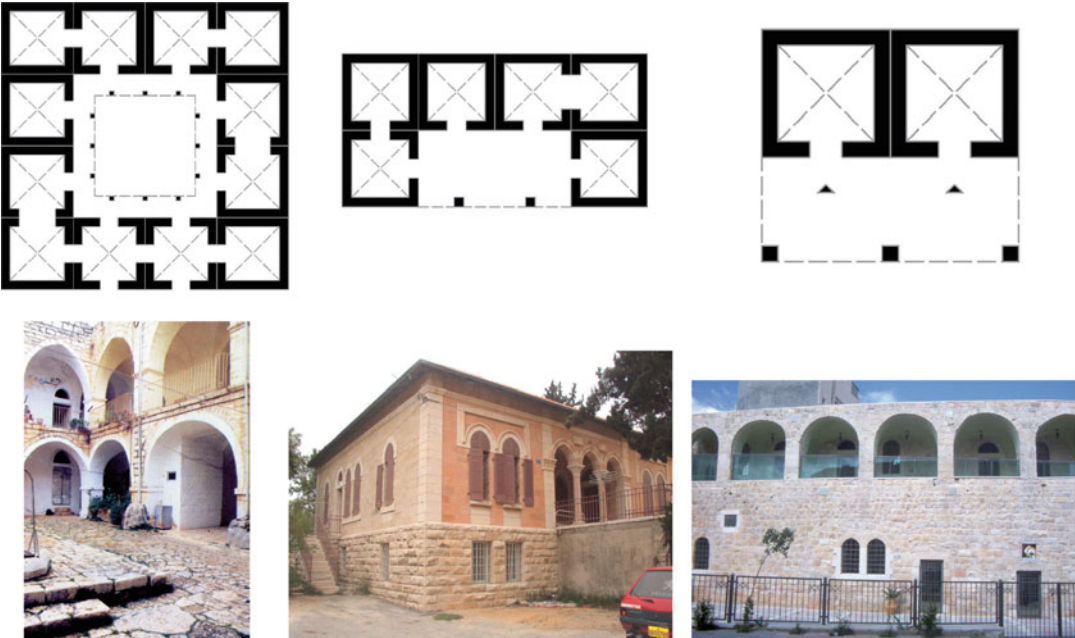
By the end of the nineteenth century, due to western influence, the central hall system was adopted widely and the design became increasingly formal. The houses turned into veritable villas that majestically dominated their surroundings outside the Old City walls. Often, the central hall house was built of stone. The lower floor was vaulted and the upper either vaulted, roofed with steel beams or timbered with red tiles.

This descriptive analysis of Palestinian traditional architecture shows that transformations in the structure of Palestinian society reflect not only the achievements of Palestinian ethnic groups, but also those realized by interaction with western identities. In this way both traditional creativity and "formal architecture" have been rationalized:

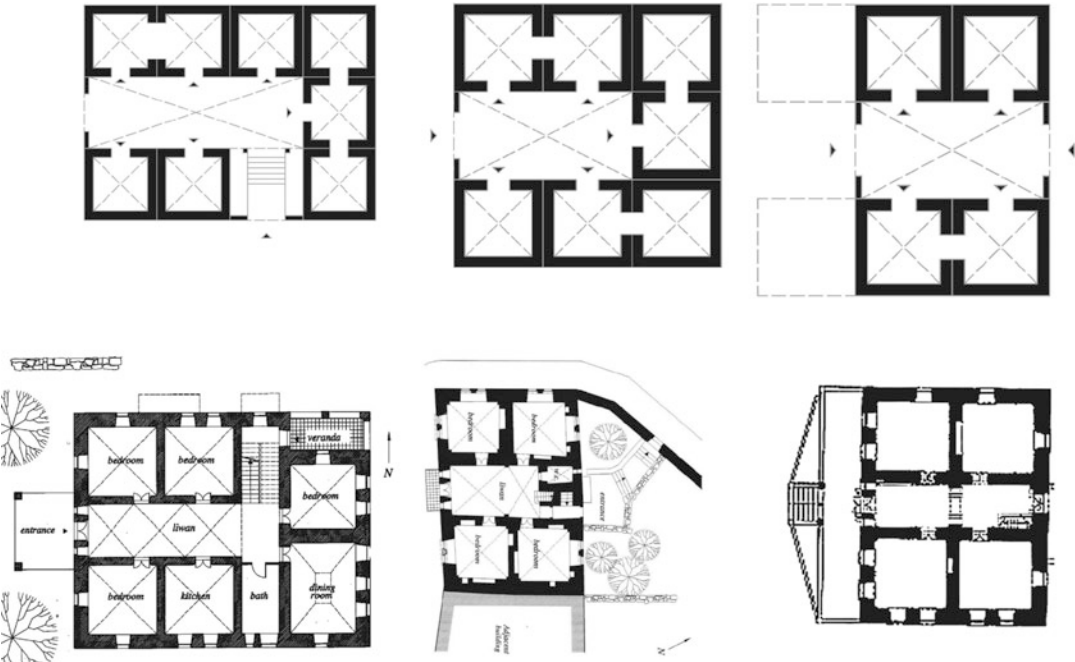
1. This architecture is a product of a simple and frugal society creating its habitat with elementary means, but also with an understanding of the functional requirements and the potential of the materials available.



Architecture in Palestine, Fig. 11 Basic schemas of the court traditional house (Drawings by the author)



Architecture in Palestine, Fig. 12 Basic schemas of the gallery traditional house (Active Version) (Photos and drawings by the author)



Architecture in Palestine, Fig. 13 Basic schemas of the central hall traditional house (Drawings by the author)

2. The artistic quality of the buildings created in the second half of the nineteenth century was not totally dependent upon imported models. The stylistic self-sufficiency of the country's architecture has continued to be expressed through numerous variations of locally rooted traditions, as well as mastery of a craft.
 1. The color and texture of the natural stone contribute to the homogeneous and organic character of Palestinian architecture. The stone finishing reveals an intimate knowledge of the material acquired by generations of stonemasons. The use of color for decorative effects is limited to a few elements at entrances, windows, or arches. Palestinian architecture is more restrained in this regard than Arab architecture in general, where structural clarity is sometimes masked by decorations.
 2. The form's simplicity of the traditional building, the massing of single buildings as well as groups of buildings and the adherence to a uniform scale are the basic means of creating harmony between house and landscape, house and house or village and landscape. The juxtaposition of houses creates a repetitive rhythm of mass and void that covers the land without destroying its relief. The human scale is maintained in the traditional architecture, where the principal masses, as masonry works, automatically introduce a clear definition of scale. Yet each gate, door, window or arch dimension is in reasonable relation to necessity and importance.
 3. The shapes of walls and roofs normally adhere to the simple geometry of squares, rectangles and trapezoids. Spans and cantilevers are strictly limited. The repetitions of similarly shaped openings reinforce continuity and their irregular distributions within one elevation sometimes create pleasant diversity.
 3. Palestinian traditional architecture occupies its place naturally and without pretension. It is imbedded in a landscape humanized by countless terraces, and built of the materials furnished by the environment. The balance of

massing and the harmony of forms were exemplary, and the arrangement of the houses reflects deep understanding of the environment, and is indicative of a remarkable social balance.

4. However, by the end of the nineteenth century this architecture lost two of its most important qualities: the flexible inner space and public participation in the building process.

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Architecture in South Africa: Domestic Architecture

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South Africa is a large country with myriad cultures, ethnic groups both immigrant and aboriginal, and vastly differing climatic zones which in turn inform the natural landscape, and, by definition, the indigenous built environment. Furthermore, the more recent effects of modernism and modernization have had effect, removing the buildings from a static construct and situating them in an environment of innovation and change. This means that discussing the non-Western domestic architecture cannot be addressed simply or concisely due to its vastness and complexity. This broadcast exercise has been competently carried out in the past, by different authors such as James Walton (1956), Biermann (1971) and Franco Frescura (1981).

It is important to address the mercurial nature of this move from stasis to change, realizing that a rapidly changing world allows for new forms of domestic architectures such as informal dwellings, which house millions in contemporary South Africa. Thus, it is pertinent to focus more on a single region and a thread of architectures that are bound within a cultural and geographical framework.

The Zulu are southern Nguni people occupying the coastal littoral of the province of KwaZulu-Natal, on the eastern seaboard (see Krige (1962 [1936]) for a full, but dated,

explanation as to the ethnography). Traditionally, they are polygamous pastoralists, relying on cattle keeping as a central focus of their lifeway, leading to authors such as Evers (1988) describing their settlement approach as the “Central Cattle Pattern.” They have legendary status, having opposed colonial forces during the nineteenth-century British expansionism into the Colony of Natal.

Zulu architecture, and “architecture” that can be deemed in its potential complexity, is broad in its distribution stylistically as well as being open constantly to reinterpretation, change, and symbolic expression. The term “indigenous vernacular architecture” (see Oliver, 1997) would apply more fully, as the buildings that are produced act as products of a changing and mobile culture and are agglomerates of found and gathered materials. No static, representational “style” exists in the contemporary landscape, although an adherence to traditional planning can apply if economic stability and space allow.

It is important to describe the historically established norms comprising buildings to be able to understand how they formed part of the both large- and small-scale cultural and physical landscapes, as this not only provides a backdrop for the discussion but in many cases informs the cognitive foundations of contemporary architectures. This next section will describe the homesteads as planned units and then speak more fully about the individual units, the *iQhugwane* (grass dome) and the *rondawel* (thatched cone-on-cylinder).

Homestead Planning

Well documented in both historical and contemporary literature, the Zulu homestead, or *uMuzi*, is located on a hill distant from other homesteads. The site is awarded to the homestead head by the King, meaning that the land is neither bought nor sold, and remains the property of the King.

The essential large-scale planning principles of the homestead in many rural examples are constant. A hierarchy of individual units with different functions is situated around a central

cattle byre, the whole enclosed with a fence. Access to the complex is usually from the bottom of the slope. At the apex is the dwelling belonging to the head of the family, the *indluNkulu*, with the paternal mother’s dwelling, or *Gogo’s* house. Each of the wives has a separate sleeping and kitchen unit. The young unmarried men usually live next to the entrance, and guests stay in a unit opposite. Internally the circular buildings are carefully demarcated, with specific places occupied by specific people with specific relationships, under the broad premise of men on the right and women on the left. A single building may be dedicated to consulting *amaDlozi*, the ancestors, and in such cases the offerings are placed in the *uMsamo* at the rear of the space.

The only constant that can be ascribed to Zulu building forms is that in a traditional society they follow a circular format. Only in more recent vernacular examples does the rectangle emerge as a dominant form (Fig. 1).

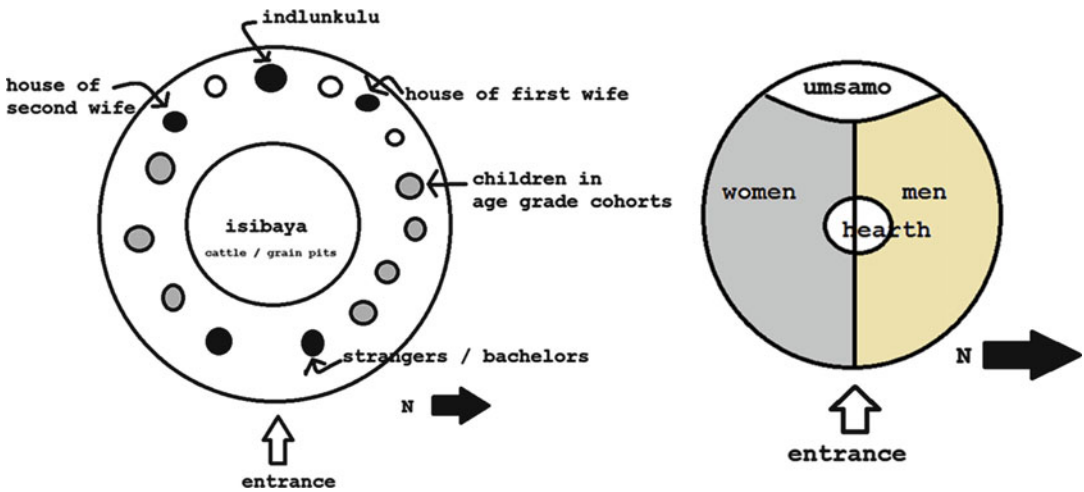
Today, change occurs through pressure from a variety of sources. In addition, dwindling natural resources used for housing, the vulnerability of the grass dome to fire, scarcity of thatching grass, and the rapid urbanization and migration of many hundreds of thousands of people in the last four decades have resulted in contemporary hybrid architectures that represent a variety of approaches to life, demonstrating origins and aspirations.

Individual Units

Two broad types of building forms exist: the domed beehive and the *rondawel*. These are not necessarily related and do not necessarily mutate from one to the other. Establishing their origins is a matter of debate.

• The Beehive Dwelling (*iQhugwane*)

The *iQhugwane* is the archetypal Zulu building, perpetuated partly by contemporary tourism initiatives as iconographic of “The Zulu Kingdom.” The grassland environment of the southern littoral ensured the availability of grass for thatch.



Architecture in South Africa: Domestic Architecture, Fig. 1 Generic layout of traditional uMuzi (left) and typical spatial layout of iQhugwane (right) (Author: 2014) derived from Kuper (1980) and Argyle and Buthelezi (1992)

In simple terms, the *iQhugwane* is constructed of a series of concentric half circles of laths, cut by men, and set into the ground to the required diameter to form a dome. These are tied with grass, and then the whole framework is thatched by the women, starting at the bottom and leaving space for a doorway low enough to force one to bend down. The size of the structure is dependent on the number of central posts or *umGodi* that support it. The thatch is usually held down by plaited grass ropes, the floor plastered or '*usinda*'d on a weekly basis with a cow dung and water mixture. The original floor bed usually contains some measure of termite mound which acts as a binder. Inside is located a central hearth ringed with stones: the smoke from these fires acts as protection against insect activity. A grass topknot known as *inQhongwane* protects the most vulnerable part of the structure from rain. The door, *omnyango*, is built by specialists and consists of a mat of interwoven withies. It neither locks nor is it hinged; a brace consisting of a stick and a plaited rope holds it in place (Fig. 2).

The "properly constructed" beehive dwelling, as documented by Knuffel (1975) amongst the amaNgwane people, consists of up to 11 different types of grass, each with

a different function and integrity. However, this is not the sole solution, as the building form is also represented by a number of other approaches, in which some are decorated with a looped rope system, others with lozenge patterns, and some are merely thatched with little regard for the more permanent fixing of the grass with rope. In addition, an extremely rare example today is that in which a number of mats cover the frame and are tied down (Biermann in Denyer, 1973).

Importantly, there is little in the historic record that documents buildings as being decorated. Other aspects of Zulu material culture such as ceramics and beadwork are internationally renowned for their decorative merits, but little in terms of house decoration exists.

• The Rondawel

This is a building form that characterizes much of the contemporary rural landscape of KwaZulu-Natal, comprising a conical roof that is thatched or under corrugated sheeting, on a cylindrical base comprised of a variety of materials. The rondawel has, in most rural communities, taken over from the beehive dwelling in which the latter was deemed unsuccessful or impractical (Fig. 3).

The adherence to these basic principles of homestead construction as practiced in recent

Architecture in South Africa: Domestic Architecture,

Fig. 2 Typical (traditional) domed iQhugwane, part of reconstruction of the umGungundlovu homestead, emaKhosini, KwaZulu-Natal (Photo: Author 1997)



Architecture in South Africa: Domestic Architecture,

Fig. 3 Rondawel structure (Photo: Author ca 1999)



times has had to face many challenges, many due to the legislations and pressures placed through apartheid, but also dwindling resources, whether land or material. In addition, a recent rapidly rising middle class has accelerated the transitions of space and tradition, adding to the manner in which the hybrid architectures are produced. Only with these factors in mind is it appropriate to discuss new hybrids and the factors underpinning their development.

Pressures Creating New Building Forms and Spatial Planning

In the past, political initiatives by the erstwhile Colonial (1843–1910) and Nationalist Governments (1910–1994) have been influential in pressuring people living in traditional and vernacular homesteads to alter the form of the spaces and the buildings that they inhabit in order to conform to a European-imposed paradigm. Such pressure to build rectangular dwellings came

from legislation such as that of Hut Tax (1849–1906) which encouraged people living in circular buildings to build orthogonal structures, or else pay tax to the Colonial Government. Other prompts were less demanding: the gradual acceptance of Western furniture into rural homesteads, and, importantly, the stove (Frescura, 1989) is considered to be motivators for change of form (see also Harber (2000) for a discussion on mutated forms of building).

Although anomalies exist, aggregation of a number of homesteads into villages is not part of Zulu spatial planning framework. Forced resettlement prompted this in the case of the baTlokwa people around the Nqutu area, while at Msinga, aggregation into village groups is perhaps as a result of densification due to population explosion, leading to dwindling resources. An oral source suggested that aggregation was also due to the high incidence of faction fighting in which the proximity of other homesteads increased personal security.

Another manifestation of homestead clusters is the creation of villages through implementation of the Tomlinson Commission (UG61/1955), which intended to create settlement areas or “Land Betterment Schemes.” These aimed to release agricultural land creating community allotments, rather than itinerant subsistence farming centered around isolated homesteads. While a village culture certainly forms part of the social and spatial organizations of some of Southern Africa’s peoples, this was not true of the Zulu, and this initiative had limited success in KwaZulu-Natal.

• **Urbanization and Its Effect on Innovation**

As unpalatable as including the informal (shack) house (*imiNjondolo*) within the scope of non-Western domestic architecture is concerned, it should be addressed.

Rapid urbanization in the decades since the collapse of apartheid, together with the population explosion due in part to immigration from neighboring countries, has meant that the palette for choice of style and material has increased markedly. In KwaZulu-Natal, the 1980s were particularly disruptive, with

internecine warfare increasing the flood of refugees moving to the cities. In addition, a major drought and subsequent flooding in 1983–1984 meant that people that had lived in subsistence fashion in rural areas moved to the cities to find work having lost two harvests. This swelled the then small informal settlements based on the peripheries of Durban, located largely close to officially declared townships. In addition, after the deregulation of the Group Areas Act, people previously not allowed residence in the city moved in, again swelling the informal settlements.

The rise of the urban poor was an unfamiliar challenge, and even more for those who had made the move, with the materials that were traditionally used in vernacular housing being unavailable for cultivation, barter or free procurement. This meant that where thatch, stone, and timber had been used in the past, a monied economy denied the luxury of these items, and more urbane solutions had to be sought. This resulted in a largely orthogonal building form, comprised of found materials, some recycled, with a monopitch roof of corrugated sheeting or other recycled metal (Fig. 4).

The innovation in style, form, material, and accommodation has boundless variation, in which the manifestation of the interface of society, culture, economy, and belief has resulted in new buildings representative of a plethora of different influences. They are not necessarily site specific, and sometimes they deny cultural affiliation, sometimes embrace it to the fullest, and sometimes only convey the smallest of hints as to the ethnic makeup of the owners.

These pressures have stimulated a series of smaller-scale conceptual and practical decisions which contribute to the variety of approaches and their implementation.

• **Assimilation of Different Ideas**

Alterations in perceptions relating to the manifestation of the spatial envelope may occur, such as the move by communities, for a variety of reasons, to different vertical interpretations, yet retaining the same intrinsic

Architecture in South Africa: Domestic Architecture,

Fig. 4 Orthogonal building development – wattle lath and packed stone (Photo: Author 2002)



plan. This is particularly evident in the recently remembered beehive dome-strewn landscape of Msinga.

This district is probably one of the last areas in KwaZulu-Natal that closely follows a strong Zulu tradition, evident in all forms of material culture. While the beehive *iQhugwane* existed until relatively recently, a variety of factors combined with strong traditional and religious convictions allowed for compromise, precipitating the preference for the cone-on-cylinder rondawel. Few move from the circular format. An extreme example is the progressive rondawel, constructed from face brick, updated accommodating orthogonal furnishings, and resolved with an octagonal plan. This “octa-davel,” has a porte cochere, thus transcending the language of architecture, but also those of status and hierarchy.

• ***Innovation: New Manifestations of an Existing Form***

In Msinga too, a further innovation, wall decoration, developed with the adoption of the rondawel. The hardened wall surface of the building, as opposed to the grassed dome, enabled this. How and why this happened is not clear, but this does stand out as a phenomenon in the vernacular architecture

of KwaZulu-Natal. Initially, it would seem that the Hlubi and Pondo influence, in which painted bands to each side of the doorway, and sometimes the dado area, was adopted. This developed into now rare, painted chevrons (Frescura, 1981) and appears to have formed the beginning of an evolutionary path of embellishment. Moreover, the rapid decay of these structures in the natural environment allows for a speedy development of building decoration (Fig. 5).

A second innovation is the incremental “American flat,” a term coined by Harber (2000) that refers to the articulated form of the two-room dwelling that has been added to in a variety of ways, with conflicting and cascading roofscapes. The buildings are usually owner-built, sometimes over a long period of time in which parts are added as finances determine. This incremental building practice is common; thus, the banal factor of irregular income may determine the building form.

A particular idiosyncrasy of rural housing forms, and their officially constructed “Reconstruction and Development Programme” (RDP) counterparts, is the extension of identity in which the house is given a specific stamp that identifies it above its neighbors, through the vertical extension of the parapet

in a molded form. The correlation of this feature, I would suggest, is linked to Harber's "American Flat." These modifications strongly suggest a vested interest in property and commitment to the inhabited space. Time, money, and effort would not be spent in the manufacture of these elaborations, and this is common of both rural and urban and peri-urban houses. In this case, the parapet of a "flat-roof" or monopitch is raised beyond the roofline, stepped, or Dutch-gabled, to create some discerning feature on the landscape.

- **Adaptation of Material**

Another means of staying within the boundaries of culture, while still embracing the traditional forms of the vernacular environment, has been the adaptation and adoption of materials in a creative and sometimes very effective manner.

This phenomenon is not new. Early documented beehive domes were often described as "badly made structures," usually made out of flexible segments of *Dichrostachys* (sickle) bush, which had to be joined. Structurally, their pliability affected the shape of the building, as early photographs show a distinctive curve at the base, partly due to people squatting against the walls for support and partly in response to the weight of the building. The arrival of wattle (*Acacia mearnsii*) from Tasmania meant that a new timber with straighter and stronger lengths could replace the somewhat unwieldy sickle bush, producing a more rigid dome. Once its efficacy had been discovered, its subsequent popularity meant that it was adopted with alacrity by the Zulu, resulting in an altered form in which the shorter, straighter lengths of wattle produced a more upright building, with less of the characteristic bulge at the base. This innovation within the strictures of the beehive form provides for discourse surrounding the assimilative natures of the Zulu people and sets the tone for the development of vernacular architectures, not only varying the types of materials that can comprise such a structure, but also notionally in the adoption of different types of structure, whether the



Architecture in South Africa: Domestic Architecture, Fig. 5 Lady standing in doorway of decorated home in Msinga (Photo: Author 1999)

rondawel popular amongst the southern Sotho and Xhosa/Mpondo people, or the rapid adoption of the rectangular "cottage" in later years (Fig. 6).

Such translation of materials is emphasized in a particular structure from Richards Bay, in which an ancestral building was constructed in a homestead consisting largely of rectangular and orthogonal buildings. Its materials mutated. Rather than the anticipated grass covering common to such structures, the wattle laths of the *iQhughwane* were covered with white building plastic membrane usually used in waterproofing roofs. The base of this structure consisted of courses of concrete brick laid in a dry-stone manner, and the inside of this space was paved with similar bricks. The light



Architecture in South Africa: Domestic Architecture,
Fig. 6 iQhugwane constructed of alternative materials,
 Richards Bay (Photo: Author 1998)

inside was no less than ecclesiastical, an unexpected irony in the considered resolution of spaces.

- **Cultural Compromise**

Travelling around KwaZulu-Natal, one often sees rondawels under corrugated sheeting, with a topnotch of thatch, often extending part of the way down the roof slope. This was, some say, to appease the ancestors who recognize thatch, for the use of modern corrugated sheeting, and to guide them to their “home.” This signal to the ancestors is thus a cultural compromise between living under a material with less maintenance than thatch and at the same time allowing for a cultural continuum of religious belief.

Conclusion

Rapid immigration into urban areas, intermarriage, rapidly erected shelter, and immigration from surrounding countries all act as factors that force compromise in some of the dwelling

solutions. Being able to embrace the African and the Western tradition, whether medicine, architecture, music, art, or drama, creates new and exciting and controversial fusions, and this is also manifest in the vernacular architecture tradition. It demonstrates the unexpected, yet totally justifiable, given that the architecture embodies the very nature of the cultural traditions and expresses, to a large extent, religious conviction.

The traditional and vernacular architectures in KwaZulu-Natal in many ways mirror the culture of assimilation and adaptation that exists in other areas. The open-mindedness of the Zulu people to novelty, as well as the impetus of poverty being a motivator, mean that the new architectures that are being created have a special quality that places them in a specific time and place. In addition, as mentioned, the short lived nature of much of the materials that are used means that these buildings form a particularly fragile part of the architectural and material cultural record, and as such say much for our current society and its value systems. Documenting the works is not easy, and much of the charm of the vernacular built environment lies in its ephemeral nature (see Healy-Clancy and Hickel (2014) for contemporary interpretations of ‘home’ in Zulu culture).

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Architecture in Suakin

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Traditional architecture, developed over time by communities in response both to ecological conditions and availability of materials, differs considerably from place to place. Conditions along the Red Sea coast combine excessively salty-humid daytime heat and strong sunlight, cold nights, strong but predictable winds, sandstorms, and rare but torrential rainfall. The particular architecture developed in response to these conditions is collectively known as the Red Sea Style, which varies slightly through local initiatives, resources, and conditions. One of the few exemplar locations is the island-port-city of Suakin on its Sudanese coast. The heavily restored old town of Jeddah survives to a greater extent and is still inhabited, but Suakin's abandonment in the early twentieth century and its detailed recording especially in the early 1950s allow its preservation to best represent the style. Sadly, its buildings have now largely collapsed over the past century or so, following the islanders' gradual migration to Port Sudan after 1909. Nonetheless,

a few are now being investigated archaeologically and some are undergoing restoration, enabling direct study of construction techniques and a glimpse of the island's underlying architecture. Greenlaw's drawn record, the most accessible and most cited, sadly is not always confirmed in excavation.

Suakin's geographical situation is highly unusual: this low and now artificially oval coral island lies in a lagoon at the end of a long open channel from the Red Sea through a thick coral reef (Fig. 1). A long seasonal stream from the Red Sea hills farther inland annually deposits sandy sediment on the flat, almost desert plain behind the reef. These physical circumstances make it a virtually ideal harbor and port and are the key to its longevity. Structures recorded in detail on the island and the *Geyf*, its mainland extension, are as known in the nineteenth–early twentieth centuries, but archaeological evidence for earlier foundations and even earlier buildings recently has been exposed below. Today, the island is just over 3.1 m above sea level, with eleventh-century occupation found just above the present water table, but written records indicate its continuous existence from at least a century earlier.

The earliest excavated levels near the island's center have revealed postholes indicating wooden post-and-wattle structures. No adaptive features can be projected from the surviving evidence, but they may compare with traditional reed-and-branch huts (*'ushshash* and other names) still in use elsewhere along both coasts today. This building technique continued to be erected after the earliest masonry structures appeared in early sixteenth-century levels that broadly coincide with the arrival of the Ottomans in 1517. João de Castro's map (1541) already depicts the island crowded with two- and three-storeyed masonry buildings, together with a tall chimney-like tower often identified as the minaret of a mosque. It is the masonry structures (ubiquitous from this time onwards) that represent the "Red Sea Style" at Suakin.

Building façades faced toward the island's shore, to catch as much breeze as possible. The entire shoreline consisted of a repeatedly extended quay installation of mostly coralline



Architecture in Suakin, Fig. 1 Aerial view of Suakin island town, showing the radiating arrangement of buildings and streets. Government buildings, structures dedicated to the caravan trade, and mosques are mostly at the

right side of the island. It is connected to the *Geyf* by a causeway at the top (© SARS Greenlaw Archive GRE P034.06)

blocks. Roads and passages emanated from its central *suq* in an irregular, haphazard manner with many irregular open squares due to differential property ownership. Some 279 still privately owned properties are registered today, in addition to the government buildings. Each was surrounded and defined by a boundary wall. Freshwater had to be brought from the mainland and stored in cisterns, and (at least from the nineteenth century but probably earlier) common vertical shafts from roof to ground level and underground piping drained household wastewater. Drainage holes with guttering on roofs also provided rainwater. It was not until 1878 that a causeway was built, linking the island to the mainland (Figs. 1–2).

The vast majority of recorded buildings were private houses of varying scale, in inappropriately

named Turkish or Ottoman style (see Um, 2010, pp. 42–43) that followed general Islamic principles and requirements especially in terms of internal segregation and privacy. They combined open yards, courtyards, and breezeways within, usually having two- to three-storey interiors accessed by one or more stairwells up to the roof that also was utilized. Most individual rooms had at least one wall against an unroofed space. Commercial storerooms at ground level were a regular feature of the large traders' establishments; those on the immediate shoreline could accept goods directly from ships docked on the quay. Most structures as recorded postdate the arrival of the Egyptian army and bureaucracy in 1821. Many nineteenth-century government buildings and houses had transplanted but less appropriate Egyptian features, but the two mosques, customs installations,

and the central *suq* shops are traditional constructions. The study of *Beit Khorshid Effendi* underlines the point that all structures would have been continuously modified, extended, and repaired



Architecture in Suakin, Fig. 2 Street scene of several houses, including *Beit Sayd el-Safi* (House 225) on the left, showing the variety of *rawashin* and other exterior decoration. *Shish*-work is best seen at center left. Note the added vertical bars on the ground-level *rawashin* and windows and the deteriorating walls at ground level (© SARS Greenlaw Archive GRE P034.01)

over their lifetimes as changing needs dictated. The only certain early structure recorded is the *Beit el-Basha*, with archaeologically confirmed sixteenth-century foundations as Matthews and Greenlaw had thought, but their widely cited “three-period” phasing must be considered problematic. Original construction dates cannot yet be quoted with any accuracy on architectural criteria alone, nor can any subsequent modifications. The nineteenth-century *Muhafaza* structure, for example, clearly incorporates an older house of uncertain date and itself exhibits considerable evidence for constant modification and structural repair over its lifetime. Nonetheless, both mosques should be of early date, although an unidentified coralline building revealed in a limited trench below the *Shafa’i* mosque courtyard suggests the present structure may have replaced an earlier mosque.

Buildings were constructed of porous coralline limestone (coral rock), quarried from the reef south of the channel. Most were roughly shaped into similar-sized blocks with only the back side left as is. Coral from the inner reef, of finer texture, was smoothly ashlar-cut and used for some structural and focal features such as door hoods and for exterior carved decoration (Fig. 3). Building foundations were necessarily rather shallow but stable, consisting of oversize coral rocks atop coral bedrock. Walls were laid in courses with the inner and outer vertical surfaces flat, then infilled with coral rubble. They were strengthened using long wooden timbers and integral cross bracing at specific intervals and

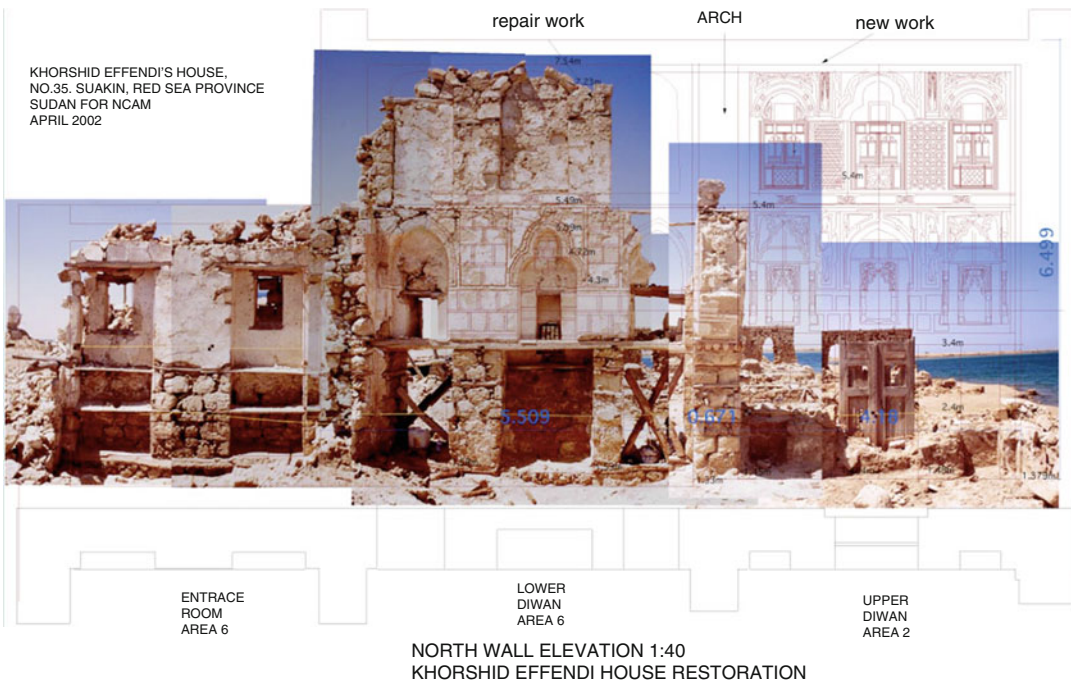
Architecture in Suakin, Fig. 3 Loose decorative blocks recovered from House 184 (*Beit el-Basha*) during Suakin Project excavations (Photographed by Laurence Smith, © Suakin Project)





Architecture in Suakin, Fig. 4 View of the upper storey of a partly collapsed house on Suakin Island, exposing its construction techniques. Note the large dressed surface blocks of the wall and its rubble infill and thick multilayered upper floor. The light-green rectangular wooden

beams in the foreground are rectangular beam fragments of a late *rawshan* (likely not from this house) and the rectangular roof and floor beams used during the island's more recent lifetime; earlier structural beams are round in section (Photo Jacke Phillips)



Architecture in Suakin, Fig. 5 Composite photograph of the north wall of House 35 (*Beit Khorshid Effendi*) as cleared in 2002 by the Suakin Project, with added line drawing of the original decorative plasterwork and its basic plan. The lower *diwan* is in the center, with the (missing) upper *diwan* at right and at left the entrance room (from the interior courtyard, a storeroom) with niches and inbuilt shelving. It is the only wall of the

house still standing; the crossed poles of doorways/windows were inserted by the excavators to prevent entry by tourists. The central niche later was realized to be an entrance doorway, blocked by the owners during its lifetime. Note the severe deterioration due to nearly a century of neglect (Photographs and compilation Michael Mallinson, © Suakin Project)

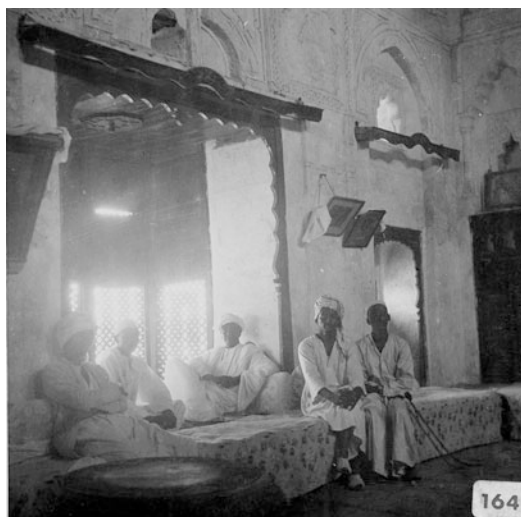
Architecture in Suakin,

Fig. 6 Individual block recovered by the Suakin Project from the upper *diwan* of House 35 (*Beit Khorshid Effendi*), with added pink plaster to infill the relief decoration (SKN02/C17, photographed by Laurence Smith, © Suakin Project)



features, including staircases and floors. Floors and roofs were usually laid palm canes over timbers, covered with palm fiber and rendered, although stone-flagging is known at ground level (Figs. 4–5). Lime mortar and render, composed mostly of powdered coral, sealed all wall surfaces and most structural timbers, reflecting the sunlight externally and brightening interior spaces, although most external timbering was exposed to allow later maintenance. Interior walls were thickly rendered, with the most important public rooms of many houses highly decorated in a wide variety of mostly geometric designs in deep relief. The elaborate relief decoration of the *Beit Khorshid Effendi diwan* was partly infilled with a contrasting soft pinkish plaster (Fig. 6). Other houses used dark pebbles decoratively inset into wet plaster, and several employed painted designs. Interior wall niches and cupboards (some with integral shelving and added doors) were framed in wood or the finer coralline, mostly rendered over. Some interior exposed woodwork such as doors, windows, niches, and shelving may have been painted. Both interior and exterior *mastaba* benches also were integral (Fig. 7).

The glory and most distinctive feature of these houses was, however, the *rawashin* (sing. *rawshan*), projecting balcony windows intricately pieced together from separate wooden



Architecture in Suakin, Fig. 7 Interior of House 35 (*Beit Khorshid Effendi*), in the upper *diwan* showing the extensive decorative plasterwork and use of structural and decorative woodwork. The men are seated on the *mastaba* (integral bench), partly in the alcove created by the projecting *rawshan* of the house façade behind them. Note the filtered light created by its *shish-work* (© SARS Greenlaw Archive GRE P102.02)

planks almost exclusively using mortise-and-tenon joints with wooden pegs (Figs. 2 and 8). Traditionally painted red and green, with individually shaped flat decorative elements added to external flat vertical surfaces to create shade patterns, they contrasted strongly with the buildings'



Architecture in Suakin, Fig. 8 Color view of *rawashin* as reerected in the *Muhafaza* courtyard in the 1930s, removed from deteriorating private houses on the island. These are late examples of simplified and inferior construction but indicate the contrasting colors typical of the decorative woodwork involved. These colors also are indicated in Fig. 2 (© SARS Greenlaw Archive GRE P147.03)

white walls. *Rawashin* incorporated large areas of overlapping, creatively shaped thin wooden strips that, when assembled, produced elaborate open latticework panels (*shish*) within an extensive structural framework. They served multiple functions, the *shish* allowing cross-ventilation, air conditioning, and sunlight filtration into the interior rooms while also ensuring privacy. Sliding sash-panels and shutters allowed greater control of wind and sun. Those on the ground floor were barred for security. *Rawashin* also provided a deep internal seating platform for social occasions (Fig. 7). Smaller windows also employed these same functional features to varying degrees, depending on size and location. The simplest and also the internal ventilation grilles

consist merely of framed *shish*-work. All elements were individually hand carved.

Recent limited analyses of Suakini architectural wood have identified almost exclusively indigenous *acacia* and *ficus* hardwoods for smaller structural timbering and carved elements and local hollowed-out palm wood for guttering. Other than *Shorea* hardwood imported from Southeast Asia for *shish*-work, virtually no other imported wood has been identified. Java teak, widely cited in print as imported from the same region for construction use at Suakin, has not yet been identified among the analyzed wood. This strongly suggests many wooden features were locally produced, not imported ready-made as sometimes suggested.

Regular maintenance was necessary to combat weathering, loss of render, and rising damp, especially following rainstorms. Even the earliest nineteenth-century photographs all illustrate the deterioration of (especially) the base and lowest courses even of well-maintained, inhabited buildings (Figs. 2 and 4). Lack of maintenance after the island's abandonment is the principal cause of still-ongoing building collapse and the present ruined state of the island.

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Architecture in Sumba

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The architecture of the Indonesian island of Sumba is to this day strongly based on vernacular traditions, which include buildings of rectangular layout, constructed from wood and bamboo with large, grass-thatched roofs. Today less than one fifth of Sumba's population live in and around one of the two towns Kota Waingapu and Kota Waikabubak on the island, while the majority of the population lives in rural settlements ("City Population," 2014). The location of the villages was traditionally dominated by the need to defend the settlements. Thus, they were preferably located on hilltops and were surrounded by thick vegetation, thorny hedges, fences, and stone walls (Forth, 1981, pp. 46–50; Kuipers, 1998, pp. 24–25, 30–31). Today many of these settlements remain in their original location, but since the need for defense has declined, numerous families have moved closer to their fields, to water sources, and to roads, and larger settlements or towns have formed around clusters of traditional villages.

Within the traditional village, the houses are the most prominent buildings. They are arranged

Architecture in Sumba,

Fig. 1 Village in West Sumba. The houses are arranged around a narrow square. In the center of the village, stone graves and a small *marapu* house are set on low stone platforms (©author)



in two rows facing each other across a longish square that may be quite narrow due to the limited space on top of the hills. The orientation of the village follows the natural features of the landscape. Since on Sumba many rivers and mountain backs run along a north–south axis, the villages are also often extended along this axis. As a consequence, the houses either face toward the east or the west, resulting in a “morning side” and an “afternoon side” of the village (Adams, 1974, pp. 326–327). In the Sumbanese perception of space, houses and villages are oriented according to the flow of rivers (upstream–downstream) and the course of the sun (sunrise–sunset) (Forth, 1981, pp. 50–57). As in many Southeast Asian cultures, this spatial orientation is imbued with a strong symbolical meaning and reflects the cosmological concept of the Sumbanese people (Forth, 1981, pp. 66–72).

For moving through the village, walkways are established along the front sides of the houses. These may be used for everyday activities, such as drying crops or as playing areas for children, together with the space directly in front of the house. During ceremonies, the whole village square is used for dancing, sacrifices, and meetings. The central village space, which is often marked through a low wall or platform, is

considered sacred, and parts of it may only be entered by certain people and on certain occasions. In this central village space, different sacred structures are located, which may include village altars; stone statues; the *marapu* house, which serves as a village temple; and traditionally also a skull tree, where in former times skulls obtained through headhunting were displayed in order to ritually renew the health and fertility of the community (Hoskins, 1996a, p. 224). Furthermore, the graves of important ancestors can be found in the center of the village, located as close as possible to the houses of their heirs to ensure their continuing guidance in all important matters (Fig. 1). The rectangular table- or sarcophagus-shaped graves are made from stone – or more recently from concrete – and some feature elaborately carved headstones. The monolithic stone slabs, weighing up to several tons, are to this day dragged by hand from the stone pit to the gravesite. The stone graves are symbols of status, since their construction and the dragging of the stones require large labor forces and are accompanied by expensive ceremonies (Gunawan, 2000, pp. 36–37; Kurniawan & Pramanasari, 1994, pp. 349–352; Tjahjono, 1998, p. 49; S. Lernet, personal communication, December 2007) (Fig. 2).



Architecture in Sumba, Fig. 2 Stone grave with a delicately carved headstone, depicting symbols and ornaments, animals, and a human figurine (©author)

Along the sides of the square, two types of houses, *uma*, are aligned, which feature a rectangular or almost square layout. Both types of houses serve as dwellings and are similar in layout, but one type is additionally believed to serve as home for the ancestors' spirits and is therefore subject to a deep spiritual meaning and frequent ceremonies. The two types of houses are distinguished by their roof shapes. The *uma kamudungu* ("bald, bare house") features a simple hipped roof, while the *uma mbatangu* ("bridge house") (Forth, 1981, p. 23) features an extremely high and steep hipped roof, which is surrounded on all four sides by a roof area of lower pitch. This towering central roof area of the *uma mbatangu* is where the spirits of the ancestors are believed to reside and where the rice crop and heirlooms are stored. It is thus the most sacred part of the house with access limited to only one or two members of the family.

In its vertical composition, the Sumbanese house follows the typical Southeast Asian

concept of the house as a tripartite structure (e.g., Lehner, 2008, pp. 9–12; Waterson, 1990, p. 100). Thus, the space between the posts, which form the substructure underneath the raised floor, is considered the zone for animals and is often used as a stable. In many Southeast Asian cultures, this area underneath the house is avoided altogether, since it is considered the area of unkind earth spirits. Above the substructure, the middle zone is the space where the people live on a raised floor. The raised floor not only provides a dry and safe living area away from all sorts of animals but also an area lifted off the spiritually ambivalent ground. Finally, the roof space is associated with the ancestors' spirits. On Sumba, as in many other Southeast Asian cultures, this upper zone is a sacred space within the house. During ceremonies, the spirits of the ancestors are believed to descend to the middle zone, the space of the people, to support and guide them in decision-making and other matters.

Inside the *uma mbatangu*, four large, wooden posts that are often adorned with carved, geometrical patterns support the towering roof. The posts are earthbound and reach all the way up to the attic that supports the central part of the roof. On their upper ends, they carry large, wooden disks that are also often covered with carvings. Similar wooden disks can be found in granaries of many cultures worldwide to prevent rats and other vermin from reaching the stored crops. Inside the Sumbanese house, these disks have lost their function as rat guards, since vermin may reach the roof via any of the other posts supporting the outer part of the roof, but they may point to the possible origins of this house type as a granary. The use of granaries as temporary or permanent dwellings for boys, men, or visitors and their subsequent development into proper dwellings by enlargement and addition of platforms can be observed in many cultures of the neighboring islands, such as the Donggo on Sumbawa, the Dagada in East Timor, the Ema in West Timor, and the Toba Batak on Sumatra or on Alor (e.g., Domenig, 2003, pp. 62–64, 2008, pp. 500–502; Waterson, 1990, p. 53). The Sumbanese house seems to be an even further developed type, where the dwelling fully surrounds the former



Architecture in Sumba, Fig. 3 3D section of an *uma mbatangu*, showing different types of posts supporting floor, roof and attic, the towering roof structure, and the design of the interior space (©R. Humenberger & author)

granary, which is now a fully integrated part of the house but still features rat guards, its own roof construction, and the spiritual meaning that granaries are generally imbued with.

During the construction process of the house, the four central posts are the first part of the house to be constructed. The right front post is raised first, with the other three posts raised proceeding in an anticlockwise direction, i.e., “moving to the right” (Forth, 1981, pp. 27–28). On Sumba, as on some other Eastern Indonesian islands, raising posts in a clockwise direction and thus “moving to the left” is associated with death (Forth, 1981, p. 172; Visser, 2003, p. 344), in contrast to most Asian cultures, where the clockwise movement, for example, in Hindu and Buddhist rituals, is considered the “direction of life” (Lehner & Doubrawa, forthcoming, p. 28). Once the central posts are planted, the attic and the towering part of the roof are constructed. Thus the central part of the house is finished, before two further concentric series of posts supporting the outer, less-sloping part of the roof are placed around the four

central posts. Only when the construction of the roof is finished, separate posts supporting the raised living area are installed, and the living area is finished. Walls are installed along the second series of posts, forming a large space inside the house with the four central posts being the only vertical structural elements inside the house. The living area is structured with different floor levels and platforms, each serving certain functions. Light walls or curtains may be added to separate private rooms for sleeping, which seems to be a rather recent development. Depending on time management, the roof may be thatched before or after the living area has been constructed (H. Ndamangilik, personal communication, April 2007) (Fig. 3).

The building material used for the main structure of the house is wood, traditionally of round sections. Smaller structural elements, such as the rafters, are made from bamboo cane. Tightly tied bamboo canes are also used to form the floor as well as internal platforms, partitions, and shelves. Floors and walls are today often made of timber

Architecture in Sumba,

Fig. 4 Detail showing different types of lashed joints to connect the beams and roof structure of a house (© author)



A

boards that allow the use of western-style furniture. All elements are traditionally tied together with rattan or lianas, structurally forming a three-dimensional grid that possesses flexibility and at the same time a high stability (Fig. 4). This makes the Sumbanese house extremely well suited for the frequently occurring earthquakes. The earthquake resistance is additionally enhanced through the storage of rice in the attic inside the towering roof. Several tons of rice may be kept in the attic at times, which accounts for a heavy and stable core structure that is surrounded by the compact, lightweight, and flexible rest of the house (I. Dapawole, personal communication, April 2007). In terms of earthquake resistance, this is an ideal structural concept.

The large roof of the house is traditionally thatched with bundles of *alang alang* grass, which are tied to the battens and fixed along the ridge with a timber board and two prominent wooden “horns.” Today, instead of grass, corrugated iron may be used as roofing material. In contrast to metal sheets, the traditional thick layer of grass provides good insulation against the heat and muffles the sound of the heavy rain. The roof features low eaves that may reach almost to the raised floor, thus blocking all direct sunlight from the interior of the house and the verandas and providing shaded, cool, and dry areas for living and working, independently of the prevailing weather. The interior of the house remains rather

dark. Only little natural light filters through the floor and walls, and the only large openings in the walls are two doorways.

The lack of light inside the house is a typical feature of many house types in Indonesia. The Sumbanese house features one or two verandas that provide well lit but shaded space in front of the house and that are used for nearly all daily activities. They serve as transitional areas between the public village space and the private interior of the house and are used for receiving guests, meetings and discussions, working, and generally spending time during the day. While more or less every person is allowed to enter the veranda after having requested to do so, access to the interior of the house is much more limited (Fig. 5).

The interior of the house is divided into two parts with different functions. In West Sumba this division is also of physical nature, and a low wall of bamboo runs from the front to the back of the house. While the left side of the house (as seen facing the front of the house) is considered the private part of the house and is closely associated with women, the right side of the house is of semiprivate character and is closely associated with men (H. Ndamangilik, personal communication, April 2007). This gendered differentiation does not refer to the actual users of each side but rather to the function and its respective connotation within Sumbanese society. Thus the private

Architecture in Sumba,

Fig. 5 Front veranda decorated with skulls of buffaloes and pigs that were sacrificed during ceremonies. This decoration represents the wealth and prestige of the house and its owners, who provided the animals (©author)



family rooms and platforms are located in the left side of the house, which is used for sleeping, working, cooking, and the storage of personal possessions, tools, and the water jars, and may only be entered by family members. In Sumbanese society these functions are closely associated with women, therefore leading to this side of the house being considered the female side of the house. The right side of the house is used for ceremonies and as sleeping area for guests and can thus be seen as a semiprivate space. Since in Sumbanese society men are expected to take care of the communication with the outside world, this side of the house is considered to be male.

Each side of the house is entered through a separate door, which can be reached via a veranda. While the door to the male side of the house is always in the front façade and can be reached via the front veranda, the door to the female side of the house, and therefore the respective veranda, may either be in the left half of the front façade or in the left or the rear side of the house. In houses in West Sumba, where the left and the right side of the house are divided through a low wall, one has to leave the house and reenter it through the other door, in order to reach the other side of the house (Fig. 6).

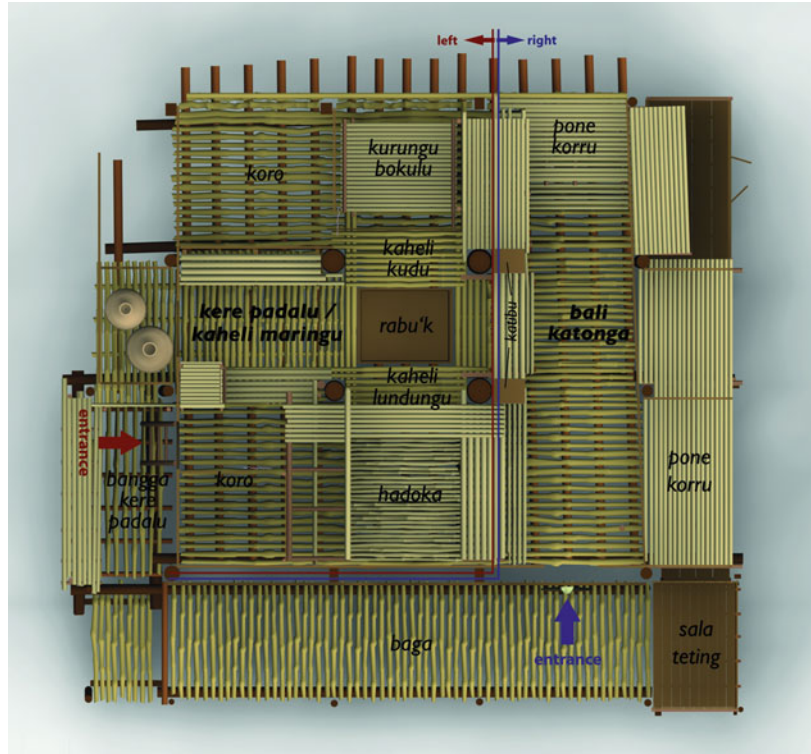
The center of the house is occupied by a large fireplace with three hearth stones. Traditionally the fireplace is the only source of light inside the

house. It is not only used for cooking, but is also the center of many ceremonies concerning the house and the clan. The four large posts surrounding the fireplace define the seating order during ceremonies and symbolize the unity of different members of society (Gunawan, 2000, p. 42; Forth, 1981, p. 27; H. Ndamangilik, personal communication, April 2007). Offerings for the ancestors are placed on the disk-shaped rat guards on the upper ends of the four posts. The four posts, the attic, and the fireplace form the physical, functional, and spiritual center of the house (Fig. 7).

The architectural traditions have been widely retained, and to this day, many examples of the above-described houses and villages continue to exist. New materials, such as corrugated iron sheets and concrete, have been introduced to the island, but the number of timber and bamboo buildings is still very high and people continue to live in the traditional houses. Consequently the house still is of central meaning for the Sumbanese society. The term *uma* not only describes the physical building, but also the family or clan feeling connected to and living in a certain house. The people in the houses are related to each other resulting in “mother houses” and “child houses.” Even if a house has been abandoned and has collapsed, the people will still try to rebuild it as soon as possible (Gunawan, 2000, pp. 56–57). Thus, the idea of

Architecture in Sumba,

Fig. 6 Ground plan of a house in West Sumba including the terms for each area of the house that each serves a designated function. The four central posts surrounding the hearth (*rabu'k*) can clearly be seen. Note the separate entrances to the left and the right side of the house (© R. Humenberger & author)



Architecture in Sumba,

Fig. 7 Interior of a house in West Sumba, showing the four central posts with wooden disks on their upper ends. They surround the hearth with three hearthstones and a rack for storing wood, food, and cooking utensils. Note the different floor levels and platforms, all constructed with tied bamboo cane (© author)



the house continues to exist through the memory of the connected people and may even lead to the rebuilding of the physical structure.

The importance of the traditional house for the people in Sumba has led to a high preservation rate of buildings following traditional concepts

and in many cases even to the construction of new houses, even though the required timber has become hard to obtain. Nevertheless, the perpetual use and rebuilding of these houses ensure the continuity of the spiritual and cultural identity of the Sumbanese people.

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Architecture in the Andes: Domestic Architecture

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The domestic built environment, encompassing domestic houses and other open spaces including patios and plazas, has been of interest to Andean archaeologists for over 100 years. For nearly as long, though, the archaeology of the everyday domestic realm and its architecture has taken a backseat to the study of temples and tombs. That said, since the 1970s, some have shifted focus to the archaeology of everyday life, which in most cases takes place in and around the quotidian built environment, which is often demarcated and internally differentiated by the structure of domestic architecture. Domestic architecture in the Andes and elsewhere can often be broken down between common and elite, and these will be discussed separately here. I wish to present the range of domestic architectural patterns in the Andes chronologically and regionally, with primary focus given to the patterns on the Pacific

coast and the central Andean highlands. I then discuss the theoretical arguments that have focused on domestic architecture.

Some of the earliest discussions of households and domestic architecture come from the north and central coasts (Donnan, 1964; Willey, 1953). In the past 30 years, though, an increased interest in the archaeology of the everyday has led some in the Andes to focus on the analysis on the household with studies of household- and community-level architectural patterns (Moore, 2012; Nash, 2009).

Early domestic architecture in the Andes was in general quite ephemeral and difficult to see or recover in the archaeological record. Over the past 4,000 years, though, a wide range of variability in domestic architectural patterns and styles has developed in the Andes on both the coast and in the highlands.

Coastal Patterns

On the coast of Peru, perhaps the most ubiquitous and long-lasting domestic architectural tradition involves the construction of *quincha* (wattle and daub) walled structures. This form of construction is economical and common in many regions of the world; walls are built from branches or reeds woven through thin vertical branches or sticks, which are inserted into linear rows in the ground. Structure corners are often formed with larger diameter vertical posts. In many cases, but not all, clay or mud is then applied to these walls, creating a relatively durable wall. Quincha has been used for several thousand years for the construction of commoner domestic houses on the coast and is still used today. Slightly more complex adaptations will have one or more foundation courses of cobbles or adobe bricks with perishable walls rising from this base.

Some of the earliest evidence for domestic architecture on the coast comes from the Chilca valley. At the preceramic site of Chilca, Donnan (1964) has described a series of conically shaped, semisubterranean domestic pithouse structures with circular or semicircular plans and largely perishable walls, some of which had fallen in

and been covered with sand, creating uncommonly well-preserved early domestic contexts. Walls were constructed here of bound cane and wood and occasionally braced with whalebone. At the site of Paloma, also in the Chilca, Quilter (1989) excavated a series of similar dwellings located near to the economically valuable lomas ecological zone.

In many of the western valleys, domestic architecture was placed on terraces, and we have good examples from the Nasca region for domestic constructions with stone and cobble foundations. In their studies of domestic and community organization, Conlee (2000), Van Gijseghem and Vaughn (2008), and Vaughn (2005, 2009) have documented semicircular to semirectangular structures which were organized into groups or households of multiple structures connected by bounding walls and often surrounding a central open space or patio. This general pattern was probably very common in coastal valleys in the north and south from early in time through to Spanish contact.

Middle-class domestic architecture within the Moche polity (or polities) (AD 100–700) has been investigated at a number of sites on the north coast, primarily at large Moche political centers. At sites like the Pyramids at Moche in the Moche valley and Pampa Grande in the Lambayeque valley, middle-class Moche constructed and lived in complex urban zones of adobe domestic architectural spaces interspersed with more public, open plazas and connected by networks of streets and alleyways (Van Gijseghem, 2001). Roofed rooms and open patios were delineated by adobe walls that were often plastered. Domestic styles also included the placement of low benches along some interior walls, some becoming the locations for domestic burials at various points in a structure's life span. Corridors and ramps connected domestic spaces, rooms, and patios. At the large Moche center of Galindo in the Moche valley, Bawden (1982) has intensively studied patterns of commoner and middle-class domestic architecture elucidating fine differences in patterns, construction styles, and materials in analyses of social and community organization and class formation.



Architecture in the Andes: Domestic Architecture, Fig. 1 Zone of U-shaped audiencia rooms within a Chimú Ciudadela at the site of Chan Chan. This is from the Tschudi Complex (Photo by the author)

On the coast, the ubiquitous and relatively simple structures of the common people can be contrasted with the massive and elaborate domestic architectural patterns of elite and ruling classes. During the Late Intermediate Period (AD 1000–1476), the Chimú Empire developed and expanded over much of the north and central coasts of modern-day Peru. It was centered at the capital of Chan Chan in the Moche valley, an urban center built up around a series of ten huge royal *ciudadelas* (Moore, 2005; Pillsbury & Leonard, 2004). These acted as the domestic palaces, administrative centers, and burial places of the Chimú ruling class. Elite domestic architecture here was characterized by the creation of monumental spaces, including large open reception plazas, repeated administrative features called *audiencias* possibly associated with state storage facilities, elaborate niched halls, domestic spaces, and large royal mortuary platform mounds (Fig. 1). Interior movement of people was carefully controlled and monitored through the use of narrow doorways, long narrow corridors, and other architectural features meant to control access. Importantly, all of these features were carefully separated from the outside, everyday world of the masses by battered compound

walls which measured nine meters in height (Moore, 1996, 2005; Moseley & Mackey, 1974). The extreme class-based social separation present in Chimú society was thus materialized and made permanent through its physical representation in the built environment of royal domestic architecture.

In the Rimac and Lurin valleys of Peru's central coast during the Late Intermediate Period (AD 1000–1476), the political environment was one of a series of interrelated and possibly confederated complex chiefdoms called the Ychma society. The characteristic architectural feature of the Ychma is the "pyramid with ramp," often considered to have functioned as elite domestic residences (Eeckhout, 1999–2000). These were characterized by large rectangular adobe platform mounds fronted by open plazas or patios and reached by long prominently located ramps. Domestic rooms, cooking areas, and storage spaces were present on the leveled summits of each of these platforms, and each of these complexes was separated from exterior spaces by a defining wall. The private living spaces of the elite were situated on high while semipublic gatherings may have taken place within the plazas below. While at some Ychma sites only a single

ramped pyramid residence was present, many existed at the oracle site of Pachacamac, forming an elite domestic zone. In both the Ychma and the Chimú cases, though perhaps the Chimú case is the more extreme, a major function of the elite domestic built environment was to physically separate ruling elites from common people, materializing existing social differences.

Highland Patterns

Although the earliest domestic spaces in the Andean highlands were probably the interiors of caves with space divided into functional zones and features such as hearths and storage pits, later open air settlements of the archaic period saw the construction of domestic houses which were often, but not always, round to semicircular in plan and were set on the surface or semisubterranean in profile. These were created from a perishable superstructure, occasionally with a partial stone foundation. These kinds of relatively ephemeral domestic structures have been seen at sites like Asana (Aldenderfer, 1998) and Jiskairumoko (Craig, 2005; Craig, Aldenderfer, Baker, & Rigsby, 2010) in the south central Peruvian Andes. At Asana, domestic architecture shifted through time from small (~2.5 m diameter) round houses bounded archaeologically by post-molds to slightly larger, semicircular structures also brush covered. Still later, Archaic domestic structures here were oval to rectangular and were probably also walled and roofed with perishable materials (Aldenderfer, 1993b).

Archaeologists have traditionally recognized a generalized dichotomy in the shape of domestic structures in the Andean highlands as opposed to those along the coast, with highland houses generally being round in shape and those on the coast often being rectangular in plan. Although this is generally the case in many regions, there are notable exceptions. Good examples of highland round domestic structures come from the work of DeMarrais (2001) and the broader archaeological project (D'Altroy & Hastorf, 2001) that traced the later prehistory of the upper Mantaro valley

through community and household levels of analysis. Domestic architecture here was characterized by circular structures and associated outdoor patios and activity areas, forming patio groups. These complexes ranged from simple, with one or two circular structures, to more complex integrating multiple circular buildings and smaller possible storage structures forming patio groups and possibly representing immediate family units. Large communities were made up of many of these patio groups integrated by a network of corridors. Bermann (1994) described similar spatially distinct circular domestic houses for villages at the southern end of Lake Titicaca in the south central highlands and documented changes to domestic and political economy at the household and community levels. Domestic architecture in the Chachapoyas region of the northeastern slope of the Andes is characterized by large circular stone structures often densely packed into hilltop or ridgeline communities (Fig. 2). Although some of these may have functioned as communal spaces, most were domestic, containing benches, hearths, storage features, and typically domestic suites of artifact classes (Guengerich, 2014).

Immediately west of Chachapoyas, the Cajamarca region of the north central Andes sees another pattern. Here, circular structures are rare to absent and domestic architecture is characterized by the construction of often-agglutinated rectangular stone rooms. Domestic complexes are often located on narrow domestic terraces, with roofed rooms closely associated with open patios and plazas and terraces connected by stone stairways (Julien, 1988). These patterns have been described at sites like Tantarica (Watanabe, 2002) and Yanaorco (Toohey, 2009) (Fig. 3). This pattern of rectangular design in the domestic built environment is also present in the Recuay culture of the Callejon de Huaylas in the central highlands (Lau, 2010).

Elite domestic residences in the highlands can perhaps best be exemplified by the country palaces of the ruling Inka elite such as at Machu Picchu (Salazar & Burger, 2004) and by elite residential structures associated with regional administrative centers like Huanuco Pampa



Architecture in the Andes: Domestic Architecture, Fig. 2 Densely spaced round domestic structures of the Chachapoyas

(Morris, 2004; Morris & Thompson, 1985). The domestic built environment of the Inka ruling elite was designed to integrate an architectural stamp of Inca power within the local physical and social landscapes, utilizing all of the classic architectural features of the Cusco Inca architectural style including the repeated *kallanka* pattern, double jammed doorways, windows, and niches and both cut stone polygonal and ashlar masonry styles.

Theoretical Directions in the Study of Andean Domestic Architecture

From a theoretical standpoint, the investigation of domestic architectural patterns has focused on a number of broad avenues of inquiry. An interest in ethnicity, identity, and interregional interaction has utilized the study of domestic architecture. Patterns in the domestic built environment have also been brought to bear on investigations of community and regional social organization

and the study of social differentiation and stratification. Finally, architectural patterns are also utilized in the analysis of domestic economy at both the household and community scales.

Community Organization, Economy, and Social Organization

Household organization and patterns of economy are reflected in the organization of domestic space. Community organization and social organization on the other hand have been documented through the analysis of patterns of domestic architecture and its variability across archaeological sites. Domestic architectural units are often described as repeated patterns of architectural areas such as living/sleeping rooms, cooking rooms or spaces, storage features, and open patios which may be the locations of craft production activities or social gatherings (Bawden, 1982; Van Gijseghem, 2001; Vaughn, 2005). These minimal suites of domestic spaces are repeated at sites in the Andes both on the coast and in the highlands,



Architecture in the Andes: Domestic Architecture, Fig. 3 Densely spaced domestic rooms and long corridors (to the *right*) on a broad domestic terrace at the Cajamarca site of Yanaorco (Photo by the author)

perhaps representing immediate family units. Variability among these units has been utilized to understand community and social organization better. Inequality in variables such as patio size, quality of wall construction, and elaboration of interior spaces can be indicative of the presence of strong economic or class distinction at sites like Galindo in the Moche valley. There, classes were physically separated with large adobe walls running between zones of low-status dwellings and those of higher-status residents. Architecture here is used to physically ensure social separation within the community (Bawden, 1982). The materialization of social separation is perhaps best seen in elite domestic architecture at the site of Chan Chan on the north coast (Conklin, 1990; Kolata, 1990; Moore, 1996; Moseley & Mackey, 1974).

Ethnicity, Identity, and Verticality

As a culturally conservative form of material culture, domestic architectural patterns are

believed to mark social identity and be slow to change (Parker Pearson & Richards, 1994). Because of this conservative nature, it has been used to study issues of cultural identity in the Andes (Aldenderfer, 1993a; Aldenderfer & Stanish, 1993). Aspects of domestic architecture including form and plan, as well as the patterning of activities within space, are seen as outward signs of ethnic identity. Aldenderfer and Stanish's (1993) work has been done within a broader interest in Andean archaeology in themes of economic complementarity and verticality. Shifts in the organization of local domestic spaces can also signal the development of novel identities as well as sociopolitical relations as has been proposed for the late Moche site of Galindo (Bawden, 2005) in the north and on the south coast in the Nasca region (Van Gijsegheem & Vaughn, 2008).

This necessarily brief review of domestic architecture in the Andes is limited in breadth and could not hope to discuss the entire range of

the subject geographically, culturally, or temporally. Here, I hope to have presented some of the range and richness of patterning in the domestic built environment of the Andes and the anthropological questions that continue to be asked of it (Figs. 1, 2, and 3).

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Architecture of Fiji

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The Fiji Islands are part of Melanesia, one of the large regions within Oceania. They are situated geographically in the easternmost part of this area. Islands belonging to Polynesia can be found very near to the East, thus making the Fiji Islands a contact zone toward several Polynesian groups. It is assumed that the Islands were first settled by the direct ancestors of the Polynesian people (Kirch, 1997). While formerly it was suggested that there was later strong contact and thus adsorbed influences from some Melanesian Islands, newest archaeological evidence does not seem to support this (Clark & Anderson, 2011). It is interesting that vernacular architecture found on parts of the islands nevertheless shows very strong parallels to Melanesian building types (for a more detailed discussion on this, see Freeman, 1986, p. 16). While Polynesian influence in the form of Samoan and Tongan cultural ideas and architecture is more recent and well documented, the possible direct Melanesian connections remain vague, strongly debated, and more difficult to trace, if present at all. The rugged landscape and the division of Fiji into many smaller Island groups allows for a comparably high diversity in built forms, in which also the proximity of certain island groups to others plays an important role: While, for example, the highland areas of the main island, Viti Levu, were for most of their history very isolated and their architecture thus subject to mostly local development and evolution, small islands like the Lau group always had been connected via intensive sea trade to other domains, as in the case of the aforementioned Tonga group. Thus, vernacular architecture on Lau is heavily influenced by Tongan building practices and can in fact be regarded closer to that tradition, than the building culture of Viti Levu (Fig. 1).



Architecture of Fiji, Fig. 1 House in Navala Village, Western Viti Levu Highlands

History of Settlement and Origins of Traditional Buildings

The first settlements on Fiji were established approximately 3,200 years ago (e.g., Lapita site of Nanutuku, Kirch, 1997), by a people whom archaeologists attribute to left behind remains named the “Lapita culture.” While some aspects of the emergence and expansion of the Lapita culture are still subject to a certain amount of debate, it can be safely argued that these people spoke a form of Austronesian language and can be regarded as the ancestors of today’s Polynesian people. They came from the West and insular Southeast Asia is regarded as the geographic area where the characteristic traits of this culture formed. As it is difficult to associate a complex of archaeological remains with ethnic and linguistic data, there are diverging scientific opinions on the formation period of the cultural complex in the insular Southeast Asia region. What seems to be sure is that the ancestors of the Polynesian people settled Fiji bringing material culture with them, which consisted apart

from a very characteristic set of pottery of a tradition of building stilt buildings over the water or on the shore near the coastline. According to Kirch (1997) gradually these settlements shifted inland as the islands were colonized. Today no stilt buildings can be found in the Fiji Islands. This can be explained by a development, in the course of which buildings were rather built on earthen platforms, rather than on stilts. The earthen platforms provide a high floor, similar to the stilt house, and keep the inhabitants safe from ground moisture. Additionally the earthen platforms did evolve strong symbolic meaning, as at some point in history people started to be buried within these mounds under the house, and thus the platform became an object associated with the spirits of the ancestors.

A very plausible reason for change from stilts to earthen platforms is that unlike in insular Southeast Asia in Oceania, no malaria and no dangerous or highly venomous kinds of snakes or spiders can be found, which would make living in a stilt house very practical. To live in



A

Architecture of Fiji, Fig. 2 Virtual reconstruction of a fortified lowland village after Parry (1997, p. 100)

a high and well-ventilated place has been proven a good protection against mosquitoes, especially the malaria-transmitting *Anopheles* variety, as they tend to fly at a certain low height and avoid places with good air circulation.

Neither are there any large predators present. In insular Southeast Asia tigers as large predators represented a real source of danger even for humans. As accounts from Java, which was sparsely settled even a 100 years ago, suggest, people were afraid (and with good reasons) of these animals.

Apparently the protection (high) stilts could offer was not needed anymore. However, the architectural type of stilt houses lived on in the Vale ni Moce (Figs. 26, 27), the so-called sleeping houses. These were small cabins (usually built for persons of special importance) on stilts offering protection against raids in the pre-colonial era. They are not built anymore, and whether they had been an archetypical remnant of earliest history or reinvented at some time later is not clear.

However, one discussion point remains: One form of vernacular building, which was common in Western Viti Levu (the main island of Fiji), the

Were Rausina, is difficult to explain architecturally as a direct legacy of stilt Lapita buildings: While Lapita houses were rectangular, the ground plan of Were Rausina is round. This is such a fundamental change that it either requires the local invention of a new house type or strong outside cultural influence. Of course we can credit local invention with the creation of the building type, but it is remarkable that on several near Melanesian island groups (e.g., New Caledonia), very similar round buildings can be found. Although archaeological evidence does not support ideas of direct connections, the geographic and typological proximity of the building types suggests that there is at least some link between these phenomena. It remains to be seen, whether further archaeological research can definitely decide this question.

Villages in the Fiji Islands

As the islands became densely settled over time and Fijian people were definitely warlike, a community had to be prepared for frequent raids and hostilities. The buildings were erected within



Architecture of Fiji, Fig. 3 The village is protected by a ditch filled with water from the nearby stream and ramparts with bamboo spikes. A wooden stockade has been erected on top of the ramparts. There are fortified gates and inside the village square can be discerned, where

the chief's house or the mens' house is located surrounded by stone stelae. Opposite to it, in the *lower right corner* in this image, the spirit house (*Bure ni Kalou*) can be seen. It is standing on a large platform (*Yavu*) and has a disproportionately high roof

villages enclosed by palisades and protected by ramparts and ditches. Sometimes gardening structures made for Taro plants, which prefer moist conditions, were located in a way to turn the surroundings of settlements into swamps to protect the inhabitants. Other places had ditches protecting their walls (Parry, 1977, 1981, 1997) (Figs. 2 and 3).

Fijian houses are built around the *rara*, the village square. It actually used to be small, confined and influenced by the space and terrain available in ancient times when the villages

were fortified to protect them from outside attacks. Nowadays, it is much bigger and more rectangular in shape and houses are set in rows along it in an orderly manner. In fact, it is a very typical element of the numerous new villages which were founded after the colonial wars when it was safe to spread out.

On one end of the square the village chief's house is built, on the opposite end the church. The living houses are lined up in two rows along the *rara* between these two foci of power (Zámolyi, 2004, pp. 52–58) (Fig. 4).



A

Architecture of Fiji, Fig. 4 Rara or village green of a contemporary Fijian village in the Western Viti Levu highlands (Navala village, Ba)

Different House Types According to Geographical Distribution

Most Fijian houses have a rectangular or at least elongated ground plan. They have either gabled or hipped roofs and are built on earthen platforms or mounds. Notable exceptions to the plain rectangular shape are the Lau and Rotuman houses which have rounded, apsidal endings and the Were Rausina, a now extinct building type of the Western Viti Levu highlands, which was round, or some of its variants square.

Eastern Highlands of Viti Levu

Buildings of this region have rectangular ground plans. Unlike buildings in the Western highlands, houses of the Eastern highlands do not have a middle post (Freeman, 1986). Often two end posts were used or king posts on tie beams. The design was very similar to coastal buildings, and usually also referred to by the

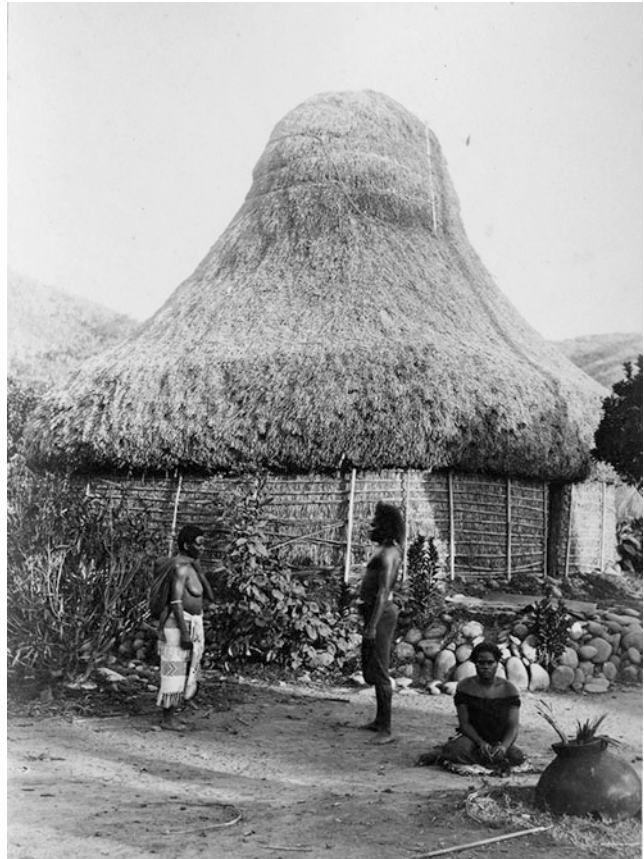
same name (*vasemasema*). However, there seem to have been regional differences in proportions, which caused a slightly different appearance.

Western Highlands of Viti Levu: Were Rausina

The Were Rausina was a building type which could be found in the Western highlands of Fiji's main island, Viti Levu. It became extinct in the course of recent history, as many temples or buildings associated with spiritual beliefs of the time before the advent of Christianity had been built in the Were Rausina style. They were mostly razed after conversion. As only a few sketches of European travelers (e.g., Kleinschmidt), descriptions, and photographs remain, we cannot be completely sure how this house type looked in every detail. Also there seem to have been at least two variants of the type. The name itself refers to its roof covering (*Rausina* = thatched with grass) and

Architecture of Fiji,

Fig. 5 A house of Were Rausina type with unthatched walls (Source: Archive of British Museum)



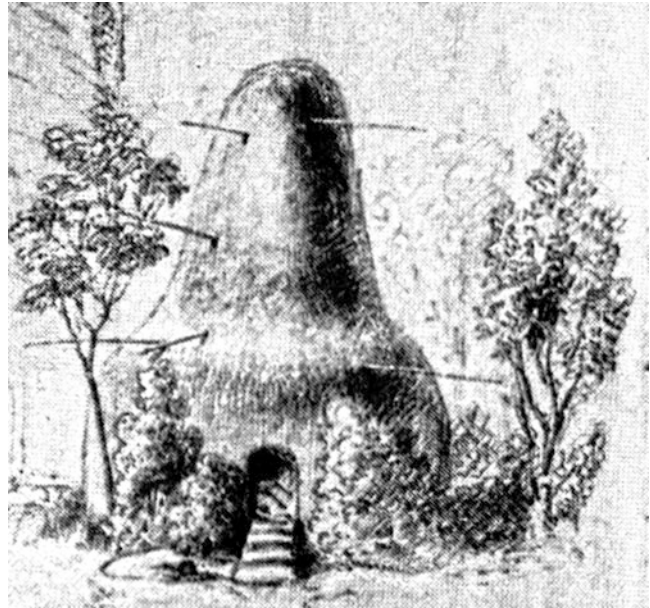
supposedly stresses the fact that all of the building was covered in grass. This is in contrast to other building types, which were also covered in grass or reed, but only to their eaves, while the wall zone remained uncovered. *Were* is a highland-dialect word for house (Vale).

The Were Rausina was definitely round, with walls made of wooden piles dug into the earth. Upon these piles a wall plate in the form of a ring made of twisted lianas rested. Higher up in the roof structure another such ring plate could be found. The building had a middle post with a short roof ridge on top. The thatch covered not only the roof but also the walls and gave the building a shape, which supposedly was the reason that the missionary Williams described some

of the Fijian houses as “haystacks” (Williams, 1858, p.79) (Figs. 6, 7). There was also a variant of the house which had a square ground plan and where the thatch apparently was not covering the walls (Fig. 5). The building had one entrance and no windows, and there was a hearth situated inside, as we know from the descriptions of the traveler Kleinschmidt (1879; Tischner, 1961, 1966). There are several Melanesian house types, which show close architectural parallels to the Were Rausina. Buildings in New Caledonia, for example, are very similar both in appearance and in inner structure to the Were Rausina, but as already discussed in this article, actual connections remain highly debated. The distribution area of the Rausina was similar to that of the Nanga cult places, and in that case a

Architecture of Fiji,

Fig. 6 A Were Rausina with thatched walls, sketched by the traveler Theodore Kleinschmidt in 1879 in the Viti Levu highlands



A



Architecture of Fiji, Fig. 7 The reconstruction of the inside of a Were Rausina after the description of Kleinschmidt (1879)

connection would be more plausible. At the end of the Nanga enclosures, usually a circular house was built, which was likely to be related to the Rausina type.

Western Highlands of Viti Levu: Rectangular Buildings

While the ground plan was rectangular, most houses of the Western highlands feature a middle post and a hipped roof with radially arranged rafters. In many cases the rafters are held together by a ring plate of twisted lianas near the ridge pole. Several of these features (middle/main post, ring plate of twisted lianas) are very likely to have been originated from the Were Rausina type. It is without doubt that while the Rausina itself is not built anymore, many of its features transformed the rectangular buildings and made them recognizably different from those of the Eastern Highlands (see also Freeman, 1986). In some villages Kleinschmidt (1879) describes the existence of both rectangular and round buildings. The rectangular house seems to have



Architecture of Fiji, Fig. 8 Rectangular house showing many characteristics of the extinct Were Rausina building type. Navala village, Ba

spread in the Viti Levu highlands in the nineteenth and twentieth centuries (Roth, 1953, p. 9) (Figs. 8, 9, 10, and 11).

of different materials and methods than in the highlands; often they were thatched with leaves or branches of certain trees (Figs. 12, 13, 14, and 15).

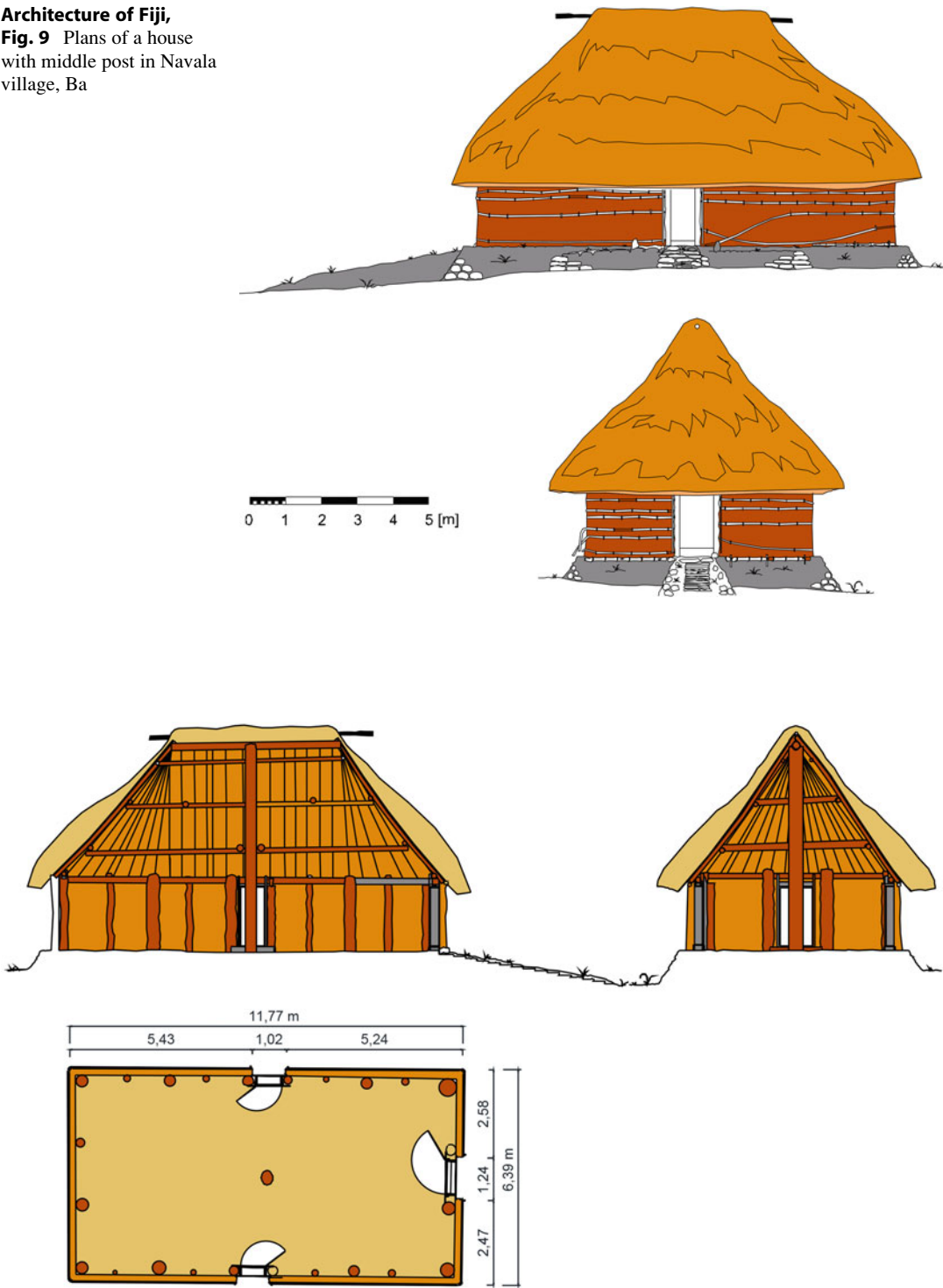
Coastal Buildings (*Vasemasema*)

The coastal buildings, which are called *Vasemasema* have gabled or slightly hipped roofs, are rectangular in ground plan and have an entrance on the longer side. With time additional doors were built, and some were even built with windows, although this seemed to be a historically very recent practice linked to European influence. The houses usually featured two main piles at the gable ends or king posts on tie beams within the building. The main piles could be set in the plane of the shorter end walls, then the roof was gabled, or somewhat toward the inner part of the house, then the building would have a slightly hipped roof. The walls were made

Coastal Regions: *Vale Leka*

The so-called short house or *vale leka* is an architectural solution which can be found in a very similar form on very exposed islands all over Oceania. It has very low or no walls at all. Instead, the roof is built directly on the ground, giving it its peculiar triangular shape. This enables the house to work with the surrounding terrain and embed itself in a streamlined manner. It is thus able to successfully withstand strong winds and tropical storms, which can occur in coastal regions or low islands. A similar house form exists in Polynesian Hawai'i and Melanesian Vanuatu. In Fiji it can be found in several

Architecture of Fiji,
Fig. 9 Plans of a house
with middle post in Navala
village, Ba



Architecture of Fiji, Fig. 10 Plans of a house with middle post in Navala village, Ba



Architecture of Fiji, Fig. 11 Vernacular house with middle post in Navala village, Ba

coastal areas. It was also said to be built on Vanua Levu. There existed two types, one with low walls of around 60 cm height, often secured with stones, and one type without any walls at all (Fig. 16).

Houses of the Lau group (*Kubololo*)

The Kubololo is a Tongan house style with apsidal, rounded ends. This building type spread in the nineteenth century with Tongan influence. Tongan and Samoan boat builders came to the Lau group, as in their home islands there was a shortage of timber, and some of the Lau islands were in fact annexed by force by Tongans during the nineteenth century. They brought with them their house building technology and style (Kooijman, 1978) (Figs. 17 and 18).

Houses of Rotuma Island

Rotuma was subject to influences from Tonga and Samoa, and the buildings were similar to those of the Lau islands (Fig. 19).

Different Building Types According to Function

Bure/Vale (Living House)

While the term *Bure* in former times referred either to men's houses, temples, or chief's houses, in modern times the term more and more is used for all types of traditionally constructed dwelling houses. The term "Vale" is used in the coastal dialects for house, while in the Viti Levu highlands the word "Were" is more common. Tippet (1968) states that these two expressions are variants of the same word and do not have any difference in meaning.

Usually living houses had one entrance on their longer side, but with time more doors became common. Today some buildings have three doors. Windows were not a common feature and were introduced only in the European colonial era. No furniture was used in Fijian houses; the earthen floor was covered with dried grass or if people were affluent enough, with mats made out of the leaves of the Vodra tree (screwpine).

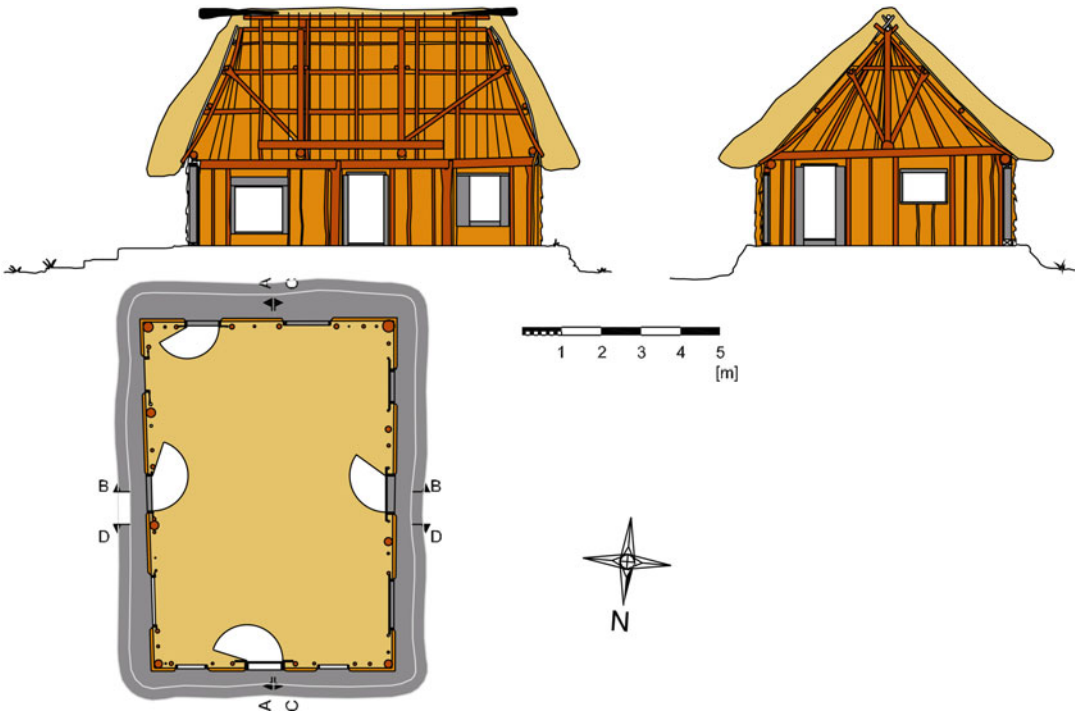
Formerly there was no separate kitchen; food was prepared in the living house. The missionaries and the colonial administration advocated separation of the kitchen in a building different of the main house, as it was deemed healthier. Finally separated kitchens became the norm.

Bure ni Sa (Men's House)/*bure ni cauravou* (House for Bachelors)

In pre-Christian Fiji family life was different from the present norm. Formerly the core family (wife husband and children) was not so emphasized, and the clan was more important. Also husbands spent more time apart from their wives and children, or they had even several wives at once. The men spent much time in the *Bure ni Sa*, a club house or men's house, while the women usually also had a women's house



Architecture of Fiji, Fig. 12 Building in Lomanikoro, Kadavu



Architecture of Fiji, Fig. 13 Plans of the house in Lomanikoro, Kadavu



Architecture of Fiji, Fig. 14 House in Lavena, Taveuni island

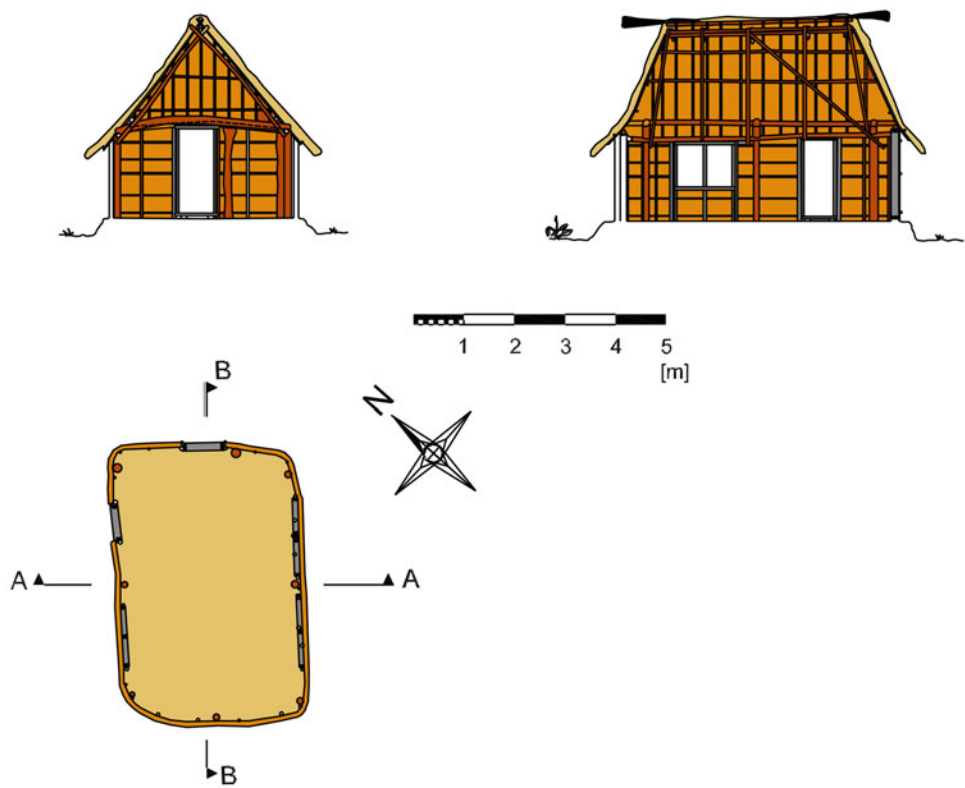
where they would stay, often even overnight. With the advent of Christianity, the missionaries abolished these types of buildings. Kleinschmidt (1879) mentions in his account of travels in the Western Viti Levu highlands that Bure ni Sa could be both round (the Rausina type) or an elongated rectangular building, according to local tradition, with separate areas fenced off within as private areas for each person (Fig. 20).

Bure ni Kalou

The Bure ni Kalou or spirit temple used to be built on high earth platforms which were covered with stones and were also fitted with disproportional high roofs. The high platform was a sign of the high status of the building. While its absolute dimensions (apart from the steep roofs) were apparently not necessarily larger or sometimes even smaller than those of ordinary houses, the quality of materials, the construction work, and also the exquisite decoration of the building set it apart from any other. The joints between the different posts and beams were lashed in

elaborate patterns and adorned by coconut cords of different colors. The tree-fern stems of the ridge were decorated with cowries, each shell marking the death of a human in sacrifice to the gods. The construction of a temple required a large number of humans to be sacrificed and gave rise to conflicts and raids with neighboring villages and tribes (Seeman, 1862; Williams, 1858). Kleinschmidt (1879) recorded that in the Western Viti Levu Highlands, Bure ni Kalou was often built in the building type of the Were Rausina. In other places the design was that of the dominant local building type (Fig. 21).

The inside of the building was apparently very similar to dwelling houses, and as within them, also here no special furniture was used. The gods were sometimes represented by two-headed whale ivory figurines. During the day they were placed in small mock houses made out of sennit, while during the night they were put into a basket to “sleep.” Additionally it is recorded that a *masi* (bark) cloth was hung either from the ridge inside the temple, or from a corner post, and symbolized



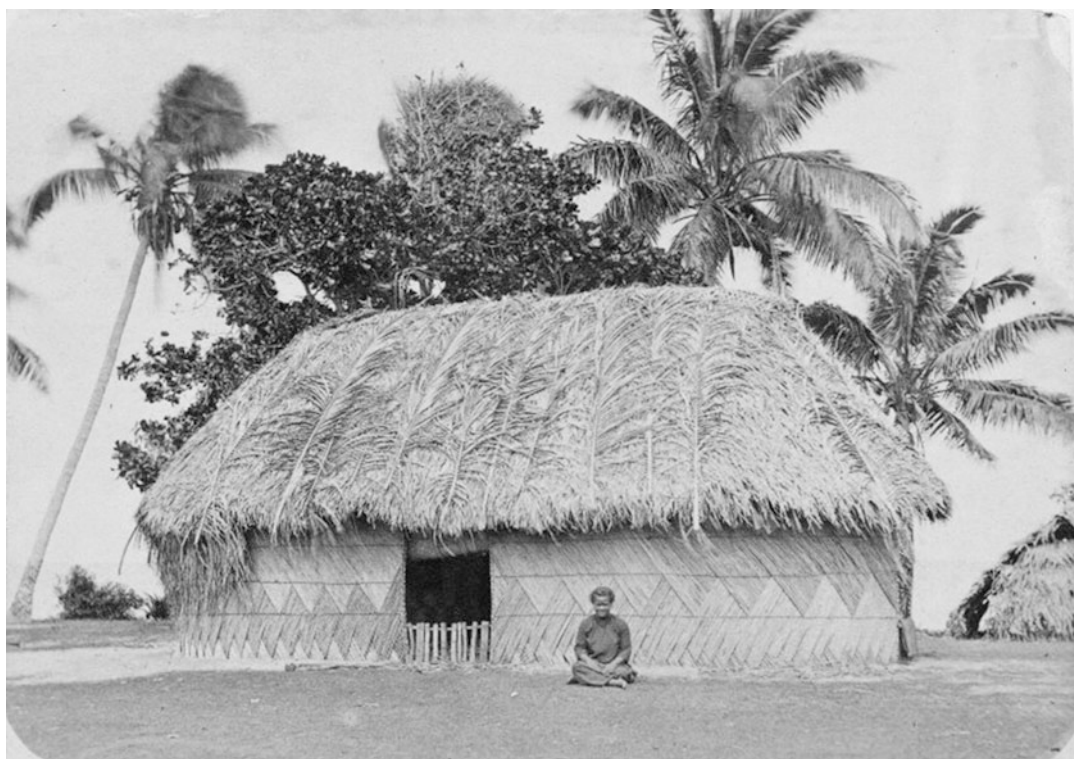
Architecture of Fiji, Fig. 15 Plans of house in Lavena, Taveuni island

Architecture of Fiji,
Fig. 16 Vale leka (short
house) on Ra island
(Source: Archive of British
Museum)





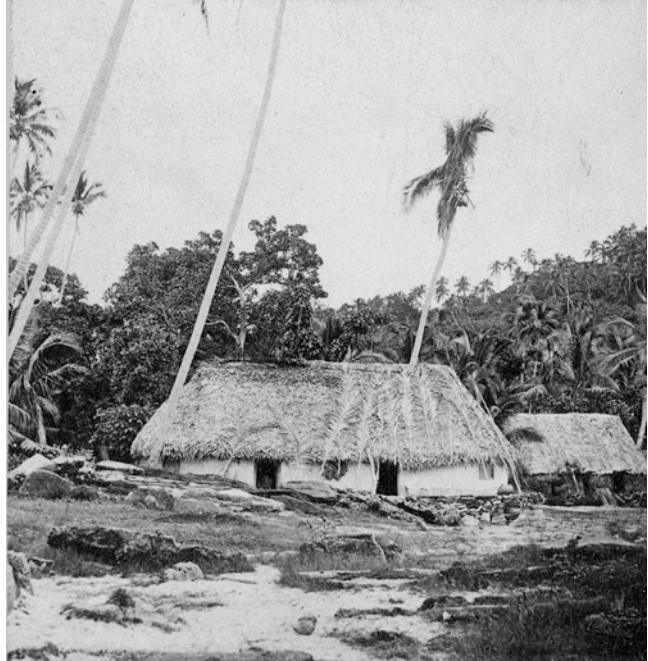
Architecture of Fiji, Fig. 17 House in the Lau group showing Tongan influence



Architecture of Fiji, Fig. 18 House in Tonga, Polynesia (Source: Archive of British Museum)

Architecture of Fiji,

Fig. 19 House on Rotuma island (Source: Archive of British Museum)



A



THE MBURE-NI-SA (CLUB HOUSE).

Architecture of Fiji, Fig. 20 Bure ni Sa on Bau island (Source: Thomson, 1908). This example is a very large and generous one. Bure ni Sa in the highlands for example seem to have been much smaller and had a rather confined

inner space. Kleinschmidt (1879) describes Bure ni Sa which had partitions for each person using it, resulting in small private spaces

Architecture of Fiji,

Fig. 21 Bure ni Kalou

(Source: Williams, 1858).

The spirit houses or temples could be recognized by their high platform and their high roof structure



Architecture of Fiji,

Fig. 22 Reconstruction of a Naga after Fison (1884)



the path on which a god could descend. Supposedly also trophies of war or weapons thought to have an especially famous reputation were displayed within the temple. There was a hearth within the building. The priest (*bete*) could reside in the temple, but more often he possessed his own building within the village (Seeman, 1862). The temple seems to have held a specific place within the village, supposedly opposite the chief's house, the same location which is today

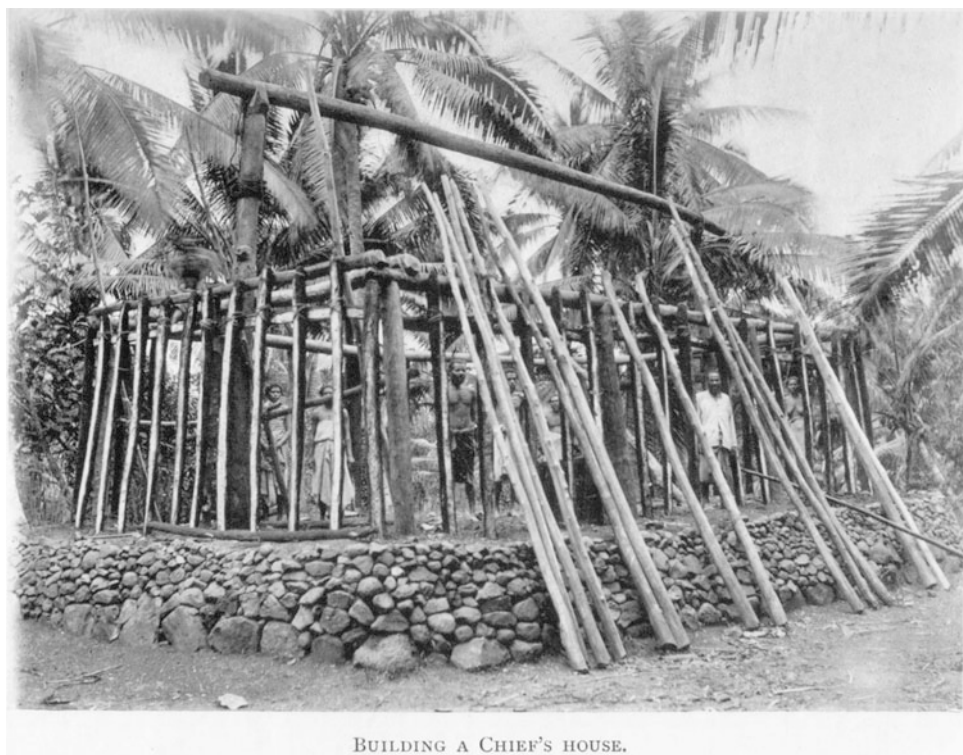
occupied by the Christian church. Although churches (at least in the beginnings) were built with the same methods of traditional buildings, they did not take over the design of temples, but were understandably oriented on western architectural models.

Ritual Enclosure: The Naga

Nagas were cult places used for ceremonial gatherings, which only existed in the southwest



Architecture of Fiji, Fig. 23 Reconstruction of Naga after Joske (1886)



Architecture of Fiji, Fig. 24 Bure (house) of a chief being built (Source: Thomson, 1908)

Architecture of Fiji,

Fig. 25 Sketch by the author showing a earth in a kitchen in Navala village, Ba, Viti Levu. The kitchen buildings are usually built in the same way as dwelling houses; they are only smaller and less elaborate

**Architecture of Fiji,**

Fig. 26 Vale ni Moce behind a chief's house (Source: private collection of Rod Ewins)



Chiefs House and Sleeping Bure.

highlands of Viti Levu. They are probably similar to Polynesian cult places, such as the marae of New Zealand and the heiaus of Hawai'i.

Nagas generally consist of three rectangular zones which are enclosed by a low stone wall or a perimeter of stone stelae and lined with aromatic trees. At the end of the third zone, there is Vale

Tembu (taboo), a forbidden or untouchable house, which symbolizes the watchful place of one's ancestors. Each zone is reserved for a specific rank and clan. Stump pyramid-shaped piles or stone walls with a gap allowing only a narrow passage in between mark the boundaries of each zone. The Vale Tembu, as the innermost

Architecture of Fiji,

Fig. 27 Vale ni Moce

(Source: Williams, 1858)



SLEEPING BURE.



Architecture of Fiji, Fig. 28 House building tool before European contact: Stone adze (Source: Archive of British Museum)



Architecture of Fiji, Fig. 29 House building tool before European contact: tortoise-shell adze (Source: Archive of British Museum)

sanctum, was entered at the culmination of the initiation ceremony, when new members of the cult were admitted to its secrets (Fison, 1884; Joske, 1886).

Nagas were used for initiation rites, harvest feasts, etc., by many villages at the same time. They were built hidden away in remote areas. The walls of the zones within a Naga are actually pervious enough to allow people to leave the place quickly in case of attacks which were a



Architecture of Fiji, Fig. 30 After iron was obtained from Europeans, the adzes were modernised (Source: Archive of British Museum). Nowadays nobody in Fiji uses adzes. Common tools are European style axes, hatchets or large bush knives



Architecture of Fiji, Fig. 31 Piles dug into the ground before the house platform (Yavu) is erected

**Architecture of Fiji,
Fig. 32** Notching of the
piles



constant threat in ancient times. After conversion to Christianity these sites were neglected and their locations forgotten. No such cult place is restored, archaeologically excavated, or

otherwise presented to a wider public. Only descriptions from the nineteenth century and observations of European travelers of that time remain (Figs. 22 and 23).

Architecture of Fiji,

Fig. 33 Men in Navala village, Ba lever a large pile of a house under construction into its final place



A



Architecture of Fiji, Fig. 34 The yavu (house platform) is built up after placing the piles

Bure Levu

Bure Levu is a term for the chief's house. This building, which sometimes also was termed *Vale Levu* (big house), was a more elaborate, lavishly decorated, and usually larger version of the commoners' houses. It also stood on a higher

platform, advertising the higher social rank of the Chief (Fig. 24).

Vale ni Kuro

The kitchen is called *Vale ni Kuro* in Fijian. It seems that the building of kitchens as separate



Architecture of Fiji, Fig. 35 After placing the wall plates, a temporary bamboo scaffolding is set up in the middle of the house. This holds the roof ridge, until the rafters are fixed to it



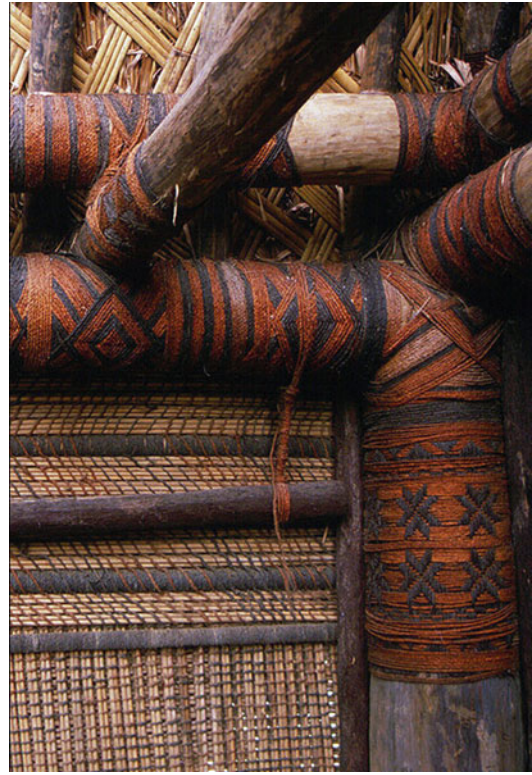
Architecture of Fiji, Fig. 36 Woven bamboo walls are attached to the sides of the building



Architecture of Fiji, Fig. 37 The length of the rafters is not calculated exactly beforehand, but they are trimmed after they have been placed in the structure

buildings started mainly in the colonial era (from 1874 on), as European authorities deemed the smoke caused by cooking within the dwelling house insanitary. Although a smoky house interior is in no way healthy, a hearth within the dwelling house could have following useful effects: The house itself was “smoked” and thus vermin did not nest within the thatch and the wooden parts of the building lasted longer. Also, at least in the highland regions, people needed the warmth of a fire, as the nights sometimes could be cold. Mosquitoes and other flying insects were also kept from entering the house by the smoke.

Several accounts from the nineteenth century describe cooking utensils and hearths for cooking within the dwelling houses (Kleinschmidt, 1879; Williams, 1858), and it seems that at least in the interior of Fiji’s larger islands, it was not usual to build separate kitchens at that time. Whether the



Architecture of Fiji, Fig. 38 Elaborate lashing of a corner joint made of coloured coconut cord in the open-air museum of Pacific Harbour (Source: Erich Lehner). Such lashings are usually not made anymore nowadays

custom was different in the coastal areas is not entirely clear, but before the annexation by the British tribal warfare was frequent, and most villages were fortified. Therefore the construction of separate buildings as kitchens seems unlikely (Fig. 25).

Vale ni Moce

Vale ni Moce were raised little house-like annexes for people to sleep in. They were built in a height of 2–3m to guard people from surprise enemy attacks and also from the inconvenience of mosquito bites. Most of the time these houses were built in such a fragile way that any time someone tried to climb the ladder and access the house, the whole house would start shaking and that way woke up the person sleeping inside. He or she was warned in time. After the colonial wars



Architecture of Fiji, Fig. 39 Man in Navala village fixing a wall plate to a pile with wire. In former times such a joint would have been lashed with lianas or coconut cord

more peaceful times arrived and the sleeping house was made redundant. Nowadays, it is not being built anymore (Figs. 26 and 27).

Building Technology, Materials

Fijian houses were built traditionally without the use of any nails or carpenter's joints. All parts were round pieces of wood; only the end of some parts (e.g., the ends of piles) had to be worked in a way that they had grooves or V-shaped cuts to receive other structural elements. First the piles of a house were buried in the ground, and usually afterwards an earthen platform (*Yavu*) was built. In some cases first the platform was built and then the



Architecture of Fiji, Fig. 40 Beautifully lashed joints of a roof structure on Bau island

piles dug in. Often old platforms were used to re-erect buildings on them (Figs. 28, 29, 30, 31, 32, 33, and 34).

On the piles wall plates were placed. The ridge of the house was held in place according to type either by one main post (*Bou*), two posts at the end of the building, or two king-posts placed on a longitudinal beam, which in turn was placed on tie-beams. Sometimes also combinations of these parts could occur (e.g., two main posts and two king posts). All parts were lashed together with lianas or coconut sinnet. Strong lianas were used to fix large timbers in place, while coconut sinnet (*Magimagi*) was ideal for producing elaborately patterned connections and lashings. According to Tipett (1968, pp. 141–172) enormous amounts of binding material could be used at larger projects. An example of a large community house built for a school in Kadavu Island in the traditional

Architecture of Fiji,

Fig. 41 A liana is beaten with a stone to loosen the bark



A



Architecture of Fiji, Fig. 42 After having been beaten, the liana is easily torn to strips which are used for lashing in the house structure

manner is mentioned using 7,200 f. (2.16 km!) of coconut sinnet (Magimagi) and 17,500 f. (5.25 km!) of various lianas (Tipett, 1968, p. 152). It has to be remarked though that such buildings were not the norm but the exception. Such a project can only be compared to a chief's house or a temple of former times and required large efforts and considerable time in preparation from the community (Figs. 35, 36, 37, 38, 39, 40, 41, and 42).

However, once the material was prepared, the building of a house itself took only a few days. Of course common village houses did not need such large amounts of binding material, as their dimensions were smaller and their joints far less or not ornamented. It has to be stressed that this particular building described by Tipett had apparently very elaborate bindings as decorations on the wall and the joints, which was the main possibility of adorning a building. At the end of the nineteenth century in certain places there seemed to be a trend of Tongan patterns to be used in binding, very likely connected to the import of the Tongan house type in the Eastern island groups of Fiji.

House walls were made of split bamboo or mats or covered by grass thatch. Especially in the Inland areas of Viti Levu, the grass-thatched



Architecture of Fiji, Fig. 43 House before thatching

Architecture of Fiji,
Fig. 44 Detail showing
 the rafters of a roof lashed
 to purlins within the roof
 structure (Navala village,
 Ba, Western Viti Levu
 highlands) (Source: Josef
 Schuller)



walls of houses were secured by bamboo strips, which produced a very characteristic horizontally striped appearance.

The roof ridge of Fijian houses was in most parts strengthened by an extra binding of lianas and also two tree-fern stems (*Bala-Bala*) were

attached slightly above the roof ridge, in a way that they projected from the roof. This gave the buildings a very typical, almost emblematic shape (Figs. 43, 44, 45, and 46).

Fijian houses can be built by only using stone tools, as no complicated or precise joints have to



Architecture of Fiji, Fig. 45 Inner roof structure of a house in Navala village (Source: Josef Schuller)

be cut into the wooden elements, nor do they have to be shaped (e.g., squared) very much. Before the advent of the Europeans, Fijians used stone knives and adzes or bone tools like tortoise-shell adzes. After European contact first simple iron blades, later European style tools became common (Figs. 28, 29, 30).

The House As Ordered Space

Fijian society is strongly hierarchical, and the use of the inner space within a house reflects this. People are seated during ceremonies according to their rank within the community and also where a particular person enters the building is regulated according to status. The house itself is divided into three zones (there are no physical barriers present, and the zonation is purely existing in custom and people's perceptions). The back part of the building is called *Loqi*, and is private. Here people sleep and guests usually do not enter this area. People who step into the

house either use the *Katuba Lailai* (small door) which is situated on the long side of the building and as a rule looks onto the *Rara*, the village green or they use the *Katuba Levu* (big door) which is situated on the shorter end of the building. The *Katuba Lailai* has high status and is only used by members of the community with high rank, while everybody can use the *Katuba Levu*. In former times, when a building used to have only one door, it was at the same position as the *Katuba Lailai* is now. On the right side, when entering through the *Katuba Lailai*, the private end of the house (*Loqi*) can be found; on the left is the public end (*Solika*). Thus having entered the building one is standing in the *Loma ni Vale* area, which is not private anymore, and also not open to all guests – only high ranking persons or persons well known to the family may sit here. The *Solika* can be directly accessed through the “low rank” door (*Katuba Levu*). If there is a hearth to be found in the building, then it will usually be located at the public end, in the right hand corner when entering through the *Katuba Levu*. Some buildings also have a door opposite the *Katuba Lailai*, but this door is seldom used as it is basically a back door to the *Loma ni Vale*, and thus ceremonially not as important as the much more prominent access from the *Rara* via the *Katuba Lailai*. In the *Were Rausina* the inner space was ordered somewhat differently, in a way that the hearth, which is in rectangular buildings in a low-ranking area, was situated behind the middle post right opposite the only entrance of the house, and thus within the *Loma ni Vale*, the higher ranking restricted part of the building. It is not clear why it was not situated in the *Solika* area. Otherwise the *Were Rausina* seems to have been used with a similar division (*Loqi-Loma ni vale – Solika*) as the rectangular buildings (Fig. 47).

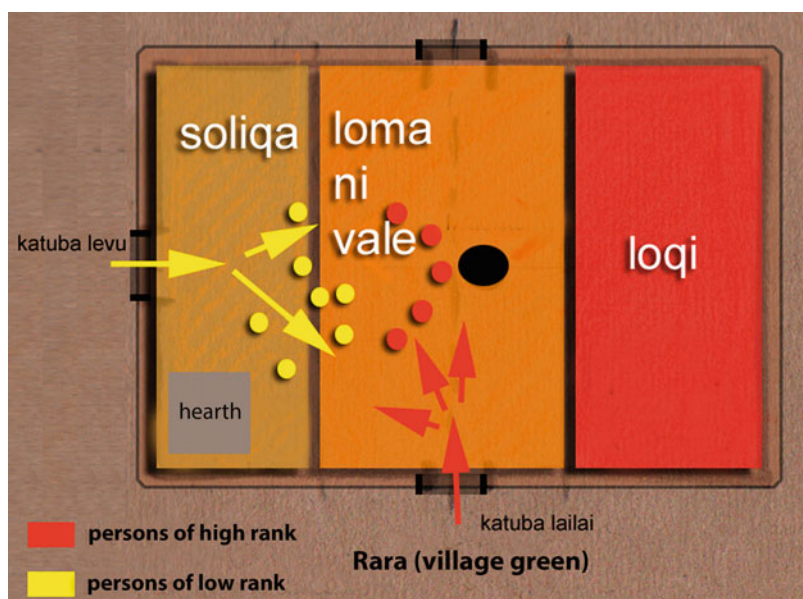
In pre-Christian times deceased people used to be buried below their house in the house mound or platform (*Yavu*) (Roth, 1953, p. 10). This might be also the reason why house mounds have special importance and are regarded almost as sacred (Ravuvu, 1983, p. 14). The missionaries abolished the practice, and only chiefs were allowed to be buried within the village. If by any means chiefs or other high-ranking persons

Architecture of Fiji,

Fig. 46 Thatching the house. As the roof ridge is most exposed to the weather and thus could be damaged, it is strengthened by being wrapped with lianas. Navala village (Source: Josef Schuller)

**Architecture of Fiji,**

Fig. 47 Hierarchy of space within a Fijian house





Architecture of Fiji, Fig. 48 Grave of a Chief on Bau island. Above the grave a platform was created, on top of which a stone or concrete monument was erected in the approximate shape of a house

were not buried in the settlement, a mound was raised over the gravesite and usually a house built over it (Williams, 1858). A good example for this practice is the grave site of chief Cakombau in Bau, where a stone monument very much resembling a house has been erected over the burial platform (Fig. 48).

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Architecture of the Cherokee

Christopher B. Rodning

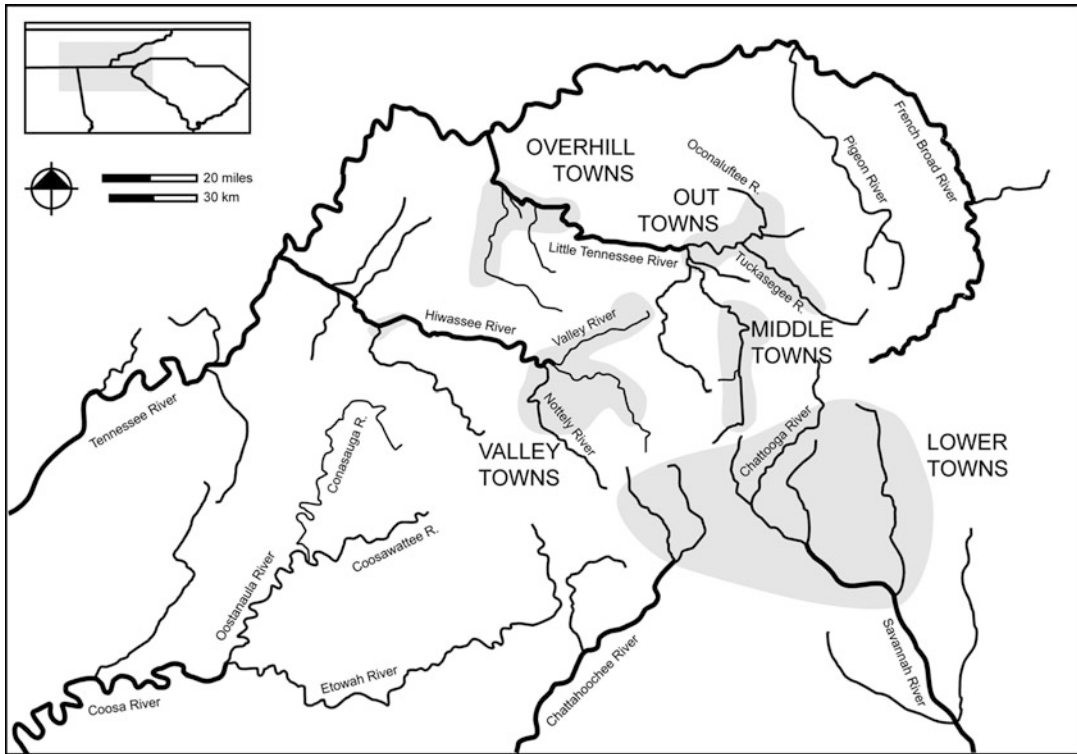
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Several groups of Cherokee towns were present in the southern Appalachians during the period of early European contact in southeastern North America (Fig. 1). Different dialects of the Cherokee language were spoken in these discrete areas, although Cherokee town groups were connected by kinship and shared language and tradition. The Lower Cherokee towns were located in northeastern Georgia and northwestern South Carolina, along the headwaters of the Savannah and Chattahoochee rivers. The Middle Cherokee towns were situated along the headwaters of the Little Tennessee River in southwestern North Carolina. The Out Towns were located along the Tuckasegee River, and the Valley Towns along the upper reaches of the Hiwassee River, both in southwestern North Carolina. The Overhill Cherokee towns were located along the lower Little Tennessee and Tellico rivers in eastern Tennessee. Spanish conquistadores probably did not enter the heart of Cherokee country during explorations of the southeastern US during the sixteenth century A.D., but members of colonial expeditions led by Hernando de Soto and Juan Pardo did interact with people from Cherokee towns while traversing the southern Appalachians (Hudson, 1976, 1997, 2005). English colonists and traders from Virginia and South Carolina developed trade relations with Cherokee towns during the early eighteenth century, and the history of the deerskin trade and the Native American slave trade significantly impacted Cherokee and other Native American towns across the American South. These changes altered the spatial layouts of Cherokee towns, the locations of Cherokee towns on the landscape, and the kinds of architecture present in Cherokee towns and in rural areas between towns.

Archeological and documentary evidence from sites and sources dating from the 1500s

through the 1700s indicate that Cherokee towns included public structures known as townhouses, large outdoor plazas adjacent to townhouses, and domestic structures and activity areas placed around those plazas (Riggs, 2008; Rodning, 2001a, 2002a, 2011a, 2015; Schroedl, 1978, 1986b, 2001). Cherokee towns typically included between 10 and 60 households, encompassing some 100–600 people. Cherokee groups traced descent through matriline, and they typically practiced matrilocal postmarital residence, meaning that households typically included a woman, that woman's parents and perhaps siblings, one or more men who had married into the family, and children. Some towns in some areas may have been enclosed by log stockades, but not all, and log stockades are more the exception than the rule during the eighteenth century. Not all households lived within towns, and some people lived in small farmsteads situated in areas between major town centers (Cable, O'Steen, Raymer, Loubser et al., 1997; Shumate, Riggs, & Kimball, 2005).

Townhouses were square with rounded corners, or octagonal, in shape, ranging from 14 to 18 m in diameter (Rodning, 2011a; Schroedl, 1986b, 2000, 2001). They were built to accommodate all or nearly all of the people within each town at some community events, although some events that took place inside townhouses included smaller numbers of people. These structures were built on cleared surfaces, and the earth generated from clearing those surfaces or digging the basins in which townhouses were then built served as raw material for earthen embankments, walls, and roofs. Townhouses were built with log posts placed vertically in the ground forming the framework for walls made of wood and earth. Narrow vestibule entryways cut through earthen embankments, forming passageways connecting outside and inside. Log roof beams and large roof support posts supported roofs made of bark, thatch, and earth, with openings in the centers of those roofs forming smokeholes that let out smoke from the fires that were kept burning constantly inside townhouse hearths. Smaller townhouses typically had four roof support posts, placed in square patterns around central



Architecture of the Cherokee, Fig. 1 Locations of the Lower, Middle, Out, Valley, and Overhill Cherokee towns in the southern Appalachians

hearths. Larger and later townhouses often included eight roof support posts. It is not known how often Cherokee townhouses were renovated and rebuilt, but given the environment and climate of the southern Appalachians, and given the perishable raw materials with which townhouses were built, renovation, maintenance, renewal, and rebuilding were probably relatively common community-wide events and efforts. They probably necessitated significant community-wide investment in labor and the accumulation of wood, bark, thatch, and other materials. Broadly comparable public structures were present at sites in the greater southern Appalachians dating from the 1400s and 1500s (Hally, 2008; Polhemus, 1987; Schroedl, 1998; Sullivan, 1987). Townhouses were architectural symbols of the status of local households as a town. They were settings for town council deliberations and other public events, including periodic community feasts and dances. After European contact,

townhouses were venues for diplomatic events involving leaders of Cherokee towns, people from other Native American towns and villages elsewhere in eastern North America, and colonial traders and agents of colonial governments.

Clay hearths at the centers of townhouses were settings for fires that imparted light and warmth and that were symbolic of the vitality of towns themselves. Community members, often male elders, were responsible for maintaining constant fires in townhouse hearths. The fires kept in townhouse hearths were sources of fire for kindling the fires in the hearths of domestic structures and household dwellings, and in some cases, the fires of townhouses in important Cherokee towns were carried to other towns. The constant or perpetual fires in Cherokee townhouse hearths symbolized the vitality and longevity of Cherokee towns and the Cherokee people. These fires were periodically put out during community renewal rituals, and ashes and

embers from townhouse hearths were carefully discarded in carefully chosen pits or heaps in the vicinity of townhouses themselves.

Many townhouses were built and rebuilt in place, forming architectural sequences (Knight Jr, 2006), and, sometimes, townhouses were built on the summits of earthen platform mounds that were originally built during late prehistory, before European contact in the southern Appalachians. Similar long-term sequences of townhouses (and domestic structures) were present at sites dating from late prehistory through the early eighteenth century (Polhemus, 1987). Such long-term emplacement of structures and entire settlements became less common as households and entire towns became more and more mobile during the history of European contact and colonialism in the Americas (Marcoux, 2012). Some townhouses are known to have been built on the summits of platform mounds that were originally built during the late prehistoric period, including the mound at the sacred Cherokee town of Kituhwa (Riggs & Shumate, 2003). Written descriptions of Cherokee towns also note the presence of some Cherokee townhouses placed on the summits of precontact earthen mounds during the eighteenth century, including the townhouse that is known to have stood on the large earthen mound at Nequassee. That was recorded in written accounts of expeditions by colonial militias to Cherokee country in 1761 (Duncan & Riggs, 2003; King & Evans, 1977). During the late eighteenth century, the Quaker naturalist, William Bartram, visited Cherokee towns in the southern Appalachians. Bartram described a townhouse on the summit of the earthen mound at Cowee in 1775, and he also noted the ruins of abandoned townhouses on the summits of mounds at abandoned Cherokee town sites in northeastern Georgia and the western Carolinas (Rodning, 2002c).

Beside townhouses were rectangular ramadas, or porticos, that had roofs but not walls. These rectangular ramadas – often referred to as “summer” townhouses, situated beside “winter” townhouses, paired structures that were particularly important during those different seasons of the year – were approximately 16 by 16 m. Beside

townhouses and townhouse ramadas were outdoor plazas, covering up to one hectare, and sometimes covered with clay or sand.

Households lived in domestic structures that were comparable in design and materials to townhouses, except that dwellings were much smaller than public structures. Just as there were townhouses and adjacent rectangular ramadas, so also were there square or octagonal “winter” houses and rectangular “summer” houses (Faulkner, 1978), and household dwellings were composed of a winter house paired with an adjacent summer structure (Schroedl, 2000). Winter houses ranged from seven to eight meters in diameter, and summer houses were roughly four meters wide by ten meters long. Winter houses typically included four roof support posts placed around central hearths, as in the case of townhouses (Rodning, 2009b; Schroedl, 1986b). These structures represent the same form of domestic architecture present at many late prehistoric Native American (Mississippian) sites in the greater southern Appalachians.

At sites dating from late prehistory through the seventeenth century, burials were often placed inside and beside public and domestic structures (Dickens, 1976; Hally, 2008; Rodning, 2001b, 2011b, 2012; Rodning & Moore, 2010; Ward & Davis, 1999). Houses and townhouses therefore marked the placements of burials and deceased ancestors. Building and rebuilding houses and townhouses in place kept living generations of Cherokee households and towns close to preceding generations and close to those structures themselves, and the increasing mobility of Cherokee households and entire towns during the course of trade and warfare in the eighteenth century probably diminished those close associations between people and particular places within the southern Appalachian landscape.

From late prehistory through the seventeenth century, dozens of Native American dotted the cultural landscape of the greater southern Appalachians. At most town sites, there were dense concentrations of houses and domestic activity areas, and some sites were very large. Beginning in the late seventeenth century, several large town sites were abandoned (Hatley, 1989), some

Cherokee towns moved to new locations (Smith, 1979), some Cherokee groups formed small settlements in remote areas (Marcoux, 2010), and architecture changed as seasonal movements related to hunting and the deerskin trade became more prevalent. These developments led to changes in regional settlement patterns (Goodwin, 1977), and town layouts became more spatially dispersed than they had been before, although townhouses and mounds continued to serve as focal points for spatially dispersed towns (Greene, 1999).

By the late eighteenth and early nineteenth century, traditional architectural forms were increasingly replaced by cabins and farm outbuildings that were broadly comparable to structures at Anglo-American settlements and farms. The traditional pattern of Cherokee towns surrounded by fields and farmsteads was replaced by a pattern of rural farmsteads spread along river valleys. By this point, some towns that encompassed houses, farms, fields, and woodlands spread across many miles of countryside, without the clear community centers in the form of Cherokee townhouses and plazas that were present through much of the eighteenth century.

Despite the “Europeanization” of the Cherokee landscape (Pillsbury, 1983) and the increasingly close resemblances between Cherokee and Anglo-American farmsteads in the southern Appalachians, some forms of traditional architecture persisted. Small, circular structures known as *asi*, or *osi*, “hot houses” associated with cabins and other forms of household dwellings were prevalent in the Cherokee landscape through the 1700s and 1800s. These “hot houses” preserved the post-in-ground wattle-and-daub architecture that was typical of Cherokee public and domestic architecture in the past. Meanwhile, townhouses were still built, including the townhouse at New Echota, the capital of the Cherokee Republic during the early nineteenth century, and at some other sites. That said, whereas each town formerly had its own townhouse, this architectural form was now built at only a relatively small number of sites.

From the period before European contact in the Americas through the early nineteenth century, the architecture of Cherokee towns and

farmsteads in the southern Appalachians demonstrates both adaptability and cultural conservatism. At the point of Spanish contact in the 1500s, native towns in the southern Appalachians included public structures and plazas, surrounded by compact arrangements of domestic houses and activity areas. At the point when English trade networks reached Cherokee towns in the early 1700s, townhouses and plazas still marked the hubs of public life in Cherokee towns, and for much of the eighteenth century, public and domestic architecture included pairs of “winter” and “summer” structures. New forms of domestic architecture were developed in the 1700s and early 1800s as Cherokee groups adapted to cycles of trade, diplomacy, warfare, and other forms of entanglement among native and colonial societies in eastern North America. Those changes aside, there was stability and conservatism in some aspects of Cherokee architecture, including the townhouses, “hot houses,” and earthen mounds that still dotted the southern Appalachian landscape in the early nineteenth century, just before the Cherokee Removal period and the forced movement of many Cherokee and other Native American people from the American South to Oklahoma.

At the end of the nineteenth century, earthen mounds and townhouses were no longer built, but mounds like those at Kituhwa, Cowee, Nequassee, and other Cherokee towns were still visible, and there was still knowledge of and cultural memory about building mounds and townhouses. The Smithsonian Institution ethnologist, James Mooney (1891, 1900), recorded a great many Cherokee oral traditions and created a compendium of Cherokee placenames based on his interactions with Cherokee elders in western North Carolina during the late nineteenth century. One of the “historical myths” documented by Mooney, “The Mounds and the Constant Fire: The Old Sacred Things” (Mooney, 1900, pp. 395–397) refers to the practices of building a mound and a townhouse, first by clearing a ground surface, burying one or several recently deceased chiefs and making other offerings and deposits in the ground, creating an earthen summit by bringing in many basketloads of earth, and building a

townhouse on the summit of that mound. Mooney and other sources (e.g., Gearing, 1962, p. 23) refer to the importance of keeping the fire within the central hearths of townhouses burning constantly, an activity taken on primarily by male elders within Cherokee towns. It is said that those fires still burn today in some of the earthen mounds in Cherokee country, including the mounds at towns such as Kituhwa, Cowee, and Nequassee. The Eastern Band of the Cherokee Indians currently owns the land on which the Kituhwa and Cowee mounds are located, and the Nequassee mound is situated within a public park and a greenway along the Little Tennessee River. These and other mounds are vestiges of ancestral Cherokee architecture; other architectural remnants are present in the southern Appalachians buried underground, and some mounds and Cherokee town sites (Chauga, Estatoe, Seneca, Keowee, and others) are partly or entirely inundated by artificial lakes along the headwaters of the Savannah River.

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Architecture of the Maori People

Michael Linzey

The most striking fact about Maori architecture is that it is a living presence in the traditional heart of the community. When a New Zealand Maori orator stands to speak in front of a meetinghouse, he (or sometimes soon it may be she) addresses the house directly and in the same breath also addresses the assembled people. This fundamental understanding that the *whareniui* (meetinghouse) is a living presence is richer than any mere simile, it is beyond the idea of a metaphor or a representation in the European

sense (Mead, 1984). The house is not *like* an ancestor, it *is* the ancestor. Maori people conceive of cosmogenesis as an evolution in three parts: *te kore* is a nothingness condition of endless possibility, *te po* is a long night that is rich in potentiality, and *te ao marama* is the world of light which is to say the actuality of the real world. These three fundamental states of existence are represented on the door lintels of traditional architecture (Simmons, 1985, pp. 43–47). This traditional understanding resembles the triadic cosmogony of Peirce (1992, v. 1, pp. 285–297); it may not be entirely surprising therefore that the idea of an interconnected life-force, *mauri*, pervades the physical world of the Maori, and that architecture is included in this universal embrace.

I am not talking here about the precontact condition of Maori architecture [about which anyway very little is known (Phillipps, 1952)]. What is more significant is that the Maori comportment toward architecture has survived within a predominantly European ambience of New Zealand life, perhaps indeed it developed more pronouncedly within the clash of cultures that was the introduction of colonialism and the rise of nationalism during the nineteenth and twentieth centuries. Modern Maori are not isolated from the majority culture, just as in New Zealand nothing European can claim to be isolated from the Maori presence. But whereas we sometimes lament the loss of meaning within European architecture, and some even go so far as to say that architecture is dead, the architecture of the Maori by contrast is radically alive. It is a living example of the scientific condition that Peirce called “objective idealism,” in which the material world itself is understood to be fundamentally alive.

In the confines of this short article three aspects of the living meaning of Maori architecture are addressed. They are its *faciality*, its ornament, and an aspect of its *space*. Relevant terms in the Maori language are *mataihi*, *whakairo*, and *kauhanga*. These are not general terms; they have meanings that are quite specific to architecture. In particular the *whareniui* is often also called (and addressed as) *whare whakairo*, meaning a house that is adorned with pattern. *Mataihi* specifically

means the gable-end (the front) face of the *wharenui*, and *kauhanga* or *kauwhanga* is the interior space down the middle of the *wharenui* specifically when it is in a *tapu* or highly potent state. Necessarily these three aspects of architecture have to be addressed separately in this article, but they are not separate, not even interrelated concepts. Rather they are three valences that together go to make up the single meaning of addressing the *mauri* or life force in Maori architecture. If I may follow Peirce for a little bit longer, this triadic situation can be compared to an ordinary street sign. A street sign also *faces* us, *points* out a direction in the world, and *tells* us something about what is happening in that direction. The three valences *together* make up the whole meaning of the sign. A reader may be advised to take in what follows here, necessarily in the sequential order of the text, and then to think about it again in a few days time. Perhaps then some small appreciation may be gained about the liveliness of Maori architecture as a whole triadic sign.

Faciality, Mataihi

In Maori, as in most of the Austronesian languages, *mata* is a word that signified the leading part or the growing tip of something. It does not indicate a direction, but a frontal *sense* of direction. As well as meaning a person's face, *mata* can also be a prominent geographical point, like a headland, or a rock which marks the leading boundary between fishing grounds. The prefix *mata-* is used in words that mean a first appearance, for example *mataika* is the first person slain in a battle. *Mataaho* is the window of a house, metaphorically perhaps we could think of it as the "eye" of the house. *Mataihi* is the gable-end "face" of the meetinghouse. In the *Williams Dictionary of the Maori Language*, the word *mataaho* was recorded as early as the first Edition (1844). *Mataihi* appeared for the first time only in the fifth edition (1917). This is not to say that *mataihi* was not a traditional word, but its architectural meaning was perhaps less obvious to early lexicographers than *mataaho* was.

Internationally, the ornamental *mataihi* of the *wharenui* is the best-known icon of Maori architecture, comparable to the full *moko* tattooing of the chiefly face. As often as not it is the stately face of Te Tokanganui-a-noho that has carried this image of Maori architecture to the wider world. Te Tokanganui-a-noho is one of the oldest extant meetinghouses. It was built and reconstructed and relocated over a period of years from 1873 to 1882 under the supervision of a visionary leader of the time, who was also the founder of the Ringatu Church, named Te Kooti Arikirangi Te Turuki (Binney, 1995, pp. 272–281). The design of this house not only reaffirmed traditional values in a time at which Maori were experiencing all sorts of upheavals, it was also without doubt the most innovative house of this period and it started many trends that were taken up in later meetinghouses. In particular Roger Neich (1993, pp. 175–185) notes that most of the carvings on the gable-end face of this meetinghouse (with the notable exception of the carved door lintel and doorposts) were brilliantly delineated with polychrome paint; naturalistic flowers and religious symbols were painted on the vertical boards inside the porch, and naturalistic portraits of historic personages were on the door panels.

Almost all modern (postrenaissance) meetinghouses in New Zealand now adopt the traditional gable-end form. However the rectangular plan of the *wharenui* and the characteristic gable-end porch is not the only form in which Maori architecture has ever been expressed. A very traditional *whare wananga* or house of learning named Miringa Te Kakara was first built probably in the 1860s and destroyed by fire in the 1980s. This beautiful work had a distinctive cross-shaped plan and four *mataihi* facing the directions of four mountain ranges. Another memorable image is that of the circular "beehive" shaped assembly house named Hiona which was built early in the twentieth century by Rua Kenana (Binney, 1996). An awkward-seeming scaffold, platform and staircase were constructed to one side of Hiona which may have been a necessary substitution for faciality in the form of this work. Many Maori churches too do not

display the traditional *mataihi* form. In the case of one early church, Rangiatea, completed in 1851 by the famous chief Te Rauparaha, it is recorded that the Reverend Samuel Williams played an important role in its design when after a dispute and in the middle of the night he cut a 10 ft length off the ridge pole. It is interesting to speculate that the dispute may have been related to a perceived conflict between the more traditional Maori expression of faciality, which would have required the extended ridge pole (*tahu*) to support a gable-end porch, and the shorter inward-looking Christian church form that was eventually adopted.

In the case of the pan-tribal meetinghouse Te Hono-ki-Hawaiki which was recently incorporated in the Museum of New Zealand Te Papa Tongarewa in Wellington, the meetinghouse almost seems to be reduced to a pure expression of *mataihi* or face (http://www.tepapa.govt.nz/virtualhighlight/Marae_english.html). The designer Cliff Whiting comments that this was partly a result of compromises that were necessary to develop a pantribal *kawa* (protocol). The Maui family group was adopted to embrace the widest possible sector of the population including Maori and Pacific Island people. Te Ati Awa and Ngati Toa, as *tangata whenua*, the local hosts, were made responsible for figures on the *amo*, the two side posts of the meetinghouse, while many other figures on the gable-end have yet to be named at all. Whiting remarks that *iwi* (tribal groups) from all other parts of the country can opt to “come into it” or not as they wish. In this sense the *kawa* of Te Hono-ki-Hawaiki is in a state of incompleteness, like the incomplete, yet to be negotiated political *kawa* of biculturalism in New Zealand. Its *mataihi* signifies a dynamic temporal sense of “facing the future” and of going forward with political intent. It has often been remarked that the classical Maori body “faced” the past and had its back to the future, and the front of a meetinghouse more often represents a region of timeless myth and legend (Neich, 1993, p. 232). This modern version of *mataihi* at Te Papa in effect employs the myth of Maui in a bicultural context in order to “face” an unformed future.

Ornament, *Whakairo*

Whakairo means to adorn with a pattern, to give direction, to form and inform aspects of any artistic construction whatsoever. The word was recorded in the first Edition (1844) of the *Williams Dictionary* but with only the limited meaning of “carved, carving, to carve.” The prefix *whaka-*, meaning “toward, in the direction of,” first appeared in the third Edition (1871). A 1915 version (which was not a separate Edition) of the *Dictionary* extended the meaning of *whakairo* to include “carve, adorn with carving.” Two years later this was replaced with the fuller meaning, “ornament with a pattern, used of carving, tattooing, painting, weaving.” Today the meaning of *whakairo* has been further extended to also embrace such activities as sculpture, printmaking and spatial design. Thus a *whare whakairo* may not necessarily be a *carved* meetinghouse at all. The decorative scheme of Rongopai, for example, a beautiful 1887 meetinghouse, comprises “a magnificent statement of tribal identity and joyous optimism” (Neich, 1993, p. 192) that is expressed predominantly through painted figures and patterns rather than through woodcarving.

The architectural meaning of *whakairo* “giving direction” and constructing an orientation for people in the world is expressed in every meetinghouse through the orientation of the *tahu*, the long imposing horizontal ridge pole which is sometimes also called *tahuhu*. The *tahu* or *tahuhu* is normally painted with distinctive *kowhaiwhai* patterns in the interior and carved where it joins with the exterior scheme of the *mataihi* under the roof of the porch. What is however a more fundamental aspect of *whakairo* of the *tahu* is its horizontal *orientation*, its direction in the world.

We might say that Te Kooti was the principal architect not only of the Ringatu Church but also of the meetinghouse in its modern form. Te Kooti adopted the meetinghouse form as a way to subvert the intention of the Christian mission church, or to transform the Christian message according to Maori protocols. In place of the tall closed box and the spire pointing upward to heaven, which was a form of church architecture already familiar in Maori villages throughout New Zealand,

Te Kooti emphatically reasserted the authority of the *wharenuī* form, and in particular the horizontal *tahu* that points to a real horizon.

Roger Neich (1993, pp. 229–234) describes how the *tahu* not only marks the place of the *marae* (the village and its formal gathering place) as a specific location in the world but also describes a direction within and across this place. Referring specifically to a Ringatu meetinghouse named Tutamure at Omarumutu *marae* near Whakatane, Neich identifies multiple layers of interconnected narratives through which the *tahu* points out and constructs a meaningful direction in the world. Firstly Neich writes it points to the openness of the *marae* forecourt in front of the *wharenuī*, and to closure at the rear. Then it points to the ocean and the land, the sea and the forest (pointing out that the technoeconomic resources of the local people are found in front of and behind the house, respectively). The ridgepole of the meetinghouse also points to Hawaiki and New Zealand (as directions in front and behind in cosmological space), and to the canoe immigrants (in this case the Mataatua and Nukutere canoes) and the Tino-o-Toi aborigines (directions of arrival, confrontation and retreat in the sociological space of tribal history).

Almost every *marae* has stories similar to this associated with the horizontal pointing form of the *tahu* of the *wharenuī*. The “point” of the meetinghouse is this fundamental *whakairo* gesture. It is interesting to note that the Anglican Holy Trinity Cathedral in Auckland recently extended the nave with a strong *wharenuī*-like horizontal gesture, but that the church authorities did not see fit to build a vertical campanile (contrary to the advice of the architect).

Space, *Kauhanga*

Kauhanga is a term that means the interior space of the meetinghouse specifically when it is *tapu*. There are other words also that refer to interior space, for example *tara iti* is the space on the inside left of the *wharenuī* and *tara nui* is that on the right (as one enters the house from the front.)

Literally *tara* refers to the side walls of the house as well as meaning the inside spaces. Whenever a new *wharenuī* is constructed a great deal of negotiation takes place to decide which ancestors and stories should be represented and the most appropriate spatial relationships. Naturally, as with any architectural design, the interior space becomes charged with potential meanings far in excess of what is actually built. The highly potent *tapu* condition of a new meetinghouse is dissipated in ritual processes called *whakanoa*.

The *tapu* space is often implicated in what might be called prophetic lore or *kupu whakaari* that is associated with the opening of meetinghouses. One famous example is a prediction or warning that Te Kooti is said to have made when he attended the reopening of Te Tokanganui-anoho in 1883. It is recorded that Te Kooti said “The day will come when the God of the Pakeha will whistle in these places, . . . entering right into the porch of the house and coming straight through the back of it. . . .” (Binney, 1995, p. 278). Te Kooti also said of another meetinghouse, Ruataupare, that “. . . one wall is arguing against the other, and the door against the back wall.” (Binney, p. 328). This is not the place to enter into the interpretation of these prophetic sayings. What is significant is the fact that the *kauhanga* space of the meetinghouse is implicated in them.

Since Maori architecture is alive and its meaning is alive, therefore it is appropriate to speak to the *wharenuī*, and also on occasion to speak as it were *through* the *wharenuī*, to allow the architecture of the house to structure and guide what is said. Even on some occasions of *whaikorero* or formal talking it is appropriate that the *wharenuī* itself speaks. As Hohepa Kereopa succinctly expressed it, “The *whaikorero* is based on the idea of how a *whare* is built” (Moon, 2003, p. 113).

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Architecture of the Maya

Kevin Schwarz

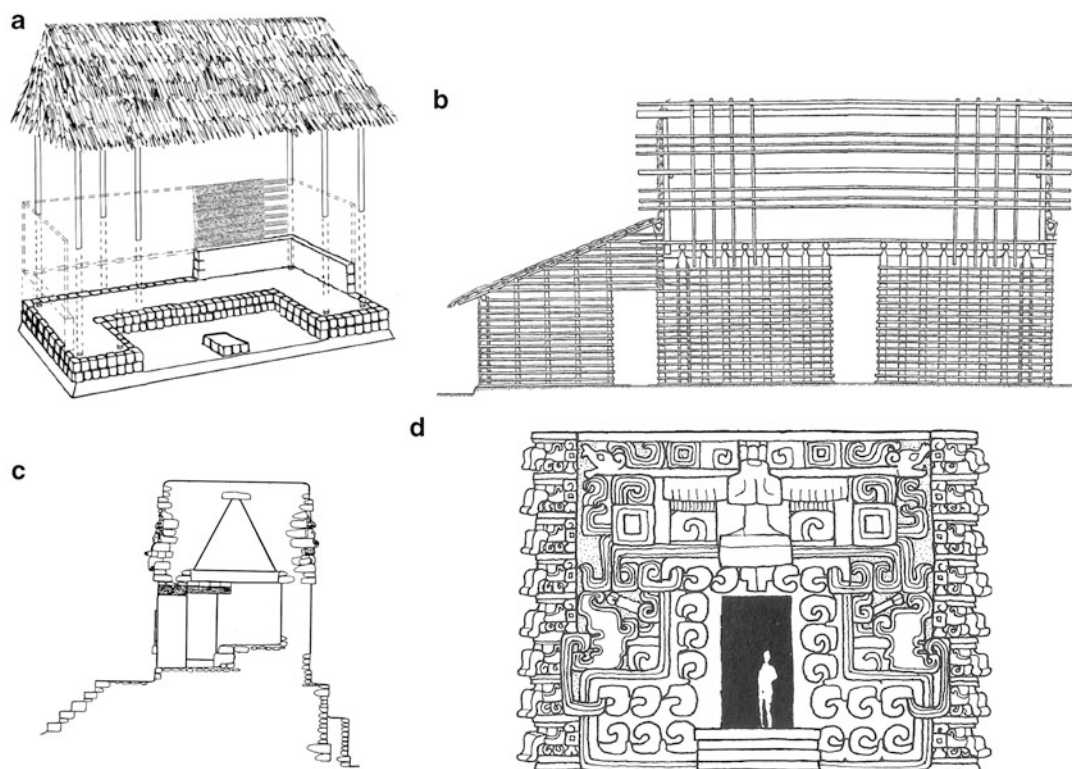
ASC Group Inc., Columbus, OH, USA

The Pre-Columbian Maya of southern Mexico and Central America had one of the most developed architectural traditions among indigenous cultures of the Americas. The Maya building tradition originated in the Preclassic period (2000 B.C.–A.D. 100) and reached an apogee of development in the Classic period (A.D. 200–A.D. 850). The Classic Maya Collapse (A.D. 800–1000), Spanish Conquest (A.D. 1521–A.D. 1697), and subsequent Colonial period (until A.D. 1821) affected Maya civilization in various ways, and this included their architecture. The Maya abandoned many of their urban civic-ceremonial centers in certain regions. Buildings crumbled and were covered by forests. The construction of large temples and carved stone stelae decreased and then ceased. Some Maya remained and built smaller-scale civic-ceremonial centers, however. Architectural traditions continued in the Postclassic period (A.D. 1000–A.D. 1525) although the Maya transformed certain aspects of their architecture

(Schwarz, 2013). Smaller temples and shrines emerged and new building types such as open halls became common (Fig. 1a). After the Spanish Conquest, the Maya only continued some of their pre-Columbian building traditions. They adapted to the new cultural setting as they found themselves becoming peasants in the developing colonies and Central American states and Mexico.

Archaeologists spent much of the late nineteenth and early twentieth century rediscovering and reconstructing pre-Columbian Maya centers and buildings. The overall emphasis was on determining architectural function and on restoring the buildings themselves. These tasks continue (Fig. 2). However, archaeologists increasingly have studied the cultural processes by which the Maya created architecture, such as their architectural technology (Abrams, 1994) and their process of design (Schwarz, 2013). They also have researched how the Maya conceptualized the built environment (Houston, 1998) and dwelt within it (Hutson, 2010). Another topic of interest is identifying how building programs corresponded to political and dynastic histories. Also, increasingly sophisticated analyses of architectural plans (Ashmore & Sabloff, 2002), coupled with better iconographic analyses and decipherment of Maya hieroglyphs, mean that now an appreciation is developing of the symbolic and semiotic aspects of Maya architecture and use of space.

With these themes in mind, this article focuses on Maya architectural design, architectural technology, and architectural symbolism and semiotics. What archaeologists had presented as a static view of a Stone Age culture of builders is now resolved to such a degree that we can see the innovation, consensus, freedom, and play inherent in the creation and modification of these buildings (Schwarz, 2013). Through the study of architecture, archaeologists can reconstruct, to some extent, the kinds of constraints and opportunities Maya architects and builders faced. And they can posit realistic reconstructions of how the Maya actively changed their buildings over time, from the royal precincts of the largest classic civic-ceremonial centers to the huts of the



Architecture of the Maya, Fig. 1 Maya Buildings. (a) Postclassic open hall, Quexil Islands, Guatemala (From Schwarz, 2013); (b) twentieth-century Maya pole-framed house, Coban, Guatemala (Adapted from Wauchope,

1938); (c) vaulted residential structure 9 N-82C, Copán, Honduras (Adapted from Abrams, 1994); (d) temple at Tabasqueño, Mexico. The entire frontal facade is a god mask (Adapted from Schele, 1998)



Architecture of the Maya, Fig. 2 Step pyramid being reconstructed at Xunantunich, Belize, in 2001. On the *right* side, the building facade is collapsed while on the *left* is a partially restored structure

modern Lacandon people. The Maya changed their architecture and innovated as their needs changed and as they responded to the social and environmental challenges they faced.

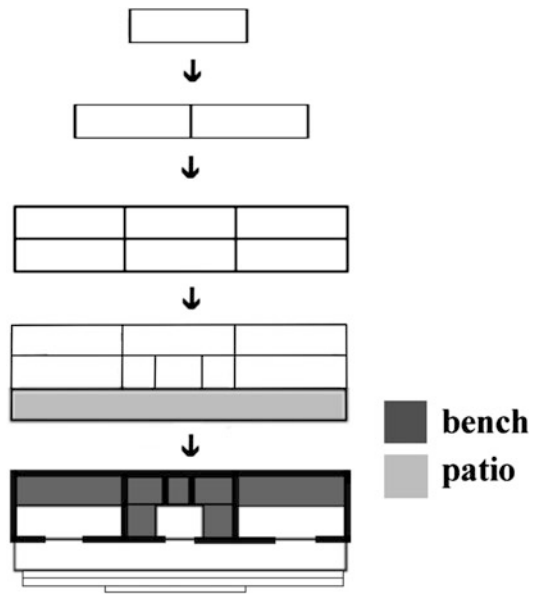
Architectural Design

The art historian George Kubler (1961) wrote that Maya architecture derives from several basic forms, including the hut, the platform, and the path. All of these forms can be found in any Maya village from the Preclassic period until today. To this list, Mary Ellen Miller (1998) adds a fourth element, the stairs, which connect platforms. Or as the Maya elaborated upon the hut or house form throughout the eventful course of Maya history, stairs led to elevated palaces or temples. A few other distinctive forms can be mentioned and are described below, including ballcourts and observatories.

Elaboration and embellishment of basic forms resulted in a variety of building types and styles. There is a cultural logic evident in Maya building on the basis of several actions, including the subdivision of rectilinear built spaces and replication of single-room cells (Fig. 3) used in buildings (Schwarz, 2004). Arrangements of these cells can form larger multiroom structures (Fig. 4). Most such Maya buildings maintained certain symmetries, particularly bilateral symmetry.

Maya buildings are massed together into distinctive arrangements of positive spaces (e.g., rooms enclosing spaces) and negative or open spaces (voids). Most generally, pre-Columbian builders positioned buildings in relation to principles of cardinal directionality. Particularly, they were oriented to the path of the sun and other celestial bodies. East is associated with the rising sun while west is associated with the setting sun. The Maya identified structures in the north and south positions of architectural groups with the mythic heavens and underworld (Ashmore & Sabloff, 2002).

The arrangement of these built and open spaces formed groups of buildings and precincts



Architecture of the Maya, Fig. 3 Example of Maya residential building from Tikal. Design of the structure can be conceived of partly as a series of replications and subdivisions of a rectangular cell (Adapted from Schwarz, 2013)

(groups of groups). Most notably, Maya buildings from the Preclassic and Classic period established a pattern whereby groups of buildings were generally arranged around broad, paved open spaces, or plazas (Fig. 5).

The Maya today make use of outdoor space, for example, the Yucatecan *solar*, or walled courtyard, where outdoor space is as integral as the building to the design and use of social space (Hanks, 1990). This indoor-outdoor integration of spatial practice apparently has great antiquity. Use-patterning at archaeologically identified residences indicates spaces in plazas, and around and behind buildings were used and segregated into activity areas (Robin, 2002).

Integration of architecture and spatial practice perhaps has its most spectacular and notable development in the Maya Classic period (A.D. 200–850) civic-ceremonial centers, such as Tikal, Copán, and Palenque. Architectural expression framed the creation of meaning and prestige. Studies of architecture, iconography, and Maya hieroglyphs in civic-ceremonial centers have



Architecture of the Maya, Fig. 4 Range structure, Tikal, Guatemala

Architecture of the Maya, Fig. 5 Domestic plaza group. Domestic structures around an open plaza at Copán, Honduras



demonstrated that elite precincts, which were the provinces of Maya divine kings, nobles, and priests, became superlatively charged semiotic environments. The architecture, arrangement of monuments, and placement of iconography and hieroglyphic texts on architectural media supported political displays of power and sacred rituals (Miller, 1998; Schele, 1998; Tate, 1992). The result was a designed or built environment that communicated the ideological values of the Maya

elites, inculcated political views, fostered social control and appropriate behaviors, and expressed deeply held religious meanings. The Maya were both the creators and users of this semiotic system, and it acted upon them.

The Maya house (Yucatec *nah*) is the most common architectural form. Generally, it is but one room or two (Fig. 1b). The low thatched roof hut of both today's Maya village and the pre-Columbian past is at base an enclosure that



Architecture of the Maya, Fig. 6 Hieroglyphic Bench at the House of the Scribes, Copán, Honduras. At Copán, benches were inscribed with texts that have cosmological and political statements, aligning the elites with the ruler and the gods

screens off interior space from the outdoor space (Kubler, 1961; Miller, 1998). The house may contain a kitchen, shrine, agricultural storage, and sleeping quarters. These elements may be parts of a single building or form a small cluster of individual buildings. The focal point of the house was often a bench-altar or, in the modern context, a table altar. At Classic Copán, Honduras, elite scribes and lineage patrons had bench-altars inscribed with texts that presented cosmological and political statements, aligning the elites with the divine king and the gods (Fig. 6) (Noble, 1999). In essence, house altars centered the household in its politico-religious setting.

Multiroomed palaces can be conceived of as elaborated designs where single rooms have been replicated and added on in a patterned fashion (Fig. 3). These multiroomed buildings, termed range structures, were prevalent in Classic civic-ceremonial centers. They were generally single-room deep sets of rooms arranged side by side along a plaza (Fig. 4). Stairs and elevated patios provided access to elevated structures and a frontal space for approaching the building and for social interaction between visitors and occupants. Range structures had highly repetitive and impressive frontal facades and exhibited the bilateral symmetry common to Maya architecture. Archaeological clearance of rooms in these buildings usually yields little evidence of what

activities the Maya carried out there. Most archaeologists think these range structures were elite palaces for housing the nobles, priests, officials, and retainers of the Maya royal courts. A related idea is that they were administrative buildings.

Maya houses or house shrines were often the sites of burials of ancestors (McAnany, 1995). Burials can take a variety of forms including tombs, crypts, or cists. Sometimes the Maya placed burials within the hearting of an elevated structure or below benches or stairways. In some cases, shrines were separate structures within a familial compound.

In Classic civic-ceremonial centers, there were elevated burial shrines associated with the ruler or related elites. Many shrines were physically closely related to elite houses. In other cases, they were associated with the civic-ceremonial core of the urban center, although the attendant concept of the house still applies (see below). Step pyramids became common in the Late Preclassic period and were the premier ceremonial temple form of Classic centers in addition to having sepulchral functions. That is, the Maya buried divine kings or their direct kin in tombs in such structures, such as the temples at Tikal, Guatemala (Figs. 7 and 8). Rites and ceremonies were performed at these temples as well.

Step pyramids sometimes were surmounted by a small temple or throne room (Fig. 7). These structures were elaborate single-room (or at most two or three rooms) stone buildings, set atop the step pyramids. Tedlock (2005, p. 197) reports that the Quiche Maya called a step pyramid with a temple on it *Kaq Ja*, “red house,” indicating an explicit association of this structure type with houses. In some cases, step pyramids exhibited radial symmetry (Fig. 9), i.e., symmetry is expressed on all four sides of the structure. It is believed that the radial design of four stairs leading to the central temple relates to a quatrefoil form in Maya iconography. The quatrefoil references several mythological and astronomical figures, such that the radial architectural form metaphorically encloses the archetypal three stone hearth central to all Maya houses (Taube, 1998).

**Architecture of the
Maya, Fig. 7** Temple
II. Tikal, Guatemala



**Architecture of the
Maya, Fig. 8** Temple
I. Tikal, Guatemala



The Maya both built buildings on platforms and utilized the platforms themselves as useful spaces. At sites such as Tikal, Guatemala, relatively frequent building and rebuilding over many centuries resulted in the creation of elevated architectural spaces. The built monumental space became so impressive that they are termed acropoli by Mayanists after the Greek usage. Excavations often yield evidence of prior building episodes of temples and palaces buried within the architectural mass of

stone and earth as the temple and palace complex (Fig. 10) was remodeled and expanded repeatedly.

Lest Maya civic-ceremonial architecture seems overly forbidding, dominated by temples atop steep step pyramids (Fig. 7), it should be said that low platforms adorn Maya sites at plaza level as well. These include oratories, round temple platforms (Fig. 11), and presentation palaces. Though archaeological investigation is often inconclusive, these low structures are sometimes

Architecture of the Maya, Fig. 9 Castillo, Chichén Itzá, Mexico. Temple pyramid exhibits radial symmetry



Architecture of the Maya, Fig. 10 North Acropolis, Tikal, Guatemala



thought to have been used for religious and political events and rituals that would have been viewed by the public.

Raised, paved pathways/roads (Yucatecan *sacbeob* or “white ways”) were built up into networks that connected Classic civic-ceremonial centers, smaller satellite centers, and even other centers. The sites of Cobá, Mexico, and Caracol, Belize, are famous for radial networks of these elevated *sacbeob*, which tied together the extensive territories that these

centers controlled. Most of the *sacbeob* led to the civic-ceremonial center. Cobá also is connected to the neighboring center of Yaxuna by a *sacbe* that is over 100 km in length. *Sacbeob* sometimes connected precincts or groups of buildings within large sites such as Tikal.

Ballcourts along with observatories (described in greater depth below) reference pan-Mesoamerican influences. They occur in Highland Central Mexico as well as in the Maya region. Ballcourts were alley-like masonry

Architecture of the Maya, Fig. 11 Round platform. Seibal, Guatemala



Architecture of the Maya, Fig. 12 Ballcourt, Tikal, Guatemala

constructions in which the Maya played a sport with a natural rubber ball. The sport involved two opposing teams in a competition that had both mythological and war associations. In the Classic period of Petén, Guatemala, most ballcourts were simple masonry alleys with angled sidewalls and elevated viewing platforms for spectators (Fig. 12), while at Chichén Itzá, Mexico, a larger I-shaped ballcourt had iconography on tall, straight-sided walls. Ballcourts are no longer built today.

Architectural Technology

Maya building has utilized a variety of materials including stacked cut stone; cut stone veneer with a rubble core; and earth, adobe, and wood. Use of multiple materials in a single building was common in the pre-Columbian period and is common today. Cut stone is frequently limestone, particularly in the karstic lowlands, while sandstone and igneous stones were also used in some settings, such as the Usumacinta Valley, Mexico, and

Architecture of the Maya, Fig. 13 Post-and-lintel structure



A

Architecture of the Maya, Fig. 14 Corbelled vault at Labna, Mexico. The facade is decorated in the famed Puuc style (Photo courtesy of Edy Barrios)



Maya Highlands of Mexico and Guatemala. Lime stuccos and plasters were common surface treatments, particularly in the pre-Columbian period.

A fundamental challenge that architectural technology addresses is the problem of spanning or development of roofed spaces to protect occupants and possessions from the elements and provide enclosure for controlled social interaction. The Maya had multiple technologies for spanning, including thatched roofs with lightly framed pole rafters (Fig. 1b), wooden post-and-lintel structures, stone post-and-lintel (or beam) structures (Fig. 13), and the corbelled vault

(Figs. 1c and 14). The use of the corbelled vault emerged sometime in the Preclassic period (Hansen, 1998) and was widely employed by the Early Classic period in the heartland of the lowland Maya civilization, the Petén of Guatemala. This method has sometimes been called the false arch, because weight is transferred laterally rather than to a vertically oriented keystone bearing weight overhead (as in the Old World arch). The corbelled vault served the Maya well enough, however. The result was that, in order to sustain the lateral forces, the Maya built relatively narrow roofed rooms in corbelled vault

Architecture of the Maya, Fig. 15 Puuc style facade at Las Monjas group, Uxmal, Mexico (Photo courtesy of Edy Barrios)



buildings and exterior walls had to be massive and made of stone and earth. In comparison to the Classic period massive vaulted stone structures, during the Postclassic and later periods, post-and-beam structures were more common. These are much more lightly built. Some Postclassic structures had partially or wholly wooden superstructures and thatched roofs (Fig. 1a).

The use of thatched roofs with native palms and grasses is known from the archaeological excavations at El Cerén, El Salvador, and in the present day. According to the author's informants, thatched roofs are preferred in Petén, Guatemala, a region with high rainfall. The natural thatching can last a long time, up to 10–30 years, if prepared properly (Wauchope, 1938). Thatched roofs seldom leak. However, corrugated aluminum roofs are more common today because of the lower labor outlay. They are much hotter for their inhabitants than traditional thatching. Wattle and daub was and continues to be a common wall fabric, particularly for houses and other small structures.

Studies have shed light on how ancient Maya buildings were built and how much labor actually was involved. From cutting stone blocks in a quarry without metal tools, to making lime plaster, to gathering palm thatch, and to assembling the actual building, a number of

procurement and construction activities were very labor intensive. This has led to theorization of what kinds of labor organization were utilized to build the Classic civic-ceremonial centers with their temples, palaces, and monuments. *Corvée* labor, feudal relations, and other obligatory systems have been put forward to explain how Maya elites commanded so much labor. Abrams (1994, p. 55), however, calculated how much labor actually would have been needed, for example, to build palaces and elite houses at Copán, Honduras, based on experimental data. For example, he estimates vaulted palace structure 10L-22 to have required 24,705 person-days to construct, while a vaulted roof elite house structure, 9N-82C, required 8,567 person-days (Fig. 1c). Structure 9N-83, a post-and-beam residence, required 5,893 person-days of labor. A person-day is the labor of one adult for one work day of 5–8 hours, depending on the task. However, he notes the long time horizons during which the Maya built many of these structures. Some were expanded and remodeled over decades and even centuries. Considering these long time spans for construction, labor outlays by commoners in the Copán kingdom may have been as little as a few days or weeks per year to account for the mass of buildings at the civic-ceremonial center of Copán.



Architecture of the Maya, Fig 16 Puuc style facade at Kabah, Mexico. Repeated geometrical designs and tenoned god masks characterize this style (Photo Courtesy of Edy Barrios)



Architecture of the Maya, Fig. 17 Palenque, Mexico. Palenque building facades preserve many reliefs displaying religious and political iconography. Also, Palenque has a unique square three-story tower (Photo courtesy of Edy Barrios)

Architecture in Politico-religious Contexts: Symbolic and Semiotic Systems

Pre-Columbian Maya architecture was, as Miller (1998) explains, designed to impart meaning, mostly political and religious messages. This sort of communication utilizes architectural signs created by architects, builders, and, importantly, sponsors. The architectural messages were received by building occupants, visitors, and other recipients (Schwarz, 2004; 2013). Effectively, architecture was a semiotic system, a means of communication with built forms, messages in stone. Architecture communicated messages important enough to invest the considerable sums of labor and materials described above and justified the pursuit of long-term construction programs by sponsors and their subjects. And architecture and the iconography were symbolic of deeply held beliefs and

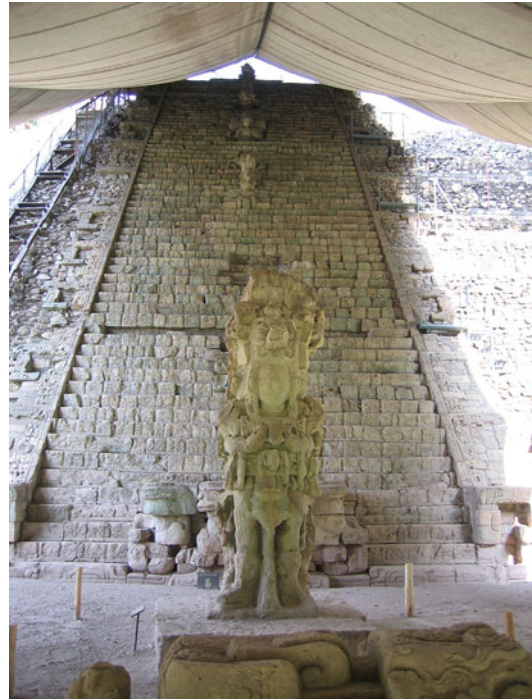
inculcated ideologies prevalent in Maya society, such as divine kingship.

Architecture across the Maya region had identifiable regional styles (Andrews, 1975), such as the Puuc style of central Yucatan, Mexico. Some civic-ceremonial centers' styles also referenced architecture from powerful highland Mexican neighbors like Teotihuacan and the later center of Tollan, home of the Toltecs. Styles apparently communicated identity, alliance, and similarity although it must be said that some cities, such as Copán, produced architecture and sculptural art so unique that they belie regional stylistic identification. They are exemplars in and of themselves. The Puuc style is noted for its repetitive, abstract facade designs punctuated regularly with masks of gods (Gendrop, 1983). These designs are of such stunning artistic quality that they compare favorably with abstract art anywhere (Figs. 1d, 14, 15, and 16).



Architecture of the Maya, Fig. 18 Relief panel at Palenque, Mexico

Three examples of architectural expression and communication indicate the achievements in composing enduring buildings, in creating innovative built forms, and in architectural messaging. Schele (1998) notes that Maya architectural facades were stage fronts for rituals and carried important messages, particularly at sites such as Palenque, Mexico (Figs. 17 and 18). Beginning in the Late Preclassic and taking on increasing sophistication during the Classic period, iconography and hieroglyphs were displayed that portrayed historical narratives, religious and creation imagery, and other subjects. God masks (Fig. 1d), flowers, snakes, sacred mountains, Maya kings, and other images adorned temples, bearing walls, freestanding stelae and altars, and a variety of other media. Such extensive integration of the hieroglyphic texts and architecture is perhaps comparable to Chinese integration of large-format calligraphy in public spaces. But the integration of pictorial hieroglyphs and a powerful and complex naturalistic iconography on architectural media is unique to the Maya. It is one of the reasons Maya architecture is so fascinating.



Architecture of the Maya, Fig. 19 Hieroglyphic stairway and stela depicting the 15th ruler of Copán, Honduras, and dynastic history

Fash (2000) refers to the hieroglyphic stairway at Copán as the great dynastic encyclical for this kingdom. This construction integrated the history of the Copán polity in a unique monument. Hieroglyphs and tenoned sculpture (Fig. 19) are arrayed on a stairway that leads to a temple on top, which is richly decorated with both Maya and Teotihuacan (Mexican) style texts and images. A large sculpted figure at every twelfth stair step depicts an important previous ruler of Copán. In this unique monument, inscriptions portray and link the fifteenth ruler of Copán with the dynastic history of the ruling house and symbolically link him to his powerful ancestors, to warrior imagery, and to the powerful Teotihuacan state.

The Caracol of Chichén Itzá, Mexico, is the largest and most famous round tower of the Maya region (Fig. 20). Aveni (2001) believes that its openings (stone windows and stone building elements) are aligned with celestial bodies on the horizon during significant astronomical events.

Architecture of the Maya, Fig. 20 Caracol, Chichén Itzá, Mexico. It is believed to be an ancient observatory (Photo courtesy of Edy Barrios)



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Several smaller observatories, mostly in the Yucatan peninsula, are also known although these are not well studied. At Chichén, the Caracol is thought to preserve alignments matching the most northerly declination of Venus at sunset, the sunset at the day of its zenith passage, and the summer solstice sunrise. These alignments, if intentional, would provide good evidence for the degree to which the Maya observed the heavens and then oriented their lives and buildings in accordance with important celestial events. Certainly, Aveni's evidence is strong though circumstantial, and the celestial alignments at Chichén Itzá and other sites fit with our knowledge of Maya astronomy and astrology in written bark-paper codices and the quite accurate solar, lunar, and Venusian elements of the Maya calendar.

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Architecture of the Maya: Domestic Architecture

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Every society in the past has built and maintained some sort of domestic, or residential, architecture for the purposes of shelter, social gathering, activity space, and material storage. Environmental conditions, social structure, and cultural expression influence the type and style of domestic architecture developed by a society. Maya domestic architecture is typical of tropical or subtropical regions with abundant natural resources for building. Investigations of Maya domestic architecture provide insight into Maya social life, family structure and relationships, as well as daily activities and productive pursuits.

The two major sources of information on Maya domestic architecture are material remains of houses excavated by archaeologists and structures constructed by “modern Maya” people. Archaeological investigations of ancient Maya houses and related domestic architecture are a more recent development in the discipline. Most early archaeologists were attracted to the grandeur and mystery of Maya monumental buildings and public spaces. Current archaeological inquiry in the Maya region has expanded to fully include detailed study of domestic and residential space. The extraordinary discovery of the ancient Maya village of Ceren in El Salvador, called the “Pompeii of the New World,” (Sheets, 2006) has been very influential in inspiring concentrated excavations of Maya households and domestic spaces. Ceren was buried and preserved in ash during a massive volcanic event. The field of household archaeology is closely tied to the Ceren discoveries and how much we have learned from the amazing preservation of Maya households at that site.

Studies of modern Maya houses and the domestic sphere of living people have also been very influential in our understanding of how ancient people lived and their daily households. The most famous of such studies was conducted by Robert Wauchope (1938) and provides extensive detail on how Maya people constructed houses and domestic areas, what domestic activities can be preserved in the archaeological record, and what materials were used for construction and daily life. Photographs from Wauchope’s work significantly inform archaeological reconstructions of ancient Maya housing and other domestic structures.

Construction

Most Maya architecture is designed with two major components, substructure (also known as base, terrace, or platform) and superstructure. For domestic architecture, substructures are typically constructed of masonry and/or earth to form a solid foundation upon which living spaces can be organized. Superstructures are typically constructed of perishable materials, such as



Architecture of the Maya: Domestic Architecture, Fig. 1 View up into a modern roof structure at the archaeological site of Tikal showing perishable materials, supporting wooden members, and covering palm thatch

(Fig. 1) thatch, widely available and renewable in the tropical environments of the Maya region. The use of more permanent materials in substructures indicate that these were meant to last, while the superstructures composed of impermanent materials were not necessarily meant to last beyond a generation's occupation of a house. Archaeological evidence and explorations of modern Maya cultural practices suggests that the superstructures of Maya houses were renovated or rebuilt on a relatively consistent cycle.

Domestic building and rebuilding events have been informally studied in modern Maya communities. Elliot Abrams (1994) suggests that continual domestic rebuilding could have been sustained by a reciprocal labor system. Families and extended kin networks likely exchanged labor for rebuilding episodes over generations and developed relationships based on reciprocal labor. This type of communal labor system likely also extended to agricultural practices. Abrams (1994) also suggests that other labor systems existed in Maya society including tribute and/or *corvée* (forced) situations for public architectural construction.

Spatial Organization and Architectural Components

Patio Groups

Maya domestic spaces are typically arranged around a central patio (or courtyard) space. This

open-air patio connects multiple domestic structures, serves as an activity area itself, and likely serves the practical need of staying cool in tropical and subtropical environments. Domestic patio groups are common throughout Mesoamerica. The patio area is typically elevated above the surrounding terrain through the construction of a substructure. Residential and other domestic structures are arranged around the patio, facing into the domestic compound. Principal buildings, such as those used for sleeping and eating, are typically located directly off the patio. Ancillary structures such as the kitchen or storage areas can be located behind the main structures or off the substructure entirely.

Structure Types

Current knowledge of Maya domestic structure types is greatly informed by work at Ceren in El Salvador (Sheets, 2006). The principal building located directly off the patio area is the domicile or living structure where sleeping, eating, and other daily activities take place. Domiciles are typically outfitted with elevated masonry benches designed for sleeping and use as a seating area. Mats of thatch or other materials would be used as cushions for sleeping on the bench surface. Domiciles typically do not have interior partitions or dividing walls but contain only single-roomed spaces. Doorways or entrances are typically short and not very wide with mechanisms for closure and security, such as curtains or sometimes wooden coverings. Activities such as household production, entertainment, and family ritual practice likely also took place in domicile structures. There is evidence at Ceren of child-rearing activities as well. Further, the use of both interior and exterior space indicates that domiciles and patio areas complemented each other as venues for domestic activities in Maya daily life.

Kitchen structures show evidence of the use of fire, certain types of ceramic vessels for cooking, and activities related to food processing and preparation. Kitchen structures typically feature walls with openings (such as between wattle sticks) that provide sufficient ventilation. Kitchen structures at Ceren are particularly informative with in situ

evidence of what the householders were cooking the day of the volcanic explosion. A multitude of specialized ceramic vessels indicate the wide range of cooking practices employed by the Maya. Further, *manos* and *metates* are particularly significant features of Maya kitchen structures as they are used to grind maize, a staple of the Maya diet, for making tortillas and tamales.

Maya households also typically contain storage structures. Storage structures are typically constructed of masonry with securable doorways. As agriculturalists, Maya people would produce their own food along with a surplus for their own contingency use or for exchange. Storage areas would be paramount for such surplus storage as well as storing valuables and prized objects such as jewelry or ancestral items. Storage areas at Ceren, known as *bodegas*, exhibit a very wide range of items from ears of corn to ducks, water containers, and broken ceramic vessels. The contents of different *bodegas*, belonging to different family units at Ceren, reveal a great deal about differences among groups. For example, one family is known as the hoarders because they seemed to keep and store every broken ceramic vessel they ever used. Another family was known as the entrepreneurs, storing a multitude of items that were likely bartered or sold to other households. Some patio groups may not have had individual storage structures but used areas of the domicile to store their surplus and valuables.

Other domestic structures that may be present in or around a Maya household could include production areas or shrines associated with family ancestry. In all, the Maya household comprised of multiple, interrelated structures that could serve diverse needs of household members. Archaeologists have recently begun using the term “house lot” as inclusive of both the architectural patio group (with multiple structures and activity areas) and household gardens or larger agricultural plots (Lohse & Findlay, 2000; Sheets, 2006). Households at Ceren often had a nearby garden with medicinal plants and subsistence crops such as manioc and maize. It is also likely that larger agricultural fields were located nearby. All of these areas should be included in the understanding of Maya domestic space and life.

Learning About Maya Daily Life

Maya domestic architecture and space are key to the archaeological understanding of how Maya people lived everyday (Robin, 2013). Sleeping quarters can reveal details about the size of family units and how everyone in the family related to one another, over generations, for example. The daily productive activities of Maya farmers in their households can help us understand subsistence practices and access to resources in the environment. Further, we can understand how changes in environment affect the majority of the Maya population. Other productive activities such as ceramic production or textile weaving provide insight into the division of labor, gendered roles, and the social organization of family units. Production in every Maya household is also the backbone of the community economy. Questions of politics and economics can be understood through detailed investigations of household production and changes over time. Communities, as collections of households and domestic units, are increasingly important in Maya scholarship (Canuto & Yaeger, 2000). Communities have genealogical, productive, and ideological ties that can all be investigated through individual households and how they compare to others.

Domestic patio groups, and particularly domicile structures, are often marked as special through the internment of deceased relatives within the floor. The Maya often dug graves for their family members into the floor of their homes and then covered the burial with a new plaster floor. These dead family members became ancestors to protect the living family and serve as their connection to the spiritual realm. Excavations of domestic buildings often reveal a great deal of information about family history and ritual practices associated with reverence for the dead (Haviland, 1988).

Elite Versus Commoner Domestic Architecture

The discussion above relates to domestic architecture that archaeologists identify with



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Architecture of the Maya: Domestic Architecture, Fig. 2 Eastern side of Central Acropolis at Tikal showing the remains of multiple elite domestic structures

“commoners,” or those making up the majority with less political and economic power than the elite minority. Elite domestic architecture is distinct from commoner domestic architecture in several ways and is most often classified as public architecture (see ► [Architecture of the Maya: Public Architecture](#)). Elite residences were almost always located in or nearby public areas (such as ceremonial buildings and plaza spaces) where members of the public sometimes had access (Christie, 2003; Fig. 2). Elite domestic architecture is reflective of the social stratification embedded in the distinction of commoner versus elite. Prestige objects, hieroglyphic inscriptions, paintings, and elite burials are often-times associated with elite domestic architecture.

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Architecture of the Maya: Public Architecture

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Like many ancient peoples, the Maya were avid builders and invested a great deal of energy and

resources to modify their environment. The result of changes to the environment made by people over time and as an expression of their lived experience is known as “the built environment.” There are many components of the built environment, one of which is architecture and the construction of buildings. Architecture itself can be divided into many types, domestic and public, for example. Using this distinction, public architecture is typically understood to be larger in scale, grander in appearance, and more reflective of a large group of people or population rather than one family or subset of a population (see ► [Architecture of the Maya: Domestic Architecture](#)). The term “public” contrasts with “private” and is used in reference to architecture associated with the congregation of people beyond their own private, or domestic, sphere. Thus, public architecture refers to buildings and spaces that were used or occupied in connection with public activities.

Scholars also use another related set of contrasting terms: elite versus commoner. Typically, public architecture is associated with elite individuals more so than commoners, while commoners are most often tied to domestic, or residential, architecture within which they would have lived. This distinction does not necessarily reflect the history of buildings, as the construction of monumental public buildings requires a large number of laborers. Often, these laborers are of the commoner ilk. Beyond these sometimes problematic distinctions, public architecture reflects some important characteristics that distinguish it from other forms of architecture.

Centralization and Nucleation

Public architecture is most often found in a central, nucleated location with historic associations to groups with social and/or political power. Centralization and nucleation are the result of long-term settlement and population growth. Many scholars investigate the origin of cities as centralized places where large portions of a society or population focus their settlement. In this way, central places become nucleated

wherein population density decreases as one moves farther away from the center. As ancient cities grew beyond the institutions of small villages, as political control developed and was sustained, and as hierarchies overtook egalitarian ways of life in a large portion of ancient societies, there was a need or demand for expressions of institutionalized social control and differentiation. In its many forms, public architecture enables such expressions and thus is most effective if present in areas of the highest population density. Further, public displays of power and/or authority are often erected in close proximity to those individuals who hold that power. Control over public architecture is often the prerogative of political leaders.

Monumentality

Public architecture is typically larger than domestic architecture and thus typically referred to as monumental. There is a general concept that architectural forms have increased in size over time since humans first started constructing buildings. The archaeological record typically bears this pattern out. Thus, monumentality is a development of architectural change and the result of changes in how people built structures over time. Building at a larger, monumental scale inevitably increases the scale of construction and requires more material resources, a larger labor force to carry out building tasks, and more preparatory planning before construction.

Monumentality can be understood as an intentioned invention or as an “unintended consequence” (Joyce, 2004) of behavioral accumulations over time. The long-held assumption of archaeologists is that ancient people desired to create enormous buildings and so invested more energy and time into construction with the result of building monumental public architecture. In this case, the intention to modify the environment would have been large scale and designed to make a large impact as a component of the built environment. From a different perspective, changes to the built environment may have been smaller but accretionary over time, continually

building atop previous constructions. Over long periods of time, the consequence of accretionary building is the development of large structures (Joyce). This development may have been unintentional originally, but as the realization of the impact of monumental structures grew, intentional monumental construction continued.

There is much archaeological evidence that Maya public buildings were often built on top of previous constructions. In opposition to the practice of renovating existing structures for continued use, the Maya often used existing structures as the internal foundation for new construction. This practice results in buildings as onions, with nested phases of previous buildings inside more recent versions. Maya monumental public buildings are often an accumulation of constructions and thus may reflect a history of unintended monumentality rather than its spontaneous invention.

Political and Ideological Expression

When buildings are in the public eye, aesthetic appearance often becomes more premeditated and inclusive of politically charged expressions. When centrally located and monumental in scale, public architecture can serve as a billboard for the display of significant social or political ideas. Motivations for such display are varied and are often tied to political messages of divineness, spiritual belief, royal pedigree, military prowess, social control, and/or group relatedness. Political and ideological expression can take the form of architectural art or ritual performance that is facilitated by the layout and design of a building. Architectural art on Maya public buildings is immensely diverse. It can range from a simply painted surface to complex carved, stuccoed, and painted masonry with inset and projecting features.

It is important to recognize that not all public architecture must be centrally located, monumental, or expressive of ideological significance. These factors most often characterize Maya public architecture; however, there are exceptions to the rule. The long history of Maya architecture demonstrates a great diversity of form, function, and meaning.

Construction

Little research has been conducted on the processes of Maya architectural construction. Generally, scholars understand that large labor forces would have been required, although for most Maya buildings, construction crews likely did not range beyond thousands of workers at any one time (Abrams, 1994). Construction tasks varied considerably depending on the type and structural form of the building. Overall, tasks can be categorized as relating to procurement, transportation, manufacture, and construction (or assembly) (Abrams). Most Maya masonry construction is composed of rough enclosing masonry (construction pins), interior masonry or earth fill, and finished exterior blocks with varying degrees of cut precision (Fig. 1). Materials for public architecture range based on architectural style but often include limestone masonry, lime-based plaster or stucco, hardwood, palm thatch, and naturally derived pigments for painting. Where limestone is not present, Maya builders used other types of stones including granite and slate as masonry materials. Masonry materials typically far outweigh the amount of wood material incorporated into Maya public buildings.

Components of Maya Public Architecture

There are several architectural components commonly found in Maya public architecture (Loten & Pendergast 1984). In particular buildings, these components may vary to a high degree. Often, different expressions of these components are found to relate to distinct regional architectural styles. There are four widely recognized Maya architectural styles: Puuc, Chenes, Rio Bec, and Peten. These styles generally correlate to geographic regions.

Substructure

Maya architectural designs can often be divided into two major components: substructure and



Architecture of the Maya: Public Architecture,
Fig. 1 View of poorly preserved masonry showing interior masonry fill and exterior finished stones in the ballcourt building of Copan, Honduras

superstructure. The substructure (also sometimes referred to as a base, platform, or terrace) is typically the largest and most massive component and serves as structural support for the smaller superstructure (Fig. 2). In pyramidal forms, substructures are typically multilayered with distinctive sections rising successively and offset from the previous edge. Substructural sections are typically battered, or sloped, as well. In combination, offsetting and battering result in the typical substructural form: broader at the base with a smaller horizontal surface area at the top. Some substructures, particularly those relatively low in height and without multiple layers, are simply battered in one plane rising from the base to the surface. On multilayered substructures, corners may be rectangular or inset. Various functional and aesthetic design elements are found on substructural walls. Moldings, or

projections from the main surface plane, on substructural walls create a more detailed design and serve to keep water away from the base of each substructural section, where it might affect the foundation. Substructural walls can also incorporate carved masonry designs or decorative stucco panels (Fig. 3). The Maya often built new buildings on top of already existing buildings. Substructures of existing buildings were often incorporated into the expanded or heightened substructure of new constructions.

Staircases or sets of steps are typically integrated into a substructure (inset) or appended to it (outset). Stair treads and risers are typically constructed of the same masonry blocks used in the substructural sections and are often battered like substructural walls to ensure water runoff. Staircases can include balustrades or edge features that delineate and emphasize their verticality. Hieroglyphic stairways are rare but striking on Maya public buildings. These staircases contain masonry blocks that are carved with hieroglyphic inscriptions on the stair risers and sometimes treads (Fig. 4).

Superstructure

Superstructures sit atop substructures and can be composed of permanent or impermanent materials. Those constructed of impermanent materials are referred to as temporary and are known to be cyclically rebuilt. Temporary superstructures are constructed like a traditional Maya house (see ► [Architecture of the Maya: Domestic Architecture](#)). Large structural posts made of cut tree trunks would be secured into the substructural surface. (Postholes are the archaeological signature of these posts.) A roof structure of large timbers would be constructed atop these structural posts, interlocking with some components, and secured with vine lashings. Smaller wood members would be added to define the interior space and create a lattice roof structure onto which thatch covering would be applied. The Maya used particular palm species for thatching. Thatch is applied in overlapping layers to ensure water protection and total coverage.



Architecture of the Maya: Public Architecture, Fig. 2 Temple II of Tikal, Guatemala. The three substructural sections of Temple II support its single-roomed superstructure with massive roof combs

Walls can be constructed in many different ways. The Maya often used the wattle and daub wall construction method. Vertical wattle sticks are placed as the structure of a wall plane and covered with the mud and claylike mixture called daub. Daub could also be covered with lime plaster for added water protection. Walls could also be constructed of free-standing masonry and coated with lime plaster. Other methods include using only wattle sticks and lime plaster together without the daub layer. Superstructures of public buildings were likely always plastered and painted (or limewashed) to appear consistent with the plastered substructures. Temporary superstructures are often smaller than permanent versions and are more affected by fire damage.

Permanent superstructures are constructed of masonry with some wooden elements (Fig. 5). Masonry superstructures are composed of rooms with individual or multiple entrances. Maya rooms are typically small in comparison to other

public architecture. Room interiors would have been quite dark as compared to the bright white or colorful exterior, open spaces of plazas. Room entrances, typically referred to as doorways, are often constructed through the use of wooden lintels (Fig. 6). Lintels span an opening, take the weight of the masonry above, and are integrated into the upper portions of the wall. Lintels can be plain, carved, plastered, and/or painted. In the absence of a lintel, doorways can be constructed as a corbel arch (Fig. 7) (see description of corbelling below). Evidence of doors is rare in Maya architecture. Instead, archaeologists have evidence that doorways were closed off by fabric panels or curtains, hung on rods that spanned the opening and fitted into curtain holders. Curtain holders were circular holes built into the threshold of a doorway opening. Some curtain holders are designed with a stick or vertical stone insert that serves as a place to tie a string, on which a curtain may have hung. Vaults and other



Architecture of the Maya: Public Architecture, Fig. 3 Carving on substructural wall on Structure 5D-43 at Tikal, Guatemala

components of superstructures are detailed below. Exterior walls of superstructures typically sport moldings similar to substructural walls that expel water and increase aesthetic appeal.

Interior stairways are not uncommon in Maya superstructures. Interior stairways typically serve to allow access to upper stories, concealed courtyards/plaza spaces, or roof combs. Corbel vaults are used to enclose interior stairways and integrate them into the superstructure masonry. Structural designs of corbel vaults above interior stairways are often creative to account for the changes in elevation (Fig. 8).

Vault

Vaults are constructed to enclose the upper sections of a room, in lieu of a ceiling (horizontal closure at the top of a room), through the creation of additional space above the floor area. The Maya are well known for the peculiar type of vaults they built to enclose their masonry rooms, called a corbel vault (Fig. 9). Distinct from a true arch vault, a corbel vault is built by

corbelling wherein vault stones are successively projected into a vault space and rest only partially on the stone immediately below. The uppermost corbel vault stone, or keystone, is placed as a cap over the vault, on the centerline above the space the vault spans. Corbel vaults require supporting stones to lock the others in place and counteract the tendency of vault stones to fall into the space cavity. The spandrel sections of a corbel vault are integral to its structural integrity. The Maya made use of this structural requirement to create upper façade sections of their rectangular roof areas. Wooden beams are often present in Maya corbel vaults, spanning the shorter, lateral dimension. Scholars debate whether these beams are structural, meant to function for storage or hanging purposes in the room, or are purely aesthetic. Vault beams can be plain or carved.

Upper Façade

The upper façade is the exterior section of a building corresponding to the corbel vault section on the interior. As a structural component,



Architecture of the Maya: Public Architecture,
Fig. 4 Hieroglyphic stairway of Temple 26 at Copan,
 Honduras

the upper façade is a masonry section that stabilizes the corbel vault. The Maya often took advantage of the exterior exposure of the upper façade to create prominent decorative panels that could contain carving, stucco installments, or painting. Upper façades typically contain large-scale architectural friezes that incorporate carved symbolic designs, hieroglyphic inscriptions, and occasional figural representations (Fig. 10).

Roof and Roof Combs

Almost all Maya roofs appear flat but in fact are gently sloped to ensure proper water runoff. Roof surfaces were protected with multiple coatings of lime plaster atop the masonry structure. Depending on the height of the building, roofs may have been designed as functional space. Political leaders may have taken advantage of the great

height of Maya buildings and used roofs as platforms from which to present themselves as nearer to the spiritual realm than the rest of the population. Ceremonial buildings also often featured roof combs, or roof crests (see Fig. 2). These were masonry features of lattice-like construction erected on the roof surface to soar above the superstructure. Most roof combs sported elaborate decorations with ideological or political significance. Roof combs appear to be important to Maya architectural design because these elements are the closest to the spiritual realm (in the sky) and thus have an intrinsic connection to the deities and spirits that were thought to dwell there. Like the upper façade, roof comb designs often incorporate carved symbolic elements, hieroglyphic inscriptions, and figural representations.

Finishes and Treatments

Most Maya buildings, both public and domestic, were protected by coatings of lime plaster. Lime plaster is derived from naturally occurring limestone and marl (powdered limestone). Lime plaster provides a permeable but protective water barrier to building surfaces that increases the lifespan of masonry materials. Depending on the constituent limestone used, lime plaster is often a yellowish or grayish white color in its final state. Lime plaster is applied in multiple coats to ensure proper coverage and to gradually refine the coat quality toward the surface. Maya public buildings were almost always treated with a limewash to seal the final coats of plaster. Other treatments to plaster include painting and coloration using naturally derived pigments. Limewashes can be colored to resemble paint. Several colors were often used to decorate Maya public buildings with red and black as the most frequent. Lime plaster and paint requires a great deal of maintenance and care.

Types of Maya Public Architecture

Ceremonial Architecture

Ceremonial buildings of the Maya have been labeled as temples, pyramids, or shrines.



Architecture of the Maya: Public Architecture,
Fig. 5 Eastern half of the Great Plaza at Tikal, Guatemala, showing the superstructure of Temple I (foreground)

and superstructures of the Central Acropolis. This view shows the great variety of height and form that superstructures can take even in Maya buildings at the same site

Architecture of the Maya: Public Architecture,
Fig. 6 Doorway with lintel in Mundo Perdido complex at Tikal, Guatemala



The term pyramid has enjoyed widespread use because Maya ceremonial buildings often have a pyramidal shape, rising from a broad substructure to a relatively compact superstructure in layers (see Fig. 1). However, Maya ceremonial buildings can also be mostly rectangular in form with vertical sides and flat roofs. Ceremonial

architecture is associated with rituals and ceremonies Maya elite would perform or conduct for both public and private audiences. Ceremonial buildings are often designed to facilitate ideologically significant rituals or performances and may be tied to specific ritual paths or processions. Ceremonial architecture is often the most



Architecture of the Maya: Public Architecture, Fig. 7 Doorway with corbel arch at Cahal Pech, Belize



Architecture of the Maya: Public Architecture, Fig. 8 Corbel vaulted interior stairway at Cahal Pech, Belize

richly and elaborately decorated type of public architecture, with distinct symbolic references or schemes that reflect the significance of the structure itself or the individual who commissioned it. Ceremonial buildings typically have interior spaces with ritual significance and that had restrictions of access related to this significance. Like most Maya buildings, interior spaces of ceremonial architecture are small and dark. Scholars suggest that the juxtaposition of a monumental, pyramid-like building and small, dark interior space reflects that natural relationship of mountain and cave. Both mountains and caves were very ideologically significant to the Maya, representing portals to the Underworld and access to otherworldly experiences. Funerary architecture can be considered a subset of ceremonial architecture. Buildings constructed to honor the dead and/or house their remains are often associated with rituals or ceremonies to commemorate death, ancestral relationships, and the spiritual relationships of elite individuals.

One type of common and very unique Maya ceremonial architecture is known as a ballcourt (Fig. 11). Ballcourts were used for the ceremonial ball game which involved a rubber ball and handless passing between teammates to facilitate “scoring” the ball in a variety of ways. Ballcourts consist of three main components: two largely identical masonry sides constructed parallel to one another and a long, level alley surface between the buildings. Ballcourt buildings have a frontal sloping ramp that may have been used during the game or as a seating location for audience members. Elaborate ballcourt buildings also have a superstructure (see Fig. 11) with interior rooms and upper façade decoration that would have sheltered either audience members or participants.

Administrative Architecture

Administrative buildings functioned as spaces for meetings, social control, and politically related housing in public places with varying degrees of



Architecture of the Maya: Public Architecture, Fig. 9 Corbel vault and room interior in the Plaza of the Seven Temples at Tikal, Guatemala, showing plastered surfaces, floor elevations, and vault beams

accessibility. Scholars have suggested that elite individuals who worked to sustain a political administration would have conducted business related to taxation, political decision making, judgment, and/or military control in administrative buildings. Administrative buildings are typically found in groups and are often arranged around or in front of ceremonial buildings. These multiroomed administrative buildings may have also served to protect ceremonial spaces and restrict access to them. Administrative buildings of this type are often called *audiencias* (Fig. 12). A special type of administrative building, known as a council house (or *popol nah*), has larger interior spaces and probably functioned as a meeting place for elite leaders and decision makers. Administrative buildings are typically rectangular and less decorated with shorter substructures than ceremonial architecture.



Architecture of the Maya: Public Architecture, Fig. 10 Reconstruction of macaw carved decoration on the upper façade of one ballcourt building at Copan, Honduras

Administrative buildings typically contain more rooms than ceremonial architecture because room interiors were used on a more regular or more utilitarian basis. Room interiors often contain different elevated floor levels and features known as benches (Fig. 13). Benches in administrative buildings are typically at sitting height, as opposed to lower benches in domestic contexts that were probably used for sleeping.

Plaza Spaces

Spaces that lack buildings and are generally open often provide venues for public activities and so should be involved in an understanding of public architecture. In the Maya world, open spaces linked to public buildings are known as plazas. Archaeological evidence indicates that these plaza spaces were used for public gatherings, feasts, and ceremonies associated with politically powerful groups. Plaza spaces often contain stelae that represent important figures or events significant to the centralized place or region (Fig. 14). Stelae are monumental carved stone blocks erected upright, sometimes plastered and painted. While often flat and planar, plaza spaces may also contain stairs, elevated areas, drainage systems, and temporary structures for shade or display. Some scholars also suggest that certain plaza spaces surrounding Maya public buildings would have been used as marketplaces



Architecture of the Maya: Public Architecture, Fig. 11 Western half of ballcourt at Copan, Honduras



Architecture of the Maya: Public Architecture, Fig. 12 East façade of structure A-2 at Cahal Pech, Belize. This multiroomed building is considered an *audiencia* as it funnels and restricts access to the more private plaza to the west

(Cap, 2011) with subdivisions of space used for distinct vendors or merchandise. Plaza spaces also serve a connective or transitory function to link distinct areas, such as ceremonial and

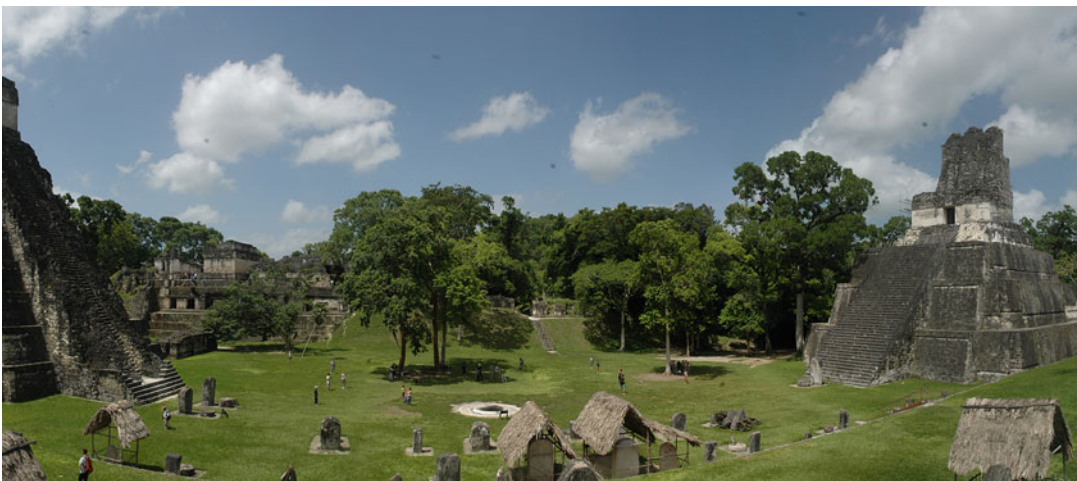
administrative areas. Much current research is concerned with better understanding the public functions of plaza spaces and their connections to adjacent and nearby public buildings.



Architecture of the Maya: Public Architecture, Fig. 13 Room interior at Cahal Pech, Belize, showing corner bench

Elite Domestic Architecture

Despite the tension between the labels of domestic and public, in the Maya culture the residential structures of elite people (often referred to as or palaces) served some public functions. Elite domestic architecture was incorporated into public space and the built environment of city centers. Archaeologists have determined that access to such “public” structures was restricted to certain people or for certain events. If only occasionally public, elite domestic architecture must be included in this category. Beyond domestic functions (see ► [Architecture of the Maya: Domestic Architecture](#)), elite residences were part of the public image of ruling and administrative elite people. These buildings likely displayed representations of the occupants’ elite status and superiority and housed rituals associated with rulership and spirituality. Like administrative buildings, elite domestic buildings often contain benches that probably served multiple functions including sleeping surfaces, sitting/conversing surfaces, and storage areas. Benches vary in size and height. Some benches were constructed with



Architecture of the Maya: Public Architecture, Fig. 14 Great Plaza of Tikal, Guatemala, showing stelae placed in the open plaza space

armrests and are referred to as thrones. Thrones are typically located directly opposite a doorway opening and look out into a plaza space or other open area.

Service Architecture

Service buildings are an oft forgotten component of public spaces that can be very instructive in understanding daily activities and significant events, such as feasting. Maya service architecture appears to resemble domestic architecture (see ► [Architecture of the Maya: Domestic Architecture](#)) in the use of permanent masonry substructures and impermanent wooden and thatch superstructures. Service buildings are typically situated on the edge of royal compounds or plazas but are hidden from the view of people in the ceremonial, administrative, or domestic areas. Service areas are most often associated with elite domestic buildings and probably represent the housing and workspace of servants to the elite occupants. Service architecture has much poorer preservation than other forms of public architecture. Poor preservation is likely due to the impermanent nature of most service buildings, disuse and abandonment of service areas over time, as well as the lack of prestige associated with the occupants.

Sacbeob

Most Maya city centers are associated with at least one sacbe (singular of sacbeob) or paved walkway/road (also referred to as causeways). Sacbeob are often elevated, are plastered, and can stretch over 100 km long. Most sacbeob connect related elite cities, villages, and natural features such as caves. Sacbeob were often large-scale constructions that required large labor forces and material resources. As a travel route, sacbeob were necessarily public. Sacbeob also served ritual functions as people attending ceremonies or rituals held in city centers would use sacbeob to enter the ritual space. Further, sacbeob were often used as procession routes and venues for traveling ceremonies. Sacbeob can integrate stairways but are typically level pathways constructed of masonry with plastered surfaces that slope for water runoff.



Architecture of the Maya: Public Architecture, Fig. 15 Figural graffiti incised into interior plaster in Structure 5D-96 of the Plaza of the Seven Temples at Tikal, Guatemala

Activities in and Among Public Buildings

Public architecture of many types offers a view into Maya public life. Archaeologists are very keen to better understand the functions and histories of public buildings because they reflect what ancient Maya people did, what they thought, and how those things changed over time. Each public building has its own construction and occupational history that provides evidence about the specific individuals who lived in or used the structure at different periods of time. Activity areas within structures and individual rooms provide details on specific activities that took place in public architecture. One striking indication of use is graffiti incised into wall plaster in room interiors (Fig. 15). Depictions in graffiti can expose the meaning of activities or rituals that took place within specific rooms. Artifact assemblages and any other decorative

elements within rooms of public architecture provide further evidence for activities that occurred there over time.

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Architecture of the Moluccas

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Introduction

Seram Island is located to the north of Ambon Island, Maluku Province, Indonesia. It extends 340 km from east to west and 70 km from north to south. Markele mount and Binaiya mount are the highest peak at Seram Island with elevation 3027 meters above sea level they having dense forest. The Kanikeh, a humble and well-maintained indigenous society, live on the Binaiya mountainside. The main settlement is a village surrounded by luxuriant forest, a river, and steep hills that have become borders separating the traditional villages from people living outside of the mountain range. Days of walking are required to reach Kanikeh village, where we carried out this piece of architectural research (Fig. 1).

We examined how the vernacular architecture of the Kanikeh people took form through detailed observation of the physical and nonphysical visual aspects of every architectural building.

The result of this study is a typology of house characteristics and features in Kanikeh village.

Our observations led to the discovery of two types of houses: the *Rumah gantong* and *Rumah tanah*. However, according to the local people, the earliest house type in the village was the grandstand house type *Rumah gantong*, while the *Rumah tanah* developed later from the *Rumah gantong* shape.

Rumah Gantong

The *Rumah gantong* is a house on a platform with one front door and a small rear door. The wall was made using a dried Sagu tree extract called *gaba-gaba*. Its floor was made of sliced bamboo, while for the roof the leaves or *rumbia* of the Sagu tree were used. The height of the foundation is about 8,090 cm above ground level. A small window, for air ventilation and also to provide light, was usually placed at the front of the house at the height of a seated person. It also provided a view outside of the house.

The house has a simple inner room, with a large kitchen for cooking and preparing dishes which also functioned as a bedroom for the owner of the house. There is also a smaller kitchen for food and clean water storage (warehouse) (Fig. 2).

As can be seen on the façade, there are height differences between the right and left sides of the *Rumah gantong* house and the middle part of the house is about 10–15 cm higher which made these houses unique. This height difference is associated with the main room or the large kitchen and is supposed to be a place to sit or to place a bed. This was not adapted to the *Rumah tanah*. Most of the *Rumah gantong* houses are inhabited by elderly people and their grandchildren. Younger villagers prefer to build the *Rumah tanah* house type.

Rumah Tanah

Rumah tanah shapes are different to those of the *Rumah gantong*, the houses being both wider and larger, but they are nevertheless a development of the *Rumah gantong*. The *Rumah tanah* house type does not have a floor height difference inside the room as did the *Rumah gantong*.

Architecture of the Moluccas,

Fig. 1 Research location on a map



A



Architecture of the Moluccas, Fig. 2 (a) Rumah gantong gaba-gaba. (b) Rumah tanah gaba-gaba

The *Rumah tanah* has a parlor, a dining room, and an additional bedroom. Referred to Kanikeh's spiritual figure, the *Rumah tanah* houses are easier to collapse or break-up as opposed to *Rumah gantong*, as *Rumah gantong* are constructed using embedded foundations for their pillars, while the *Rumah tanah* house types only use above-ground foundations such as the house's columned poles. These are attached to each other and roped together using bamboo rope or forest plant root.

Kanikeh's traditional houses mostly use materials taken from the forest for their structures. Among those materials are wood used for the pillars of the traditional houses. The owner would have collected wood from deep inside the

jungle to make the house's poles. The diameter of the wood is about 5–10 cm, straight and strong. These poles were inserted into the ground and then tightened into the floor's structure until a mutually reinforcing structure is achieved (Fig. 3).

The inserted poles have additional cantilevers made of pine wood set in a diagonal position. The purpose of these additions is to increase the stability of the poles and make them strong enough to hold both a vertical and horizontal weight force (Fig. 3).

The floors are made of split bamboo sliced according to the room length inside the house. *Rumah gantong*, the original house form, has an elevation gap between the left/right flank



Architecture of the Moluccas, Fig. 3 *Left: Installing the pillars; Right: pine wood in a diagonal position*



Architecture of the Moluccas, Fig. 4 *Left: House floors; Middle and Right: elevation gap between left/right flank of the house*

and the median of the house. The gap is continuous up to the kitchen. The house owners used to spit when they chewed *sirih pinang* inside the house and for this they made a small hole in the floor.

The walls of the traditional houses are made from an arrangement of Sagu tree midribs. In the local language these midribs are called *gaba-*

gaba. This arrangement can be vertical or horizontal. Wider midribs (5–6 cm) are used to make the horizontal arrangements while the smaller (4 cm) ones are used for the vertical arrangements. The horizontal arrangement uses a midrib pile up installation system while in the vertical arrangement they are installed adjacent to each other.



Architecture of the Moluccas, Fig. 5 *Left: A structure formed of connected single poles; Middle: connected walls; Right: connected floor*



Architecture of the Moluccas, Fig. 6 *Left: Door; Middle; window for the semipublic room; Right: window for the private room*

Every single pole, wall, and floor structure is connected by rope made from bamboo leather or roots so that they are attached to each other without using nails (Fig. 5).

Walls, windows, and doors are made using a dry *Sagu* midrib arrangement. The door's width is about 60–80 cm while its height is about 150 cm. They made the doors and windows in such a way that they do not cover the whole frame. These gaps provide air ventilation and light. The *Rumah gantong* house type always has a small window placed at the height of a seated person. In contrast, the *Rumah tanah* house types have inclined wider and bigger windows in their parlor (semipublic); some are coverless or wide open without security. The bedroom (private) utilizes *gaba-gaba* covers (Fig. 6).

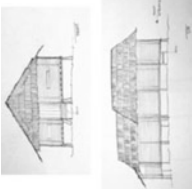
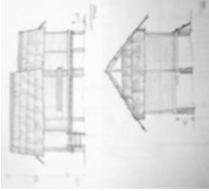
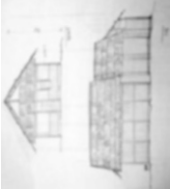
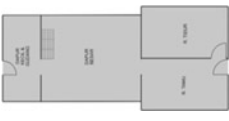
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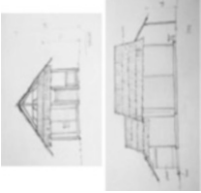
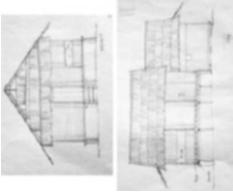
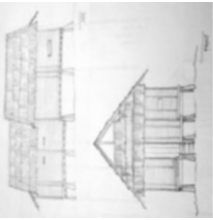
Table 1 presents similarities between façades, functions, and distinctions of the rooms in some Kanikeh houses.

There are three types of Kanikeh vernacular architecture: *Rumah gantong*, *Rumah tanah*, and a combination of both types, *Rumah gantong dan tanah*.

Rumah gantong are further classified into three sizes: original/common, large, and small. Although there are various sizes, the functions and types of room are similar, including the main room (guest room) as a multipurpose room, rest room, recipient room, and bedroom; the large kitchen used for cooking, as a bedroom and as a dining room; and a small kitchen or

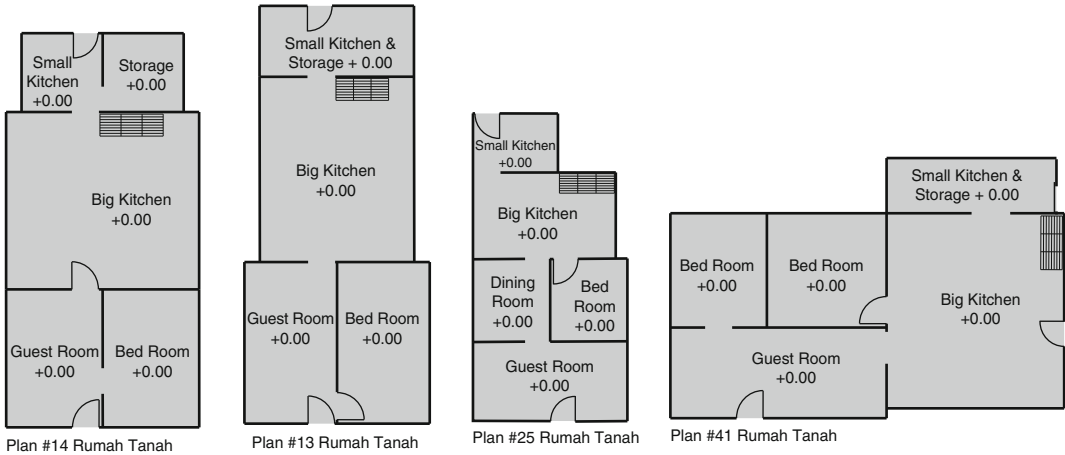
Architecture of the Moluccas, Table 1 Table Identification

Number of house	Type of house	Photos	Sketch	Plan	Name of room	Room function
03	Rumah Gantong				1. Guest room	1. Multi function room, sitting, guest room, sleeping
					2. Big kitchen	2. Cooking, sleeping, eating
					3. Small kitchen	3. Food storage and drinking water
12	Rumah Gantong				1. Guest room	1. Multi function room, sitting, guest room, sleeping
					2. Big kitchen	2. Cooking, sleeping, eating
					3. Small kitchen	3. Food storage and drinking water
13	Rumah Tanah				1. Guest room	1. Multi function room, sitting, guest room
					2. Bed room	2. Sleeping
					3. Big kitchen	3. Cooking, sleeping, eating
					4. Small kitchen	4. Food storage and drinking water

25	Rumah Tanah				1. Guest room 2. Bed room 3. Living room 4. Big kitchen 5. Small kitchen	1. Multi function room, sitting, guest room 2. Sleeping 3. Eating 4. Cooking, sleeping 5. Food storage and drinking water
32	Rumah Gantong and Tanah				1. Guest room 2. Sleeping room 3. Kitchen	1. Multi function room, sitting, guest room, sleeping 2. Eating, sleeping 3. Cooking, food storage and drinking water
50	Rumah Gantong				1. Guest room 2. Big kitchen 3. Small kitchen	1. Multi function room, sitting, guest room, sleeping 2. Cooking, sleeping, eating 3. Food storage and drinking water



Architecture of the Moluccas, Fig. 7 Plan view of Rumah Gantong



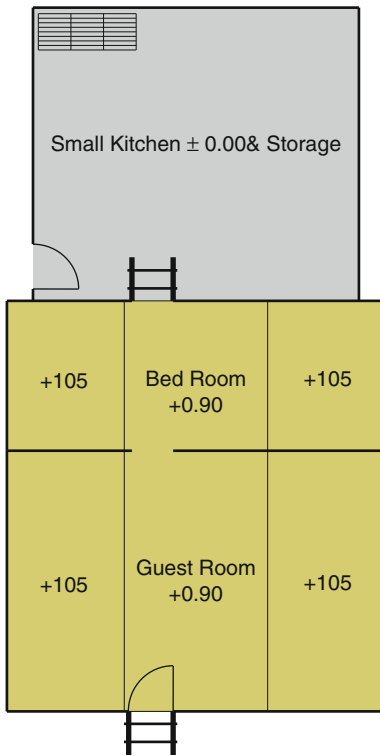
Architecture of the Moluccas, Fig. 8 Plan *Rumah Tanah*

storage kitchen as a place to keep food/ingredients and clean/drinking water (Fig. 7).

Rumah tanah are usually large in size: the front room is bigger than the room after it and the rear room is the smallest. It is usually had one

or even more separate rooms that functioned as a room for the house owner or as a guest bedroom.

Although there is still some variation, the *Rumah tanah* preserves the *Rumah gantong*'s main rooms such as the guest room, large kitchen,



Plan #32 Rumah Gantong/Tanah

Architecture of the Moluccas, Fig. 9 Plan Rumah Gantong and Tanah

and the small kitchen/warehouse. The large kitchen is still used as a bedroom for the house owner and as a place to cook and prepare dishes (Fig. 8).

The house variation *Rumah gantong and Tanah* combines both types of house, the *Rumah gantong* and *Rumah tanah*. There are only two such hybrid units, both of them are front-side *Rumah gantong* (parlor) and rear-side *Rumah tanah* (large kitchen and storage room). The inner room of the hybrid unit is similar to the *Rumah gantong*. The distinction is that the back rooms are same with the large kitchen and storage kitchen at *Rumah Tanah* which was used to cook in and as a sleeping place for homeowners. The cooking function is carried out in the storage kitchen which is at the rear of the house as in the *Rumah tanah* (Fig. 9).

The architecture of the living houses in Kanikeh village reflects local characters by optimizing and utilizing surrounding local materials.

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Architecture: El Morro of Puerto Rico

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El Castillo de San Felipe del Morro, known as El Morro, is the second fort built on the islet of San Juan, Puerto Rico. It is a six-level citadel rising 140 ft and covering over 70 acres above the northwestern point of the islet named in honor of Philip II, the son of King Charles V. “El Morro” means a promontory or headland. The Spanish began to build this second fort quickly after completion of La Fortaleza, San Juan’s first fort. Because La Fortaleza was placed inside the harbor, critics pointed out, approaching enemies would believe the island was unprotected.

The construction of El Morro started in 1539, with a vaulted masonry tower about 60 ft above sea level, midway up the cliff, with bracing for four cannons. At this time, only three cannons were mounted in the tower. In the early 1580s, with English freebooters like Sir Francis Drake and Sir John Hawkins pilfering the Spanish Caribbean, Philip II sent two defense experts:

Field Marshal Juan de Tejada, a military veteran, and Juan Bautista Antonelli, an Italian engineer-architect, to inspect Spain's American ports. In September 1587, Tejada and Antonelli, back from their inspection tour, proposed that the Crown fortifies ten key ports, one of which was San Juan, Puerto Rico. In March 1589, with Philip's approval, Tejada and Antonelli returned to San Juan with artisans, stonecutters, masons, and blacksmiths. They also used local laborers and slaves.

Antonelli's new design for El Morro consisted of shelter for 3,000 people, guardhouses, magazines for munitions, plus structures that military engineers call "hornwork." The hornwork was comprised of two half-bastions with a straight wall, known as a curtain, between them. For the additional appearance of height and protection against an assault, a narrow moat was dug in front of the curtain wall and half-bastion walls. A drawbridge for crossing the moat was located at the center of the curtain wall in front of the gate for entering the fort. Just inside the gate were guardhouses provided for shelter from the weather since the hornwork was a basic parapet, which provided no shelter. In order to shield the gate and drawbridge a ravelin, small fortification of two embankments that are shaped as an arrowhead pointing toward the larger defensive area was built with a cannon placed within the embankments to cover the approach.

Antonelli's design, plus additions made by his successors, was tested in 1595, when Sir Francis Drake attacked San Juan. Drake's men were unable to take the fort by surprise, and after an hour of fighting, the English ships left El Morro. While waiting for the funds to repair El Morro's defenses after Drake's attack, a much reduced garrison of 176 men was able to ward off another attack by Sir George Cumberland on June 17, 1598. The city of San Juan surrendered to Cumberland the next morning, but El Morro was not taken until July 1, after Cumberland blockaded the fort and ordered continuous cannon fire. Cumberland and his men withdrew after 6 weeks, leaving San Juan and El Morro in ruins.

Puerto Rico's new governor, Captain Alonso de Mercado, rebuilt the fort, and his preparations

were tested on September 25, 1625, when Dutch admiral Boudewijn Hendricksz attacked the harbor. Hendricksz was able to sail past El Morro's cannons and enter the San Juan harbor. Governor Mercado gathered his supplies and soldiers into the fort, allowing Hendricksz to take the city. Three days later, Hendricksz attacked El Morro with his heavy Dutch guns. But El Morro's artillery, plus the efforts of Puerto Rican militiamen outside the fort, forced the Dutch back to their ships.

This successful sidestepping of El Morro brought new construction and repairs. A new barrier wall was begun which encircled the whole city following along the contours of the land. These new reinforcements stood against attack for over 100 years.

In 1765, Spanish engineers updated the fort and other city defenses, increasing its firepower from 3 to 37 cannon, building an 18-ft thick wall and enlarging the interior spaces. In 1843, Puerto Rico's first lighthouse was built atop El Morro. Except for a few pirate raids, San Juan stayed peaceful until the USA attacked on May 12, 1898, in the Spanish-American War. After bombing El Morro all day long, the USA managed to damage the tip of the Santa Barbara Bastion. In 1908, the US Navy built a lighthouse atop El Morro, which still stands today.

During World War II, the USA added a concrete sentry tower to the Santa Barbara Bastion, as well as hidden command and communication centers, and underground bunkers. In 1961, the US Army turned El Morro over to the jurisdiction of the US National Park Service to be preserved as a museum. The United Nations declared the site a World Heritage site in 1983. Today it is the most visited tourist attraction in Puerto Rico.

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Architecture: La Citadel of Haiti

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Located in northern Haiti, the impressive fort Citadel Laferrière sits at 3,000 ft (over 900 m) on the Bonnet-à-Lévêque, a mountain overlooking Haiti's northern plain, near the village of Milot. The city of Cap Haitien is about 25 miles (40 km) away. An important symbol of Haitian independence, the fort was recognized as a World Heritage Site by UNESCO in 1981. The location of the fortress offers a panoramic view to the entire northern region of Haiti and to the Caribbean Sea and the eastern side of Cuba.

There are few archival sources on the architects and builders of the Citadel. The fortress is said to have been designed in 1805 by a Haitian, Henri Barre or Besse, and other sources attribute its completion to a Scottish architect named Ferrier. Other accounts say it was designed by a French architect named Laferrière. None of this has been documented, however. Stretched across the mountain peak incorporating three sheer cliffs, the fort has four irregular sides, a long triangular jetty and a high rounded bastion. Its walls are up to 130 ft tall and its stone foundation is directly laid into the mountain, covering an area of 108,000 ft², roughly four acres. The Citadel has large cisterns and storehouses to enable its residents to store food and water for 1,500 defenders for up to 3 years. The plan of this fortress included living quarters for the king and his family, kitchens, bakery, foundry, dungeons, bathing quarters, and powder magazines.

Construction lasted from 1805 to 1817 and is said to have involved more than a 100,000 workers, who hoisted half-a-million pounds of rock to the site, as well as 275 brass cannons. Limestone, molasses, and the blood of local cows and goats were used to fasten stones together. Eleven small brick and tile workshops supplied materials for the fortress. It is said that more than

20,000 workers lost their lives during the construction process.

The Citadel Laferrière was built to defend Haitian independence, proclaimed on January 1, 1804. It was commissioned by Henri Christophe, one of the ex-slave generals who had led the Haitian Revolution, but who had refused to accept the leadership of a republican state based in Port-au-Prince. Seceding to develop his own northern Kingdom of Haiti, Christophe controlled what had been France's most valuable plantation zone and major colonial port. Most European states as well as the United States refused to recognize Haiti's independence and Christophe was deeply concerned that France might attempt to retake its former colony.

Though it overlooks the northern coast, the Citadel is about 9 miles (15 km) from the sea, too far for its cannons to reach naval attackers. Instead, it was part of a network of interior forts Haitian leaders built to protect the country's high interior plateau. In the war for Haitian Independence, French armies had controlled the coastal zones and sugar plantation areas, but had been unable to tame the mountains. In the lowlands, thousands of soldiers newly arrived from Europe had died of malaria and yellow fever for which they had no antibodies. The Citadel would have allowed the Haitians to redeploy this strategy, in the event of a foreign attack.

The Citadel was only the most spectacular of Henri Christophe's building projects, which may have included as many as 9 royal residences and 15 forts. The second most impressive of these structures is the palace of Sans Souci, built at the foot of the Citadel. Though partially destroyed by an earthquake in 1842, considerable ruins remain at the town of Milot, including a striking circular chapel 82 ft (25 m) in circumference. In this large and elegant palace, with its running water, marble statues, extensive gardens, and circular chapel, the King held court from its completion in 1813 until his death in 1820, at which time his Kingdom was dissolved. In 1825, Haiti signed a treaty with France, ending the threat of invasion.

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Architecture: Nomadic Architecture of Inner Asia

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The Sinor Research Institute for Inner Asian studies defines the term *Inner Asia* as follows:

Inner Asia, or the interior of the Eurasian landmass, comprises in historical terms the civilizations of Central Asia, Mongolia, and Tibet, together with neighbouring areas and peoples that in certain periods formed cultural, political, or ethnolinguistic unities with these regions. In the past the Inner Asian world was dominated by pastoral nomadic communities of the great Eurasian steppe, and its history was shaped by the interaction of these societies with neighbouring sedentary civilizations. (Website of the [Sinor Research Institute](#), Indiana, Bloomington).

Thus, Inner Asia is not only a geographic term but even more a cultural-historical term for defining the broader region which led to the emergence of different nomadic populations in Asia. These civilizations and peoples were and are mostly inhabiting the arid steppe areas in the interior of the continent. Their economy was mostly based on cattle herding; the ecology of the steppe made it necessary to move the animals at certain intervals to avoid overgrazing. This frequent change of location together with the requirements and benefits of animal husbandry led to the emergence of certain specific dwelling forms, several of which endure and are still used even in our modern age. The fact that these buildings are

still present may be a proof of their sophistication and adaptation to local climate and prevailing lifestyle. However, as everywhere, in many Inner Asian countries, the lifestyles and economy of the people are changing, and these changes lead in many places to sedentarization and the abandonment of nomadic habits.

Types of Nomadic Dwellings

Historically, we can discern several types of nomadic dwellings, which were used in Inner Asia:

- Tents with a load-bearing inner structure
- The yurt (Turkic) or *ger* (Mongolian), a trellis tent with a load-bearing inner structure and felt covering
- Carts with tents attached to them
- The black tent, a very special tent form made out of black goat hair or yak hair
- Different tents, usually for very temporary purposes and not intended for permanent dwelling

At present, only the trellis tent (the so-called yurt or *ger*) and the black tent are still in use among Inner Asian nomads for permanent dwelling. Tents with a load-bearing inner structure (the precursors of trellis tents) and carts with attached tents are only of historical significance. While the more permanent nomadic structures remain in one place usually for a period from 2 to 3 weeks to several months, according to the environment and time of the year, various simple tent types, usually made of light materials, are used for a few days' stay during hunting, traveling or attending festivities.

While in Mongolia the harsh climate makes agriculture a not very viable alternative to animal husbandry, in many Central Asian countries there is an option, especially with the advent of modernization, to switch to agriculture. Especially in those countries formerly part of the USSR, this change was forcedly introduced. Thus, it is not always clear to what extent the nomadic lifestyle is still a living tradition. In Mongolia, gers and people living a nomadic life are still dominant in



Architecture: Nomadic Architecture of Inner Asia, Fig. 1 Mongolian nomad camp

the countryside (Fig. 1), and many trellis tents can also be found in the suburbs of the main cities. In other countries, the amount of nomadic trellis tents still used is supposedly far less. However, the success of the trellis tent can be only estimated if one realizes that approximately 50 years ago, some people as far as central Anatolia and other parts of Turkey were still living in them. Nowadays, on the other hand, they have become extremely rare or maybe even do not exist anymore in the same region. Anatolia of course can only be counted as part of Inner Asia in a very broad cultural sense, but it shows that certain types of nomadic dwellings were used in a very broad geographic area, usually due to historic migrations of certain steppe people.

Tents with a Load-Bearing Inner Structure

Such tents had an inner frame of wooden sticks supporting a covering made out of textile or felt

and thus may have functioned somewhat similar to a Native American teepee. There are also hints that in certain regions, mobile huts with curved wooden poles were in use. These dwellings can be considered the predecessors of the more sophisticated trellis tent. A better-documented ancient historical example for a tent with an inner frame might be the Sarmatian tent as there have been paintings showing such tents found, while a contemporary example is the dwelling of the reindeer-herding minority of Tuva people living in Mongolia (Fig. 2).

Trellis Tent

The trellis tent has walls made of a wooden lattice bound together with rawhide stripes. There are many variants in size or number of these lattice wall elements used. The trellis tent has a wooden roof ring (roof wheel) which in certain areas may be supported by columns.

Architecture: Nomadic Architecture of Inner Asia, Fig. 2 Tent with load-bearing wooden inner structure, N-Mongolia



The wooden roof wheel and the walls are connected by wooden poles (roof struts). The wooden frame is usually strengthened by ropes wound around the perimeter of the wall (girths) and also through the roof structure. The trellis tent is usually covered by layers of felt made of sheep wool. In case of Turkic variants also, a decorated reed mat (cane screen) is put up along the wall before it is covered with the wall felt. Nowadays, trellis tents do have a proper door; formerly, only a more makeshift door frame was made and the entrance covered with a piece of felt. According to Andrews, the trellis tent was invented supposedly around the eighth century AD by Turkic tribes. At the time of Ghenghis Khan, it seems to have been used side by side with nontrellis tents of a similar form, as passages in the *Secret History of the Mongols* (dating from approximately 1240) suggest (Andrews, 1999) (Fig. 3).

Tents on a Cart

Models of four-wheeled wagons dated to 600 BC were found in Kerch in East Crimea, and several authors of classical antiquity mention nomadic people of their time living in felt-covered tent cars. Some mention structures resembling wickerwork attached to these wagons (Andrews,

1999, pp. 13–17). Apparently later there was a shift to two-wheeled cars. Cuman (Polovtsy) people fleeing from Mongols are depicted in two-wheeled carts with steep tents in the thirteenth-century Radziwill Chronicle. Also dwellings which could be taken from the cart and placed on the ground seemed to have been introduced with time.

Szalay (2009) remarks that in the Chinese chronicles of the Heida Shilue (1237), the Chinese envoys Peng Daya and Xu Ting from the Sung Dynasty write about the form of life of a nation they call "Black Tartars":

Their dwellings are felt tents which have no [solid] walls or beamed rooms.[...] On the day for traveling when the camp is broken up, cows, horses and camels are used to pull the cabins on carts in which one can sit or lie down. These are called tent carts.

The yurt [qionglu] is of two kinds. The Yenjing style uses willow sticks as a structure which is like lattice work of the south and is collapsible. [...] They are carried on horses. The grassland style uses willow sticks to weave a rigid enclosure and across its diameter felt is used to pull it taut; these are not collapsible and are carried on carts.

In the seventeenth century, the Noghay are reported to have been living in similar tents. These dwellings did not have a trellis yet; however, there is a photograph from the beginning of

Architecture: Nomadic Architecture of Inner Asia, Fig. 3 Trellis tent being erected. Mongolia



Architecture: Nomadic Architecture of Inner Asia, Fig. 4 Noghay tent-cart, after Andrews (1999)

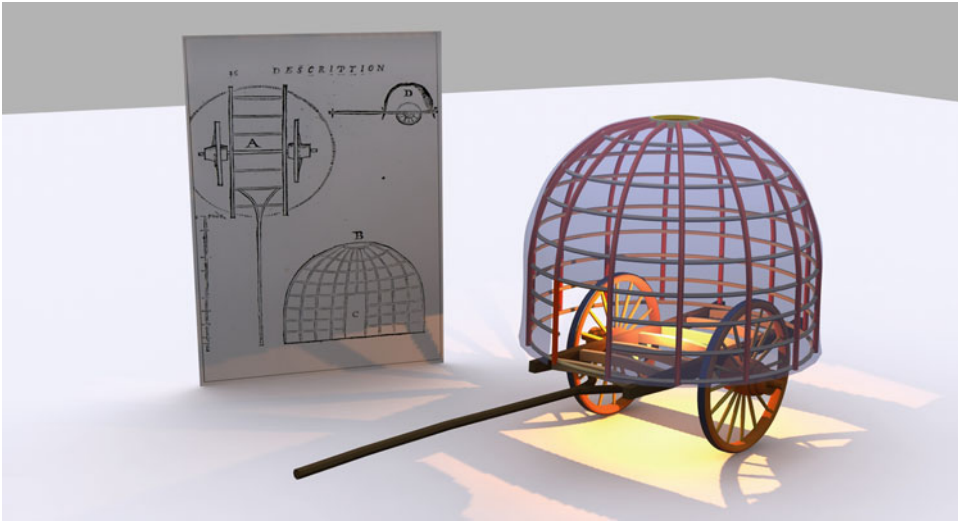
the twentieth century showing a Noghay tent cart with a tent apparently having a fixed trellis (Andrews, 1999) (Figs. 4 and 5).

Black Tent

There are two regions of Inner Asia where nomads use black tents as dwellings: Tibet and Baluchistan. If Inner Asia is meant in a very broad definition, there would be other areas (e.g., parts of Iran, Anatolia - Fig. 7) where black tents are in use. For a detailed description

of black tents, see Andrews (1997) or Ambrosch (2005) or Pfeifer (formerly Ambrosch 2015). In this article, only the Tibetan and the Baluchistan tents will be described.

The Tibetan tents can be divided according to Ambrosch (2005) into three types. All these three are made of Yak hair, which is different to other types of black tents, which are made of goat hair. The shape of Tibetan tents is extraordinary, as they are all quite low, and one of their variants is almost domelike in appearance, as most of the supporting



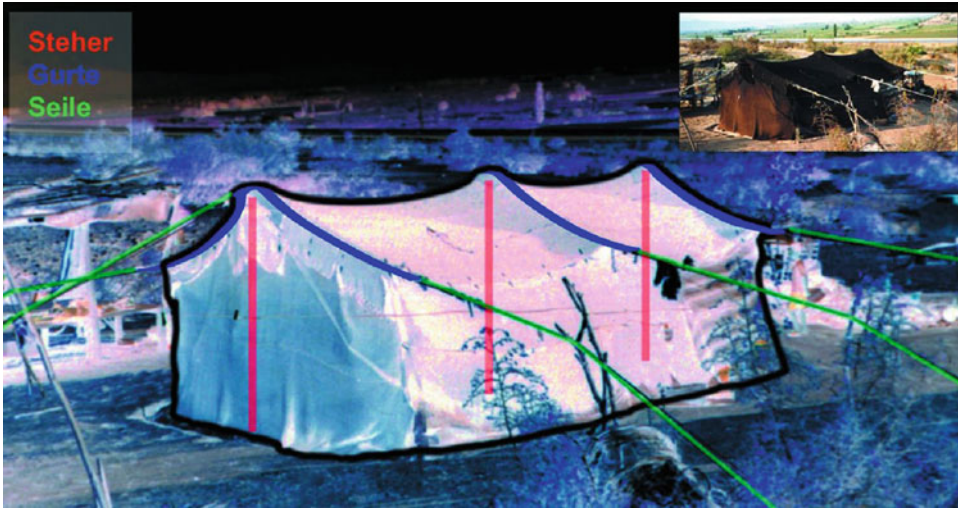
Architecture: Nomadic Architecture of Inner Asia, Fig. 5 Noghay tent-cart, after Andrews (1999)



Architecture: Nomadic Architecture of Inner Asia, Fig. 6 Black tent in Ladakh (Source: Gisela Hayfa, Helga Zimpel-Erlor, Ulrich Zimpel)

wooden poles are arranged outside the tent itself and are higher than the ridge. Thus, the ropes first go upward and are redirected via the poles to the ground. The appearance of this tent is much like a spider sitting on the ground with its legs being the guy ropes. The form of the tent itself, however, is very similar to modern tent forms used by mountaineers, which is of course an adaptation to strong winds and the cold climate. The short roof ridge of the tent is held up by two poles, and at the apex, an opening can be found where the smoke of the fire

can exit (Figs. 6 and 8). The other types of Tibetan tents do not have such a spectacular form. The second type uses no high wooden poles for the guy ropes, but they are directly staked to the ground, and a low stone circle is put up around the tent. The third type is similar in appearance but incorporates a low stone wall into its design. Tibetan tents are cold as the fabric does not insulate well. People have adapted to these conditions and have to be able to bear very low temperatures.



A

Architecture: Nomadic Architecture of Inner Asia, Fig. 7 Different parts of a Yörük (Turkish) black tent. Red: wooden posts under pressure, blue: fabric under tension, green: guy ropes under tension (Source: Ambrosch, 2005)

Architecture: Nomadic Architecture of Inner Asia, Fig. 8 Tibetan tent
(Source: <http://enjoyingindia.com>)



Baluchi tents are made of goat hair, and they have an inner frame of arches made of willow wood. However, this frame is not capable of supporting itself without the tent fabric, and the structure needs guy ropes to stand. Most other black tent types which can be found in Arabia, northern Africa, or Asia Minor do have straight poles supporting the tent fabric, thus the Baluchi

tent can be regarded as an unusual construction. It is not only used in Baluchistan but in a few other neighboring regions of Afghanistan (Ambrosch, 2005, pp. 79–81).

Tents for Temporary Use

A variety of tents for short trips, hunting or using at festivals were known to nomadic people.

Architecture: Nomadic Architecture of Inner Asia, Fig. 9 Mongol tent of the Maixan type (Source: Birtalan, Rákos, Tartsák, & Zámolyi, 2009)



Architecture: Nomadic Architecture of Inner Asia, Fig. 10 Mongolian trellis tent (ger)(Source: Birtalan et al., 2009)



To illustrate the topic, Szilágyi's description of Mongolian tent types will be cited:

Asar. This is a generic term for several tent types, such as cacar (one without vertical walls) and cačir (one with vertical fabric walls). The word asar means "tent, tent palace, pavilion", and one can find references to it written as early as in the Mongolian times. It is usually used at great festivals or to welcome visitors. The size of an asar can vary from small (for one or two persons) to large capable of hosting 500 people. In his account of the enthronement of Güyük khan (1246), Plano Carpini, the Franciscan friar, reports about a giant tent that could hold two thousand people, and the support pillars of which were adorned in gold. In

later times, the plans of several Mongolian Buddhist temples were designed after cačir. (Szilágyi, 2009).

The Mongols use other tent types, for example, the Maixan, which is a tent with an inner structure of two forked vertical poles and a ridge pole laid across them. The tent cloth is held up by this roof ridge and has to be fixed with ropes and stakes. These variants, as the other temporary tents, need the tensile strength of the tent fabric to stand. Trellis tents and tents with a load-bearing wooden structure, which are usually used by Inner Asian nomads as dwellings, are

**Architecture: Nomadic
Architecture of Inner
Asia, Fig. 11** Uzbek
trellis tent (Source: Erich
Lehner)



**Architecture: Nomadic
Architecture of Inner
Asia, Fig. 12** Kirgiz trellis
tents (Source: Gisela
Hayfa, Helga Zimpel-Erler,
Ulrich Zimpel)



capable of standing by themselves without their covering or any guy ropes. According to Szilágyi (2009), at festivals an ornate version of the maixan (*ugaljtai maixan*), mostly of blue color, is erected, which is decorated with the patterns of “endless knot” (*öljī utas*) and “longevity” (*piŋ*) (Fig. 9).

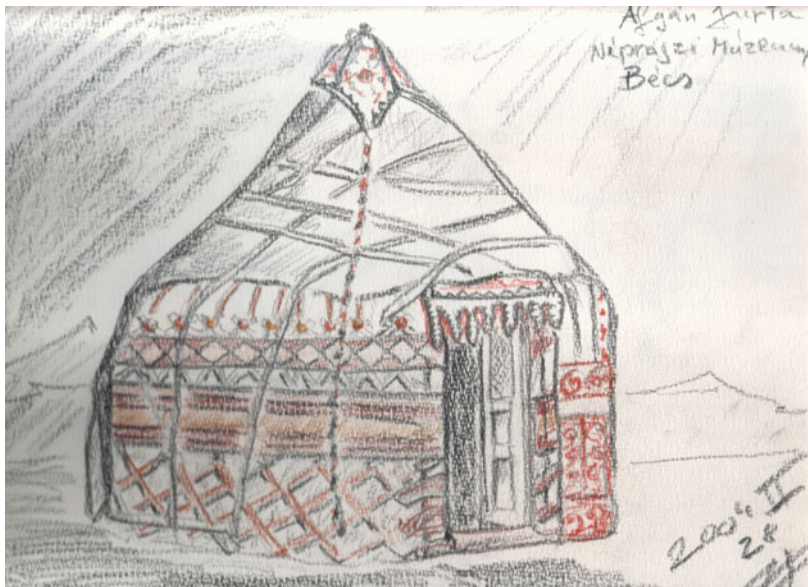
Difference Between Turkic and Mongolian Trellis Tents

Although there is quite a large variety of Turkic trellis tent types (yurts), in this article only the Mongolian ger will be described in detail. The basic characteristics of trellis tents are similar

**Architecture: Nomadic
Architecture of Inner
Asia, Fig. 13** Kirgiz trellis
tents (Source: Gisela
Hayfa, Helga Zimpel-Erler,
Ulrich Zimpel)



**Architecture: Nomadic
Architecture of Inner
Asia, Fig. 14** Afghan
trellis tent at the
Anthropological Museum
Vienna, sketched by the
author



everywhere and will be discussed when describing the Mongolian ger. For a detailed account on Turkic trellis tents, please refer to Andrews (1999), which is the best and most comprehensive work available.

There are certain basic differences between Turkic and Mongolian trellis tents:

- The roof wheel of Turkic yurts is not supported by columns.
- Usually, the roof wheels of Turkic yurts are made of one piece of wood, which is steamed and bent in a circle, while the roof wheels of the more common type of Mongolian ger is assembled out of several parts carved in a curved shape.



Architecture: Nomadic Architecture of Inner Asia, Fig. 15 Decorated cane screen of a Kirgiz tent (Source: Vidák István)



Architecture: Nomadic Architecture of Inner Asia, Fig. 16 Felt rugs of a Kirgiz tent (Source: Vidák István)

- The roof struts of Turkic yurts are usually bent to form a dome-like shape.
- The roof of Turkic yurts is definitely steeper than that of gers.
- The roof struts of Mongolian gers are usually heavier and thicker than those of Turkic yurts.
- The trellis laths of Turkic yurts are also bent, often in elegant curves to form somewhat



Architecture: Nomadic Architecture of Inner Asia, Fig. 17 Traditionally the ger was either packed onto camels or transported on two-wheeled carts when nomads moved from one grazing area to the next with their herds

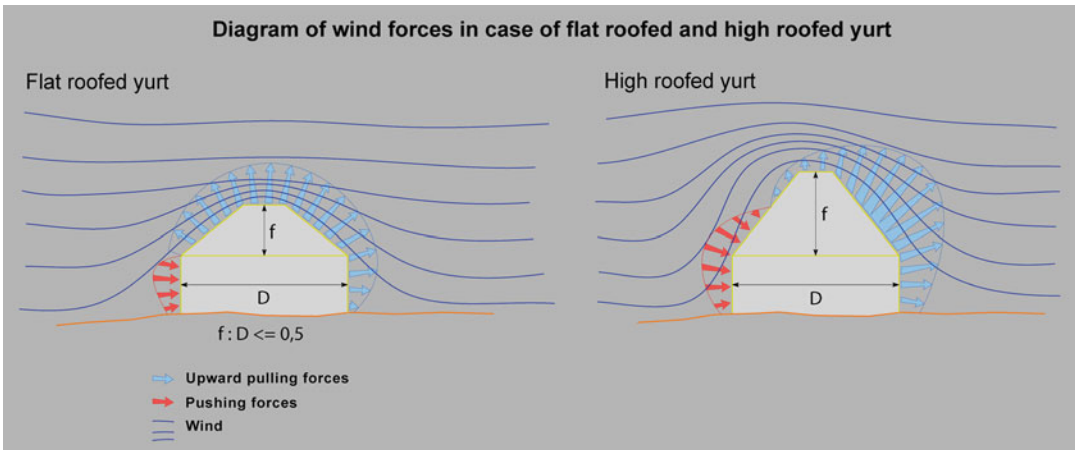
Architecture: Nomadic Architecture of Inner Asia, Fig. 18 Transport of a ger by modern means on a truck



- spherical walls (the trellis laths of Mongolian gers are only bent minimally).
- Turkic yurts usually have a (decorated) cane screen around the trellis walls, which Mongolian gers only very seldom have.
- Turkic yurts have more and elaborately decorated felt rugs inside the dwelling. Usually the floor is covered in such rugs, while in the Mongolian ger it is not. Also Mongolians decorate their felt rugs in a somewhat different technique.

Architecture: Nomadic Architecture of Inner Asia, Fig. 19

The ger in winter. It is optimised to loose as little heat as possible, but its light structure cannot take snow loads. Thus as soon as snow falls, it has to be scratched from the roof (Source: Kevin Tierney)



Architecture: Nomadic Architecture of Inner Asia, Fig. 20 In strong winds trellis tents with high pitched roofs are in danger of being toppled, those with low pitched roofs are in danger of being “lifted” by the

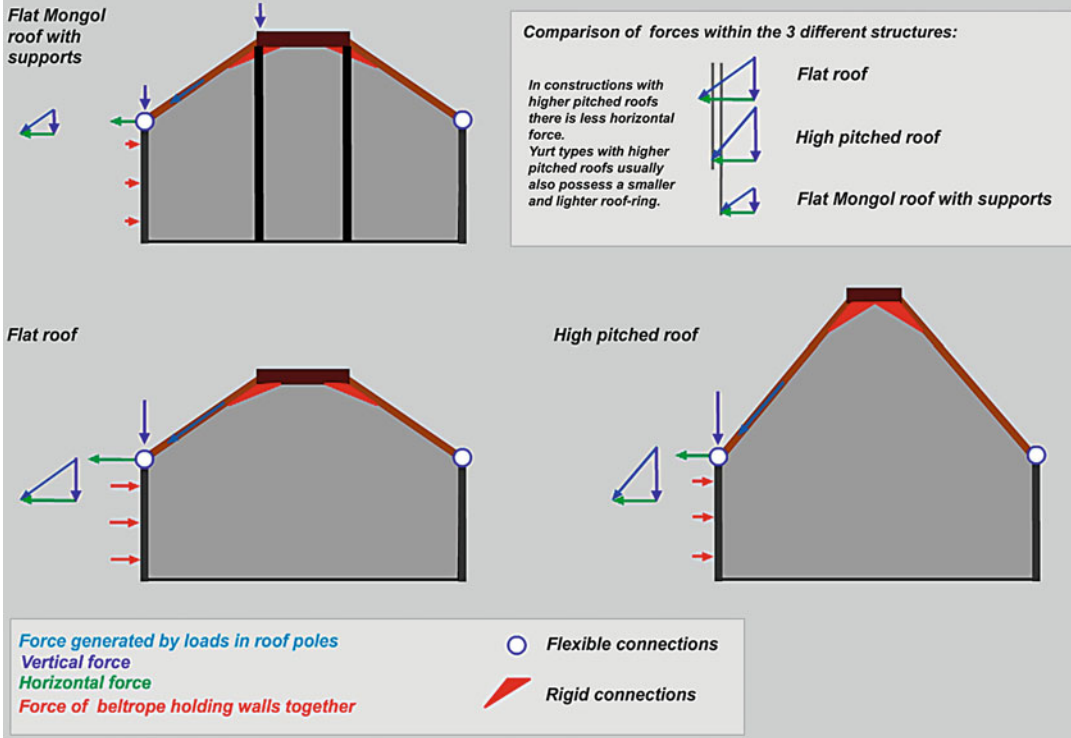
slipstream. Thus the roof structure of the Mongolian ger is low, comparably heavy, and in case of a storm extra weight is attached to the roof wheel to hold the dwelling down

- Turkic yurts tend often (but not always) to be more decorated on the outside than Mongolian gers, which have a plainer appearance.
- In Mongolian gers sometimes roof wheels and roof struts are painted elaborately with different symbolic designs. Often also the door is painted similarly.
- In spring Mongolian people often have to take newly born lambs or other animals

- into the ger, as the weather can still be very harsh at that time. Thus a small pen is set up near the entrance for that purpose. In Turkic yurts this measure is usually not necessary.
- While Turkic yurts are usually put up facing east, Mongolian gers are always erected facing south with their entrance (Figs. 10, 11, 12, 13, 14, 15, and 16).

Forces within the frame of the yurt

originating from vertical loads (dead load, snow load)



Architecture: Nomadic Architecture of Inner Asia, Fig. 21 Forces in a Mongolian ger (*low roof*) as opposed to some Turkic yurts (*higher roof*)

The Mongolian Ger as an Example of a Nomadic Dwelling

The yurt, or as the Mongolian nomads call it, the ger, was designed to function as a mobile dwelling used all year round in a climate which in winter is extremely cold and stormy but is comparably arid. Although snow is a typical phenomenon during the Mongolian winter, high precipitation is not; the climate can be described as continental.

The location of a ger is altered very frequently; a camp is abandoned depending on surrounding resources for 2–3 weeks (Gobi region) to 2–3 months (in the more northern parts of Mongolia).

This means that well-designed heat insulation and an easy possibility of heating are essential for the inhabitants to survive the winter. As heating

material (in this case animal dung) is scarce, it has to be used very effectively.

Mobility is another defining factor of nomadic architecture. People must be capable of disassembling the building into parts and load it on animals or carts in a comparably short time and with a minimum of effort involved. For transport, it has to be as light as possible and should occupy only a small space. After transport, the dwelling has to stand as soon as possible.

The criteria mentioned above define most structural properties of the yurt. It is a dwelling with a very light but strong wooden frame, which is covered with layers of felt for insulation and for protection against storm and rain. However, it is only in ethnographical terminology that the yurt is called a “trellis tent,” “round tent,” or “felt tent.” From the architect’s point of view, it is more related to a house, as it has a wooden



Architecture: Nomadic Architecture of Inner Asia,
Fig. 22 Kirgizian craftsman building a yurt with hand tools (Source: Vidák István)

frame, which stands by itself without any supports or need of guying. Real tents do not stand without their textile skin, which takes an active part in carrying loads and tensile forces. A tent always needs guy ropes, which fix the construction to the ground, while a yurt does not. In the case of the yurt, the felt provides protection against wind, rain, and snow. It has no significant structural function.

It seems that in former times mobility was even more important than it is today, as ancient nomadic tribes are reported to have moved around mainly in tents or yurts fixed permanently to carts. However, nowadays these solutions have disappeared, and the dwellings are always dismantled when transported. Today, if no motorized transport is available, the yurt is still packed on animal-driven carts pulled by yaks, oxen, or camels. If the terrain is rugged, everything is

loaded on camelback. A camel can carry approximately 300 kg on short distances and 200 on longer ones. This means a yurt and household items can be transported by three to four camels (Figs. 17 and 18).

When assembled, the pieces of the yurt, which themselves are small and light (and in case of the wall elements even foldable), form an optimized spatial structure. The form of the yurt is favorable for several reasons: firstly, the dome or flat cone-shaped interior with the low wall section offers a maximum of free inner space while using a minimum of construction material; secondly, the form is almost half dome shaped. The sphere has the smallest surface area-to-enclosed volume ratio of all geometric bodies. The loss of heat energy is directly proportional to the surface area.

This means that a half-dome-shaped house loses less energy than all other forms. Thus, the form of the yurt is optimized to lose as little heat as possible. Additionally, its comparably low structure, which integrates well into the surrounding landscape, offers as little surface to wind forces as possible. Usually, the emerging forces are pulling the structure upward. That is why in case of stormy weather usually a weight is attached to a central rope, which hangs from the roof wheel. The roof structure of the Mongolian yurt is also heavier than the roofs of other yurt types. This could be also an adaptation to strong winter storms, as the heavy roof ring and the roof poles attached to it are not easily susceptible to being dragged away. Also in case of low cone-shaped roofs no pushing forces appear. Pushing forces are more dangerous than pulling forces as they can lead to toppling of the structure (Figs. 19, 20, and 21).

As the Mongolian ger roof does not have a high pitch and the roof ring is heavy, it is necessary to support it with posts. Other yurt types that possess higher roofs and lighter rings do not need any supports.

The pitch of the roof essentially determines the forces submitted by the roof poles to the wall construction, thus pushing it outward. The lower the roof pitch, the larger the outward pushing

Architecture: Nomadic Architecture of Inner Asia, Fig. 23

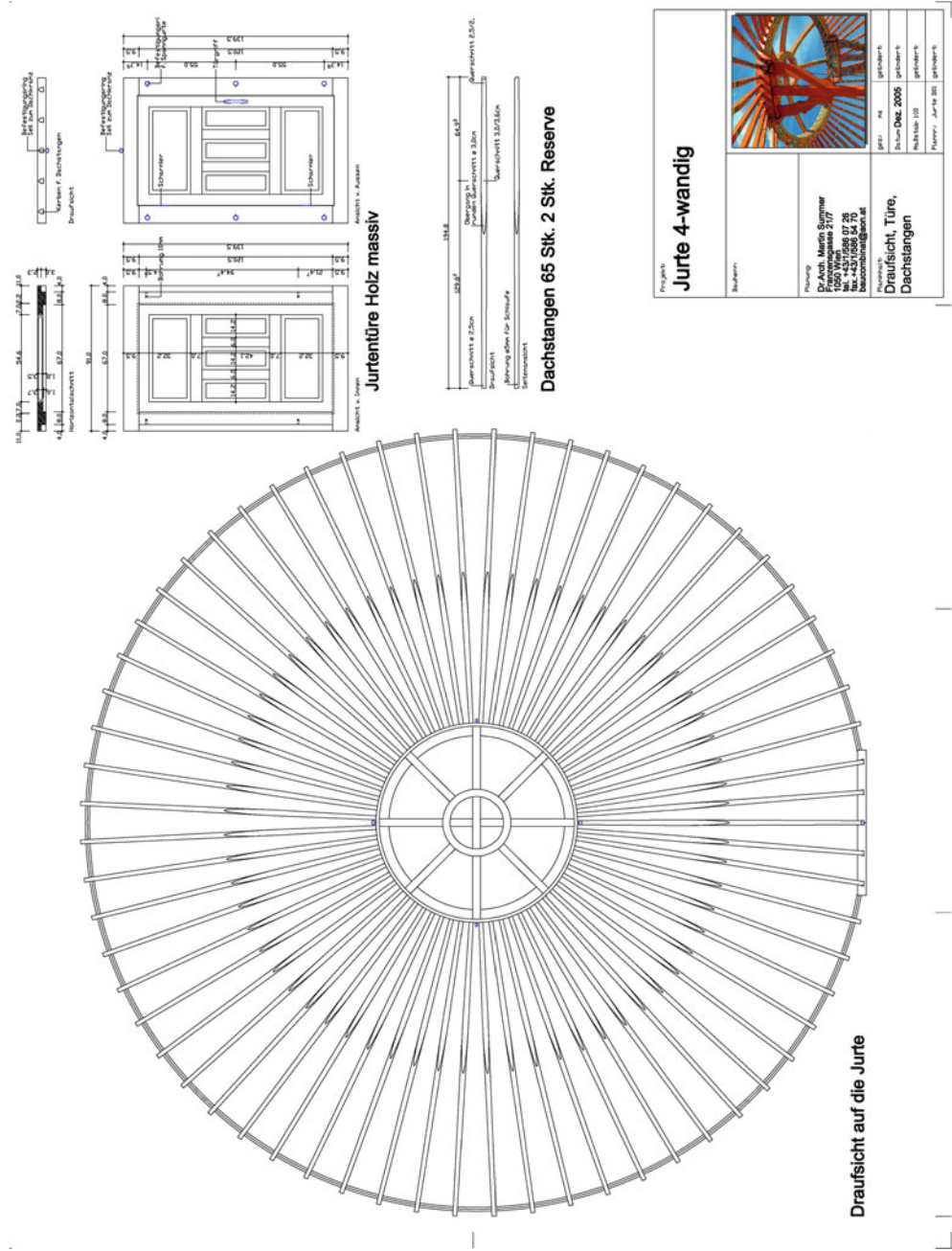
Feltmaking: The horse is dragging rolled up new felt over the steppe to compress it (Source: Jillian Van Ells)



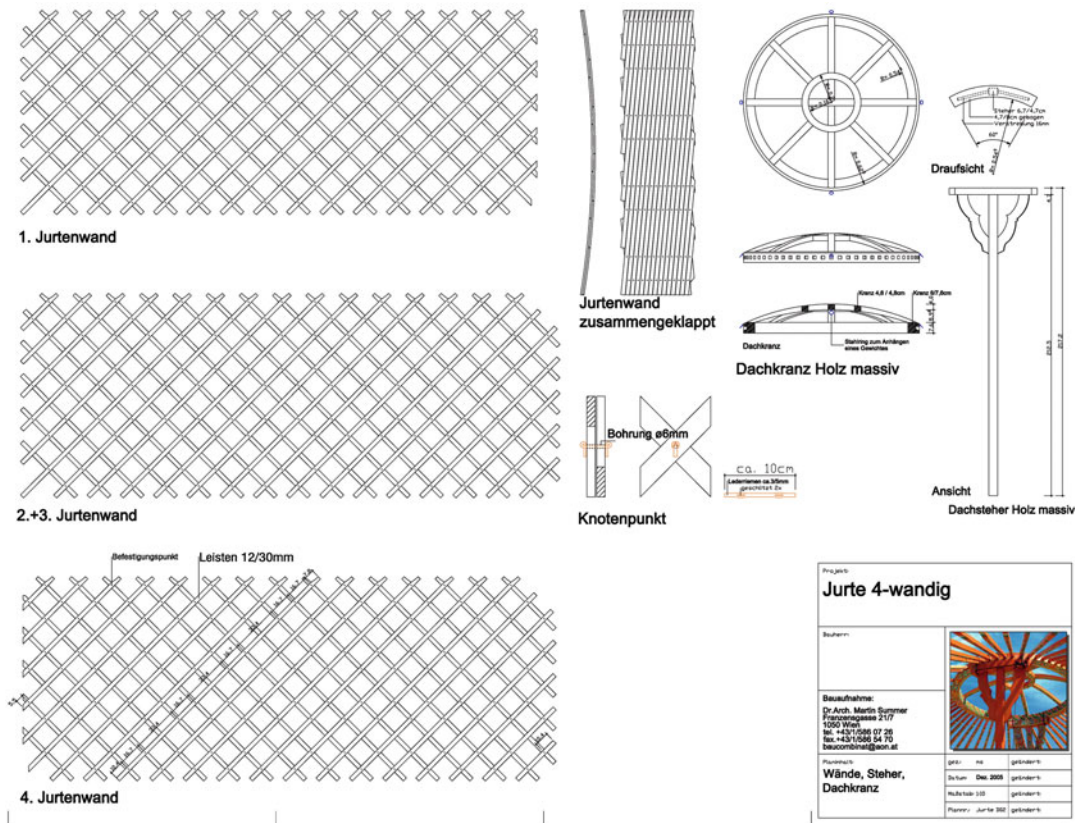
Architecture: Nomadic Architecture of Inner Asia, Fig. 24 Preparing to roll up the wool placed on the “mother felt” (Source: Birtalan et al., 2009)



Architecture: Nomadic Architecture of Inner Asia, Fig. 25 Preparing to roll up the wool placed on the “mother felt” (Source: Birtalan et al., 2009)



Architecture: Nomadic Architecture of Inner Asia, Fig. 26 Plans of a Mongolian ger, survey by Martin Summer



Architecture: Nomadic Architecture of Inner Asia, Fig. 27 Plans of a Mongolian ger, survey by Martin Summer

forces. If supporting middle posts are used, much of the load and thus of the outward pushing forces is taken over by them.

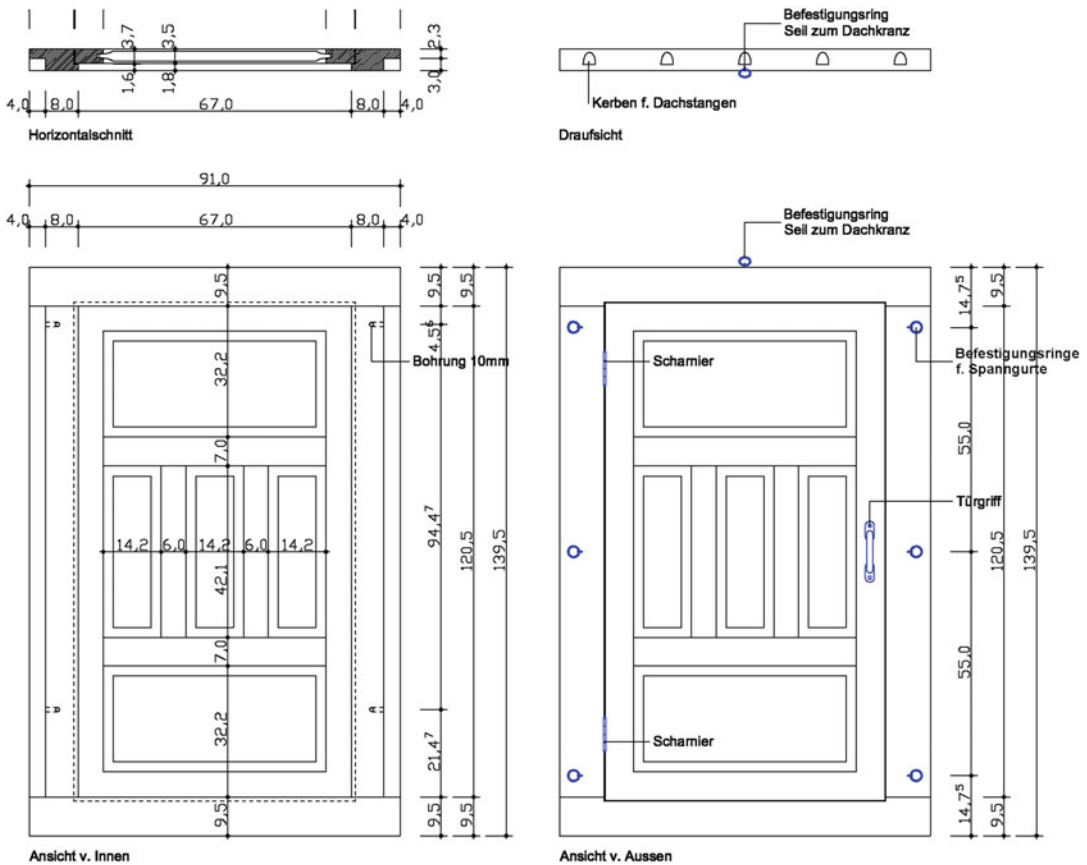
To strengthen the walls, several ropes are tied from one door jamb to the other, holding together the wall elements like a belt or a ring, adsorbing the forces pushing in the outer direction. If these ropes are cut, the walls will lean outward, and eventually the whole construction will collapse.

It is also these ropes that ensure that no fixed connections between the roof poles and the heads of the wall elements are needed (the connections are flexible ones, a loop fixed to the end of the roof poles being wound on the heads of the wall elements). The only more or less fixed connections in the structural system of the dwelling are those joints where the roof poles are sunk into

cavities of the roof ring and of course those of the roof frame, which add a lot to the stability of the structure.

The form of the Mongolian yurt apparently changed at least to a slight extent from the Middle Ages on. One essential difference seems to be that as nowadays no open fire is used anymore and smoke is led by a chimney pipe outside the dwelling, the roof ring and maybe also the roof shape has become lower. When open fire is used, a high pitched roof is more favorable. This roof can also be topped by a chimney-like roof ring, thus generating even more effective upward draught transporting the smoke outside.

The reasons for change in the form of yurts through the ages have not been thoroughly examined so far, so maybe further research will provide more insight into this topic.



Architecture: Nomadic Architecture of Inner Asia, Fig. 28 Plans of a Mongolian ger, survey by Martin Summer

Manufacture of a Nomadic Dwelling

The wooden frame of trellis tents is usually manufactured by specialists (Fig. 22), that is, somebody of the community versed in carpentry work. The production of the felt cover is done by nonspecialists (Figs. 23, 24 and 25).

In Mongolia, larch wood is traditionally used for the trellis, the roof wheel, and the columns, while willow or birchwood is used for the roof struts. It is important to note that after felling the wood it is usually put for some time into a lake, river, or creek, as the water leaches out the nutrients and the sap inside the wood and thus makes it less prone to insects and decay. While formerly yurts were made by a carpenter with simple hand tools, nowadays there are often factories producing yurts or gers with the help

of power tools and modern machinery (Figs. 30, 31, 32, 33 and 34).

The size of a ger is usually measured by the number of its trellis wall elements, the *xan*. The most common gers have 4, 5, or 6 *xan*, which means their diameter ranges from about 4.25 m to 5.5 m and 6.4 m respectively. There are gers which only have 3 *xans*, but they are only used as storage buildings and not for dwelling purposes. When Mongolians talk about gers, they not only mention the number of *xans* but also sometimes the number of roof struts (*uni*).

The most common gers have a ground floor area of 20–30 m², and if dismantled and packed for travel, a middle-sized ger weighs around 1,000 kg. The wall height is around 1.5 m; the overall height of a ger in use nowadays is around 2.3–2.5m (Figs. 26, 27, 28 and 29).



Architecture: Nomadic Architecture of Inner Asia, Fig. 29 Painted column (*bagana*) of a Mongolian ger (Source: Birtalan et al., 2009)

The felt covering is made by the whole community in late summer or autumn. First the sheep are sheared, and then the wool is beaten with sticks. This procedure loosens the wool and helps to free it from dirt. After that, the wool is laid on an already finished piece of old felt (the mother felt) and is wound around a wooden axle. It has to be taken care how the wool fibers are placed and which quality of wool is used in which place. The axle is bound to the saddle of a horse and dragged behind on a clean flat stretch of 300–350 m around 15 times. After that the felt bundle is opened, and the new piece of felt (son felt) turned, wound up again, and dragged again around (Birtalan et al., 2009) (Figs. 23, 24 and 25).

Use of Space Within the Ger

When entering a ger from the south through the entrance, the most prestigious part can be found exactly opposite the door to the north in front of the wall. Here, usually sacral objects, Buddhist icons, or butter lamps can be found; sometimes photos of family members are placed here. This part of the inner space has the highest rank, which diminishes

Architecture: Nomadic Architecture of Inner Asia, Fig. 30 Ger manufacture in Ulan Bataar



Architecture: Nomadic Architecture of Inner Asia, Fig. 31 Ger manufacture in Ulan Bataar, using modern tools



Architecture: Nomadic Architecture of Inner Asia, Fig. 32 Ger manufacture in Ulan Bataar



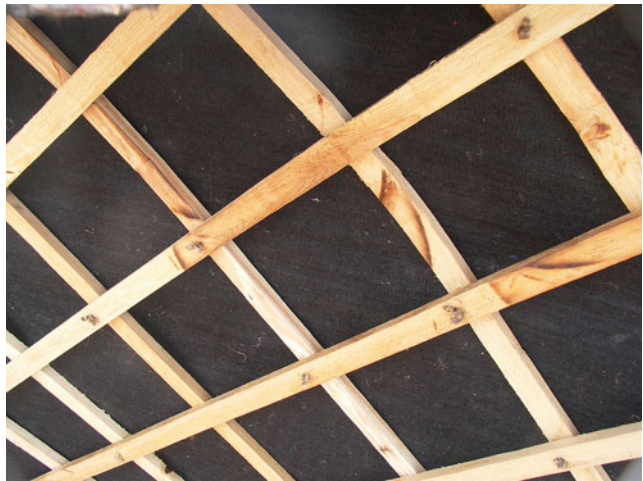
when moving toward the door. Guests are seated according to this plan: The most respected, the higher ranking, or maybe also the oldest are given a place more to the north, near the prestigious part, while younger or nether-ranking guests are seated nearer to the doorway (Fig. 37).

Customarily one moves inside a ger from left to right in a clockwise direction. The central part of the dwelling is avoided; the roof-supporting columns, which demarcate this space, should not be touched. Also one should not pass between them. The inner space within a ger is divided

**Architecture: Nomadic
Architecture of Inner
Asia, Fig. 33** Ger
manufacture in Ulan Bataar



**Architecture: Nomadic
Architecture of Inner
Asia, Fig. 34** The black
marks on the trellis laths of
this Mongolian ger show,
that they are bent over fire,
and not steamed and bent
into shape like the laths of
Turkic yurts, which have a
more elegant curve



into two halves: the mens' part (the Western half) and the womens' part (the Eastern half). Upon entering the dwelling one would first see the saddles and tools stored on the left-hand side from the entrance in the men's half. Also newly born sheep and goats are usually brought into this part of the ger if the spring weather turns very severe. Somewhat more inside there is a container for *koumiss*, the fermented mare's milk. Also further, tools or weapons (if there are any) can be found here.

From this first part one enters the living or sleeping part of the yurt; the boundary is usually signified by chests or boxes, and also beds can be found here. On the womens' side the subdivision of the space is similar: near the door there are kitchen utensils, pots, and a water container, while more inside there are chests and a bed. People sleep always with their heads pointing toward the north. Formerly people slept on felt mats, but nowadays almost everybody owns a proper bed.

Architecture: Nomadic Architecture of Inner Asia, Fig. 35 Roof wheel of an Uzbek yurt (Source: Erich Lehner)



A

The ger is heated by an iron stove situated in the center of the dwelling, right below the *tonoo*, the roof wheel. Nowadays a chimney pipe leads the smoke out of the dwelling; in former times there was an open fire. As usually in the steppe there is not enough firewood to be found, dried animal dung is used for fuelling the fire. The ger is lit mainly by the opening in the roof wheel (Figs. 35 and 36) and partly by the translucent walls themselves if the felt is not too thick. The lighting from above has a pleasant quality. The light coming through the tonoo produces a spot within the inner space, which changes its position according to daytime and thus functions like a sundial.

From a Nomadic Lifestyle to Modern Sedentary Forms

Mongols usually only choose a sedentary lifestyle when migrating to towns or when other reasons make staying in one place possible or necessary. Tourism can be such a reason.

In the northern forested areas a long tradition of sedentary architecture exists. These buildings are mostly log cabins of some kind. The Buriat people have evolved a traditional way of building with wood and log structures; the other timber buildings usually have a little bit makeshift and improvised appearance (Figs. 38, 39, and 40).



Architecture: Nomadic Architecture of Inner Asia, Fig. 36 Detail of a roof wheel of an Uzbek yurt (Source: Erich Lehner). The rim of such wheels is steamed and bent to a circular shape. The roof wheel of Mongolian gers is assembled from several pieces and not bent

In urban areas timber is an expensive building material; so many poor people use bricks or concrete instead. Loam is sometimes applied over a wooden latticework as plastering to walls of both

Architecture: Nomadic Architecture of Inner Asia, Fig. 37 Inside a Mongolian ger, looking northward from the entrance



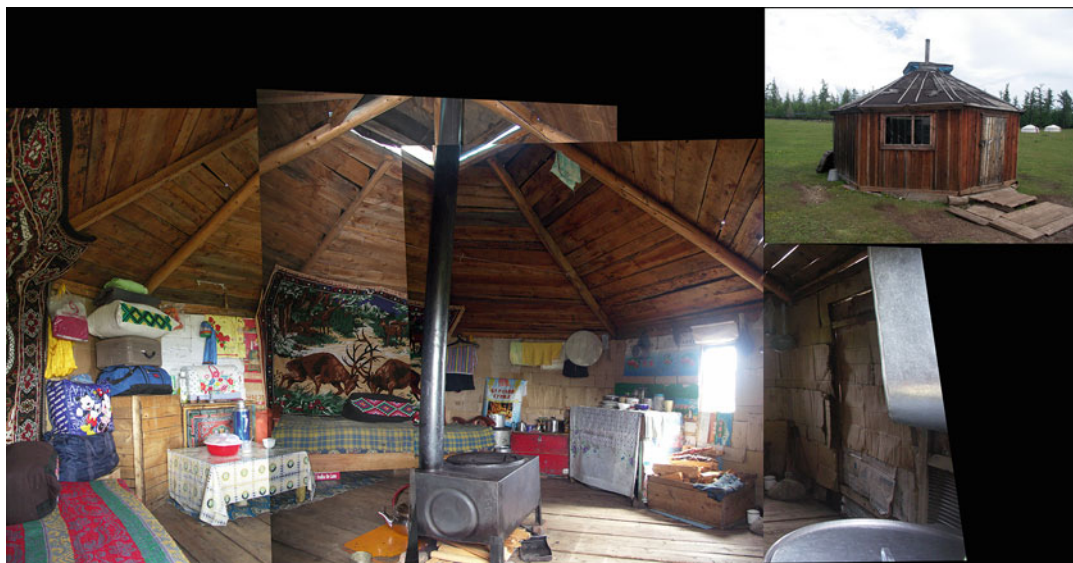
Architecture: Nomadic Architecture of Inner Asia, Fig. 38 Log cabin being built, Mongolia



wooden and concrete houses. Most of the building materials are imported from China or Russia; bricks are also manufactured in Ulan Bataar in several factories.

If a sedentary or more or less sedentary lifestyle is chosen, the ger is only abandoned after a longer period of time. It is usual to see in most

cases a parallel existence of the nomadic dwelling and houses made out of wood or stone. In this case the houses are mostly inhabited in winter and the yurt in summer. A reason for this is that the yurt is airier. In winter as one house dweller in Ulan Bataar said, the ger can be heated up very fast, but it gets cold again very



Architecture: Nomadic Architecture of Inner Asia, Fig. 39 Many wooden houses are built in a form closely related to the ger, and have also a similar inner organisation



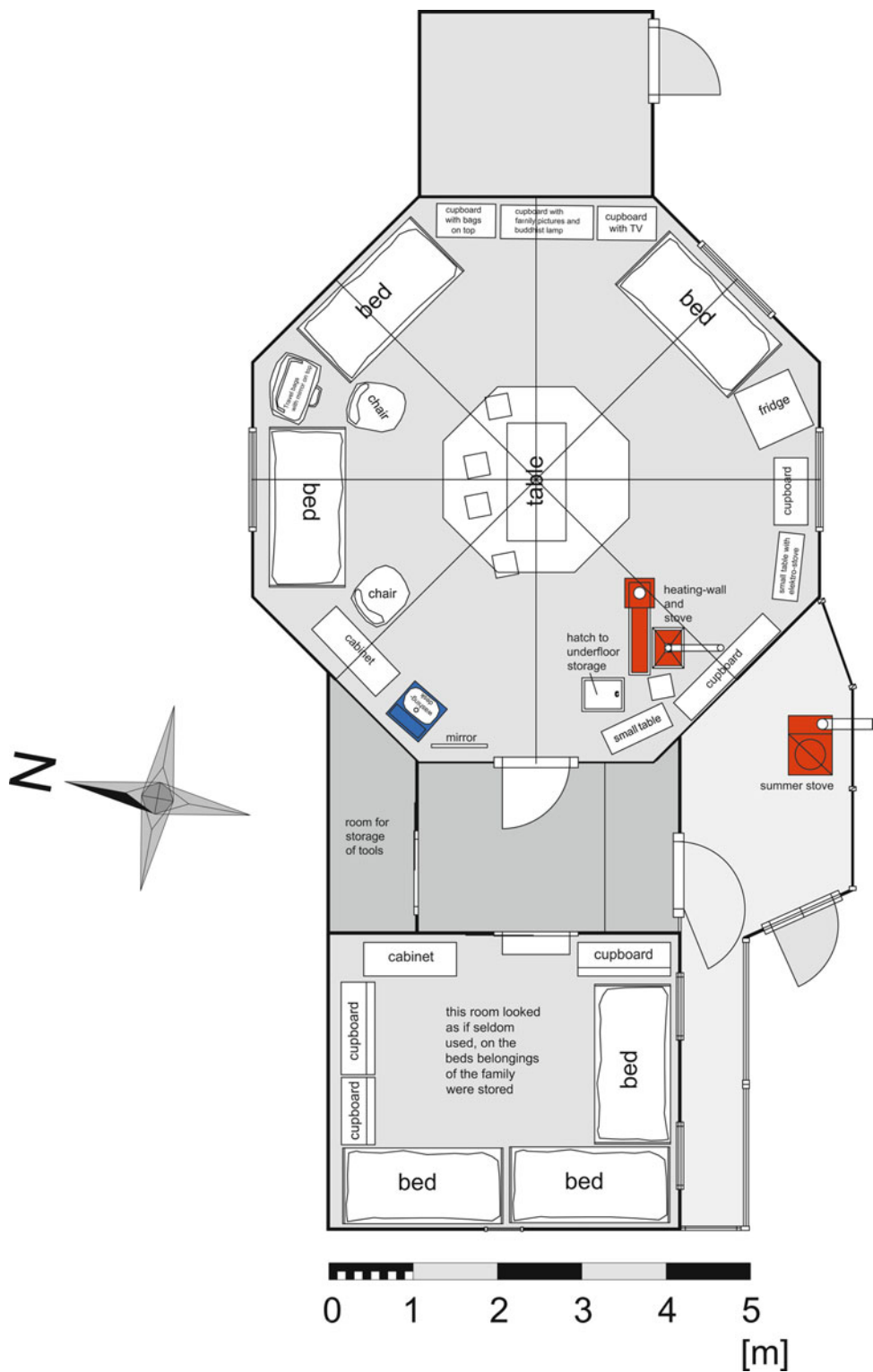
Architecture: Nomadic Architecture of Inner Asia, Fig. 40 Log cabin in the shape of a ger



Architecture: Nomadic Architecture of Inner Asia, Fig. 41 Octagonal house in Ulan Bataar

Architecture: Nomadic Architecture of Inner Asia, Fig. 42 Stove with heating wall inside an the octagonal house. The wall ensures that heat is radiated slowly to the surrounding room in winter





Architecture: Nomadic Architecture of Inner Asia, Fig. 43 Ground plan of the octagonal house shown above



Architecture: Nomadic Architecture of Inner Asia, Fig. 44 Buriat log cabin



Architecture: Nomadic Architecture of Inner Asia, Fig. 45 Buriat log cabin with peculiar roof structure

fast as well. This is because the walls have no thermal storage capacity. The houses with their thick walls hold the heat better but are usually badly ventilated because of inferior design and material quality (especially the windows). This makes living in them during summer not really comfortable (Figs. 41, 42, and 43).

In the northern forested areas the Buriat people have developed an octagonal house, which closely resembles the yurt. Its walls are made of timber logs, the corners connected usually with a butt-and-pass method, sometimes with interlocking saddle notches. However, most log architecture in Mongolia is built with a local variant of the butt-and-pass method, where half



Architecture: Nomadic Architecture of Inner Asia,
Fig. 46 Corner detail of a Buriat log cabin

of each log is left longer and protrudes over the wall plane. One fourth of the logs are sawed away on the upper and lower part of the corner joint, so an interlocking pattern of log ends in both directions emerges. This method is one of the simplest connection methods in log building and is mostly used over all of Mongolia. Some houses in the Buriat regions use or used interlocking saddle notches as corner joints, which already needs more expertise in woodworking. Gaps between logs are stuffed with moss to prevent wind blowing through the building (Figs. 44, 45, and 46).

In some Buriat houses there is a quadratic space in the center, which is lowered slightly below floor level and also contains the hearth. It is flanked by four posts, which support a frame in the ceiling, above which there is a kind of lantern with windows or at least a roof-covered smoke

hole. In smaller houses the pillars are maybe not necessary; the radially running rafters are able to hold the structure up by themselves. In other houses the rafters are not radial. The roof construction is supported by beams placed diagonally over the corners and then in layers on top of each other, thus diminishing the open span each time until only the smoke hole is left free.

These buildings are traditionally covered with earth, wooden shingles, timber boards, or tree bark. In recent time tar-bitumen roof sheeting or corrugated iron sheets are also used.

In areas where log building has not much tradition or where the stationary buildings also have a more temporary character, octagonal houses are also often built out of timber boarding with a slightly stronger wooden skeleton. Here the substructure is connected with the timber boards by nailing, forming panels in much the same technique a wooden garden door is made. These makeshift panels are put together to form an octagonal shape, with a roof made with the same method. On top of the roof a lantern with windows is placed, and some of the wall panels have windows as well. All in all these are usually not very well-built houses, but they show direct structural relation and proximity to the Buriat houses and the nomadic yurts. Usually in these octagonal houses the central hearth is replaced by a table, and the oven is shifted to the kitchen area on the right side from the entrance near the wall.

There are some intermediary types of these houses, where a yurt roof ring is still used, sometimes planted on a pole (Figs. 47, 48, and 49).

In the northern regions there is also a strong tradition of rectangular house building. These houses are usually log structures and often show strong Russian influence. In cases where the house interior is still one single room, people try to adhere to the spatial organization of areas within the yurt.

In urban areas houses stand on plots surrounded by high timber board fences which prevent passing people and neighbors from looking inside. The gates of the plot are usually painted with traditional motifs. Houses are



Architecture: Nomadic Architecture of Inner Asia, Fig. 47 Wooden house resembling a ger. Mongolia, Terelj



Architecture: Nomadic Architecture of Inner Asia, Fig. 48 Wooden house resembling a ger. Mongolia, Terelj



Architecture: Nomadic Architecture of Inner Asia, Fig. 49 Inside a wooden house resembling a ger. In this house even a roof wheel has been used. Mongolia, Terelj

mostly situated on the northern part of the plot, entrances looking south. Very often there is still a yurt standing on the plot in front of the house, and in the southeast or southwest corner an outhouse and other auxiliary buildings can be found. Sometimes houses show a double organization pattern, which means that they are built symmetrically and can accommodate two families. Very typical features are the heating walls, which are walls made of bricks which lead the smoke from the iron oven with inner tubes in many bends to the chimney. As the smoke has a long way to pass through the wall its energy heats up the bricks which provide a large surface area radiating warmth into the house interior. The negative side effect is that as the smoke cools down on its lengthened path, acidic substances contained within start to condense and corrode the chimney. This can also lead to gases escaping into the living area, which can have adverse health effects.

Constant features of urban living are sheds and auxiliary buildings. Some of them are built on runners to be movable within the plot boundaries. In some cases these sheds are also used as

Architecture: Nomadic Architecture of Inner Asia, Fig. 50 Little rectangular shed, Mongolia



Architecture: Nomadic Architecture of Inner Asia, Fig. 51 Rectangular anteroom attached to a ger-like hall of Gandan Monastery, Ulaan Bataar



entrance buildings for yurts and houses as a kind of anteroom. This seems to be quite an old invention, as yurt-like halls of monasteries also frequently show these features (Figs. 50 and 51).

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Arithmetic in India: *Pāṭiḡaṇita*

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Pāṭiḡaṇita, which literally means “mathematics (*gaṇita*) by means of algorithms (*pāṭi*),” is the name of one of the two main fields of medieval Indian mathematics, the other being *bījagaṇita* or “mathematics by means of seeds.” The two fields roughly correspond, respectively, to arithmetic (including mensuration) and algebra.

The compound *Pāṭiḡaṇita* seems to have come into use in relatively later times. In older works, the expressions, *gaṇitapāṭi* and *gaṇitasya pāṭi* (mathematical procedure, i.e., algorithm), are common, and sometimes the word *pāṭi* occurs independently. *Pāṭiḡaṇita* is also called *vyaktaḡaṇita* or “mathematics of visible (or known) [numbers],” while *bījagaṇita* is called *avyaktaḡaṇita* or “mathematics of invisible (or unknown) [numbers].” Some scholars maintain that the word *pāṭi* originated from the word *paṭṭa* or *paṭa* meaning the calculating board, but its origin seems to be still open to question.

The division of mathematics (*gaṇita*) into those two fields was not practiced in the *Āryabhaṭīya* (AD 499), which has a single chapter called *gaṇita*, but it existed in the seventh century, when Brahmagupta included two chapters on mathematics in his astronomical work, *Brāhmasphuṭasiddhānta* (AD 628). Neither the word *pāṭi* nor *bījagaṇita* occurs in the book, but chapter 12 (simply called *gaṇita*) deals with almost the same topics as later books of *pāṭi*, and chapter 18, though named *kuttaka* or the pulverizer (solution of a linear indeterminate equation), has many topics in common with later books of *bījagaṇita*. Śrīdhara (ca. AD 750) is known to have written several textbooks of *pāṭi* and at least one of *bījagaṇita*.

Extant works of *pāṭi* include Śrīdhara’s *Pāṭiḡaṇita* (incomplete) and *Triśatikā* (and *Gaṇitapañcaviṃśī?*), Mahāvīra’s *Gaṇitasārasaṃgraha* (ca. AD 850), chapter 15 (*pāṭi*) of Āryabhaṭa’s *Mahāsiddhānta*

(ca. AD 950 or 1500), Śrīpati’s *Gaṇitatilaka* (incomplete) and chapter 13 (*vyaktaḡaṇita*) of his *Siddhāntaśekhara* (ca. AD 1050), Bhāskara’s *Līlāvātī* (AD 1150), Ṭhakkura Pherū’s *Gaṇitasāraḡaumudī* (ca. AD 1315), Nārāyaṇa’s *Gaṇitakaumudī* (AD 1356), Gaṇeśa’s *Gaṇitamañjarī* (ca. AD 1600), and Munīśvara’s (b. AD 1603) *Pāṭisāra*.

A book (or chapter) of *pāṭi* consists of two main parts, namely, fundamental operations (*parikarmāṇi*) and “practical problems” (*vyavahārāḡh*). The former usually comprises six or eight arithmetical computations (addition, subtraction, multiplication, division, squaring, extraction of the square root, cubing, and extraction of the cube root) of integers, fractions, and zero, several types of reductions of fractions, and rules concerning proportion including the so-called rule of three (*trairāśika*). The latter originally consisted of eight chapters (or sections), i.e., those on mixture (*miśraḡa*), mathematical series (*śreḡdhī*), plane figures (*kṣetra*), excavations (*khāṭa*), stacking [of bricks] (*citi*), sawing [of timbers] (*krāḡacika*), piling [of grain] (*rāśī*), and on the shadow (*chāyā*).

To this list of the practical problems, Śrīdhara added in his *Pāṭiḡaṇita* one named “truth of zero” (*śūnyatattva*). A large portion of the work including that chapter is, however, missing in the only extant manuscript. The way the *Gaṇitasārasaṃgraha* of Mahāvīra divides its contents into chapters is unusual, but still it can be characterized as a book of *pāṭi*. It is quite rich in mathematical rules and problems.

In his *Līlāvātī*, Bhāskara separated the rules on proportion from the arithmetical computations and created with them a new chapter named *prakīrṇaka* (miscellaneous [rules]), in which he also included the *regula falsi*, the rule of inverse operations, the rule of sum and difference, etc. After the ordinary topics of practical problems, he treated *kuttaka* as well as *anakaḡpāśa* or the nets of numerical figures (combinatorics). Written in elegant but plain Sanskrit and organized well, the *Līlāvātī* became the most popular textbook of *pāṭi* in India.

The *Gaṇitasāraḡaumudī* written in Apabhraṃśa by Ṭhakkura Pherū consists of five

chapters. The first three chapters treat the traditional contents of *pāṭi*, namely, the fundamental operations of integers and fractions, several kinds of reductions of fractions, and the eight types of “procedures” such as mixture, series, plane figures, etc. The remaining two chapters contain supplementary material from diverse areas of contemporary life such as mathematical riddles, conversion of dates from Vikrama era to Hijrī era, and average yield per *bīghā* of several kinds of grains and pulses. It is in this part that magic squares were treated for the first time in mathematical works in India.

In his *Gaṇitakaumudī*, Nārāyaṇa included in the practical problems not only *kuṭṭaka* and *aṅkapāśa* but also *vargaprakṛti* or the square nature (indeterminate equations of the second degree including the so-called Pell’s equation), *bhāgādāna* or the acquisition of parts (factorization), *aṁśāvatāra* or manifestation of fractions (partitioning), and *bhadragaṇita* or mathematics of magic squares. These topics had already been dealt with to a certain extent by his predecessors, but he developed them considerably. He also investigated new mathematical progressions, some of which turned out to be useful when Mādhava (ca. AD 1400) and his successors obtained power series for the circumference of a circle (or π), sine, cosine, arctangent, etc.

In his *Gaṇitamāñjarī*, Gaṇeśa gave many rules and examples based on the *Līlāvātī*, but he was not a blind follower of Bhāskara. Following Jñānārāja, Gaṇeśa explicitly criticized Bhāskara’s assertion of the invariability of *kahara* (“zero divisor”). He also expressly pointed out that one of Bhāskara’s rules for concurrence, that is, $(a^2 - b^2)/(a - b) = a + b$, is indefinite when $a = b$. He prescribed the so-called Gelosia method of multiplication under the name *kapāṭasandhi* (“door junction”); other writers used this name for the slide multiplication which was most popular in India, but Gaṇeśa does not mention it at all. He gave a chord table for a circle of diameter 3,438 and used 600/191 for π .

Munīśvara, nephew of the Kṛṣṇa who wrote the commentary *Bījapallava* on Bhāskara’s *Bījagaṇita*, composed a work on *pāṭi* called

Pāṭīsāra, which consists of three chapters: Miscellany (*prakīrṇaka*), Mixture (*miśra*), and Geometrical Figures (*kṣetra*). One of the interesting features of this book is that not only the rules and examples but also rationales (*upapatti*) of the rules are given in verse.

See Also

- [Algebra in India: Bījagaṇita](#)
- [Bakhshālī Manuscript](#)
- [Combinatorics in Indian Mathematics](#)
- [Līlāvātī](#)
- [Magic Squares in India](#)
- [Mahāvīra](#)
- [Nārāyaṇa Paṇḍita](#)
- [Śrīdhara](#)
- [Śrīpati](#)

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Arithmetic in Islamic Mathematics

Julian A. Smith

Mathematics flourished during the golden age of Islamic science, which began around the seventh century AD and continued through to about the fourteenth century. Both arithmetic and algebra were advanced dramatically by Muslim mathematicians, who adopted Indian innovations such as decimal numbers and considerably extended them – they also developed earlier Greek concepts of geometry, trigonometry, number theory and the resolution of equations. Islamic mathematicians did far more than just copy Greek and Indian techniques – their additional researches developed and systematized several fields of mathematics. Even modern mathematical language, including terms like “algebra”, “root” and “zero”, owes an important debt to Arabic scientists. Algebra, for example, comes from the ninth-century Arabic Astronomer and mathematician ► **al-Khwārizmī** (ca. 780–ca. 850), whose book *Algebra* (*al-Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa 'l-muqābala*) described techniques of transposing quantities from one side of an equation to another (*jabr*), then simplifying them (*muqābala*).

Yet while Arabic contributions to algebra have been widely discussed by historians of science and culture, their parallel work in arithmetic

has been until recently far less well known. During the early nomadic period of Arabic history, numbers were given names – and around the time of the Prophet Muḥammad (ca. 570–632), the letters of the Arabic alphabet were often used as numerals. However, it was not until the rise of Islam in the seventh and eighth centuries that a recognizably modern system of arithmetic was developed. Muslim arithmetic operations were largely based on ancient Greek definitions, but Islamic scholars pioneered new techniques, including the network or lattice method (*shabaqah*) to multiply numbers, and various techniques of long division.

Muslim mathematicians are best known for their contributions to the pivotal system of modern “Hindu-Arabic numerals” – i.e. the technique of expressing all numbers through the repeated use of a few basic symbols. Though originally invented in India, Arab scholars dramatically improved both the writing and manipulation of decimal numerals, and also developed the Hindu idea of positional notation. It is not known exactly when Indian mathematicians began using decimal numbers, but they seem to have been in place by the early sixth century AD – astronomer Āryabhaṭa I (476–ca. 550) did not use them, but they were employed in a limited way by the middle of the sixth century. Decimal numbers were quite popular and spread quickly – by the seventh century, they had reached Iraq and the Middle East, and were praised by Syrian Nestorian bishop Severus Sebokht (fl. AD 630), who considered this new Hindu arithmetic “done with nine signs” even more ingenious than the calculations of Greek mathematicians. Arabs began using Hindu decimal arithmetic around the seventh century, but it was not until the ninth century that Arabic works describing this type of reckoning appear. The earliest known Arabic treatise on decimal arithmetic, *Kitāb al-hisāb al-hindī* (Book of Addition and Subtraction According to the Hindu Calculation), was written by Al-Khwārizmī around AD 800 – the Arabic text is lost, but a twelfth century Latin translation is still extant.

Al-Khwārizmī is better known among historians of Muslim mathematics for his many

contributions to algebra. Yet his investigations into arithmetic were equally important, and were so widely read in the medieval Latin West that they later gave Europeans one of their early names for arithmetic, the “algorism” or “algorithm”. Al-Khwārizmī’s book treated all arithmetic operations, spreading knowledge of Hindu techniques throughout the Muslim world. Another important early treatise that publicized decimal numbers was Iranian mathematician and astronomer Kūshyār ibn Labbān’s (fl. 1000) *Kitāb fī uṣūl ḥisāb al-hind* (Principles of Hindu Reckoning), a leading arithmetic textbook.

Coupled to the important development of decimal numbers was the equally significant Arabic use of the *sifr* (meaning “empty”), or zero, again from Indian roots. An early symbol for zero appears in an AD 876 inscription at Gwalior, India; in the Arab world, Kūshyār introduces the zero in the tenth century as a sign to be placed “where there is no number”.

Though scholars concede that much of Arabic arithmetic has its ultimate origins in India, Muslim mathematicians were the first to integrate the various discoveries of Hindu mathematicians into a coherent whole. Historian J. L. Berggren, for example, concludes that while the Hindus were the first to use a “cipherized, decimal positional system”, the Arabs pioneered in extending this system to “represent parts of the unit by decimal fractions”. In Europe, meanwhile, the zero and decimal system were not widely used until the late twelfth century.

Following ► [al-Khwārizmī](#), many Arabic mathematicians developed Indian techniques of arithmetic over the next few centuries. The astronomer, translator, and editor ► [al-Kindī](#) (801–ca. 873), for example, wrote several important treatises on arithmetic, including manuscripts on the use of Indian numbers, on lines and multiplication with numbers, on measuring proportions and times, on numerical procedures and cancellation, and many more.

Two centuries later, ► [al-Karajī](#) of Baghdad (fl. 1020) wrote mathematical works that led to his being called “the most scholarly and original writer of arithmetic” by historian Al-Daffa. Al-Karajī’s works included a manuscript on the

rules of computation entitled *Al-Kaḥḥ fī al-ḥisāb* (Essentials of Arithmetic), and *al-Fakhrī fī l-jabr wa'l-muqābala*, which was named after his long-time friend, the Baghdad grand vizier.

The depth of early Islamic knowledge of arithmetic is often quite unexpected. Arabic mathematicians were well aware of the existence of irrational numbers, and sometimes developed complex theories to explain their properties. Persian poet and philosopher 'Umar al-Khayyām, or Omar Khayyam (ca. 1048–ca. 1122) and Persian astronomer ► [Naṣīr al-Dīn al-Ṭūsī](#) (1201–1274) both argued that every ratio of two magnitudes can be considered a number, whether that ratio be commensurable (rational) or incommensurable (irrational). Islamic arithmetic used many of the same Hindu techniques for operating with irrationals as it did with rationals. Also from Indian sources came various operations with numbers, including transformations such as $\sqrt{x^2y} = x\sqrt{y}$ and $\sqrt{xy} = \sqrt{x}\sqrt{y}$.

Islamic arithmeticians did not accept everything offered them by Hindu scholars. For example, negative numbers, long a staple in Indian arithmetic, were transmitted to the Arab world but rejected by it – Arabic mathematicians instead held that negative numbers did not exist.

Modern notation for fractions is also based in part on Muslim arithmetic. Celebrated Hindu mathematicians such as ► [Bhāskara II](#) (1114–ca. 1185) wrote common fractions by just writing a numerator above a denominator, but the idea of a line of separation between the numerator and denominator was an early Islamic development. Decimal fractions, meanwhile, appear in seminal tenth century Arabic texts, such as the *Kitāb al-ḥisāb fī l-ḥisāb al-hindī* (Book of Chapters on Hindu Arithmetic), written by Damascus mathematician ► [al-Uqlīdisī](#) (fl. 952). In the late twelfth century, al-Samaw'al (fl. 1172) used decimal fractions for division, root extraction and approximation. By the fifteenth century, decimal fractions had been formally named and systematically developed, but they were not widely used in Europe until the Dutch physicist and engineer Simon Stevin (1548–1620) published *La Thiende* (The Tenth) in 1585, and Scottish mathematician John Napier

(1550–1617) reintroduced his decimal point in the early seventeenth century.

While Arabic mathematicians pioneered in decimal arithmetic, they also made considerable contributions to the ancient sexagesimal (base 60) system of arithmetic, which had been developed by the Babylonians in Mesopotamia around 2000 BCE. This system was widely used for astronomical calculation throughout the ancient world, particularly in Alexandrian astronomer and geographer Claudius Ptolemy's (ca. AD 100–170) cosmological treatise, *Almagest*, which was later adopted by Islamic scholars as the theoretical base of their astronomy. Sexagesimal addition, subtraction, multiplication and division became so commonplace among Islamic astronomers it was renamed "the astronomer's arithmetic". Arabic astronomers and mathematicians such as Kūshyār and Samarqand's al-Kāshī (fl. 1406–1429) used sexagesimal numbers to determine approximate roots, extract square roots and even find the fifth roots of certain numbers.

Islamic arithmetic was often influenced by the needs of astrology, talismans and sorcery, as in the casting of horoscopes and magic spells. Muslim mathematicians such as Syrian scholar Thābit ibn Qurra (ca. 836–901) and Tunisian historian Ibn Khaldūn (1332–1406) studied amicable numbers, or number pairs where the sum of the factors of each number is equal to the other number. Two hundred and twenty and 284 are amicable numbers, because the sum of the factors of 284 (1 + 2 + 4 + 71 + 142) equals 220, and vice versa.

Muslim mathematics was also affected by practical considerations such as problems of inheritance and finance, and the need to calculate events in the lunar-based Islamic calendar. For example, ► [al-Khwārizmī](#) devoted the second half of his treatise on algebra to the question of 'ilm al-farā'id, or the calculation of shares of an estate given to various heirs. These problems employed the arithmetic of fractions, and were heavily influenced by religious law and custom. A typical example treated by al-Khwārizmī was to calculate the shares of a dead woman's estate that would accrue to her husband, her son, and her three daughters. As the law required that the

husband receive a fourth and each son get twice what a daughter would receive, al-Khwārizmī simply divides the estate into 20 parts, giving five to the husband, six to the son, and three to each daughter. Similar problems involved the topic of *zakāt*, which was the calculation of the share of private wealth that various persons would pay to the community each year.

Islamic arithmetic was often ingenious. Arabic scholars gave us much of the modern system of arithmetic, and while many of its foundations were borrowed from Indian and Greek sources, it is clear that Islamic mathematicians united the various strands of arithmetic into a form recognizable to us today.

See Also

- ▶ al-Karajī
- ▶ Al-Kāshī
- ▶ al-Khwārizmī
- ▶ al-Kindī
- ▶ *Almagest: Its Reception and Transmission in the Islamic World*
- ▶ al-Uqlīdisī
- ▶ Ibn Khaldūn
- ▶ Mathematics
- ▶ Naṣīr al-Dīn al-Ṭūsī
- ▶ Number Theory in Islamic Mathematics
- ▶ Sexagesimal System
- ▶ Thābit ibn Qurra
- ▶ Trigonometry in Islamic Mathematics

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Armillary Spheres in China

Jiang Xiaoyuan

The equatorial armillary sphere was a traditional Chinese astronomical instrument used to observe celestial bodies in an equatorial coordinate system. Its origin is still not very clear. Astronomer ▶ [Luoxia Hong](#) (ca. 100 BCE) of the Western Han Dynasty was probably the first maker of this instrument which possessed a very basic form.

The early equatorial armilla was composed of two layers: the outside layer included a meridian circle, equatorial circle, and vertical circle – all three of these were fixed. The inside layer included a polar axis, right ascension circle, and sighting tube. The right ascension circle could rotate around the polar axis, and the sighting tube could rotate in the right ascension circle freely so it could point to everywhere in the sky.

In the Tang Dynasty (AD 618–907), a third layer was added to the equatorial armillary which included an ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) circle and a circle of the moon's path. Astronomers could then measure three coordinate systems with one instrument, but the three-layer armilla was too complex to observe, so from the Northern Song Dynasty (AD 960–1126) a course of simplification was begun. The third layer was canceled, and the so-called “abridged armilla” (*Jian Yi*) appeared. It is in fact two different instruments (one equatorial armilla and one altazimuth) on the same pedestal.

The equatorial armilla was one of the most important astronomical instruments in ancient China. It was the result of the equatorial tradition of Chinese astronomy which lasted more than 2,000 years. In ancient China, armilla (and almost all astronomical instruments) were only made by the imperial government, so their size was always very large.

See Also

- [Astronomy in China](#)
- [Luoxia Hong](#)

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Armillary Spheres in India

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The armillary sphere was an important instrument used by Indian astronomers for demonstrational and observational purposes. In an age when satellite-aided observatories or even the telescope did not exist, the study of planetary positions was possible only with the aid of working models, which in turn depended on the little that naked eyes could observe of planetary and sidereal positions. The armillary sphere was one such model. It was known in India as *golayantra* (globe machine) or *golabandha* (globe band).

The *Sūryasiddhānta* gives a description of the construction of an armillary sphere. Āryabhaṭa describes it briefly in his *Āryabhaṭīya*. Its construction is treated at different lengths in Varāhamihira's *Pañcasiddhāntikā*, Brahmagupta's *Brahmasphuṭasiddhānta*, Lalla's *Śiṣyadhīvrddhida*, Śrīpati's *Siddhāntaśekhara*, Bhāskara II's *Siddhāntaśiromaṇi*, and Vaṭaśseri Parameśvaran's *Goladīpikā*.

We do not know when the armillary sphere was introduced in India, nor are we in a position to say whether it was developed by the Indian astronomers or borrowed from the Greco-Romans who were perhaps familiar with it in the days of Aristotle. Aristotle's contemporary

Eratosthenes (ca. 276–196 BCE) is likely to have used it for studying eclipses. This might have been a simple instrument, as were the three spheres mentioned a few centuries later by Ptolemy in his *Almagest*.

The *Āryabhaṭīya* (476 CE) is by far the oldest text in India that speaks of the armillary sphere. It is not forthcoming enough in its description of the sphere, though. All we gather from it is that the sphere must be completely spherical, shaped in wood with uniform density throughout, and made to rotate with the help of mercury, oil, water, and the application of one's mind! Several writers tell us how the models are constructed, but many shy away from describing how the spheres rotate. The *Sūryasiddhānta* urges that the technique of (rotating the sphere by) using mercury must remain a secret learned from a teacher, never to be described (in writing).

Sūryadeva proposes the following method. The sphere to be rotated is mounted on two vertical posts fixed on the ground, one in the north and the other in the south. These are connected with an iron string, which functions as the axis to which the sphere is fastened. The holes at the north and south of the sphere are lubricated with oil to ensure a smooth rotation. A cylindrical water container with a hole at the bottom is placed in a pit to the west of the sphere. The hole is fashioned in such a way that the water drains away completely in 60 *ghaṭis* (24 h). A nail is fixed close to it, and a string is tied to the nail and bound on the sphere across the line represents its equator. The other end of the string is tied to a hollow gourd containing enough mercury to keep it afloat. The gourd is placed in the water container. Once set in motion, the gourd reaches the bottom of the container in 60 *ghaṭis* in course of which time the sphere connected to it with the string completes one rotation.

The method described by Sūryadeva is too simple to be a secret. It does not warrant the use of mercury either. Besides, a major limitation of this model is that the outflow of water from the container is greater when the container is full and slows down as pressure decreases with the decrease in water level. The rotation of the sphere is never uniform.

The real purpose of using mercury seems to have been different, which is described in the *Brahmasphuṭasiddhānta*. This description is striking in its theoretical simplicity, although difficult to practice under premodern conditions. A wheel is mounted on two supporting posts with the help of a horizontal axis passing through its center. Several small tubes are filled with mercury to the desired quantity and fixed like spokes between the center and the circumference of the wheel. The to-and-fro motion of mercury within the hollow spokes makes the wheel rotate at a uniform speed. The speed of the wheel is determined by the quantity of mercury present in the hollow spokes.

Simple models involving one or two globes do not seem to have been used in observations, as it could at best serve demonstrational and pedagogic needs. Armillary spheres of greater complexity are required for determining the latitudes and longitudes of the planets. Brahmagupta tells us how to construct an armillary sphere in which 51 globes are simultaneously in motion. Bhāskara II describes a model that is exceptional for its intricate constructions. There are three parts to this model: the *bhagola*, a sidereal sphere of fixed stars; the *khagola*, a sphere beyond the *bhagola* to represent the firmament; and the *ḍṛggola*, a sphere beyond the *khagola* where the two other spheres are brought together.

The model described by Parameśvaran consists only of the inner *bhagola* and the outer *khagola*. It operates around a central axis, which both spheres share. The *bhagola* is constantly in motion while the *khagola* remains fixed. At the center of the axis is a globe that represents the earth, its position being the figuration at zero latitude.

The components of this model are made of bamboo, iron, and strings. The earth, the moon, and the planets are made of wood or clay. Śripati prescribes hard woods like *śrīparṇi* (*Gmelina arborea*) for making them. A thin bamboo strip fashioned into a band runs in the north–south direction of the model as the solstitial colure (*dakṣinottara*). It is divided into 360 parts of equal size. Another strip in the east–west

direction indicates the celestial equator (*ghaṭikā-maṇḍala*) and is divided into 60 equal parts. More bands are placed at appropriate positions: one made of 360 equal parts to indicate the equinoctial colure (*unmaṇḍala*), another inclined at 24° north and south of the zenith and the nadir to record the ecliptic (*apama-vṛtta*), and several others to represent the diurnal circles (*ahorātra-vṛttas*). Outside the *bhagola* and the *khagola*, three other bands are introduced: a horizontal band to represent the horizon (*kṣitiṇi*), a band in the east–west direction to indicate the prime vertical (*samamaṇḍala*), and a third band in the north–south direction to mark the meridian (*dakṣinottara*). The movement of the moon and other planets is then projected on to this by introducing movable globes. The orbits are so orchestrated as to enable the planets cross the ecliptic at their respective nodes and reach their maximum latitudes at 90° from the nodes.

The model described by Parameśvaran is also found in Brahmagupta. It appears that Brahmagupta's armillary sphere was massive in size. In his model, the globe representing the earth is placed at the center of the three outer circles, viz., the prime vertical, the meridian (which he calls *yāmyottara*), and the horizon. What is intriguing is that the observer is made to stand on the globe, an indication of its enormous size.

Lalla's model also has the *bhagola* and the *khagola*. Here, a pin is introduced to correspond appropriately to the equator and the ecliptic, and the *bhagola* rotated in such a way that the pin's shadow passed through the center of the sphere. The arc of the equator intervened by the pin and the horizon indicates the time elapsed since sunrise, and the one on the ecliptic, the degrees risen since sunrise. This is Lalla's method of determining time and the orient ecliptic point (*lagna*).

The armillary sphere was invaluable, and perhaps indispensable, in the preparation of almanacs. A direct testimony to this effect is found in Lalla's text where the "globe machine" is said to have been deployed to determine time and the *lagna*.

See Also

► Astronomical Instruments in India

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Armor in Japan and Korea

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The Roman Empire (27 BCE–476 CE) and the Han Dynasty (206 BCE–220 CE) overlapped in time as the great empires of Eurasia. Both had to deal with mounted, often pastoralist, and frequently aggressive steppe peoples on their northern borders. Horse-riding equipment and iron armor styles were transmitted among these northerners from west to east all the way into the Korean Peninsula and Japanese Islands (Fig. 1). These latter areas will be collectively referred to below as the Pen/Insulae (following Barnes, 1999). The time period under discussion is between the second half of the first millennium BCE and the fifth century CE, within the Samhan or Proto-Three Kingdoms (300 BCE–300 CE) and Three Kingdoms (300–668 CE) periods on the Peninsula (Barnes, 2001) and the Yayoi (800 BCE–250 CE) and Kofun (250–710 CE) periods in the Japanese archipelago (Barnes, 2007).

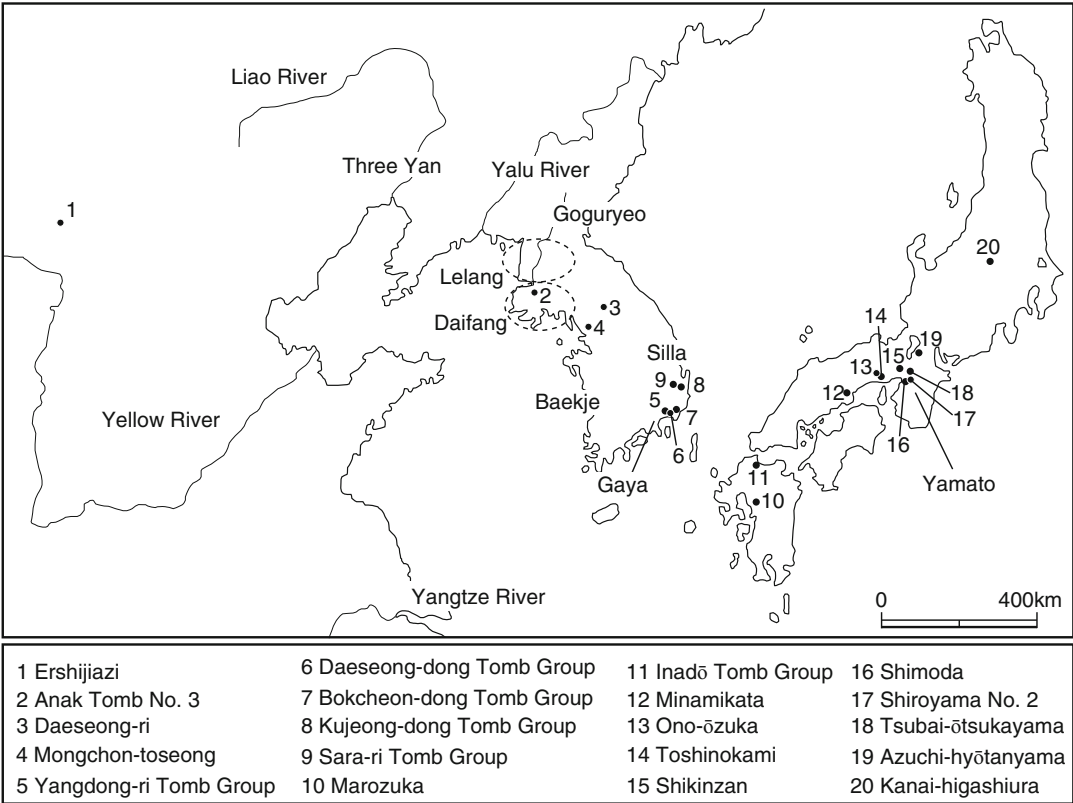
During the Late Han Dynasty (29–220 CE), horsemen of the Manchurian Basin Puyo and Goguryeo (Koguryō) peoples were used by the Han as cavalry in protecting against the steppe Xiongnu and Xianbei warriors. The Goguryeo turned on the Han, raiding the commanderies established in the lower Manchurian Basin and

northern Korean Peninsula. The Lelang commandery near modern Pyongyang was a particular target but also influenced armor development in the Pen/Insulae. Goguryeo, as a rising state after the demise of the Han, took over the commandery areas in the early fourth century and began pushing into the southern Korean Peninsula. Politics existing on the southern coast, which had begun as iron producers during the commandery era, turned their skills to making armor and weapons to combat this aggression.

Sporadic finds of flexible lamellar armor from Han are found in Pen/Insular sites, but local manufacture began with fixed-plate iron cuirasses which replaced organic cuirasses that had been used in the Pen/Insular regions until then. Within the East Asian context, “plate armor” refers to a cuirass composed of wide sheets laced or riveted together. As plate armor was made to wrap around the torso, the shape and curvature of each plate is greatly determined by its unique place within the cuirass. In contrast, lamellar armor is composed of a great number of small, narrow tabs that are often rounded at one end. While dedicated lamellae do exist for the waist and hem, the remaining majority are of the same all-purpose size and shape (Furuya, 1996). Additionally, not only do plates and lamellae display significantly different styles of lacing and placement of their lacing holes, but riveting was used solely in plate armor.

Plate-armor manufacture was initiated in the southeastern Peninsula in the early fourth century and was developed further in the Japanese Islands (see Barnes, 2000). The Mongolian helmet, made of vertical strips of iron, was transferred in from the steppes. Used as it was on the Korean Peninsula, it was transformed into two different types in the Japanese Islands: a visored helmet still consisting of vertical strips and a keeled helmet, with the iron strips running horizontally to meet in a keel at the forehead. In the fifth century, lamellar armor suits replaced cuirasses on the Peninsula and were introduced to the Japanese Islands in response to Goguryeo’s fielding of troops down to the southern Peninsular coast in 400 CE.

While a comprehensive treatment of protective armor requires consideration of helmets and



Armor in Japan and Korea, Fig. 1 Map of sites mentioned in the text and figures

other auxiliary wear such as guards for the shoulder, shin, and neck, this entry will focus mainly on body armor and only through the fifth century CE.

Organic Armor

Before Pen/Insular domestic production of iron armor began in the fourth century CE, the need for bodily protection was satisfied with imports of iron armor from China and locally made organic armor. Unfortunately, organic material does not fare well in the Pen/Insular acidic soil, leaving archaeologists with only a fragmentary record.

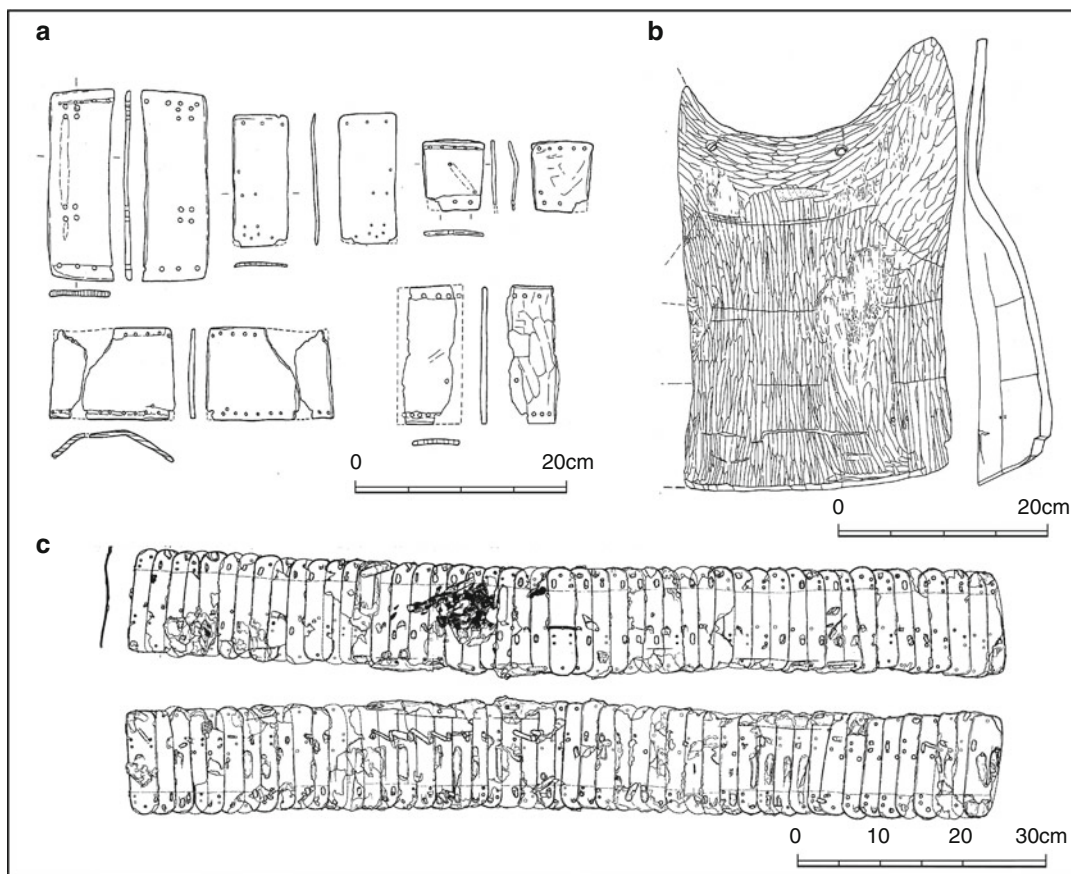
Korean Peninsula, Organic Armor

The earliest example of organic armor is a set of lacquered leather lamellae uncovered in Pyongyang dating to the first century BCE (Song, 2004; Yi, 2008). Accompanying artifacts suggest Han

influence through the Lelang commandery. Subsequent scattered finds of wooden and lacquered leather lamellae are found through the third century. Additionally, bone lamellae have been found from several sites, most notably the late fifth-century Mongchon-toseong (Mongch'on T'osōng) site in Baekje (Paekche). The discovery of only iron neck guards, lamellae that circle the waist in a long lamellar suit, or helmets at several tombs in the Daeseong-dong (Taesōng-dong), Bokcheon-dong (Pokch'ōn-dong), and Yangdong-ri (Yangdong-ni) tomb groups suggests the existence of organic armor or composite armor combining organic and iron materials, even after local production of iron armor began in the fourth century (Fig. 2c).

Japanese Archipelago, Organic Armor

Wooden armor from the Japanese archipelago can be categorized into two types: plate armor made by binding numerous wooden tabs together



Armor in Japan and Korea, Fig. 2 Examples of organic armor. (a) Wooden plate armor from the Minamikata site, Okayama, Japan (After Okayama City Board of Education, 2005, Fig. 53). (b) Wooden fitted cuirass from the Shimoda site, Osaka, Japan (After

Osaka Center for Cultural Heritage, 1998, Fig. 198). (c) Iron waist lamellae from a composite iron/organic suit excavated from Bokcheon-dong Tomb No. 21, Busan, South Korea (From Busan University Museum, 1990, Fig. 34)

(Fig. 2a) and “fitted” cuirasses made by hollowing out a log and comprising a single rear and two front sections (Fig. 2b) (Hashimoto, 1996; Kamiya, 2010). The former are confined to the second half of the first millennium BCE and may represent continental influence. The latter are believed to be a domestic development and stretch from the second half of the first millennium BCE to the late fourth century CE.

In addition to wooden armor, lacquer-coated leather cuirasses, fiber cuirasses, leather tassels, and leather-keeled helmets are also known. Moreover, the discovery in late 2012 of dozens of bone lamellae at the early sixth-century Kanai-higashiura site in Gunma Prefecture attests

to the diverse nature of materials used. The existence of composite armor using both organic and iron materials has also been inferred from the discovery of iron “placket” plates excavated from fourth-century tombs. While organic body armor is replaced by iron armor in the fourth century, the above finds testify that organic materials nevertheless continued to be used to some extent.

Iron Plate Armor

Approximately 60 examples of iron plate armor have been discovered from the Korean Peninsula

and approximately 530 examples from the Japanese Archipelago. Significant differences existed between Peninsular and Insular manufacture, dependent primarily on the shape and orientation of the plates. Peninsular cuirasses are composed of long rectangular plates oriented vertically, while Insular examples utilize shorter rectangular, square, or triangular plates fixed in horizontal bands – until long rectangular plates were utilized horizontally in the latest style (Fig. 6c).

Vertical-Plate Armor, Korean Peninsula

To date, no vertical-plate cuirasses have been found in Goguryeo or Baekje territory. The production of vertical-plate armor began in the early fourth century solely in Gaya (Kaya) and Silla in the southeastern Peninsula (Kim, 2009; Song, 2004, 2008; Yi, 2008). The fourth century can be divided roughly into three stages based on technological development (Figs. 3, 4).

Stage-1 (early fourth century) examples emerged already equipped with base plates running along the bottom edge of the cuirass and extended shoulder plates that project out to the side (Fig. 3), which may suggest their evolution from an organic predecessor. Almost all were fixed with iron rivets; the only known leather-thonged example is from Bokcheon-dong Tomb No. 38, which is morphologically considered one of the oldest examples of vertical-plate armor. It is believed that iron riveting replaced lacing almost immediately. Neck guards comprise long, narrow plates that curve outward from the cuirass neck and wrap around the side of the head (Fig. 3).

While cuirasses from Stage 2 (mid-fourth century) retain the base plates, the extended shoulder plates and outward-curving neck guards all but disappear. A new type of rear neck guard appears that extends vertically and is composed of fewer, wider plates and is almost always accompanied by two crescent-shaped side protectors that extend along the sides of the neck from the shoulder (Fig. 4a). Stage 2 is characterized by standardization of a horizontal shoulder plate (which a majority of Stage-1 cuirasses did not have), in addition to the appearance of an outer frame that wraps across the chest and under the arms. This

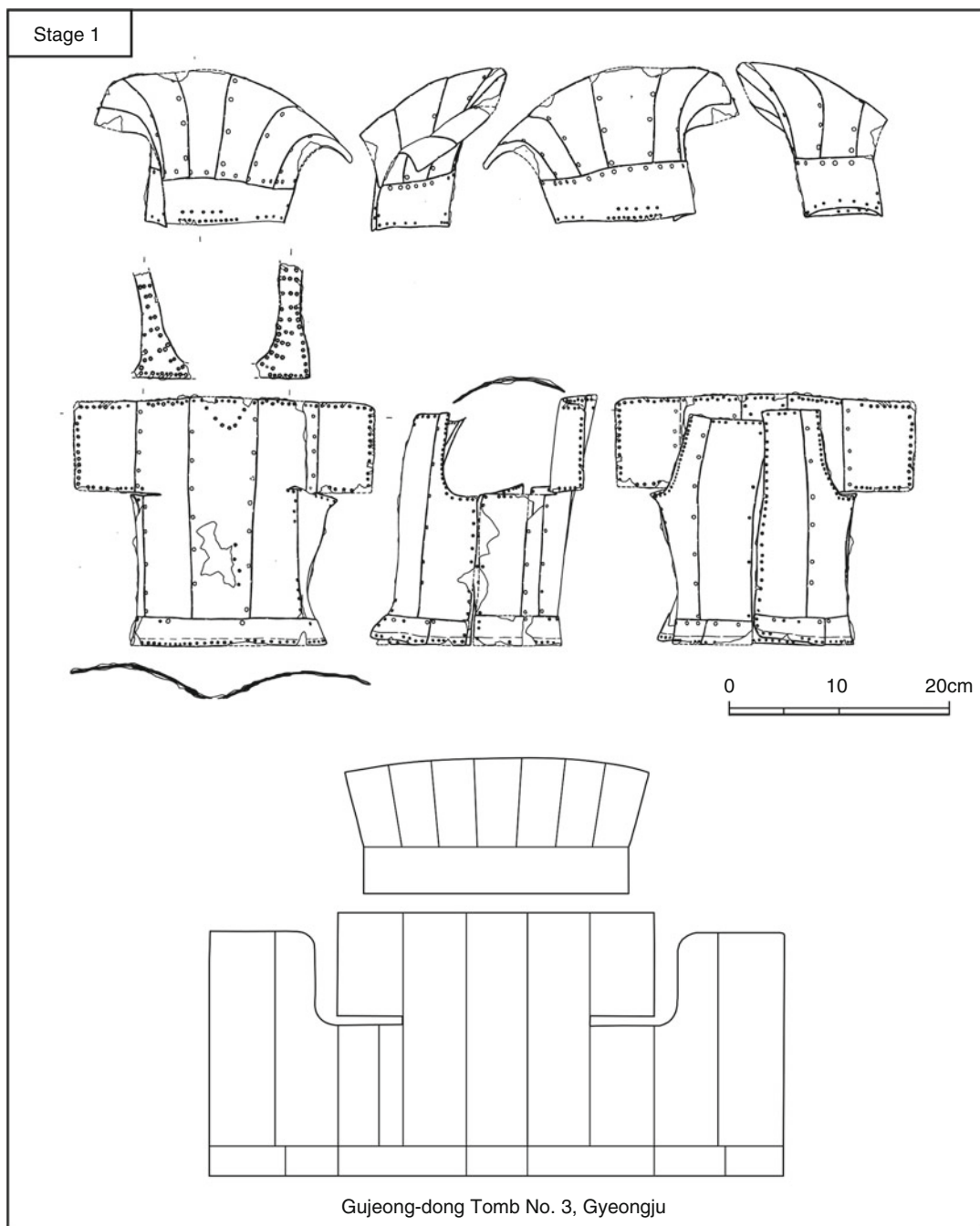
frame offered increased stability. While not present in all Stage-2 cuirasses, it is considered a major technological development and it becomes fairly standard in the following stage. Stage-2 frames, however, are composed of two plates fastened together, perhaps representing the technological difficulty of forming a curved piece that wraps from the chest to the underarm.

In Stage 3 (late fourth century), the curved border frame of many examples is now made from one plate that wraps from the chest, down through the underarm, where it is riveted to the rear border frame. Further developments include a marked increase in ornamentation (Fig. 4b) and a general increase in the number of vertical plates. This increase in narrow plates is accompanied by greater plate curvature (long the armpit) and an enhanced fit to the torso, separating Stage-3 cuirasses from the previous boxlike suits. They are believed to represent improved wearability. While a very small number of vertical-plate cuirasses remain into the fifth century on the Peninsula, they are generally replaced by lamellar armor.

In addition to vertical-plate cuirasses, almost 30 cuirasses with plates arranged in horizontal rows have been found in the southern half of the Peninsula, making up almost half the total number of iron plate armor uncovered. Typological considerations, however, strongly suggest that these are imports from the Japanese archipelago (Hashimoto, 2013; Kim, 2011).

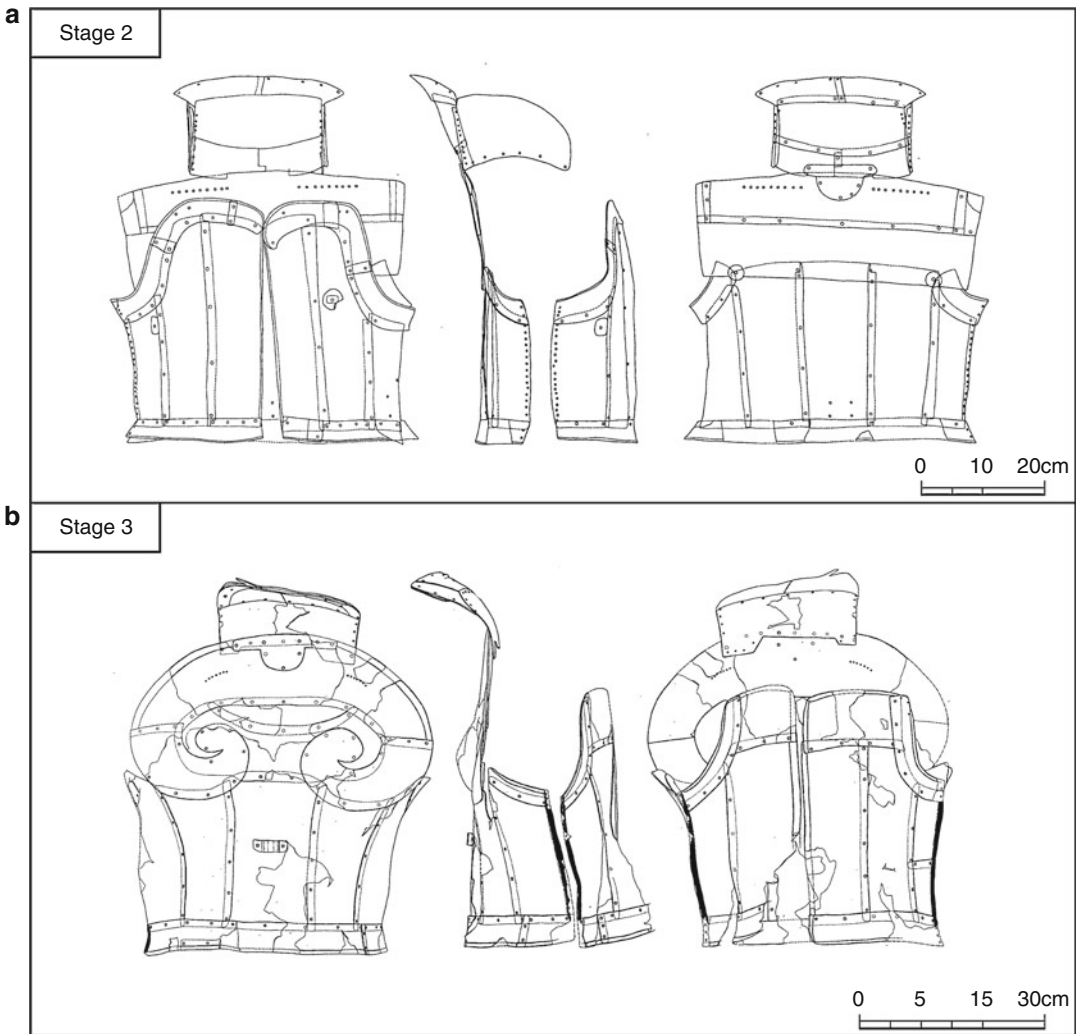
Horizontal Plate Armor, Japanese Archipelago

Vertical-plate cuirasses appear in the first half of the fourth century (Fig. 5a) (Hashimoto, 2013; Sakaguchi, 2010). The three known examples share the same vertical-plate alignment as those of the Peninsula, leading many to view them as imports. Significant differences do exist, however. All Insular examples are laced, rather than riveted, and lack the base plates, neck guards, extended shoulder plates, and decoration customary in Peninsular examples. It thus seems appropriate to consider them as having been domestically produced under Peninsular influence.



Armor in Japan and Korea, Fig. 3 Expanded view (bottom) of an iron cuirass (top). Iron cuirasses are often represented in expanded form, viewed from the rear, so

their structure can be readily understood (Top: After Gyeongju National Museum, 2006, Fig. 21. Bottom: After Song, 2008, Fig. 10)

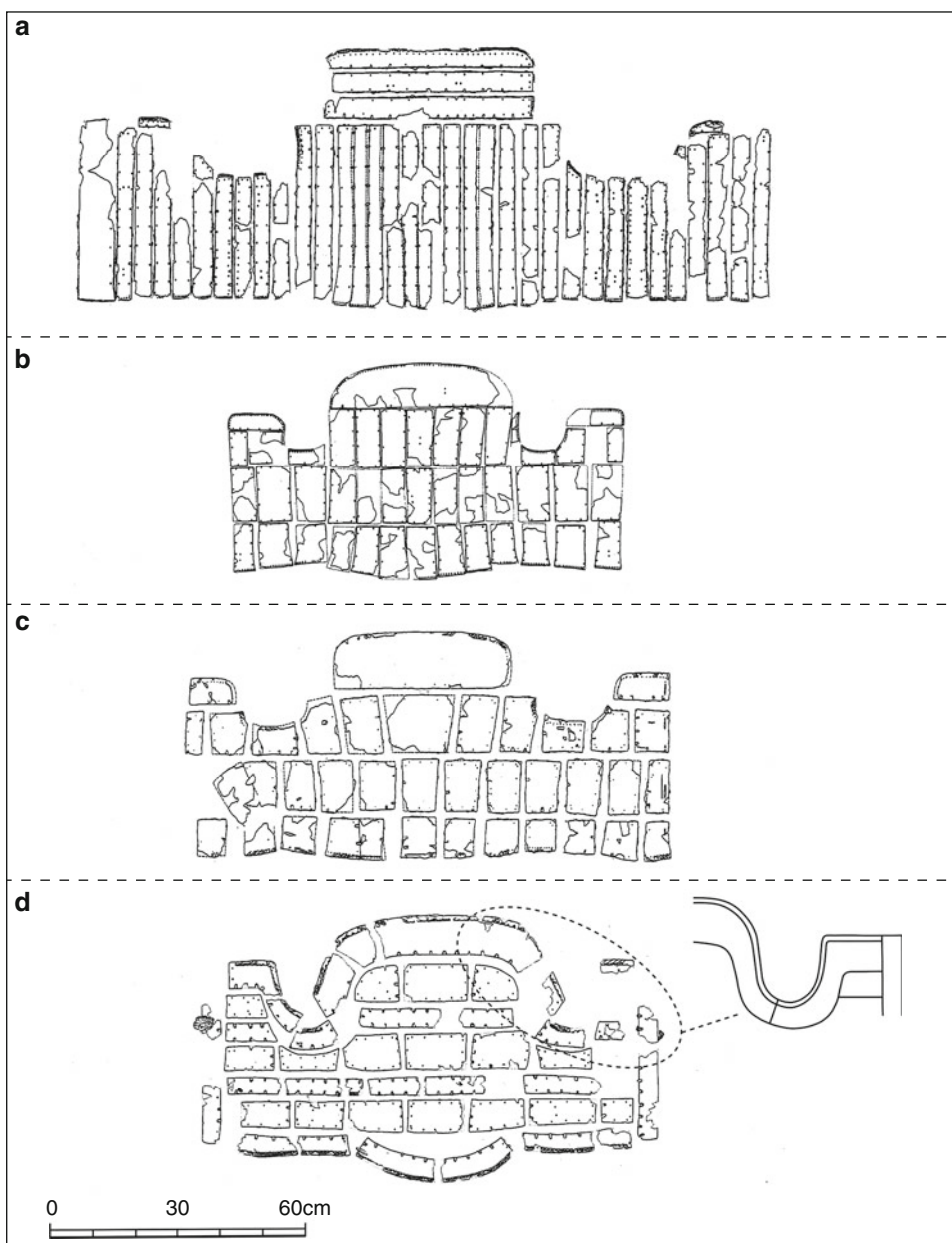


Armor in Japan and Korea, Fig. 4 Typological development of Peninsular vertical-plate armor. (a) Sara-ri Tomb No. 55, Gyeongju, South Korea. (b) Bokcheon-dong Tomb No. 10, Busan, South Korea (a: After

Yeongnam Institute of Cultural Properties, 2007, Figs. 96, 97. b: After Busan University Museum, 1983, Fig. 4)

These early cuirasses are soon replaced by those consisting of short rectangular or square plates laced into horizontal rows (Fig. 5b), 16 examples of which have been excavated from fourth-century tombs. This shift to a horizontal alignment represents a significant technological break from the preceding vertical-plate tradition and has been interpreted as a functional development to accommodate the curvature of

the torso more effectively. While these cuirasses utilize a horizontal alignment, the long side of each plate is situated longitudinally, attesting to their evolution from their vertical-plate predecessors. These cuirasses are also not riveted and lack the base plates, decorative elements, neck guards, and underarm-wrapping frame seen in contemporaneous vertical-plate armor from the Peninsula—thus, they seem likely to be domestic products.



A

Armor in Japan and Korea, Fig. 5 Evolution of the earliest iron cuirasses in the Japanese archipelago (After Sakaguchi, 2010, Fig. 2). (a) Vertical-plate cuirass—Shikinzan Tomb, Osaka, Japan. (b) Horizontally organized plate cuirass (longitudinal alignment of plate edges)—Azuchi-hyōtanyama Tomb, Shiga, Japan.

(c) Horizontally organized plate cuirass (longitudinal alignment weakens)—Inadō Tomb No. 15, Fukuoka, Japan. (d) Horizontally organized plate cuirass in a frame (latitudinal alignment of plate edges)—Ono-ōzuka Tomb, Hyogo, Japan

The existence of horizontally organized examples with weakened longitudinal alignment is worthy of attention (Fig. 5c). This shift to a horizontal alignment of independently laced rows and a weakening of the longitudinal alignment set the stage for a major epoch in Insular iron armor production: the development of the Insular-style frame. All subsequent plate armor is equipped with this frame.

The late fourth-century framed armor (Fig. 5d) consists of rectangular plates positioned with their long sides horizontally aligned. An extensive frame provides enhanced strength and stability; in addition to the underarm-wrapping frame and the base plates, two ranks of narrow metal bands, one between each row of plates, act as supporting ribs. While the first two elements appear in Silla and Gaya examples from the early to mid-fourth century (Fig. 4), the iron bands across the chest and abdomen are an Insular development. Nevertheless, all three elements appear almost simultaneously in the Japanese archipelago at the end of the fourth century.

Shortly after framed cuirass production began, yet still within the late fourth century, cuirasses utilizing triangular plates appeared (Fig. 6a). Early examples utilize equilateral plates. The number of plates per row quickly decreases with a switch to wider obtuse-angle plates. Concerning the production of triangular-plate armor concurrent with rectangular-plate cuirasses, it was long assumed that a curved cuirass would be easier to construct using triangular plates. However, the plates across the underarm, which require the greatest curvature, are mostly rectangular in shape – there are almost no examples of triangular plates used across this area. Sharing the repeating triangle design with numerous ritual artifacts, the sustained use of triangular plates would seem to be the adoption of a magico-symbolic design, rather than a functional consideration (Sakaguchi, 1998). Construction of laced cuirasses continues through the first half of the fifth century.

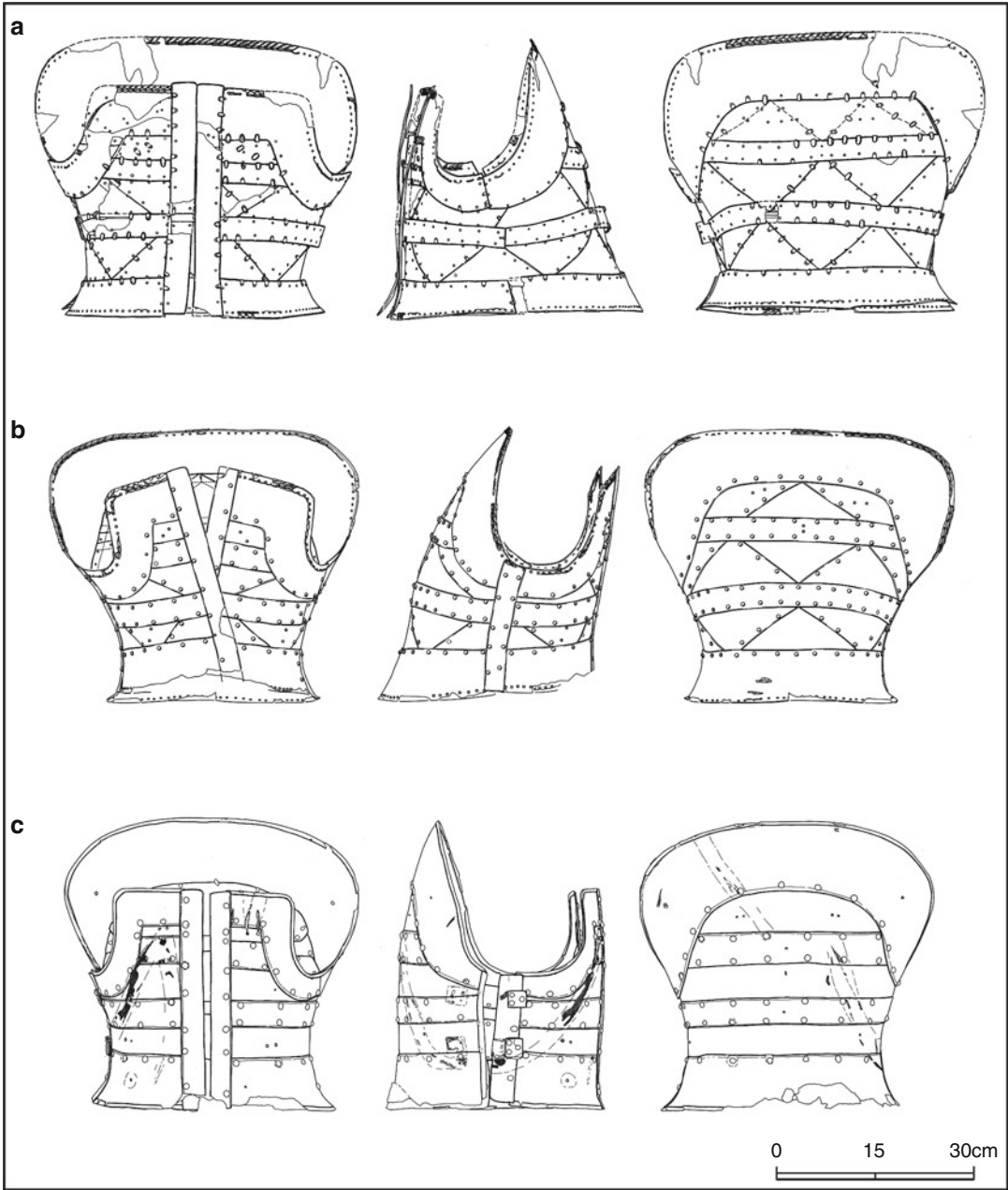
Riveted cuirasses (Fig. 6b, c) appear in the archipelago during the early second quarter of the fifth century, approximately a century after Peninsular examples. While riveting technology was certainly introduced from the southeastern

Peninsula, there are two factors worthy of consideration. Plate-armor production on the Peninsula had all but ended by this time in favor of lamellar armor, and the type of rivets used differed. In contrast to the flat-headed rivets used in Peninsular cuirasses, insular rivets display rounded or conical heads. Similarity with the rivets used in contemporary auxiliary neck protectors and horse trappings offers a clue as to the route of introduction (Sakaguchi, 2008; Tsukamoto, 1993). Rivets did not immediately put an end to leather lacing, however, which is attested by overlap between both types during the mid-fifth century.

The earliest riveted cuirasses had triangular plates (Fig. 6b), suggesting that the new riveting technology was incorporated into the existing armor tradition. In quick succession, however, riveted rectangular-plate cuirasses (Fig. 6c) also appear, most likely developing from the previous laced cuirasses with latitudinally organized rectangular plates (Fig. 5d; Takizawa, 1990). Both styles of riveted cuirasses, however, follow a similar labor-saving trajectory: during the latter half of the fifth century, the number of rivets decreases, the diameter of each rivet head increases, the characteristic horizontal bands become wider, and the use of hinges on the right side of the cuirass becomes standardized (Yoshimura, 1988). Moreover, riveted rectangular-plate cuirasses are found in the greatest number and from the widest spread of tombs, both geographically and sociopolitically; these riveted rectangular-plate cuirasses display striking similarities between cuirasses (Takizawa, 2008), and recent analysis via 3D laser scanning even suggests the possibility of common “blueprints” among the riveted rectangular-plate cuirasses (Yoshimura, 2014). Armor production of the late fifth century is thus considered to have entered a period of mass production. Nevertheless, however, the production of all plate armor is considered to have ended with the close of the fifth century.

Iron Lamellar Armor

Approximately 100 lamellar suits have been unearthed in the Korean Peninsula. Kofun-period



Armor in Japan and Korea, Fig. 6 Iron plate armor from the Japanese archipelago. (a) Triangular-plate-laced cuirass (Toshinokami Tomb, Hyogo, Japan) (After Hyogo Prefectural Board of Education, 2002, Figs. 10, 11). (b) Triangular-plate-riveted cuirass (Ono-ōzuka Tomb,

Hyogo, Japan) (After Ono City Board of Education, 2006, Fig. 31). (c) Rectangular-plate-riveted cuirass (Marozuka Tomb, Kumamoto, Japan) (After National Museum of Japanese History, 2012, Figs. 44, 46, 47)

Armor in Japan and Korea, Table 1 Lamellar armor traditions of East Asia

			Imbrication	Waist			Alignment		Hem		
				1	2	3	A	B	1	2	3
Continent											
	Han		Inward	—	—	—	●	—	—	—	—
	Three Yan/ Goguryeo		Outward	●	●	—	●	—	—	—	—
	Baekje		Outward	●	?	○	●	—	—	—	○
	Gaya/Silla	4c	Outward	●	—	—	●	—	—	—	—
		Late 4c- 5c	Outward	○	●	○	●	○	●	—	○
	Peninsular standard:		Outward	—	●	—	●	—	●	—	—
Insulae											
	Early 5c		Outward	○	○	—	○	—	○	—	—
	Late 5c		Outward	—	○	●	○	●	●	—	●
	Insular standard:		Outward	—	—	●	—	●	—	—	●

—: Not present in the armor tradition ○: Not dominant ●: Dominant

While various types existed within each region, only the characteristic or dominant types are represented above. A certain type's exclusion from the chart does not signify its nonexistence, but simply that it was not the most well attested.

“Alignment” here refers to waist lamellae; in the case that waist lamellae are not present in the armor tradition, it refers to the majority of body lamellae.

“?” indicates that the type has not yet been found, but its discovery may be expected.

lamellar suits unearthed from the Japanese Islands number approximately 200 (although the majority of these date to the sixth century) (Table 1).

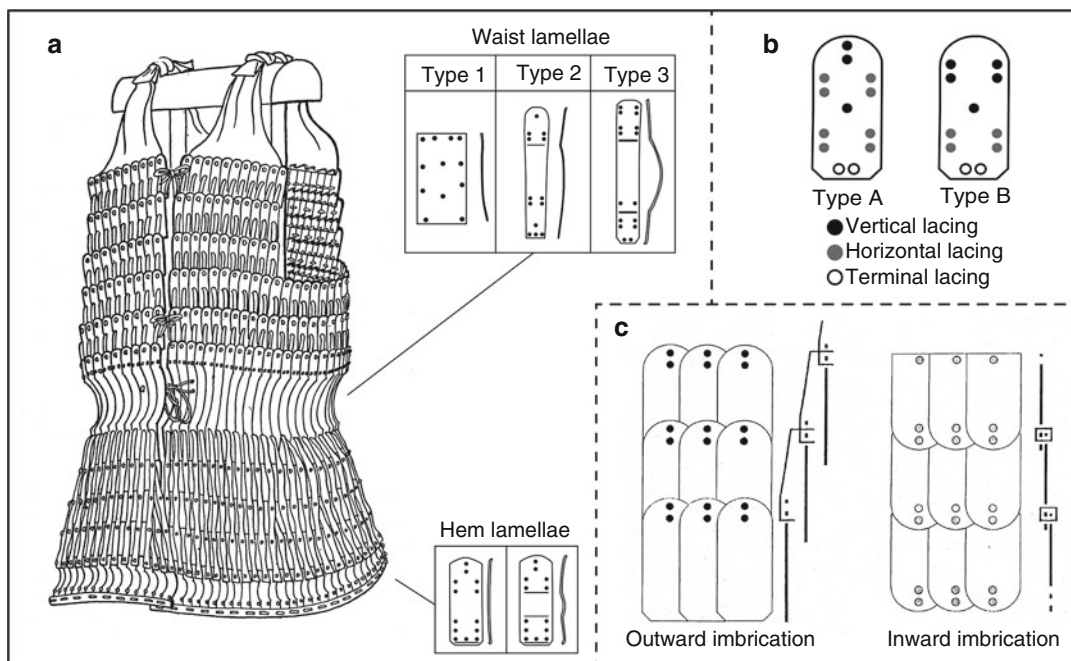
Outward-imbricating lamellae (Fig. 7c) are normally laced only through the head, progressively moving away from the wearer's body. There are examples of outward-imbricating lamellae laced at both ends in the Chinese tradition. These appear to have comprised auxiliary protectors, which required much more flexibility than body armor. As this entry focuses on body armor, outward imbrication will here refer to lamellae laced solely through the head. In contrast, inward-imbricating lamellae are laced at both ends and progressively move toward the body. This difference has a significant effect on wearability, with the former being much more flexible than the latter.

Lamellae situated around the waist tend to be of a different size and construction (Fig. 7a, inset). Based on their cross section, they can be

roughly divided into straight or slightly outward curving (Type 1), S shaped (Type 2), and Ω shaped (Type 3). Additionally, lamellae are laced together horizontally utilizing pairs of holes located along the lamellae edges; the holes used for lacing vertical columns of lamellae are located at the head (Fig. 7b). While older lamellae have only one row of hole(s) for this purpose located in the center of the head (Type A), newer lamellae may have two rows located on either side of the head (Type B).

Lamellar Armor, Korean Peninsula

Dating to around the turn of the Common Era, the earliest finds of iron lamellae concentrate in the central Peninsula (Fig. 8a) and are accompanied by artifacts betraying strong Han influence through the Lelang commandery (Shimizu, 1996; Morikawa, 2008; Yi, 2014). Subsequent finds through the second century also display similarities in lamella shape and hole placement (including Type A placement) to Han examples.



Armor in Japan and Korea, Fig. 7 Lamellar armor. (a) Major types of waist and hem lamellae (After Suenaga, 1944, Fig. 8). (b, c) Examples of lacing holes and styles (After Shimizu, 1996, Figs. 1, 3)

Discoveries of actual Goguryeo armor are sparse and most treatments rely on tomb murals. Several scattered finds dating back to the late third century, however, hint at when lamellar armor first appeared in the region. While there is a dearth of Goguryeo materials until Type 2 waist lamellae dated to the mid-fifth century appear, the neighboring lower Manchurian Basin has proven useful in filling in this gap. This area was occupied by three successive states of the Murong Xianbei, often referred to as the Three Yan, during the Sixteen Kingdoms period (304–439). Type 2 waist lamellae with Type A hole placement appear in the first half of the fourth century in Former Yan tombs. Type 1 waist lamellae have been uncovered from contemporaneous tombs, suggesting that Type 2 waist lamellae did not completely replace Type 1 examples. Judging by the mid-fourth-century mural discovered inside Tomb No. 3 at Anak and subsequent fifth-century excavated materials, outward-imbricating suits became standard in the equestrian cultures of both Goguryeo and

the Three Yan. Similarities in the lamellae morphology of both also suggest a common armor tradition.

Examples of iron armor from Baekje territory are also limited. Type 1 waist lamellae with Type A hole placement dating to the late fourth century are the oldest confirmed find and display technological influence from the Three Yan (and presumably Goguryeo). Subsequent finds from the fifth and sixth centuries continue to display similarities with northern examples. In the first half of the sixth century, however, lamellar suits incorporating design elements from the Japanese archipelago (Type 3 waist lamellae with Type 3 hem lamellae) appear accompanied by Kyushu-style stone chambers, revealing the diverse nature of Baekje foreign relations.

In contrast, the Silla and Gaya regions offer a relatively large amount of material for analysis. Local production of iron lamellar and plate armor began in the early fourth century; one of the earliest examples of both has been found at

Bokcheon-dong Tomb No. 38. The lamellae are Type 1 waist lamellae with Type A alignment. Throughout the fourth century and into the early fifth century, Type 1 waist lamellae are dominant. From the late fourth century through the late fifth century, Type 2 are found throughout these regions. While few in number, Type B hole placement is seen from the early fifth century. Its advent is believed to represent increased flexibility. Type 3 waist lamellae appear in the latter fifth century and are often paired with Type B holes. The evolution of Type 3 waist lamellae from Type 2 is believed to represent a significant functional development. Not only did it bring the suit snug against the waist, decreasing unnecessary movement (Hatsumura, 2011), it also served to decrease friction against the inner lacing of the lower lamellae (Shimizu & Takahashi, 1998). While the handful of known examples of Type 3 present strong ties to the Japanese archipelago, early transitional examples may eventually be found in the southeastern Peninsula.

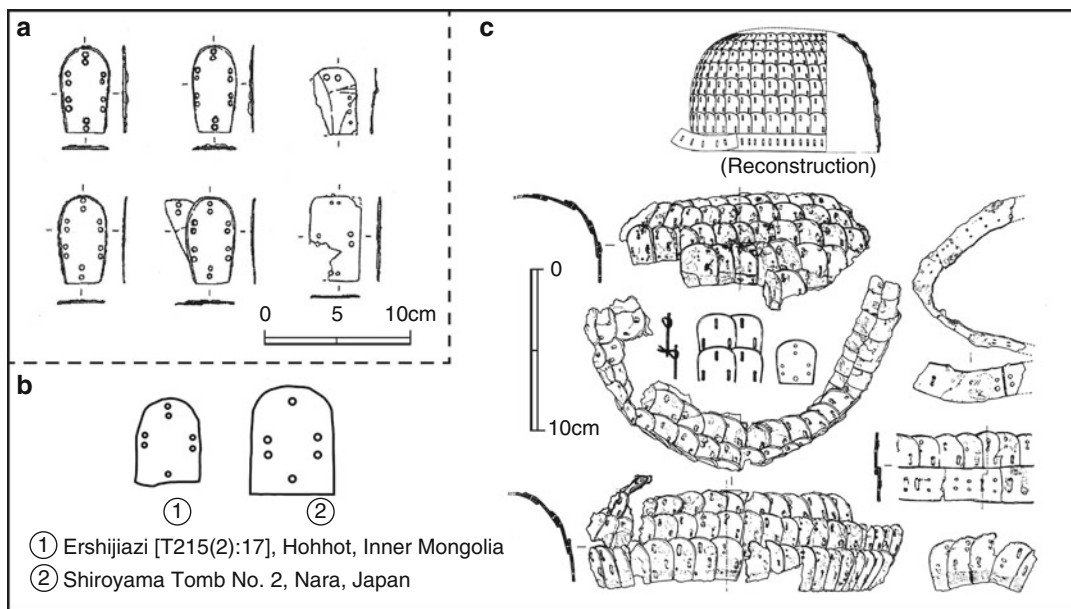
To summarize, the fourth-century appearance in Three Yan and Goguryeo territory of outward-imbricating suits with Type 2 waist lamellae represents a major technological break from the previous sporadic finds of Han-style lamellae, which were traditionally laced at both ends and used inward imbrication. The horse-riding culture of this region is believed to have necessitated this development. Type 2 waist lamellae subsequently appear in the southern Korean Peninsula from the late fourth century, more or less replacing Type 1 waist lamellae. Furthermore, Type 3 waist lamellae date from the latter fifth century and are often paired with Type B hole placement. Nevertheless, Type 2 waist lamellae with Type A hole placement and Type 1 hem lamellae remain the standard combination throughout the fifth century. Additionally, lamellae comprising one suit decrease in size and greatly increase in number in the fifth century. After the late fifth century, however, the burial of armor and weapons all but disappears from Goguryeo, Baekje, and Silla, attending changes in mortuary ritual. However, the burial of armor continued for a time in the

Yeongsan River Basin of the southwestern Peninsula and in Gaya territory.

Lamellar Armor, Japanese Archipelago

Lamellar armor in the Han tradition first appeared in the archipelago in the late third and fourth centuries (Fig. 8c). There are 14 lamellar helmets and 2 lamellar suits (Hatsumura, 2011; Uchiyama, 2008). While lamella shape and hole placement are almost identical to late Western Han examples (Yang, 1985, 2000, Fig. 8b), the significant temporal gap and lack of viable contemporaneous examples from China warrant caution. Nevertheless, these early lamellar examples from the archipelago can no doubt be placed within the Chinese tradition and were most likely introduced after Queen Himiko sent a diplomatic mission in 239 CE to the successor of the Han, the Wei Dynasty (220–265 CE), and the Japanese archipelago was subsequently incorporated into the Wei geopolitical investiture system. Lamellar armor makes its next appearance in the second quarter of the fifth century. Following the limited appearance of Type 1 and Type 2 waist lamellae (which are similar to those of the southeastern Peninsula), domestic production is believed to have come into full swing in the late fifth century. The majority of suits have Type 3 waist lamellae with Type B hole placement and Type 3 hem lamellae – in stark contrast to the standard Peninsular combination of Type 2 waist lamellae with Type A hole placement and Type 1 hem lamellae. The suits of the Japanese Islands display a high level of standardization.

The introduction of lamellar armor has traditionally been interpreted as signaling the spread of horse-riding culture and the establishment of an equestrian elite. An analysis of the earliest lamellar armor and horse trappings in the archipelago, however, reveals they are not discovered together; approximately half a century passes before they appear together with any frequency. Moreover, the common assumption that lamellar armor was for equestrian and plate armor was for foot soldiers has also been called into question. Of fifth-century tombs, horse trappings are found paired with lamellar armor in 31 tombs and plate armor in 83 tombs (Hashimoto, 2010).



Armor in Japan and Korea, Fig. 8 Earliest examples of Pen/Insular iron lamellae. (a) Lamellae from the Daeseong-ri site in Gapyeong, South Korea (After Bokcheon Museum, 2010, Figs. I-1~4). (b) Comparison

between Han-style and Insular lamella (Redrawn from Yang, 1985, Fig. 12). (c) Lamellar helmet from Tsubai-ō tsukayama Tomb, Kyoto, Japan, with reconstruction (After Umehara, 1964, Figs. 15, 16)

Conclusion

A symbol of the elite, Pen/Insular iron armor was imbued with sociopolitical importance and characterized by strong regional variation. As with weapons and horse trappings, iron armor is highly instructive of international relations in ancient East Asia. The meticulous typological and technological research conducted by Japanese and Korean archaeologists has enabled reconstructions of these relations on an unprecedented level.

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Āryabhaṭa

R. C. Gupta

Āryabhaṭa (b. AD 476) was a celebrated astronomer and mathematician of the classical period of the Gupta dynasty (AD 320 to ca. 600). This era is called the Golden Age in the history of India, during which Indian intellect reached its high water mark in most branches of art, science, and literature, and Indian culture and civilization reached a unique stage of development which left its deep impression upon succeeding ages. Āryabhaṭa played an important role in shaping scientific astronomy in India. He is designated as Āryabhaṭa I to differentiate him from Āryabhaṭa II, who flourished much later (ca. AD 950–1100) and who wrote the *Mahāsiddhānta*.

Āryabhaṭa I was born in AD 476. This conclusion is reached from his own statement in the *Āryabhaṭīya*: “When sixty times sixty years and three quarters of the *yuga* (now *Mahā*) had elapsed, twenty three years had then passed since my birth” (III, 10).

Since the present *Kaliyuga* (the last quarter of the *Mahāyuga*) started in 3102 BCE, Āryabhaṭa was 23 years old in 3600 minus 3101, that is in AD 499. The exact date of birth comes out to be March 21st, when the Mean Sun entered the zodiac sign of Aries in AD 476. The significance of mentioning AD 499 is that the precession of equinoxes was zero at the time, so that the given planetary mean positions did not require any correction. According to some commentators, AD 499 was also the year of composition of the *Āryabhaṭīya*.

We have no knowledge about his parents or teachers, or even about his native place. Āryabhaṭa composed the *Āryabhaṭīya* while living at Kusumapura, which has been identified as Pāṭaliputra (modern Patna in Bihar State), the imperial capital of the Gupta empire. It is possible that Āryabhaṭa headed an astronomical school there.

The association of Patna, where Āryabhaṭa taught and wrote on mathematics and astronomy, with his professional career, does not settle the question of his birthplace, but it may have been a place where he was educated.

Āryabhaṭa's fame rests mainly on his *Āryabhaṭīya*, but from the writings of ► *Varāhamihira* (sixth century AD), ► *Bhāskara I*, and ► *Brahmagupta* (seventh century), it is clear that earlier he composed an *Āryabhaṭa Siddhānta*. Although voluminous, the *Āryabhaṭa Siddhānta* is not extant. It is also called *Ārdharātriṅka Tantra*, because in it the civil days were reckoned from one midnight to the next. Its basic parameters are preserved by Bhāskara I in his *Mahābhāskariya* (Chap. VII). Rāmakṛṣṇa Ārādhyā (AD 1472) has quoted 34 verses on astronomical instruments from the *Āryabhaṭa Siddhānta*, of which some were devised by Āryabhaṭa himself.

The *Āryabhaṭīya* is an improved work and the product of a mature intellect. Considering the genius of Āryabhaṭa, it is easy to agree with the view that he composed it at the age of 23. The date is also in fair agreement with the recent research and analysis by Roger Billard. Unlike the *Āryabhaṭa Siddhānta*, the civil days in the *Āryabhaṭīya* are reckoned from one sunrise to the next – a practice which is still prevalent among the followers of the Hindu calendar. The *Āryabhaṭīya* consists of four sections or *pādas* (fourth parts):

1. *Daśagītikā* (10 + 3 couplets in Gīti meter)
2. *Gaṇitapāda* (33 verses on mathematics)
3. *Kāla-kriyāpāda* (25 verses on time-reckoning)
4. *Golapāda* (50 verses on spherical astronomy)

That the *Āryabhaṭīya* was quite popular is shown by the large number of commentaries written on it, from Prabhākara (ca. AD 525) through ► *Nīlakaṇṭha Somayājī* (ca. 1502) to Kodanḍarāma (ca. 1850).

An Arabic translation of the *Āryabhaṭīya* entitled ► *Zīj al-Ārjabhar* was made in about 800, possibly by al-Ahwāzī. In spite of the *Āryabhaṭīya*'s popularity, H. T. Colebrooke failed to trace any work of Āryabhaṭa anywhere in India.

The use of modern scientific methodology, as described by Roger Billard in his *L'astronomie indienne*, along with new ephemerides, clearly shows that both of Āryabhaṭa's major works were based on accurate planetary observations. In fact, the use of better planetary parameters, the innovations in astronomical methods, and the concise style of exposition rendered the *Āryabhaṭīya* an excellent textbook in astronomy. In opposition to the earlier geostationary theory, Āryabhaṭa held the view that the earth rotates on its axis. His estimate of the period of the sidereal rotation of earth was 23 h, 56 min, and 4.1 s, which is quite close to the actual value.

Āryabhaṭa has been also considered the father of Indian epicyclic astronomy. The resulting new planetary theory enabled Indians to determine more accurately the true positions and distances of the planets (including the sun and the moon). He was the first Indian to provide a method of finding celestial latitudes. He also propounded the true scientific cause of eclipses (instead of crediting the mythological demon Rāhu). In fact his new ideas gave rise to the formation of a new school of Indian astronomy: the Āryabhaṭa School or *Āryapakṣa*, for which the basic text was the *Āryabhaṭīya*.

Exposition and computation based on the new astronomical theories were made easy by Āryabhaṭa, because of the development of some mathematical tools. One of them was his own peculiar system of alphabetic numerals. The 33 consonants of the Sanskrit alphabet (Nāgarī script) denoted various numbers in conjunction with vowels which themselves stood for no numerical value. For example, the expression *khyughr* (= *khu* + *yu* + *ghr*) denoted

$$2 \times 100^2 + 30 \times 100^2 + 4 \times 10^3 = 4,300,000,$$

which is the number of revolutions of the sun in a Yuga.

The development of Indian trigonometry (based on sine instead of chord, as the Greeks had done) was another of Āryabhaṭa's achievements which was necessary for astronomical calculations.

Because of his own concise notation, he could express the full sine table in just one couplet, which students could easily remember. For preparing the table of sines, he gave two methods, one of which was based on the property that the second order sine differences were proportional to sines themselves.

Āryabhaṭa seems to have been the first to give a general method for solving indeterminate equations of the first degree. He dealt with the subject in connection with the problem of finding an integral number N which will give a remainder r when divided by an integer a , and s when divided by b . This amounts to solving the equations

$$N = ax + r = by + s.$$

Although at present the topic of indeterminate analysis comes under pure mathematics, in ancient times it arose and was used for practical and astronomical problems. In fact, Āryabhaṭa successfully used his theory of indeterminate analysis to determine a mean conjunction of all planets at the zero mean longitude at the start of the *Kaliyuga* (3102 BCE). Recently it has been shown that his algorithm solves more general problems than the Chinese remainder theorem, and works irrespective of the sign of numbers.

The solution of a general quadratic equation and the summation of certain series were some other algebraic topics dealt with by Āryabhaṭa. The methods of adding an arithmetical progression were known in all ancient cultures, but he was perhaps the first to supply a general rule for finding the number of terms (n) when the first term (a), the common difference (d) and the sum (s) were given. His solution is a root of the quadratic equation

$$dn^2 + (2a - d)n = 2s,$$

which comes from the usual formula for the sum of an arithmetical progression.

In geometry, his greatest achievement was an accurate value of π . His rule amounts to the statement

$$dn^2 + (2a - d)n = 2s.$$

This implies the approximation 3.1416 which is correct to its last decimal place. How he arrived at this is not known.

From what we know about Āryabhaṭa, it is clear that he was an outstanding astronomer and mathematician. His scientific attitude, rational approach, and mathematical methodology ushered in a new era in the history of the exact sciences in India. It was quite befitting that the first Indian satellite launched on the 19th April 1975 was named Āryabhaṭa.

See Also

- ▶ [Astronomy: Indian Astronomy in China](#)
- ▶ [Mathematics in India](#)
- ▶ [Trigonometry in Indian Mathematics](#)

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Asada Goryu

Nakayama Shigeru

Asada Goryu (1734–1799) was a Japanese astronomer who was instrumental in turning Japanese astronomy and calendrical science away from the traditional Chinese style and toward Western models.

In adopting the traditional idea of secular diminution of tropical year length, astronomers at the time were required only to account for the ancient records and modern data of Chinese solstitial observations by a single formula. Classical Western data, such as those listed in the *Almagest* of Ptolemy, became available to Asada through the Jesuit treatises. He endeavored to synthesize Western and Chinese astronomy and to give a numerical explanation, by means of a single principle, of all the observational data available to him – old and new, Eastern and Western.

Copernicus appears in the Sino-Jesuit treatises, not as an advocate of heliocentrism but as an observational astronomer and the inventor of the eighth sphere of trepidation. He is said to have believed that the ancient tropical year was longer than that of the Middle Ages, which in turn was shorter than the contemporary constant. Asada, perhaps struck by this passage, formulated a modified conception in which the length of the ancient tropical year tended to decrease until it reached a minimum in the Middle Ages and to grow longer afterward, varying in a precession cycle of 25,400 years.

It is apparent that what Asada really intended to do was account for the newly acquired Western data. His basic goal, that of “saving the ancient records” by numerical manipulation, differs not at all from that of the traditional approach. His consideration of the precession cycle was theoretical decoration.

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Astrolabe

Julian A. Smith

The astrolabe is a portable wooden or metal astronomical instrument which is used to measure the positions and altitudes of celestial bodies, to find the observer's time or latitude, or to solve other mathematical problems. In its complete form, it consists of a main body, or flat plate (“mater” or “mother”) to which is attached a series of smaller plates (called climates) engraved with various coordinate lines, according to various latitudes. An alidade, a rotatable straight rule with sights used to find altitudes, is fastened to the back. Attached to the front, above the climates, is a smaller fretted circular plate called the rete – this is a moveable map of the heavens, with pointers indicating various stars. The whole rotating assembly is fastened together by a pin through the center of the mater and climates, and it is secured at the top by a wedge-shaped piece of metal called the horse, after its fanciful resemblance to a horse's head.

To use the astrolabe, an observer would typically rotate the alidade until a star became visible through the sights, and then read its

altitude in degrees from a scale on the back of the instrument. Then one would turn the rete until that star corresponded to the almucantar (curves representing parallels to the horizon) for the right altitude. The time could then be determined from the place of the “sun” on the instrument. Astrolabes could measure solar time, sidereal time, and time in unequal hours, depending on how the hour lines were marked.

Although the astrolabe is usually considered an Arabic invention, its true roots go back to the mathematical astronomers of ancient Greece – the word itself comes from the Greek terms for a “star-taking” instrument. Engraving great circles and hour lines demanded considerable skill – in essence, the instrument-maker had to collapse a three-dimensional celestial sphere into the flat, circular plane of the astrolabe. Some historians attribute this discovery to Appolonius of Perga (ca. 262–ca. 190 BCE), but according to Otto Neugebauer, the planispheric or stereographic projection of the heavens upon a flat surface was first accomplished by Greek astronomer Hipparchus of Nicea/Rhodes (ca. 190–ca. 120 BCE). In addition, Hipparchus may have built simple astrolabes, consisting of solid sky maps covered with open networks of lines. Finally, he is credited with developing the projection for an anaphoric clock, an ancestor of the astrolabe. This is an axle with a large circular star map, laid out in a stereographic projection – attached to it is a smaller stationary grill showing the projection of the horizon, and a visible hemisphere for a given latitude. The dial is powered by a clepsydra, and as it rotates, a model of the sun traces out the hours of the day. The anaphoric clock was described by Roman engineer Vitruvius (ca. 25 BCE), and may have been built in the famous Athenian “Tower of the Winds” around 50 BCE.

The first clear descriptions of the construction of the astrolabe occur in the *Planisphere* of Alexandrian astronomer Claudius Ptolemy (ca. 150 AD). By this time, the complexity of various lines had made the astrolabe’s covering bulky, a problem Ptolemy solved by switching the lines to the mater and the star map to the rete.

The astrolabe was further developed in the works of Greek mathematician Theon (fl. AD 360–380), now lost, and John Philoponus (fl. 520), both of Alexandria. Syrian Severus Sebokht (fl. 630) also wrote an early treatise on the astrolabe.

Medieval Islamic scientists took the basic planispheric astrolabe of Hellenistic astronomers and improved it dramatically between AD 700–1500, applying it to questions of astronomy, surveying, mathematics, geography, and much more. In AD 843, Baghdad mathematician ► [al-Khwārizmī](#) (fl. AD 810–850) claimed his astrolabe could solve 43 problems – a century later, Persian astronomer al-ṣūfī (AD 903–986) said that it could answer a thousand astronomical questions. David King divides Arabic astrolabe innovations into five basic categories: the making of tables, nonstandard retes, qiblas, multiple climates, and the development of three new forms of the instrument.

Astronomers like ► [al-Farghānī](#) of Baghdad (ca. 830–ca. 861) compiled numerical tables of radii and center distances of both azimuth and almucantar circles for every degree of latitude and azimuth, for every terrestrial latitude. These tables, which exceeded 13,000 entries, were used extensively by Arabic astronomers alongside geometric projections to construct astrolabes for different latitudes. Islamic astronomers also constructed nonstandard retes, which would symmetrically represent the otherwise dissimilar northern and southern halves of the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course). The Oxford myrtle astrolabe is an example.

Arabic astrolabists inscribed specific markings on their instruments, corresponding to Islamic prayer times and directions. By the thirteenth century, they engraved lists of cities with latitudes, longitudes, and Mecca directions, known as qiblas – this would help observers orient themselves for prayers. Arabic astrolabes also developed multiple plates or climates, giving astronomical tables usually found in handbooks or textbooks. An early example is referred to by ► [Abū Jaʿfar al-Khāzin](#) (d. 961/971).

Finally, Islamic scientists developed at least three new types of instrument: the linear, universal and geared astrolabes. The linear astrolabe consists of a series of scales on a stick which represents the meridian for a given latitude, to which are attached a series of threads through which one can perform all the standard operations of an astrolabe. This was invented by Iranian mathematician ► [Sharaf al-Dīn al-Ṭūsī](#) (d. ca. 1213), and was known as “al-Ṭūsī’s cane.” The universal astrolabe was developed by Ḥabash of Baghdad (d. ca. 864–874), and Alī ibn-Khalaf (al-Shakkāz) in Toledo in the eleventh century, who devised a special shakkaziya plate for it. Though powerful, it was not widely known, and was reinvented in early fourteenth century Syria. This astrolabe could determine the risings, culminations, and settings of celestial bodies at all latitudes using a single plate. Astronomer al-Zarqāllū (Azarquiel) of Toledo (ca. 1029–1087/1100) simplified this by replacing the rete with an alidade having a movable cursor, and by putting the ecliptic and star pointers on the shakkaziya plate. Geared astrolabes contained complex mechanisms to reproduce the motion of the sun and moon mechanically – their date of invention is unknown, but they were described by Persian astronomer ► [al-Bīrūnī](#) (ca. 973–1048).

The astrolabe was reintroduced into Europe from the Arabs by the tenth century. Gerbert of Aurillac, Pope Sylvester II (ca. 945–1003), imported much astronomical knowledge into the medieval Latin west from Islamic sources, and may have used the astrolabe as a teaching tool. Meanwhile, Hermannus Contractus (1013–1054) transmitted many Arabic concepts in his two influential Latin treatises on the astrolabe: *De Mensura Astrolabii* and *De Utilitatibus Astrolabii*. Ptolemy’s *Planisphere* was translated by Hermann the Dalmatian in the twelfth century, and in 1276, an influential Arabic astrolabe treatise by the Egyptian Jew Māshā’allāh (fl. 762-ca. 815) was translated into Latin, where it formed the basis for the first English book on the

astrolabe, by poet Geoffrey Chaucer (ca. 1340-ca. 1400) in 1391.

Though the astrolabe was widely developed in Arab countries, it was virtually ignored in the East. Joseph Needham says that Chinese astronomers made no astrolabes of their own, though they did develop the anaphoric clock independently. The reasons are twofold: Chinese scientists instead developed sophisticated ► [globes](#) and armillary spheres quite early, and they lacked the analytical techniques in their mathematical astronomy which led to the stereographic projection in the West. Needham suggests the astrolabe was imported to China from Persia in 1267 by the Maraghan Observatory astronomer Jamāl al-Dīn ibn Muḥammed al-Najārri, but the mathematical projections remained obscure until the arrival of the Jesuits in the sixteenth century.

Indian scientists also borrowed the astrolabe from Islamic sources. Astronomer ► [Bhāskara II](#) (1114-ca. 1184) used spherical astronomy to construct a wheel-like instrument, called the *phalaka yantra*, which essentially served the same purpose as a primitive astrolabe. However, the true planispheric astrolabe, the *ustaralava*, was first imported by Muslims in the thirteenth century – a Damascus astrolabe of 1204 is still preserved in the Rampur State Library. The astrolabe was described in detail in the *Yantrarāja* of ► [Mahendra Sūri](#) in 1370 – this work is based on Islamic sources. Lahore later became a center for its construction, under families of instrument makers like those of Shaikh Allāh-Dād (fl. 1570–1660). Indian astronomers also developed some of the largest astrolabes in the world. The great brass astrolabe at the Jaipur observatory of Sawai Jai Singh (1686/1688–1743) is 3 m tall, 2.12 m across, and weighs over 400 kg. Jai Singh’s *Yantrarājaraṇā* also gives instructions for astrolabe construction based on stereographic projections.

The astrolabe was popular as an astronomical instrument until long after the introduction of the telescope in the early seventeenth century. It survived another century, until it was replaced in the 1730s by English astronomer

John Hadley's (1682–1744) reflecting quadrant, a precursor to the sextant.

See Also

- ▶ Abū Ja'far al-Khāzin
- ▶ al-Farghānī
- ▶ al-Khwārizmī
- ▶ Al-Bīrūnī
- ▶ Al-Šūfī
- ▶ Astronomical Instruments in the Islamic World
- ▶ Bhāskara I
- ▶ Ibn Al-Zarqāllu
- ▶ Jai Singh
- ▶ Mahendra Sūri
- ▶ Māshā'allāh
- ▶ Qibla and Islamic Prayer Times
- ▶ Sharaf al-Dīn al-Ṭūsī

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Astrology in Babylonia

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Astrology remains a feature of popular culture in the modern west. Most histories of the subject, from Thorndike (1923–1958) to Tester (1987), assume a fundamental conceptual and technical break between Babylonian and Greek astrology in the last centuries BCE and that western astrology also effectively came to an end in the late seventeenth century, when it lost its intellectual respectability. The Encyclopaedia of Religion (Culianu, 1987, p. 472) states categorically that “astrology, a product of Hellenistic civilisation, appeared at the end of the third century BCE,” completely denying any Mesopotamian connection. Chambers' Encyclopaedia is more circumspect, considering that “It was in Greece, about the fourth century BCE that astrology underwent a great development and was regarded as regulating all things in the universe, including the fates of men (1970, p. 724).” However, while it is clear that astrology, like any other belief system, experiences periods of reinvention as it passes between different cultures and periods, it is possible to identify a fundamental continuity from the earliest Babylonian astrology to the present day. Contemporary popular astrology may therefore be seen as a remarkable revival of the practical applications of an ancient

non-western astronomy: that of Mesopotamia of 4,000 years ago (Campion, 2012). Recent scholarship includes Rochberg's work on horoscopes (1998), the collection of papers by Steele and Imhausen (2002), Steele's work on calendars (2007), general histories by Brown (2000a) and Rochberg-Halton (2004), and the discussion in Campion (2009, pp. 35–86).

Mesopotamian Astrology

The civilizations of Mesopotamia flourished between 2,000 and 5,000 years ago. Like many societies, they adhered to the belief that the terrestrial, physical, and human worlds were so intimately connected to the celestial, intangible, and divine realms as to effectively constitute a single entity. The natural environment, it was believed, provided the principal means of communication between humanity and the pantheon of invisible gods and goddesses. From this sense that the entire world was alive, there developed various means of reading divine intentions; for example, the practice of omen (from the Latin meaning "sign") divination relied on the assumption that any visible natural phenomenon, whether predictable or not, might represent an attempt by a god or goddess to communicate their intentions or instructions to humanity.

Divination took on many forms, from the rolling of dice to the royal reliance on extispicy, or divination from the livers. Gradually, over the second millennium BCE, astrology (the divinatory use of celestial phenomena) appears to have grown in importance. As it did so, it encouraged the increasing observation of planetary and stellar patterns and ultimately, by the seventh to eighth centuries BCE, their extrapolation into the future. Thus, by the time that the Greek astronomers first began to speculate on the nature of the heavens, the Mesopotamian astrologers had made the crucial transition from a purely observational astronomy to one which was both mathematical and predictive.

There are a number of very good reasons for studying the history of Mesopotamian astrology. Firstly, it offers a point of entry into understanding Mesopotamian culture. Then there is the

question of the astronomical records, which were not only used by the ancient Greeks but are of relevance for modern science. The use of eclipse records to demonstrate that the slowing in the Earth's rotation is much greater than previously thought is ample demonstration of the value of such ancient observations (Stephenson, 1998). But there is also the vexed question of the connections between the endeavors of Babylonian astronomers and astrologers and their counterparts in the Greek world and the extent to which classical culture borrowed from the Mesopotamians. Such issues run to the heart of European respect for the Greeks as inventors of the western rational and scientific tradition and raise deep questions concerning European self-identity and ambivalent relationship between the Occident and Orient. At the broadest level then, we are not just examining the history of culture or science but also touching on issues which are alive today as they ever were.

Babylonian astrology can be described as practical theology, its express function being to enhance dialogue with the gods. Bartel van der Waerden set out a seductively neat scheme in which the development of the first millennium BCE astronomy and astrology is related to a steady drift towards monotheism. He identified three main phases in which religion, astronomy, and astrology progressed together from the simple observational astronomy, stellar polytheism, and omen astrology of the beginning of the first millennium to the monotheistic religion, mathematical astronomy, and natal astrology of its end (1974, vol. II, pp. 127–128, 178). This is a point of view challenged by many historians of religion, and as applied to Mesopotamia, the supposed connections between astronomy and religion are roundly rejected by some scholars. At the very least, van der Waerden's generalizations provide a worthwhile interdisciplinary model for approaching developments in the history of astronomy.

Questions of Definition

The interlocking relationship between Mesopotamian astrology and astronomy has a particular

relevance to contemporary debates on the nature of science and perceptions of its relationship with “superstition” or “rational” and “magical” thought. Indeed, no study of Mesopotamian astrology can begin until we have at least acknowledged such questions of definition (Bottéro, 1992, pp. 125–137). Modern comparisons may counter a natural tendency to see ancient cultures as being so inherently different to our own that they can never be approached. All we can do is remember that our descriptions of Mesopotamian thought can never entirely recapture its true nature.

Whereas modern definitions generally categorize astronomy, the observable measurement of the heavens, as scientific, and astrology, the interpretation of those measurements, as superstitious, the Mesopotamian experience suggests that those definitions are fluid and might even be reversed. For the sake of simplicity, I shall stick to modern usage, and I shall use astronomy when talking specifically about measurement of the heavens and astrology when discussing the interpretation of those measurements.

The final problem of definition concerns the alternative use of the terms Mesopotamian and the more common Babylonian. Mesopotamia is a geographical designation for much of the area is covered by modern Iraq. Between the mid-third millennium and the end of the first millennium BCE, the region passed through a series of political eras from the period of the city states of Sumer and Akkad through the Babylonian and Assyrian empires, a second Babylonian Empire, and finally the Persian and Greek Seleucid periods. Given that Babylon appears to have retained a special cultural status from around 1800 BCE onwards, the terms Babylonian and Mesopotamian are often used interchangeably to describe the astrology of the entire region (Koch-Westenholz, 1995).

Translation Issues

There are substantial source difficulties in this field, largely due to the sheer volume of primary source material which has either only recently become available or is yet to be translated. The difficulties involved in working out what the

Mesopotamians actually thought, though, are genuinely problematic. Even slightly differing nuances between different translations can suggest entirely different conclusions. For example, one version of the moon’s function in the creation epic – the *Enuma Elish* (V.13), “When Above” – is “to make known the days” (Heidel, 1942, pp. 44–45), while another is “to measure time” (Jacobsen et al., 1946, p. 181). The latter expands the use of the moon to announce the name or nature of the day to the notion that in the second millennium BCE, the Mesopotamians had a concept of time as a continuous entity which can be understood mathematically. Similarly, when Sachs (1952) translated the first known horoscopes for the birth of infants, dating back to 410 BCE, he converted Babylonian constellation names into Greek zodiac signs, creating the impression that the Greek zodiac was in use. All translations are therefore to be treated as provisional.

Divination and Science

In what sense was Babylonian astrology scientific? There is a clear argument that it was not, given that it did not fulfill one of the criteria of modern science, namely, verification of predictions through large samples in controlled conditions. The astrologers’ success was measured in terms of one-off forecasts, a satisfactory means of measuring success at the time, if not for modern scientists. When the astrologers were wrong, it was seen as a result of human error, not a sign of the fallibility of the essential hypothesis that the stars were conveying messages from the gods. The statement that divination equals science may seem a strange one by modern standards, but not if the definition focuses on the logical procedures of prediction and ignores the surrounding belief system.

The fundamental process involved in all divination was one of circumstantial associations. In other words, if event *y* correlates with sign *x*, then when *x* next appears, *y* will happen. If we again remove the gods from the equation, then there is no direct link between *x* and *y*. That is, the “signs

indicated events in a variety of ways, mostly by means of schematic symmetries, associations and analogy. The relationship between the sign (*ittu*) and its prediction (*parassu*) had no component of causation, nor necessity of any particular temporal relation, be it synchronistic or sequential” (Rochberg-Halton, 1998, p. 52). Although the gods caused both the omen and the succeeding event, there was no cause and effect relationship between the two. Thus, if Babylonian astrology was scientific, it was because it relied on a deductive methodology and logical inferences made on the basis of empirical observation, and emphatically not because it posited a set of physical relationships between stars and society.

Larsen argues that if the development of modern science has seen the replacing of “imaginary representations of “intentional” causes by the representation of unintentional and inevitable relationships” (1987, p. 208), then by removing the intentions of the gods from the equation, we are left with the inevitable relationship between the present omen and future event, between astronomical observation and political action. A relationship which is inevitable rather than intentional, so this argument runs, is scientific.

Babylonian astrology’s scientific qualities are also said to be evident in its foundation in empirical observation, its mathematical rigor, and the value-free objective procedures which meant that there was no bias in the forecasts, which might imply criticism of the king’s conduct as much as praise. Just as scientific method can be seen as a mode of inquiry, so astrology might be seen as language, yet one with a code which was written into the fabric of the universe. To this end, the Babylonians compiled lists of lexicographical correspondences between stars, gods, mundane objects, terrestrial events, and geographical regions which are themselves identified as characteristic of astrology’s scientific nature (Larsen, 1987).

The Origins of Astrology

In 1997, Carlos Jäschke (135–145) set out a standardized, speculative pattern for the

development of astronomy, moving from the measurement of solar and lunar risings and settings to the identification of first individual stars and then planets, the creation of calendars (to facilitate political order), and the recognition that celestial movements are periodic, allowing the crucial transmission from an observational to theoretical astronomy. In this process, astrology occupies a crucial place between these last two stages, its requirement for correct forecasts eventually making it essential to predict future planetary positions.

However, we really have little idea of how complex divinatory practices evolved in Mesopotamia, although a number of explanations have been proposed. They may, for example, have “developed from a simple folk practice, capable of giving yes-no answers to specific questions, to a systematized science, covering nearly all observable phenomena and permitting detailed predictions of unanticipated events, as well as giving detailed answers to queries” (Koch-Westenholz, 1995, p. 14).

All accounts of astrology’s origins are speculative and limited as they have by serious source problems and the tendency to apply modern theories in what might be an inappropriate manner. Could the development of astrology be the direct consequence of what we might call an “environmental theology”? From the title of Jacobsen’s description of the Mesopotamian cosmos, “The Cosmos as a State” (1946), I have derived the term cosmic state (2009) to describe societies in which the earthly system is thought to be inseparable from the celestial. The Mesopotamian system was obviously autocratic in the sense that once a royal order had been given, only the astrologers could amend it. Actually, even though the king had the power to dismiss or punish astrologers who gave him poor advice, it is a debatable point as to who was the master: the astrologer who interpreted the divine will or the king who implemented it.

The reasons that one culture should develop a system of complex astrology and another should not may be found partly in environmental factors. One argument refers to distinctions between Egyptian culture, which developed

a highly codified astral theology, and Mesopotamian, which made the leap from the use of the stars as religious objects to their application to forecasting and the precise management of the state. It is true that both cultures believed that the stars offered a means of communication between the divine and humanity and that they applied this knowledge to political management, but astrology is essentially an extrapolation from astral religion, distinguished by its interpretative complexity. According to (Jacobsen et al., 1946, pp. 126–127), the most obvious natural difference between the two cultures is found in Mesopotamia's existential insecurity: Mesopotamia had no natural boundaries and was surrounded by hostile enemies and the flooding of the rivers on which its agriculture depended was erratic. By contrast, according to Jacobsen, Egypt was well protected by desert, had few neighbors, and could rely totally on the Nile's annual flood. Such environmental factors fed directly into political cosmology and conduct. However, the proposition that the development of astrology was a direct response to collective insecurity has been challenged firstly on the general grounds that it represents the inappropriate projection of modern concerns onto an ancient society and, secondly, by the specific argument that the omen literature indicates a society which, far from being insecure, was very certain of its beliefs (Koch-Westenholz, 1995, pp. 17–18).

If the environment produces political forms, then politics, in turn, requires divination. Jacobsen found evidence in the idea of the divine assembly and in mythical claims that the divine pantheon took its decisions democratically, at least in part. In the *Enuma Elish* (VI.17–18), Marduk assembles the divine council and gives it its orders, yet his supremacy was not unqualified: destiny itself was determined by seven other gods (VI.81). This is a persuasive argument which gives us further insights into the motives behind divination. Not only was the city or temple assembly obliged to ascertain its divine counterpart's views before it could reach satisfactory solutions to the many mundane problems it had to consider, such as drainage and irrigation or disputes over field boundaries, but it also seems that

decisions were reached by consensus. We can imagine situations in which extispicy or the casting of lots might have been the only way to break an impasse. Oppenheim (1977, p. 208) supports Jacobsen's view that divination emerged as a possible solution to the difficulties involved in political decision-making, pointing out that it might have had social functions. For example, he drew attention to the casting of lots to determine the division of an estate amongst the sons. A further development was the emergence of sacred kingship, an institution which took on different forms in each culture, whether in Egypt or Mesopotamia (Engnell, 1943; Frankfort, 1948). In Mesopotamia, the monarch was but a human servant of the gods, whereas the Egyptian pharaoh was himself divine. Babylon was built as the gods' sanctuary on earth and the city's heart was the Esagila, Marduk's temple and the residence of Ea and Enlil. The physical hierarchy of earth and heaven was therefore reflected in a political order in which the king was subordinate to the divine council, headed by Enlil, or to Marduk.

The king's greatest attribute, perhaps even more than military prowess, was the wisdom necessary to navigate his way through a world of omens, dreams, and oracles, to understand and heed the advice of the astrologers and to perform the correct action at the appropriate moment. Kingship was a sacred office (Engnell, 1943), and divination was no mere optional accessory; it was a central part of the political machinery.

Others have proposed religious reasons for the development of astrology. Leo Oppenheim has argued that third millennium BCE Sumerian religion was underpinned by an earlier near-eastern formulation which reveals the existence of "an age-old pre-deistic deterministic concept of life" (1964, pp. 203–204) which was conducive to astrology's development. This proposition is supported by astrologers' letters from the Assyrian period, in which there are frequent references to auspicious times to undertake rituals. The Mesopotamians' purpose was to describe the world. Having done that, divination allowed them to participate in its management through divination and, increasingly, astrology.

The Development of Astrology

The earliest examples of astrological practices have been traced to the third millennium, but the evidence is now challenged. In 1939, Jacobsen found evidence of the use of an eclipse in 2403 BCE (1939, pp. 203–204), but his account relies too heavily on the reconstruction of missing words in broken tablets and is now dismissed. There are a number of examples of astrological omens dated to the reigns (for which dates are uncertain) of Sargon of Akkad (ca. 2334–2279 BCE), Ibi-Sin (ca. 2028–2004 BCE), and Shulgi of Ur (ca. 2094–2047 BCE) (Weidner, 1928–1929, pp. 231, 236; Walker, 1982, p. 22). Although some scholars, such as David Pingree (1998, p. 125), regard these tablets as genuinely Sumerian, there is some skepticism about their precise origin, and it is thought that they may represent later accounts written as if they were omens from earlier times (Rochberg-Halton, 1988b, p. 7, n 32; Koch-Westenholz, 1995, p. 35). This is a fairly standard practice in prophetic literature, occurring notably and almost two millennia later in the Book of Daniel, which was written perhaps 300 years after the time in which it is supposedly set. A similar practice is found in extispicy, and there are references to liver omens relating to rebellion against Ibi-Sin apparently written 50 years after the event (Bottéro, 1987, p. 131). There is also the problem that some of the eclipses mentioned could not have occurred as claimed (Koch-Westenholz, 1995, p. 35). The skeptical argument holds that as the most substantial sources date from the Assyrian period, the eighth and seventh centuries, the evidence for astrology's importance in earlier periods is unconvincing.

We do know, however, that the Sumerians watched the sky, naming some of the constellations and planets, and that these played a role in their religion. For example, the goddess Nisaba, who may have been an antecedent of the god Nabu, who himself was associated with Mercury, was said to measure heaven and earth, to know the secrets of calculation and, together with Suen, the lunar deity, to “count the days.” Her temple in the city of Eresh was called the e-mul-mul, the

“House of Stars,” and she was the owner of a lapis lazuli tablet which is known variously as the dub mul-an or dub mul-an ku, “the tablet with the stars of the heavens” or “the tablet with the stars of the pure heavens.” Her associated functions as goddess of grain and as the expert on accounting and the fair management of resources hint at both the practical uses of astronomy and the benefits of a well-regulated calendar in maintaining social order.

A sophisticated astrology had developed by the reign of the Babylonian emperor Ammisaduqa, Hammurabi's great-great grandson, from the survival of the so-called Venus Tablet (Reiner and Pingree, 1975; Van der Waerden, 1974, vol. II, pp. 50–58). The tablet contains 59 omens based on the first and last visibilities of the Venus, each of which will occur twice in one of the planet's 584-day synodic cycles. The omens are grouped into 8-year cycles and have attracted attention partly on account of their use in the dating of Ammisaduqa's reign and hence the chronology of the old Babylonian Empire. Nothing could illustrate better the source problems afflicting Mesopotamian studies, at least before the first millennium: even when we have historical chronicles and astronomical records, it is still impossible to agree on a definitive date. The tablet tells us that by the middle of the second millennium BCE, consistent astronomical observations were being made for the express purpose of producing astrological omens, anticipating divine intentions, predicting the weather (and hence agricultural productivity), and preparing for possible political crises. The first omen, which is typical in the information it gives, set the tone:

In month XI, 15th day, Venus in the west disappeared, 3 days in the sky it stayed away, and in month XI, 18th day, Venus in the east became visible: springs will open, Adad his rain, Ea his floods will bring, king to king messages of reconciliation will send. (Pingree and Reiner, 1975, p. 29)

This observation was made in late winter, following the full moon (the 15th) in the 11th month. The 3-day period represents the shortest possible time that Venus might be invisible,

following its last appearance in the west as morning star and its reappearance in the east as evening star. The omen reveals information about Babylonian astronomy, astrology, and politics. Regarding astronomy, it was understood that Venus as morning and evening star was the same body. Second, although their records were based on continual observation, not on extrapolation into the future, it is clear that they did recognize the concept of planetary periods (Pingree, 1998, p. 126) – an understanding of regular planetary orbital periods – and hence that they either could not or did not feel the need to calculate future planetary positions. Moreover, given that the purpose of the omens was to correlate astronomical patterns with terrestrial events, the tablets have a historical function. The Venus Tablet provides a deeply practical rationale for astrology's apparent popularity: used exclusively by the kings, it provided the government with "the hope of stealing a march on fate and forestalling catastrophe by a timely recognition of divine intentions" (Frankfort, 1978, p. 255).

There are a number of other astrological tablets from the Old Babylonian period, including some eclipse omens, but following the Venus Tablet, the two most substantial sources are the *Enuma Anu Enlil* ("when the gods Anu and Enlil..."), a comprehensive compendium of astrological lore which includes material dating back to the Venus Tablet and the *Mul Apin*, the first great star catalogue, both of which are known from Assyrian tablets of the early first millennium BCE. However, there are suggestions that both may have been compiled in the second millennium, afar from controversial idea in view of the *Enuma Anu Enlil*'s inclusion of the Venus Tablet. Thus, while the first three centuries of the first millennium offer us virtually no sources whatsoever, suggesting that either astrology and astronomy were ignored or that the records were destroyed or, if they survived, have yet to be discovered, there is circumstantial evidence of intense astrological and astronomical activity over the same period.

The full text of the *Enuma Anu Enlil* was excavated in the ruins of Ashurbanipal's library

at the Assyrian capital, Nineveh. It consisted of around 6,500–7,000 omens grouped into some 70 tablets, of which 13 are now available in translation or transliteration (Reiner and Pingree, 1975, 1981; Rochberg-Halton, 1988b; Van Soldt, 1955; see also Baigent, 1994, pp. 67–75; Koch-Westonholtz, 1995, pp. 74–82). An indication of the prevailing astronomical priorities is revealed in a breakdown of the topics covered. Twenty-two tablets cover the moon, while a further 18 concern the sun. Of the remainder, five relate to Venus, perhaps four to Mars, two to Jupiter, three to thunder and lightning, and one to the Pleiades. The absence of specialized tablets for Mercury and Saturn indicates the lack of attention paid to the planets as opposed to solar and lunar phenomena. The small proportion of material on, or attention paid to, Jupiter is most mysterious in view of the fact that Marduk, the planet's god, was Babylon's presiding deity.

The *Mul Apin* is usually described as an astronomical compendium, but it clearly served an astrological function (Hunger & Pingree, 1989). The extant tablets date from the eighth century, although may either have been compiled by 1000 BCE or be based on observations as far as back as 1350 BCE. The date of its compilation, though, is less important than the fact that, with the *Enuma Anu Enlil*, it indicates that scholars of the Assyrian Empire were deeply concerned with the mapping and naming of the heavens. This may be why they began to keep comprehensive records of lunar eclipses, beginning on February 6, 747 BCE, in the reign of Nabonassar.

The dramatic reassertion of Assyrian power under Tiglath-Pileser III (745–728 BCE) marks astrology's reappearance on the public stage. The evidence for this lies in the remarkable increase in extant astrological texts, but the reasons are far from clear. Sargon II (721–705 BCE) was perhaps the first of the new line of Assyrian monarchs to take an astrologer on his military campaigns, and an inscription from a tablet in the Louvre recording his attack on Musasir suggests that the timing of his invasion may have been arranged by reference to astronomical factors (Koch-Westenholz, 1995, p. 153).

Astrology was essentially a means of communication, similar to prayer in that it was conducted with a divine partner, yet in that it utilized the technology of planetary observation and measurement, its function might be comparable to that of modern information technology. Certainly its perceived advantages were similar, and the observation of Jupiter's movements prior to Sargon's campaign offered intelligence of a similar character to that provided by modern satellites in preparing for military action: modern technology reveals the disposition of enemy forces, while the location of the stars also indicated the strength of Sargon's opponents.

Sargon's lessons were not lost on his successors, Sennacherib (704–681), Esarhaddon (680–669), and Ashurbanipal (668–627). These kings maintained astrologers across the empire that effectively formed a civil service, sending reports and letters to the emperor and offering the best possible advice on the basis of their observations (Oppenheim, 1969). These paint a portrait of a society in which the scribes maintained their personal relationships with each other and with the king, offering sometimes contradictory advice on astronomical observations and astrological predictions, finding excuses for their mistakes, and claiming due credit for their successes (Baigent, 1994, pp. 50–57).

The astrologers' communications reveal an astronomy which was still based on daily records, with the result that no stellar observations could be made or omens taken in inclement weather – except for meteorological ones. It was precisely those elements in astronomy which were unpredictable which preoccupied the Babylonians, for if the cycles of the sun, the moon, and the seasons represented the endlessly repeating rhythms of fate, rich variety in natural and celestial phenomena offered a chance to negotiate with fate by opening a dialogue with the gods. Thus, astronomy was directed to goals which were theological and political rather than scientific in the modern sense of examining celestial phenomena for their own sake.

Great emphasis was placed on other meteorologically induced phenomena, such as the

presence of haloes around the stars and planets, as well as their color or brightness, all of which were unpredictable. Neither was astrology absolutely distinct from other forms of divination, as Sargon II's inscription makes clear. The sun's main role was as representative of the oracle god, Shamash.

Having made their observations, the astrologers' first task was to communicate their findings to the king and offer whatever advice they felt necessary. This might be no more than to stay in the palace (SAA: 320). The king was also required to pray, offer sacrifices, and perform rituals, each of which might have its own auspicious time. When there was no other solution to a threatening omen, a substitute king was appointed (Bottéro, 1992, pp. 138–155). A letter from the astrologer Mar Istar suggested that a substitute be allowed to sit on the throne for 100 days before meeting his fate, a euphemism for death (LAS: 292).

The astrological reports are couched in more formal terms than the letters and tend to concentrate on prediction rather than advice. The information they contain makes no explicit distinction between planets, stars, and other celestial matters, "If the Pleiades enter the moon and come out to the north: Akkad will become happy; the king of Akkad will become strong and have no rival" (SAA: 443), "If Adad (the storm god) thunders in Tishri (month 7); there will be hostility in the land" (SAA: 444), and "If Jupiter passes to the right of Venus: a strong one will conquer the land of the Guti in battle" (SAA: 448).

Political demands heightened the need for accuracy of forecasting and observation and resulted in a renewed attempt to perfect astrology's predictive powers. A further innovation was taken in the mid-seventh century with the production of the so-called *Astronomical Diaries*, compiled almost continuously for over 600 years, beginning in 652–647 BCE (Sachs & Hunger, 1998–1999). The Diaries are records of astronomical, meteorological, and political events, presumably as a means of establishing common patterns. They represent a fresh determination in the ongoing attempt to create an empirically based astrology, in which both

planetary phenomena and their relationship to political and economic matters might be properly understood.

It may be that it was the success of the Assyrian regime which encouraged the Diaries' compilation, in an attempt to further improve the state's evidently beneficial relationship with celestial matters. It may equally be the case that the empire's collapse in 626 BCE, shortly after their collation began, concentrated the astrologers' minds on the maintenance of stability and the need to perfect astrology's ability to predict and avert political crises: the relationship between intellectual endeavor and political change is a complex one. The bulk of extant astrological reports cease about 30 years before the fall of Assyria, and while there might be later examples, we lack the ability to date them with any certainty. Most importantly, the period from the eighth to fifth centuries witnessed a scientific revolution: first the creation of mathematical models for the calculation of planetary positions in advance and, secondly, the development of horoscopic astrology, consisting of planetary omens based on the date of birth and the invention of astrological techniques which did not require direct observation.

That cultural revolution occurred under the Assyrian Neo-Babylonian and Persian monarchies is not questioned. But what is not fully understood is its nature, partly because it involved dramatic changes in both astronomy and astrology, paralleled by profound religious developments in the form of the introduction of Zoroastrianism.

The Ritual Calendar

Astronomy possessed one great function, the improvement and eventual perfection of astrology's role in managing the state. An essential component of political management was the regulation of the calendar. Tablet VI of the *Enuma Elish* describes how Marduk ordered the moon to mark out its synodic period, with a hint (the tablets are broken) that its crucial phases signified the moments when he (Marduk)

communicated destiny to the watching astrologers and that these were thus important moments for divination.

Each month began with the rising of the crescent moon, the new moon's first appearance after the spring equinox marked the beginning of the first month, Nisan. The problem, though, was the need to keep the lunar months in some sort of relationship with the solar year, and this necessitated the insertion of intercalary months. The "Diviners Manual," dating from the early first millennium (Oppenheim, 1974), gave the rules for intercalation, although the sheer variety of calendars used in the third millennium and the fact that in the Old Babylonian period 2 or 3 years in a row might contain intercalary months, suggest that there was no single set of recognized systems. It must be possible that divination (perhaps including extispicy) played as much a role in the selection of years for intercalation as did astronomy, and the purpose may have been to shift the average beginning of the year. In addition, kings in the Old Babylonian period often added intercalary months at the beginning of their reigns.

The fear that astronomical phenomena might occur on the wrong day is demonstrated vividly in the astrological reports. The Assyrian astrologer Balasœ advised the king that if the new moon occurs on the first or the full moon is seen on the 14th, then "the land will become happy," but if the full moon took place on the 12th, then "business will diminish... a strong enemy will oppress the land," and even though "the king of Akkad (i.e., Assyria) will bring about the downfall of his enemy," the prognosis is "bad for Akkad... good for Elam and the Westland (Amurru)," in other words, favorable for Babylon's hostile neighbors (SAA: 87–89).

We also have examples of Marduk's own planet, Jupiter, breaching its order by remaining visible for 5 days longer than expected. The astrologer Mar-Ishtar reported that it appeared on the sixth Simanu (month 3), close to Orion and in the way of Anu and that each of these three factors carried its own warning in the *Enuma Anu Enlil*. However, the planet then remained visible for another 4 days, an omen so bad that no ritual

could appease divine wrath, and all communication with heavens was broken off.

The Planets

Even though the Mesopotamians identified dozens of different deities, and acknowledged the existence of hundreds of others who were not even given names, one god was not necessarily entirely separate to another. Thus, Enlil, the originator of earthly kingship, played a role which tended to merge with that of Marduk, the supreme king, who was himself venerated as the “Enlil of the gods” (Parpola, 1997, p. LXXIV) or described in terms usually reserved for solar deities.

There is evidence that the planets themselves were seen as divine (Koch-Westenholz, 1995, pp. 120–121), but the consensus amongst Assyriologists is generally that the planets were not themselves divine but were objects manipulated by the gods as agents or expressions of their divinity. There was not necessarily a one-to-one correlation between individual deities and planets. Ninurta was normally the god associated with Saturn, but in the *Mul Apin* (II.i,5) we read about “Mercury whose name is Ninurta.” This blurring of identities is of considerable significance for astrology, in which the relationship between gods and planets was similarly flexible.

The astrology of the *Enuma Anu Enlil* and the *Mul Apin* tends to make little distinction in terms of astrological significance between the planets and the brightest stars, such as Sirius, or the most prominent constellations, such as Orion or Ursa Major. However, the planets were obviously distinguished by their erratic movements and were known in Sumerian as the *udu.idim.mes* or wild sheep (Akkadian *bibbu*). Time and space were interdependent in the Babylonian cosmos, and the crucial considerations in a planetary observation were its position, which indicated the terrestrial region at which the omen was directed and the nature of the predicted event (e.g., being in Scorpio could mean an attack by scorpions), and time (either of night or month), which might

indicate the location of the event. In addition, there was the question of whether the phenomena were on time (favorable) or early or late (unfavorable).

Attention was paid to a planet’s color and brightness, and careful observations were made of acronychal rising (the last visible rising in the evening after sunset), heliacal rising (first visible appearance on the eastern horizon before sunrise) and heliacal setting (the last visible setting after sunset). The birth charts began to include lunar and planetary latitude as well as zodiacal position.

In the *Mul Apin* (II.i,1-6), the sun and the five planets are classed as the six gods who travel in the path of the moon. Each planet possessed a range of associations with deities, colors, and times of year and with each other. They indicate the presence in Babylonian astrology of one of the central features of classical and medieval astrology: a web of relationships between planets and zodiac signs without which it would often have been impossible to reach a firm conclusion or offer definite advice.

The Sun

The sun was known in Sumerian as *Utu* and in Akkadian as *Shamash*; its *bit nisirti* (treasure) was the *Hired Man* (Aries) and in the *Mul Apin* its corresponding calendric event was the spring equinox. *Utu* and *Shamash* are also the names of the solar deities, but the two words could mean either the visible body or the hidden power within it, i.e., the god. *Shamshu* was also used for the solar body.

Nineteen of the tablets in the *Enuma Anu Enlil* were devoted wholly or partially to the sun, mainly to its rising or eclipses, but its invisibility at night imposed a clear restriction on its astrological use, for, however, many omens were devoted to its color or relationship with clouds, as soon as it appeared the stars vanished. However, as a god of justice *Shamash* became the god to whom oracles were addressed, presiding over the art and science of divination from entrails.

The Moon

The Sumerian moon god was known as Nanna or Suen, a name later contracted to Sin, by which the moon is generally known in the cuneiform texts. Nanna, it is thought, may refer specifically to the full moon and Suen to the crescent moon, while there also appears to be a third name, Asimbabbar, the new light. Nanna was the presiding god of the third dynasty Ur, and when the moon was invisible Nanna was believed to have gone to the netherworld to judge the dead, along with Utu, and special offerings were made. Fourteen tablets in the *Enuma Anu Enlil* were devoted to the moon's appearance and a further eight to lunar eclipses, which were thought to represent a demonic attack on Nanna. Nanna travelled the heavens in a boat and had associations with bulls and cowherds. His bit nisirti was Mul Mul, "the Stars," or Pleiades. Aside from the *Enuma Anu Enlil*, about half of the astrological reports deal with lunar phenomena. The reasons are obvious; for the moon is the second brightest celestial object after the sun, it possesses the fastest and most dramatic cycle, moving rapidly from one phase to another and, unlike the sun, can be tracked at night and hence form relationships with the stars, visibly passing through constellations.

Saturn

The planet Saturn is sometimes referred to as Ninurta in the texts, but also as udu.idim.sag.us (Akkadian kajamanu) meaning "the steady" or "the stable planet." Saturn has no single tablet dedicated to it in the *Enuma Anu Enlil*, and only 25 mentions in the reports published by Hunger, in spite of the fact that Ninurta was the son of Enlil and god of the thunderstorm, the spring flood, and the plow. Indeed the name may mean "Lord Plough." The god had an earlier form as Imdugud (the hailstone) and was also commonly known as Ningirsu (perhaps indicating the flood waters). He also had a military role as the "thunder" of the war chariot. The planet was also known as Mul Utu, the star of the Sun,

a connection which may derive from a shared concern with justice and may be evident in the fact that Saturn's bit nisirti was in Zibanitu (Greek Libra), opposite the Sun's in Aries.

Jupiter

It might be thought that Jupiter, as the planet sacred to Marduk, would have more omens devoted to it than any other planet, and the fact that it does not tell us that astrology was not simply a direct projection of theology on to the stars. It was not thought necessary to devote a large number of omens to the chief god, who merited less attention in the literature than the moon or Venus. The planet Jupiter was given various names. It was known as saggemgar ("the bearer of signs to the inhabited world") when it was in the eastern sky, sulpaea ("lord of the bright rising") at its heliacal rising, nibiru ("crossing") when culminating at the meridian, muludaltar ("the heroic one"), mul.babbar ("the white star"), Bel ("Lord"), or just simply Marduk. Jupiter might signify the moon in what might have been an imitation of Saturn's relationship with the sun, and although its proximity to the moon was in general a bad omen, its presence during a lunar eclipse cancelled the evil omen. Together with Shamash, Jupiter was "Lord of the secrets of Akkad," and its brightness was therefore good for the king and the state. It was associated with the summer solstice in the Mul Apin and its bit nisirti was the crab.

Mars

Mars invariably sent evil omens, being associated with Nergal, a god of the underworld, forest fires, fever, plague, and war. When the planet was not known directly as Nergal, it was called sanumma (different, i.e., hostile), nakru (enemy), sarru (liar), lemnu (evil), ahu (strange), or sa (red). In the Mul Apin, it is referred to as Salbatanu, a name which may mean "the incalculable star" or "constantly portending pestilence." Mars' malefic tendencies were heightened when it was

bright and diminished when it was faint, and when it was at its reddest, it might signify prosperity but also an epidemic of plague. Its bit nisirti was the goatfish, and in the *Mul Apin* it was linked to the winter solstice.

Venus

Venus was the subject of one of the first extant body of omens, and its goddess, the Sumerian Inanna (Akkadian Ishtar), was the most important single female deity, on a par with Sin and Shamash, with whom she forms a trinity, and even with Ea and Enlil. Her worship extended throughout the near east, and in Syria she was known as Astarte (Heimpel, 1982). In the texts the planet is usually known as Dilbat or Delebat, “the brightest star,” or Ishtar. Although Venus was invariably female, there was a Semitic male version of Ishtar, and sometimes the morning star was considered to be male (and malefic). In other traditions, it was the evening star that was male. However, this bisexuality does not appear in the extant omen literature, and Venus’ mere appearance was often considered to be benefic. Venus’ bit nisirti was Anunitu (Pisces), and the planet was seen as the precursor of spring.

Mercury

Mercury was known as gu.ud (Akkadian sihtu), “the jumping one,” and in the *Mul Apin* is consistently linked with Ninurta, the god normally connected with Saturn. Mercury is more usually identified as the planet of Nabu, the son of Mercury, and is therefore connected to the crown prince. Thus, if Mercury approaches Regulus (mul-lugal, the “king-star”), this warns of an attempt by the heir to seize the throne (SAA: 245). While Mercury’s appearance warned of rain and flood, Nabu himself was the scribe of the gods. In this role, he wrote the destinies, announcing divine intentions to the diviners and astrologers, and thus joined Ea and Marduk as a god of wisdom. Mercury’s bit nisirti was Ab.sin

(Virgo), and in the *Mul Apin* the planet was regarded as the precursor of autumn.

The Development of the Zodiac

The mathematical methods used by the Mesopotamian astronomers are well documented (Neugebauer, 1975, vol. II; Van der Waerden, 1974). The three principal priorities of the second millennium astronomy were fairly straightforward: to record the rising and setting of stars and planets and to quantify and calculate such phenomena as the length of lunar visibility in the beginning, middle, and end of the month and the length of day through the year. It is the development of the zodiac, though, without which classical and medieval astrology would never have existed in any recognizable form, which is of most immediate interest for the history of astrology. Mesopotamian astronomy’s enduring contribution to late astrology is undoubtedly the creation of the 12 signs of the zodiac, the equal-sized divisions of the ecliptic which are the most familiar feature of modern popular astrology. The first step to their formation was the creation of the constellations.

All theories concerning the reasons for the creation of constellations are essentially speculative. The creation of calendars for agricultural purposes or the use of the heavens for navigation requires only the recognition of single bright stars, not the fabrication of unlikely images such as the Aquarian water pourer. The creatures identified in the sky are, perhaps, more likely to be the consequence of mythical and religious projections, and we may assume that the constellations’ creation was initiated at whatever time human beings began observing the heavens, worshipping the stars, keeping a rough calendar, creating art, or all four. Gurshtein (1993, 1998) controversially gives a date of around 14000 BCE for the beginning of this process and argues that the naming of important constellations was related to precession of the equinoxes and the sun’s shift in relation to the stars. Owen Gingerich (1984, pp. 219–220) lent his authority to the possibility that some of the constellations, notably the Great Bear, may

date from the last Ice Age. Rogers (1998) speculates that in the Mesopotamian period, one set of constellations had religious origins, another agricultural applications. Such speculation aside, serious questions have been raised concerning the antiquity of the Greek and therefore the Babylonian zodiac, by Zhitomirsky (1999), who dates it to c. 2000 BCE $\pm$ 300 years.

Individual fixed stars offer a natural frame of reference for locating planetary position, and it appears that by the Old Babylonian period, a system had been established which grouped stars according to the calendar. Three groups of 12 stars were arranged in three “paths” (translated as “bands” below) across the sky, related to the three creator gods, Anu, Ea, and Enlil (Mul Apin: Gap A 1–7, Hunger & Pingree, 1989, pp. 88–89; Koch-Westenholz, 1995, pp. 24–25). The lists of the 36 stars which are divided between the three ways are preserved in three copies known to Assyriologists as “astrolabes” but to the ancient scribes themselves as the “three stars each” (Van der Waerden, 1949).

The evolution of the 36 stars was accompanied by a parallel development, the differentiation of the 18 constellations “which stood in the path of the moon,” the first known attempt to relate a sequence of constellations to a planet. The full list of these is given in the Mul Apin (I.iv, pp. 33–39, Hunger & Pingree, 1989, pp. 68–69):

- Mul.Mul The Stars (i.e., the Pleiades)
- Mul GALENA The Bull of heaven (Taurus)
- Mul SIPA.ZI.AN.NA The True Shepherd of Anu (Orion)
- Mul SU.GI The Old Man (Perseus)
- Mul GAM The Crook (Auriga)
- Mul MAS.TAB.BAGAL.GAL The Great Twins (Gemini)
- Mul AL.LUL The Crab (Cancer)
- Mul UR.GU.LA The Lion (Leo)
- Mul AB.SIN The Furrow (Virgo)
- Mul Zi-ba-ni-tu The Scales (Libra)
- Mul GIR.TAB The Scorpion (Scorpio)
- Mul Pa-bil-sag The god Pabilsag (Sagittarius)
- Mul SUHUR.MAS The Goat-Fish (Capricorn)
- Mul GU-LA The Great One (Aquarius)

- Mul KUN mes The Tails (Pisces)
- Mul SIM.MAH The Swallow (SW Pisces)
- Mul A-nu-ni-tu The goddess Anunitu Mul HUN-GA The Hired Man (Aries)

This list seems to be a clear attempt to formulate a lunar zodiac based on visible constellations. However, it clearly represents a stage towards the formulation of a solar zodiac, and most of the future zodiac signs are identified.

The process by which the establishment of a constellational lunar zodiac and the attribution of astrological meaning to stars or groups of stars led to the creation of the 12-sign zodiac is not clear. Clearly planetary meanings depended partly on their position in relation to the stars, and the Enuma Anu Enlil contains omens such as “If Mars approaches the Scorpion: there will be a breach in the palace of the prince” (50.111.8a, Reiner & Pingree, 1981, p. 41). However, we cannot be sure whether the crucial factor here was Mars’ position in the sky or whether the constellation Scorpio was thought to contain meaning. The astrological letters and reports contain similar observations, referring to stars as well as constellations, suggesting that in the eighth century, there was still no neat and all-encompassing division of the sky into distinct regions.

Our earliest evidence for the existence of the zodiac occurs on a lunar tablet dated to 475 BCE, and a tablet of 419 BCE gives the positions of planets in the signs, almost certainly as an aid to drawing up birth charts (Van der Waerden, 1952–1953; Koch Westenholtz, 1994, p. 174). The development of the zodiac required the production of another form of astronomical document, the Almanacs, which survive for the years between 262 BCE and 75 CE (Sachs, 1948, pp. 279–280; Rochberg, 1993, p. 41).

Van der Waerden speculates that the formulation of 12 signs of 30° each was a projection onto the sky of the 12 months and 360 days of the year. In the Enuma Elish (II, 27–32), Tiamat creates 11 creatures to fight with her, including a few who share identities with constellations, including “the great lion, the mad dog, and the Scorpion-man.”

The equal-sized signs of the Mesopotamian zodiac were defined by relation to the stars, and lunar tables in the fourth to second centuries BCE indicate that the vernal equinox took place at 8° or 10° Aries, as measured from the vernal point. The zodiac signs evolved as a system of measurement, but were also assigned astrological meanings. Indeed they have been described as “mighty powers” (Van der Waerden, 1952–1953, p. 224). An additional advantage, though, was to be the ability to tabulate planetary positions in terms of zodiac degrees. The 12 signs did not replace the three ways or constellations but could be used alongside them. Thus, a tablet of 164 BCE records that Halley’s comet had been “seen in the east in the path of Anu in the area of Pleiades and Taurus, to the west...and passed along in the path of Ea” (Stephenson & Walker, 1985, p. 24).

The attention paid to the variable timing of new and full moons gives us an insight into the mind of the Assyrian astronomers. They knew that there was an inevitability about both the moon’s synodic cycle, for without it they would not have had the month, and the sun’s annual rhythm, for without that there would have been no years. Yet they clearly believed that it was possible for the gods to manipulate the moon’s synodic period within certain limits. This might suggest that there was an awareness that the universe operated within mathematical limits and that the gods and goddesses themselves were subject to the same destinies as was humanity.

A study of planetary measurements in horoscopes (Rochberg-Halton, 1998) suggests the possibility of continuing theological motivation, for planetary synodic periods were recorded only when the planet occupied the same sign as the sun. This might have been because such information told the astrologer whether the planet was visible or not, but there might also be a trace here of the sun’s growing religious significance. However, even if religious considerations did remain high, increasing levels of observational accuracy were required to provide for astrology’s increasing demands in the Persian period, such as the *dedekatemoria* (see below), divisions of the zodiac signs by 12.

The Development of Birth Charts

According to Jacobsen (1976, p. 108), it was believed in the second millennium BCE that the “time of the shaping of the child in its mother’s womb is one during which it is susceptible to both good and bad influences and so is the moment of birth; an incautious word then may saddle the child with any manner of unpropitious fate.” Given that astrology relied on signs rather than influences, one would still have thought that the diviners present at birth would have been listening keenly to the gods’ and goddesses’ words expressed through the stars. However, the use of astrological indications based on the date of birth is a relatively late development, and the earliest known examples date to 410 BCE.

It may be that the birth chart was less an entirely new form of astrology than a variant form of divination, one created from the combination of the celestial omens of the *Enuma Anu Enlil* and the large corpus of birth omens (Rochberg-Halton, 1989, p. 110). Such omens, normally taken from abnormal or “monstrous” births, mainly of animals, can be dated back to the second millennium BCE and were collected in the *Summa Izbu* (Jastrow, 1914; Leichty, 1970). Some birth omens might include references to the date of birth and probable destiny. There was also, within the near east, a tradition of birth rituals.

The first cuneiform birth chart was discovered in the late nineteenth century and published in 1888. When Sachs published his collection in 1952, there were just six known cuneiform birth charts. By 1989, the total had risen to just 32. This must represent a fraction of the charts cast in the Persian and Seleucid eras. The development of birth charts placed fresh requirements on the astronomers, for while astrology had always been based on the observation of nocturnal messages from the gods and had ignored phenomena which could not be seen, children had a habit of being born during daylight hours. Sachs (1952, p. 52) speculates that there may therefore have been a halfway stage in which prediction of individual destiny was based on various combinations of visible and invisible planets at birth.

We do know, though, that the earliest surviving birth chart to include an interpretation was cast for a nameless child, apparently born on April 29, 410 BCE (Sachs, 1952, pp. 54–57). The text gives the date; the names of the child's father and grandfather, Shuma-usur and Shumma-iddina; the relevant astronomical details; and just one surviving line of astrological interpretation which Sachs reconstructs as "(Things?) will(?) be good before you." The rest of the tablet is missing apart from two lines which read "Month Du'uz, year 12...[ye]ar(?) 8..." suggesting that forecasts for specific dates might have been included.

We can draw various conclusions from this chart, concerning both the history of astrology and the broader cultural context. It is instructive, for example, that Mercury was not given a zodiac sign position, for its proximity to the sun rendered it invisible, suggesting that it was not taken into consideration. The development of the birth chart opened the door to the full development of Greek horoscopic astrology and the belief that accurate astrological investigation must be based on exact timing. The path was set for the development of the highly detailed technical procedures which have survived largely intact in Indian astrology, were adhered to strictly by medieval astrologers, and still form the basis of modern western astrology. If astronomy's increasing accuracy had provoked a seventh-century crisis in astrology, then it is clear that in the fifth century, it had been restored and reformed (Van der Waerden, 1974, p. 128). The new astronomy, which calculated planetary positions for decades ahead, may have been both motivated by the new developments in astrology and made them possible. As to which came first, we cannot say. But new studies suggest that the priests, the astronomers, and the astrologers were usually the same people (Rochberg, 1993; Parpolá, 1993), implying that the intimate relationship between theology, divination, and science was as strong as ever. Here we have a picture of theology encouraging the development of scientific astronomy rather than inhibiting it.

The development of the birth chart represented a move away from an astrology

which was structured by direct astronomical observation to one directed by worldly mundane concerns. That is, rather than waiting for a celestial omen to interpret, and having nothing to say if it did not appear, the astrologers were now obliged to construct omens for terrestrial events over which they had no control. Simple observation was no longer enough. The logic of the new astrology required that planetary positions should be plotted whether they were visible or not.

Decline and Transmission

Following Alexander's conquest of Babylon 311 BCE, the work of the astrological scribes in the temples continued, but by the second century, astrology's creative hub had moved to Egypt where the fusion of Egyptian religion, Greek philosophy, and Babylonian astrology and astronomy gave rise to the complex technical astrology of the classical world. However, there is evidence that a visual astrology based on the observation of celestial deities survived to the late classical world (Campion, 2005), while certain features of Babylonian astrology are still evident in modern western astrology (Campion, 2012).

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Astrology in China

Ho Peng Yoke

In traditional China there was no distinction between astronomy and astrology. The common word *tianwen* covered both. There was also no distinction between astronomy and astrology in Europe before the end of the seventeenth century. According to the *Oxford English Dictionary*, there were two kinds of astrology (a) natural astrology, which involved the calculation and foretelling of natural phenomena, as the

measurement of time, fixing of Easter, predictions of tides and eclipses, and also of meteorological phenomena and (b) judicial astrology, which was the art of judging the reputed occult and nonphysical influences of the stars and planets on human affairs, also known as star divination or astromancy. Since the end of the seventeenth century the term natural astrology was replaced by astronomy and meteorology, while judicial astrology became the astrology commonly known today.

Traditional Chinese astrology included the two elements of natural and occult science. The latter provided the motivating force that enabled Chinese astronomers to produce comprehensive and continuous observational records for almost 2,000 years. These records are of interest to modern astronomers, but they were never made with such an intention. They were meant primarily to enable the emperor to have foreknowledge of future events concerning himself, his imperial household, his senior officials, his empire, his subjects, and foreign countries. Astronomical observations also played a part in the calculation of calendars that gave auspicious and ominous times and dates for various kinds of events in daily life, ranging from wedding ceremonies to having a bath or a haircut. Traditional Chinese judicial astrology differs from its counterpart in Europe in that it was tailored exclusively to serve the emperor and not the individual. Officially this system is now obsolete among the Chinese, but unofficially there were some whispers linking the event of the demise of their Great Helmsman to the 1976 Tangshan earthquake. What is popularly known today as Chinese astrology is not the traditional official Chinese astrology referred to above. Official and popular astrology are two different entities.

Official astrology found its place in the “Astronomical Chapters” of the Chinese Dynastic Histories, beginning with the *Shiji* (Historical Memoirs) of Sima Qian (145–186 BCE). Based on the traditional Chinese belief in the close relationship between heaven (*tian*), earth (*di*), and man (*ren*), the emperor was regarded as the representative of heaven on earth – human actions on the part of the emperor and celestial

phenomena had mutual effects. Chinese astrologers divided the whole sky visible to them, making the stars and asterisms correspond to geographical regions. Almost all of them corresponded to China and only a few smaller asterisms corresponded to neighboring countries.

The Polar Star, which was supposed to remain stationary, was regarded as the counterpart of the emperor in heaven. Perhaps because there was seldom any bright star near the North Pole, and the scope for making predictions would be much more limited when a star was far away from the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) beyond the reach of the planets, a number of other stars were also designated to represent the emperor. The asterisms in the circumpolar region, known as the *Ziweiyuan* (Purple Subtlety Enclosure), included those that represented the emperor, the empress, the imperial concubines, and the crown prince. There were stars representing his hierarchy of officials, including ministers and military commanders, and there were stars representing the utilities in the palace, for example the kitchen. The region was enclosed by two chains of stars, representing the walls of the Forbidden City. Many parts of the Forbidden City and the circumpolar region shared the same names. Outside the "walls" of the circumpolar region was the Plough (*Beidou*), an important asterism in both Chinese astrology and Daoism.

Next come the asterisms along the ecliptic. Two other special regions, the *Taiweiyuan* (Great Subtlety Enclosure) and the *Tianshiyuan* (Celestial Market Enclosure), were located there. The former again pertained to the emperor, his household, and his official hierarchy and the latter to the general state of economy in his empire. Distributed along the ecliptic were the 28 lunar mansions. They were used to make a wide range of predictions, from flood and drought in the empire to military activities among the border tribal people. The asterisms near the 28 lunar mansions were also significant. The astrologer could observe, for example, four stars in Pisces, called *Yumyu*

(Cloud and Rain) to make a forecast for rain, thus performing the task of the modern meteorologist.

The Sun was the most important astrological object, because it represented the emperor. Solar eclipses and sunspots reflected blemishes on the part of the emperor. Likewise lunar eclipses referred to the empress. The astrologer looked for the presence of planets, comets, and novae near a particular star or asterism to predict an event and where it would happen. The astrologer also noted changes in the color or brightness and scintillation due to atmospheric conditions. He also observed aurora borealis and clouds, noting their color and shape. These were particularly important in the battlefield for gaining advanced information on enemy movements and the outcome of the combat. The astronomical bureau also produced an astrological almanac using the art of *zheri* (calculations of auspicious and inauspicious days) to work out days and times that were auspicious or unlucky for certain events in private and social life, for example having a bath or a haircut, meeting a friend, doing a business transaction, moving house, and holding a wedding ceremony.

There were often occasions when the astrologer was required to give an answer to a specific event, for example when something was lost, when a candidate set out to take the civil examinations, when two armies were facing each other preparing for battle, and so on. There were three sophisticated techniques of divination which fell within the syllabus of candidates taking examinations in the astronomical bureau in the Song Dynasty, namely *taiyi* (Supreme Unity), *dunjia* (Concealing the *jias*), and *liuren* (Six *rens*). These three methods did not restrict themselves to the imperial family and the official hierarchy.

Naturally the common people also wished to have foreknowledge of their individual fate and destiny. The Chinese developed many systems for this purpose, but none of them relied on direct astronomical observation. In the strict sense of the word they hardly qualify to be called astrology. However they generally employed the results of astronomical observations and

calculations by using some or all the elements of year, month, day, and time. Furthermore, at least one of the systems contains traces of Greek and Hindu astrology. There are two systems of fate calculation in general circulation among the Chinese today, namely the *Ziping* method and the *Ziwei doushu* method. These two systems of fate calculation do not rely on direct observations of the stars and in the *Ziwei doushu* horoscopes are worked out without requiring the practitioner to know how to identify the stars that occur in the horoscope.

The history of fate calculation in China is rather obscure as this was not regarded as an orthodox branch of study, and experts writing on this subject often used imprecise language to put off the uninitiated. By the Han period (206 BCE–AD 220), Confucian scholars were talking about three types of human fate (*sanming*). One was endowed during birth and was the only element that could be calculated. One was under the influence of good or evil deeds, and one was governed by catastrophic events that would overrule the first two. It is interesting to draw comparisons with the Han scholars' contemporaries in Europe where the Romans were adopting Stoicism as their state philosophy, believing in the devotion to duty while leaving things to the inevitable. The Chinese had a different belief in life, by talking about three types of life rather than one. To the Chinese it was only the fated life that was predictable, but any predicted event was by no means inevitable. It might be changed according to one's deeds, or by what we nowadays describe as an "act of God". The Chinese system gave encouragement to lead a good life. In this respect it certainly sounded more attractive than Hellenistic astrology.

At first it seems that only the year of birth of the person concerned was taken into account. Even today some Chinese still speak about the "twelve animal cycle" of the years they were born. As time went by, first the month, then the day, and finally the hours (or rather double hour) of birth were gradually included to develop newer systems. The *Ziping* method is one of the most sophisticated systems of fate calculation. It is

attributed to Xu Juyi, said to have lived during the latter half of the tenth century. He was the first to use the time of the day for fate calculation. Many books were also attributed to him, but we do not know exactly which were actually written by him. The most authoritative and comprehensive text that we have on the *Ziping* method is the *Sanming tonghui* (Confluence of the Three Fates) written by Wan Mingyong during the Ming period (1368–1644). Since then the system has frequently been revised to keep abreast with changes in social structure. This can be testified to by the large number of books written on this subject in China, Hong Kong, Japan, and Korea during the past few decades.

However, back in the third century Indian astrology had entered into China when the *Sārdulakarnāvadāna* was translated, introducing the names of the "Seven Luminaries" (Sun, Moon, and the five planets) and the *nakṣatras* (Moonstations). In the year 718 Gautama Siddhārtha translated the *Navagrāha* calendar and introduced the names of two imaginary heavenly bodies, *Rahu* and *Ketu*. Some time afterward a Nestorian named Adam translated a work called *Simenjing* (lit, Book on Four Departments). This book has long been lost, but it could have been a translation of Ptolemy's *Tetrabiblos*, according to recent Japanese authorities on the subject such as Kiyoshi Yabuuchi. Michio Yano has suggested that another book with the title *Duliyusijing* carried the name of Ptolemy in a corrupted form. Hellenistic astrology also went from Persia to China through Korea. Another important route taken by Hellenistic astrology was through India, where it was modified under the influence of Hindu astrology. Tantric monks played an important role in the introduction of this form of astrology to China. Amoghavajra (705–774) produced a book known under its abridged title *Xiuyaojing* (Book on the *Nakṣatras* and the Luminaries), in which the 12 signs of the zodiac appeared for the first time in China. Thus by the eighth century imported systems of astrology with Hellenistic and also often Hindu roots had become quite popular. A number of actual horoscopes cast during the Tang period are preserved

in the *Qinding gujin tushu jicheng* (Imperial Encyclopedia), edited by Chen Menglei et al. in 1726.

Changes took place when new ideas came into the same melting pot with something that was originally in it. Traditional Chinese star names and astrological terms were adopted by the new imports. Gradually the latter became sinicized. One can hardly notice the Hellenistic and Hindu origin of the *Ziwei doushu system* by looking at its name alone. We do not know when exactly the term “*Ziwei*” was first used here. During the Tang period several names were used; among them was the term *Taiyi*. The “star” *Taiyi* played the same role as the “star” *Ziwei* in the modern system, and both have somewhat similar reference to the occupant of the most supreme position below or above. The term *Ziwei doushu* first appeared in the title of a book incorporated in the Daoist *Tripitaka*, the *Xu Daozang* in 1607. Similarly traditional fate calculation methods were at the same time influenced by imported cultures. The Ziping system for example employs a cycle of 12 phases, reminiscent of the 12 *Nidā nas* in Buddhism.

See Also

- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [Geomancy in China](#)
- [Lunar Mansions in Islam](#)

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Astrology in India

Vijaya Narayan Tripathi

In India, astrology, *Jyotiṣa*, is defined as *Jyotiṣam sūryādi grahāṇām bodhakamśāstram*, the system which explains the influences of the sun, moon, and planets.

Indian astrology came explicitly to light around 1200 BCE, when the monk Lagadha compiled the *Vedānga-Jyotiṣa* on the basis of *Vedas*, in which lunar and solar months are described, with their adjustment by *Adhimāsa* (lunar leap month). *ṛtus* (seasons), years, and *yugas* (eras) are also described. Twenty-seven constellations, eclipses, 7 planets, and 12 signs of the zodiac were also known at that time.

In the period from 500 BCE to the beginning of the Christian era some texts were written on the subject of astrology. Nineteen famous sages composed their *Siddhāntas* (texts). *Candra-prajñapti*, *Sūrya-prajñapti*, and *Jyotiṣakaraṇḍaka* were written. The *Sūryasiddhānta*, the ancient text of Indian astrology, was composed around 200 BCE.

In the first five centuries of the Christian era, there were some important contributions by Jain writers. *Angavijjā* is a large collection about *Śakuna* (omens). *Kālaka* and *ṛsiputra* also contributed around this time. At the end of the fifth century, Āryabhaṭa I mentioned in his text *Āryabhaṭīya* that the sun and stars are constant and that day and night are based on the movement of the earth.

The period AD 500–1000 was very productive. Lallācārya, the disciple of ► [Āryabhaṭa](#), composed two texts – *Śiṣyadhīvr̥dhi* and *Ratnaśa* – dealing with mathematical theories. The astrologer ► [Varāhamihira](#) composed several texts, and his son Pṛthuyasā composed a brief horary called *ṣat-Pañcāśikā*. Bhāskaraṇḍaka I wrote a commentary on the *Āryabhaṭīya* in the seventh century, and ► [Brahmagupta](#) composed the *Brāhmasphuṭasiddhānta* and the *Khaṇḍakhādya* around AD 635. Other scholars

wrote commentaries on the texts of their predecessors and independent texts of their own.

In 1000–1500, there was a great deal of enhancement to the literature concerning the construction of astronomical instruments for observation. In the twelfth century, Bhāskara composed the famous text *Siddhāntaśiromaṇi*. The Līlāvātī of Rājāditya is another of the texts of that century. In the fifteenth century, Keśava wrote more than ten books, and his son Gaṇeśa composed the *Grahalāghava* at the age of 13.

Many more texts and commentaries were written from the sixteenth century onward. A few noteworthy ones are: *Tājikanīlakaṇṭhī* of Nīlakaṇṭha (sixteenth century), *Meghamahodaya* by Meghviṇayagaṇi (seventeenth century), *Janmapatrīpaddhati* by Lābhacandragāṇi (eighteenth century), and the nineteenth century works of astrologer Bāpūdeva Śāstri.

A knowledge of *pañcāṅga* is a prerequisite to understanding the subject of astrology. This is the fivefold system of *tithi* (lunar day), *vāra* (weekday), *nakṣatra* (asterism), *yoga* (sum of the solar and lunar longitudes), and *karaṇa* (half lunar day). *Tithi*, the lunar date, is the duration of time in which the Moon moves 12°. The 15 *tithis* of the white fortnight (from new moon to full moon) are:

1. *Pratipadā*
2. *Dvītyā*
3. *Tṛtīyā*
4. *Caturthī*
5. *Pañcamī*
6. *ṣaṣṭhī*
7. *Saptamī*
8. *Aṣṭamī*
9. *Navamī*
10. *Daśamī*
11. *Ekādaśī*
12. *Dvādaśī*
13. *Trayodaśī*
14. *Caturdaśī*
15. *Pūrṇimā* ($15 \times 12^\circ = 180^\circ$)

In the black fortnight (from full moon to new moon), the 15th day is called *Amāvasyā* and the remainder are the same as above. *Tithis* are

Astrology in India, Table 1 Twenty-seven *nakṣatras* (asterisms)

<i>Ḳṛttikā</i>	<i>Rohiṇī</i>
<i>Mṛgaśīras</i>	<i>Ārdrā</i>
<i>Punarvasu</i>	<i>Puṣya</i>
<i>Āśleṣā</i>	<i>Maghā</i>
<i>Pūrvāphālgunī</i>	<i>Uttarāphālgunī</i>
<i>Hasta</i>	<i>Citrā</i>
<i>Svātī</i>	<i>Viśākhā</i>
<i>Anurādhā</i>	<i>Jyēṣṭhā</i>
<i>Mūla</i>	<i>Pūrvāṣāḍhā</i>
<i>Uttarāṣāḍhā</i>	<i>Śrōṇā</i>
<i>Śraviṣṭhā</i>	<i>Śatabhiṣaj</i>
<i>Pūrvā-Bhādrapada</i>	<i>Uttarā-Bhādrapada</i>
<i>Revatī</i>	<i>Aśvīnī</i>
<i>Bharaṇī</i>	

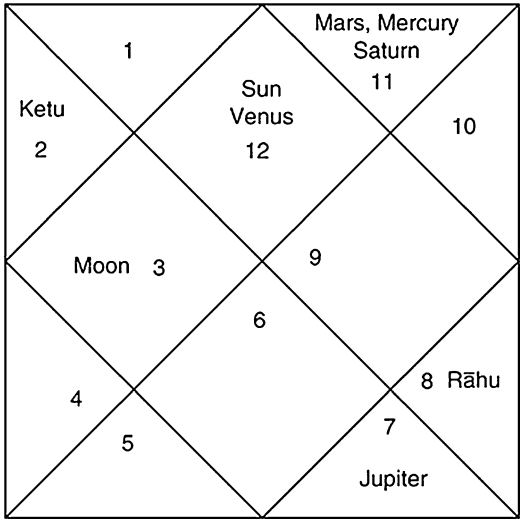
classified into five groups: *Nandā* (*tithis* 1,6,11), *Bhadrā* (2,7,12), *Jayā* (3,8,13), *Riktā* (4,9,14), and *Pūrṇā* (5,10,15).

The seven *vāras* (weekdays) are based on the names on the *grahas*: Sun, Moon, Mars, Mercury, Jupiter, Venus, and Saturn.

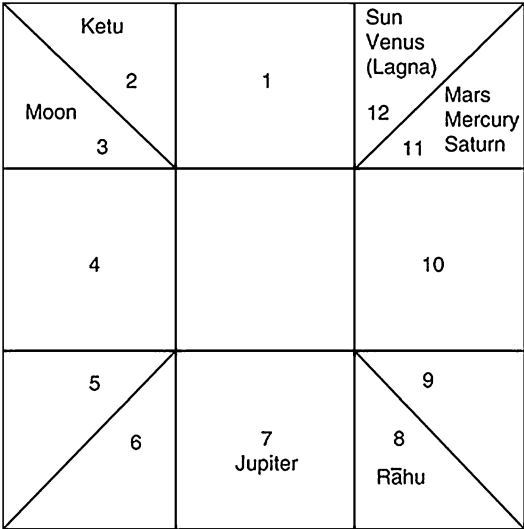
There are 27 *nakṣatras* (asterisms) bifurcating the ecliptic into 27 parts, each of 13.33° . These are mentioned in Table 1.

The ecliptic is again bifurcated into 12 parts through *Rāśis* (signs, each of 30°). The 12 signs are equal to 27 *nakṣatras*, or 1 sign = 2.25 constellations. For example, *Aśvīnī*, *Bharaṇī*, and one-quarter of *Ḳṛttikā* make the sign *Meṣa* (Aries). The remaining three quarters of *Ḳṛttikā*, *Rohiṇī*, and half of *Mṛgaśīra* make the sign *Vṛṣa* (Taurus). The same pattern holds true for the other signs: *Mithuna* (Gemini), *Karka* (Cancer), *Singha* (Leo), *Kanyā* (Virgo), *Tulā* (Libra), *Vṛścika* (Scorpio), *Dhanu* (Sagittarius), *Makara* (Capricorn), *Kumbha* (Aquarius), and *Mīna* (Pisces). Thus 27 constellations represent 12 signs.

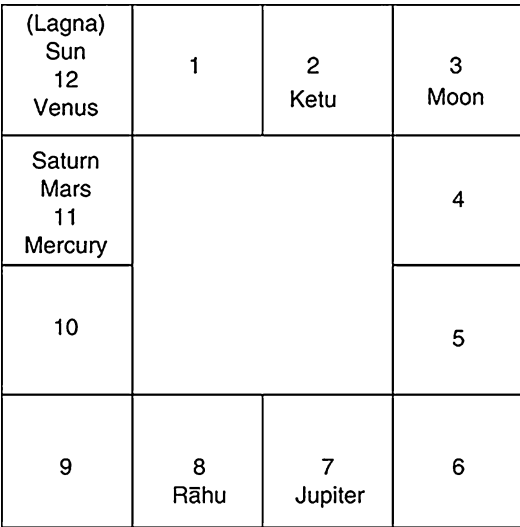
Yoga is the sum of the solar and lunar longitudes. If the sum of their degrees is between 0 and 13.33° , that is called *Viṣkambha Yoga* – from there until 26.66° it is *Prīti* – up to 40° it is *Āyusmāna*. The remaining yogas are *Saubhāgya*, *Śobhana*, *Atigaṇḍa*, *Sukarmā*, *Dhṛti*, *Śūla*, *Gaṇḍa*, *Vṛdhi*, *Dhruva*, *Vyāghāta*, *Harṣaṇa*, *Vajra*, *Siddhi*, *Vyatīpāta*, *Varīyāna*, *Parigha*,



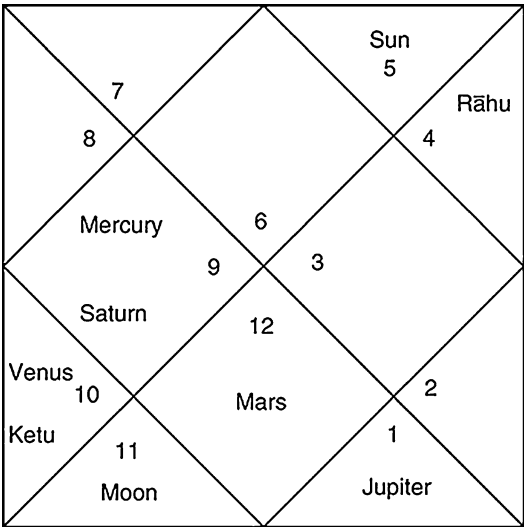
Astrology in India, Chart 1 Ascendant as sketched in northern India



Astrology in India, Chart 3 Ascendant as sketched in eastern India (West Bengal and Orissa)



Astrology in India, Chart 2 Ascendant as sketched in southern India



Astrology in India, Chart 4 Navamanśa chart

Śiva, Siddha, Sādhyā, Śubha, Śukla, Brahma, Aindra, and Vaidhṛti ($13.33^\circ \times 27 = 360^\circ$).

Karaṇa (constant or moveable) is the half part of the *tithi*. Constant *Karaṇa Śākuna* belongs to the second half of *Caturdaśī Catuspada* and *Nāga* to that of *Āmāvasyā* in the black fortnight, while *Kistughna* exists in the first half of the *Pratipada* of the white fortnight in every lunar

month. The remaining 14.5 *tithis* of the white and 13.5 *tithis* of the black fortnight contain eight rounds of seven moveable *Karaṇas*: *Bava, Bālava, Kaulava, Taitila, Gara, Vaṇija, and Viṣṭi*.

The subject matter of astrology may be divided into five groups: *Samhitā, Siddhānta, Jātaka, Prasāna, and Śākuna*. In ancient India, *Samhitā* was the miscellaneous collection of astrological materials out of which the remaining four grew.

Astrology in India, Table 2 Positions of *grahas* (planets) on 21 March 1994 at 6:02 a.m. at Varanasi

<i>Grahas</i> (planets)	Sun	Moon	Mars	Mercury	Jupiter	Venus	Saturn	<i>Rāhu</i>	<i>Ketu</i>
<i>Rāśi</i> (sign)	11	2	10	10	6	11	10	7	1
<i>Anśa</i> (degree)	6	15	16	9	23	22	8	3	3
<i>Kalā</i>	21	7	57	51	19	13	21	3	3
<i>Vikalā</i>	27	45	18	17	40	8	21	44	44

Siddhānta or *Gaṇita* refers to mathematical calculations about time, distance, and position of the planets. On the basis of the proper positions of 12 signs and 9 planets, a chart containing 12 chambers may be sketched. In northern, southern, and eastern India, astrologers sketch Charts 1, 2, and 3 which are called *Janmāṅga* or ascendant.

Jātaka (native) is the person about whom a prediction is made on the basis of a birth chart. Twelve houses represent the health, wealth, brother/sister, mother, offspring, diseases/enemies, wife/husband, death, fate, father, income, and expenses, as in Chart 1. *Daśās* (periods) are defined in numerous ways. The period of any planet becomes favorable or harmful according to its position and power in the horoscope (Chart 4).

There are many other astrological methods in India. As an example, in the Kerala system, numbers are assigned to alphabets, and the astrologer advises the person to say the names of a flower, river, or god on which the calculation depends.

Astrology is applied to many aspects of Indian life. There are rules concerning times for traveling, planting, and building. Favorable times for the preparation of medicines and treatment are also prescribed (Table 2).

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Astrology in Islam

Richard Lemay

A few considerations about the historical development of the term and concept of astrology as an intellectual discipline are in order, so as to avoid the many misconceptions that prevail in this field of historical enquiry.

The first question concerns the terminology applicable in medieval Arabic culture. What we consider astrology in our epistemology has very little connection with its medieval definition. Horoscope-making and interpreting are of course part of the game but with a rather remote bearing on its definition as a science in medieval eyes. In the mind of medieval Arab writers there is but one science of the sky with the moving bodies set in it. It was called *ʿilm an-nujūm* (science of the stars) and it consisted of two distinct treatments of the subject matter of the heavens: a purely mathematical one or *ʿilm al-falak* corresponding to our astronomy, and a humanistic but rather

conjectural one which aimed at deducing from the celestial motions their probable significance for the evolution of human affairs, more directly what we now call astrology. The name for this latter discipline was *ʿilm aḥkām an-nujūm* (science of the judgments of the stars): hence the new term *scientia iudiciorum* or judicial astrology in medieval Latin culture. The two methods of treatment were indissolubly linked in the overall picture, and it must be further stressed that the dominating interest of medieval Arabic civilization was the “science of the judgments of the stars.” On the practical level, the second portion of this dichotomy was considered an art, and the term *ṣanʿa* applied to it was the equivalent of any other trade or profession.

There were three levels through which Arab authors would approach the study of astrology: a first level through the general science of the stars which could be a predominantly philosophical enquiry bordering on what may be actually labeled cosmology. A second level, purely mathematical, consisted of the consideration of the movements of the spheres, of the celestial bodies they contained, and of phenomena affecting them. This approach corresponded more closely to our astronomy. A third level was in the extension of the above observations to judge their probable impact upon human affairs. The technique of these judgments (*aḥkām*) was determined according to very intricate rules embodied in the age-old lore of astrology proper: but the three levels were considered together to constitute the one science of the stars (*ʿilm an-nujūm*).

This tripartite structure of the science of the heavens among medieval Arab writers was not entirely their creation, for the historical event of early Arab conquests of the entire Middle East had put the young Arab civilization in direct contact with both the still active Hellenistic (Alexandrian) world of thought thriving in Egypt and in the Eastern Mediterranean on the one hand, and the very ancient Babylonian, Persian, and even Hindu cultural traditions on the other. In examining medieval Arabic astrology it is wise to keep in mind these major cultural orientations varying in importance according to

the stages of those historical convergences. During the first century of Arab conquests, which corresponds roughly with the rule of the Umayyad Caliphate of Damascus (660–750), the predominant cultural influence came from Syria and Egypt, in which Hellenistic culture and further Christianized Hellenism dominated. Even so, the impact of Greek learning was not directly linked at first with classical Greek science or philosophy, but rather with its late Hellenistic phase heavily marked by neo-Platonic and Alexandrian speculation or mysticism (hermeticism). The full force of the Greek example of learning and of its formative impact on Arabic astrology emerged only under the Abbasid rule (beginning in 750), tentatively at first under al-Mansūr (754–775) and Harūn al-Rashīd (786–809), but dramatically under ► al-Maʾmūn (813–833) through the direct importation of the works of thinkers and of scientists such as Aristotle in physics and cosmology, and of Ptolemy in astronomy/astrology. Al-Maʾmūn established at Baghdad an astronomical observatory and *Bayt al-ḥikma* (House of Wisdom) endowed with a great library. It was because of these favorable conditions that the science of astrology, like philosophy and medicine, took its definite hue in Arab literature under the label of *falsafa* (a transliteration of the Greek term philosophy). Maʾmūn’s patronage brought scientists and philosophers from all over the Muslim empire. It was likely in the midst of this intellectual fervor that the greatest writer in Arab astrology, Abu Maʾshar, came from his native Balkh in Khurāsān (now Afghanistan) to settle in Baghdad. Although Abū Maʾshar’s major work, the *Kitāb al-mudkhal al-kabīr* (Greater Introduction to Astronomy, AD 848) was completed during the generation following the death of al-Maʾmūn (AD 833), its success in molding the framework of Arab astrology that merged the diverse astrological traditions of Greece, Persia, and India must be ascribed to the lively interest in *falsafa* engendered by al-Maʾmūn’s sponsorship. With Abū Maʾshar’s work, Arab astrology acquired its definitive structure, the result of a syncretism of all Middle East traditions under the umbrella of Aristotelian cosmology and Ptolemaean astronomy/astrology.

Abū Ma'shar came to be quoted as the authority, even by those who criticized him (► *al-Bīrūnī*, Ibn Ridwān). His *Kitāb al-mudkhal al-kabīr* became the “bible” of Arabic astrology because it buttressed the science with a theoretical foundation based on *falsafa*, with Persian and Hindu traditions more or less coherently merged into it. Yet it provided only the introductory theory of astrology as part of the science of Nature. Further extension of the science of judgments of the stars to the full range of human affairs was seen as a kind of adjustment to their inevitable cosmic framework. Arabic astrological science came to include these five principal divisions.

1. A theoretical or introductory part (*mudkhal*) exploring its foundations in physical science and metaphysics. Here Abū Ma'shar's *Kitāb al-mudkhal al-kabīr* shared ultimate authority together with Ptolemy's *Tetrabiblos*.
2. A section dealing with Nativities (*mīlād*, *mawālīd*) which consisted of drawing up diagrams (horoscopes) of the state of the sky at the time of any beginning. Its most natural occasion was at the time of birth (hence “nativities”), or even of conception when possible, and it would be held as an indication of the probable unfolding of the various life circumstances of the individual person or object for whom it was drawn up. It is not without interest to recall that before the establishment of individual identity status such as birth registers, beginning with the sixteenth century in Europe, natal horoscopes constituted the most reliable record of the chronological span of individual lives. Not every one was born of sufficiently wealthy or honorable stock to be able to afford this luxury. Abū Ma'shar himself lamented the fact that he did not know the exact date of his birth, to compensate for which he had drawn up for himself a “general” (approximative) horoscope.
3. Interrogations (*masā'il*) which dealt mostly with enquiries about objects hidden or lost, innermost thoughts or intentions, purposes, etc. A kind of oracle, it aimed to assist individuals in their important decision making or help recover missing objects.
4. Elections or Choices (*ikhtiyārāt*), which were concerned with determining the most favorable moment for starting on important undertakings, such as the construction of cities, opening of hostilities in wartime, investiture or inauguration, or starting on a journey.
5. Weather predictions or meteorology, which were almanacs which astrologers operating for courts, cities, or institutions like universities would issue at the beginning of each new year, as part of their official duties. Weather predictions were of course a prime concern in any predominantly agrarian society.

The art or trade of the astrologer on the other hand was referred to by the term *ṣan'a* and was treated like any other profession. More specialized applications of astrological science still flourished beside the main stream, particularly in medicine where some Greek treatises of Hippocrates (*On Airs* and *De hebdomadibus* for instance) and Galenic ones about duration of pregnancy were merged into astrological prognostication (*taqdimat al-ma'rifa*) and enjoyed enormous vogue among physicians. Finally all sorts of “predictions” or “interpretation of signs” proliferated in a number of specialized practices of quackery into which some pretense of astrological judgments was introduced. Some of these are chiromancy (interpretation of lines of the hand), spatulomancy (interpretation of form of shoulder blade), and sternutomancy (on sneezing).

An influential sequel to Abū Ma'shar's *Greater Introduction* appeared by Aḥmad ibn Yūsuf, a physician, mathematician, and astrologer of the Tūlūnid era (870–904) in Egypt. Aḥmad wrote a chronicle of this Turkish dynasty and he authored several works of mathematics. He put together an astrological compendium which he entitled *Kitāb aṭh-ṭhamara* (Liber Fructus). Since it comprised 100 short propositions, each one accompanied by a substantial commentary, it came to be designated as *Centiloquium*. In fact its major doctrines are taken straight from Abū Ma'shar's *Kitāb al-mudkhal al-kabīr*. The very passage in Abū

Ma'shar's work which probably gave Aḥmad the inspiration for his forgery is met in a special section of the magnum opus (III, 1–2) where ► [Abū Ma'shar](#) enumerates the six benefits to be derived from astrological science, the most alluring of which are the “fructus” (*tamara*) to be anticipated from it.

These two works by Abū Ma'shar and by Ibn Yūsuf, respectively, the second in the footsteps of the first, influenced the West from the time of their translation into Latin during the twelfth century until the demise of astrology as a science in the Scientific Revolution of early modern times. The nature, influence, and significance of Arabic astrology in the East and the West during the Middle Ages were polarized around the success of these two major works.

See Also

- [Abū Ma'shar](#)
- [al-Bīrūnī](#)
- [al-Ma'mūn](#)
- [Ibn Riḍwān](#)

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Astronomical Instruments in India

Yukio Ōhashi

Astronomical knowledge in India can be traced back to the Vedic literature (ca. 1500–500 BCE), the earliest literature in India, but no astronomical instrument is mentioned there. Naked eye observations of the sun, moon, and lunar mansions were carried out. It is not clear whether five planets were observed or not.

There is a class of works called *Vedāṅga*, probably composed toward the end of the Vedic period, which is regarded as auxiliary to the Veda. It consists of six divisions, including *Jyotiṣa* (astronomy) and *Kalpa* (ceremonial). The *Kalpa* further consists of four divisions, including *Śulba* (method of the construction of the altar). The earliest astronomical instruments in India, the gnomon and the clepsydra, appear in the *Vedāṅga* literature.

The gnomon (Sanskrit: *śaṅku*) is used for the determination of cardinal directions in the *Kātyāyana-śulbasūtra*. A vertical gnomon is erected on a leveled ground, and a circle is drawn with a cord, whose length is equal to the height of the gnomon, with the center the foot of the gnomon. At the two points where the tip of the gnomon-shadow touches the circle, pins are placed, and they are joined by a straight line. This line is the east-west line.

The annual and diurnal variations of the length of the gnomon-shadow are recorded in the political work *Artha-śāstra* of Kauṭilya, the

Buddhist work *Śārdūlakarṇa-avadāna*, and Jaina works such as the *Sūrya-prajñāpti*. These records seem to be based on observations in North India.

The clepsydra is mentioned in the *Vedāṅga-jyotiṣa*, the *Artha-śāstra*, and the *Śārdūlakarṇa-avadāna*. It was like a water jar with a hole at its bottom from which water flowed out in a *nāḍikā* (one-sixtieth of a day).

Toward the end of the *Vedāṅga* astronomy period, certain Greek ideas of astronomy and astrology had some influence in India from the second to the fourth century AD. After that, Hindu astronomy (*Jyotiṣa*) established itself as an independent discipline, and several fundamental texts called *Siddhāntas* were composed. I call this period, from about the end of the fifth to the twelfth centuries AD, the classical *Siddhānta* period. The main astronomers who described astronomical instruments are ► *Āryabhaṭa* (b. AD 476), ► *Varāhamihira* (sixth century AD), ► *Brahmagupta* (b. AD 598), Lalla (eighth or ninth century AD), ► *Śrīpati* (eleventh century AD), ► *Bhāskara II* (b. AD 1114), and the anonymous author of the *Sūrya-siddhānta*. The *Siddhāntas* composed by Brahmagupta, Lalla, Śrīpati, and Bhāskara II contain special chapters on astronomical instruments entitled *Yantra-adhyāya*. The Sanskrit word *yantra* means instrument. No observational data are recorded in the *Siddhāntas*, and the extent of actual observations in this period is controversial. Roger Billard maintained that astronomical constants in the *Siddhāntas* were determined by actual observations, while David Pingree argued that they were exclusively borrowed from Greek astronomy. In this connection, we should note that the method of determination of astronomical constants by

means of observations was correctly explained by Bhāskara II. Let us see the instruments in this period.

The gnomon (*śaniku*) was continually used in this period. The theory of the gnomon – such as the relationship between the length of gnomon-shadow, the latitude of the observer, and time – was developed in this period, and a special chapter called *Tripraśna-adhyāya* in the *Siddhāntas* was devoted to this subject. Trigonometry, invented in India, was fully utilized for this purpose.

The staff (*yaṣṭi-yantra*) is a simple stick, used to sight an object. There are some variations of the staff, such as V-shaped staffs for determining angular distance with the help of a graduated level circle.

The circle instrument (*cakra-yantra*) is a graduated circular hoop or board suspended vertically. The sun's altitude or zenith distance is determined, and time is roughly calculated from it. Variations of the circle instrument are the semicircle instrument (*dhanur-yantra*) and the quadrant (*turya-golaka*).

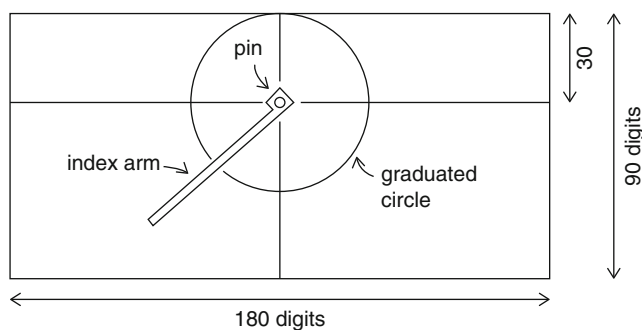
A circular board kept horizontally with a central rod is the chair instrument (*pīṭha-yantra*), and a similar semicircular board is the bowl instrument (*kapāla-yantra*). They determine the sun's azimuth, and time is roughly calculated from them.

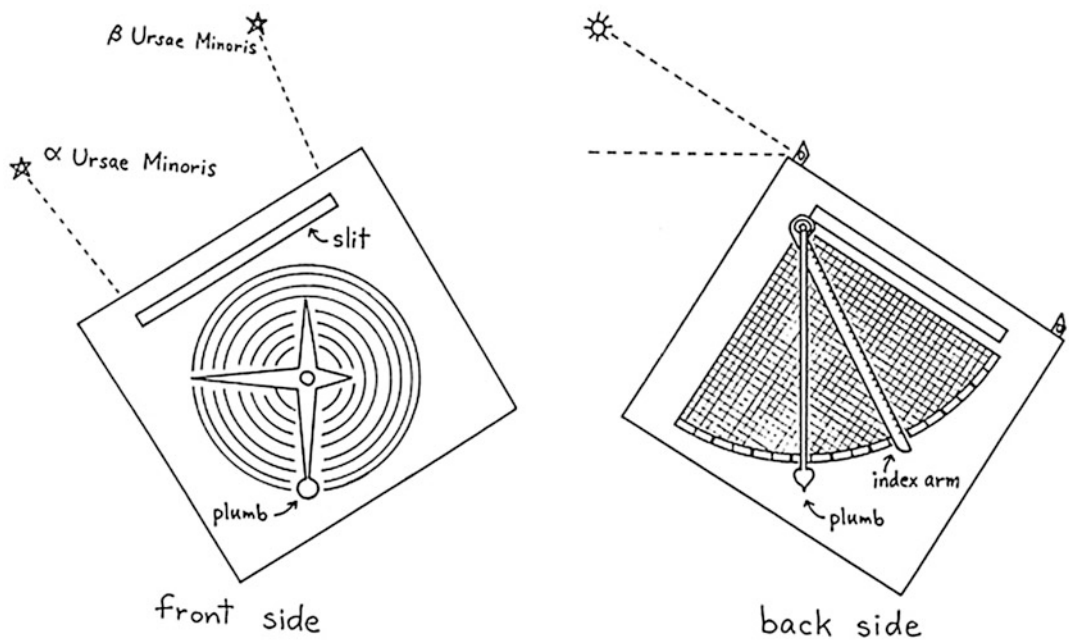
A circular board kept in the equatorial plane is the equator instrument (*nāḍīvalaya-yantra*). It is a kind of equatorial sundial. The combination of two semicircular boards, one of which is in the equatorial plane, is the scissors instrument (*kartarī-yantra*). Its simplified version is the semicircular board in an equatorial plane with a central rod.

Astronomical

Instruments in India,

Plate 1 The armillary sphere in the Government Museum, Jaipur (a), and in Rao Madho Singh Museum, Kota (b), (both in Rajasthan)

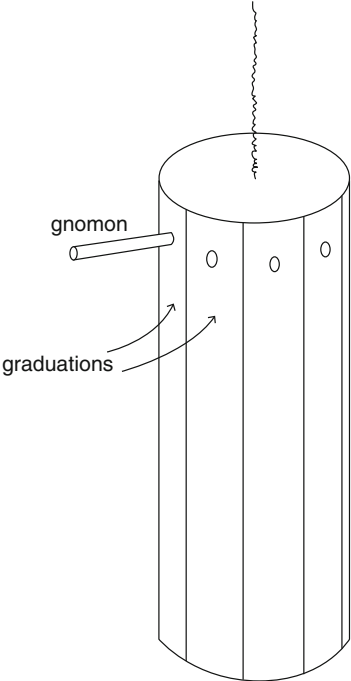




Astronomical Instruments in India, Plate 2 The clepsydra preserved in Rao Madho Singh Museum, Kota (Rajasthan)

The Indian armillary sphere (*gola-yantra*) was based on equatorial coordinates, unlike the Greek armillary sphere, which was based on ecliptical coordinates, although the Indian armillary sphere also had an ecliptical hoop. Probably, the celestial coordinates of the junction stars of the lunar mansions were determined by the armillary sphere since the seventh century or so (see Plate 1). There was also a celestial globe rotated by flowing water.

The clepsydra (*ghaṭī-yantra*) was widely used until recent times. Unlike the clepsydra of the *Vedāṅga* period, which was the outflow type of water clock, the clepsydra of this period is a bowl with a hole at its bottom floating on water. Water flows into the bowl, and it sinks after a certain time interval. The Chinese Buddhist traveler Yijing (AD 635–713) recorded the actual use of the clepsydra of this type. The clepsydra can be seen in use in a museum at Kota (Rajasthan) (see Plate 2). Several astronomers also described water-driven instruments such as the model of fighting sheep.



Astronomical Instruments in India, Fig. 1 *Phalaka-yantra*

**Astronomical
Instruments in India,
Fig. 2** *Dhruva-bhrama-
yantra*

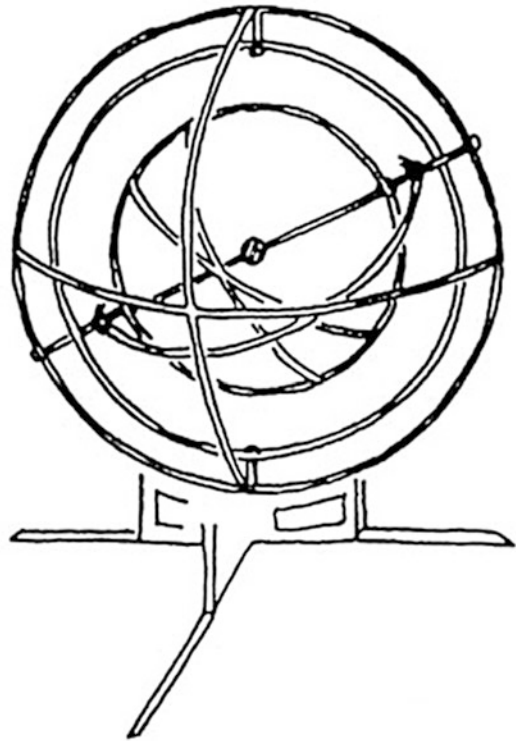


A

The board instrument (*phalaka-yantra*) invented by ► **Bhāskara II** is a rectangular board with a pin and an index arm, used to determine time graphically from the sun's altitude (see Fig. 1). This is an ingenious instrument based on the Hindu theory of the gnomon.

The astrolabe was introduced into India from the Islamic world at the time of Fīrūz Shāh (r. AD 1351–1388) of the Tughluq dynasty. Fīrūz Shāh's court astronomer Mahendra Sūri composed a Sanskrit work on the astrolabe entitled *Yantra-rāja* (King of Instruments, the Sanskrit term for the astrolabe) in AD 1370. This is the earliest Sanskrit work on Islamic astronomy. Use of the astrolabe rapidly spread among some Hindu astronomers, and Padmanābha (AD 1423) and Rāmacandra (AD 1428) described the astrolabe in their works.

Some new instruments were made in the Delhi Sultanate and Mughal periods. Padmanābha invented a kind of nocturnal instrument called *dhruva-bhrama-yantra* (polar rotation instrument) (see Fig. 2). It was a rectangular board with a slit and a set of pointers with concentric graduated circles. Adjusting the slit to the direction of α and β Ursae Minoris, time and other calculations could be obtained with the help of pointers. Its backside was made as a quadrant with a plumb and an index arm. Thirty parallel lines were drawn inside the quadrant, and trigonometrical calculations were done graphically. After determining the sun's altitude with the



Astronomical Instruments in India, Fig. 3 *Pratoda-
yantra*

help of the plumb, time was calculated graphically with the help of the index arm.

Later, Cakradhara described the quadrant as an independent instrument, and a more exact method to calculate time was explained.

Astronomical Instruments in India, Plate 3 Jai Singh's observatory at Jaipur (Rajasthan), Viewed from its larger Samarāt-yantra



Astronomical Instruments in India, Plate 4 The larger Samarāt-yantra in Jai Singh's observatory at Jaipur

Another new type of instrument in this period was the cylindrical sundial called *kaśā-yantra* (whip instrument) by Hema (late fifteenth century AD) or *pratoda-yantra* (whip instrument) by Ganeśa (b. AD 1507) (see Fig. 3). It is a cylindrical rod having a horizontal gnomon and graduations of time according to the vertical shadow below the gnomon.

The quadrant and the cylindrical sundial exist in the Islamic world also, but the possibility of their influence on these Indian instruments is still to be investigated.

The Mahārāja of Jaipur, Sawai Jai Singh (AD 1688–1743), constructed five astronomical

observatories at the beginning of the eighteenth century. The observatory in Mathura is not extant, but those in Delhi, Jaipur, Ujjain, and Banaras are (Plate 3). There are several huge instruments based on Hindu and Islamic astronomy. For example, the *samarāt-yantra* (emperor instrument) is a huge sundial which consists of a triangular gnomon wall and a pair of quadrants toward the ► east and west of the gnomon wall. Time has been graduated on the quadrants (Plates 4).

By this time, European astronomy had begun to be introduced into India, and Jai Singh had certain information about it. The earliest

Astronomical**Instruments in India,**

Plate 5 Image of the sun projected on the *ṣaṣṭāṃśa-yantra* in Jai Singh's observatory at Jaipur



- ▶ [Gnomon in India](#)
- ▶ [Jai Singh](#)
- ▶ [Lalla](#)
- ▶ [Lunar Mansions in Islam](#)
- ▶ [Mahendra Sūri](#)
- ▶ [Observatories in India](#)
- ▶ [Quadrant](#)
- ▶ [Śrīpati](#)
- ▶ [Śulbasūtras](#)
- ▶ [Trigonometry in Indian Mathematics](#)
- ▶ [Varāhamihira](#)

Astronomical Instruments in India, Plate 6 The *Misra-yantra* in Jai Singh's observatory at Delhi

European style astronomical observatory in India is a private one of William Petrie, an officer of the British East India Company, which was set up in 1786 at his residence in Madras (Plates 5 and 6).

See Also

- ▶ [Armillary Spheres in India](#)
- ▶ [Āryabhaṭa](#)
- ▶ [Astrolabe](#)
- ▶ [Bhāskara II](#)
- ▶ [Brahmagupta](#)
- ▶ [Clocks and Watches](#)
- ▶ [Globes](#)

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Astronomical Instruments in Japan

Nakamura Tsuko

Beginning around the sixth century, Japan was under the strong cultural influence of China (via Korea), and astronomy was no exception. Although by the beginning of the eighth century an institutional form of the Chinese Astronomical Office had been introduced into the Japanese court government along with primitive gnomons and water clocks, astronomy as a science did not become part of Japanese society, and only the astrological aspects of Chinese astronomy survived. This situation continued for many centuries throughout medieval times, partially due to the domestic turmoil caused by frequent civil wars. It was not until after the shogun Tokugawa Ieyasu finally ruled over Japan in 1615 that the Japanese people could afford to nurture their own culture. In the mid-sixteenth century, European astronomy was first brought by the Christian missionaries from Portugal and Spain, though their influence did not last long. The reason was that the shogunal government ousted them because it suspected that the true aim of the Christian missionary activities in Japan was political occupation. Thereafter, import of foreign books relating to the Western religion and culture was strictly prohibited, and only Dutch traders were allowed to come to Nagasaki.

Astronomy as a science and the development of astronomical instruments started from the

seventeenth century in Japan (Nakayama, 1969). In the 1680s, ► [Shibukawa Harumi](#) was nominated to be the first astronomical officer of the shogunate, after the government adopted his proposed new luni-solar calendar. For observations in this calendar reform, he made a gnomon with an apparatus to sharpen the blurred shadow of the sun. He also constructed an armillary sphere of 90 cm in diameter which was a simplified version of the traditional Chinese armillary sphere, and he measured the positions of many stars with it to produce the first Japanese star map. His compiled star catalog reveals that the observational error of his armillary sphere was about half a degree, though this instrument has since been lost. The only existing armillary sphere actually used for astronomical observations is the one preserved at Sendai City Observatory, which is about 100 cm in diameter and made of bronze with scales of half a degree interval.

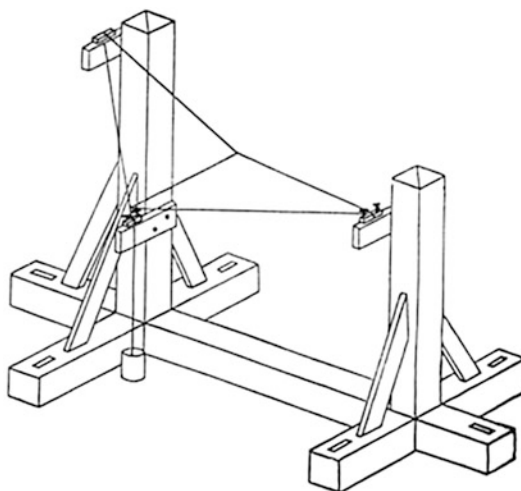
After Harumi, there was no one to inherit and develop his scientific achievements till the advent of the eighth shogun Tokugawa Yoshimune in the 1710s. He was deeply interested in the natural sciences and made efforts to organize and cultivate the study of science. In 1729 he relaxed the ban of importing Chinese books written by Jesuit priests in China and also allowed Dutch interpreters at Nagasaki to learn Dutch books. This was because, he recognized the superiority of Western astronomy over Chinese traditional astronomy and planned a calendar reform using Western astronomy. He took some astronomers and mathematicians to the shogunal astronomical office and ordered an optician from Nagasaki to devise good telescopes for astronomical observations. Yoshimune himself was also engaged in astronomical observations by inventing a few new armillary spheres and transit quadrants. Despite Yoshimune's enthusiasm, his intended calendar reform was unsuccessful, due to the poor abilities of the shogunal astronomers and the opposition of the court astronomers based at Kyoto.

Because of the hereditary system for the position of the shogunal astronomers, the scholastic ability of some amateur astronomers overpowered that of the shogunal astronomers

around the end of the eighteenth century. The shogunate eventually summoned the two civil astronomers of Osaka, Takahashi Yoshitoki and ► **Hazama Shigetomi**, to take leadership for a new calendar reform as the shogunal astronomers (Watanabe, 1987). The former was superior in theoretical astronomy and the latter in developing astronomical instruments. Before their nomination to the position, they already possessed some knowledge of Copernican and Keplerian theories of planetary motions learned through Sino-Jesuit astronomical books, and they also devised accurate astronomical instruments by consulting *Lingtai Yizhi* (Astronomical Observatory Instruments, by Verbiest et al. (1674)). This book described with many detailed illustrations the structure and usage of several new astronomical instruments constructed by the Jesuit astronomers serving the Qing Dynasty, which were hybrids of the traditional Chinese instruments and European ones invented by people such as Tycho Brahe.

The principal instruments among the ones produced by the Takahashi-Hazama group were the quadrant of 195 cm in radius with a telescope and the wire meridian transit of about 3.6 m in height, both installed at the shogunal observatory of Edo (ancient Tokyo). The quadrant was equipped with a diagonal subscale, which was reinvented by Brahe, so that it could measure stellar positions (altitudes) with an error of 10–15 arcsec. For measuring the meridian-transit time of stars, they used an astronomical pendulum clock which was also devised by the Takahashi-Hazama group with hints from *Lingtai Yizhi*. This astronomical clock could give stellar-transit timings with an accuracy of about 1 s. Although several such astronomical clocks made before 1850 still exist, all the instruments used at the shogunal observatory of Edo were lost or destroyed in the disorder of the Meiji Restoration in 1868.

► **Ino Tadataka**, one of Takahashi's disciples, conducted a large-scale land survey all over the Japanese archipelago starting from 1800. This was the first scientific expedition of geodesy conducted in Japan. Although the methods of mapmaking and measuring



Astronomical Instruments in Japan, Fig. 1 Transportable wire meridian transit used by Ino Tadataka in his land survey expedition of Japan (Otani, 1932)

instruments by Ino were not innovative ones, his 16-year-long enthusiasm led him to complete the entire map of Japan. For the fieldwork, he designed and constructed a few portable quadrants for astronomical latitude observations; the most frequently used one has the quadrant whose radius is 115 cm. Analysis of his field notes shows that the accuracy of single observations with this quadrant was about 20–30 arcsec. Ino also used a transportable wire transit (Fig. 1) for observing the meridian passage of stars along with a pendulum clock. This transit instrument was not useful for determining longitudes of triangulation points because of the lack of a precise chronometer, but it was mainly used for maintaining the local time. As for azimuth measurements, he devised semicircular magnetic compasses with an alidade. His 57-volume azimuthal catalog of more than 2,200 triangulation points reveals that the typical error of Ino's azimuth measurements was 5'. All of those instruments are now preserved at Ino's memorial museum. Astronomers of the Takahashi-Hazama group including Ino did not adopt the Vernier subscale but exclusively adhered to the diagonal subscale for precise measurements.

Telescopes

Telescopes in Japan have a fairly long history. As far as historical records tell us, the first introduction of a telescope into Japan goes back to 1613, when a captain of the British East India Company offered a telescope to the first Shogun Tokugawa Ieyasu for trade promotion; this telescope does not seem to exist now. The earliest existing telescope in Japan was the one owned by Tokugawa Yoshinao, the ninth prince of Ieyasu (now preserved at the Tokugawa Fine Arts Museum). Since Yoshinao died in 1650, it means that his telescope was produced in or before that year. Our recent investigation made clear that this telescope was of the Schyrlean type, made of four convex lenses giving erect images, with a magnifying power of about four. Analysis of the design, the fabrication method, the surface decoration of the telescope, and the relating historical episodes all suggest that it was not a Western make at all but produced around the southern coastal area of China, or Taiwan, or Nagasaki, by the East Asians. In the 1720s, the optician of Nagasaki, Mori Nizaemon, responding to the order of the Shogun Yoshimune, produced at least several telescopes for astronomical observations, a few of which still exist. The largest one has a tube length of 340 cm with an objective lens diameter of 73 mm, giving the magnifying power of about ten. It is likely that the shogunal astronomers used this telescope for observations of the planetary surfaces.

Around the 1790s, Iwahashi Zenbei of Osaka started production of refractor telescopes on a commercial basis. His telescopes were characterized by special decorative patterns on the tube surface, so that plenty of imitations and fakes with similar decorations appeared at later times. High-quality telescopes by Iwahashi gave the magnifying power of more than 10–20. Because the Iwahashi's family continued to fabricate their telescopes for four generations, they are most commonly seen in museum collections and antique markets. All the telescopic tubes and caps from Yoshinao's to Iwahashi's were produced by the traditional technique called

Ikkan-bari, which utilizes paper and thin wood glued with urushi lacquer. In 1834, the gunsmith, Kunitomo Tobei, succeeded in completing his first Gregorian reflector telescope for the first time in Japan (Yamamoto, 1937). Currently four brass telescopes of nearly the same size (with an inner tube diameter of 62 mm) are identified as his products. Although it is quite unknown how he could polish the bronze primary mirrors without knowledge of Western modern optics and a mirror-grinding machine, Foucault's method of mirror testing has revealed that at least a few of Kunitomo's telescopes possess parabolic surfaces nearly as accurate as those of contemporary Gregorian telescopes. With one of them, Kunitomo made continuous observations of sunspots for more than 1 year, and during that time he independently discovered the penumbra of the sunspot. It is a shame that his excellent engineering could not find any successors, as pioneering achievements like Kunitomo's have often had a similar fate in the history of Japan.

Octants and Sextants

Octants and sextants are certainly worth mentioning in the history of Japanese astronomical instruments. Dutch sailors first brought octants, superb handy navigational and astronomical instruments, into Japan in the 1770s. Because of having no previous information on the principle of an octant and the Vernier subscale inscribed on its arc, both the issues greatly annoyed Japanese astronomers (Nakamura, 2002). Only the practical usage of an octant on the sea had been known since 1782, through a Japanese translation of the Dutch book on octants written by Cornelis Douwes (1749). It was not before 1800–1810 that scholars in Japan began to understand how an octant works and the principle of the Vernier subscale. Since at that time the shogunal government kept a strict seclusion policy and prohibited construction of ships large enough to enable remote voyages, the Japanese had no chance to use octants and sextants in ocean navigation. This motivated some people to apply octants in

Astronomical Instruments in Japan,

Fig. 2 Drawing of Murata's range finder (1852)



measuring angles of distant targets on the ground. Several books explaining how to use octants and sextants in land surveying were written up to the middle of the nineteenth century. One problem with an octant in measuring angles of ground targets was systematic errors due to the parallax caused by a separation between the two mirrors comprising major components of an octant. On the contrary, some land surveyors, like Murata Sajuro, made positive use of the parallactic problem. He introduced, in his book of 1852, a range finder which is a heavily deformed octant having a very wide mirror separation (Fig. 2); Murata's book describes range finders with mirror separations of 1.8, 3.6, and 5.4 m. The left panel of Fig. 2 indicates that this instrument was invented for military purposes to measure the distance of a ship on the sea. After the Meiji Restoration of 1868, modern astronomical instruments imported from Europe soon replaced all the Japanese ones.

See Also

► [Ino Tadataka](#)

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Astronomical Instruments in Korea

Young-Ho Hahn

As a country which shares its border with China, ancient Korea also shared many of her neighbor's astronomical achievements. Korea adopted Chinese calendars as a standard and kept identical seasons of the year. But rulers of the Korean peninsula had also tried to establish an independent calendar system, especially during the Chosun dynasty (1392–1910). They attempted to bring out their own almanac at the same level of precision as the Chinese one. Several astronomical projects carried out under the initiative of King Sejong are the best-known examples of such efforts. From 1432 to 1439 a platform, *Ganeuidae*, for the royal observatory was built in the palace and every necessary astronomical instrument was added to it.

Korea has one of the world's oldest observatories, *Chomsungdae*, shown in Fig. 1. It was built in the early seventh century. Another observatory was constructed in the early tenth century and is also extant. Unfortunately only a small number of astronomical instruments and records prior to the fifteenth century have survived. But, as these observatories show, there had been many attempts to read heavenly phenomena even before the Chosun began.

All the astronomical instruments mentioned in this article, although many of them have been lost and are known only through records, are those made during the Chosun period. King Sejong's projects were very important to Korean astronomy. In addition to establishing the first independent calendar, *Chiljeongsan*, various instruments, such as equatorial torquetums [the torquetum or turquet is an instrument designed to take and convert measurements made in three sets of coordinates: horizon, equatorial, and ecliptic], armillary spheres, celestial ► [globes](#), sundials, and auto-striking clepsydras, were introduced. Some of them were made after Chinese models and others were original. The most



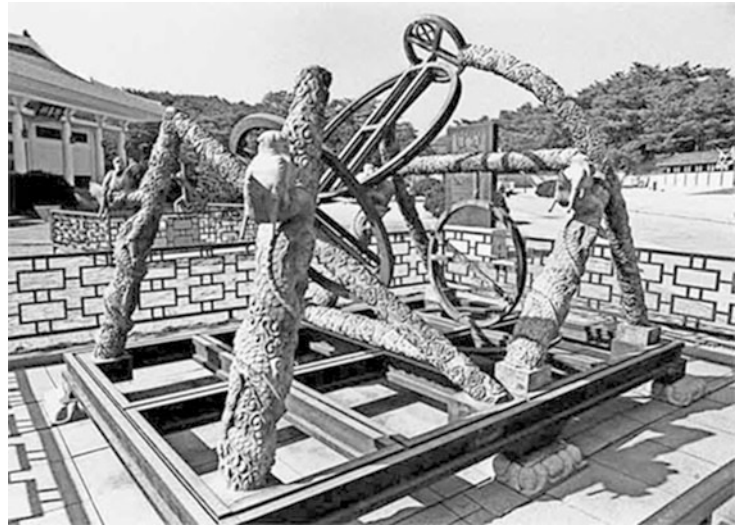
Astronomical Instruments in Korea, Fig. 1 World's oldest observatory, *Chomsungdae* in Kyongju

comprehensive description of Sejong's instruments is in Needham's *The Hall of Heavenly Records* (1986).

When Japan invaded Korea in 1592 and burnt down the royal palaces in Seoul, almost every instrument was lost, and Sejong's astronomical instruments were burned. Parts of these were restored after the war according to original designs. While the Court of Chosun was struggling to rebuild after successive raids by Manchurian Qing, Jesuit missionaries in China worked to change the Chinese calendar system to that based on Western astronomy. Officials and scholars of Chosun had to confront unfamiliar Western mathematics and astronomy to catch up with the advanced Chinese calendar. Using projection geometry, they made planar instruments such as astrolabes and sundials for themselves. Finally at the end of the eighteenth century,

Astronomical Instruments in Korea,

Fig. 2 Reconstructed model of simplified instrument *Ganeui* in Yeosu



A

the Korean royal observatory was able to create a pair of unique Western-style sundials.

Each instrument that follows is classified according to its structure and function.

Equatorial Torquetums

An approximately 7 m high, 10 m long and 7 m broad platform of the royal observatory was named *Ganeuida*, because the equatorial torquetum, *Ganeui*, the largest representative of Sejong's observing instruments, was installed on it.

The Korean *Ganeui* was based on Guo Shou-Jing's *Jianyi*, shown in Fig. 2. Guo, of the Chinese Yuan dynasty, invented a new instrument by taking equatorial and meridian rings out and eliminating ecliptic and selenic rings from the traditional armillary sphere. Details of *Jianyi* (literally, simplified instrument) are described and illustrated in Needham's *Science and Civilisation in China*, vol.3 (1959).

Sejong's officials made a wooden prototype and checked the exact polar elevation of Seoul. They completed a bronze-cast *Ganeui* in 1433. Although much simpler in shape than an armillary sphere with multiple-layered rings, the full-scale Simplified Instrument was too large to handle easily. In 1434 King Sejong ordered his

scholars to make a smaller version, and they made two copies of the portable *Soganeui* (Small Simplified Instrument), shown in Fig. 3.

Sejong's astronomers also created a unique observing device, *Ilseongjeongsieui* (Sun-and-Star Time-Determining Instrument). As its name implies, this instrument was both a sundial and stardial. With triple equatorial dial plates, double axially protruded polar-sighting rings, an alidade, and two sighting threads, the direction of the sun and some specified stars near the north pole could be read. This in turn revealed the time of observation. Figure 4 shows the reconstructed model of the round-the-clock time-determining instrument.

Armillary Spheres, Celestial Globes, and Astronomical Clocks

After Guo Shou-Jing's *Jianyi*, armillary spheres in East Asia were based on the Simplified Instrument, not on platforms of observatories. They became the driving mechanism of the indoor astronomical clock. Although the first Chinese astronomical clock dates back to the second century AD, it was at the end of the eleventh century that Su Sung's *Shuiyunyixiangtai* (Water-Powered Sphere and Globe Tower), appeared in China. The inner rings of the armillary sphere and



Astronomical Instruments in Korea, Fig. 3 Reconstructed model of small simplified instrument *Soganeui* in Yeoju

the star-embedded sphere of the celestial globe were rotated by a water wheel in accordance with each heavenly body. The sketch of the clock tower in Fig. 5 is taken from Su Sung's book, and more details of this gigantic clock may be found in Needham's *Heavenly Clockwork* (1986).

China's long tradition of astronomical clocks culminated in Su Sung's work in the Sung dynasty. During the succeeding Yuan period, such water-driven clocks as Guo Shou-Jing's Lantern Clepsydra and Emperor Shun-Ti's Palace Clepsydra were made. But they were not classified as astronomical clocks because they did not have any devices like spheres or ► globes to indicate heavenly motions.

King Sejong revived the East Asian tradition of astronomical clocks in Korea by equipping a

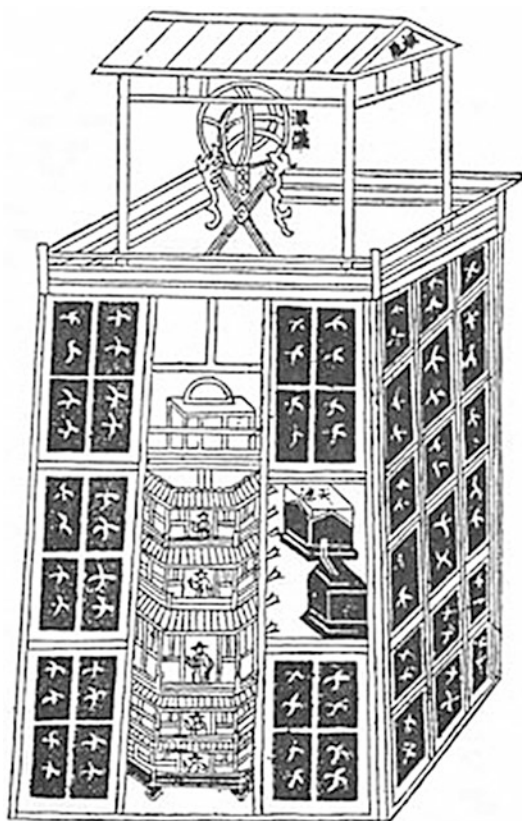


Astronomical Instruments in Korea, Fig. 4 Sun-and-star time-determining instrument *Ilseongjeongsieui* reconstructed

water-operated sphere and globe near his observatory. Except for the layout and size of the instruments, the basic structure of Sejong's clock is thought to be the same as Su Sung's.

In 1438 the artisan Jang Young-Sil made one more water-powered astronomical clock, *Heumgyonggaknu*, close to King Sejong's inner palace. The Clepsydra of the Respectful Veneration Pavilion, although it vanished long ago, is one of the most spectacular astronomical clocks ever made in Korea.

A ball-shaped golden figure moved round the 7 ft. high mountaintop while keeping the same polar distance and directions of rising and setting to the sun for each season. Below the sun image



Astronomical Instruments in Korea, Fig. 5 Su Sung's water-powered sphere and globe tower

stood four jade female gods at the four cardinal points, each with an animal-figured direction god. The ringing of a golden bell in the hand of a god and the turning of the accompanying animal god announced the beginning and middle of the double hours. There was a high platform at the southern foot of the mountain, on which hammers struck their respective instruments to announce the assigned double hour or night watch. On the ground level 12 jade gods surrounded the mountain, paired with each hour god. In addition to the extra platform carrying an inclined vessel, there were paintings of rural scenery during the four seasons and wooden carvings of men, birds, and plants.

This splendid clepsydra was totally destroyed and restored twice over 200 years. Two decades after the abolition of *Heumgyonggaknu*, Yi Min-Cheol made an armillary clock as the

successor of Jang Young-Sil's clockwork in the mid-seventeenth century. The new armillary clock was derived from Sino-Korean astronomical clepsydras, but it had a considerably different appearance. Yi built a cabinet in which water-operated driving mechanisms and a time-announcing apparatus were contained. An armillary sphere, as a part of astronomical clock, was installed on the plinth connected to the box.

Song Yi-Young, in close cooperation with Yi Min-Cheol, made an additional weight-driven armillary clock at the same time in 1669. Instead of Yi's water-powered device he adopted the driving mechanism that had been applied to Western mechanical clocks. Fortunately, as shown in Fig. 6, an improved version of Song's armillary clock has survived and is preserved in the Museum of Korea University, Seoul. Needham devoted one whole chapter of *The Hall of Heavenly Records* (1986) to describing this clock; he wrote that the Song Yi-Young/Yi Min-Cheol clock deserved widespread recognition as a landmark in the history of East Asian horology.

Western astronomy and astronomical instruments began to spread to Korean scholars from the early part of the eighteenth century. Hong Dae-Yong made the last astronomical clock in East Asia. He coupled a mechanical clock directly with the sidereal components of his armillary sphere and attached kinds of differential gears to distinguish solar and lunar motions from sidereal movement.

In 1789 the royal observatory made an equatorial armillary sphere to correct the records of meridian transits. Taking a Westernized, Chinese armillary sphere as a model, Kim Young made Chosun's first observing armillary sphere that could measure heavenly bodies at the accuracy level of 15 s.

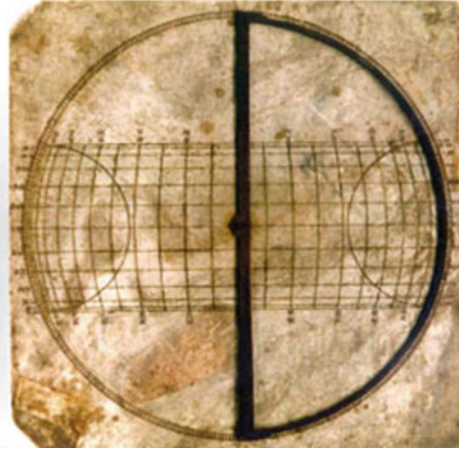
Astrolabes

The early Jesuit missionaries introduced astrolabes to China. Books on planispheric or universal astrolabes had been published in Chinese

Astronomical

Instruments in Korea,

Fig. 6 Armillary clock in the Museum of Korea University, Seoul



Astronomical Instruments in Korea, Fig. 7 Korean relics of celestial planisphere (left) and universal astrolabe (right)

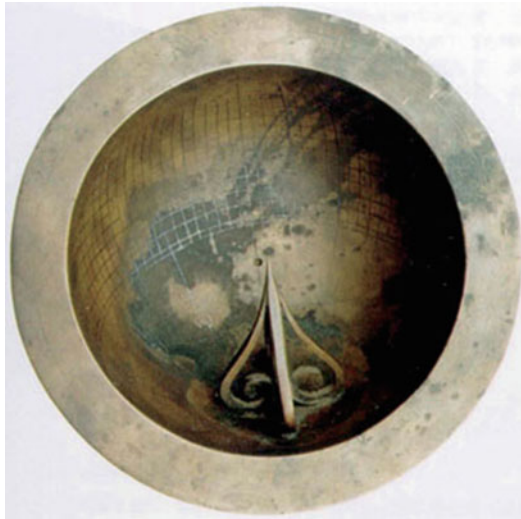
during the first quarter of the seventeenth century. However, the actual astrolabes did not arouse as much interest from Chinese scholars as the books introducing those instruments. Thus China did not leave any trace that showed practical uses for Western-style astrolabes except the celestial planisphere, *Pinghunyi*.

More than 100 years later, Korean scholars made all the Western planar instruments for themselves from reading these foreign books. But the planispheric astrolabe was uncommon in Korea too. The plate of the Western astrolabe was replaced with the planispheric star chart in

Pinghunyi, and the rete was revised simply to an arc of horizon on the eastern instrument as shown in Fig. 7. Although several celestial planispheres have been handed down, universal astrolabes are very rare. Moreover, no planispheric astrolabe has survived.

Sundials

Ancient Korea contributed to the diversity of sundials by adding her unique shadow-tracking instruments. Especially during King Sejong's



Astronomical Instruments in Korea, Fig. 8 A scaphe sundial *Angbuilgui*

reign, several distinguished solar devices were invented and equipped. The best-known representative is the scaphe sundial, *Angbuilgui*. This sundial, shown in Fig. 8, has a hemispherical surface of grid lines. Since the end point of the gnomon coincides with the center of the sphere, the shadow of the sharp end is cast to the grid surface always at a right angle and can be read clearly and accurately even at times near sunrise and sunset. The scaphe sundial was used as a main time indicator throughout the Chosun dynasty.

During the eighteenth century a few horizontal sundials were made; they replaced the role of the scaphe sundial in the Court. The new Western-origin sun trackers had the simple appearance of a flat slab, although the construction of the shadow lines was not easily attainable. Once the geometrical essentials to construct foreign sundials became known, the royal observatory preferred to make horizontal instruments rather than the scaphe sundial with its hemispherical surface of shadow lines.

Among these horizontal sundials, *Ganpyongilgui* and *Hongaeilgui* are quite unique. In 1785 these two were carved side by side on the same 1.3 m-long stone table as

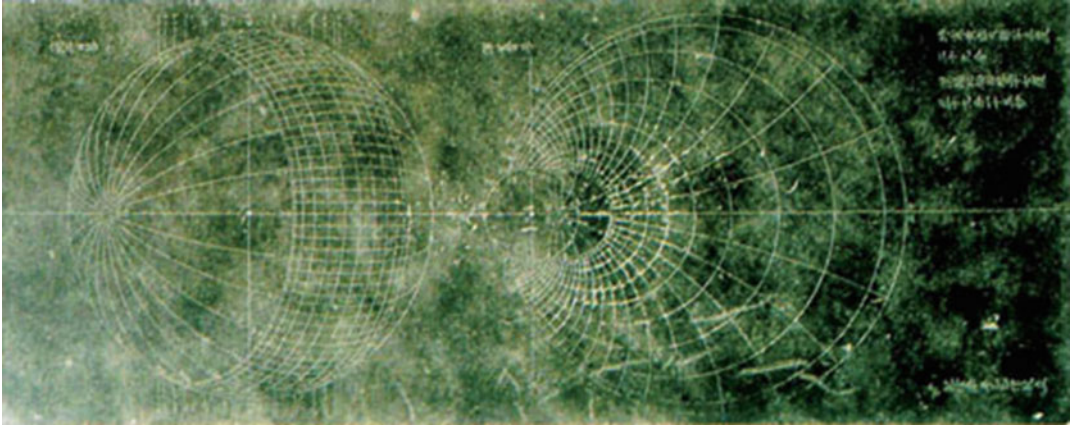
shown in Fig. 9. The stone slab with 52 cm width is now preserved in the Royal Relic Exhibition Hall of Deoksu Palace in Seoul.

Ganpyongilgui was based on a Rojas type universal astrolabe and *Hongaeilgui* on a planispheric astrolabe. But the way they were developed was far from simply duplicating the original instruments. The inventor of these sundials, probably one of the high officials of the royal observatory, must have been a master of the principles of planispheric projection to carry out significant modifications for these particular horizontal instruments.

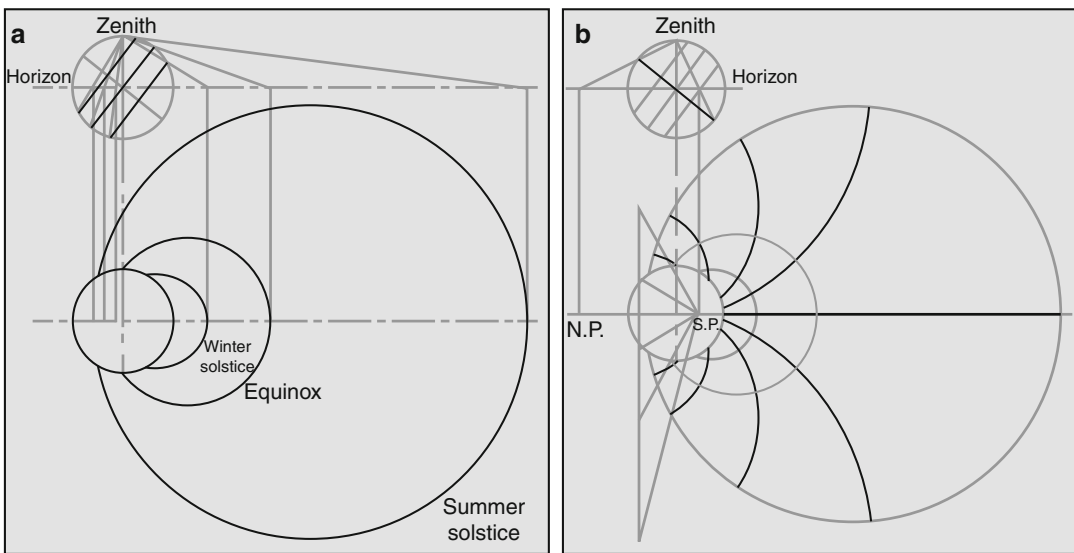
The grid lines of the Rojas type universal astrolabe, *Ganpyonggeui* in Korean, can be obtained by an orthographic projection, whose center of projection is at infinity outside the equinox of the celestial sphere. By analogy, it can be said that *Ganpyongilgui* is a Rojas type sundial since its grid lines were also drawn by orthographic projection. The center of projection of this sundial was located at infinity outside the zenith of Seoul. As the center of projection was moved from infinity outside the equinox to that of local zenith, the straight season lines of the astrolabe *Ganpyonggeui* were transformed to parallel ellipses of the sundial *Ganpyongilgui* because the inclined circles were projected orthographically.

The name of the other sundial was *Hongaeilgui*. Its origin can be traced from the name *Hongaetongheon*, the planispheric astrolabe. The ecliptic on the rete and the lines on the plate of a planispheric astrolabe are obtained by stereographic projection from the south celestial pole. The same rule of projection was followed to get the star chart of a celestial planisphere. Moreover, the season and hour lines of *Hongaeilgui* were also drawn by stereographic projection.

The way to get the grid lines for *Hongaeilgui* is sketched briefly in Fig. 10. Unlike having the center of projection at infinity as in an orthographic projection, the center of the stereographic projection remains on the surface of the celestial sphere. Whenever curves on a sphere are mapped onto a flat surface, there are two characteristic features of the stereographic projection. One is



Astronomical Instruments in Korea, Fig. 9 *Ganpyongilgui* (left) and *Hongaeilgui* (right)



Astronomical Instruments in Korea, Fig. 10 Stereographic projection of *Hongaeilgui*; (a) season lines, and (b) hour lines

the preservation of the circle and the other the rule of conforming. Every circle on the sphere maps onto a plane as a circle by the rule of preserving the circle. And, according to conforming, two circles that intersect at a certain angle will intersect at the same angle on the mapped surface.

The sun is traced for the Korean planispheric sundial, *Hongaeilgui*. The altitudinal and azimuthal data are cast as shadows of the gnomon

onto the surface of the sun tracker. Season and hour lines were constructed as grids on the sundial. By shifting the center of projection to the local zenith, the horizontal coordinates of the sphere were transformed to the polar coordinates. The equatorial coordinates were mapped to the sundial as the bipolar coordinates of the season and hour lines as shown in Fig. 10. The direction of the shadow directly gives an azimuthal coordinate and its length; the altitude

of the sun yields a radial coordinate through a simple transformation:

$$\frac{r}{R} = \tan\left(\frac{90^\circ + \beta}{2}\right) = \frac{1 + \sin \beta}{\cos \beta}$$

$$= \frac{1}{a} + \sqrt{1 + \frac{1}{a^2}}$$

where r is the radial coordinate, R is the radius of the base circle representing horizon, β is the altitude of the sun, and a is the length of the shadow when the height of the gnomon equals unity. With the polar coordinates of the shadow in hand, the point that specifies the current date and hour would be located from the bipolar coordinates.

This Korean horizontal sundial is more of a graphical calculator than a mere time indicator. Most problems concerning the position of the sun throughout a year could be answered straightforwardly without any further calculation. While keeping the geometric characteristics and drawing procedure unchanged, the well-established astrolabe was completely modified by a Korean expert to an extraordinary sundial.

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Astronomical Instruments in the Islamic World

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Most Islamic observational instruments are lost and known to us only through texts. The state of documentation of the other, smaller Islamic astronomical instruments that do survive leaves much to be desired. Many of the most important instruments are still unpublished, and much that has been written on instruments is on a very amateur level. For these reasons a project has been underway in Frankfurt to catalogue all Islamic instruments (and European ones) to ca. 1550 as well as various historically significant later Islamic pieces.

Also the most important writings on instruments have not yet received the attention they deserve. For example, a hemispherical observational instrument for a fixed latitude was devised by the tenth century astronomer ► [al-Khujandī](#), the leading instrument maker of the early period, and this was modified in the twelfth century to serve all latitudes. There are no surviving examples, and the available manuscripts have yet to be studied. An important work on instruments was compiled in Cairo ca. 1280 by Abū ʿAlī al-Marrākushī – this has yet to be subjected to a detailed analysis. The author collected all of the treatises on instruments known to him and incorporated them into his book. An exciting find of the 1980s was a treatise by the early fourteenth century Cairo astronomer Najm al-Dīn al-Misrī. In this the author described and illustrated over 100 different instrument types, including every kind of instrument known to him as well as those

he invented himself. This treatise is now published with an exhaustive commentary. The same holds for the earliest surviving corpus of texts on the astrolabe, quadrant, and sundials by ► [al-Khwārizmī](#).

Armillary Spheres and Globes

In the eighth century al-Fazārī wrote a treatise on the armillary sphere, called *dhāt al-ḥalaq*, which means “the instrument with the rings.” No early Islamic armillary spheres survive, but several other treatises on it were compiled over the centuries. The earliest treatise in Arabic dealing with the celestial globe, called *dhāt al-kursī* (the instrument with the stand) or simply *al-kura* (sphere), was written by ► [Qusṭā ibn Lūqā](#) in the ninth century. This treatise by Qusṭā, who was one of the most important translators of Greek works into Arabic, remained popular for a millennium. Of the various surviving celestial ► [globes](#), which number over 100, none predates the eleventh century.

The spherical astrolabe, unlike the armillary sphere and the celestial globe, appears to be an Islamic development. Various treatises on it were written from the tenth to the sixteenth century, and only one complete instrument, from the fourteenth, survives. In the ninth century Ḥabash wrote on the spherical astrolabe, the armillary sphere, and the celestial globe, as well as on various kinds of planispheric astrolabes.

Astrolabes

Al-Fazārī also wrote on the use of the astrolabe (Arabic *aṣṭurlāb*). The tenth century bibliographer Ibn al-Nadīm states that al-Fazārī was the first Muslim to make such an instrument – he also informs us that, at that time, the construction of astrolabes was centered in Harran and spread from there. Several early astronomers, including Ḥabash, al-Khwārizmī, and ► [al-Farghānī](#), wrote on the astrolabe, and introduced the features not found on earlier Greek instruments, such as the shadow squares and trigonometric grids on the

backs and the azimuth curves on the plates for different latitudes, as well as the universal plate of horizons. Also extensive tables were compiled in the ninth century to facilitate the construction of astrolabes.

Another important development to the astrolabe occurred in Andalusia in the eleventh century, when al-Zarqāllu devised the single universal plate (*ṣafīḥa*) called *shakkāziyya* and the related plate called *zarqālliyya* with two sets of *shakkāziyya* markings for both equatorial and ecliptic coordinate systems. The latter was fitted with an alidade bearing a movable perpendicular straight edge (transversal). Several treatises on these two instruments exist in both Western and Eastern traditions of later Islamic astronomy – the Europeans knew of them as the *saphea*. Ibn al-Zarqāllu’s contemporary, ‘Alī ibn Khalaf, wrote a treatise on a universal astrolabe that did not need plates for different latitudes. This treatise exists only in Old Spanish in the *Libros del Saber*, and was apparently not known in the Islamic world outside Andalusia. The instrument was further developed in Syria in the early fourteenth century: Ibn al-Sarrāj devised in Aleppo a remarkable astrolabe that can be used universally in five different ways.

The astrolabes made by Muslim craftsmen show a remarkable variety within each of several clearly defined regional schools. We may mention the simple, functional astrolabes of the early Baghdad school – the splendid astrolabe of ► [al-Khujandī](#) of the late tenth century, which started a tradition of zoomorphic ornamentation that continued in the Islamic East and in Europe for several centuries – the very different astrolabes of the Andalusian school in the eleventh century and the progressive schools of Iran in the thirteenth and fourteenth centuries – and the remarkable instruments from Mamluk (thirteenth and fourteenth century) Egypt and Syria. In the early fourteenth century Ibn al-Sarrāj of Aleppo, a school unto himself, produced the most sophisticated astrolabe ever made. After about 1500 the construction of astrolabes continued in the Maghrib, in Iran, and in India until the end of the nineteenth century. Many of these

instruments, especially those from Iran, were beautiful objects of the finest workmanship.

Quadrants

Another category of observational and computational devices to which Muslim astronomers made notable contributions was the quadrant, of which we can distinguish three main varieties. Firstly there is the sine quadrant with an orthogonal grid. This instrument, in a simpler form, had already been described by ► [al-Khwārizmī](#) and was widely used throughout the Islamic period. Some Islamic astrolabes display such a trigonometric grid on the back. The grid can be used together with a thread and movable marker (or the alidade of an astrolabe) to solve all of the standard problems of spherical astronomy for any latitude. Secondly there is the horary quadrant with fixed or movable cursor. This instrument is described already in an anonymous ninth century Iraqi source and was likewise commonly used for centuries (albeit usually without the cursor, which is not essential to the function of the device). A set of arcs of circles inscribed on the quadrant display graphically the solar altitude at the seasonal hours (approximately, according to an Indian formula). Other Islamic quadrants from the ninth century onwards had markings for the equinoctial hours. The instrument can be aligned towards the sun so that the time can be determined from the observed altitude using the grid. Again this kind of marking was often found on the back of astrolabes. Thirdly there is the astrolabic quadrant displaying one-half of the altitude and azimuth circles on an astrolabe plate for a fixed latitude, and a fixed ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The effect of the daily rotation is achieved by a thread and bead attached at the center of the instrument rather than by the movable astrolabe rete. The quadrant with astrolabic markings on one side and a trigonometric grid on the other generally replaced the astrolabe all over the Islamic world (with the notable exceptions of Iran, India, and the Yemen) in the later period of Islamic astronomy.

Sundials

We learn from Islamic tradition that the pious Umayyad Caliph ʿUmar ibn ʿAbd al-ʿAzīz (fl. Damascus, 718) used a sundial to regulate the times of the daytime prayers in terms of the seasonal hours. The earliest sundials described in the Arabic astronomical sources are planar, usually horizontal, but also vertical and polar. The mathematical theory for computing the shadow for the seasonal hours at different times of the year and the corresponding azimuths was available from Indian sources, which seem to have inspired the Islamic tradition more than any of the available Greek works. The treatise on sundial construction by al-Khwārizmī contained extensive tables displaying the polar coordinates of the intersections of the hour lines with the solstitial shadow traces on horizontal sundials for 12 different latitudes. The treatise on sundial theory by Thābit ibn Qurra contains all the necessary mathematical theory for constructing sundials in any plane – likewise impressive from a theoretical point of view is the treatise on gnomonics by his grandson Ibrāhīm.

The earliest surviving Islamic sundial, apparently made in Córdoba about the year 1000 by the Andalusian astronomer Ibn al-ṣaffār, displays the shadow traces of the equinoxes and solstices, and the lines for the seasonal hours as well as for the times of the two daytime prayers. There is a world of difference between this simple, carelessly constructed piece and the magnificent sundial made in the late fourteenth century by Ibn al-Shāṭir, so devised that it can be used to measure time with respect to any of the five daily prayers. In the late period of Islamic astronomy a sundial was to be found in most of the major mosques.

Miscellaneous

Muslim astronomers devised several multi-purpose instruments. Notable examples are the rule (*mīzān*) of al-Fazārī, fitted with a variety of non-uniform scales for various astronomical functions, and the compendium of Ibn al-Shāṭir,

comprising a magnetic compass and qibla-indicator, a universal polar sundial, and an equatorial sundial. Of particular interest is three circular qibla-indicators made in Isfahan ca. 1675 (but invented much earlier) which consists of a cartographic grid with Mecca at the center, so devised that the qibla can be read off the outer scale and the distance from Mecca can be read off the non-uniform scale on the diametrical rule.

There are several Islamic treatises on eclipse computers and planetary equatoria for determining the positions of the planets for a given date. With these the standard problems of planetary astronomy dealt with in *zīj*es are resolved mechanically, without calculation. Treatises on eclipse computers are known from the early tenth century, and ► [al-Bīrūnī](#) in the early eleventh describes such an instrument in detail. A newly discovered manuscript (not yet available for research) contains a treatise by the tenth century Iranian astronomer ► [Abū Ja'far al-Khāzin](#) describing an equatorium called ► [Zīj al-Safā'ī](#) (the Zīj of Plates). The only known example of this instrument, made in the twelfth century, is incomplete: it is in the form of an astrolabe with tables engraved on the *mater* and additional markings for the foundation of an equatorium. Otherwise the only known early Islamic treatises on planetary equatoria are from eleventh century Andalusia. The most interesting aspect of the equatorium described by al-Zarqāllu is the ellipse drawn on the plate for the center of the deferent of Mercury – it seems that he was the first to notice this characteristic of Mercury's deferent. Al-Kāshī, the leading astronomer of early fifteenth century Samarqand, has left us a description of a planetary equatorium with which not only ecliptic longitudes but also latitudes could be determined and eclipses calculated.

See Also

- [al-Farghānī](#)
- [Al-Fazārī](#)
- [Al-Kāshī](#)

- [al-Khujandī](#)
- [al-Khwārizmī](#)
- [Armillary Spheres in China](#)
- [Astrolabe](#)
- [Astronomy](#)
- [Globes](#)
- [Ibn al-Shāṭir](#)
- [Ibn Al-Zarqāllu](#)
- [Maps and Mapmaking: Celestial Islamic Maps](#)
- [Quadrant](#)
- [Sundials in China](#)
- [Thābit ibn Qurra](#)

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Astronomical Monuments in Polynesia and Micronesia

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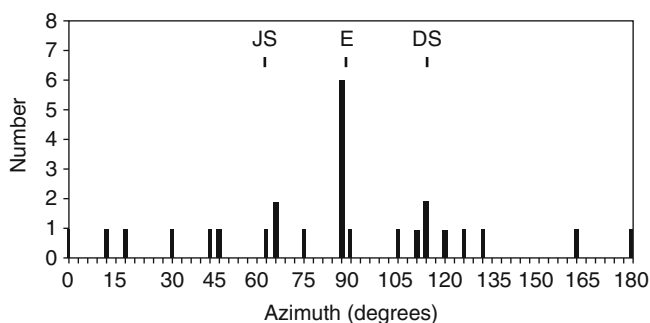
The pre-European inhabitants of the Pacific Islands were skillful and frequent interisland navigators. The most accurate directional indicators used by the Polynesian and Micronesian islanders – still used today in several parts of Oceania – were the rising and setting positions of stars (Akerblom, 1968; Gladwin, 1970; Goodenough, 1953; Grimbale, 1931; Lewis, 1994). The measurement of stellar positions and their movement over the celestial sphere was an important task for the ancient seafarers. In fact, astronomy was treated as a branch of navigation by the ancient Tongans (Collocott, 1922), and, as the Jesuit priest Fr. Cantova reported from castaways from Woleai (Caroline Islands) at Guam in 1721, “The only thing they learn are some vague principles of astronomy to which most apply themselves due to its usefulness in navigation” (Lewis, 1994, p. 112). The navigators defined the sailing directions by the use of “star compasses,” which divide the horizon into a number of parts identified by the rising and setting positions of the stars. There is ample evidence of the use of a 32-direction “star compass” by the ancient and contemporary navigators of the Caroline Islands (Goodenough, 1953, pp. 5–24; Gladwin, 1970, pp. 147–165; Lewis, 1994, pp. 102–111). The references for the use of a “star compass” in Polynesia are ancient and scarce. The most

detailed one is by Andía y Varela, who led a Spanish expedition to Tahiti in 1774 (Corney 1913–1919, 2, pp. 284–285; Lewis, 1994, p. 84).

There are few ethnohistoric references about systematic observation of the Sun or Sun worshiping in Polynesia. For example, Behrens, in 1737, says that in the early morning, Easter Island inhabitants “had prostrated themselves towards the rising sun and had kindled some hundreds of fires which probably betokened a morning oblation to their gods” (Behrens, 1908, p. 133). There are some vague indications of solstitial observation in pre-European Pukapuka and New Zealand (Beaglehole & Beaglehole, 1938, p. 349; Makemson, 1941, pp. 85–86) and the more explicit ones are in Hawaii (see Kirch, 2004a, and references therein). However, the most clear evidence of Sun observations is in Mangareva (Gambier Islands), where Buck (1938, pp. 414–415) indicates that “two stones were set up to form sights” to determine the solstices exactly.

There are several ethnological studies about Polynesian names of stars, constellations, and the calendar, the most important compilations being those by Makemson (1941) and Johnson and Mahelona (1975). A new revised work by Johnson, Mahelona, and Ruggles is expected to appear in 2014. In a recent synthesis of historical anthropology, Kirch and Green (2001, pp. 260–276) have reconstructed essential aspects of ancient Polynesian time reckoning and ritual cycle. They describe:

1. An annual seasonal cycle divided in two parts originally based on a wet–dry seasonality and the yam cultivation cycle.
2. A sidereal cycle based on the observation of the heliacal and acronychal rising of the Pleiades (named Mataliki in Proto-Polynesian).
3. An agricultural annual lunar calendar of 13 months.
4. A system of intercalation for keeping the synchronization between the lunar calendar and solar year. This system was based on the observation of Pleiades risings but, in some cases, at least in Mangareva and Hawaii, also on solar observations at solstices.



Astronomical Monuments in Polynesia and Micronesia, Fig. 1 Number histogram of the orientations of the perpendicular to the long side of 26 *ahu* within 500 m of the coast and with long axes skewed by more than 20° to the adjacent shoreline of Easter Island measured by

Liller (2000b). Data are binned in 3° interval. JS, E, and DS indicate the azimuths of the rising sun at June solstice, the equinoxes, and December solstice, respectively. Note the overwhelming tendency of east–west orientations (Diagram adapted from Liller (2000b))

It is surprising that there have been rather few attempts to correlate the ethnographic material about celestial lore and the alignments of the ubiquitous ceremonial stone structures across the whole Pacific area.

There are few archaeoastronomical studies in Polynesia and they are not systematic except for Easter Island and – in recent years – Hawaii. In the case of Micronesia, the situation is even worse. As far as I know, there has been no archaeoastronomical fieldwork on orientations of prehistoric Micronesian stone monuments except the works by Esteban (2007, 2014). In the following, I will review the main results of different research works in the Pacific area. Not all the islands groups are included because an important number of them are lacking any kind of archaeoastronomical study.

Ferdon (1961) made the first report of astronomical alignments in Polynesia as part of the investigations of the Norwegian Archaeological Expedition to Easter Island in 1955–1956. This author proposed that a group of cup-marked boulders (the so-called Sun stones) at the village of Orongo was oriented astronomically; however a reanalysis made by Lee and Liller (1987) has shown that such claims can be discounted. The archaeologist Mulloy (1975) discovered the unusual orientation of one of the scarce inland *moai* platforms (the *moai* are the large imposing Easter Island statues): Huri A Urenga, which faces the point where the Sun rises at the June

solstice. Liller and Duarte (1986) performed an excellent analysis of the orientations located at this monument, reinforcing the astronomical interest of the site and finding other possible astronomical orientations. Mulloy (1961) and Smith (1961) also reported possible solar alignments in other coastal *moai* platforms of Easter Island, such as those of Vinapu 1 and 2 (December solstice sunrise and equinox sunrise, respectively) and Tepeu (December solstice sunrise).

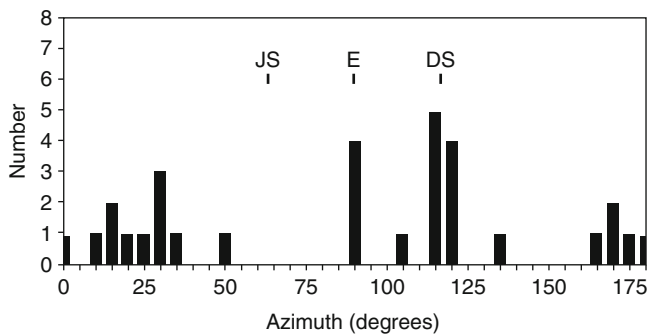
Liller (1989) has made a systematic study of orientations defined by several hundred *ahu* (an *ahu* is a raised platform inside a temple) and *moai* platforms on Easter Island, finding that there is marginal evidence of alignments related to the solstices or equinoxes. He finds a definite trend among coastal *ahu* being oriented parallel to the coast (approximately 90 %), with the sculptures or *moai* facing out to sea. Considering the *ahu* with long sides nonparallel to the shoreline (a sample of 26 *ahu*), there is an overwhelming tendency for these monuments to be oriented in the direction of the equinox rising points and an extra one or two *ahu* aligned in the direction of the solstice rising points (Fig. 1). Regarding the inland platforms, Liller finds there is a weak tendency to have the *moai* look in the direction of the rising of the Sun at the June solstice, and Huri A Urenga stands out as the most remarkable case. More recently, Edwards and Belmonte (2004), considering the outstanding ethnographic importance of Matariki (the Pleiades star cluster see,

e.g., Tilburg, 1994, pp. 100–103) and Tautoru (Orion's Belt) as markers of ceremonies and agricultural activities in the traditional calendar of Easter Island and the absence of solar references or cults, propose that the aforementioned solstitial and equinoctial alignments of the *ahu* platforms could be interpreted as being instead alignments to the Pleiades and Orion's Belt risings or settings. The declination of those asterisms is incidentally very similar to those of the Sun at the June solstice (Pleiades) and to the Sun at the equinoxes (Orion's Belt).

Since the pioneering studies of the Hawaiian stone temples (*heiau*) by Stokes in 1906–1909 (published in 1991: Stokes, 1991), Emory (1924) and Bennett (1931) it has been usually considered that the orientation of the *heiau* was determined by the local topography and environmental considerations, commonly facing the sea or valley. Moreover, as Kirch (2004a) has pointed out, the rich Hawaiian ethnohistory is largely silent about *heiau* orientations. Only the native Hawaiian scholar Malo (1951) indicates that the cardinal directions could have been important for the positioning of the audiences in the *heiau* during the ceremonies. Chauvin (2000) defends the low probability of premeditated solar alignments in the stone temples considering that neither solstices nor equinoxes played any role in the Hawaiian calendar or in religious practices. On the other hand, Kirch (2004a) indicates that the major Hawaiian deities were associated with particular directions and seasonal orientations on the basis of what is known of traditional Hawaiian theology. This assertion suggests that the finding of astronomical alignments in temple platforms may not be disregarded. On the other hand, Ruggles (2001) is also optimistic, at least in the possibility of some symbolic celestial connections in the *heiau* taking into account the large number of names of stars and other celestial objects in the traditional Hawaiian names for places in the landscape. Ethnographical data give evidences of solar observations among the ancient Hawaiians. For instance, Kamakau (1976, pp. 13–14) indicates the existence of persons who observe the stars and a class of priests who advised concerning building and locating

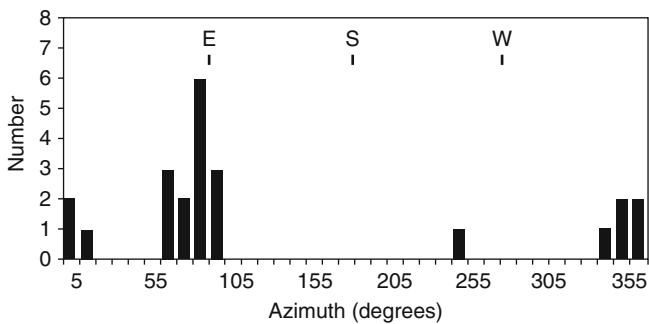
temples who were skilled in reckoning the months of the year and following the Sun movement. This author (1976, p. 14) also describes solar observation from the island of Kauai based on the rising or setting of the Sun over relevant topographic features of the horizon in particular moments of the year.

Rubellite Johnson carried out the first archaeoastronomical studies in Hawaii in the 1980s. Da Silva and Johnson (1982) first suggested a possible “astronomical-directional register” in the *Ahu a 'Umi Heiau*, a platform located on the island of Hawaii, the highest and the farthest inland *heiau* of the Hawaiian archipelago. Johnson (1993) also studied the small island of Kahoolawe, where oral tradition suggested that it had once been a place of important astronomical and navigational activity. Meech and Warther (1996) have made an interpretation of some *hula* or sacred chants of the Hawaiians in terms of astronomical alignments that can be found in the archipelago, specially related to the solstices. However, reassessments based on more precise measurements have shown that the alignments claimed by those authors are not sufficiently precise in most cases (Ruggles, 1999). Moreover, the results obtained by Ruggles seem to indicate an interest in solar zenith passage as much as and perhaps more than in the solstices. In a subsequent paper, Ruggles (2001) presents a systematic study in Kaua'i trying to correlate ritual and sky traditions with the architectural alignments of a large sample of *heiau*, a promising new approach in Polynesia where many traditions are still alive or collected in the rich ethnological legacy. In this last study, Ruggles finds no consistent patterns with regard either to orientation upon topographic features or to orientation upon celestial objects, although some intriguing relationships are found in some particular sites. However, other works have been successful in finding rather clear astronomical orientations in ancient Hawaiian temples. Liller (2000a) has studied the orientations of 32 stone temples in the tiny Necker Island. This island has two relevant particularities: (a) it has an astonishingly large number of temples considering the small size of the island and (b) the island center



Astronomical Monuments in Polynesia and Micronesia, Fig. 2 Number histogram of the orientations of the perpendicular to the back side of 32 *stone temples* of Necker Island (Hawaii Archipelago) measured by Liller (2000a). Data are binned in 5° intervals. JS, E, and DS

indicate the azimuths of the rising sun at June solstice, the equinoxes, and December solstice, respectively. Note that the *temples* show two preferred orientations: one east–west and the other around the December solstice sunrise (Diagram adapted from Liller (2000a))



Astronomical Monuments in Polynesia and Micronesia, Fig. 3 Number histogram of the orientations of 23 *heiau* at Kahikinui (Maui Island, Hawaii Archipelago) measured by Kirch (2004a). Data are binned in 10° intervals. The position of the cardinal points is indicated by

letters. The data show three clear concentrations: one facing the east, another facing east–north–east, and a third one facing north, Kirch (2004a) believes these orientations were deliberate and likely related to a particular god of the Hawaiian pantheon

is located almost exactly at the latitude of the Tropic of Cancer in the year AD 1000. This last particularity implies that the ancient inhabitants of Necker would have realized that the Sun was directly at their zenith at midday of the June solstice. In fact, Liller has found that 9 of the 32 temples of Necker are aligned with the setting June solstice and/or the rising December solstice (Fig. 2). Finally, Kirch (2004a) has performed an analysis of the orientations of a sample of 23 *heiau* of Kahikinui (Maui Island). This author has found that temple foundations tended to have three preferred orientations: east, east–north–east, and north (Fig. 3). Kirch has correlated these results with ethnohistoric and ethnographic data proposing that:

1. The east orientations may be associated with god Kane, because this deity was associated with the Sun and the east direction.
2. The east–north–east cluster of orientations may be related to either the summer solstice sunrise or the rising of the Pleiades. In fact the acronychal rising of this asterism determined the onset of the Makahiki season and the new year; this group of temples may be dedicated to the god Lono, who was linked to the annual rising of the Pleiades.
3. The temples oriented to the north face the summit of the high mountain Haleakala (“House of the Sun”) and may be dedicated to Ku, a deity linked to high mountains, to the sky, and to forest.

Archaeoastronomical studies in islands of Eastern Polynesia, apart from the aforementioned ones for Easter Island and the Hawaiian archipelago, are very scarce. Liller (1993) presents an analysis of orientation data (obtained from direct measurements by the author and from good quality topographical maps) of over 50 ceremonial stone platforms in various archipelagos of Polynesia (Society Islands, Hawaiian Islands, Rarotonga, and the Trilithon of Tonga) finding no clear astronomical trends except perhaps in some isolated cases. In a subsequent paper, Liller (2000b) gives an excellent review of archaeoastronomical fieldwork carried out in Polynesia and presents some new results based on the reanalysis of large sets of published plans from the literature and some other new data obtained by the author. Concerning the archipelagos of Eastern Polynesia, Liller presents histograms of orientations of temples belonging to the Tuamotus (52 temples) and the Society Islands (105 temples) as well as some preliminary and sparse data of Mangareva, the Cook Islands, and the Austral Islands. The general conclusion of that paper is that the orientation of the Polynesian ceremonial platforms was controlled by the physical situation. Most of the monuments are located on the shore and lie parallel or perpendicular to the immediate shoreline. Astronomical alignments are present only in some isolated cases. The remarkable *mara'e*. (*Mara'e*, also spelled *mala'e* or *maa'e*, are stone or coral slab temples) Tapu-tapu-a-tea, possibly one of the most important in all Polynesia, located on Raiatea (Society Islands) has its long inland-facing wall oriented to an azimuth of $6.^\circ 3'$. Liller (2000b) suggests that the perpendicular to the wall may be oriented to the rising point of the southern portion of the constellation of Orion: perhaps Orion's Belt or Rigel. Other important *marae* of the Society Islands, such as those of Tainu'u (Rai'atea), Mataireia-rahi and Anini (Huahine), Marotetina (Borabora), Mahaiatea (Tahiti), and Tetii (Mo'orea), are also oriented to within a few degrees of that of Tapu-tapu-a-tea (Liller, 2000b). This finding could be relevant in the context of the ethnohistorical accounts of Henry (1928, p. 363) who writes the following concerning the birth of

heavenly bodies in ancient Tahitian tradition: "the chiefs of the skies... were royal personages... from the period of darkness, and they each had a star. They bore the names of those stars, and those names have been perpetuated in their temples in this world." This account suggests that the finding of stellar alignments in the *mara'e* cannot be considered strange (Kelley & Milone, 2005, p. 347). On the other hand, unpublished archaeological surveys of *mara'e* in the Faaroa Valley (Raiatea) and Mataireia Hill (Huahine) carried out by Edmundo Edwards indicate that a fraction between 20 % and 30 % of the monuments show solstice orientations, although Liller (2000b) considers that Edward's results, at least for Huahine, are only circumstantial.

As in the case of the aforementioned Necker Island in the Northern Hemisphere, there are several islands of Eastern Polynesia located close to – in this case – the Tropic of Capricorn. Tubuai (Austral) was located only 23 km north of this tropic in AD 1000 (Liller, 2000a). Vérin (1969) found that four out of six *mara'e* reported on this island show alignment with the December solstice sunset. However, Edwards (2003) indicates that those presumed orientations could be only accidental considering that the nearby shoreline has precisely the same orientation. This last author reports a survey of 92 *mara'e* on Raivavae (Austral Islands), an island also very close to the Tropic of Capricorn, finding that about 14 % of the monuments are astronomically oriented. In particular, the large *mara'e* Unuaru (whose walls are not parallel to the shoreline) as well as other *mara'e* of Raivavae are oriented very close to the true north.

The Mangareva Islands (also known as Gambier Islands) are the only case in Polynesia where there is unequivocal ethnohistoric evidence for systematic solar observations. The account of the priest Honoré Laval provides a description of traditional Mangarevan time reckoning and the methods of solar observations at solstices and the places where they were performed (Laval, 1938, pp. 213–215). Peter Buck (1938) gives another detailed ethnographic account about these activities. Here are some relevant astronomical information (see Kirch, 2004b):

1. Solstice observations were used to keep the lunations in sequence with the solar year and to divide the year into two seasons.
2. The locations for solstitial observations are given. The observatory at Atituiti, named Te Rua Ra (the pit of the Sun), is said to be the “most favorable position” for this purpose.
3. In at least one site, upright stones are used to mark the rising Sun at December solstice, and the backsight was a big flat stone.
4. The observation of solar risings and settings on distant topographic markers was used to achieve precision.
5. The movement of a shadow cast by a certain mountain was also used as a solstitial marker.

Kirch (2004b) has rediscovered the precise site of the Atituiti observatory, finding an uncommon platform oriented along the cardinal directions and the central flat boulder where observations were performed. That author has been able to confirm the most important aspects of the ethnohistoric records. For example, the position of the December solstice sunset coincides with the western edge of the high cliff Ana Tetea (the burial place of two renowned high chiefs of Mangareva) on Agakautai Island; the shadow of Auorotini (Mount Duff) is also cast onto the central flat boulder during the June solstice.

In recent years, the Centre d'Investigation en Ethnoastronomie Locale (CIEL) of Tahiti led by L. Cruchet is carrying out ethno- and archaeoastronomical studies in the area of East Polynesia. In his last work, Cruchet (2013) presents results for a number of *mara'e* and archer platforms in the Society Islands. He proposes that they are oriented to the rising and setting of certain important stars in Tahitian mythology (the so-called pillar stars) and that these relationships can be explained in the light of linguistic and ethnographic data and even attending to their relation with the traditional landscape. Although, in my opinion, these studies have certain methodological deficiencies, the importance of some stellar alignments seems rather plausible.

In the Kingdom of Tonga, we have a remarkable and unique monument in Polynesia: the Ha'amonga a Maui (Burden of Maui) trilithon

which according to tradition, was built in AD 1200 (see Fig. 4). (A trilithon is a structure consisting of two large vertical stones supporting a third stone set horizontally across the top) In 1967, the current monarch, King Taufa'ahau Tupou IV, discovered that the lintel is aligned along the sunrise at December solstice; this was later confirmed by Liller (1993) and Esteban (2002–2003). According to Collocott (1922), “the Tongan year is said to have begun at about the same time as the Christian year” and this fact would indicate a possible calendrical importance of the December solstice. As has been commented before, Makemson (1941) and other authors state that in most of the Polynesian archipelagos (including Tonga), the new year began in late November or early December with the first Moon after the acronychal rising of the Pleiades. These dates are not far off but obviously do not coincide with the December solstice. In any case, as Esteban (2002–2003) has suggested, the solstitial orientation of the trilithon may be accidental because its axis is roughly parallel to other related archaeological structures and to the nearby shoreline. Some controversy was raised by the presence of an enigmatic zigzag figure carved into the top of the lintel of the trilithon whose axes point roughly to the two rising solstice directions. However, Dhyne (1994) argues that there are reasons to believe that the marks were made relatively recently.

The most common archaeological features of Tonga are round or rectangular mounds of earth with considerable size range. These mounds can be house platforms, burial mounds, *esi* mounds (resting places for members of the chief's family), and mounds for pigeon snaring (McKern, 1929). The *esi* and pigeon mounds are usually situated upon natural rises that command a splendid view of the surrounding countryside. The anthropologist Wragge (see Liller, 2000b; McKern, 1929, p. 17) reported that the *esi* platform called Makahokovalu in Uiha Island (Ha'apai group) was a religious site connected with ancient Sun worshipping. However, McKern (1929, p. 17) and Gifford (1924, p. 68) failed to find any archaeological or ethnological evidence of Sun worship in the island.



A

Astronomical Monuments in Polynesia and Micronesia, Fig. 4 *Left:* The Ha'amonga a Maui trilithon seen from the south (Heketa, Tongatapu Island, Kingdom of Tonga). This is a unique monument in Polynesia that stands about 5 m tall. *Right:* View of the eastern horizon as seen from the lintel of the trilithon. The position of the rising points of the Sun at solstices and equinoxes has been

cleared of vegetation by the Tongan authorities. The lintel is aligned approximately along the December solstice. The current Tongan monarch, King Taufa'ahau Tupou IV, discovered this alignment (Images taken from Esteban (2002–2003). Reproduced with permission of University of Texas Press)

Liller (2000b) reports that in McKern's plan of Makahokovalu, the long axis is oriented at an azimuth of 2° (perpendicular 92°), suggesting some solar relation, but this is also the orientation of the nearby shoreline. Esteban (2002–2003) has estimated the approximate orientation of the ramps of the mounds from the plans published by McKern finding no clear trends.

Since the burial mounds of Tongan commoners are just earth mounds, the sites relating to the chief and royal family have stone facing and are often loosely called *langi*. The *langi* are large rectangular monuments with stone slab retaining walls, generally consisting of a number of terraces in the manner of truncated pyramids. One of Collocott's (1922) informants suggested a connection between the skies and the great burials at Mu'a (Tongatapu Island) and elsewhere, and it is worthy of note that the sky and vault are called by the same name: *langi*. In a detailed study of the largest collection of *langi* at Mu'a, Esteban (2002–2003) finds that the general disposition of the tombs is parallel to the shoreline, although much less probable stellar orientations related to sailing directions are also discussed by that author.

Bellwood (1978) reports that Samoan ethnographic records indicate the existence of open spaces for ceremonies (*mala'e*) as well as god houses. Scattered among Samoan settlements

are the so-called star mounds. They are large, raised platforms with several rounded projections extending from the central area and built with a loose rubble of basaltic stones. The interpretation of star mounds has been controversial. Modern informants tend to view them as pigeon-snaring mounds. No evidence of use for habitation or burial was found. The mounds were perhaps also used for religious purposes, as some ethnological references have pointed out (Davidson, 1979), and also for some divination rituals, as it is indicated in the information panels of the Tia Seu Lupe (literally “earthen mound to catch pigeons”) star mound in Tutuila Island (American Samoa). Esteban (2002–2003) considers it impossible to define useful alignments in these kinds of mounds taking into account their common irregular shape and large number of rounded irregular projections.

The island of Sava'i (Independent Samoa) has what is quite probably the largest surviving prehistoric monument in Polynesia, the Pulemelei stone mound. It is a huge flat-topped and roughly rectangular structure that covers 60 by 50 m at the base and is 12 m high. There are slightly sunken ramps to the top on the eastern and western slopes. The monument was built between 1100 and 1300 AD. There are several oral traditions about its purpose. Some tell that the mound was used to catch

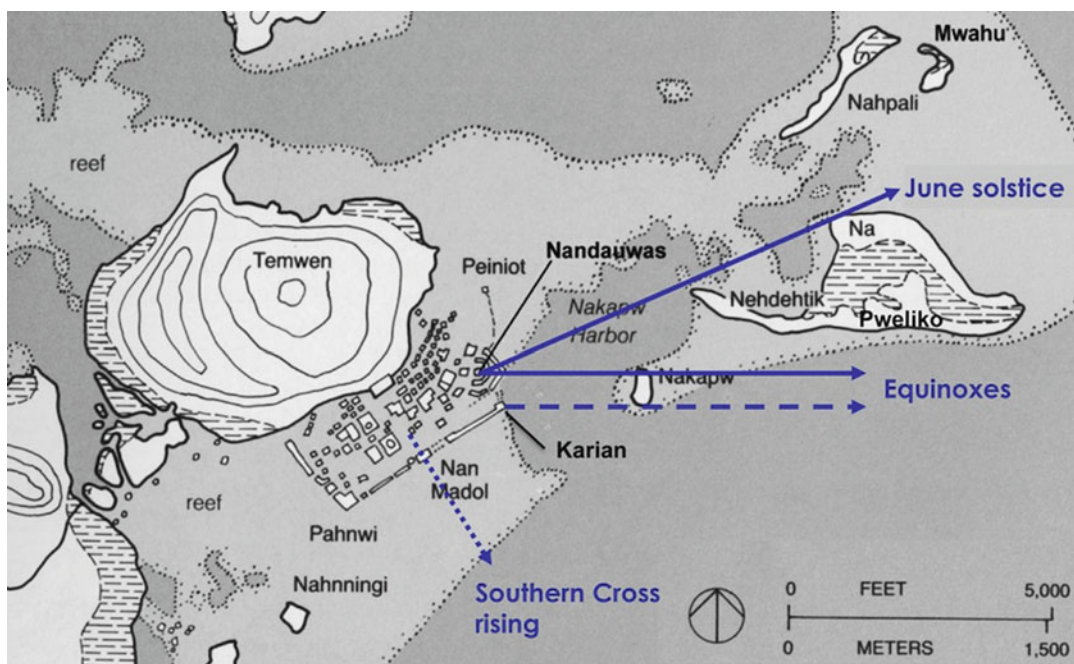
pigeons, while others say it was the residence of former chiefs of the island. Moreover, no few local traditions consider Pulemelei as the residence of gods and spirits. In any case, the archaeological investigations point out its ceremonial character (Martinsson-Wallin, Wallin, & Clark, 2007). This huge monument is part of a large complex of more or less contemporary structures as smaller mounds and traditional footpaths. It is located within a coconut plantation and almost completely covered with vegetation, making it very difficult to make accurate measurements of the orientation of the structure or the horizon without an extensive clearing of vegetation. This took place during the 2002–2004 excavations led by Swedish and Australian archaeologists (see Martinsson-Wallin et al., 2007). Talbot and Swaney (1998, p. 141) and Esteban (2002–2003) indicated that the sides of Pulemelei were oriented approximately along to the cardinal axes, which can be graphically confirmed on the detailed plans of the archaeological site published by Martinsson-Wallin et al. (2007, Fig. 3a) and after correcting for magnetic declination. Clarke and De Biran (2007) report that several of the other large mounds of Samoa also show their major axes oriented along the east–west line, as does the stone platform known as Kine He’e in the relatively nearby island of Rotuma (Fiji), culturally related to Samoa.

The largest island of the Republic of Palau (in Micronesia) is Babeldaob. From the astronomical point of view, the most interesting prehistoric remains known in Palau are the unique sculpted stone faces at Melekeok, on the eastern coast of Babeldaob. They are nine stones ranging from 1 to 2.5 m in height and arranged very precisely in two rows parallel to the nearby shoreline. All the surviving stones are facing the sea. Morgan (1988, pp. 14–15) collected the following legend concerning the origin of these stones: Odalmelech, the god of Ngermelech Village in Melekeok, “and his councilmen set out to lay a huge stone work over the village ground. That night, they started bringing in huge reef stones for the project, but the work was only partially completed when dawn approached. Odalmelech, seeing that his cohorts could not accomplish the project before daylight, called his crew together

and told them of the shame of being caught working in the morning sun. So he ordered his crew to carve all their faces on the monoliths and place them to eternally face the rising sun.” This story indicates the possible astronomical motivation of the site. Esteban (2002–2003) finds that the orientation of the faces may be close to the June solstice rising based on the site plan published by Morgan (1988, p. 13). Direct measurements and additional ethnographic data on the site are necessary to check this suggestive finding.

Nan Madol, in Pohnpei Island (Federated States of Micronesia), is the largest archaeological site in Micronesia and perhaps of all the Pacific Islands. It consists of 92 human-made rectangular islets separated by many waterways. The islets are generally surrounded by retaining walls of long, naturally prismatic basalt which are often built up over foundations of immense basalt boulders. The site was constructed on a reef located in the southeast side of Pohnpei which is called Sounahleng or “Reef of Heaven.”

Esteban (2007, 2014) has analyzed the orientations of several mortuary enclosures of the monumental megalithic city of Nan Madol, finding that the most relevant one, Nan Douwas – the tomb of the former rulers of Pohnpei, located at the easternmost edge of the city – is rather closely oriented with respect to the cardinal points. Towards the eastern horizon, Nan Douwas is facing a narrow channel between two nearby small islands, Nahkapw and Pweliko. Sunrise at the equinoxes or the midpoint in time between solstices occurs just on the north tip of Nahkapw. Some legends tell that the islet of Pweliko – to where Nan Douwas is oriented – is a sacred area, a transit place for the souls of the dead on their way to the final judgment (see Esteban, 2014 and references therein). According to Eastlick (1995), the division between the dry and wet seasons in the traditional Pohnpeian calendar occurs in March and September, approximately at the time of equinoxes. All these facts suggest that the location and orientation of Nan Douwas were carefully planned and that this huge enclosure had a rich ritual, funerary, and perhaps even calendrical symbolism. Another possible astronomical marker on the eastern horizon seen



Astronomical Monuments in Polynesia and Micronesia, Fig. 5 Map of the southeast edge of Pohnpei including Temwen Island, Nan Madol area, and several small reef islands (Na, Pweliko, Nahkapw, and others, map adapted from Morgan, 1988, p. 60; courtesy of the author and the University of Texas Press). The location of the two largest funerary enclosures, Nan Douwas and Karian, is also indicated. The continuous and long-dashed

blue arrows indicate relevant astronomical orientations defined for Nan Douwas and Karian, respectively. The short-dashed arrow indicates the orientation of the perpendicular to the long axis of the outer wall of Nan Madol, which represents the dominant orientation of the southwest part of the city and coincides with the rising point of the Southern Cross (Figure taken from Esteban (2014))

from Nan Douwas is the northern tip of the island of Na, which coincides with the point where the sun rises in the June solstice. An alternative astronomical interpretation also formulated by Esteban (2007, 2014) for the orientations found in Nan Douwas is based on the rising of stars or asterisms at the time of the construction of Nan Madol (about 1200 d. C.). The monument is pointing approximately to the area of the horizon where the stars of Orion's Belt rise. This was an important asterism around the Pacific and one of the directional points of the sidereal compass used by the traditional Micronesian navigators. On the other hand, the northern tip of the island of Na could be related to the rising point of the Pleiades, the most important constellation for the Pohnpeians. Like elsewhere in the Pacific, the heliacal rising of this group of stars has a relevant calendrical significance (Fig. 5).

See Also

► [Astronomy in Hawai'i](#)

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Astronomy

Roger B. Culver

Astronomy, the study of celestial objects, is a universally human endeavor whose roots lie deeply buried in prehistory. For the sky-watcher devoid of optical aid, the heavens can be thought of as a sort of earth-centered celestial sphere on to which have been sprinkled hundreds of tiny points of light we have called the stars. Half of this inverted bowl of blackness is almost completely dominated by the dazzling presence of the sun, the most prominent and important of the celestial objects. Such is the sun's brilliance that any attempt to view this object directly is to risk serious eye damage or even total blindness. As a result of the earth's spinning motion or rotation, an observer at a given location on the earth sees a sky that alternates between a daytime sky dominated by the sun and a nighttime sky characterized by its absence. As the earth turns on its axis, the sun appears to rise up from a given observer's eastern horizon, pass through a "high noon point" or maximum angle above the horizon, and then descend toward the western horizon. Approximately one half an earth rotation later, the sun once more rises to repeat the

cycle. This rising and falling effect is not limited to the sun. As the earth rotates relative to all celestial objects, they too appear to go through the rising and falling diurnal motions of the sun. Since the rate of the earth's rotation is very nearly constant, this diurnal motion of the sun and stars has long been employed as an important and reliable way of measuring time. The earth's rotation also creates the illusion that the stars of the celestial sphere seem to revolve about two imaginary points located exactly opposite each other. One, the south celestial pole, is visible only from the southern hemisphere of the earth, while the other, the north celestial pole, is visible only from the northern hemisphere. The earth's long-term precessional motion carries the locations of these celestial poles along a 47° diameter circular path among the stars once every 26,000 years. From time to time, a relatively bright star can be found near the position of one of the celestial poles for a few centuries. Such is the case at present for the north celestial pole, which is currently located near the fairly bright star Polaris, the Pole Star.

In addition to its daily rising and setting, the sun also appears to travel along a great circle on the celestial sphere, which is called the ecliptic. This latter movement is the direct result of the earth's orbital motion about the sun. As the earth arcs along in its orbital path, the apparent position of the sun relative to the more distant background stars appears to change. For an observer on the earth, the sun thus seems to creep gradually from west to east among the stars, completing an entire 360° journey around the ecliptic in exactly the same 1 year time interval it takes the earth to complete one orbital revolution about the sun. The background stars hence appear to be gradually overtaken in the western sky by the sun as it moves eastward along the ecliptic, engulfed by the solar glare for a month or so, and then reemerge in the predawn sky as the sun leaves them behind in its ongoing easterly movement. The overall result of this annual movement of the sun is a seasonal parade of the heavens in which different stars are visible at different times of the night at different times of the year.

The earth's axis of rotation is also found to be tilted at an angle of $23\frac{1}{2}^\circ$ off the vertical to the earth's orbital plane. As the earth orbits the sun, this tilt causes the sun to shine alternately more directly on the northern hemisphere and less on the southern hemisphere and then vice versa over the span of a simple year. This effect is observable as a yearly variation of the sun's highest altitude above the horizon at a given location, and as a change in the time that the sun spends above the horizon. Thus when the sun is shining most directly on the northern hemisphere at the time of the summer solstice, the sun's diurnal motion in the northern hemisphere is characterized by long days and short nights, and in the southern hemisphere by short days and long nights. Half an orbital revolution or 6 months later at the time of the winter solstice, when the sun is shining more directly on the southern hemisphere, the lengths of night and day are reversed. Halfway between these extremes the sun shines directly down on the earth's equator twice each year. On these dates, the lengths of the days and nights all over the earth are equal, except at the poles, and hence these dates are said to be the equinoxes. It is this combination of the tilt of the earth's axis of rotation and the earth's orbital motion that gives rise to our cycle of seasons here on the earth.

Firmly entrenched in second place in the brightness hierarchy of celestial objects is the moon. Although not as important as the sun, the moon, none the less, exerts several significant influences on the earth, most notably as the chief agent by which tides are produced in the world's oceans. The reflected sunlight we receive from the moon is over one million times fainter than that emanating from the sun, and as a result, the moon can be readily viewed against the backdrop of the stars of the night sky. As the moon orbits the earth in space, it appears to traverse a great circle about the celestial sphere in a fashion not unlike the annual motion displayed by the sun. There are however some important differences between the lunar motion and that of the sun. The moon swings along an apparent path that is tilted at an angle of about 5° to the ecliptic and takes one-twelfth of the sun's time to make a

single journey about the celestial sphere. The moon thus moves at an average rate of about half a degree per hour relative to the background stars, an angular speed easily detectable over the course of a single night by a naked eye observer.

Although the moon's half degree angular diameter is almost exactly the same as that of the sun, the diminished brightness of the moon permits us to look directly upon its face without fear or danger. As a result, the moon presents a number of most interesting and fascinating phenomena to the naked eye observer. Perhaps the most familiar of these is the set of seeming shape changes or phases exhibited by the moon as it journeys about the celestial sphere. These phases arise from the fact that as the moon orbits the earth, the half of the moon's spherical surface which faces the sun, and is hence illuminated by the sun's light, is viewed at different angles by an observer situated on the earth. When the moon is very nearly lined up between the earth and the sun, almost all of the moon's sunlit hemisphere faces away from the earth, and all we see of the moon is a very thin crescent of light. As the moon moves toward progressively larger angular distances from the sun, the thickness of the crescent grows or waxes until the angle between the moon and the sun as seen from the earth is 90° . At this point we see exactly one half of the moon's sunlit surface and the moon appears to have a semicircular or "quarter-moon" shape. As the sun-moon angular separation increases past 90° , the moon takes on a bulging or gibbous shape whose thickness continues to grow until the moon is very nearly opposite the sun in the sky. When this configuration occurs, the entire sunlit hemisphere of the moon faces the earth, and the now circular-shaped moon is said to be a "full" moon. After passing through the full phase, the moon's shape changes now proceed in reverse order, successively passing through waning gibbous phases, a second or last quarter phase, and finally a waning crescent phase as the angle between the moon and the sun decreases from 180° to nearly zero. The waning crescent moon eventually slides into the predawn solar glare for a few days and then reemerges as a silvery crescent-shaped "new" moon in the postsunset twilight.

The moon is also unique among celestial objects in that it is the only one for which surface detail can be easily viewed with the unaided human eye. This detail manifests itself in the form of the dark areas on the moon's disk which are called maria or seas and the light areas called continents. This terminology dates back to the Western European Renaissance observers of the moon who imagined the lunar surface to be divided between bright land and dark waters.

In addition to the sun and moon, human beings have recognized since prehistoric times that five other naked eye objects also move about the sky relative to the back-ground stars. These star-like wanderers are called planets, and historically have enjoyed the appellations of the gods and goddesses of ancient Greek and Roman mythology. The five so-called naked eye planets have been named, in order of their increasing distance from the Sun, Mercury, Venus, Mars, Jupiter, and Saturn. A sixth planet, Uranus, possesses a brightness which is just at the limit of naked eye visibility, but the planetary nature of this object does not seem to have been recognized until the English astronomer William Herschel accidentally stumbled upon it in 1781.

Two of the planets, Mercury and Venus, have orbits about the sun which are interior to that of the earth. As a result of this orbital geometry and the sun's gravitationally induced faster orbital speeds, these planets exhibit a marked pattern in their appearances in the earth's sky. In a typical cycle, the planet is first visible as an evening "star" in the west after sunset, then appears to move out to a maximum angle of greatest elongation away from the sun before retreating back into the sun's light. After several days or weeks, the planet reemerges from the solar glare, but this time as a morning "star" in the predawn sky. The planet once more moves out to an angle of greatest elongation and then drops back into the solar light. The swiftly moving planet Mercury goes through a complete cycle of appearances or synodic period in about 4 months, while Venus, whose orbital speed is more closely matched to that of the earth, takes a year and a half for its cycle of appearances. Typically Mercury's appearances as a morning or evening star last

about 3 weeks, while those of Venus extend over several months at a time.

Visually, the planet Mercury appears in the sky as a sparkling object having a somewhat reddish-orange tint. Its apparent brightness is actually comparable to the brightest stars, but because it is almost always observed in twilight, it is usually not as impressive an object as it otherwise might be. The most spectacular of the naked eye planets and the third brightest object in the sky behind only the sun and moon is the planet Venus. The orbital path of Venus can carry it out to an angle of greatest elongation as large as 47° , or about twice that exhibited by the planet Mercury. Thus it is possible to observe this splendid object for as long as 4 h after sunset or before sunrise. At its greatest brilliancy, the soft white light of Venus has even been observed to cast very faint shadows as it gleams in the darkness of the predawn or postsunset night sky.

The three remaining naked eye planets Mars, Jupiter, and Saturn, move in vast orbits about the sun which are exterior to the orbit of the earth. As a result, these planets appear most of the time to move about the celestial sphere in a fashion similar to the west to east movement exhibited by the sun and moon. The times required for each of these planets to make a complete cycle about the celestial sphere, however, are far longer than those for the sun and moon. Mars, for example, completes a single journey around the celestial sphere in just under 2 years, while Jupiter and Saturn require nearly 12 and 30 years, respectively, to complete similar journeys. As the faster moving earth catches up to and passes one of these exterior planets, the planet exhibits an illusionary phenomenon in the earth's sky called retrograde motion in which the given planet seems to stop its normal west to east motion among the stars, moves "backward" or east to west for several months, stops again, and then resumes its direct or west to east movement. In the midst of its retrograde motion, a given planet will appear to be opposite the sun's position in the celestial sphere as seen from earth. When such a configuration occurs, the planet is said to be "in opposition to the sun," or more simply, "at opposition." At the time of a given planet's opposition,

the earth makes its closest approach to the planet, and as a result, the planet shines more brightly than at any other time. Moreover, at opposition the planet rises at sunset, sets at sunrise, and is thus visible throughout the night.

Visually, the planet Mars is perhaps the most remarkable of the exterior planets owing to its distinctly reddish hue. At times of closest approach to the earth, the apparent brightness of this ruddy world is exceeded only by that of the sun, Moon, and Venus. When Mars is not at a close opposition, the fourth brightest object in the sky is the yellowish-white planet Jupiter which shines some ten times more brightly than the average of the brightest of the background stars. The golden-colored planet Saturn is the most distant of the naked eye planets from both the earth and the sun, and thus exhibits a reduced apparent brightness which is comparable to the average of the brightest background stars.

While the paths of the planets about the celestial sphere are not coincident with the ecliptic, they are, none the less, nearly coplanar with it. As a result, the sun, moon, and five naked eye planets move about the celestial sphere in a relatively narrow band of sky centered on the ecliptic which is called the zodiac. Because the sun, moon, and planets move along the zodiac at differing rates, it is possible for objects in the sky to appear to pass close to other objects along the zodiac. When such a passage occurs, the resulting configuration of the two objects is said to be a conjunction. Conjunctions can occur among the sun, moon, and planets, as well as between these moving objects and the bright stationary stars which are to be found along the zodiac. From time to time conjunctions can involve three or more objects, and on rare occasions a conjunction can be so close that the two objects cannot be seen as separate with the unaided eye.

In addition to the imaginary band of planetary paths that is the zodiac, there exists a quite real band of diffuse light, called the Milky Way, which is stationary relative to the stars and girds the celestial sphere like a gigantic faintly glowing heavenly belt. The Milky Way is the naked eye manifestation of the vast galactic system of gas, dust, and stars in which our sun is located.

The Milky Way Galaxy, as this system is called, is in the shape of a huge, flat pinwheel which has a substantial bulge at its center. Our sun is situated about two-thirds of the way toward the outer edge of this system, and as a result, our view of the summertime Milky Way in the northern hemisphere is the more prominent one, since at this time we are looking toward the direction in which most of our galaxy is located. On the other hand, in the northern hemisphere winter, our view is now directed away from the galactic center toward the less prominent regions of the galaxy, with the visual result that the wintertime Milky Way is much fainter than its summertime counterpart.

Off the plane of the Milky Way, there exist approximately a dozen or so lesser diffuse objects which are visible to the naked eye and are also set in fixed positions among the stars. Modern telescopic observations reveal that these “fuzzy patches of light” are in reality quite a diverse lot, including clouds of glowing gas, star clusters, and even other galaxies well outside of our Milky Way.

From time to time transitory apparitions and events occur in the sky which can be as awesome as they are spectacular. One such event is a total eclipse of the sun. When the moon passes directly between the earth and the sun, a moving shadow of the moon about 240 km wide is cast upon the surface of the earth. An observer located in the shadow’s path will see the sun’s disk gradually covered by the dark lunar disk until the sun’s light is almost completely blotted out. During this “total” phase of the eclipse, only the light from the sun’s outermost atmospheric layers is visible and a darkness comparable to a full moon night descends on the land for a time period ranging from a few seconds to as long as 7 min. Finally the moon moves out of its direct alignment between the earth and the sun, and the sun reemerges to its full disk and full brightness.

The sun, earth, and moon can also align in such a way that the moon passes into the earth’s shadow, thereby producing a total eclipse of the moon. When such an event occurs, an observer on the earth sees a full moon gradually enter the curved shadow of the earth. When the moon is

totally immersed in the earth’s shadow, it can take on a variety of ruddy hues ranging from an almost totally darkened red to a bright coppery shade of red-orange. This illumination even at the total phase of a lunar eclipse is caused by sunlight being refracted on to the moon’s surface by the earth’s atmosphere. The variety of colorations exhibited during various lunar eclipses is thus the direct result of the weather conditions in the earth’s atmosphere, especially the degree of cloud cover at key locations around the earth. Typically the eclipsed moon spends an hour or so in the total phase before reemerging from the earth’s shadow and regaining its full moon brilliance.

Every few years or so the night sky is visited by a strange apparition, a diffuse “long-haired” star-like object called a comet. Comets are known to be collections of ices, dust grains, rocks, and frozen gases which wheel about the sun in huge elongated orbits which alternately carry them from relative proximity to the sun out to the most distant parts of the solar system, thousands of earth-sun distances away. As a comet approaches the sun, the sun’s radiant energy causes the ices and frozen gases to evaporate into a glowing coma which surrounds the dust and rocks at the comet’s nucleus. As this diffuse, star-like object draws ever closer to the sun, the solar proton wind and radiation pressure drive material out of the diffuse head into a long, streaming tail which can extend over millions of miles of space. For several weeks, like a cosmic messenger, a comet will approach the sun, blossom with a flowing tail, and then fade into the cold blackness that is the periphery of the solar system.

The debris left behind by both these interlopers as well as from the formation process of the solar system permeates the interplanetary medium. As the earth sweeps along its orbit, it is constantly bombarded by objects ranging in size from tiny grains of dust up to small asteroids several kilometers in diameter. Fortunately collisions with the latter are extraordinarily rare! When a given interplanetary particle, called a meteoroid, strikes the earth, it does so at speeds as high as 50 km s^{-1} . At such speeds, friction

with the earth's atmosphere causes the object to heat up quickly and glow brilliantly as it falls toward the earth. An observer at the earth's surface sees this event as a "falling star" or "shooting star." Most of the time, such objects disintegrate in the upper layers of the earth's atmosphere, but occasionally a meteoroid is able to traverse the earth's atmosphere and strike the earth's surface. Such an object is then referred to as a meteorite.

Occasionally the earth passes through a large stream of meteoric debris left behind by a comet. Under these conditions, large numbers of meteors can be seen in the form of a meteor "shower." During a typical meteor shower, one can see anywhere from 15 to 60 meteors per hour above the normal sporadic or background meteor counts of about six meteors per hour. About three or four times per century the earth strikes a particularly large and dense aggregate of meteoroids. Under these circumstances, thousands of meteors per hour flash across the heavens in a display of celestial fireworks which is unmatched anywhere else in the natural world.

From time to time in the remote recesses of interstellar space a star will end its life in a spectacular event called a supernova explosion. For a few days the energy output of this dying object rivals that of all the stars in an entire galaxy. If a supernova detonation occurs at a distance sufficiently close to the earth, the observed result is the transitory appearance of a "new" star in the terrestrial night sky. For time periods ranging from a few days to several months, the star shines at or near its maximum brightness before fading back into naked eye invisibility. One of the more notable of these objects was observed in the year AD 1054. At its maximum brightness, the supernova of 1054 was nearly three times brighter than the planet Venus and could be readily seen in broad daylight. The remains of this stellar blast can be telescopically viewed today as the tattered and twisted gaseous cauldron called the Crab Nebula.

Unlike the mathematical and monolithic universality which characterized the scientific philosophy emergent from the Western European Renaissance, the explanations tendered for the considerable array of celestial phenomena by

non-western cultures as well as those of pre-Renaissance Europe and the Mediterranean were far more qualitative in nature and represented a diversity of ingenious viewpoints that were nearly as numerous as the cultures from which they sprang. Generally such explanations appear in a given culture in the form of myths, legends, and folklore, and pay considerable homage to the observed characteristics of the sky and its resident objects. As such, they represent the beginning attempts on the part of human beings to provide rational explanations consistent with observations for the variety of events which occur in the physical world, thereby making that world more comprehensible.

Perhaps the most familiar example of this process in action is to be found in the myths and legends pertaining to the fixed stars. Out of the more or less random distribution of stars in the night sky, one can imagine a variety of figures, shapes, and patterns not unlike the variety of faces and forms that one often fancies in the puffy clouds of a springtime sky. In some instances, a given pattern of stars can bear a striking resemblance to a familiar terrestrial entity. For virtually every culture, such similarities were not fortuitous, but in fact were intrinsic characteristics of the sky which were significant and demanded explanation. The most common approach was to regard the sky as a kind of "Celestial Hall of Fame" into which various legendary characters from a given culture's folklore had been inducted for various reasons. Such "inductees" thus became figures outlined in stars or constellations. The outline of some of the constellations are so compelling in their shapes that a variety of far-flung cultures would often envision very similar portraits for a given star group. Thus, the stars of the highly prominent wintertime constellation of Orion, for example, seem to outline a very fit and trim individual possessed of considerable physical strength. Thus Orion, the mighty hunter of Greek mythology is also al-Babādur (The Strong One) for the Arabs, the great hunter "Bull of the Hills" for the Blackfoot Tribe of the western Canadian plains, and the "Slender First One" to the Navajos of the American southwest. As one might expect,

there is also a considerable amount of variation in the sky pictures of various cultures. Even though the J-shaped array of summertime stars which we call Scorpius the Scorpion has been widely depicted as a celestial version of its earthly arachnid namesake, there are many other interpretations of this asterism from other cultures. The Polynesians, for example, saw this star group as the fishhook of their great hero Maui, while the Chinese viewed it as the noble Azure Dragon, the Bringer of Spring. To the Mayas of Central America these stars represented the death god Yalahau, the lord of blackness and waters.

The constellations through which the sun, moon, and planets travel in their respective journeys about the celestial sphere were quite naturally assigned a particularly significant status as the constellations or signs of the zodiac. Traditionally there are 12 such constellations, each of roughly equal extent along the zodiac, and which include Aries the Ram, Taurus the Bull, Gemini the Twins, Cancer the Crab, Leo the Lion, Virgo the Virgin, Libra the Scales, Scorpius the Scorpion, Sagittarius the Centaur-Archer, Capricornus the Sea-Goat, Aquarius the Water Carrier, and Pisces the Fishes. In addition to the standard 12 constellation zodiacs employed by a majority of the world's cultures, the zodiac has been variously divided throughout human history into as many as 28 constellations by the Chinese and as few as six by the early Euphratean cultures. The denizens of the zodiac exhibit a considerable variation from culture to culture. The Aztec zodiac was graced with the starry presence of a frog, a lizard, a rattlesnake, and a jaguar, while that of the Incas contained a tree, a bearded man, a puma, and the sacred cantua plant.

Numerous explanations were offered for the observed movement of the sun, moon, and planets along the zodiac, virtually all of which centered on the basic idea that only gods and goddesses could possess the power to move among the stars. In the case of the sun the concept was further reinforced by the fact that to look directly on the face of the sun's disk was to incur the sun deity's wrath in the form of severe

damage to one's eyes. Thus the sun was the sun god Amon-Ra to the Egyptians and the sun goddess Amaterasu to the early Japanese, and so on.

Eclipses and conjunctions in the sky have also inspired a number of mythologically based explanations. In the Hindu culture, for example, the mortal Rāhu is said long ago to have attempted to partake of the forbidden nectar of immortality. The god Viṣṇu was told of Rāhu's transgression by the sun and moon, and as punishment Viṣṇu proceeded to decapitate Rāhu. Ever since, Rāhu has sought to take vengeance on the sun and moon by pursuing them across the sky in an attempt to eat them. Once in a while, at the time of an eclipse, Rāhu actually catches either the sun or the moon and attempts to devour his prey. As the sun or moon is devoured, it gradually disappears into Rāhu's throat for a time before reappearing at the base of his severed neck as Rāhu attempts to swallow. The entire event is observed here on the earth as an eclipse of the sun or moon.

The sky watchers of antiquity were able to identify a number of basic characteristics relating to the background objects of the celestial sphere. The recognition of the variety of intrinsic colors that characterize the stars, for example, is manifested in names for stars such as the Arabic *Qalb al' Aqrab* (Heart of the Scorpion) for the bright red star Antares located at the center of Scorpius and the Hindu *Rohini* (Red Deer) for the ruddy star Alphard in the chest of the constellation of Hydra the Sea Serpent.

Bright stars near the celestial poles have held great meaning and significance to the watchers of the sky. In the third millennium BCE the north celestial pole was located in the constellation of Draco the Dragon near a second magnitude star called Eltanin. Because the heavens of the day appeared to rotate about this star, it was quite literally regarded as an object of pivotal importance. As a result, Eltanin was worshipped by a number of cultures, including the Egyptians who used this star to align a number of their important buildings and structures. As the earth's axis of rotation has precessed, other stars have taken on the mantle of Pole Star, most notably by the stars Thuban in the constellation of Draco and Kochab

in the constellation of Ursa Minor, the Lesser Bear, and in more recent cultures by the star Polaris at the tip of the tail of Ursa Minor. Both Kochab and Polaris were regarded by the Chinese as Da Di the Great Imperial Ruler of the heavens, about whom the other stars circled in homage. The Pawnee tribe of the American plains named Polaris "The Star That Does Not Walk Around." To the Pawnee this star was related to the god Tirawahat, and as such, was chief over all the other stars. It was this star that saw to it the other stars did not lose their way as they moved across the sky.

Attempts to explain the true nature of the diffuse objects that dot the sky are understandably less prolific in light of the difficulties that are often encountered in observing them. The major exception is, of course, the Milky Way. Of the diffuse objects detectable in the heavens with the unaided eye, the Milky Way is far and away the most extensive and prominent. This delicate band of light which is also highlighted by an array of brighter stars has thus inspired a variety of explanations which include its portrayal as a celestial river by the Chinese and Japanese, as a Path of Souls to an eternal home by the Algonquin tribe of the Lake Ontario region of southern Canada, and as a band of glowing cinders by which one could find one's way home when lost in the darkness by the Bushmen of Africa's Kalahari Desert.

As imaginative and rational as they were, however, the explanations advanced by different cultures for the variety of celestial phenomena observed in the heavens generally became intertwined with the religious beliefs and societal mores of these cultures. As a result, there was a marked tendency for the explanations of celestial phenomena to take on dogmatic qualities in which they were seldom questioned or challenged by alternate points of view. Moreover, the lack of a telescopic astronomy placed severe and fundamental limitations on the level of insight that was possible regarding the nature of celestial objects. Thus the explanations proposed for various celestial phenomena tended to remain largely unchanged in a given culture, and whatever changes that did occur were not so much the

result of additional observational insights, but rather due to a gradual evolution brought on as these explanations were passed on from generation to generation or from culture to culture. Even while armed with an impressive instrumental technology, however, human beings still continue to struggle with questions relating to the fundamental nature of what we see in the sky.

Certain observable aspects of the heavens readily lend themselves to practical usage here on the earth, and the greatest levels of achievement enjoyed by non-western astronomers have come in the discovery, recognition, and application of these characteristics. Systematic observations of the sky reveal, for example, that many celestial phenomena, most notably the diurnal and annual motions of the sun and the cycle of lunar phases, occur with precise and predictable regularity. This observable fact of the heavens has thus been employed by cultures worldwide as a method of accurate time keeping.

The diurnal rising and setting of the sun, with its alternating cycle of daylight and darkness, is the shortest and most convenient unit of astronomical timekeeping, and as a result human beings the world over have employed it, quite literally, as an integral part of their daily lives. A second, much longer unit of astronomical time is defined by one complete journey of the sun around the ecliptic. This annual astronomical cycle is of considerable importance owing to the fact that it is intimately related to the cycle of seasons which occur here on the earth. The cycle of seasons, in turn, is virtually identical to the cycle of vegetative growth and those of some animal activity and migrations. Thus agricultural methods and hunting techniques developed by various cultures were necessarily tied deeply to the cycle of seasons and the sun's annual journey along the ecliptic. Intermediate in length between the day and the year is the time interval required for the moon to pass through one complete cycle of its phases. The lunar cycle is particularly attractive as a timing cycle due to the fact that the ever-changing shape of the moon is readily observable on a daily basis. Sequences of shapes inscribed on Cro-Magnon cave walls and artifacts strongly suggest their use as lunar phase timing

devices in just this fashion. Similar sequences carved by the inhabitants of Nicobar Island in the Bay of Bengal are known with certainty to be employed for this purpose.

Unfortunately these cycles are not quite numerically compatible with each other. For example, there are about 365 days in a year, but in reality it takes the sun precisely 365.242199 days to complete one cycle around the ecliptic. Similarly there are 29.530588 days to a cycle of lunar phases and 12.36827 cycles of lunar phases in a year. These discrepancies can create difficulties if one wishes to reckon the time of the year, the start of a given season, or the date of an important religious holiday by simply counting the number of days which have elapsed from some defined starting point such as the day of a solstice or equinox. If one counts the number of days as the year progresses, for example, one would find that after 365 days had passed, the sun would not quite yet have completed its journey around the ecliptic, and after 366 days had elapsed, the sun would have moved slightly past one complete cycle. Over several years' time such an effect can add up to a significant discrepancy between the sun's actual position along the ecliptic and the position dictated by the day count. As a result, a variety of schemes, called calendric systems or calendars, have been developed by various cultures around the world which are designed to synchronize two or more astronomical cycles. The most familiar of these is the addition of 1 day to our calendar every fourth or leap year in order to keep the day count in a given year in agreement with the sun's actual position along the ecliptic.

A number of ingenious techniques were developed by various cultures to monitor the astronomical timekeeping process. The Aztec Temple Mayor, now buried beneath modern Mexico City, was designed in the fifteenth century with two spires that provided a V-shaped notch through which the rays from a sun rising at the time of an equinox shone on to the temple of Quetzalcoatl. At no other times of the year would a rising sun produce this effect. Thus the Aztec temples served quite nicely and deliberately as a device with which the Aztec calendar

could be corrected whenever necessary. Similar structural alignments are to be found at Stonehenge in England, in the temples of ancient Egypt, and among the buildings of the ancient peoples of the American Southwest. The Mayas of ancient Mesoamerica developed not only astronomical alignments for many of their structures, but also an incredibly accurate but somewhat complicated astronomical calendar which was based on the annual solar cycle and the synodic period of the planet Venus. The Maya calendar was accurate to within 1 day every 5,000 years. By contrast, the simpler Gregorian calendar used by contemporary society is accurate to within 1 day in 3,300 years.

In addition to the structural alignments, various cultures have also employed natural terrain as calendar correctors. On the top of Fajada Butte at the mouth of Chaco Canyon in the American Southwest, for example, there stand three rock slabs, each of which is about 3 m in height. On the rock wall behind these slabs a first millennium AD people called the Anasazi carved a spiral petroglyph in such a way that precisely at noon of the day of the summer solstice, a dagger-shaped beam of sunlight would neatly slice the petroglyph exactly through its center. Through this clever manipulation of sunlight, the Anasazi were able to mark the time of the summer solstice precisely.

The Hopi and Zuni tribes, also of the American Southwest, make use of a so-called sunrise horizon calendar. As the sun moves along the ecliptic, the points of sunrise and sunset along the horizon at a given location exhibit an annual cyclic shift in which the sunrise and sunset points appear to migrate along the horizon from south to north while the sun is moving from the winter solstice to the summer solstice and then north to south along the horizon while the sun is moving from the summer solstice to the winter solstice. As the sunrise and sunset points pass over various key landmarks along the horizon, each passage is taken as a signal to begin the appropriate agricultural activity such as planting various crops, harvesting, etc.

In addition to timekeeping, earth-sky relations can also be employed to find one's way about the

surface of the earth. Such techniques are referred to overall as celestial navigation and have been of considerable importance to human cultures, particularly those which are maritime in nature. There are a number of aspects of the heavens which readily lend themselves as navigational aids. As the earth spins on its axis, for example, a star at or near the celestial pole will not appear to change its position in the sky significantly. More importantly, the point on the horizon directly beneath such a star will also remain in a relatively fixed position as well. Thus for observers in the northern hemisphere, the relatively bright star Polaris is located very close to the north celestial pole, and the point on the horizon directly beneath this signpost star has been used for centuries by northern hemisphere peoples to mark the direction we call north.

Other cultures took advantage of the fact that the angular distance of the pole star above the horizon as well as the locations of the rising and setting points of bright stars and constellations along the horizon changed with one's location on the earth's surface. Thus the Caroline Islanders of the central Pacific skillfully navigated by means of this star compass in which 32 points on the horizon were defined by the rising and setting points of bright stars and constellations such as Vega, the Pleiades, Antares, and the Southern Cross. The Polynesians employed a device called the sacred calabash, which was a gourd into which four holes were bored at the same height near the neck. The gourd was then filled with water to the level of the holes. Using the water level as a horizon, altitudes of stars were then measured by sighting through one of the holes over the opposite edge of the gourd. Thus armed with what was in effect the equivalent of our modern sextant, the Polynesians became most adept at deep-water navigation.

Systematic observations of the heavens also reveal that there exist a number of correspondences between celestial events and configurations and natural phenomena here on the earth. For example, the Egyptians recognized that the annual flooding of the all-important Nile River was at hand when the bright star Sirius made its heliacal rising or first appearance out of the

predawn solar glare. The Incas of the South American Andes Mountains noticed that the cantua plant blossomed beautifully each year when the sun was located in our zodiacal constellation of Cancer, but which they named appropriately from their observations as the asterism of the sacred cantua plant. The heliacal risings of the bright stars Rigel, Aldebaran, and Sirius served to warn the tribes of the high plains of western America that cold weather was at hand. In light of such readily observable earth-sky correspondences, it was very logical to assume that similar correspondences exist between celestial phenomena and human affairs. Thus evolved the endeavor which we now call astrology.

Whether the astrological leap of logic from earth-sky to human-sky correspondences is a valid one has, of course, been a topic of considerable debate for many centuries, and since the 1600s the premise that such human-sky correlations exist has been emphatically rejected by western science. Nevertheless, astrology, more so than either timekeeping or celestial navigations, demands access to careful and ongoing observations of the entire heavens for the purpose of interpreting the significance here on earth of what is seen to occur in the sky, and whenever possible, to predict future events in the sky as well. Thus a well-developed [▶ astrology in China](#) was certainly an important factor in the preparation of the earliest known star catalog in the fourth century BCE, and in the recording of a variety of celestial events, most notably the transitory appearances of sunspots and astrological omens such as comets, which were referred to as *huixing* (broom stars or sweeping stars) and of novae and supernovae explosions, which were called *kexing* (guest stars or visiting stars). So detailed were the records of the Chinese, Japanese, and Korean observations of the supernova event of AD 1054, for example, that modern astronomers were easily able to identify its present remains as the Crab Nebula in the constellation of Taurus, despite the fact that the event went virtually unobserved and unrecorded in Western Europe.

From some cultures, most notably those of the Mayas, Egypt, China, and the Islamic world,

careful observations of the sky combined with centuries of relative social and political stability to make possible the discovery of much more subtle and long-term astronomical cycles. The Mayas, for example, were aware of the long-term reappearances of the planet Venus and built the planet's 584-day synodic period into their calendar. Both the Chinese and Islamic observers were aware of the fact that the lunar nodes, or the points on the celestial sphere where the moon's orbit crosses the ecliptic, drift in a westerly direction along the ecliptic at a rate of one complete revolution every 18.6 years and used this knowledge to predict the occurrences of both lunar and solar eclipses.

The Chinese and Islamic observers also recognized that the sun's equinox points drift in a westerly direction along the ecliptic at a rate of nearly 1° per year and made appropriate adjustments in their respective star catalogs and calendric systems in order to account for the protracted effect of this equinoctial precession. Awareness of the shifting equinoxes may have also been the province of the Egyptians as well. A number of additions and reconstructions are found to exist in Egyptian temples and other structures which strongly suggest an architectural response to just such long-term changes in the positions of the equinoxes.

See Also

- ▶ [Celestial Vault and Sphere](#)
- ▶ [Time](#)

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Astronomy in China

Ho Peng Yoke

Chinese astronomy became a subject of long debate among historians and astronomers in the first half of the twentieth century. Some based their argument on the *Shujing* (Book of Documents) and concluded that Chinese star clerks had already made astronomical observations between 2000 and 3000 BCE. Richard Schlegel even asserted that they knew about the 28 lunar mansions as long ago as the year 1600 BCE. Others doubted the reliability of the records in the *Shujing* claiming that Chinese astronomy could not have originated earlier than 500 or 600 BCE. Some said that Chinese astronomy originated from India, others said from Arabia, and there were yet those who said that it was from Mesopotamia. Joseph Needham, for example, favors a Mesopotamian origin.

Recent archaeological studies carried out in China have thrown more light on early Chinese astronomy and enabled scholars to re-examine some of the old interpretations. Archaeologists have been hard at work during the last two decades to establish the Xia dynasty, which, according to tradition lasted from the twenty-first century BCE to the sixteenth century BCE, and which has until now been regarded as legendary. They have yet to recover written records of that period. Erlitou in Henan province, where bronze vessels dating back to the year 1700 BCE

were recovered in 1971, is one of their important sites. Even the records in the *Shujing* have recently been re-examined by comparison with computed ancient astronomical phenomena.

In the oracle bone writings we can find records of eclipses, novae, and names of stars and some asterisms. The records indicate that the Yin people between the fourteenth and twelfth centuries BCE were already using a lunisolar calendar, where 1 year consisted of 12 moons or lunar months of either 29 or 30 days each, with an extra month known as the intercalary month added about every 3 years. From about the sixth century BCE until the use of the telescope for astronomical observations in Europe in the seventeenth century, Chinese star clerks kept the most consistent and continuous astronomical records on eclipses, comets, novae, sunspots, and aurora borealis in the whole world. Star catalogs were produced during the Warring States period (481–221 BCE) by ► [Gan De](#), Shi Shen, and Wu Xian. Chinese astronomical records have found many applications in modern astronomy. One application is in the calculations of the period of Halley's comet. The Crab Nebula has been identified with the supernova observed in China in the year 1054. The first pulsar was discovered in 1967. It was found to be near a site where a "guest star" was recorded by the Chinese. A "guest star" in Chinese astronomy could refer to a supernova or nova, but it could also mean a comet or even a meteor, depending on the context. In this case it refers to a supernova or nova. As a result some astronomers made use of Chinese records in their attempts to discover other pulsars. Chinese records on sunspots have been used to determine sunspot cycles, and recently they were used in the study of the variation of the earth's period of rotation. There are many other applications for Chinese astronomical records, such as in a recent study of the Star of Bethlehem in the Bible.

There has been a prolonged dispute since the last century over the question of the origin of the 28 Chinese lunar mansions. These are 28 asterisms distributed along the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course). The moon changes its position among the stars night after night, and appears

successively in each of these asterisms, appearing from the earth as if it changes its lodging each night. Hence they were known as lunar mansions or lodges. Chinese astronomers also picked one of the stars in every lunar mansion as a reference point from which distances of other stars in its vicinity were measured. The stars used as reference points were called determinant stars. In ancient Hindu astronomy there were 27 *nakṣatras*, each of which had a principal star (*yogatarā*). Nine of the *yogataras* are identical with the Chinese determinant stars. Some thought that the lunar mansions and the *nakṣatras* had a common origin, often with Sinologists and Indianists taking opposite sides. Before a conclusion was reached came a third contender, the *al-manāzil*, the moon-stations in Muslim astronomy. Then it was argued that Muslim astronomy was predated by Hindu astronomy. During the middle of the twentieth century the most favored candidate was Mesopotamia, from which ancient Chinese astronomy and others were thought to be originated. This is the view favored by Joseph Needham. The argument against China's favor until then was that all the names of the 28 lunar mansions were not found earlier than the fourth century BCE. However, in the year 1978 the names of all the 28 lunar mansions were found inscribed on the lid of a lacquer casket of the early Warring States period, showing that the 28 lunar mansions were already there in China not later than the fifth century BCE. Chinese archaeological discoveries in the second half of this century and recent archaeological excavations carried out in India have also shown that both Chinese and Indian civilizations existed much earlier than they were thought. Whether the lunar mansions in Chinese astronomy were influenced by the Hindu *nakṣatras* or whether it was the other way round is an open question. Perhaps there was no influence between the two systems at all. The important thing in the study of history of science and civilization is to learn about mutual exchange of ideas among different cultures rather than to engage in futile disputes, claiming priorities and making scores in meaningless contests, in which there is no prize for the winner other than false pride.

The earliest existing Chinese documents on astronomy are two silk scrolls discovered in the Mawangdui tombs in Changsha, Hunan province in the year 1973. One of them, the *Wuxingzhan* (Astrology of the Five Planets) contains records of Jupiter, Saturn, and Venus, the accuracy of which suggested the use of the armillary sphere for measurement. These records were made between 246 and 177 BCE. The other, the *Xingxiangyunqitu* (Diagrams of Stellar Objects and Cloud-like Vapors of Various Shapes) illustrates different types of comets. Among the ancient astronomical instruments discovered by archaeologists are the bronze clepsydra from the tomb of Liu Sheng of the second century BCE and a bronze sundial of the Eastern Han period (25–220). The title of an early Chinese book on astronomy and mathematics, the [► Zhoubi suanjing](#) (Mathematical Manual of Zhoubi), calls to mind either the Zhou dynasty or the circumference of a circle, and the vertical side of a vertical right-angled triangle. The book contains the so-called *Zhoubi* or [► Gaitian](#) cosmological theory in which the heavens are imagined to cover a flat earth like a tilted umbrella, and shows paths for the sun at different seasons of the year. From the positions of the stars and planets mentioned in the text, Japanese scholars established a period between 575 and 450 BCE for the observations and inferred that the book was written within the same period. Christopher Cullen recently showed that the book could well be a work of the early first century.

During the second century [► Zhang Heng](#) (78–139) constructed an armillary sphere as well as a seismograph for making astronomical observations and for detecting the direction of earthquakes. An armillary sphere consisted of a system of rings corresponding to the great circles of the celestial sphere and a sighting tube mounted in the center. With such an instrument Chinese astronomers could measure the positions of heavenly bodies. The mounting of the Chinese armillary sphere deserves special attention. As pointed out by Needham, it has always been equatorial unlike its counterpart in Europe which was ecliptical, but only changed to equatorial in modern telescopes. The new armillary

sphere made by Zhang Heng resulted in more accurate observations and better star maps.

An important role of Chinese astronomy was calendrical calculation. The emperor regarded calendar making as one of his duties associated with the mandate that he received from Heaven. The Chinese calendar took into account the apparent cycle of the sun and the cycle of the moon, both of which, as we know, cannot be expressed in an exact number of days. The astronomer responsible for constructing a lunisolar calendar had to make accurate observations of the sun, the moon, and the planets, but however accurate his observations and his calculations, his calendar would sooner or later, in just a matter of decades, get out of step with observations. Hence throughout Chinese history no less than 100 calendars had been constructed. Besides, sometimes there were also unofficial calendars adopted in certain regions in China. During the seventh century Indian calendar-making made its presence felt in China. We can read the names of a number of Indian astronomers and calendar experts who lived in Changan, the capital of Tang China.

In the early days of the Tang dynasty the calendar officially adopted was the *Lindeli* calendar constructed by the great early Tang astronomer, mathematician and diviner [► Li Chunfeng](#) (602–670). By the early eighth century a new calendar became overdue. Eventually the old calendar was replaced by the *Dayanli* calendar constructed by the Tantric monk Yixing (683–727). Yixing's secular name was Zhang Sui. He is regarded as the most outstanding astronomer of his time for his recognition of the proper motion of the stars. In the year 721 the Tang emperor Xuanzong entrusted Yixing with the task of constructing a new calendar. To do this he constructed new astronomical instruments, including an armillary sphere moved round by wheels driven by water, and he also carried out a large scale research project to measure the length of the earth's meridian. He employed the method of difference, involving equations of the second degree, as well as the method of the remainder theorem in the *Suanzi suanjing* to calculate his new calendar.

From the late seventh century Indian Tantric monks had also come to reside in the Tang capital. Later Yixing made frequent contact with them and assisted them in the translations of some of their *sūtras* into Chinese. Yixing could have acquired from them some knowledge of astrology and mathematics, including the idea of a spherical earth and the sine table. There were then three clans of Indian calendar experts living in the Tang capital, namely the Siddhārtha clan, the Kumara clan and the Kaśyapa clan, of which the Siddhārtha clan was the most active and famous. At least two members of that clan had served as Directors of the Astronomical Bureau. The most distinguished member was Gautama Siddhārtha, who constructed an iron armillary sphere when he was director and translated the *Navagrāha* calendar into Chinese in the year 718. Most important of all, he compiled the *Da-Tang Kaiyuan zhanjing* (Prognostications Manual of the Kaiyuan Period of Tang Dynasty) between the years 718 and 726. The word *Navagrāha* means the “Nine Luminaries,” namely the Sun, the Moon, Mercury, Venus, Mars, Jupiter, Saturn, and two imaginary planets *Rahu* and *Ketu*. Although this calendar was never adopted in China, it found its way from there to Korea, where it was used for a period of time.

During the Song dynasty (960–1279) astronomers made more accurate astronomical observations using new and larger armillary spheres. They constructed several such instruments, the most famous of which was that made by Su Song (1020–1101). It was an armillary sphere driven by a water-wheel using the principle of escapement. A full-scale study of Su Song’s instrument is given in Joseph Needham’s *Heavenly Clockwork*. Su Song’s instrument was both an armillary sphere and a clock, but it was known only as an armillary sphere. Hence until it was pointed out by Needham, Price, and Wang Ling, nobody knew that the clock already existed in China when Matteo Ricci introduced the clock in the late sixteenth century.

Astronomy during the Mongol period (1271–1368) was closely connected with the name of Guo Shoujing (1231–1316), the last of the great traditional Chinese astronomers. The

Shoushili calendar that he constructed was the most advanced and accurate calendar ever produced in traditional China. It was made possible by the precise instruments he built and the method of finite difference he used in his calculations. This was also the time when astronomers from the Arab world came to work in China. The Muslims were still active in the Astronomical Bureau when the Jesuits came toward the end of the sixteenth century. The Jesuits arrived at a time when Chinese astronomy was in a state of stagnation, when no one with the knowledge and skill of Guo Shoujing could be found. The Chinese learned pre-Copernican astronomy from them. Modern astronomy came to China only around the middle of the nineteenth century. It did not take long for Chinese astronomy to join the mainstream of modern astronomy. Just as Nakayama Shigeru said that the history of Japanese astronomy was the history of Chinese astronomy in Japan, Chinese astronomy has already become modern astronomy.

See Also

- [Armillary Spheres in China](#)
- [Calendars in East Asia](#)
- [Clocks and Watches](#)
- [Eclipse Observations](#)
- [Gan De](#)
- [Guo Shoujing](#)
- [Li Chunfeng](#)
- [Lunar Mansions in Islam](#)
- [Zhang Heng](#)

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Astronomy in Egypt

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We have few written records dealing explicitly with the heavens, and those that we possess are usually derived from the Greek astronomical tradition and therefore are very late in Egyptian history. Thus, in order to assess the astronomical knowledge of ancient Egypt, we rely on such limited pieces of evidence as “diagonal calendars”

that decorate some Middle Kingdom (ca. 2150–1780 BCE) coffins, orientation of tombs and pyramids relative to the cardinal compass points, and astronomical ceilings (and their accompanying inscriptions) used in New Kingdom (ca. 1550–1085 BCE) temple or tomb decorations.

Evidence from the region of Nabta Playa indicates that systematic observations of the heavens were already well developed during the predynastic period (prior to 3100 BCE) of Egyptian history. Here, an ordered array of stones grouped in a rough circle around a central stone are reminiscent of the artificial arrangement of megaliths at Stonehenge, although the Egyptian arrangement is much older.

One of the primary incentives for study of the heavens in ancient Egypt was the necessity to establish the cultic calendar on a firm basis. This cultic calendar, growing out of less formal agricultural and ritualistic calendars, defined the beginning of the year using the heliacal rising of Sothis (modern Sirius). For administrative purposes, a civil calendar was superimposed upon the older luni-stellar cultic calendar. The determination of the administrative year was not defined by astronomical observations, however, but by counting off 365 days from the beginning of the year. Because the civil year contained exactly 365 days, it was typically out of step with the natural or solar year. The two coincided only every 1,460 astronomical years (the so-called Sothic cycle).

The determination of cultic celebrations, however, continued to be based largely on lunar phenomena. In order to correlate the two calendars, the Egyptians used the observation that there are very nearly 309 lunar cycles in 25 civil years. In general, any two successive lunar months had 59 solar days, but every 4 years, the last two months were given 60 days, a correction reminiscent of our leap year. This correlation allowed the priests to predict with fairly consistent accuracy where lunar festivals should fall within the civil calendar, obviating the necessity to observe the heavens in order to determine the time for a particular festival.

The civil year was divided into 36 “decans” of 10 days each, to which five epagomenal days

were added. These decans are represented in the diagonal calendars or star clocks depicted on several Middle Kingdom coffins, presumably as a way for the deceased to know when specific spells needed to be recited during the journey to the afterlife. Such star clocks may also have been associated with nightly timekeeping in temples for religious observance. In order to predict the coming of the dawn so as to be prepared to perform essential temple rituals, each hour of the night was associated with one or more bright stars whose heliacal rising would signal the beginning of each hour of the night. Because the sun moves slightly slower than the stars in its apparent circling of the Earth, any chosen star will rise farther and farther in advance of the sun, so that it is an effective indicator of the first hour of the night only for about 10 days, after which the asterism which had originally indicated the second hour now introduced the first hour of the night.

In the New Kingdom, the focus shifted from heliacal rising of each decan star to its zenith transits – an easier phenomenon to observe. But this shift required that the decan asterisms be redefined. These observations apparently involved noting the position of stars relative to the body of an assistant (e.g., when the star is located above his right eye). Charts illustrating this method are seen in the tombs of Ramses VI, Ramses VII, and Ramses IX.

It has often been noted that pyramids, and especially the pyramids of the Giza plateau, as well as numerous tombs and temples, seem to be aligned with the cardinal compass directions. The precision of such alignments points to an astronomical determination of the cardinal directions, although we do not know exactly how this was done. The older hypothesis was that a level artificial horizon was constructed, against which the rising and setting points of a given star would be marked. Bisection of the angle between these two sightings, as measured from the center of the artificial horizon, determines true north. This technique, although possible, appears cumbersome. A somewhat simpler method would have been to erect a gnomon perpendicular to the Earth and to construct around it a circle of arbitrary

radius. Mark the two points at which the shadow of the gnomon touches this circle, once before noon and once after noon. The line bisecting the angle formed between these two observations and the gnomon determines true north. We have, however, no surviving evidence to reveal which of these two procedures the ancient Egyptians used. (It is also fair to say that many temples and tombs are not so precisely oriented – many merely face the Nile, which flows roughly from south to north, without regard for local geographical variations.) Although most temples appear to be aligned east and west, two directions that are associated with solar worship, others are explicitly oriented to stars, especially Sothis.

The scanty surviving evidence suggests that the Egyptian observer of the heavens used only the simplest of observational tools, and even these may not have been used extensively prior to the New Kingdom period (ca. 1550–1085 BCE). Nocturnal observations typically involved a *merkhet* (a palm rib notched at its wider end, used in conjunction with a plumb line) to determine the zenith transit of a celestial object. Daytime observations generally involved determination of solar altitude using length of shadows. These measurements were sometimes made using a horizontal graduated bar, with a small perpendicular block at one end to cast a shadow on the horizontal bar. Herodotus reports that the Egyptians knew sundials, but surviving evidence favoring that view is scanty. The shadow clock, however, suffers from the same problems as the sundial. Both are constructed to divide the day into equal parts, although the inclination of the Earth's axis creates unequal lengths of daylight throughout the year, complicating any attempt to regulate time through astronomical observations.

When astronomical observations were not possible, the Egyptians sometimes used a water clock similar to a Greek clepsydra to determine hours. Water is allowed to escape from a container of known volume through a small orifice at the base. The interior is graduated to show the lapse of time. The ancient Egyptians apparently did not appreciate that the rate of outflow is not constant. Here, too, we find that

a degree of inaccuracy or indeterminacy seems to have been accepted.

Astronomical ceilings are among the most striking pieces of evidence concerning the ancient Egyptian's knowledge of the heavens. Central to these documents are a group of figures whose composition and orientation change very little with time. These are usually considered to represent the circumpolar constellations, although all attempts to match these figures with visible star groupings, apart from the foreleg (Big Dipper, part of the constellation Ursa Major), have so far been unsuccessful. In addition to these groupings, there are often iconographic and inscriptional references to the naked-eye planets and to individual bright stars (most notably Sothis/Sirius). All of this indicates that the ancient Egyptians were careful observers of the night sky, although probably not overly concerned with reducing these observations to mathematical models of the kind found in Greece.

We know very little about practitioners of astronomy. Only in very rare instances do funerary titles indicate someone who may have observed or studied the heavens for some specific purpose beyond personal curiosity. The evidence indicates, however, that there was a continuing effort to observe and describe celestial phenomena.

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Astronomy in Hawai'i

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There were two important tasks that drew on ancient Hawaiians' understanding of space and time. One was constructing a ritual calendar for determining the length of the day, week, month, and year; the other was navigating on the seas between island destinations.

The first, calendrics, was the responsibility of the priests, among whom were stargazers called *kilo hoku*, from *kilo* (to observe or to watch), and *hoku* (star). The same stargazers, however, observed more than stars. They knew the sun's

motions and those of the moon and the planets, but the stars were the most challenging.

Let us look at this from the standpoint of the student who starts out in "class," which was a place set aside for men and boys to worship the gods. In a place where men only spoke with one another in the men's eating house, the *hale mua*, the "front" (*mua*) house in the compound of the household (*kulana kauhale*), a young boy began his training in these subjects. Since they were part of required religious training, he found himself within rock-walled enclosures, or temple (*heiau*) grounds set aside for men's worship, the *tabu pule* scheduled through seven nights, *na la kapu kauila*, totalling 56 nights in an 8-month period. The 240-day *tabu* period was followed by 120 days of the *makahiki* season during which taxes (*auhau*) were collected.

No one knows how astronomical subjects were taught, although some information has survived through stories and chants from the migration period of discovery and exploration, with wayfinding practice associated mainly with places visited in ancestral lands to the south. The sun's motion between the north and south and across the equator may have been the first fundamental horizon system to be learned, combined with the observations of stars nearest the rising and setting points of the sun in the morning and evening.

The sun's rising (*hiki*) gives the cardinal direction east its name: *hikina*. When above the horizon, it is *kau*, to be placed or to be hung, but it also means to set, as of the sun afloat westward, *kau lana ka la*. When the sun sets, it "enters" (*komo*) into the world below, so that cardinal direction west is called *komohana*, the "entering" place of the setting sun. When the sun has stopped on its northern journey, that point is called the sun "afloat," *kau lana ka la*. Its daily motion as it arches upward from its eastern azimuth or "pit" (*lua*) to local zenith (*nu'u*) and after noon "declines" (*'au*) is called *ka'a*, *ka'a ka la ma lalo*, the sun moves down. When it crossed the equator, the sun was said to "trample" (*ke'ehi*) the "diaphragm" (*houpo*) of the god Kane (*ke'ehi i ka houpo o Kane*), the sun being the "eyeball" of

Kane (*Kane 'ono*hi o ka la). This is the basic compass, adding north for the right (*'akau*) and south for the left (*hema*) sides of the body.

The days were counted as nights of the moon, and there were two revolutions tracked, one synodic, and the other sidereal. Each "night" was clocked into quarters. The clock began at midnight, called *Kau*, or *Aumoe*, the latter meaning "time of sleep." *Kau* situates the clock on meridian, as at midnight and so also at noon, so the midday was also called *Kau*. When the sun was in the zenith (*nu'u*, *lolo*) it was called *kau ka la i ka lolo*, the "sun was over the brain (*lolo*)." This position of the sun, not only on meridian but in the zenith as well, took place twice in the year – once when the sun was going north, between May and June, and again when the sun was going south, between June and July. People today may call this "Lahaina noon," but generally the zenith sun appears at the southernmost part of the island of Hawai'i, about 19° north about May 15th (although the date is variable). All other "noons" when the sun is on meridian are called *awakea* after Sky Father, Wakea, whose name is synonymous with noon and the center of the celestial equator, called *Ka Piko o Wakea*, the "Navel of Wakea" (Sky Father). *Piko* means "center of the body," which has three such *piko*: one at the top of the skull in the soft spot, the fontanel; one at the navel, and one at the midpoint of the genital area in line with the *piko* in the middle of the skull. When one lies down, then the *piko* at the center of the horizontal body, called the *'opu*, is in contact with navel center of Mother Earth, *Ka Piko o ka Honua*. "The Navel of the Earth," or terrestrial equator, which extended beyond earth into the sky is *Ke Ala i Ka Piko o Wakea* (Path to the Navel of the Sky); *Ka Piko o Wakea* is the celestial equator.

The clock having thus two *Kau*, midnight and midday, is an indigenous concept of the "mean day," by which day and night are divided into equal parts. There were no hours, except the quartering for the night, commencing about sunset (i.e., 6:00 p.m.), called a "corner" (*kihi*), and the next "corner" at sunrise, *Kihi puka*; *puka* means "to emerge," as a celestial body, whether

sun, moon, stars, or planets. Between the kihi corners were the *pili* quarters, meaning “close to,” as in *pili ‘aumoe*, about 9:00 o’clock at night, and *pili puka*, about 3:00 a.m., meaning “close to sunrise.” From these data it appears that the shape of the Hawaiian clock between the two Kihi is angular rather than circular, perhaps a rectangular shape. The day clock is spread out on both sides of noon (Kau, Awakea) by morning (*kakahiaka*), afternoon (*‘auinala*, from *‘au*, “to decline,” as of the sun), and evening (*ahiahi*). Day and night are *ao* (daylight) and *po* (night).

The moon was regarded as feminine, as passive light or a reflection of the goddess Hina, perceived as ruling the tides, as well as growing sea life on and around the living reef. Each night of the moon had a separate name through one synodic revolution of the moon, or that passage from the first crescent perceived in the west until it returned to that point again in 29.5–30 nights.

The new moon, or dark phase, was *Muku* (cut off or severed). Hina, the moon goddess, was thought to have gone into and through the Milky Way (*Ka Wai Ola a Kane*, “Living Waters of Kane”), in which her dying soul (*Mauli*) revived in the life-giving semen of the creator god. Her spirit was the last crescent waning moon (*Mauli*). On the night of Muku, Hina’s spirit was in the Milky Way. After Hina comes through the *Wai Ola a Kane*, the first braid of her gray hair is seen at Hilo after sunset, low on the horizon, alive again. The waxing (*ho’onui*) moon begins at Hilo, moving south until first quarter at ‘Ole, thus:

These ten “nights,” or 10 days, were the first *anahulu* decan week of the month and year. In this circuit of 10 days the lighted part of the moon’s crescent increased as the moon continued southward. This was followed by two more *anahulu* decan weeks of rounding (*poepoe*) of the moon when the lit portion lost its “cusps” (*Ole*, milk teeth) until the fully lit circle, after which it began to wane or “shrink” (*‘emi*) back to the dark phase of new moon (*Muku*).

The ritual period of tabu days during 8 months of the year was coordinated between synodic and sidereal lunations, zenith stars, and azimuths of sun and stars in the ecliptic. [The following is excerpted (and readjusted) from Johnson 2000.]

The first ritual tabu period of the month, called a pule period, was imposed on the night of Hilo and raised on the morning of Kulua. . .

This period of the Ku pule tabu amounted to 2 and 1/2 days, between Hilo, Hoaka, Kukahi, Kulua. . .

During the poepoe rounding decan of the waxing moon, the tabu pule period was called the tabu of Hua, imposed on the night of Mohalu (12th night) and raised on the morning of Akua (14th night), i.e., from Mohalu, to Hua, and Akua. This added 1 and 1/2 more days to the 2 and 1/2 day Ku tabu before first-quarter moon. . .

A tabu pule period was assigned to the god Ka (na)loa. Imposed for 1 and 1/2 days, it began on the night of ‘Olepau and ended on the morning of Ka (na)loa-ku-lua, i.e., from ‘Olepau to Kaloakukahi and Kaloakulua. . .

After Kaloa-pau came the 27th night of Kane when began the tabu pule for this god on 1 and 1/2 days, from the night of Kane to the morning of Maui, i.e., Kane, to Lono, and Maui. While including the 28th night of god Lono, no tabu pule was set aside for the god Lono during the month.

The tabu period was in force for 240 days and relaxed for 120 days, beginning in the month of October, or the last month of the summer (Kau) season. This anticipated the shift of prevailing winds from the southwest (Kona) and the beginning of the agricultural year, *makahiki*, in November when the Pleiades star cluster (*Makali’i*) was expected to rise above the eastern horizon in the evening, opposite the sun and after the new moon in November.

David Malo, native Hawaiian scholar at Lahainaluna Seminary in the mid-nineteenth century, said:

The makahiki period began in Ikuwa, the last month of the period called Kau, and the month corresponding to October, and continued through the first 3 months of the period Hooilo, to wit: Welehu, Makalii and Kaelo, which corresponded with November, December, and January. . .

There were 8 months of the year in which both chiefs and commoners were wont to observe the ordinary religious ceremonies, three of them being the Hooilo months of Kaulua, Nana, and Welo, corresponding to February, March, and April; and five, the Kau months of Ikiiki, Kaaona, Hinaialeele, Hilinaehu, and Hilinama, which corresponded to May, June, July, August and September. (Malo, 1951, p. 141)

The moon calendar was a coordination of synodic revolutions of the moon between Hilo and

Muku of 29.5–30 days/nights of the month with sidereal lunations of 27.3 days/nights based on the transit of the meridian by a star, probably during quarter moon ('Ole nights) until the next transit.

What is the significance of the sidereal/synodic count in lunations of the moon's revolution around the earth and sun in 1 year? (1) The principle of the sidereal count is that, with respect to a star on the meridian, the moon's period of revolution around the earth is 27.3 days (Kane is the 27th night of the lunation). (2) The principle of the synodic count says that from its starting point at new moon, until it returns to that point, the moon revolves around the earth once every 29.5 days. Thus, (3) For every sidereal revolution of the moon around the earth in 27.3 days, the earth moves 1/13th of its orbit around the sun (with respect to a star on the meridian).

What was then the mode of intercalation to coordinate the sidereal with synodic lunations? We may only infer how that would have been done.

1. If we erase the 1/3rd fraction (Kane = 27 nights)
2. Then: 27 days $\times$ 13 months = 351 days = 1 sidereal year
3. We intercalate the fortnight (14 days) = 365 days = 1 tropic year
4. If we include the 1/3rd fraction, then: 13 sidereal months = $27.3 \times 13 = 351.39$ days
5. Intercalate 13.86 days = 365.25 days

This segment in *Kumulipo Mind* explored the relationship between the indigenous system and that borrowed from nineteenth century European calendrics after contact:

This formula provided an iconography of time in the sacred structure of temples and ritual schedule to a numerology, such as 16 sidereal lunations is equivalent to 32 fortnights ($13.5 \text{ days} \times 16$) and 432 days, the significance of which has been explored in the discussion of the decan system and tropic. (Johnson, 2000, p. 111–112)

Perhaps by pure chance the formula appears again in the Babylonian use of base 60 in the division of time connected to the earth's rotation

on its axis such that 15° equal 1 h circle of the earth's rotation, thus:

1. 1 min = 60 s
2. 60 min = 1 h
3. 1 h = 3,660 s
4. 24 h = 1 day
5. 1 day = 1,440 min
6. 1 day = 86,400 s
7. 12 h = 43,200 s
8. 6 h = 21,600 s
9. 3 h = 10,800 s
10. 1 1/2 h = 5,400 s
11. 3/4 h = 2,700 s
12. 3/8 h = 1,350 s

By this may be comprehended that the basic determination is made that the "turning" (kahuli) of the earth on its axis, or because of its rotation, creates the meridian, called *kaupoku o ka hale*, the 'ridgepole of the house' (meaning the house of God, the heiau), cutting the night/day into two halves by which celestial bodies ascend to the zenith (nu'u) and transit by descent to the horizon.

The motion, however, is the earth rotating on its axis, which could not be seen except as a change.

O ke au i kahuli, wela ka honua
 O ke au i kahuli, lole ka lani. . .
 In the time of turning over and around,
 The earth became hot; the sky changed
 [Wa Akahi, Kumulipo].

The passage of time is then measured by equalizing time on either side of the meridian, as between noon and midnight, or midnight to midnight, or noon to noon. The clock is geared to time elapsing between meridians, rather than between sunset and sunrise, or vice versa. The Hawaiians, like the Babylonians, had discovered the "mean day". By it they set their clock to keep track of the length of one day as from one midnight to the next.

The apparent movement of the sun was observed along the horizon between November and February as a slow period (actually, of the earth's orbit around the sun) and the fast sun between March and October. Perhaps the ancients had determined when the sun appeared to have crossed the celestial equator sometime in

April and again in October, or the minor axis of the ecliptic, the major axis between January and July constituting the anomalistic, rather than the tropic year (i.e., the orbit of the earth around the sun).

This was essentially the story of demigod Maui lassoing the sun to make it go more slowly during the winter months by tying down all 16 legs of the sun to a *wiliwili* tree on the western slopes of Haleakala in east Maui. The sun's motion north and south between the solstices was perceived as the motion of a spider (*ke ala a ke ku'uku'u*) as it laid down a web of the celestial grid through which the stars are tracked in their fixed courses from east to west in the night sky.

Finally, as in classic cosmologies of the Mediterranean and Eurasian systems, the sky becomes a pictorialized storyboard conveying by imagery and metaphor the positions and movements of constellations as characters from the ancestral heroic traditions of the past, so that the sky is not filled with nameless lights. The following is part of a continuing quotation excerpted from *Kumulipo Mind*:

The 'way of the spider' is known in Hawaii as the ecliptic, Ke-ala-a-ke-ku'uku'u 'pathway of the spider' (ku'uku'u, 'to let down, as a net') who is called Tukutuku-raho-nui (spider-of-large-scrutum) 'Great Spider', Tahitian (and Tuamotuan) tutelary deity of net-weaving in the Tahaki cycle.

The pathway of this spider was shown on the navigation gourd (ipu makani) diagrammed by Kaneakaho'owaha, counselor to Kamehameha I, in old Hawaii. It had several markings: the celestial equator, Ka Piko o Wakea 'The Navel of Wakea (Sky Father)'; the ecliptic, Ke ala a ke Ku'uku'u 'The Path of the Spider', which was divided into four parts:

1. The limit of the sun's path in the north on the 15th or 16th day of the month Kaulua (June, for Gemini), the summer solstice, Ke Ala Polo-hiwa a Kane "The Black Shining road of Kane"
2. The limit of the sun's path in the south on the 15th or 16th day of the month Hilinama (December, unidentified), Ke Ala Polohiwa a Kanaloa "The Black Shining Road of Kanaloa"
3. The eastern quarter, Ke Ala'ula a Kane 'The Dawning of or the 'Bright (Red) Road of Kane'
4. The western quarter, Ke Ala Ma'awe'ula a Kanaloa 'The Red-Track (as of a spider's thread, from *awe*, strand, thread; 'awe, tentacle) of Kanaloa'

A line was drawn in by burning in (pyrogravure) between the North Star (Polaris) and the Southern Cross, indicating the meridian. From another tradition of the navigation gourd, according to Theodore Kelsey, the night sky was graphed, in the form of a net (koko) woven over the calabash of mesh squares, a grid numbering 24–36 spaces (maka), as of a net ('upena), called na maka o 'Alihi 'the eyes of 'Alihi. Below the rim of the gourd, securing the mesh to the rim, was a red cord of 'olona twine called the 'Alihi, corresponding to the name of Tahaki's loyal cousin and helper, Karihi, who assisted Tahaki in reaching the sky world (Kelsey, in Johnson & Mahelona, 1975, pp. 150–152).

The Hawaiian navigation gourd net which bears the name of Karihi as the supporting red cord, 'alihi, and the 'eyes of Karihi', na maka o 'Alihi, is a parallel to the net of Tahaki fashioned by Tukutuku-raho-nui 'Great Spider' (Tahiti) whose path was outlined between the solstices and equinoxes on the ecliptic.

Tahaki's birth, like that of Maui, was in a West Polynesian home, and the place where Hema (Sema) was 'caught by the 'A'aia' was in Kahiki-west, or Viti, meaning in the direction of Fiji. In the Ulu genealogy, Kaha'i appears in the tenth generation after Maui.

In Hawaiian myth the spider's web as the shape of the spider in the sky is a form of the supernatural hero, Kana, son of Haka-lani-leo and Hina, chief and chiefess of Hilo, island of Hawaii. Kana was the grandson of Uli, the goddess, and Ku. Uli was the sister of the sky god Wakea and Manu'a (god of the underworld). The name Manu'a belongs to Samoa.

Kana is born supernaturally as a rope which was thrown into a pig pen and forgotten. He is the 12th son. The spirit of the cast-away baby visits the grand-mother Uli, and she recovers the neglected rope, putting it into a calabash of water where it grows 40 fathoms in 40 days, or one fathom a day, but no more than 400 fathoms.

In the meantime Kana's older brother, Niheu, who is only half as tall (5 feet) as his ten brothers, is the only person able to lift the 10-fathom 1-yard-long great *ulua* fish. Niheu tells his father he is unable to rescue his mother.

Kana is sought to help Hina because of his superb stretching powers, so Kana is sent by Uli to help Niheu rescue Hina from Keoloewa of Moloka'i. Meanwhile Keoloewa orders the turtles to raise the fortress, Ha'upu, on Moloka'i, higher. Niheu tries to climb it but is distracted by the plover who plucks five hairs from his head, whereupon Niheu falls, breaking his leg. (All of Niheu's strength is in his hair, which is never cut). So Kana employs his bodies to reach Haupu fortress:

...Kana was very angry, for he knew that now they would have a great deal of trouble in rescuing their mother again. Kana turned over in the mats and having thus broken the ropes, stood up. The king saw that this man was taller than his fortress. As Haupu was slowly raised higher and higher, Kana stretched his body, first his human body, then his rope body, next his *convolvulus* (morning glory) vine body, his banana (cordage) body, and last his spider web body. (Fornander, 1969, pp. II: 16–18)

In a Kaua'i variant the motif of Kana's changing the hill by stamping (on) it with his foot (*ke kapua'i a Kana; kapua'i*, measuring foot; (vs.) *wawae*, "foot," as of the body) is repeated. The name of the hills raised by the turtles, both on Moloka'i and Kaua'i, is Haupu:

Kana was afraid that it would reach too high, so he stretched himself up until his body was no larger than a spider's web. When he was tall enough, he put his foot on top of the mountain and crushed it down [Another trait of his demigod is that he possessed two large, staring eyes].

In the tale of Kana the spider's web is the equivalent of the cord kept in a calabash of water. The cord measures out from the calabash, forming a 40–400 fathom rope. This may be interpreted again as the bailing gourd (*Hina-ke-ka*) filled with water and kept on the canoe.

The god of the golden plover, *kolea*, was Lono-kolea-moku, symbolized as a red stone in the heiau foundations at Cape Kumukahi, Puna, Hawaii. The rock was the first in a row of five stones, four of which were called "The Wives of Kumukahi," spaced around the cape and used to

mark positions of the sun at its northern (*Hanakaulua* [Gemini]) and southern (*Kanono*, unidentified) limits.

The name Kumukahi (First Foundation) given to the easternmost point of land in the Hawaiian group is associated with the migration of Mo'ikeha from Tahiti. His younger brother, Kumukahi, got off the canoe near the place bearing his name, while Mo'ikeha continued northward. Several others jumped ship between Hawaii and Kaua'i, and Mo'ikeha pressed onward with his companion, La'amaomao, who had the wind calabash (*Ipu makani a La'amaomao*). La'amaomao would call the winds into the *ipu* when they were too strong for the canoe or summoned them forth out of the *ipu* when the sea was dead calm. Yet, when Mo'ikeha sent Kila, his youngest son, to Tahiti to get another son (or nephew), La'amaikahiki, La'amaomao was not in the returning crew doing all of the navigation for Kila.

About four to five centuries later, in the sixteenth to twentieth generation after Mo'ikeha, his mother, La'amaomao-wahine, bequeathed the wind calabash of La'amaomao to Ku-a-Paka'a:

When La'amaomao finished talking, she opened the cover of a large gourd (*ipu nui*) and drew out a certain small gourd (*ipu hokeo* 'u'uku) which had been woven tightly with 'ie (Freycinetia) cord with a cover (*po'i*) on top.

Then she turned to her son: "I give this gourd to you, as its name was your grandmother's name and mine also, and within it are her bones. When she was alive, all of the winds of this archipelago were her servants, beneath a marvelous power which she received, and she gathered all of the winds into this gourd, and they are still in this gourd until now, and their names were committed to her memory, those from Hawaii to Ka'ula, and when there was no wind, she would remove the cover and call the wind, and the wind would then blow, and when the cover was replaced the wind would cease, and this gourd was famous as the 'Wind Calabash of La'amaomao'." (Nakuina n.d.).

The account of the wind calabash of La'amaomao finds a parallel in the Rarotongan tradition of the wind god, Raka-maomao, whereas in Samoa La'amaomao was a war god. In the tradition of Rata, the wizard Nganahoa combats the demons of the sea in a floating calabash called a "red gourd" (*'ue kura*) from which

he divines their approach and continues to warn the doubting Rata. Nganahoa, a wizard who flies kites, applies to Rata to go with him on his voyaging canoe to find Vahieroa. Rata considers him useless and leaves without him, but Nganahoa follows him on a large gourd floating on the sea:

At the time that the canoe sailed away there were only eleven men on board. The canoe sailed on until the land was out of sight, when the crew descried a large gourd floating on the surface of the sea. The crew threw Ngana'oa and his gourd overboard, and left him to his fate (as they thought).

...The canoe proceeded on its voyage, and had sailed on for some distance when the crew noticed another gourd floating on the ocean; they at once cried out, 'There is our 'ue-kura floating on the sea.' Rata heard them and called out, 'Pick it up.' They did so, and when they opened it they were again confronted by the glistening eyes of Nganahoa. (Nakuina, 1910)

Nganahoa in this form is the bailing calabash, like Hina-ke-ka. In the Tuamotus, Nganahoa is a star represented in Rarotonga as a character prominent in the Rata story. Like Tahaki (Kaha'i), Rata (Laka), grandson of Tahaki, goes on a voyage to find his father, Vahieroa (Wahieloa).

In Hawaii, Nganahoa is the name of the phallic rock on Moloka'i, Ka Ule o Nanahoa (Penis of Nanahoa). This ule was Ul or Uun "Aldebaran" (Hyades, in Taurus) in Micronesian star names. Aldebaran was one of the "four royal stars" or "Guardians of the Sky" in Persian astronomy, 5,000 years ago, when it marked the vernal equinox (Allen, 1963, pp. 383–385).

A peculiar attribute of Nganahoa in the Rarotongan version is that when the bailing calabash was brought aboard the canoe, all that was seen inside were the staring eyes of the wizard. In the Ipu-makani-a-La'amaomao carried by Mo'ikeha on his journey, La'amaomao was, apparently, not a body on the canoe, but rather, the bones of an ancestor in the calabash by which Mo'ikeha called the winds to come out when the ocean was dead calm, calling them back when the winds were too strong.

Aldebaran (Nganahoa, Ka Ule o Nanahoa, Ul, Uun) in Taurus has been an ancient ancestor of star-worshipping wind-watchers on deserts as

well as oceans. That the gourd was encased in basketry in Hawaii is clear in the case of the wind calabash of La'amaomao, but the Unu o Lono shrine, as the Ipu o Lono god image in the hale mua men's eating house, was suspended from a net (koko), reminiscent of the net ('upena) that went across the sky in the Kaha'i story.

Often ignored but present in the tradition of the Ipu o Lono is a small note, "This image had suspended from its neck a gourd, ipu, which was perforated to receive a wooden bail" (Malo, 1950, p. 88). This means that the larger gourd of Lono, the *unu* (temple), also carried the *ka* bailing cup, gourd symbol of the goddess Hina-ke-ka, canoe-bailer form of the moon (goddess) (Johnson, 1989, p. 50).

The Ipu-makani-a-La'amaomao wind calabash is, in part, derived from the Malay word for 'compass', *mata angin*, 'eye of the wind' (*angin*). The standard Polynesian wind compass had eight 'eyes' (*maka*) or as many as 32 wind directions ('Aitutaki, Cook Islands). Hina-ke-ka, the bailing gourd, was not the wind compass (Ipu-makani-a-La'-amaomao). It was a reflecting mirror or an instrument used as a plumb bob or water level. The Nganahoa calabash carried by Rata (Laka) was thrown out into the sea ahead of the canoe.

If Rigi was the Milky Way in the Caroline Islands (Micronesia) whose worm body became the "Eyes of the Pleiades" (Mata-riki, Makali'i) and was the companion (*hoa*) of Rigi, Aldebaran? After the Pleiades sets, Aldebaran is right behind it all of the time. When the Pleiades rise, Aldebaran is right behind them again. It was called "The Follower" (Al Dabaran), i.e., of the Pleiades, originally given to the entire group of the Hyades (Allen, 1963, pp. 383–384). This composed the letter A as the *alpha* in the alphabet derived from the head of the bull consisting of Aldebaran as the eye in the face and the other stars above the head constituting the horns. This eye was the Ule o Nanahoa (Nganahoa) in the wind calabash of La'amaomao (Hawai'i) that had helped Rata sail his canoe in the lands between Samoa, Tonga, and probably, Rarotonga where the tradition is prominently remembered as it is in Hawai'i.

The sky was a place to picture the characters and creatures in the heroic Polynesian past. The major figure was the culture hero and demigod

Maui-ki'iki'i-a-Kalana whose position in the stars favored the constellations of Hercules, Ophiucus beneath, and Sagittarius in the ecliptic to the south. Available to Maui in that hour circle and the adjoining one is the constellation of Scorpius, with which the hero pulled up the land of Hawai'i as a giant fish. Scorpius is pictured as the fishhook that Maui used (Ka makau nui o Maui), three stars lying from east to west above the bright star and mid-shank of the hook, Antares, first magnitude star in the fishhook constellation as it curves around Shaula (Mohalu) to Leshaa in the barb. From the city of Honolulu this "hook" rises over the crater of Diamond Head to the southeast and drags over the sky until it sets to the west. Maui in Hercules sets before the hook ascends, 180° away on the eastern horizon, or a composition of Maui's three brothers, Maui-mua, Maui-roto, and Maui-pae, who are the three stars in the Belt of Orion stretched over 10° on either side of the equator. They are pictured as sitting in a canoe as they are helping Maui to pull together the fish that Maui caught and which drifted into separate parts. They were told not to look back, and as one of the three brothers does look back, the fish comes apart again into separate islands. Otherwise they are three men in a boat in a canoe house straddling the equator. Beside the Belt of Orion in the place of his sword, the ancient Hawaiians evidently saw the same shape of a weapon, calling it Na Kao, the javelins, i.e., the Belt and Sword of Orion, or perhaps they mistook it for Na Ka o Makali'i, the bailers (i.e., bailing gourds) of Makali'i (in the Pleiades).

Another interesting facet of Scorpius is that it lies within the swirling, twisting motion of a stream or pond of water, the Milky Way, as it courses or spirals across the sky during its own moving about. It will be seen stretched across the sky as a diagonal, from northeast to southwest, and only certain stars and constellations lie in the stream, called the Wai Ola a Kane, or living waters of Kane, the creator-god. In the same stream lies a reptile or shark called 'Ai-kanaka, whose wife is the moon, Hina-hanai-aka-malama. Through the year the lizard or reptile will jackknife across the overhead skies as

the swirling stream moves until it is lying from northwest to southeast. Then it lies in two separate streams across the north and across the south, and then arches around the entire visible horizon before it slips off the edge of the world and comes back again, spiraling across the sky from northeast to southwest.

This is the galaxy, and the center around which it spirals is the galactic equator, and by it the ancient priesthood also told time. The motion of breaking up of the spiral was called *Kaha'i*, *Ha'iha'i*, *Ha'imoha'i*, for another hero of the migrations, Kaha'i, who went to the skies on a rainbow to look for his missing father, Hema. Only certain stars and constellations are found in the *Wai Ola*, pictured also as a coconut tree, with branches opening to the north and the roots growing to the south. Sirius lies outside this swirl, seeming to be alone and thus called, Lono-meha, "Lone Lono." Another star that seems to shine alone and brightly to the north is Arcturus in Bootes, called Hokule'a, meaning "clear star" or "star of gladness," according to the Polynesian Voyaging Society which named the canoe after Arcturus.

Otherwise, the Milky Way was called the "spine," *Kuamo'o*, in which the following were always found: Castor and Pollux in Gemini, called the "Twins"; Mahana Kaulua, or Na Mahoe, the twin in front, Castor, Mahoe Mua, and the twin behind, Pollux; Mahoe Hope; the Hyades, Kaomaaiku or Kanukuokapuahi; the Magellanic Clouds, "butterflies," Pulelehuakea, Pulelehualei; stars in Lyra, Keoea, Keho'oea, and Scorpius.

In the opposite pole, Canopus was called the solitary "Lord of Space," Ali'i-o-Kona-i-kalewa. It occupies the pole at one time, the star Achernar at another, and then there is the Southern Cross, rising on its side in the east, then coming upright, before tilting to the west and going out of sight. Some Hawaiians see a triggerfish, *Humu*, as the *humuhumu-nukunuku-a-pua'a*, or pig-snout fish in which the pig demigod, Kamapua'a, made his journeys by sea assuming the form of a triggerfish. The snout of the fish is pointed downward and the fin upward. Others knew the Southern Cross as a "cross" Hoku Ke'a, or a batfish, one of the skates or rayfish

with wings outspread, tail upward, guilty for stealing the moon and hiding her, mother of culture hero Maui-ki'iki'i-a-kalana. So Maui retrieved Hina from the clutches of the batfish by waiting for the demon fish to close all of its eight eyes in sleep before he cut all of them out of the head of the monster. Another *humu* star, meaning, to be sewn or patched together, *humu*, is Humu, or Altair in Aquila, west of Maui-ki'iki'i-a-kalana. The pole star to the north, Polaris, is called Hokupa'a, "Fixed Star," but then all stars fixed in their tracks were called *na hoku pa'a* as against "wandering stars" or planets, the *hoku ae'a*, "wandering" or "vagabond" stars. The whole constellation of the Big Dipper was called "The Seven," Na Hiku.

Below the pole starting with Perseus is a line of stars that meets up with the asterism of the Pleiades in the head of the Bull, Taurus. These stars are called *a line*, i.e., Ka Lalani. Near the Pleiades, called "Little Eyes", Makali'i, are the Hyades, which are the opening of the fireplace, *Ka Nuku o Kapuahi*, recalling perhaps, as on the island of Mangaia in the Cook group, that a tribe of people suffered being cooked alive in an oven. Aldebaran in the eye of the Bull is called *Ka Oma Aiku*, meaning the adze of Aiku, one of the heroes of the migrations in the south, also known as Aukele-nui-Aiku, a navigator who found the home of Pele's sister in Ra'iatea and Borabora. The other "twins," Mahapili, are in Scorpius. The orbit of the stars was called the "circular road," *Ala Poai*. For the most part, so many star names retained in the nomenclature are unidentified, indicating the loss of much that the ancients had identified about the sky concerning the heroic past of their own wanderings, as they often called it, to go over the horizon ever receding.

Muku	0	"cut-off"	New moon, dark phase
Hilo	1	"braid"	Moon in the west
Hoaka	2	"tusk" (moon shadow, boar tusk)	

(continued)

Ku-kahi	3	Ku-1 "cusp" (moon going south)	
Ku-lua	4	Ku-2	
Ku-kolu	5	Ku-3	
Ku-pau	6	Ku-end	
'Ole-ku-kahi	7	'Ole-1 "eye-tooth" (moon in the south)	
'Ole-ku-lua	8	'Ole-2	No planting nights
'Ole-ku-kolu	9	'Ole-3	Moon southeast
'Ole-pau	10	'Ole-end = one <i>anahulu</i> decan week of 10 days	

Huna	11	"hidden" as cusps of the moon
Mohalu	12	Shaula, in Scorpius
Hua	13	Jupiter = one-half sidereal lunation
Akua	14	God (moon in the east)
Hoku	15	Star (full moon)
Mahealani	16	16th moon (full moon)
Kulu	17	"drop" (waning moon)
La'aukukahi	18	"plant" 1 (moon going north)
La'aukulua	19	"plant" 2
La'aupau	20	"plant end" = two <i>anahulu</i> decan weeks
'Ole-ku-kahi	21	'Ole-1 (quarter moon, north)
'Ole-ku-lua	22	'Ole-2
'Ole-pau	23	'Ole-end
Kaloa-ku-kahi	24	Ka(na)loa 1 "god of the sea" (fishing)
Kaloa-ku-lua	25	Ka(na)loa 2
Kaloa-pau	26	Ka(na)loa-end
Kane	27	Milky Way = one sidereal lunation
Lono	28	Lono (moon west of north)
Mauli	29	"spirit"
Muku	30	"cut-off" = three <i>anahulu</i> decan weeks
		=one synodic lunation

(1) Tabu pule of Ku	2 1/2 nights	Hilo, Hoaka, Kukahi, Kulua
(2) Tabu pule of Hua	1 1/2 nights	Mohalu, Hua, Akua
(3) Tabu pule of Kanaloa	1 1/2 nights	Olepau, Kaloakukahi, and Kaloakulua
(4) Tabu pule of Kane	1 1/2 nights	Kane, Lono, Maui

See Also

► [Stars in Arabic-Islamic Science](#)

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Astronomy in Japan: A Cultural History

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Japan's astronomical heritage, like so much of the culture's history, is one of enigma. Navigationally remote in ancient times and perhaps somewhat still socially remote amidst modern urbanization, it is easy for native and foreigner alike to perceive that there must be something unique and mysterious about what is "Japanese." Yet, this island country is a mixture of Eastern and Western imports, and the social, political, and pragmatic processes related to such importation have origins dating back at least two millennia. One who actually visits the country may be somewhat overwhelmed

by a large number of temples, shrines, and other architectural landmarks, some dating back many centuries, all reflecting an interaction of native sociocultural systems with those derived from the Asian continent. The visitor may also be somewhat disappointed to find much of the nation's heritage engulfed by high-rise buildings and accompanying elements of industrialization, a factor which is also very much a part of modern Japan. Illumination from such industrialization is a thorn to every lover of the stars, from amateur to professional. Perhaps it is indeed the mixture of foreign imports with indigenous belief systems, a mixture more subtle than that of cultures such as the United States whose multiethnicity is so pronounced, that indeed proves to be the most unique aspect of Japan. In order to understand the deeper significance of Japan's heritage with the sky, one must often look beneath what appears on the surface.

For many in the West, astronomy in Japan is generally connected to Japanese names attached to comets, asteroids, and supernova discovered by one of her many amateur astronomers, to astronauts accompanying NASA missions, to space probes launched from Tanegashima Island, or to the building of a huge telescope on Mauna Kea sporting the name of one of the most prominent asterisms of Japanese star lore, *Subaru*. A complete review of issues related to this heritage is far beyond the bounds of a single article. We will concentrate primarily on the cultural relations with the stars that have developed over the centuries in Japan. To provide an overview as well as a basis for understanding what astronomy means to this land, we will concern ourselves with (1) the development (or perhaps nondevelopment) of astronomy as a science in Japan and (2) the significance of historical, social, and political purposes and their relation to star lore, mythology, and other aspects of cultural astronomy.

Astronomy as Science in Japan: Chinese and Western Influences

Many professional and amateur astronomers in Japan have asked, "Were ancient Japanese people

not interested in the stars?" (e.g., see Yokoo, 1997). Such a question reflects the fact that compared with Western traditions, it is quite difficult to find early star mythology and records of scientific or prescientific development that compare with many other ancient cultures. Though the exact date is uncertain, writing was introduced relatively late to the Japanese islands (the system was based on Chinese characters), and thus there is very little written record of ancient views of astronomy earlier than the seventh or eighth century.

In looking at Japan's development of astronomy, Aveni's (1989) allusion to a kind of ethnocentrism inherent in viewing *History of Astronomy* only through the eyes of the modern West and its evolved science is echoed in reverse. The Meiji Reformation (1867–1868) with a "de-emphasis" of Buddhist traditions followed by post-World War II rejection of the most meaningful aspects of indigenous Japanese mythology left many in this country with a sense that there is and always has been little which can be considered original in astronomy emerging from Japan. On the other hand, the reader needs only to pick up any professional journal of astronomy to quickly find the names of Japanese authors who are conducting research in the science of astronomy using Western methodologies. Thus, to look at modern astronomy in Japan is not to look at any real cultural difference but instead to find an industrial country which is producing an increasing number of eminent scientists trained in Western methodologies. The importance of understanding cultural context relative to astronomical "knowledge" has been recently revived, and one cannot help but sense a certain "lack of self-esteem" among Japanese researchers who wish to pursue it.

In his *History of Japanese Astronomy*, Nakayama (1969) gives a very thorough account of the ways in which Chinese and later Western influences were imported into Japan throughout its history. Japanese astronomy was greatly conditioned and restricted by geographical, historical, and cultural barriers, and its early phases were dominated by Chinese influence and later by Western ideas. It is doubtful that any

"scientific" expansion of Japanese astronomy occurred prior to close contact with China or with China via Korea. Further, while the primary purpose of calendrical study both in the West and in China was to develop precise means of time reckoning, calendar development in Japan generally focused on divination and securing the position of rulers rather than trying to develop precise theory, cosmology, or observation methods designed to explain the workings of the universe.

Nakayama's work is written in English and parallels the two-volume work on the *History of Astronomy* in Japan written in Japanese by the esteemed scientist and historian Watanabe (1986, 1987). A view of most Western discussions of the subject will lead the reader to conclude that little has changed in perception relative to Nakayama's assessment (e.g., see Hashimoto, 1997; North, 1995; Pannekoek, 1961; Ronan, 1996; Sugimoto & Swain, 1989). While Aveni (1993) does emphasize more ethnographic and less ethnocentric viewpoints, he also tends to place Japan within the broader context of the "rich Chinese heritage" and does not really deal with Japan's cultural astronomical heritage.

When the English scholar, Chamberlain (1971), was assessing the general state of affairs in Japan in his *Japanese Things*, he indicated that even apart from any scientific originality, one would never find much creative lore composed in Japan relative to the stars. Viewing astronomy in Japan from only these perspectives, it is easy to get the impression that early and perhaps even later inhabitants of Japan who never "looked up" were never inspired by much in the sky, patiently and/or eagerly waited for (or perhaps at times were even antagonistic toward) enlightenment from the Asian continent or later from the West, but nevertheless developed keen observational skills once such imports were implanted.

It is certainly true that almost everything which can be viewed as scientific astronomy was imported from the Asian continent or from the West in more modern times, and if only that side is viewed, discussion of the *History of Astronomy* in Japan can basically stop here. However, to discard the culture's relations with the sky by judging it only by its origination or

development of scientific concepts dismisses what is perhaps one of the most unique case studies in how indigenous native beliefs (and accompanying views of the heavens) were integrated, seldom by forceful means (at least from the importer's side), with belief systems of other cultures (and their consequent views of the heavens). Such a pattern of coexistence has been paradoxical if not downright baffling to most Western eyes. By neglecting the sociocultural side of Japanese history, one misses the complexity of the manner in which ancient Japanese (not only rulers, astrologers, and calendar scholars but average farmers, fishermen, and other common citizens) incorporated astronomy into an extant system of belief and purpose, such providing culturally based reasons for the way astronomy did or did not develop in these islands.

Although we discuss many other examples of Japanese adaptation and development in the next section, it is worth noting particular historical events that we have explicated elsewhere (Renshaw & Ihara, 1999). Consider the large influx of Chinese learning in the Asuka (late sixth to early eighth centuries AD) and Nara (710–784 AD) periods. (An exhaustive account of these periods and the influence of continental imports are far beyond the scope of this article. The reader may find articles from Vol. I of *The Cambridge History of Japan* series including Brown (1993a, b, c), Kidder (1993), Inoue (1993), Naoki (1993), Matsumae (1993), and Sonoda (1993) to be particularly relevant to a deeper understanding of these processes.) Certainly, palaces and Buddhist temples were being laid out using Chinese-derived geomantic principles, and Chinese methods of calendar reckoning were adopted (Nakayama, 1969). However, each aspect of Chinese learning that was incorporated had to find juxtaposition with a set of beliefs or purposes that sometimes stood in direct contradiction. Juxtaposing the descendancy of the emperor as a child of the sun goddess Amaterasu with the Chinese perception of imperial rule centered on the north celestial pole required some compromise. Buddhist temples aligned in north–south directions had to fit within a terrain

that had Shinto shrines aligned in less celestial fashion but more along the flow of natural sites such as prominent sacred mountains, forests, waterfalls, or distinguished outcroppings of rocks. Apart from the necessary attendant “blessing” of a particular Shinto deity on a Buddhist temple, the said deity often had a shrine built directly within the precincts of the temple grounds and was even given a form of “Buddhahood.” Compromises also included such practices as substituting Shinto ritual objects for bones of the Buddha in the treasures buried beneath pagodas (see Brown, 1993c; Matsumae, 1993; Sonoda, 1993).

The picture we see from reading Krupp (1983, 1989) substantive accounts of temple layout and practice of seasonally based ritual in ancient Chinese capitals was only partially incorporated within the layouts and attendant rituals of ancient Japanese palaces and their imperial owners. Certainly, as will be seen in the review of social consciousness and purpose in the next section, rituals such as human sacrifice found no place in a belief system based on ritual purification and abhorrence of death. It is also significant to note that while China underwent several dynastic changes, some accompanied with revisions in cosmology and astronomical perception, Japan retained virtually one dynastic descendancy reaching well into the twentieth century, thus often seeing no need for “advances” taking place on the continent (Brown, 1993a, c).

When cultural perspectives are included, it seems clear that the history of Japanese astronomy is not simply the history of Chinese astronomy or even, for better or worse, a direct mirror of such. While it may be impossible to distinguish anything as having been uniquely Japanese, cultural practices from earliest to modern times bear distinct marks of a social consciousness and purpose inherent in Japan's cultural development. Too, while Chinese astronomy may not have been given its due in modern scholarship, it is also evident that all Asian cultures cannot be “lumped together” with China in order to gain a full understanding of the relation of astronomy and culture in any particular one.

Socio-Political Purposes and Their Impact on Development and Adaptation of Star Lore and Mythology

Ruggles and Saunders (1993) ask, “What do people see when they look at the sky?,” and further state that the answer is as much a cultural as an astronomical one. Their perception is especially relevant to unraveling the enigma of Japan’s heritage with the sky. A growing database of archaeological evidence, renewed postwar and nonreactive scholarship with regard to historical texts, and the development of interdisciplinary approaches reveal Japan as a culture that has always been guided by an indigenous social consciousness and for most of its history a rather consistent set of social and political purposes (Brown, 1993a). Such was certainly a factor in how Japanese developed myth, legend, and lore related to the stars, and it is in this area that we can find the rich sources of cultural astronomy in Japan. (A good chronology in English of Japan’s general history may be found in Torao and Brown’s (1991) *Chronology of Japan*. The most exhaustive history of Japan in English is the recently released Cambridge series (Hall et al., 1993). For shorter and perhaps more approachable views of Japanese history written in English, the following may be of value: Sansom’s (1974) prewar but still viable 3-volume *A History of Japan* and his (1973) *Japan: A Short Cultural History*; Hall’s (1971) *Japan From Prehistory to Modern Times*; Mason and Caiger’s (1973) *A History of Japan*; and Morton’s (1995) *Japan: Its History and Culture*.)

The ancient sense of social consciousness and purpose may best be understood by using the analogy of a lake fed by two springs. The lake represents the historical and modern sociocultural milieu of Japan, and the springs feeding it are the sources from which that milieu has been formed. The first and nearest spring is composed of a native social consciousness and a specific set of socio-political purposes that we detail later. The second spring (better viewed as many secondary springs) consists of the infusion of ideas, concepts, technologies, philosophies, and religions including a virtually continuous input

from the Asian continent and in later centuries large contributions from the West.

It is important to realize that the primary spring has always been fed by the second. The flow may have been slow or even imperceptible at times, but it has always been there (Oguma, 1995). On the other hand, this primary spring (regardless of its diverse historic origins) has always been deep and has formed an archetypal base through which everything must be filtered to become “Japanese.” At least within the last 1,600–1,800 years, the secondary spring has probably never had a direct route to Japan’s archetypal lake; such flow has almost always passed through the primary spring.

Brown (1993c), Kidder (1993), and Matsumae (1993) have provided a cogent paradigm through which Japanese social consciousness and attendant Shinto beliefs and practices may be understood as well as socio-political purposes that guided the early formation of Japan as a unified country. From this paradigm, three primary aspects of early Japanese consciousness emerge: “linealism,” “vitalism,” and “optimism.” Linealism emphasizes ancestral descendancy with filial duty to parents, siblings, friends, nation, etc. Vitalism emphasizes life along with the abhorrence of anything that has to do with death and stresses ritualistic (not moralistic) purity. Optimism places emphasis on being concerned, not so much with the distant past or future but rather with moving forward through seasons and cycles of life, regardless of circumstances. The socio-political purposes which played a role in Japan’s early development as a nation may perhaps be best paraphrased as follows: (1) unification of often warring petty “kingdoms” (along with their local myth, legend, and lore) through (2) cooperative efforts of common people in various ways such as cultivating rice (using celestial signs and allegories for seasonal determination of planting and harvesting as well as agriculturally based festivals) in order to (3) establish a singular lineal order of imperial rule (resulting in perhaps one of the greatest national Japanese myths that of the sun goddess Amaterasu and her place as ancestral head of the imperial line). (From our earlier discussion, the

reader should have a good idea of the kinds of conflicts many imported ideas created for early Japanese. Other brief examples will further clarify the point: while the infusion of Confucianism reinforced many aspects of “lineality,” especially with regard to the development of bureaucratic governmental practices, the Confucian idea of a cyclical rise and fall of dynasties was never really accepted in Japan and stood directly against the idea of a singular imperial line. The fourth- and fifth-century infusions of Buddhism with beliefs, which emphasized a better life in death than in the present, directly contradicted the concept of vitalism and optimism. In addition, the Buddhist idea of eventual decay and the Confucian idea of a “glorious past” were incongruent with virtually all aspects of Japanese consciousness and purpose.) It can easily be argued, given the political developments of the twentieth century, that while some commodities have changed and political power has not always been imperial based, these fundamental aspects of Japanese consciousness and purpose still form a prime keystone of the culture’s psyche. (It is easy for the reader to get full insight into the significance of these ideas by reading the many excerpts of manuscripts from periods throughout Japan’s history which are accompanied by commentary in the excellent *Sources of Japanese Tradition* compiled by Tsunoda, de Bary, and Keene (1964). The sense of Shinto consciousness and its pervasiveness in modern Japanese life is also discussed by Shigemitsu (1996).)

One of the few writers in English to deal with Japan’s cultural star lore and myth is Krupp (1991, 1997). Readers may be familiar with the several accounts he provides of the fundamental Japanese myth of Amaterasu and its relation to the Japanese political history. However, while this myth, itself closely tied with the political purpose of unification, is a prime example of lore that reflects Japanese sense of consciousness and purpose, there are many other aspects of Japanese traditions and bodies of star lore which show the complex relation between indigenous native belief, pragmatic social need and purpose, and the kinds of celestial ascriptions that developed therefrom. Little of this material

has found its way into English sources, and in the remainder of this article, we discuss some of the many examples of relations between Japanese values and social purpose and the stars. Specifically, we will look at (1) values applied to particular star groupings such as Oyaninai Boshi; (2) cooperative efforts such as planting, harvesting, and fishing reflected in star lore closely tied to such asterisms as Subaru and the belt stars of Orion; (3) ancient Japanese purposes as seen in star paintings of archaeological sites such as the tombs of Takamatsu Zuka and *Kitora Kofun*; (4) mixtures of Shinto belief and values seen in adaptations of continental legend and ritual such as that of the legend of Orihime and Kengyuu and its relation to the festival of Tanabata; and (5) the preeminent holiday of the year for Japanese, New Year’s Day, in which the values of linealism, vitalism, and optimism come together in a celestial greeting of new beginnings.

Oyaninai Boshi: Linealism, Vitalism, and Optimism in the Stars

There are a number of celestial symbols which concern various groupings of three stars: Oyaninai Boshi including Orion’s belt stars (Nojiri, 1973), three stars of the fifth moon station of the Azure Dragon of Spring which includes Alpha Scorpio flanked by Sigma and Tau, and three stars discerned in the constellation Aquila including Alpha flanked by Beta and Gamma Aquila (Uchida, 1973). (Here and in later sections, we discuss the Chinese-derived *Sei Shuku* or “moon stations” along with the animals of cardinal directions. Though used extensively in Japan from earliest Chinese infusions, a discussion of their complexity is more appropriate in a work on Chinese astronomy. The reader is urged to look at sources such as Needham (1959), Ho (1985), or Nivison (1989).) All have to do with seeing the image of two parents standing or being supported on either side by their child in the middle. Such symbols of filial duty are numerous in Japanese star lore and reflect the strong sense of lineality later reinforced by Confucian ethics. Further, particular attention is

placed on this value relative not only to parents but to friends as well. An example of a sense of Japanese identity is seen in Kenji Miyazawa's more modern "lore," the *Milky Way Railroad* (Sigrist & Stroud, 1995). (*Douwa Shu; Ginga Tetsudou no Yoru* (A Collection of Tales; Night of the Milky Way Railroad) was originally started in 1924, adapted for some years, and finally published posthumously in 1951 (Miyazawa, 1951). It remains one of the most popular stories in Japan, loved by children and adults.)

Another legend incorporating the aforementioned sense of Japanese consciousness includes the belt stars and M42 region of Orion. According to Uchida (1973), one day, two sisters were walking down the road, the younger dutifully following her older sister and shouldering a tub of water. Being chased by an ogre, they found a rope leading to the heavens and began to climb. Though the sisters escaped the ogre, the younger sister sadly had her foot bitten off. These days, we see the bamboo pole (the three belt stars called Take no Fushi in this story) with which she continues to carry water as she follows her sister (the moon) around the sky. Her remaining foot (M42 region) peeks from the folds of her kimono. Western readers may find the end of this legend disturbing or even somewhat cruel. However, all the fundamental values of Japanese consciousness are found in this story: linealism in the form of filial duty, vitalism in strength and courage, and optimism in a will to "go on" within one's present condition to an immediate brighter future.

The anecdotal nature of such star lore and legend takes on a completely different meaning when viewed within the context of ancient Japanese social consciousness and purpose. Again, while it would be futile to argue that such lore developed independent of external sources, it is also clear that its Japanese development reflects a unique cultural identity.

Cooperative Activity: Pragmatic Signs in the Stars

As in many cultures, the three belt stars of Orion (called *Mitsu Boshi*), the Hyades (*Ame Furi Boshi*)

or rain stars), and the Pleiades (*Subaru*) played a prime role as symbols of fertility and timepieces relative to seasonal change, specifically planting and harvesting during the rice cultivation period (1982; Hirose, 1972; Nojiri, 1973, Uchida, 1973). Their earlier and later heliacal setting in spring as well as heliacal and later rising in fall encapsulate that season and in more ancient times provided symbols related to festivals such as Spring *Higan* and *Ura Bon*. Spring *Higan* is celebrated within a period of 7 days surrounding the spring equinox. At this time, as any casual observer in latitudes similar to Japan will note, the Pleiades, Hyades, and Orion, all begin to set earlier and earlier each evening. For early Japanese, this setting was allegorical to planting of rice seedlings (*Subaru* or the Pleiades appearing as united seedlings), the rainy season (Hyades or *Ame Furi Boshi* seen as rain stars), and cultivation (one of the earliest symbols seen in the three belt stars of Orion was that of *karasuki* or plow). *Ura Bon* is celebrated in the fall when ancestral *kami* (deity) visits and is sent on their way in thanks for bountiful harvests. In more ancient times, when this festival was celebrated on the lunar calendar-based 14th–16th days of the 7th month (late August or early September in the Gregorian calendar), these three prominent star patterns were indeed seen to transit the zenith as the full moon set and dawn arrived, a signal that ancestral spirits had indeed departed for yet another "season" (Miyata, 1996). The appearance of *Subaru* rising in the evening at this time of the year seems to have had significance not only in its relation to the end of the rice harvest but to the coming of winter.

The mythology found in the *Kojiki* (Records of Ancient Matters; see Chamberlain, 1981; Philippi, 1968) and the *Nihongi* (Chronicles of Japan; see Aston 1972) places much importance on the deity (sun goddess) *Amaterasu*, who "conquered" lesser deities (local states) and was considered the progenitor of the imperial line. Interestingly, one of the earliest and most significant aspects of *Subaru* was related to the myth of *Amaterasu*. Apparently taken from the phrase *mi Sumaru no Tama*, the name *Sumaru* was used to describe this asterism referring to the string of the

August jewels known to have been hung on the *sakaki* tree while deities danced to lure Amaterasu from the cave (Nojiri, 1973). Allegorically, just as the sun (Amaterasu) was seen to depart for the winter, jewels (Subaru or Sumaru) were seen to appear in the sky, jewels which could be seen throughout the winter months and serve as a reminder for early Japanese that at some time the sun would indeed return with her spring warmth and another planting season could begin.

Lore related to Subaru is extensive, but its prime importance can be seen in the fact that it not only played a role in what would become a central myth for unification of the country but also a timepiece for the pragmatic need of farmers and fishermen who played a role in such unification efforts. For common people, struggle for unification was of secondary importance. What was of prime concern was that they know good and bad times for planting, harvesting, or setting lines for fishing. While the three star patterns we have mentioned were of significance because of their heliacal rising and setting, the three belt stars of Orion, due to their prominence, apparent equal spacing, and perceived change in position as they traced their way across the winter sky, were of particular pragmatic use to early and later Japanese citizens.

When viewed in early evening, the perceived angle of the three belt stars, seen rising in the east, moving across the sky, and setting in the west at different times of the year, provided the base for particularly interesting lore in which farmers used Orion as an agricultural symbol (Hara, 1975; Nojiri, 1988; Uchida, 1973). The three belt stars are variously called *Awainya Boshi* (Millet Stars), *Komeinya Boshi* (Rice Stars), or *Awaine Boshi* (Millet and Rice Stars). All these names relate to seeing *Mitsu Boshi* as a fulcrum, balancing the yield of rice or millet crops as they move across the heavens. The star *Alnilam* (*Epsilon Ori*) is seen as the center of this fulcrum. *Mintaka* (*Delta Ori*) being higher or lower than the center indicates the yield of millet; *Alnitak* (*Zeta Ori*) represents the yield of rice. In latitudes of Japan, *Mitsu Boshi* rises in an apparent vertical position. As the three stars move across the sky in

the fall, they appear at an angle that gives rice a strong weight on the balance; this is the time to harvest rice and plant millet. As this constellation is seen setting in the West in late spring, Zeta Ori begins to dip lower and lower; this is the time to harvest millet and plant rice.

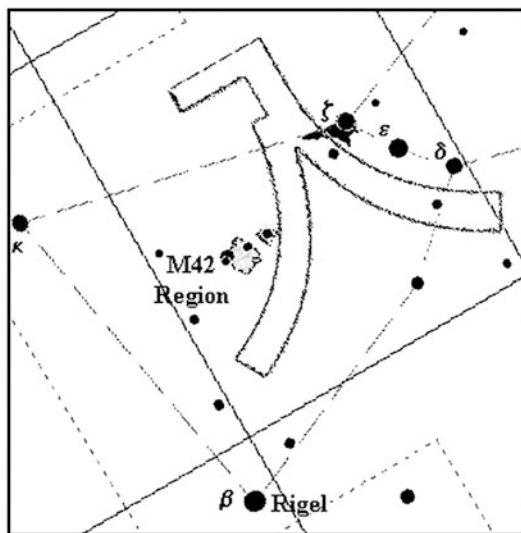
Especially in the cultivation of rice, several symbols of agriculture have been seen in the relation of the three belt stars to the M42 region. One of the oldest object references associated with this configuration uses the term *karasuki* to describe the three belt stars as prongs of a plow with the M42 region being the handle used to pull it in the field. As mentioned earlier, this symbol is especially meaningful related to the evening appearance of the three stars in the time of early spring.

As a further example of adaptation of imports to suit unique and indigenous Japanese needs, it is interesting to look at some of the Chinese interpretations of star groupings such as Subaru or the three stars of Orion's belt and the differences in names applied by each culture. By the seventh century (perhaps earlier), the Chinese "cosmology" which gave rise to the concepts of 28 *Sei Shuku* or lunar stations encircling the celestial globe had found its place in Japan (Nakayama, 1969; Watanabe, 1987). The constellation of Orion contains two such *Sei Shuku*: the 20th which includes the small *Meissa* (*Lambda, Phi Ori*) and the 21st which embodies a much larger section of Orion and is most distinguished by the belt stars (*Mitsu Boshi*). Chinese characters were used by later Japanese writers to represent these configurations; however, the original Chinese term for the 21st *Sei Shuku* was simply *Shin* (three) while earliest records of Japanese nomenclature use *karasuki* or plow (Ozaki et al., 1993; Shinmura, 1994). Early Japanese gave little significance to the 20th station. Though continental influence can certainly not be dismissed as a major factor in Japan's agricultural development especially with regard to tools, it would appear that seeing this agricultural symbol in Orion may indeed have been in use before introduction of writing and other imports of more advanced Chinese culture into Japan.

Following massive infusions of culture from China and Korea, Japanese emperors practiced the custom of “plowing the first furrow” around the lunar New Year. However, Japanese lore associating the three stars with a plow seems to have preceded and perhaps only been augmented by the introduction of this Chinese-based ritual. See Krupp (1983, 1989) for a description in English of this and other cultivation-related ceremonies that were practiced by the emperor in China. As they were recognized in Japan, some became part of the imperial ceremony, but many never found a place either because they did not fit within the imperial “purposes” mentioned earlier or because they were in direct conflict with native *Shinto* belief (e.g., ritual sacrifice.) “Astronomy” as practiced in China during Japan’s early formation as a nation had depended for some time on somewhat more precise estimates of a lunar calendar for fixing dates (Ho, 1985; Nakayama, 1969). Because of its pragmatic use as an agricultural sign (though nonprecise), especially its prominent evening setting at what later was called Spring *Doyou* (the period of 18 days prior to the sectional term “Summer Begins,” the official time for preparation to begin planting rice), *karasuki* may have been original with early Japanese farmers. At any rate, its setting has certainly survived as a symbol of planting in most rice-producing parts of Japan.

Another symbol for planting indeed reflects Chinese influence, and this is clearly seen in the incorporation of *kanji* or Chinese characters. This symbol, again related to the setting of Orion in the west during the beginning of the rice cultivation season, was yet another reinforcement for use of the belt stars and M42 region as a sign for planting. Uchida (1973) indicates that Japanese in some agricultural areas see the *kanji* for “entry” in the configuration and call it *Hoshi no Iri* (Entry of Stars). As fishermen saw stars set into the sea, Japanese farmers saw stars set into the western landscape. This symbol of *Iri* was merely another sign that it was time to plant (enter) rice seeds into the earth (Fig. 1).

Agricultural associations discussed so far have generally been related to the setting of *Mitsu*



Astronomy in Japan: A Cultural History, Fig. 1 The *kanji* for *Iri* or Entry superimposed on the belt stars and M42 region of Orion (Computer graphic by Steven L. Renshaw)

Boshi during early stages of annual rice cultivation. As mentioned, the rising of the three belt stars in the east was also an agricultural symbol and was allied with the end of the period of rice cultivation. Hara (1975) records that in many rice-farming areas, the stars were called *Haza no Ma*, a term that refers to a three-pole stand that is used in the field to dry rice. In the early phases of autumn, when Orion is no longer seen at sunset but rather rising earlier and earlier each night, farmers looked to the belt stars and saw them as a symbol that “only *Hasa* are left in the field,” the harvest of rice being over.

While the combination of a lunar calendar and later adoption of a Gregorian calendar in post-Meiji era in Japan led to more precise methods for determining times for planting and harvesting, many old farmers in rural agrarian areas still use methods that are centuries if not millennia old. According to Uchida (1973), the following time-piece is still recited in such areas: “When *Mitsu Boshi* are one fathom high, it’s time to go to bed; when *Mitsu Boshi* are in the middle, it’s the middle of winter; and when *Mitsu Boshi* lay, it’s time to wake up.” This refers to the vertical alignment of the three belt stars as they rise in

early fall, the angular position in the middle of the southern sky in winter and the horizontal visual alignment in the west in spring. These metaphors are related to, respectively, fall harvest, winter rest, and spring planting.

Star lore related to fishing is somewhat more rare than that which is related to crop cultivation. It was primarily through cooperation of local farmers along with their local ancestral *kami* in the production of rice that early Japanese rulers were able to fulfill their purpose of unifying the country. Still, incorporating the legends of families of fishermen was an important part of this unification, and a mix of agrarian and fishing lore is found (see Nojiri, 1982, 1987).

In some fishing areas, the three belt stars are called *Kanatsuki*, which is a name given to a spear with three prongs used in fishing (Nojiri, 1973; Uchida, 1973). We can note some similarity in pronunciation of *karasuki* (plow) and *Kanatsuki*. As a sign, *Kanatsuki* was used as a timepiece for favorable catches. When prospects for such seemed to be particularly good in the fall, old fishermen were often heard to say “Let’s wait for *Kanatsuki*” before going out for the evening’s catch.

Perhaps one of the most significant relations to “fishing” found with *Mitsu Boshi* relates to their designation by some fishermen as Sumiyoshi Boshi. Sumiyoshi were the three deities mentioned in the *Kojiki* as being created from the ocean and being particularly favorable to seafarers (Nojiri, 1988). Incorporation of these deities in the *Kojiki* and *Nihongi* was no doubt designed to find favorable reaction from the *be* or local families of fishermen. However, their use in legends which also included allusions to agricultural symbols makes them a significant aspect of the way in which Japanese developed celestial allegories.

Obviously, ancient Japanese were not blankly “staring at their rice fields” while the heavens “revolved” overhead. Creative and pragmatic use of star patterns played a central role in the day to day life of common citizens. Using the example of the belt stars of Orion, we have briefly discussed some of the more significant associations used in cooperative activity.

Adaptation of Asian Cosmology for Power and Centrality: *Takamatsu Zuka* and *Kitora Kofun*

Some archaeological sites may provide cogent information relative to the early interaction of Japanese values and purpose with imported cosmology. One of the major archaeological discoveries was made in the early 1970s (Hirose, 1972) in Asuka village, Nara prefecture. From an Edo era painting showing this mound with a tall pine tree atop, this tomb was called *Takamatsu Zuka Kofun* (Tall Pine Burial Tomb; Fig. 2).

Dating indicates that the tomb was built in the latter part of the seventh or early part of the eighth century. As was and is the case with most burials in China, Korea, and Japan, the tomb was aligned with celestial north. Paintings of animals related to the four cardinal directions were found on the walls, and careful inspection of the ceiling revealed a chart including the 28 *Sei Shuku* (lunar stations). Only a few scholars knew of the tomb’s existence in the Edo era (1603–1867), and most believed it was that of the Emperor Monmu (emperor from 697 to 707). Modern excavation revealed no inscription, and Monmu’s tomb was later determined to be to the east. Similar tombs have been found in both China and Korea, and the construction period was also one in which scholars from Korea had been invited to the imperial court.

What is significant about *Takamatsu Zuka Kofun* is the fact that it clearly shows the influence of Chinese and Korean cosmology on Japan in the Asuka era (late sixth to early eighth centuries). In 1998, another such tomb, located about 1 km to the South of *Takamatsu Zuka Kofun* on Mount Abe and named *Kitora Kofun* (after the Kitaura area of Asuka village), was explored. The tomb was not actually entered but probed with subminiature cameras. Preliminary dating placed its construction within the same Asuka period as *Takamatsu Zuka Kofun*. While there are some remarkable similarities, there are also some anomalous differences in the paintings of the two tombs.

In *Kitora Kofun*, the paintings of the animals of cardinal directions appear to be in somewhat

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Fig. 2 *Takamatsu Zuka Kofun* is aligned with celestial north. This view from due south shows the bamboo-covered mound of the tomb. The doors are to chambers of relatively recent origin; inside are housed temperature maintenance and dehumidifying equipment used to protect the small tomb's delicate paintings. The tomb is not opened to the public (Photo by Steven L. Renshaw)



better condition than those of *Takamatsu Zuka Kofun* (in which some paintings appear to have been defaced in ancient times). The animals do seem to have been painted in a freer style than those that are found in the tomb to the north. There also appear to be more stars in the *Kitora* tomb paintings of the *Sei Shuku*. Unlike *Takamatsu Zuka Kofun*, the celestial equator and ecliptic as well as “the heavenly river” or Milky Way appear distinct. Like *Takamatsu Zuka Kofun*, the tomb appears to have been plundered of any “treasure” it may have held. The south wall of *Takamatsu Zuka Kofun* was obliterated by entry in ancient times thus eliminating the painting of the Red Bird of Summer.

With regard to astronomical content, there are other significant differences. First, the paintings of *Sei Shuku* in *Kitora Kofun* appear to be based on Chinese/Korean charts of a much earlier period than that of *Takamatsu Zuka Kofun*. Second, the point of the crossing of the ecliptic with the celestial equator can be seen in *Kitora Kofun* and appears to be near a point in Aries closer to Taurus and corresponding with a position several centuries earlier than the Asuka era or the tomb's construction (the vernal equinox was shifting into Pisces by the end of the seventh century). Third, since enough stars are seen in *Kitora Kofun* to

determine just which ones could and could not be seen on the horizon, a relatively good estimate of observer latitude can be made. Fourth, the painting of the “White Tiger of the West” is reversed from that of *Takamatsu Zuka Kofun* and tombs with similar paintings found in China. In *Kitora Kofun*, the tiger is painted facing north. This point is especially interesting. When looking at the west wall of *Takamatsu Zuka Kofun* (note the photograph of the White Tiger in the Chinese tomb of similar dating in Krupp's *Echoes of the Ancient Skies* 1983, p. 112), the tiger is seen to face south, and this indeed corresponds with the placement of the figure of this animal among the stars. (Editor's note: see a detailed discussion of *Kitora Kofun* in this encyclopedia.)

These tombs provide us with a view of how Chinese/Korean astronomical thought found its way to Japan and how such thought was incorporated into the social purposes of Japan's rulers. It seems evident that it is not the accuracy of the cosmology reflected in the tombs' paintings but rather the almost wholesale adoption of Chinese perceptions to further strengthen the centrality of imperial rule that was most important, especially in the case of *Kitora Kofun*. Japanese rulers wished to give themselves the same legitimacy that Chinese rulers had; incorporation of symbols

and astronomical methods in order to accomplish this did not necessitate complete awareness of the underlying principles, but rather their mere presence. As mentioned earlier, such was the case with the introduction of Buddhism as well as other aspects of Chinese thinking. One can still see this kind of use of foreign import without substantive understanding in the almost playful use of foreign language in what sometimes appears to be gibberish in slogans and advertising of modern Japan. Use of foreign icons brings esteem, regardless of whether or not they are understood. Again, it must be stated that the central beliefs, ritual ceremonies, and social purposes of Japan appear to have remained and do remain somewhat constant regardless of import, such imports merely being incorporated within this larger “spring.”

Adapting Chinese Lore to Native Beliefs and Purposes: Orihime, Kengyuu, and Tanabata

When we look at the adaptation of myth and legend imported from other cultures, we also find the obvious sense of indigenous Japanese values and socio-political purposes infused over time. Perhaps one of the best examples of this is the legend of Orihime and Kengyuu (Nojiri, 1973). This story and associated festival were probably imported from China in the Heian era (794–1185). The story involves the stars of Vega and Altair, and the reader should consult Krupp (1991) for an explanation of the story in its Chinese form. Essentially the same in character, there are some noticeable adaptations made based on the unique social and pragmatic needs of Japanese culture. In Japan, the star Vega is often called Orihime Boshi (Weaving Princess Star), and Altair is often called Kengyuu Boshi or Hiko Boshi (Puller of Cows Star). To give the reader one Japanese version of the legend, we will paraphrase Hara (1975).

One day, the emperor’s daughter, Orihime, was sitting beside the Milky Way. She had been weaving because her father, the emperor, “wished it” (he loved the beautiful clothes that

she made). On this day, she was very sad because she realized that she had been so busy that she did not have time to fall in love. Her father, Tentei, the ruler of the heavens, felt sorry for her and arranged a marriage with Kengyuu (who lived across the river, the Milky Way). Their marriage was one of sweetness and happiness from the start, and everyday thereafter, they grew happier and happier. But Tentei became very angry, because in spending so much time in her happy marriage, Orihime was neglecting her weaving. Tentei decided to separate the couple, so he placed them back in their original places, separated by the Milky Way. On only one night of the year would he allow them to meet, the 7th day of the 7th month. Every year on that day, from the mouth of the river (the Milky Way), the boatman (of the moon) comes to ferry Orihime over to her beloved Kengyuu. But if Orihime has not done her weaving to the best of her skills and ability, Tentei may make it rain. When it rains, the boatman will not come (because the river is flooded). However, in such a case, *Kasasagi* (a group of magpies) may still fly to the Milky Way to make a bridge for Orihime to cross.

Related to this legend, ancient Japanese celebrated the festival of *Tanabata* on the 7th day of the 7th month each year (lunar calendar). The 7th day of the 7th month generally falls in August or September in the Gregorian calendar. At this time of the year, the constellations of Lyra and Aquila are prominent in the evening sky with their major stars (Vega and Altair) separated by the Milky Way. The 7th day of the 7th month also finds a waxing crescent moon (boat) reaching its first quarter. If it is not raining, both *Orihime Boshi* (Vega) and *Kengyuu* (Altair) are quite conspicuous at the time of the *Tanabata* festival.

Tanabata may be translated as “weaving with the loom (*bata*) placed on the shelf (*tana*),” and the festival celebrates improvement of technical skill and ability. As in China, ancient Japanese added specific values to their wishes that Orihime should hone her skills and work hard so that she could meet Kengyuu. In modern celebrations of *Tanabata*, people throughout Japan write wishes (generally for themselves or relatives) to the *kami* Orihime on colorful strips of paper. On the

evening of Tanabata, they tie these paper wishes to freshly cut bamboo. Wishes may be for increased skills in work or school but may also be for anything that reflects a person's dreams and hopes for the future. Summer vegetables such as eggplant and cucumbers are prepared, and horse or cow figures made out of straw and water oats are decorated.

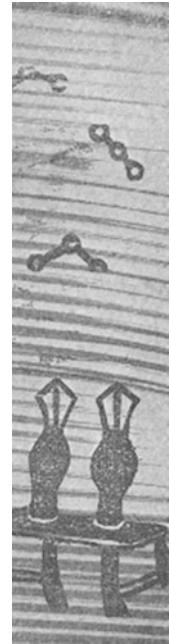
While the myth probably held seasonal significance in its Chinese origins, specifically the celebration of the end of the rainy season (reflected in a desire that it not rain), it found a variety of interpretations related to seasonality in its Japanese form. Particularly in relation to agricultural development in Japan, "wishes" related to celebrations of *Tanabata* ranged from desire for dry weather to desire for wet weather depending on the particular geographic region and whether a crop was to be planted or harvested at this time.

Following Shinto practice and ancient values, the concept of purification (generally including use of water) before the Bon Festival (centered on the 15th day of the 7th month) was also added to the *Tanabata* festival. Before the legend was brought from China, a ritualistic festival had been held to welcome the water kami at this time of the year; infusion of the legend of Orihime and Kengyu added a motif of the ritual celebration of the marriage of a weaving lady and the water god (Okada & Akune, 1993). In eastern parts of Japan, an associated ritual called Nebuta was celebrated. On the early morning of Tanabata, bamboo would be set afloat in the river, and people would brush their bodies with leaves from "silk" trees. By doing so, they were said to take their sleepiness (*nebuta*) away, another form of purification and preparation for Bon (Yoshinari, 1996). The close relation of Tanabata to the indigenous Bon Festival has obviously led to a number of adaptations of the imported Chinese mythology. In short, one makes the coming of the Bon Festival sacred by excluding impure spirits from the body at the first quarter moon, thus being pure for the coming of Bon at full moon. It is interesting that in some regions of Japan, *Tanabata* is accompanied by a taboo forbidding swimming or bathing in a river. Noting the relation with the celestial

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Fig. 3 Decorated strip of *Tanabata* bamboo from the Tottori region of Japan.

Note the representation of *Hiko Boshi* (Altair and two-flanked stars in Aquila) at the top and *Orihime Boshi* (Vega flanked by two stars in Lyra) near the middle (From Nojiri, Houei Nihon Seimei Jiten of Star Names in Japan, 1973, p. 60. Used with kind permission of the publisher)



"river" or Milky Way, the taboo is based on the idea that a *Kappa* or water deity resides in the river and one should not make the pure water dirty by entering the water deity's home.

When it was first imported, *Tanabata* was celebrated only by imperial court officials. It was considered a graceful event, full of the simple elegance so associated with the Heian era of Japan. Lanterns were lighted, and poems were written on mulberry leaves still holding their dew (Nojiri, 1973). Of course, as the custom spread to local areas, towns became covered with bamboo at *Tanabata*, and the festival took on more of the values inherent in Japanese consciousness and purpose (Fig. 3).

The process of adapting this imported legend and developing indigenous practices evolved in complex ways over the centuries, and we have touched on but a bit of this complexity. In modern times, the festival is generally celebrated on a solar July 7th, a date that is generally still within the rainy season. Sadly, the festival has lost much of its seasonal significance with modern industrialization. Of course, the vitalistic ethic of improved work and skill is still valued, regardless of whether or not the day of celebration is attuned astronomically.

Prevalence of the Sun: Akemashite Omedetou Gozaimasu

No discussion of Japan's heritage with the sky can avoid the prime significance of the sun. Symbolism related to the sun is heavily incorporated in Japanese myth and is still seen in its flag. Being the most eastern of East Asian nations and indeed being seen as the land which the sun first greets in the morning, the phrase "Land of the Rising Sun" developed special meaning for Japanese from ancient times. Along with the significance of Amaterasu as sun goddess, there are other ways in which the sun has become a central part of Japanese consciousness. The celebration of the New Year represents yet another way in which indigenous values are mixed with Chinese imports to provide a unique cultural perspective on the significance of vitalism and optimism.

While Christmas is celebrated in Japan to some degree, it is not considered a national holiday, and the attendant Western religious aspects of that day are certainly missing. New Year's Day is by far the more significant holiday. Before the Meiji Restoration, the New Year was celebrated according to the Chinese lunar calendar. In modern times, though the lunar calendar still has influence on scheduling of festivals and celebrations, the Gregorian calendar change is celebrated by most people as the "official" New Year.

In the days before the New Year begins, people busily prepare by cleaning the house and cooking food to welcome the kami of new life. At this time, the post office is flooded by New Year's cards which each person sends to friends, relatives, and associates. Rail and air terminals are jammed with people trying to get back to their hometowns to spend the New Year's "night" and "daybreak" with family members.

Japanese express wishes for the New Year by saying "Akemashite Omedetou Gozaimasu." Only one kanji (Chinese character) is found in this phrase (within the first word). This kanji is a combination of the characters for sun and moon and, among other meanings, entails the sun and the moon getting together and becoming "bright." It represents "changing" and "opening," in a sense, "dawning" (Fig. 4).

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Astronomy in Japan: A Cultural History, Fig. 4 The *kanji* for *Ake*. Symbols for the sun and moon are placed together in this character to represent "bright" or "beginning" (Computer graphic by Steven L. Renshaw)

In ancient lore (under the lunar calendar), the New Year was seen in relation to change in both the sun and moon as well as the symbol of their luminance. The meaning of the phrase "Akemashite Omedetou Gozaimasu" reflects the values of linealism, vitalism, and optimism. Perhaps it is expressed in English most appropriately as follows: "The year is changing; darkness gives way to light; new life begins; Congratulations!" Following tradition, many Japanese on New Year's morning brave the cold to find places with unobstructed views of the eastern horizon and eagerly await the rising sun, the break of day, the symbol of new life. Incorporating the ideas of much ancient mythology, the sun is seen to be making its journey back to the north, and the vernal equinox is eagerly awaited.

As in other aspects of Japanese astronomy that we have discussed, Chinese imports and traditions were incorporated from early times. The New Year of 2008 was special in that it began another 12-year cycle of the Chinese calendar (based on positions of Jupiter with its 12-year orbit and consequent position about the ecliptic; Uchida, 1981). The tradition of using Chinese-based animal names for the 12 directions and associated years is popularly maintained in Japan. In 2008, things turned around once more to the direction of *ne* (mouse), the north, to the direction of the star Polaris, sometimes called *Ne no Hoshi* (mouse star) but also called *Shin Boshi*, the "Heart" star, the "soul of the Heavens." 2008 began the clockwise cycle again which from ancient Chinese geomancy means moving from N to NNE (2009, *ushi* or cow), to ENE (2010, *tora* or tiger), to E (2011, *u* or rabbit), and so forth.

The mixture of Chinese geomancy and symbolism with indigenous social values is clearly seen in the Japanese celebration of the New Year. Yet the quiet tolling of temple bells on New

Year's Eve brings a certain calm and solitude unseen in most any other culture. It is in this very symbolic act that centuries of Japanese history and tradition, for better or worse, can be seen and truly appreciated.

Hopes for the Future Built on a Rich But Hidden Past

Most of Japan's recorded history reflects a culture continually influenced by imports, even when on the surface, the country appeared to be isolated. At the same time, a cultural consciousness combined with quite distinct social and political purposes has always been a source through which most any idea, foreign or domestic, had to be filtered.

Though we can still see much of the ancient heritage of Japanese astronomy in layouts, structures, mythology, and ethnographic lore, it is often difficult to find too many Japanese citizens aware of this sphere which incorporates a complex interaction of ancient values and purposes with celestial symbols. Feeling that the culture has adopted almost every modern concept that East or West has to offer, many Japanese themselves are unaware of the richness of their ethnoastronomic heritage. As in the West, many young Japanese are more likely to know the name of Pleiades rather than Subaru and associate the latter with an automobile company rather than the celestial symbol which meant so much to their ancestors. While Tanabata is still observed and the legend of Orihime and Kengyuu still finds its way into modern songs and prose, few people are concerned about the festival's shift away from its seasonal association. In many ways, however, Japan's embracing of the West and virtual denigration of its past reflects a process which has been a part of the culture's way of handling infusion from its earliest times. Still, when the "face" is lifted, one still finds an enduring set of values and purposes that appear to predate written history.

In discussing some modern approaches to archaeoastronomy, Aveni (1989) has alluded to the inclination to disassociate science from the social and historical context in which it was

developed. He points out how such isolation lacks the notion of process or change and in a sense leads to a "predetermined goal of seeking ourselves out in the tattered pages and crumbling walls of other peoples' history (p. 8)." Aveni further mentions the danger of relying solely on written records and emphasizes using additional evidence in the form of archaeology and architectural icons to understand a nation's cultural astronomy. In taking a narrow view of astronomy as it developed into modern Western science, Aveni contends that we pursue what is interesting to us instead of what was important to the people we study.

The specific irony of Aveni's observations relative to the study of astronomy in Japan may rest in the view taken by many Japanese themselves. In a sense, the view is that we (Japanese) seek others' selves (Western science in particular) within the tattered walls of our own culture and come up sadly lacking. To further paraphrase, we (Japanese) tend to pursue what is of modern interest (to the West in particular) instead of what was actually important to our own ancestors throughout history. These perhaps enigmatic Japanese views are the result of a long and complex history involving interaction of native belief and consciousness with a perception that while unique, the native culture is somehow inferior to those imports it filters. Such lack of "cultural self-esteem" has led to a number of enigmatic events in Japanese history, not merely the denigration of its own astronomical heritage.

In looking at the overall influence of Japanese value, past and present, it may be worth noting that modern astronomical practice, while totally within the rubric of Western science, reflects a long heritage of curiosity combined with concern for future generations. A good example of this may be found in the diary of a young Kochi resident rediscovered in the 1980s. In 1664, while astronomers in Europe were trying to learn more about the motion and nature of comets, Matasaburou, a young boy age 12, began to observe what would later be known as Comet C/1664 W1. Encouraged by his teacher, Jian, he diligently observed the comet for over 4 months, wrote his impressions, and drew the changing

shape of the comet in his diary. Despite the lack of astronomical knowledge, Matasaburou showed remarkable curiosity about the true nature of the *houki boshi* (brush star) and an abundant skepticism of the prevailing view among townspeople that the comet signaled doom. While his drawings do not have the flamboyance of those of Hevelius and others observing the comet in Europe, his diary shows every attempt to precisely plot the location and shape of the comet as it crossed the celestial sphere nightly. Matasaburou passed on to his own pupils the joy of discovery, and it is no doubt due to this that copies of his diary have survived the centuries. Such diligence is still seen in the work of amateur and professional astronomer alike. One cannot help but be reminded of the tireless efforts of professionals and amateurs who venture out on every clear night to observe and try to discover yet another celestial wonder.

Future astronomers, archaeoastronomers, and ethnoastronomers in Japan will no doubt come from an increasing number of young Japanese who have grown up in the intellectually free environment of modern Japan. Those not raised within the culture may find the door to Japan's astronomical past opening wider if there is a will to engage in exploration of consciousness and purpose still so evident beneath the surface of Japan's modern society. However, much work lies ahead in uncovering the vast richness of Japanese astronomy in history, and the future is probably most "optimistic" for those young Japanese scholars who find the riches of their heritage and culture inspiration and justification enough to seek knowledge about their nation's long pilgrimage with the sky.

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Astronomy in Mainland Southeast Asia

Yukio Ōhashi

Southeast Asia is divided into two parts, mainland Southeast Asia and insular Southeast Asia (also called the Indo-Malay Archipelago). Mainland Southeast Asia is further divided into two parts. One is Vietnam, where Chinese influence is

greater than Indian influence, and the other includes Burma, Cambodia, Laos, and Thailand, where Indian influence is greater. The Malay Peninsula is a part of mainland Southeast Asia geographically, but is culturally closer to insular Southeast Asia.

Astronomy in Burma, Cambodia, Laos, Thailand, and Yunnan

Traditional Calendars in Burma, Cambodia, Laos, Thailand, and Yunnan

The traditional calendars of Burma, Cambodia, Laos, and Thailand in Southeast Asia, and those of the Tai (or Dai in the Pinyin system of Chinese transliteration) people in Sipsong-panna (or Xishuang-banna in Pinyin) in the Yunnan province of China have similar characteristics. (For the calendars in mainland Southeast Asia, except for Vietnam, see Eade (1989, 1995). For the Burmese calendar, see Irwin (1909), de Silva (1914), and Htoon-Chan (1918). For the Cambodian calendar, see Faraut (1910). For the Lao calendar, see Phetsarath (1940) and Dupertuis (1981). And also, for the Dai calendar in Yunnan in China, Zhang and Chen (1981) may be consulted. It may also be mentioned here that de Casparis (1978) may be consulted for calendars in insular Southeast Asia.) They are basically based on the Indian (Hindu) calendrical system, which is a luni-solar calendar, with certain simplifications. The Indian influence is seen, for example, in the fact that the length of a year used in most of these calendars is 365.25875 days. This is similar to the sidereal year (not tropical year) of the Ārdharātrika school, one of the schools of Hindu astronomy. Dikshit, an authority on Hindu astronomy in the second half of the nineteenth century, pointed out that the length of a year used in an astronomical work procured by a French envoy from the Ayutthaya dynasty of Siam (present Thailand) is the same as that of the *Sūrya-siddhānta* quoted in the *Pañca-siddhāntikā* of ► [Varāhamihira](#) (sixth century AD) (Dikshit, 1981, p. 378). This *Sūrya-siddhānta* belongs to the Ārdharātrika school.

Besides the Indian influence, there is also Chinese influence in this area, notably the animal names of the 12-year cycle.

The main differences between Indian (Hindu) traditional astronomy and the calendars in mainland Southeast Asia (except for Vietnam) are as follows. (The traditional calendar of Vietnam is based on the Chinese system, which I shall discuss in the next section.)

1. In the Hindu traditional calendar, an intercalary month is inserted when two successive new moons occur during which the sun remains in the same zodiacal sign. In mainland Southeast Asian calendars, the 19-year cycle is usually used for intercalation during which seven intercalary months, which consist of 30 days, are inserted after the fixed month of a year. Actually, the 19-year cycle is not harmonious with the sidereal year which is used in Hindu and mainland Southeast Asian calendars, and I suspect that this 19-year cycle might have been introduced from China.
2. In the Hindu traditional calendar, 1 month is divided into 30 *tithis*, which are the periods during which the longitudinal difference between the sun and moon changes by 12° , and the number of the *tithi* at the beginning of a day (usually sunrise) becomes the name of the day. So, the number of days in a month is automatically determined. In mainland Southeast Asian calendars, 29-day months and 30-day months are usually distributed alternately at definite months of a year, and 11 intercalary days are distributed in 57 years at the fixed month of a year. Actually this method is slightly inexact.

One thing may be added here. Among Tai (or Thai) people, lunar months are named by serial number, and there are some variations of this method. This method is similar to the Chinese method, but is absent in the Hindu traditional calendar. The method used by Dai people in Sipsong-panna in Yunnan province (in China) is quite similar to an ancient variation of a Chinese method.

I suggest the following tentative hypothesis. The 19-year cycle intercalation and the method of month reckoning using serial numbers were introduced from China, and were modified after the introduction of the Indian calendar (Ārdharātrika school). (For details, see Ōhashi, 2002). It may also be mentioned here that the calendar used in the inscriptions of Champa, which was a kingdom that existed in present central and south Vietnam until the seventeenth century AD, was also based on the Indian calendar.

Controversy Regarding the Dai Calendar in Yunnan, China

There was a controversy between Dong Yantang and Zhang Yong, both of whom are Chinese scholars, in the first half of the twentieth century regarding the origin of the Dai peoples' calendar in the Yunnan province of China. In 1938, Dong Yantang published a paper on the origin of the Dai calendar (Dong, 1938). In this paper, Dong Yantang argued that the Dai calendar was based on the Qin calendar of ancient China.

In 1939, Zhang Yong wrote a paper on the Dai calendar (Zhang, 1939). Zhang Yong criticized Dong Yantang's paper, and concluded that the Dai calendar was based on the Indian calendar. Zhang Yong pointed out some reasons. For example, the Dai calendar uses half months just like the Indian calendar, and the Dai calendar divides a year into three seasons just like the Indian calendar. These reasons are justified. Zhang Yong mentioned other reasons also, and tried to show that the Dai calendar was completely based on Indian calendar without Chinese influence.

I think that the Dai calendar is basically based on Indian calendars, but there may be some Chinese influence also, as I mentioned in the previous section.

Historical Development of the Traditional Calendars in Yunnan and Burma

According to Zhang Gongjin and Chen Jiujiu (Zhang and Chen 1981), the texts entitled *Suding* and *Suliya* were followed by the Dai people for making calendars before AD 1931, but the text

entitled *Xitan* has been followed since AD 1931 or so. Zhang and Chen also say that the *Suding* and *Suliya* do not follow the 19-year cycle of intercalation strictly, but the *Xitan* follows the 19-year cycle of intercalation. The calendrical luni-solar year of the *Xitan* practically keeps pace with the tropical year, although the solar new year's day is calculated by the sidereal year as before. I compared their astronomical constants with Indian constants, and found that the *Suding* and *Suliya* follow the Ārdharātrika school, while the *Xitan* follows the Saura school (Ōhashi, 2002).

According to Irwin (1909), the *Makaranta* (there are two methods of epoch: AD 638 and AD 1436), which probably follows the "original *Surya Siddhanta*" (i.e., Ārdharātrika school), was followed in Burma originally. Afterwards the *Thandeikta* (epoch: AD 1738), which chiefly follows the "present *Surya Siddhanta*" (i.e., Saura school), was used. Irwin writes that the *Thandeikta* is said to have been composed in about AD 1738 or AD 1838, and that the present *Sūryasiddhānta* was introduced into Amarapura, Burma, in AD 1786, and translated into Burmese after about 50 years. Irwin also states that the 19-year cycle of intercalation was followed in the *Makaranta*, but was not strictly followed in the *Thandeikta*. We should note that the Burmese *Makaranta* is probably different from the well-known Indian Sanskrit astronomical table *Makarandasāraṇī* (AD 1478) of ► [Makaranda](#), which follows the Saura school.

Here, the treatment of the 19-year cycle of intercalation is just the opposite of the Dai calendar (Yunnan, China) and Burmese calendar. More detail about the calendar reform in these regions should be investigated.

Traditional Astronomy and Modern Astronomy in Thailand

In the mid-fourteenth century AD, Lithai (King Ruang) of the Sukhothai dynasty wrote the *Traiphum* (Three Worlds) (Reynolds & Reynolds, 1982). This is a celebrated text of traditional Thai cosmology, which is based on Buddhist cosmology. Some information about traditional astronomy and the calendar is also found there.

In 1685, King Narai of the Ayutthaya dynasty observed a lunar eclipse with a telescope with the Jesuits sent by the French King (See Tachard, 1688/1981, pp. 230–246; Choisy, 1993, p. 215). King Narai requested mathematicians from France, and planned to build observatories at Louvo (now Lop Buri) and Siam (now Ayutthaya). This event may be considered the beginning of modern astronomy in Thailand.

In 1687, a French envoy, Simon de la Loubère, visited the Ayutthaya dynasty and procured an astronomical work entitled *Souriat*. This work was later analysed by a celebrated astronomer, Jean Dominique Cassini (See Loubère, 1693/1969, pp. 64–67 and 186–199; Bailly, 1787). This is the earliest information of India-based astronomy reaching Europe. Dikshit pointed out that the length of a year used there is the same as that of the *Sūryasiddhānta* quoted in the *Pañcasiddhāntikā* of ► *Varāhamihira* (sixth century AD) (Dikshit, 1981, p. 378).

In the nineteenth century, King Mongkut (Rama IV) (r. 1851–1868) studied European astronomy as well as Thai traditional astronomy. He ordered his own observatory near Phetburi. He predicted the total solar eclipse of 1868. According to the *Dynastic Chronicle*, the King calculated the eclipse “by using the old astrological texts of Siamese and Mon, as well as many old American and English texts.” According to Thongchai, the Mon text used by the King is the *Saram*, one of the two Mon treatises for planetary calculation known in Siam; the other text more conventionally used by astrologers at that time was *Suriyayat*. (See Thiphaakorawong, vol. 2 1966 of 1965–1974, pp. 532–539; Cook, 1992; Thongchai, 1994, chapter 2). This was a symbolic event in the course of the introduction of modern astronomy into Thailand.

There are several inscriptions with calendrical data in Thailand, which are also important sources of Thai astronomy (Eade, 1996). There was an independent kingdom, Lanna, in North Thailand from the end of the thirteenth century to the beginning of the twentieth century. The people of Lanna had their own astronomy, which was based on Indian astronomy. (See Soonthornthum, 1998; for the Northern Thai calendar, see Davis, 1976).

Burmese Constellations

Burma has a special system of constellations, and there are three beautiful star maps drawn on the ceilings of corridors of the Kyauktawgyi Pagoda at Amarapura (near Mandalay, Burma) (Fig. 1a–d are the star maps photographed by the author in 1984).

King Pagan (r. 1846–1852) built the Kyauktawgyi Pagoda in 1847 on the model of the Ananda Temple at Pagan (Lu Pe Win, 1960, p. 5). There is a pioneer study of Burmese constellations by Francis Buchanan (1799) (also see Nishiyama, 1997). Although Burmese constellations include Indian constellations, there are many Burmese unique constellations, which are very important for investigating the original Burmese contribution.

Astronomy in Vietnam

There are four main countries where Classical Chinese was used as the official language of traditional learning: China, Korea, Japan, and Vietnam. In this section, I will discuss some aspects of Vietnamese astronomy based on the sources I consulted. When a Vietnamese or East Asian person is referred to in this section, the surname is written first as is the custom in these regions, unless commented upon otherwise.

Previous Researches

In 1934, Mikami Yoshio, a pioneer of the study of the history of Eastern ► *mathematics in Japan*, wrote a paper on a mathematical work of Vietnam. This is a study of a Vietnamese mathematical work entitled *Chi-minh toan-phap*, written in classical Chinese, which was brought to Japan by Matsumoto Nobuhiro, an authority on Vietnamese study in Japan.

In 1940, Yung Chang (as transliterated in his own paper where Chang is the surname, or Zhang Yong in modern Pinyin transliteration) (1911–1939), a Chinese scholar, wrote a paper on the Vietnamese calendar. This is a pioneer study of the Vietnamese calendar, and I was much impressed by this work. In the 1960s,



Astronomy in Mainland Southeast Asia, Fig. 1 (continued)



Astronomy in Mainland Southeast Asia, Fig. 1 Star maps drawn on the ceilings of corridors of the Kyauktawgyi Pagoda at Amarapura

Huard and Durand wrote popular articles on the history of Vietnamese science (Huard & Durand, 1961/1965; Durand & Huard, 1964/1966). In 1964, Ho Peng-Yoke wrote a paper on the records of natural phenomena, including astronomical phenomena, recorded in a historical work of Vietnam. It is necessary to continue this kind of work, comparing the records with other East Asian records, and checking them with modern calculations.

In 1979, a monograph on the history of science in Vietnam was published in Vietnamese in Hanoi (Vien Su hoc, 1979). This book includes 12 papers, including a paper on the history of Vietnamese mathematics written by Ta Ngoc Lien. As far as I know, this book is the most detailed work on the history of science and technology in Vietnam. In 1991, Han Qi, a Chinese scholar, wrote an overview of the history of astronomy and mathematics in Vietnam (Han, 1991). [Ed. note: See Han Qi's article on Jesuits and Knowledge Exchange in China in this volume].

In 1999, the ninth International Conference on the History of Science in East Asia was held at Singapore. In this conference, there was a session on "New Topics in the History of Science in East

Asia-Preliminary Research on Vietnamese Scientific Tradition." In this session, Chu Tuyet Lan and Nguyen Xuan Dien from the Institute of Sino-Nom Studies, Hanoi, introduced Vietnamese works on science, medicine and technology (Nguyen, 2002), and Alexei Volkov read a paper on the *Toan-phap dai-thanh* of Luong The Vinh, a Vietnamese mathematical work. I think that this conference marked a kind of breakthrough for the study of the history of Vietnamese astronomy and mathematics.

In 2000, I visited the Institute of Sino-Nom Studies in Hanoi, and consulted some Vietnamese astronomical works with the help of Ms. Chu Tuyet Lan and Mr. Nguyen Xuan Dien. When I visited Vietnam, I found a small book on 13 Vietnamese scientists, both premodern and modern, written in Vietnamese (Le, 1999). This is a popular book for youths.

In 2002, Alexei Volkov published a paper on the *Toan-phap dai-thanh*. I think that this is a monumental paper on the history of mathematics in Vietnam. Also in 2002, a convenient bibliography of classical literature of Vietnam was published in Taiwan. Several astronomical and mathematical works are listed there (Liu, Wang & Chen, 2002, part 1, pp. 452–459).

Vietnamese Astronomy

Rough History of Vietnamese Calendars

1. Acceptance of Chinese calendars, notably the *Shoushi* calendar

The *Yuanshi*, the official history of the Yuan dynasty of China, says that a Chinese calendar was given to the Vietnamese king (Tran dynasty) in 1265 (*Yuanshi*, vol. 209, Annan, the second year of Zhiyuan). At that time, the *Shoushi* calendar, the celebrated calendar of the Yuan dynasty, had not been made, and the *Daming* calendar of the previous Jin dynasty was still used in China.

The *Dai-Viet su-ky toan-thu*, an official history of Vietnam written in Classical Chinese, says that the *Shoushi* calendar was given to a Vietnamese king (Tran dynasty) from the Chinese Emperor in 1324. (*Dai Viet Su Ky Toan Thu*: 220, vol. 6, 42 b in the original block print). From the above sources, we can suppose that Chinese calendars were accepted in Vietnam until the early fourteenth century.

2. *Hiep-ky* calendar

The *Dai-Viet su-ky toan-thu* states that the *Shoushi* calendar was changed into the *Hiep-ky* calendar in 1339 (Tran dynasty) (*Dai-Viet su-ky toan-thu*: 229, vol. 7, 9 b-10 a in the original block print). This record possibly means that the name of the calendar was changed, and does not necessarily mean that the method of calculation was changed. The *Mingshi*, the official history of the Ming dynasty of China, says that the *Datong* calendar of China was given to the Vietnamese king (Tran dynasty) in 1369, the next year of the establishment of the Ming dynasty (*Mingshi*, vol. 321, Annan, the second year of Hongwu). It may be that the *Datong* calendar, which is a revised version of the *Shoushi* calendar, was accepted in Vietnam at that time.

3. *Thuan-thien* calendar

The *Dai-Viet su-ky toan-thu* tells that the *Hiep-ky* calendar was abolished, and the *Thuan-thien* calendar was adopted in 1401 (Ho dynasty) (*Dai-Viet su-ky toan-thu*: 267, (vol. 8, 39a in the original block print).

The difference between these two calendars is not recorded.

4. Acceptance of the Chinese *Datong* calendar

Vietnam was directly ruled by the Ming dynasty of China from 1413 to 1428, and the *Datong* calendar must have been used. The Le dynasty was founded in 1428 in Vietnam, but there is no record that the calendar was changed.

The *Mingshi* states that the *Datong* calendar was given to the Mac, who ruled Vietnam for certain period, in 1540 (*Mingshi*, vol. 321, Annan, the 19th year of Jiajing). In 1829, Nguyen Huu-than wrote in his *Y-trai toan-phap nhat-dac-luc* that the *Datong* calendar had been used until the *Hiep-ky* calendar (Vietnamese adoption of the Chinese *Shixian* calendar) was adopted in 1813 (Zhang, 1940, p. 34.).

5. *Hiep-ky* calendar (= *Shixian* calendar)

According to Nguyen Huu-than, as we have seen above, the *Shixian* calendar of the Qing dynasty of China was adopted in Vietnam as the *Hiep-ky* calendar in 1813 (Nguyen dynasty). This *Hiep-ky* calendar should not be confused with its previous namesake. Zhang Yong compared Vietnamese chronological tables with Chinese calendar, and pointed out that the *Shixian* calendar was actually used in Vietnam from 1813 to 1840.

6. Consideration of the longitudinal difference

Zhang Yong pointed out that the Vietnamese *Hiep-ky* calendar has differed from the Chinese *Shixian* calendar since 1841. This must be due to the consideration of the longitudinal difference between Vietnam and China.

Calendar Reformation Under Minh-manh

In order to reform the calendar, astronomical observations were made under the emperor Minh-manh (r. 1820–1840) of the Nguyen dynasty. There are some source materials about this reformation.

The *Dai-Nam hoi-dien su-le* (1855) is a comprehensive official record of the system of government of the Nguyen dynasty. It has a section on the Kham-thien-giam (National Astronomical Observatory). According to this section, it was

declared in 1837 that the prime meridian for Vietnam passed through its capital (Hue), whose latitude was determined to be $16^{\circ}22'30''$, and longitude measured from the Western prime meridian to be 105° (*Dai-Nam hoi-dien su-le*, vol. 259, 13a–b). The actual position of Hue is $16^{\circ}27'N$, and $107^{\circ}33'E$ (from Greenwich). So, the above-mentioned Western prime meridian must be Paris ($2^{\circ}20'E$ from Greenwich).

There is another interesting work entitled *Thien-van-khao* (Study of Astronomy), which is volume 1 of the *Su-hoc bi-khao* of Dang Van-phu. This text records longitude and latitude (from Hue) of several places determined in 1837. According to this text, the longitude seems to have been determined by the observation of lunar eclipses using local time. From the above sources, we know that Vietnamese astronomers made efforts to make the calendar more suitable for Vietnam.

Another interesting work is the *Quoc-trieu thien-van-chi*. This is a chronological compilation of the records of heavenly phenomena from 1569 to 1888.

The traditional astronomies in several regions of mainland Southeast Asia are very interesting, but their detailed study is our future task. Several original sources are still in manuscript form or extremely rare. Fortunately, some people are now going to study this subject, and I hope that more results can be reported in the near future.

In the case of Vietnamese astronomy, it is necessary to compare it with Chinese astronomy, and in the case of Burmese, Cambodian, Lao, and Thai astronomies, it is necessary to compare them with Indian astronomy. Thorough study of the regional differences and their relationships with regional cultures are needed. I hope some readers of this article contribute to this subject in the future.

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Astronomy in Medieval India

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Introduction to Islamic Astronomy

Muslims are obliged to discharge three major religious duties (*arkān*), which could be planned quite accurately using mathematical sciences, particularly astronomy (King, 1993). They are (1) Islamic prayer times that are defined according to the rules of astronomical time reckoning (*ʿIlm al-Mīqāt*), (2) calculating the direction of *Kaʿba* (*Qibla*) – the rectangular-shaped room at the center of the Grand Mosque in Mecca – to which Muslims face while praying, and (3) the sighting of the lunar crescent (*Hilāl*) at sunset, by which begins the first day of every month of the Islamic calendar. Evidently this sighting depends on the position of the Sun and Moon and also their positions with respect to the local horizon. Consequently, in the first few centuries of the spread of Islam (eighth to ninth century), Muslims began an intensive and extensive reception of the natural and even social sciences. A multitude of scientific works from Babylon, India, Iran, and Greece were translated into Arabic. This transmission had an official sanction as well. Beginning with the reigns of Umayyad Caliph ʿAbd al-Malik ibn Marwān (ca. 700) and his successor son Hishām (724–743) and particularly during the reigns of the Abbasid Caliphs al-Manṣūr (754–775), Hārūn al-Rashīd (786–809), and al-Māʾmūn (813–833), the transmission of foreign or ancient sciences achieved its climax. At this time, Sasanian, Indian, and finally Greek astronomy and mathematics were assimilated and led to the writings of great scholars. Some of these are al-Khwārizmī, al-Farghānī, and al-Battānī (ninth to tenth centuries); Ibn Sīnā, Ibn al-Haytham, and al-Bīrūnī (eleventh century); and Naṣīrūddīn al-Ṭūsī (thirteenth century), to name just the most important ones. For example, al-Ṭūsī was the director of the Marāgha observatory, and he initiated the

so-called *Hayʿa* tradition by developing a non-Ptolemaic theoretical model of planetary motion. For details see Saliba (1994).

India was ruled by the sultans of Central Asia and their descendants during the Sultanate period (1191–1526). The Indian Mughal period (1526–1857) began with the dynastic rule of Ṣāḥīrūddīn Bābur (reigned 1526–1530), followed by his son Humāyūn (r. 1530–1556) and Akbar (r. 1556–1605) whose grandson Shāhjahān (r. 1627–1658) is famous for building the Tāj Maḥal at Agra. During the Indian medieval period, both sultans and particularly Mughal emperors were very keen to patronize the scholars from Central and West Asia. Those scholars (*Ulamā*, *Fuḍalā*), including also mathematicians and astronomers, thronged the courts of sultans, emperors, and even local rulers and nobles (*Umarā*). They brought with them various scientific (mathematical and astronomical) texts, such as the writings of Abuʿl Rayḥān al-Bīrūnī (d. 1048), Naṣīrūddīn Ṭūsī (d. 1274) of Marāgha, Sulṭān Ulugh Bég (d. 1449) of Samarqand, and Bahāuddīn al-ʿĀmilī (d. 1622). Mughal Emperor Bābur (prior to his conquest of India) had forged an alliance with the Shāh Ismāʿīl-I of Persia and his son Emperor Humāyūn, who had bonded a friendship with Shāh Tahmāsp bin Ismāʿīl (d. 1576). Consequently, even during the following reigns of Mughal emperors, Akbar, Jahāngīr, and Shāhjahān, the cordial relationship with Iranian Safavid rulers, namely, Shāh ʿAbbās-I (d. 1629) and Shāh ʿAbbās-II (d. 1666), strengthened further (Riazul Islam, 1970). An interesting anecdote is that Shāh ʿAbbās-I sent to Jahāngīr on his request as gift the *original* astrolabe of Sultan Ulugh Bég – the founder of the astronomical observatory at Samarqand in 1420. The Shah of Iran kept for himself only its copy (Riazul Islam, 1970). Evidently in such a politico-cultural milieu, several Iranian/Central Asian scholars and scientists flocked to the courts of medieval Indian sultans and emperors who patronized them liberally. In this context, one may understand the origin of the exact sciences, e.g., astronomy and mathematics, which were transmitted to the Indian subcontinent during the medieval period and which were developed further by indigenous

Indian scholars (for a survey on Islamic astronomy and its transmission into India, see Ansari (1995), Appendix I).

A specific feature of Islamic astronomy was the emphasis on observational astronomy. Even in the early Abbasid period (750–850), astronomical observatories were established, in which practical astronomy was carried out quite diligently. The earliest observatories, the Shammāsiya and Qāsiyūn observatories, both founded by Caliph al-Mā'mūn (d. 833), resulted in an observatory movement which culminated in the establishment of the Marāgha observatory in 1259 (Director, Naṣīruddīn al-Ṭūsī), the Samarqand observatory in 1420 (founded by Sulṭān Ulugh Bég, for whom see van Dalen (2007b)), and the Istanbul observatory in 1575–1577 (Director, Taqī al-Dīn Muḥammad) (see for details Sayili (1960) Chapters II, VI, and VIII). An important task at those observatories (*Raṣad Gāh/Khāne*) was the compilation of *Zīj* (plural *Zījāt*), which are astronomical-mathematical tables or handbooks to be used for determining the position of the Sun, Moon, and various planets. All *Zīj*es, in Arabic, Persian, Hebrew, and Turkish, contain tables for functions of spherical astronomy and of trigonometrical functions. The compilers deal briefly also with the following topics: solar and lunar parallax and their eclipses, lunar visibility, gazetteers, star catalogues, and tables of ascendants for astrological purpose. To overview the *Zīj* literature, cf. the pioneering survey by Kennedy (1956), an updated interim report by King and Samso (2001), and the comprehensive *Zīj* survey of about more than 200 *Zīj*es by van Dalen (2007a). For *Zīj*es compiled in India, see also Ansari (2014), forthcoming.

Zijes of the Sultanate Period

Zij-i Nāṣirī (ZN)

We know now that this was the first Indian *Zīj* of the period written by Maḥmūd ibn 'Umar al-Rāzī, who dedicated it to Naṣīruddīn Maḥmūd bin Sulṭan Shamsuddīn Iltutmish (r. 1246–1265 in Delhi), hence its title, abbreviated hereafter as

ZN. Storey (1972, pp. 74–75) informed about only one manuscript then extant in the Ḥusayn Agha Nakhjawānī Library (Tabriz), which does not seem to exist now. For its brief history, cf. Ansari (2008, pp. 62–63). Fortunately I have been able to find another complete manuscript of this *Zīj*, in the Āyat Allāh Najafī Mar'ashī Library (Qum), Ms. 9176, comprising 165 ff., copied close to the time of the author (see Ḥusaynī & Mar'ashī, 1994, p. 293). Note that Emperor Akbar's chronicler Abū'l Faḍl 'Allāmī mentioned ZN in the list of 86 *Zīj*es given in his book: *Ā'in-i Akbarī (Institutes of Akbar)*. It means that it was available in India even in the sixteenth century. In the first *rukn* ("pillar") on fol.111a, 65 fixed stars (*Thawābit*) are catalogued for the year 615 Yazdigird (AD 1246) with their longitudes and latitudes. In one of his numerical examples (fol.10b), the given date is Thursday 22 Sha'bān AH 641 (4 Feb. AD 1244). The author's base meridian is Delhi. In fact, his numerical examples lie mostly between AD 1235 and 1245, during which time Maḥmūd ibn 'Umar evidently had been compiling his *Zīj*. In other words this first Indian *Zīj* was compiled even before *Zīj-i Ilkhānī* (AD 1271) of Naṣīruddīn Ṭūsī at Marāgha observatory.

ZN consists actually of two *rukn*, the first of which contains tabulated material for detailed calculations of heavenly bodies in 66 chapters (120 ff). The second *rukn* (paginated afresh) deals with the theory or general principles of astronomy, illustrated by direct calculation without recourse to tables; it consists of 60 chapters (44 folios). The topics are chronology; functions of trigonometry and spherical astronomy; planetary positions, conjunctions, and eclipses; astrology; and geographical tables. According to a detailed comparative study by Dalen (2004, p. 831), the mean motions in ZN were calculated with very high accuracy, and these tables agree with *Zīj al-'Alā'ī* compiled in Arabic by al-Fahhād, who is mentioned by Maḥmūd ibn 'Umar in his list of 14 astronomers, whose *Zīj*es he studied particularly (fol. 1b-2a of ZN). 'Abd al-Karīm al-Fahhād al-Shīrwānī (ca. 1180) originally wrote this *Zīj* in Arabic. It is nonextant presently. It was translated into Persian by

Shamsuddīn al-Bukhārī (Tabriz, 1295/1296), whose Greek disciple Gregory Chionides prepared in ca. 1305 in Constantinople (now Istanbul) its recension in Byzantine Greek, which is fortunately extant. David Pingree published its text with an English translation and commentary, cf. van Dalen (2004, p. 826). In fact *Zīj al-‘Alā’ī* was mentioned by Abū’l Faḍl ‘Allāmī in the list of 86 *Zīj*es given in his book: *Ā’in-i Akbarī*, i.e., it was extant in the sixteenth century in India. However, Abū’l Faḍl named the compiler as Fakhruddīn Abu’l Ḥasan ‘Alī bin Karīm al-Shīrwānī, also known as al-Fahhād.

Zij-i Jāmī ‘Maḥmūd Shāh Khiljī (ZJ)

This *Zīj* is dedicated to Sultan Maḥmūd Shāh Khiljī (r. 1435–1469) of Mālwa province. This anonymous *Zīj* was written during 1448–462 because of the interruptions of the author’s travels from Cairo to Bīdar in India. An incomplete but unique manuscript copy is extant in the Bodleian Library (Oxford), Ms. Greaves 6, with 104 folios (Persian Mss. No. 1522 in the *Catalogue* by Ethé), scribed by Mawlānā Fiṭr in AH 878 (AD 1473). The Persian text of the manuscript is not complete, for it ends with the first chapter. The second chapter and the epilogue are missing. The colophon is written at the end of the first chapter. John Greaves (1602–1652), Savilian Professor of Astronomy (1643–1648) at Oxford, translated into Latin an excerpt – first section (*faṣl*) of the first chapter of the Persian text – in his *Astronomica quaedam* (London, 1650). Cf. de Young (2004), for all details about John Greaves and his work.

This *Zīj* comprises a prolegomena (*Muqaddama*), two chapters, and an epilogue (*Khātimah*). The *Muqaddama* is further divided into 36 sections (*faṣl*), in which the author deals with arithmetic, astronomical mathematics, calendars, and astrolabes. Thereafter sections contain astronomical material: treating the Sun and Moon planets and calculating their ephemerides (*Taqwīm*).

Observatory at Balāghāt

During the rule of the Khiljī’s sultans (1288–1321), practical astronomy became quite

popular because of its astrological usage. The historian Ḍiyāuddīn Barnī reported in his famous *History of Firoz Shah (Sīrat-i Fīrūz Shāhī)* that:

In Delhi the science of astrology [*‘Ilm-i Nujūm*] was very much in vogue and it was supported by the nobility and scholarly circles. ... No locality was without an astrologer [*Munajjim*]. ... The astrologers of ‘Allā’ī era [i.e., of ‘Allā’uddīn Khiljī and his descendants] were great experts and specialists of the astrological calculations and also in the astronomical observations [*raṣadbandī*]. (Ghori & Khan, 1969, p. 28) quotes Barnī’s text, p. 162.

Fīrūz Shāh Bahmanī (r. 1397–1422), the eighth sultan of the Bahmani dynasty of Deccan, was reported to have been quite an expert in several sciences, particularly in natural philosophy, logic, mathematics, and astronomy. He used to lecture 3 days a week on standard treatises of mathematics and astronomy: recension of “Principle of Euclid Geometry” (*Tahrīr Usūl Uqlidis*) by Naṣīruddīn Ṭūsī (d. 1274) and on a commentary of his “Memoirs on Astronomy” (*Tadhkira fī ‘Ilm al-Ha’ya*). However, the sultan’s interest in astronomy culminated in commissioning the first observatory on Indian soil at Bālāghāt – the summit of the pass near the Indian town of Daulatābad. The construction started in 1407 AD, i.e., before Ulugh Beg’s observatory at Samarqand in 1420 AD. However, it remained incomplete due to the sudden death of the Director-Designate Ḥakīm Ḥasan Jīlānī (Farishtah/Briggs, Vol. II, p. 27).

Zijes of the Mughal Period

Zij-Ulugh Bég (ZUB)

As mentioned above (section “Introduction to Islamic Astronomy”), the original astrolabe of Sultan Ulugh Bég’s observatory at Samarqand was a gift from the Shāh ‘Abbās I of Iran to the Mughal Emperor Jahāngīr s/o Akbar. Another noteworthy gift by the Shah was a large ruby inscribed with the name of Ulugh Bég, which was presented to the then crown prince Shāhjahān by the Iranian ambassador in about 1620–1621 (Riazul Islam, 1970, p. 80). Sultan Ulugh Bég’s madrasa and observatory, founded in Samarqand

in 1417 and 1420, respectively, were known in Mughal India. Emperor Babur visited the observatory and described it in his Memoirs (*Bābur Nāmah*). The director of the madrasa, Ṣalāḥuddīn Mūsā Qāḍī Zādeh al-Rūmī's writings are extant today in Indian manuscript collections (Ansari, 1995, Appendix, p. 292). However, the main proponent of the astronomical tables compiled at Samarqand, ZUB, was Mīr Faṭḥullāh Shīrāzī (d. 1589), a pupil of Ghiyāthuddīn al-Manṣūr Shīrāzī (d. 1506) who wrote a tract on the "Rectification (*Taṣḥīḥ*) of Zīj-i Ulugh Beg." Mīr Faṭḥullāh, who also drew the horoscope of Akbar and has been known as the inventor of Akbar's Ilāhī calendar, had been commissioned by the emperor to get ZUB translated into Sanskrit by a team of Muslim and Hindu astronomers (Abū'l Faḍl/Blochmann (Tr.), Part I, p. 110). A unique manuscript of the Sanskrit translation is extant in Maharaja Man Singh II City Palace Library (Jaipur). The importance of ZUB lies in the fact that all its tabulated material is based on actual observations. Cf. van Dalen (2007a, pp. 97–100).

According to my own survey, more than 50 copies of ZUB are available in manuscript collections/libraries of India and Pakistan (Ansari, 1995, p. 293). This is surely the indicator of the spread of ZUB. It is therefore not surprising that Zījes compiled in Mughal India were based more or less on ZUB, in style and even in content. I enumerate them in the following.

Mulla Chānd's Commentary on ZUB

Mullā Chānd ibn Bahā'uddīn was the astrologer-astronomer at Emperor Humāyūn's and later also at Akbar's courts. He is known to have drawn horoscopes of Akbar (b. 25 Oct. 1542 AD) and of Jahāngīr (b. 30 Aug. 1569); see the reproduction in Abū'l Faḍl's *Akbarnāma*, Vol. 1 (pp. 56–57) and Vol. 2 (pp. 506–507), respectively. On Akbar's horoscopes and their historical significance, see Orthmann (2005). I thank her for presenting me a copy of her publication.

A unique copy of his commentary, rather a simplified version (*Taṣḥīl*) of ZUB, is extant in the Man Singh Museum Library (Jaipur), Ms. No. 6 (Arabic and Persian). This manuscript copy

bears the seal of one 'Abd al-Khāliq ("a slave of Shāh Jahān"), dated AH 1038/AD 1628–1629. This *Taṣḥīl* by Mullā Chānd is mentioned by Farīduddīn in his *Zīj-i Shāh Jahānī* and also by Raja Jai Singh in *Zīj-i Muḥammad Shāhī*. Mullā Chānd has more or less followed the style of ZUB in the text of his commentary. He has inserted a chapter or two here and there for making the contents easily understandable. At the end of each *maqāla*, he added tables, which are updated versions of the corresponding tables of the ZUB, because of the passage of time of about 150 years between the compilation of the original ZUB and *Taṣḥīl*. Cf. Ghorī (1985, pp. 33–34).

Zījes Compiled by Farīduddīn Munajjim

Farīduddīn Mas'ūd bin Ḥāfiẓ Ibrāhīm Dehlavī, known also as Farīduddīn Munajjim (astronomer), attended the famous madrasa of Shāh Nizām of Nārnol and was also a pupil of Faṭḥullāh Shīrāzī from whom he learned rational sciences ('*Ulūm-i 'Aqliya*) including astronomy and astrology. His elder brother Ṭayyab Muhandis was also a famous mathematician, who wrote on calendars and made an astrolabe for Mirzā 'Abdul Raḥīm Khān-i Khānān (d. 1627), Emperor Akbar's Chief of Army Staff (*Sipāh Sālār*), and who became renowned as a scholar and translator of Babur's Memoirs (*Tūzak-i Bābarī*) from Turkish into Persian in 1590. Farīduddīn became well known when he prepared the horoscope of the son (b. 1613) of Sultan Ibrāhīm 'Ādil Shāh II (ruler of Bījāpūr, r. 1580–1627), the manuscript of which is extant in Berlin. Farīd began his career in the service of Khān-i Khānān and remained with him till about 1615. Three of his astronomical writings are known today: a manual on astronomical calculations, *Sirājul Istikhrāj* written in AH 1006/AD 1598, and *Zīj-i Raḥīmī* written in 1617. In 1598 he joined the service of Khān-i Khānān. The title is a chronogram, but adding only the numerical values of its dotted letters: *j* (3) + *t* (400) + *kh* (600) + *j* (3) = 1006, according to *abjad* notation. Both these works are dedicated to his patron Khān-i Khānān. The third is *Zīj-i Shāhjahānī*, compiled about 1629 and dedicated to Emperor Shāhjahān. I confine myself here only to these two Zījes.

Zij-i Raḥīmī (ZR)

The unique copy of ZR is extant in the Central Library of the Holy Shrine of Raḍawī, Ms. No. 5554 with 441 folios (cf. Fikrat's *Catalogue*, p. 299), but the manuscript is incomplete. It ends after the few tables of the planet Saturn, with no colophon evidently. As Farīd tabulates the equation of time (*Ta'dīl al-Ayyām*) for the Sun and Moon for the year 1026 AH/1617 AD (ff. 152b, 153a), he might have been compiling ZR around that year.

ZR is modeled on ZUB; it comprises an introduction (*muqaddimah*) and four discourses (*maqālas*). Farīduddīn eulogizes “the nearest of his times, the most trustworthy and accurate *Zij-i Raṣadī* compiled by Mirzā Ulugh Beg” (fol. 2b, line 7–9). Farīd distinguishes here two kinds of Zijes: *Zij-i Raṣadī* based on theoretical principles and practical observations of the positions of stars and their motions in longitude and latitude. On the other hand, *Zij-i Ḥisābī* is one of those Zijes which are corrected by calculating the discrepancies and changes occurring during the course of time in the mean motions of Sun, Moon and planets. In fact, ZR contains a section on each calendar/era as usual in Zijes, viz., Hijrī, Philip, Persian (Yazdigird), Malikī, Chinese (*Qatā*), and Chinese-Uighur. It consists also of detailed tables of trigonometrical functions (ff. 21–39), tables for solar declination (*mayl awwal*) and second declination (*mayl thānī*), and for right and oblique ascensions. The last ones are for the latitudes of Samarqand, the Indian capital town Akbarābād (modern Agra), and for Lahore. Farīduddīn included also in his Zij a geographical gazetteer of 325 cities. Cf. Ansari (2013, section 3.2).

Zij-i Shāhjahānī (ZShJ)

It was completed in AH 1039/AD 1629, but the epoch year is AH 1041/AD 1631–1632. Farīduddīn compiled this Zij in collaboration with his brother Ṭayyab and under the supervision of Yamīn al-Dawlah Āṣaf Khān. As the title indicates the Zij is dedicated to Shāhjahān. The complete title is *Kārnamah-i Ṣāhib Qirān-i Thānī, Zij-i Shāhjahānī* (Great Work of the Lord of Second Conjunction, Shāhjahān's Zij). This ceremonious title owes its origin to the fact

that Venus and Jupiter were in conjunction (*Qiran*) at the time of Shāhjahān's birth on 5 Jan. 1592 in Lahore. R. C. Kapoor (Bangalore) has checked this statement by calculating for 00:00 UT the elliptical longitudes of Venus and Jupiter at the time of birth of Shāhjahān. They are 8 s 15°.1290 and 8 s 3°.4112, respectively, i.e., both in the same zodiac sign Scorpio. I thank Kapoor for this assistance. Exactly the same conjunction occurred at the birth of Amīr Tīmūr, the great great grand forefather of Shāhjahān. Therefore Tīmūr and Shāhjahān were entitled as “Lord (*Ṣāhib*) of the first and second conjunctions (*Qiran*).” Actually this is an astrologically auspicious conjunction. ‘Abdul Ḥamīd Lāhorī, the emperor's chronicler in his *Pāḍshāh Nāmāh*, reported that “in view of its many benefits and [containing] numerous principles and rules, [the Emperor] ordered that it should be translated into the language of Hindustan by Indian astronomers in consultation with Persian astronomers for the sake of public utility” (Ṭāhir/‘Ināyat Khān, *Mulakhkhaṣ* p. 82). In fact Pandit Nityānanda, the Hindu court astronomer of Shāhjahān, translated the ZShJ into Sanskrit in 1630. Four copies of this text with the title *Siddhāntasindhu* are extant in the Maharajah Man Singh Museum and Royal Collection in Jaipur.

The ZShJ consists of the same chapters as in ZUB, i.e., one introduction and four discourses (*maqālas*). Each *maqāla* is divided into many chapters (*bāb*); a chapter is further divided into sections (*qism* or *faṣl*). The introduction is similar to Farīduddīn's ZR, defining and explaining *Zij-i Raṣadī* and *Zij-i Ḥisābī*. The chapter on calendar/eras comprises the usual Hijrī, Rūmī, Yazdigird, Malikī, and Chinese-Uighur, but with the addition of the Indian calendar, *Shākhā Sālbāhan* (*Śālivāhana Śākha* in Sanskrit). The tables of ZShJ are not confined to the basic tables but contain auxiliary tables for simplification, as in ZR or in any commentary. For technical details cf. van Dalen (2007a), p.148.

Zij-i Muḥammad Shāhī (ZMS)

Sawā'i Jai Singh (1688–1743), raja of Amber (modern Rajasthan), was an erudite scholar of

Sanskrit literature and particularly of astronomy. He wished to implement his program of improving ancient and medieval Indian astronomy. To that end he is known to found a number of observatories with masonry instruments. These astronomical observatories were built in five Indian cities, namely, Delhi (1721–1724), Jaipur (1728–1735), Banaras (~1730), Ujjain (~1730), and Mathura (year unknown), so that observations of the same phenomenon could be carried out from many locations. As he was extremely receptive to astronomical ideas of different cultural areas, he established a school of translations at Jaipur for translation of Islamic astronomical treatises into Sanskrit (Sarma, 1998) and later also European scientific texts, especially Philippe de La Hire's *astronomical tables* and Homann's *Atlas*. Johann Baptist Homann's *Grosser Atlas über die Ganze Welt* (Nürnberg 1725), acquired in 1730, is preserved in the Sawai Man Singh Museum (Jaipur). This Atlas is important, since it contains charts for the planetary systems of Copernicus, Tycho Brahe, and Riccioli. These were brought to Sawā'i Jai Singh by his delegation of Indian astronomers sent to the Portuguese King, which was headed by Jesuit Emmanuel de Figueiredo; the delegation returned in Nov. 1730. What immortalized Jai Singh's name throughout the world of astronomy was in fact the *Zīj-i Muḥammad Shāhī*. In fact Emperor Muhammad Shāh (r. 1719–1748) on the advice of his astrologer, Mubashshir Khān, directed Sawai Jai Singh to get a modern (*Jadīd*) Zīj compiled, so that the actual title is *Zīj-i Jadīd Muḥammad Shāhī*. Various sections in ZMS are based solely on *Zīj-i Ulugh Bég*. The tables and texts concern the Sun, Moon, and planetary mean motions adapted from de La Hire's tables. See details in Mercier (1984), van Dalen (2000), and Pingree (2002). ZMS became quite popular among the Persian-knowing Indian scholars (14 mss. extant in India), also in Iran (32 mss.) and Central Asia (13 mss.), where it almost replaced the *Zīj-i Ulugh Bég*. The earliest extant manuscript copy to date is in Tashkent and is scribed by Ḥuḍūr Ilāhī Kāshmīrī, dated 1775.

Sawai Jai Singh mentioned in one chapter of ZMS that he had a telescope constructed in his kingdom and used it for observing the crescent of Venus, satellites of Jupiter, rings of Saturn, and sunspots. Ansari (1985a) has discussed the diagrams of these observations, which appear on the margin of a couple of manuscripts of ZMS. However for want of micrometer and cross-wire attachments, he could not use them as devices for accurate measurements (Ansari, 1985b, pp. 364–369).

According to a number of Persian sources, Mirzā Khayrullāh Khān (d. 1747), director of Jai Singh's observatory at Delhi, was the actual compiler of ZMS, who was supervised by Jai Singh. Muḥammad 'Alī s/o Khayrullāh Khān, who scribed a copy of ZMS (Ms. 2144, fol. 105A, in the National Library, Tehran), confirmed his father's authorship of ZMS. Another evidence is from Iranian commentator, Muḥammad 'Alī alias Mubashshir Khān, who came to India to study under Khayrullāh Khān the text of ZMS and its method of calculations. His commentary on ZMS is extant in the National Library, Tehran (Ms. No. 6447, scribed in 1884). See details in Ansari (2007/2014).

Zīj-i Bahādurkhānī (ZBK_h)

This Zīj in Persian was composed in 1838 by Abul Qāsim alias Ghulām Ḥusain Jaunpūrī, on the order of the Rāja Khān Bahādur Khān, the raja of Tikārī (in south of Bihar), to whom it was dedicated. This Zīj was written in India between 1855 and 1858 and lithographed at the Cadre (*Kādar*) Press, Banaras (modern Varanasi). The printed copy is extant in the Salar Jung Museum Library (Hyderabad). It consists of 906 pages of about quarto size. A good copy of *Zīj-i Bahādurkhānī* is also extant in the Andhra Pradesh Oriental Manuscripts Library (Hyderabad). A recent facsimile reprint of ZBK_h was published in 2009 by Islamic Azad University (*Dānishgāh-i Āzād Islāmī*), Tehran, with a preface by Farid Ghassemlou. ZBK_h is actually a reworking of ZMS based on Ghulām Ḥusain's own observations, in which especially the new elements of European astronomical knowledge were included and explained.

Zij-i Sa'īdī by Muḥammad Amīn (ZS)

The author Muḥammad Amīn Mas'ūdī bin Muḥammad Nasīm al-Ḥanafī with the *nom de plume* Kāshī came from the Indian city of Bareilly. To date only this much is known about him. The Zij is dedicated presumably to his patron Sa'īd. A unique copy of this Zij is extant in the Wellcome Library (London), scribed in AH 1244/AD 1828 (at colophon fol. 51b), with author's name as Muḥammad Amīn Mas'ūdī. However, his full name on fol. 1a, line 7-8, is as mentioned above but without Amīn. The manuscript was discovered by van Dalen (2007a, p. 150). I thank him for a copy of this manuscript.

ZS consists of an introduction with three discourses (*maqāla*) and an epilogue. In the section on the calendar, he treats Hijri, Yazdigird, Jalālī, Byzantine (*Rūmī*), the Chinese (*Khaṭā*), and Turkish eras. Muḥammad Amīn has drawn actually on *Zij-i Ulugh Bég*, which is his basic source even for the calculation of ephemerides of the Sun, Moon, planets, etc. His sections are quite short. While calculating the position of the constellation Cassiopeia, he mentions using ZMS and the year 737 Jalālī/AD 1815 (fol. 26a). His source for the astrological material is Ptolemy, Māshā'allāh (d. ca. 815), and Ya'qūb al-Kindī (d. 870) (fol. 48a). The section on gazetteer (ff. 17–18) contains entries of 311 localities, out of which 70 are Indian cities and interestingly the last entry is London.

Zij-i Mazhari (ZM)

The author is Mazharuddīn Muḥammad Qārī bin Bahā'uddīn 'Alī (sixteenth century) Shīrāzī. The manuscript of this Zij belonged to the Urdu Promotion Board (*Anjuman Taraqqi-i Urdu*), Karachi. It was originally in the collection of Mawlawī 'Abdul Ḥaq (Hyderabad), who presented it to the Urdu Promotion Board. It is now in the National Museum (Karachi). Monzavi (Cat. Ms. No. 493, pp. 278–279) has given some historical information about the author. However, this is the first time that the contents are being described here. I thank Mr. Rashid Ashraf (Karachi) for procuring for me the copy of this unique manuscript. It is dated AH 987/AD 1579 (fly leaf/f. 1a). It has 33 ff. The first two pages are missing, since

the manuscript begins abruptly with the sixth section (*faṣl*) of the contents. Altogether there are 12 sections (*faṣl*). The last is on fixed stars, which is not present in this manuscript.

The first part of ZM is on usual astronomical calculations according to *Zij-i Ulugh Bég* (mentioned specifically on f. 4b), as an aid to the second part on astrology which is concerned with determining various astrological parameters. The epilogue (*khātma*) begins with the “invisible and inauspicious [actually pseudo-planet] *Kaid* (f. 32a) and calculation of its ephemerides in the year 929 Yazdigird/AD 1560” (f. 33a), determination of planetary exaltation (*sharaf*), and dejection or depression (*hubūf*). Our author's source for this part is mainly Ptolemy's *Tetrabiblos*. Some examples to illustrate the rules are dated 1558, 1560, and 1565. I thank Mr. Rashid Ashraf (Karachi) to arrange for me a copy of this unique manuscript.

Astrolabe Makers in India

In the Sultanate period, Sultan Fīrūz Shāh Tughlaq (r. 1351–1388) was famous as an expert on astrolabes. Astrolabes used for both Northern and Southern celestial hemispheres are attributed to him. Fīrūz Shāh possessed five astrolabes constructed under his guidance. They were one each in brass and silver, in gold and silver, in brass only, and two in silver. A large Northern-Southern astrolabe in gold and silver was named *Asturlāb-i Fīrūz Shāhī*, which was completed by AH 771/AD 1370–1371. In the text of *Sīrat-i Fīrūz Shāhī*, positions of constellations for the period 1370–1520 equivalent to 136 lunar years are also tabulated. This table was engraved on the back of Fīrūz's astrolabe. Moreover, the coordinates of 18 fixed stars are marked on the *rete* corresponding to 11 March 1370 (Sarma, 1998, pp. 9–10). However, Fīrūz Shāh's most significant achievement was actually “the dissemination of the science of astrolabe in India among the Jains and Hindus” (Sarma, 1998, p. 12). The Sultan's court astronomer, the Jaina scholar Mahendra Sūrī, composed the first ever treatise on the astrolabe in Sanskrit: *Yantrarāja* (the King

Astronomy in Medieval India, Table 1 Astrolabes by Alāhadād's descendants

Number of specimens	Astrolabe maker	(Period of activity)	Current location	Year of manufacture
3	Mullā 'Īsā s/o Alāhadād		Two in Chicago; one in Cambridge (UK)	1601, 1604
6	Qā'im Muḥammad s/o 'Īsā		Calcutta	1624
			Patna	1626
			Baghdad	1631
			Oxford	1634
32	Diyā'uddīn s/o Qā'im	(1645–1680)	In India: two formerly in Aligarh	1653, 1663
			Hyderabad, Patna	
			Three in Jaipur observatory	
37	Muḥammad Muqīm, s/o 'Īsā	(fl. 1609–1659)	In India: two in Delhi	1624
			Calcutta, Hyderabad. In Pakistan: Lahore, Karachi	1637
12	Hāmid s/o Muqīm	(1628–1691)	One in Hyderabad	1658
			One in Allahabad	1677
5	Jamāluddīn s/o Muqīm	(1666–1691)	None in India	

Note: The specimens are mostly in museums. Sarma (formerly at Aligarh Muslim University and now in Düsseldorf) is compiling a worldwide *Catalogue of Astrolabes made in India* by (see “Ghulam Hussain Jaunpūrī”) Indian astrolabe makers. I thank him for putting at my disposal his data before his monumental publication

of Instruments) written about 1370. The importance of this text is indicated by the fact that there are extant 100 manuscript copies (Ohashi, 1997, p. 211 et seq. and Sarma, 1999, 2000).

Lahore School of Astrolabe Makers

The founder of the Lahore school of astrolabe makers was the famous Ustād Alāhadād Aṣṭurlābī Humāyūnī (flourished ca. 1567) who had been invited to Lahore by Mughal Emperor Humāyūn; the emperor was himself an expert on the astrolabe; main reference to this section is Sarma (1994) and Ansari (2011). One of Alāhadād's two surviving astrolabes is in Salar Jung Museum (Hyderabad) dated 1567 with a diameter of the *mater* (main body) of 199 mm, containing five latitude plates (tympan) and with a gazetteer (geographical coordinates) of 96 cities. The second astrolabe is extant in the Museum of History of Science (Oxford). It is not dated, and its diameter is 256 mm with six disks and a gazetteer of 157 cities. In the following, I tabulate the work of the descendants of Alāhadād.

According to S. R. Sarma (*personal communication*, dated 11 May 2010), “there are extant nearly 120 astrolabes signed by the various

members of the Lahore family, and several more which are not signed but can be attributed to the family on stylistic grounds.” The Lahore school of Alāhadād also made celestial globes; 23 are extant today (Sarma, 1994, p. 219). For astrolabes with Sanskrit legends made in medieval India, cf. Sarma (1999) and Ansari (2011) (Table 1).

Conclusion

My effort has been to delineate the efforts of promoting in Medieval India the Islamic astronomy as developed in the Middle East and Central Asia. The practical astronomy – compiling Zīj, establishing observatories and a school of astrolabe makers – developed because the individual astronomers and madrasas were patronized by sultans, emperors, local rulers, and nobles. Even modern European astronomy of the eighteenth to nineteenth century was well received; cf. Ansari (2002) in which a few sources in Persian have been discussed. The political upheaval due to the colonization of India by European powers during the eighteenth to nineteenth centuries led to the

withdrawal of patronization, marginalizing the madrasas, the institutions of higher education, which were the lifeline for the development of mathematics and astronomy, thereby smothering the scientific renaissance initiated by Raja Sawa'i Jai Singh in the eighteenth century. The compulsory replacement of Arabic and Persian by English as medium of instructions cut off the continuity of India's education and scientific development during the Raj. Thanks to independence, that situation was reversed. Modern India is now playing its role in the world to develop astronomy and space science quite actively.

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Astronomy in Mesoamerica

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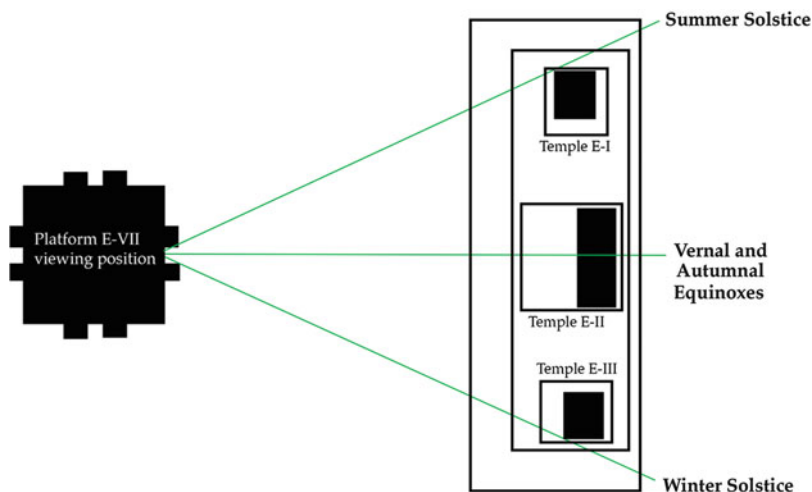
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Astronomy in Mesoamerica developed in apparent isolation from the cultural traditions outside of the Americas and its unique advancement provides an important comparison with parallel developments of astronomical science elsewhere in the world. Containing hundreds of distinct ethnic groups and indigenous languages, the Mesoamerican culture area extends south from central Mexico into Belize, Guatemala, Honduras, El Salvador, and Nicaragua. While highly diverse, many of the cultures and language groups in this region share innovations such as intensive maize agriculture, stratified urban development, megalithic architecture, and an elaborate calendrical system consisting of a unique, repeating cycle of 260 days and a cycle of 365 days that estimates the length of the year. Together, these cycles combine to form the 52-year Calendar Round, historically shared by more than 50 linguistic groups in Mesoamerica.

It is clear that the development of writing in Mesoamerica was deeply interwoven with calendrical and astronomical observations that were

Astronomy in Mesoamerica,

Fig. 1 Uaxactun E-Group, ideally commemorating rising azimuth positions of the solstices, and the equinoxes (Drawing by author)



themselves inseparable from religious, divinatory, and political interests. Having persisted for perhaps 2,000 years, much of this intellectual legacy did not survive the initial invasion of the Spanish and the subsequent decimation of indigenous populations as a result of violence, disease, and centuries of political and religious persecution. Indigenous writing systems were effectively extinguished, and many written records did not survive. However, recognizable astronomical traditions have endured in many communities.

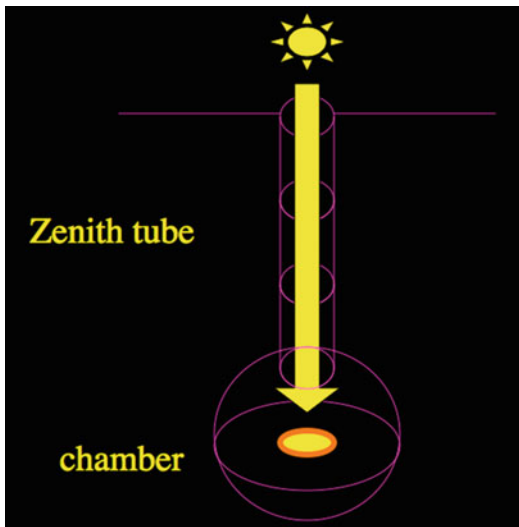
What is currently known about Mesoamerican astronomy has been reconstructed from architectural alignments, surviving written texts, and the persistence of astronomical and calendrical knowledge among contemporary indigenous groups. While it remains difficult to reconstruct and reinterpret the full extent of Mesoamerican astronomy from fragmentary sources, the existence of explicit written sources as well as implied astronomical alignments and ethnographic evidence has led to a more solid consensus among researchers, while there still remain specific areas of controversy.

It is generally agreed that Mesoamerican architectural alignments commemorate repeating celestial observations of horizon-based azimuth positions. Most obvious and familiar among these are those that suggest references to the rising and setting positions of the sun on the solstices and equinoxes. Multiple so-called “E-Group” building configurations in the Maya lowlands, such as

those first identified in Uaxactun (Fig. 1), generally commemorate solstitial alignments, though the actual precision of these alignments is questionable and they may have served additional astronomical, calendrical, and ritual functions (Aimers & Rice, 2006). While the equinoctial alignments of E-Groups appear to be much less certain, a functional east-west sight line does appear at the northern Maya site of Dzibilchaltun.

Unique to the tropics, the phenomenon of the two solar zenith passages appears to have provided Mesoamericans with a precise means to calculate the length of the tropical year and to predict the seasonal rains that follow the zeniths through the migrating intertropical convergence zone. The early ethnographic record demonstrates that the observation of the solar zenith was widespread in Mesoamerica, and these days were attended with religious celebrations that were a concern to the Spanish crown (Aveni, 2001, p. 42). Contemporary Ch’orti farmers continue to predict the solar zeniths through observing the rising and setting azimuths of the sun on the 2 days when the sun reaches the zenith, and these positions actually replace the cardinal directions of east and west. According to anthropologist Raphael Girard, the Ch’orti also observe the relative positions of the Pleiades, Orion’s belt, and the Southern Cross in order to predict the occurrence of the two zeniths.

At different latitudes in the tropics, the two solar zeniths occur on different dates separated by



Astronomy in Mesoamerica, Fig. 2 Idealized zenith tube, commemorating the two solar zenith passages (Drawing by author)

variable intervals that are equidistant from the solstices. Several scholars, including Zelia Nuttall, Vincent Malmström, and Raphael Girard, have suggested that the unusual 260-day calendar found only in Mesoamerica arose in Preclassic sites to commemorate the long interval between the two zenith passages at 14.8° North latitude, namely, on August 12–13 and on April 30 to May 1. If so, it then would have spread northward throughout Mesoamerica into latitudes where the two zeniths would be at very different intervals. This astronomical explanation differs from the more widely held indigenous belief that the interval arose as a means to calculate the length of human gestation. Nevertheless, these proposals may not be mutually exclusive.

Vertical tubes that would be useful for observing solar zeniths are evident in several sites throughout Mesoamerica, including Monte Alban, Xochicalco, and Chichen Itza. These consist of subterranean chambers located beneath vertical tubes that connect to a narrow oculus (Fig. 2). At the moment of the solar zeniths, dramatic beams of light shine vertically through the oculus and into the chamber below. Though none of the surviving zenith tubes are located at 14.8° N, another similar structure in Teotihuacan with a wider oculus

appears to commemorate not the local zeniths but the fixed cycle of 260 days between August 13 and May 1. In fact, as Malmström points out, the entire layout of the city of Teotihuacan, including the Temple of the Sun, is oriented toward sunset on August 13 and May 1, again implicating this fixed cycle, and we find similar architectural alignments and hierophanies to this fixed cycle throughout Mesoamerica.

The zenith tube located in Building P in Monte Alban is curiously associated with a direct line of sight to Building J (Fig. 3), an arrow-shaped building that is offset from the layout of the city. While some have proposed that the back side of the arrow intended to align with the rising of Capella in association with the zenith in the second century BC, the arrow actually points quite precisely to the base of the Milky Way in the southwest when it reached its vertical position at dawn at the time of the May zenith in the Preclassic. As such, this recognition of the vertical Milky Way parallels known contemporary observations among the Ch'orti and Tzotzil.

We also learn from Girard that the Ch'orti commemorate the solar nadir or anti-zenith in February, while Barbara Tedlock reports that K'iche' astronomers determine that the solar nadirs correspond to the time of year when the full moon reaches the zenith. The Ch'orti, who live precisely in the zone where the two zeniths are 260 days apart, do maintain a fixed cycle of 260 days that follows the agricultural year, though this begins on the February solar nadir and ends on the solar nadir in late October. Similarly, in a survey of 23 Late Preclassic and Classic structures in Campeche, Mexico, Ivan Sprajc (2009) has determined consistent alignments to sunrise on February 12 and October 30 that clearly delimit the agricultural year at multiple latitudes.

As Alonso Mendez, Edwin Barnhart, Christopher Powell, and Carol Karasik demonstrate, the Temple of the Sun in Palenque contains multiple alignments to hierophanies on the solar nadirs, the solar zeniths, and the summer solstice. Architectural alignments to local zeniths and nadirs are likewise evident in both the Caracol (Fig. 4) and the Castillo (Fig. 5) at Chichen Itza. While popular interpretations of the hierophany of the



A

Astronomy in Mesoamerica, Fig. 3 Arrow-shaped Building J in Monte Albán, Oaxaca. Dramatically offset from site layout. “Monte Albán archeological site, Oaxaca.” Licensed under Creative Commons

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Astronomy in Mesoamerica, Fig. 4 Caracol at Chichen Itza (Photograph by author)



shadow of the descending feathered serpents on the Castillo have assumed that this structure intended to commemorate the equinoxes, Susan Milbrath (1988) demonstrates that the east-west axis is more precisely aligned to the local zenith passages and solar nadirs. At the same time, the vertically descending serpents with their rattles pointing toward the zenith (Fig. 6) immediately recall the Pleiades, known to contemporary Yucatec observers as *tzab*, a rattlesnake’s rattle. The Pleiades crossed the zenith at the latitude of

Chichen Itza at the time of the construction of the Castillo, and it would have been heliacally rising at the time of the local zenith in late May, which announced the arrival of the rains. Indeed, contemporary Maya farmers continue to use the disappearance and reappearance of the Pleiades to time the planting of maize. In its descent, the feathered serpent of the Castillo evokes similar diving gods, which Nuttall believes to be representative of both the zenith and the time of planting.

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Fig. 5 Castillo at Chichen Itza, showing serpents descending on either side of the stairway (Photograph by author)



Astronomy in Mesoamerica, Fig. 6 Rattle of descending serpent pointing toward zenith, Temple of the Jaguars, Chichen Itza (Photograph by author)

The Caracol in Chichen Itza was constructed in the shape of a round turret, and buildings like this are known to be associated with Ehecatl-Quetzalcoatl, an Avatar of Venus. Along with its alignment to zeniths, the Caracol shows significant alignments with the northern and

southern extremes of Venus, and similar Venus alignments have been proposed for Temple 22 in Copán (Closs, Aveni, & Crowley 1984). As Sprajc demonstrates, the House of the Governor at Uxmal contains numerous iconographic references to Venus, while it also aligns to the setting positions of Venus at its northerly extreme. While not a yearly phenomenon, this northerly extreme would correspond with the onset of the rainy season, and the symbolic association between Venus and fertility is evident.

Unfortunately, without clear associations to text references, the intentionality of architectural alignments is difficult to verify. Therefore, astronomical references in the written record are particularly significant, and these are most explicit in Maya hieroglyphic records. Recognizable Venus glyphs appear in the Preclassic Maya site of San Bartolo in iconographic association with named deities (Fig. 7), while two important text references to Venus appear in the early La Mojarra Stela, a non-Maya monument written in the Isthmian script and dated to the second century AD (Kaufman & Justeson, 2001).

Surprisingly few hieroglyphic text references to Venus appear in the Classic period inscriptions. Copán Temple 11 records a Venus event similar to those found in the Postclassic Dresden Codex Venus Table, while multiple scholars have proposed that various other historical dates intended to commemorate the appearances of Venus at various points in its cycle, among



Astronomy in Mesoamerica, Fig. 7 San Bartolo Mural, showing Venus glyph in *upper left*, second from last, along with Venus deity in bloodletting scene. Photograph licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons – <http://commons.wikimedia.org/wiki/File:SBmural.jpg#mediaviewer/File:SBmural.jpg>

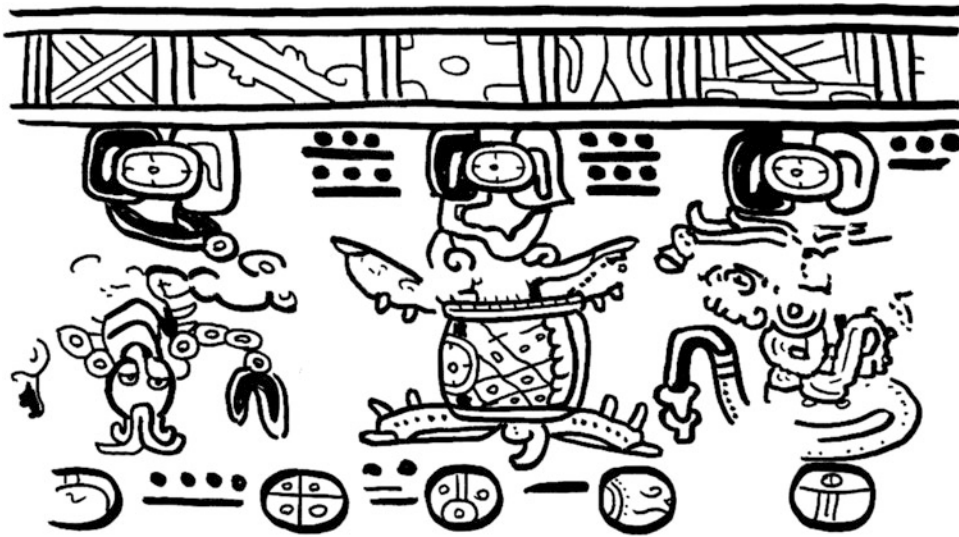
other astronomical rationales. Such arguments were quite popular in the earlier days of the decipherment, since the emphasis on astronomical interpretations was popularized by their prevalence in the few extant Maya hieroglyphic codices, the calendrical and astronomical significance of which was deciphered long before the historical content of the inscriptions was recognized. As a reaction to this overemphasis on astronomy, subsequent historical interpretations have often chosen to overlook problematic astronomical references.

There are only four surviving Maya screenfold books, all of which contain astronomical information, including widely acknowledged references to constellations, lunar synodic cycles, eclipses, and planetary cycles. The Paris Codex

contains an apparent “zodiac” of 13 distinct constellations shown in association with eclipse glyphs, including a scorpion that is curiously in the same position as Scorpius (Fig. 8). However, it is debated whether these figures represent a true zodiac, given that a turtle constellation may represent Orion, which is south of the ecliptic. The Dresden Codex contains the most extensive astronomical information, including a Venus Table (Fig. 9) consisting of a canonical 584-day synodic cycle divided into 5 cycles of 584 days, equivalent to 8 cycles of the 365-day year, effectively returning the heliacal rise of Venus to the same time of year. This table is recycled for 104 years, which then commensurates with the 260-day cycle, and calendrical data associated with the table demonstrate that additional corrections would enable variously proposed calculations of the heliacal rise of Venus over much longer periods of time. Various other tables in the Dresden Codex suggest other planetary cycles. Tables of 780 days in the Dresden Codex suggest the synodic cycle of Mars, while Anthony Aveni and Harvey and Victoria Bricker have proposed that another table in the Dresden Codex was used to calculate the sidereal cycle of Mars.

We find similar Venus almanacs in the codices from Central Mexico, such as those from the Borgia group, though none quite as explicit as that found in the Dresden Codex. Nevertheless, several scholars, including Victoria Bricker and Susan Milbrath, have variously attempted to correlate the tables and the imagery in the Borgia Codex with specific astronomical events, such as historical eclipses, appearances of Venus, and seasonal configurations of stars. While it is difficult to verify the astronomical intention of these narrative scenes without explicit dates, we do find such unambiguous dates in association with Maya inscriptions. However, even fixing these more explicit dates in time remains somewhat problematic and controversial, let alone interpreting the intent of their associated inscriptions.

In addition to the Calendar Round found throughout Mesoamerica, a chronological system known as the Long Count first appeared in the



Astronomy in Mesoamerica, Fig. 8 The Paris Codex “Zodiac.” Scorpion at the *left*; turtle in the *center*; rattlesnake at the *right*. Each devours (or stings) the glyph for a

solar eclipse beneath a Sky Band, representing the ecliptic (Drawing by author after FAMSI photograph)

Preclassic and spread throughout the Maya area where it was ubiquitously used on monuments throughout the Classic period. This largely vigesimal positional system functioned as a precise count of days and 360-day periods reckoned from a back-calculated base date over 3,000 years prior to the first evidence of the use of this system. In this respect, the Long Count resembles the Julian Day Number (JDN) system used by contemporary astronomers to count the number of days elapsed from January 1, 4713 BC. As such, the Long Count was extremely useful as a means by which to calculate and record astronomical observations over long periods of time.

Long Count dates are typically given together with the 260-day cycle as well as the 365-day cycle (Fig. 10), and these interwoven cycles were remarkably continuous and unadjusted, though some examples of slightly offset Calendar Rounds do occur. However, it is more difficult to assess whether the Long Count itself was ever corrected or shifted from its original count, and many scholars have assumed that it remained unbroken. Various attempts to correlate the Long Count with the Julian and Gregorian calendars have often used assumed astronomical references to support their correlations, yet these

approaches have proven to be problematic if only one their assumptions is incorrect.

Utilizing several ethnohistorical references to Calendar Round and K’atun positions – along with contemporary and historical 260-day counts maintained by living Maya calendar keepers – John Goodman, Juan Martínez Hernández, and Eric Thompson provided the original proposals which have resulted in the two most widely used correlations that match the Era base date of the Long Count with two different Julian Day Numbers (584283 and 584285). These are collectively known as the GMT correlation constants, and there is still disagreement among scholars regarding which is more accurate, though astronomical data strongly supports both. Given some of the unresolved discrepancies, some scholars maintain that neither correlation is correct, calling into question any proposed astronomical references that result from these correlations.

Goodman first noted that the Long Count Initial Series dates are often given together with what he named the Supplementary Series, and John Teeple first demonstrated that Glyphs D and E of this series record the age of the moon as measured from various points near the



Astronomy in Mesoamerica, Fig. 9 Dresden Codex Venus Table. Dresden Codex, page 49. Photograph Licensed under Public domain via Wikimedia Commons – http://commons.wikimedia.org/wiki/File:Dresden_codex,_page_2.jpg#mediaviewer/File:Dresden_codex,_page_2.jpg

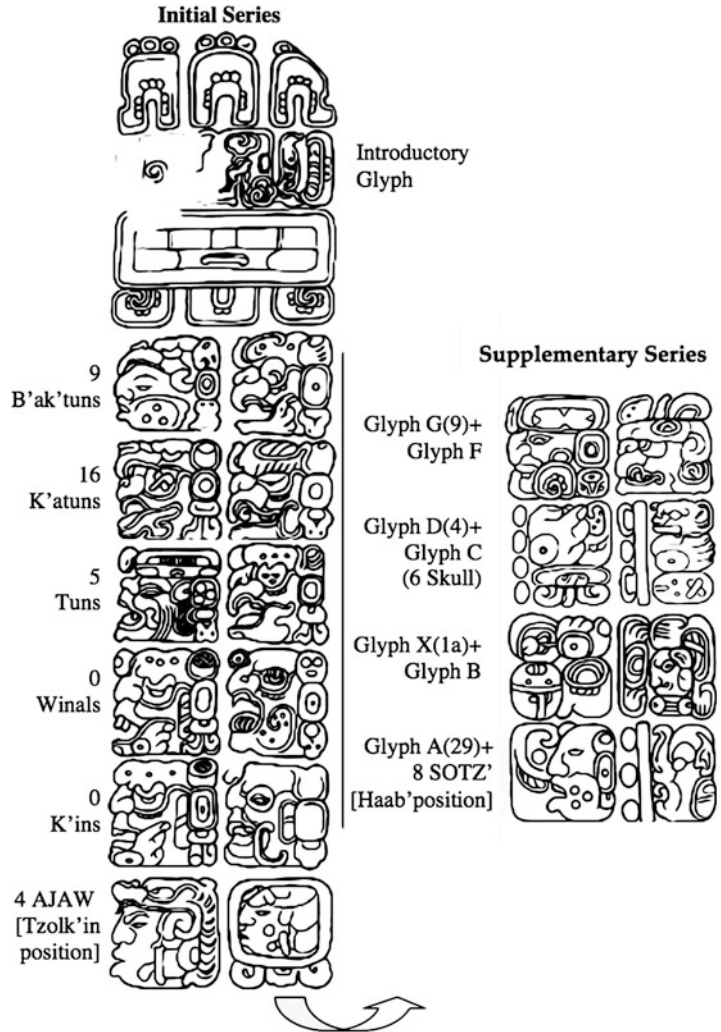
new moon, while Glyph A designates a lunar month of either 29 or 30 days in length – the alternation of which closely corresponds with the true synodic lunar month of 29.53059 days. As a whole, lunar data from the Supplementary Series strongly supports *both* of the GMT correlations while it does not appear to favor either

one, since it is unclear exactly on which day Maya observers were recording the first day of the new moon. Significantly, the lunar data from the Classic period inscriptions is consistent with that from the Lunar Table found in the Dresden Codex, and one run of this table corresponds with 11,960 days, which is equivalent to 46 cycles of 260 days and 46 synodic lunar months of 29.5308642 days. Teeple found that this exact same value for the synodic lunar cycle was used in Classic period Palenque to back-calculate lunar data for precise mythological dates found in the Cross Group. Indeed, a recently discovered series of painted texts from a wall in Xultun provides clear evidence for an earlier precedent for the Dresden Lunar Table in the Classic period.

The Dresden Lunar Table also significantly includes important eclipse data that closely corresponds with the eclipse year when using either of the two GMT correlation constants, and Harvey and Victoria Bricker (1983) have shown that the table could be used to determine repeating eclipse “warning stations,” whether or not actual historical eclipses were visible. Surprisingly, overt references to eclipses are extremely rare throughout the Classic period inscriptions, with the exception of one recognizable reference on Poco Uinic Stela 3. First noticed by Teeple, this reference shows a solar eclipse glyph similar to those found in the codices, and it is associated with the Long Count date 9.17.19.13.16. A near total eclipse is known to have occurred just after noon at Poco Uinic on JDN 2009802, which corresponds with July 16, 790 AD. Therefore, Simon Martin and Joel Skidmore (2012) conclude that the correct correlation should place the Era base on JDN 584286, one day forward from one of the GMT correlations. However, Vincent Malmström (1999) maintains that the 584285 GMT correlation can be reconciled with the Poco Uinic eclipse, given that the Maya day began and ended at sunset. Therefore, the Long Count may actually overlap two Julian days, which begin and end at noon Greenwich Mean Time or sunrise in the Maya area. The Poco Uinic eclipse lends some support to the 584285 GMT correlation, while it would not support the competing 584283 correlation. Given that the

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Fig. 10 Maya Initial Series from Quirigua Stela J. Long Count, 260-day Tzolk'in and 365-day Haab, along with Supplementary Series, showing lunar information (Drawing after Matthew Looper in Grofe (2011a))



260-day count preserved by the Highland Maya supports the latter, it is apparent that a shift of the 260-day cycle may have occurred at some time in the Postclassic, after the Long Count fell out of use.

Establishing the validity of the Long Count correlation holds great promise in that it provides the ability to observe specific, historical astronomical patterns and potential intentions in association with hieroglyphic texts and architectural alignments. Given that the 584285 GMT correlation places the Era base of the Long Count on August 13, 3114 BC Gregorian (September 8, Julian), both Robert Merrill and Vincent Malmström proposed that the Long Count Era

base corresponds to the August 13 zenith passage at 14.8° N latitude where the two zeniths are precisely 260 days apart. Such a precise correspondence not only implies an intentional and highly accurate calculation of the tropical year but also suggests the means by which such a calculation could have been performed using the solar zenith. If the originators of the Long Count did in fact make such a calculation, it would follow that, at the time of the earliest attested Long Count date from Chiapa de Corzo in 36 BC, Mesoamericans had already achieved a measurement of the tropical year that was unsurpassed until Johannes Kepler in 1627. For some, such a bold assertion may be difficult to

accept without additional supporting evidence. Therefore, it is all the more important to investigate this question further with a great deal of scrutiny.

Based on evidence from Copán Stela A, Teeple deduced that the drift of the 365-day Haab from alignment with the tropical year would have provided for a highly accurate tropical year of 365.2419355 days, derived from the equation of $1,403,990 \text{ days} = 3,844 \text{ tropical years}$ and slightly more accurate than the Gregorian year of 365.2425 days. Using this so-called determinant theory, Teeple and Thompson identified various values for the tropical year in different sites at different times. However, this theory lost favor when it was later determined that the dates used refer to historical events in the lives of Maya rulers. Nevertheless, the intentional association of such historical events with astronomical underpinnings should not be overlooked.

Indeed, Maya inscriptions in the Classic and Postclassic contain many long-distance numbers that link specific historical events with contrived, back-calculated mythological events that suggest astronomical measurements. Several of these dates imply tropical year calculations that apparently targeted the canonical February nadir at 14.8° N . This is visible in the base date for the Dresden Venus Table, Copán Stela C, the Palenque Temple of the Foliated Cross, and Naranjo Altar 1. In addition, historical commemoration of both actual and canonical February nadirs is apparent in multiple inscriptions, particularly as a common date for the accession of kings in Copán, Tortuguero, and Naranjo (Grofe, 2011b).

Analysis of the back-calculated February 8, 310 BC canonical nadir from Naranjo Altar 1 also reveals that it would have placed the sun at a lunar node during the heliacal rise of Venus and in precisely the same sidereal position in which it historically appeared 304,263 days later, the interval given by the distance number. This suggests that Maya astronomers were able to calculate the sidereal year, since 304,624 days is very nearly a whole multiple of 834 sidereal years. The value for the sidereal year here results in 365.2553957 days, while the actual current

value is 365.25636 days. Evidence for this kind of sidereal year calculation has also been proposed within the immense distance numbers from the Serpent Series in the Dresden Codex that exceed 15,000 and 30,000 years. Similar calculations are apparent in Copán Stela J, Tortuguero Monument 6, and in the Palenque Temple of the Inscriptions and Temple of the Cross (Grofe, 2007, 2011b). Like proposed measurements of the tropical year, these proposals remain controversial, and it is not entirely clear from the evidence whether these measurements of the sidereal year were distinguished from the measurement of the tropical year. Certainly, making such a distinction would indicate that Maya astronomers were well aware of the precession of the equinoxes, a proposal that finds some support in the 3–11 Pik title (Grofe, 2003, 2011a; MacLeod, 2008). Given to Maya kings who have reached an advanced age, the 3–11 Pik title represents a 33 Bak'tun cycle, or 13,200 cycles of 360 days, approximating one-half of a precessional cycle of some 26,000 years. A bone from Burial 116 in Tikal indicates that this count began on the Era base, while an inscription from the Caracol in Chichen Itza suggests that another cycle was completed on the Era base. Together, these two cycles comprise a full cycle of precession. Additionally, a smaller interpretation of the same Calendar Round reached by this larger interval is equivalent to 25,980 days, approximating 1 day of precessional drift between the sidereal year and tropical year.

Further analyses of numerous distance numbers from the Maya hieroglyphic inscriptions and codices promise to either reveal or refute the intentionality of proposed astronomical calculations and patterns and the potential significance of their associated texts. A more complete, interdisciplinary understanding of the capabilities of Mesoamerican astronomers likewise requires a more fully developed exploration of the religious and political motivations of these observations and the persistence of astronomical knowledge that has endured as a living tradition. The unique features of Mesoamerican astronomy necessitate that scholars be aware of the tendency to incorrectly attribute their own motivations to peoples

quite different from themselves. While remaining rigorously skeptical and open to what the evidence does or does not reveal, it is equally important and enlivening to recognize our shared humanity and the structural similarities that are evident in the historical development of widely separated astronomical traditions.

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Astronomy in Native North America

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Introduction

The astronomical activities and traditions of the American Indians north of Mexico were based upon practical observation of the sky but were not supported by a written language. For that reason, our knowledge of North American Indian astronomy relies upon the archaeological data, ethno-historic reports from early encounters between Europeans and the indigenous peoples, and ethnographic information collected more recently by anthropologists. Although this material is distorted and incomplete, it enables us to outline the general character of North American Indian

astronomy and to understand some of it in detail. All of these sources confirm that North American Indians farmed, hunted, and gathered by the sky. They developed calendric techniques to order the sacred and ordinary dimensions of their lives. They timed ceremonies by the sky. They extracted symbols from the sky. They told stories about the sky. Throughout all of the cultural territories, physical environments, and linguistic traditions of North America, celestial phenomena were incorporated into ritual, iconography, myth, shamanic activity, and worldview (Krupp 1978, 1983, 1984, 1991, 1996).

North American Indians were familiar, of course, with the fundamental cycle of day and night, the daytime path of the sun, and the unmoving pole of the night sky. Cardinal directions, which emerge from the daily rotation of the sky and the circular parade in which the stars march at night, were important to many groups. The moon's phases were monitored, and each monthly cycle was often associated with a seasonal change on earth. The seasonal shift of sunrise, sunset, and the sun's daily path was known. Solstices were recognized, and the rising and setting points of the summer and winter solstice sun sometimes established an alternate directional scheme. Seasonal appearances and disappearances of stars were noted. Constellations were contrived from conspicuous and useful stars. In the historic era, unusual events like eclipses, bright comets, fireballs, and meteor showers attracted notice and sometimes provoked ritual response. Planets were recognized by at least some groups, but explicit evidence of detailed indigenous knowledge of their cyclical behavior has not survived (Williamson 1984).

Like traditional peoples everywhere, the Indians of North America saw the sky as a realm of power. Access to that power required knowledge of the sky. They acquired that knowledge through careful observation and used that knowledge to order and stabilize their lives. This practical understanding of the sky – the sun, the moon, and the stars – is not the same thing as modern scientific astronomy, for it did not attempt to test and abandon metaphors of nature in the same way science does today. It did,

however, help integrate human behavior with nature and consolidate social cohesion. Celestial objects were not just convenient metronomes. They were powerful, supernatural beings, and they revealed the basic structure – the fundamental order of the world. Because cosmic order is, in part, what is meant by the sacred, the Indians' interaction with the sky was an encounter with the sacred.

Main Text

The earliest account of North American Indian astronomy was reported in 1524 by the Italian explorer Giovanni di ve Verrazzano (Wroth 1970). He encountered the Narragansett Indians of Rhode Island and mentioned that their seeding and cultivation of legumes were guided by the moon and the rising of the Pleiades (Ceci 1978). The Pleiades comprise a distinctive cluster of stars. Its value as a signal of seasonal change was recognized throughout the continent. In California, for example, there is explicit evidence of Pleiades lore in all but 12 of the 58 native cultural territories. Those 12 actually correspond to a very small fraction of the entire area and population of the state, and their lack of Pleiades tradition is primarily due to linguistic and cultural extinction. Despite the extraordinary linguistic diversity represented by the 75 mutually unintelligible California Indian languages and 300 different dialects, names for the Pleiades, myths about the Pleiades, and seasonal references to the Pleiades are documented in all five major families of indigenous California languages.

Studies of North American Indian astronomy have emphasized the prehistoric Southwest and the historic Pueblos (Malville & Putnam 1989). This is due to the survival of Ancestral Pueblo architectural monuments and rock art and to the preservation of some information about historic Pueblo astronomical techniques and celestial lore in ethnological reports. Close to the end of the last century, Stephen (1936) described in detail the horizon calendar used by the Hopi Sun Chief to establish key dates in the ceremonial and agricultural cycles of the village of Walpi. More

recently, historian of science McCluskey (1977) demonstrated that Hopi observations of the sun were accurate to 4 arcmin. This is, however, an average error, and it is difficult to do much better than 30 arcmin in any single horizon event. McCluskey verified that the Hopi actually allowed themselves a few days' leeway in scheduling the winter solstice ceremony.

If Stephen had not seen the Sun Chief perform his duties, we would not know where his sunwatching station was located. Nothing marks the point out at the end of a mesa or on the roof of the highest house. Other references to North American horizon observatories suggest that many were just as subtly blended into the community landscape, and that makes the identification of prehistoric observatories a challenge. Symbolic astronomy was, however, often incorporated into monumental architecture and rock art. By analyzing alignments and iconography, it is sometimes possible to spot the hand of the ancient skywatcher. For example, Pueblo Bonito, an 800-room, five-story, D-shaped apartment-town in Chaco Canyon, New Mexico, makes good use of passive solar heating to stabilize room temperatures in summer and winter. It was completed in the twelfth century AD, and its east–west front wall is oriented cardinally with an accuracy of 8 arcmin. Such accuracy is achievable with simple surveying techniques that rely upon the unaided eye, but it is nevertheless respectable. In addition, archaeologist Jonathan Reyman interpreted corner windows in two rooms as winter solstice sunrise apertures (Krupp 1978; Williamson 1984).

The Ancestral Pueblo built large subterranean community ceremonial chambers known as Great Kivas. Most of these, like Chaco Canyon's Casa Rinconada, possess cardinal orientation, and the plan of a Great Kiva is thought to mirror the Pueblo concept of the cosmos.

There are many pictographs and petroglyphs in Chaco Canyon, and the star and crescent on a panel near the Penasco Blanco ruin have been promoted by some as a representation of the AD 1054 Crab supernova explosion. Prehistoric Indians in the American Southwest very likely saw that spectacular event, but there is no way to

verify that the Penasco Blanco pictographs are an eyewitness record of it. The supernova interpretation of star/crescent elements in Southwest rock art was first offered in 1955 as an explanation for two sites in northern Arizona. Since then, the number of reported star/crescent groupings has multiplied, but opinion on the supernova is divided. Reyman argues thoughtfully that the Penasco Blanco site is actually a sunwatcher's shrine and implies that the Crab supernova has nothing to do with these star/crescent designs. Even if they do depict the supernova rising with the waning crescent moon on the morning of 5 July 1054, they tell us nothing substantive about Ancestral Pueblo astronomy. In 1990, Robbins and Westmoreland (1991) revived the argument all over again with an analysis of numerical symbolism on prehistoric Mimbres ceramics. One of these has a rabbit in the shape of a crescent moon accompanied by a "star" with 23 rays. This detail is argued to be consistent with the Chinese historical account of the Crab supernova, for the Chinese reported it was visible in the daytime for 23 days.

A spiral petroglyph on Fajada Butte, the most conspicuous landmark in Chaco Canyon, interacts with "daggers" of midday sunlight at the solstices and the equinoxes. These light-and-shadow effects, first reported by Sofaer et al. (1979), received a great deal of international attention and inspired considerable controversy. Initially, the "Anasazi Sun Dagger" was interpreted as a "precise solar marker," but it may be more correct to regard it as a symbolic seasonal display.

One of the best candidates for a sunwatcher's observing platform is also located in Chaco Canyon, on an upper ledge on a rincon (a square-cut recess or hollow in a cliff) near Wijiji ruin. Rock art on the ledge includes elements as old as the Ancestral Pueblo and as recent as the Navajo. A line-of-sight to the southeast coincides with a natural rock chimney on the other side of the rincon, and this feature dramatically marks the winter solstice sunrise.

Astronomer Zeilik has emphasized the importance of "anticipatory" observations of the solstices and other astronomical events (Zeilik 1985).

The Sun Chief must know ahead of time, with accuracy, when the solstice is due in order to mobilize the community for the ceremonial activity that culminates in the solstice. This is exactly what Walpi's Sun Chief did, and Wijiji has the ability to deliver advance information and confirmation of the solstice. The site is interpreted, then, by extending significant information from the historic period back into the prehistoric context.

Astronomical components have been identified at many other sites in the Southwest, including Hovenweep, Yellow Jacket, Chimney Rock, Casa Grande, and Mesa Verde (Malville 1991). Celestial rock art elements are present throughout the Southwest. Few of these involve accurate mapping of constellations, but several seem to invoke magical power attributed to the stars. Chamberlain (1989) has studied Navajo star ceilings in Canyon de Chelly and concluded that most of them are connected with symbolic protection or other celestial magic. Schaafsma (1990) interprets war and star imagery in the petroglyphs of New Mexico's Galisteo Basin as part of a tradition of Southern Tewa celestial war magic.

Nine years after astronomer Hawkins (1963) rekindled interest in ancient and prehistoric astronomy in 1963, with his studies of solar and lunar astronomical alignments in Stonehenge, another astronomer, Eddy (1984), identified celestial sightlines in the Bighorn Medicine Wheel, a North American antiquity *Time* magazine headlined as "Stonehenge USA." The Bighorn Medicine Wheel is located at an elevation of 9,600 ft, above the timberline on Wyoming's Medicine Mountain. It is a ring, 87 ft in diameter, drawn in small rocks. Originally, the Wheel had 27 or 28 spokes of stones that converged on the main cairn at the center. Five other cairns were constructed on the Wheel's rim, and the one spoke that extends beyond the rim ends in its own cairn. The ring is actually a flattened circle. Its axis of symmetry coincides with the spoke that reaches from the outside cairn, southwest of the rim, to the cairn at the center. Eddy demonstrated that this line also continues to the northeast horizon and the point of summer solstice sunrise.

He associated other lines between cairns with the sequential risings of three bright stars in the predawn sky in summer. Although the age of the Bighorn Medicine Wheel is uncertain, a radiocarbon date for a piece of wood retrieved from the central cairn associates it with the seventeenth century. Eddy thought that the Bighorn Medicine Wheel might have been used at that time by historic Plains Indians to make astronomical observations.

It seems likely, however, that the Bighorn Medicine Wheel is much older. It resembles other similar structures, especially in southern Canada, that are known to be thousands of years old. Who built the Bighorn Medicine Wheel and when it was built are still not known with certainty. There is reason to be skeptical about the practical value and validity of the stellar alignments, but the summer solstice sunrise line is congruent with the design. If the solstice alignment were part of the original plan, it may have had as much to do with vision quests and shamanic retreat as with calendric observation.

In the historic era, Plains Indians incorporated the sky into symbols and ritual. The well-known Sun Dance was intended to inspire prayer and visions through self-infliction of pain, fasting, and thirst. Gazing at the sun while suspended from a pole with ropes looped through the flesh of the chest was thought to purify and spiritually strengthen the participant. Although not all Plains tribes practiced this demanding regimen in the Sun Dance, acquisition of sacred power was a common theme. The enclosure in which the ceremony took place is called a Sun Dance Lodge, and it is sometimes built with 28 posts said to represent the days of the lunar month. Originally, the ritual was performed at the time of the summer full moon nearest to the time of the bison hunt.

Another Plains group, the Skidi band of the Pawnee, is known to have possessed a rich and detailed tradition of star lore. This knowledge has been reviewed and analyzed by Chamberlain (1982) in *When the Stars Came Down to Earth*. The Skidi Pawnee Morning Star sacrifice was timed by the movements of planets,

especially Mars and Venus, and mythologically, the planets were key players in the Skidi Pawnee Creation myth.

In Nebraska, the Omaha devised a symbol of social cohesion and tribal stability out of the Sacred Pole that was erected ceremonially at tribal gatherings. Omaha myth and ritual allow us to deduce that the Sacred Pole was oriented on the north celestial pole. Its power was linked to the stabilizing character of the hub of the sky.

It is a curious fact that so much public interest in ancient North American Indian astronomy has been directed toward the prehistoric Southwest and the Bighorn Medicine Wheel. Although these sites are valid targets of study, they belong to relatively unpopulated parts of the continent. Even the well-documented traditions of the Plains Sun Dance, the Skidi Pawnee Morning Star Sacrifice, and polar axis symbolism of the Omaha Sacred Pole must be considered marginal traditions of North America.

The mainstream, on the other hand, belongs to the most populated zones of North America. To understand, then, the true character of North American Indian astronomy, it is necessary to look at the Mississippi Valley and California. Nowhere north of Mesoamerica had a comparable population density.

Unfortunately, we know relatively little about the astronomical traditions of the ancient Mississippi Valley. In 1961, however, archaeologist Wittry (1973) excavated a feature he called the Sun Circle at Cahokia, a great population center and powerhouse of regional trade in central Illinois between AD 700 and 1200. Cahokia is best known for its large mounds, some of which supported temples and residences. Others hosted burials. Monks Mound, the largest prehistoric earthen construction in the world, is the centerpiece of what was the Chicago of the prehistoric Midwest.

Originally, the Sun Circle was a 410-foot-diameter ring of 48 tall posts (perhaps 30 ft high), with a pole in the middle of the circle but offset apparently intentionally 5 ft from the true center. Three of the posts that once occupied the holes that now remain combined with the center pole to deliver alignments to the rising sun at

summer solstice, winter solstice, and the equinoxes. Wittry believed that the Sun Circle's purpose was calendric. It is difficult to understand, however, why a complete ring of posts would be needed and why the posts were so tall. On the other hand, the intentional displacement of the central post makes the astronomical alignments possible.

Despite the ambiguity that persists with Cahokia's Sun Circle, archaeologist Fowler verified the ancient Cahokians' interest in cardinal directions. The city's limits were established by a particular type of earthen mound, and these mounds also defined the primary, and cardinal, axes of the site. In 1994, Fowler described another post circle on the main north-south axis of Cahokia. Its design, size, and astronomical potential mimic the Sun Circle.

The Incinerator Site, a smaller stockaded Mississippian village near Dayton, Ohio, included an arrangement of posts also thought to have astronomical meaning. The largest post, 2 ft in diameter, was located in a plaza, and it formed a line with a post inside a nearby building. This line pointed to the sunrise on April 24 and August 20. Both dates potentially have agricultural significance. The April date could mark the end of the frost and the beginning of planting. The August date is linked to the Green Corn Ritual, performed in the historic era when the corn filled the husk but was not yet ripe. Cardinaly oriented logs were kindled at this time into the New Fire, which also had solar associations.

European explorers encountered the descendants of the Mississippian mound builders in the southeast United States. The chief of the Natchez was known as the Great Sun. He claimed to be the brother of the sun and greeted the sun each morning, when it first appeared from the top of his residence mound. We also know the Natchez subdivided the daylight hours into four periods based upon the position of the sun. They measured the year in months based on the observed phases of the moon and named each lunation for an appropriate seasonal phenomenon.

In the Far West, before Columbus, California competed respectably with the Mississippi

Valley for the distinction of being the most populous and densely populated zone north of Mesoamerica. Some indigenous astronomical traditions persisted in California until quite late, and valuable information was collected by ethnographers, especially Harrington. The revival of interest in California Indian astronomy was largely initiated by Hudson and Underhay (1978), whose book, *Crystals in the Sky*, reconstructed the sky lore of southern California's Chumash Indians. Explicit references to horizon observations of the solstice sun and solstice rituals have been collected from the entire state. The moon's phases were counted, and the lunar months were named by most California groups. They recognized familiar patterns of stars, including the Big Dipper and the Belt of Orion. They named many other stars and used them as seasonal signals. They saw the Milky Way as a route to the sky followed by the souls of the deceased. Elaborate Milky Way ceremonialism is known among the Luiseño, who incorporated it into ritual initiation of the youth, mourning songs for the dead, sacred myth, and rock art.

California possesses many rock art sites and some of the most complex rock art in the world. Some of these sites have been associated with solstitial light-and-shadow events that interact with the rock art. Often, particularly at winter solstice, the light develops into a pointed, knife-like shape that pierces a carved or painted element. These effects appear to be symbolic, for they do not generally pinpoint the solstice with high accuracy. Rather, they "work" over a solstice "season" perhaps 2–4 weeks long. Although there is no explicit evidence that links solstice effects with California rock art, we do know the names of two Chumash shamans who went into the mountains at the time of winter solstice to paint on the rocks.

Conclusion

In detailed application, Native American astronomy was richly varied in North America, but its purpose and basic character were broadly the

same throughout the continent. For that reason, we can rely upon Francisco Patencio, Chief of the Palm Springs Indians of southern California, for words that could apply to nearly all Indians:

When the sun swung to the north and the moon showed quartered by day overhead, or west, they knew by the signs of the sun and the moon when the seeds of certain plants were ripe, and they got ready to go away and gather the harvest. Every plant that grew, the nesting time of all birds, the time of the young eagles, everything they learned by the signs of the sun and the moon. *Stories and Legends of the Palm Springs Indians* (Los Angeles: Times Mirror, 1943).

See Also

- ▶ [Medicine Wheels](#)
- ▶ [Time](#)
- ▶ [Time in Native North America](#)

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Astronomy in Sub-Saharan Africa

Keith Snedegar

At the turn of a new millennium the study of astronomical practices in precolonial African societies remains an open field. Major sources of evidence have yet to be fully scrutinized – astronomical texts in Arabic, Ge'ez, Hausa, Malagasy and Swahili, celestial

iconography in the African arts, and perhaps most importantly, astronomical knowledge encoded in the vast reservoir of oral tradition. It should be no surprise that Muusa Galaal's groundbreaking monograph on Somali ethnoastronomy derives wholly from oral literature (Galaal, 1992). As for the built environment, a few African architectural structures have been surveyed for astronomically meaningful features with interesting if not definitive results; further archaeoastronomical research would doubtless reveal more about the cosmologies behind African material culture. Nonetheless, scholars from various disciplines have already demonstrated that African time reckoning, divination systems, performance art and literature utilized the sky as a cultural resource. Jarita Holbrook of the University of Arizona is a leader of a new generation of scholars exploring African cultural astronomy (Holbrook, 2004, 2005). At a popular level the documentary film *Cosmic Africa* (2003), featuring the South African astronomer Thebe Medupe, has done much to introduce the subject to wider audiences.

Sahara Region

Ancient astronomically aligned structures have been discovered in a megalithic complex in the southern Egyptian desert at Nabta, where nomadic pastoralists made their summer camps by a playa, or seasonal lake, between 6,500 and 5,300 years ago. The Nabta site probably served as a ceremonial center. It comprises several oval clusters of stones and isolated megaliths, and numerous tumuli containing cattle and sheep burials. The burials are analogous with ritual practices of modern African pastoralists who slaughter animals to mark socially important occasions. Archaeoastronomer McKim Malville used theodolite and GPS measurements to map the site. He found three lines of megaliths radiating from the largest structure. A nearby stone circle containing four sets of upright slabs, which may have been used to fix positions along the horizon, exhibits two line-of-sight "windows," along a north-south axis and at an azimuth

of 62°; the rising mid-summer sun would have been visible through the second line of sight circa 6,000 years ago. Malville has theorized that the geometry of the standing stones reifies a conceptual system integrating death, water, seasonal fertility, and the motion of the sun (Malville, McKim, Wendorf, Mazar, & Schild, 1998). Presumably, the ancient Nabtans correlated solstice observations with the onset of summer monsoon rains. It is intriguing that the megaliths, located in the playa deposits, would have stood in the shallow lake water. The rising and falling water level marked against the stones could have been a powerful indicator of seasonality. With climatic change bringing hyperaridity and desertification to the Sahara region around 4,800 years ago, the seasonal occupation of Nabta came to an end. The Nabtan pastoralists may have migrated to the Nile Valley, contributing their practice of solar observation as well as their reverence for cattle to the cultural development of predynastic Egypt (Wendorf & Schild, 2001).

While Nabta is the earliest Saharan site thought to have astronomical alignments, surveys of pre-Islamic tombs in the Tassili N'Ajjer region of Algeria and parts of southern Morocco have also indicated structural orientations suggestive of some calendrical purpose (Belmonte et al., 1999, 2002). In the historic period the nomadic Tuareg people have practiced celestial navigation in their travels across the great desert. When traveling north the Tuareg oriented themselves according to the mother camel constellation *Talamt* (Ursa Major), and when traveling south they watched the gazelle stars *Ineren* (α and β Centauri). *Əmanar*, "The Guide" (Orion) and *Tələzdak*, the date palm (Scorpius) are other important asterisms in the Tuareg sky (Donaint, 1975).

West Africa

By the first millennium AD the trade between West Africa and Mediterranean North Africa was functioning as an important mechanism for cultural exchange. The transmission of Islam to West Africa would engender formal academic

traditions based on written texts in Arabic. From the fifteenth century onward a number of scholars in Timbuktu and other Islamic centers studied astronomy as an adjunct to the Quranic sciences. The corpus of Arabic scientific writings of West African provenance has yet to be analyzed in any detail, but a number of manuscripts preserve meteorological observations, particularly floodings of the Niger River, and details of solar and lunar calendars (Saad, 1983). Rebstock (1990) located numerous mathematical, astronomical and astrological texts in Mauretania, 13 of them having to do with the Islamic calendar. Results of a study by the Al Furqan Foundation suggest that roughly 1 % of Arabic manuscripts in West Africa contain astronomical material (Hunwick, 1997). There are probably several hundred texts yet to be identified and analyzed. A Library of Congress exhibit of manuscripts from Timbuktu afforded a glimpse of this raw material, including tracts entitled *The Important Stars among the Multitude of the Heavens* and *The Rise and Setting of Auspicious Stars* (Library of Congress, 2003).

The existence of these texts indicates that at least some West African scholars engaged Arabic mathematical astronomy at rather advanced level. However, the reputed fascination of Aḥmad Bābā al-Tinbuki (1556–1627) and al-ḥājj Muḥammad al-'Iraqi (fl. 1650) with esoteric astrology likely typifies the chief matter of interest. Many West African literati dabbled in celestial divination; others considered astrological prediction spiritually dangerous. The great Fulani scholar Muḥammad al-Wali (d.1688) wrote a diatribe against astrology and its practitioners. Ironically, his pupil Muḥammad ibn Muḥammad gained fame with an astrological opus, *al-Durr al-Manzūm* (Strung Pearls). It was not an original work. Its chief source was the *Secret Concerning the Dialogue with the Stars* of the Persian sage, Fakhr al-Dīn ► *al-Rāzī* (Ullmann, 1972). The lack of any coherent school of astronomy or astrology in West Africa is perhaps attested by Muḥammad Bello of Sokoto, who recorded his observations of a bright comet in 1825. Several people asked him to explain the phenomenon so he wrote a treatise on it. Unable

to find any scientific writings on comets, he was reduced to quoting theological opinions to assure his readers that the object did not signify the end of the world (Ogunbiyi, 1991–1992) (Fig. 1).

The science of the stars did not remain solely in the Arabic language. Savants in the city of Kano translated Arabic star lore into Hausa. The anonymous pedagogical text, *Hisabi 'Assawwakai*, gives an elementary account of Islamic astronomy, and is still circulating in northern Nigeria (Kani, 1992). The Hausa took up astrology with enthusiasm, astrological verse becoming a prominent genre of vernacular literature. A Hausa poem attributed to Abdullah ibn Muḥammad describes the 28 *anwā*, 12 signs of the Zodiac, and planetary rulership of parts of the sky, according to the foreign practice. Ibn Muḥammad apparently learned his astrological theory from the writings of Moroccan practitioners such as 'Abd al-Hāqq, whose *Kitāb al-falak* (Book of the Planets), was widely read in Northern Nigeria. While the Ibn Muḥammad text largely retains Arabic terminology, other Hausa works apply indigenous epithets for the stars which were not derivations from the Arabic but reflect local tradition (Hiskett, 1967, 1975).

As for the built environment in West Africa, studies by Drucker-Brown (1984) and Blier (1987) have shown that certain vernacular architectures perform a symbolic as well as a functional purpose; home design not only manages light and heat resources but incorporates visual metaphors of directional affiliation and spatial organization alluding to the sun's diurnal and annual motion. Among the Mamprusi of northern Ghana the *zonga* or entranceway of one's home faces west so that the rays of the setting sun are directed into an area where family elders sit. It is here where in the late afternoon the position of light falling onto a wall is judged as an indication of the agricultural seasons. Elaborating on this theme, the Batammaliba people of Togo and Benin believe that the home should be representative of the solar deity, Kuiye. When a house is constructed, the builders perform a ritual in hour of Kuiye. It occurs at local noon when the sun is on the meridian, the "center" of the sky, and

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Fig. 1 A page from *Kashf al-Ghummah fi Nafa al-Ummah* (The important stars among the multitude of the heavens). Mamma Haidara Commemorative Library, Timbuktu, Mali (Library of Congress, 2003)



A

involves the placement of cooked cereal on the *tabote* stone in the center of the homestead. The home itself is aligned on an east-west axis, with its portal and family shrines facing west. This allows the rays of the setting sun to strike the shrines of the family's deceased elders; it is believed that when such shrines are illuminated, Kuiye communicates with the ancestors about the affairs of living family members. Batammaliba granaries are also identified with Kuiye's domain, being divided into three sections, each associated with a different crop harvested in accordance with the three seasons delimited by tradition (Fig. 2).

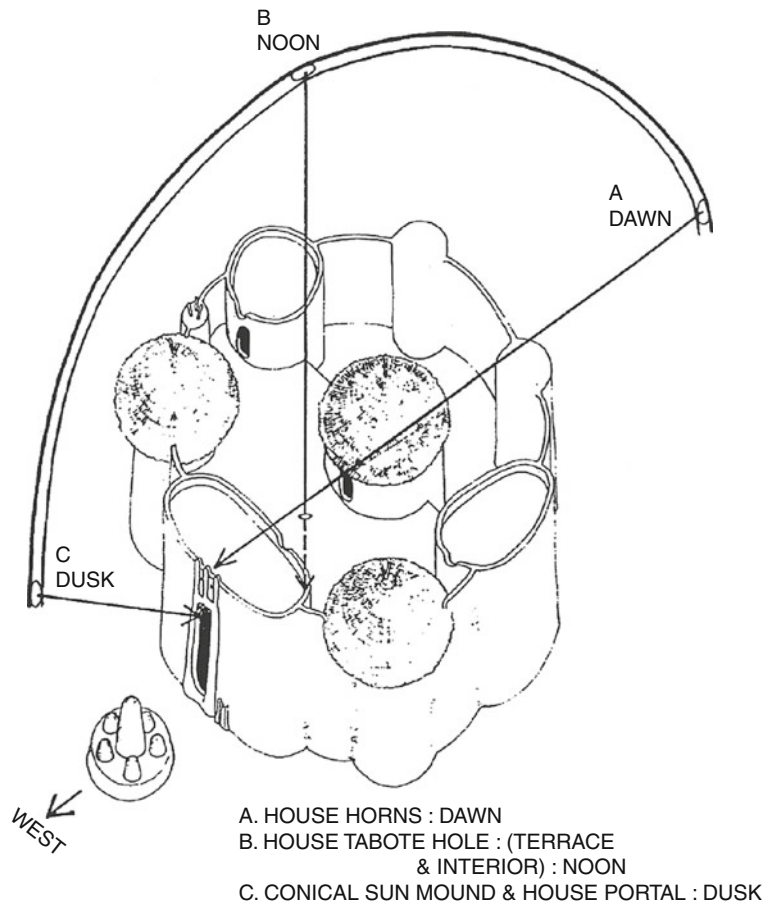
Unfortunately, while West African astronomical traditions have not as a whole attracted much attention, an inordinate amount of publicity has surrounded exaggerated claims for an advanced state of knowledge on the part of the Dogon

people of Mali. Based on their fieldwork conducted in the 1930s, Griaule and Dieterlen (1950, 1965) reported that the Dogon were aware of Sirius B, a small star invisible to the unaided eye. Such was the fuel for Temple (1975), among others, who claimed for the Dogon a heliocentric model of the solar system and independent knowledge of the satellites of Jupiter and the rings of Saturn. Thanks to television series such as "In Search of . . ." (1979) the Dogon have entered the popular imagination. Penetrating criticism by respected scientists and a field evaluation of Griaule's reportage, determining many elements, including the astronomical portions, to be either misconstrued or altogether unsupported by ethnographic evidence, have done little to stay the proliferation of misinformation on Dogon cosmology (Van Beek, 1991).

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Fig. 2 The sun's path and corresponding parts of a Batammaliba homestead (Blier, 1987)



East Africa and Madagascar

By the shores of Lake Turkana a megalithic site designated ► [Namoratunga II](#), comprising 19 basalt pillars and at least one grave marked by upright slabs, has been surveyed for possible astronomical alignments (Lynch & Robbins, 1978). Although there is no proof positive that the Namoratunga stones were erected with an observational purpose in mind, they appear to be nonrandomly aligned in directions corresponding with the rising positions of seven conspicuous stars and asterisms – Bellatrix, Orion's Belt (δ , ϵ , ζ Orionis), Saiph, Sirius, the Pleiades, Aldebaran, and Triangulum – on the local horizon ca. 300 BCE. These stars may have served as calendrical markers for the ancient Cushitic people who erected Namoratunga. However, efforts to elucidate a cultural linkage

between the purported Namoratunga tradition and calendrical practices of the Borana people in the historical period have met with doubtful results (Soper, 1982; Doyle & Wilcox, 1986). Most scholars have identified the Borana asterism *Lami* as the constellation Triangulum, but when Tablino (1994) asked Borana time-reckoning experts to identify *Lami* they invariably pointed out α and β Arietis. The Triangulum alignment at Namoratunga, at least, looks to be questionable.

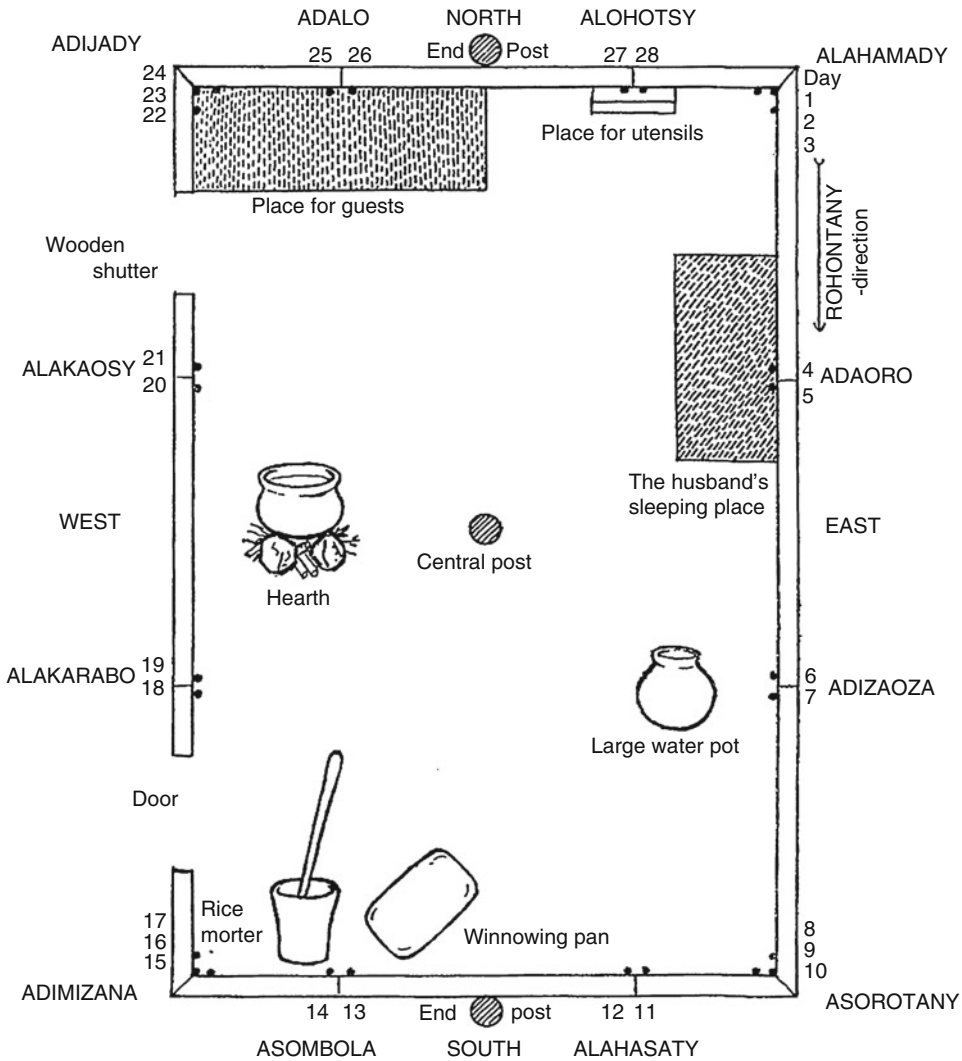
Christian Ethiopia has a tradition of skywatching documented in manuscripts dated back to the Middle Ages. Neugebauer (1979, 1981) found that Ethiopian astronomical knowledge applied almost exclusively in religious contexts. The astronomical chapters of the Ethiopic *Book of Enoch* contain simple arithmetical schemes for the motion of the sun and moon. The origins of this treatment are obscure, but

they are more likely to derive from the rudimentary astronomical traditions of Egyptian Judeo-Christian communities than from early Babylonian schemes. Other texts and Easter tables of the Ethiopian Church reflect the computus of Alexandrian Christianity. A thirteenth-century computus of Abu Shaker of Alexandria, for reckoning Easter and other movable feasts, is extant in a number of Ethiopic manuscripts dating from the sixteenth century. Ethiopian chronicles record comets, eclipses, and other astronomical events from the fifteenth century onward.

The folk astronomy of Islamic Somalia appears to be directly influenced by the practices of south Arabia. Nomadic Somali herders know Polaris as *Hhiddigo*, the Prayer Star; by noting its direction after establishing an evening camp, they can orient themselves toward Mecca for their five daily prayers. Somalis have also adopted the 7 day week, and the folk practice of *taawil*, or assigning a good or evil value to each day. The most telling indicator of Arabic influence, however, is the recognition of lunar stations (Arabic: *anwā'*), 28 stars or asterisms, noted for their risings and settings over the year. Although the camel and sheep herding peoples of Somali used the *anwā'* (called *god* in Somali dialects) as a framework for a seasonal calendar, they viewed lunar stations primarily as divinatory signifiers. It is still held by many Somalis that the Moon's passage through the stations releases favorable or unfavorable celestial influence. *Dirir* (Spica) which means "good omen" is the most important station, as it is believed to govern the summer rains. Traditional Somali weather experts judge the quantity of future rain when *Dirir* is in conjunction with the Moon; a majority consider the Moon and *Dirir* rising in conjunction to be an auspicious sign. However, if the Moon passes north of *Dirir* a drought is expected. A child born on the night of a conjunction is thought to possess *buruud*, the ability to inspire respect among the people. A *Dirir* child will also have good fortune in owning camels and horses. At all events, a considerable body of Somali proverbs, songs and folktales has grown around the import of lunar stations (Galaal, 1992).

Peoples of the East African coast have for centuries engaged in long distance trade with the Middle East and South Asia. The fifteenth-century master seafarer Aḥmad ▶ *ibn Mājid* left behind an Arabic memoir on Indian Ocean navigation techniques which relied heavily on stellar observation. He noted that navigators of Mombasa, Sofala, and Madagascar sailed by the stars of Ursa Major, which they called *al-Hīrāb* (Tibbetts, 1981). Swahili manuscripts at the University of Dar es Salaam also attest to celestial navigation on the part of East Africans. The Arabic element was considerable nonetheless: a majority of the 105 Swahili star names collected by Knappert (1993) are derived from Arabic, and Kiswahili lunar station vocabulary preserves the Arabic terminology essentially unaltered. Moreover, the adoption of Islam by Swahili-speaking peoples brought with it the Islamic lunar calendar and the practice of orienting mosques in the direction of Mecca. Nonetheless, the Swahili lived in an environment of parallel time-reckoning systems. The indigenous Bantu tradition of the Pleiades or *Kilimia* remained distinct from the *anwā'* system and continued to be used for the regulation of agricultural work. In Swahili the Pleiades are *Kilimia*, the Ploughing Stars. Referring to the *vuli* and *masika* monsoon periods, and their respective planting seasons, a proverb runs: "If the Ploughing Stars set in sunny weather they rise in rain, if they set in rain they rise in sunny weather." As viewed in the evenings from equatorial Africa the Pleiades disappear in the Sun's glare, they "set" about early May, reemerging in the morning sky just as June's *vuli* rains begin. Observed in the predawn sky *Kilimia* are seen to set at the end of the *masika* rains in November; when they are glimpsed rising in the evening twilight they herald a dry or "sunny" period. Alongside the Islamic lunar calendar Swahili-speaking peoples kept a 365-day year subdivided into 36 and a half "decades" of 10 days each. This solar year, which begins with the *Nairuzi* festival, appears to be of Persian origin (Gray, 1955).

On the island of Madagascar the highly syncretic *Mpandandro* astrological system appears



Astronomy in Sub-Saharan Africa, Fig. 3 Plan of a Malagasy house indicating directional associations with 12 months and 28 lunar stations (Ruud, 1960)

to integrate Arabic and South Asian practices with indigenous culture. Writing in a modified Arabic script, scholars among Antaimoro and Antambahaoka peoples of southeastern Madagascar compile *Sorabe*, or “great books” containing history, medicine, geomancy and astrology. Malagasy astrologers utilize lunar stations and assign favorable/unfavorable values to days within a 7-day week. The temporal scheme is represented spatially in the orientation and lay out of the traditional rectangular house (Verin & Rajaonarimanana, 1991) (Fig. 3).

Central and Southern Africa

The African states centered on Great Zimbabwe and Mapungubwe between the twelfth and fifteenth centuries presumably developed temporal and spatial ideologies involving the sky. Even so, there is no conclusive evidence for intentional astronomical alignments at Great Zimbabwe, despite the recent conjectures of independent archaeologist Richard Wade (Campbell, 2002). Other southern African sites have not been surveyed specifically for their archaeoastronomical

potential, but the features of an Iron Age village called Ntsuanatsatsi are very suggestive. Situated a kilometer west of a prominent hill in the grassy highveld of the Orange Free State, South Africa, the stone-walled ruins face eastward. The place name, Ntsuanatsatsi, attested to as early as the 1830s, means “sunrise” in the Sesotho language. For local Sotho clans the hill is reputed to have been where the first ancestors rose from the earth. In former times, Bafokeng chiefs held their councils on top of the ridge across from the hill. Their ability to gauge the annual motion of the sun by the sunrise locations on Ntsuanatsatsi hill may have contributed to the prominence of these early Sotho leaders (Maggs, 1976).

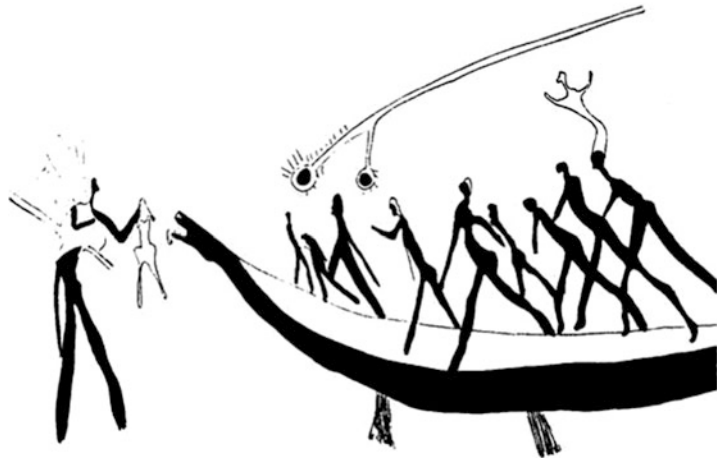
The ritual initiation of adolescents into full membership of the community is an important aspect of African society. A “morning star,” usually identified in the literature as the planet Venus, traditionally had strong associations with male rites of passage in Central and Southern Africa. The Mbunda people looked for an object they called *gongonosi*; the Tsonga of Mozambique used the cognate term *ngongomela* “towering in strength.” Victor Turner noted the visibility of such a morning star on the last morning of the Ndembu ceremonies he witnessed; he further recorded that the initiation title of the third boy to be circumcised was *kaselantanda*, “he of the morning star” (Turner, 1967). According to Junod (1927), Tsonga initiation schools were synchronized with the appearance of Venus in the morning sky during a winter month (June–September in the southern hemisphere). One of Junod’s informants, the Tsonga elder Shinangana, chronicled a few of the schools in the last half of the nineteenth century: they occurred in 1862, 1873, 1881, 1887, and 1893. Venus was indeed a morning star in the first 3 years, but not in 1887 or 1893, although in the later year Jupiter was located in the morning sky and could have served as *ngongomela*. Hence, it would be rash to assert any correlation between periods of the morning visibility of Venus and the age-sets of Tsonga initiates. In a praise poem which inspired the young Nelson Mandela, Krune Mqayi sang of counting the years of manhood by the rising “Morning Star.” For the Xhosa

of South Africa this object was unquestionably the Pleiades, the dawn rising of which occurs late in June. It is said that the month of the Pleiades, *Eyesilimela*, symbolized new life; the coming-out ceremony of the *abakwtha* circumcision school was synchronized with the appearance of the star cluster (Snedegar, 1997). The morning star, however imprecise its own identity, was recognized across central and southern Africa as a key identifier of the male child’s passage into the daylight of adulthood.

The night figures prominently in the cognitive universe of the Khoisan peoples, who articulate their knowledge in oral traditions which have been transmitted across generations. The evening campfire traditionally served as the venue for sky stories. Appropriately, many San groups recognize a “Fire Finisher” star whose position above the horizon indicates the time on cold winter nights. Fire Finisher is said to rise in the evening and set before dawn, about the time the night’s fire has burned to embers. By all accounts, Fire Finisher is a brilliant star which seems to be alone in the sky. Three stars fit the profile and are in fact identified as Fire Finisher by different San groups: Antares (by the Nharo), Arcturus (!Xo), and Regulus (G/wi). Like Fire Finisher, all stars are associated with fire. In the Ju/’huoan dialect the act of stoking a fire, causing sparks to fly into the air, is described with the same words as a shooting star. One of the most famous myths concerns a girl of the “early race” who created the Milky Way by throwing ashes from her campfire into the sky. For many San, however, the Milky Way is the Backbone of the Night. There may be a connection with the moon. A nineteenth-century explanation of the Moon’s waning phases claims that the Sun chases the Moon; as it catches up, the Sun slices away pieces of the Moon until nothing remains. But before the Moon is altogether devoured, it says, “Oh Sun! Leave for the children the backbone!” (Bleek & Lloyd, 1911). Sirius is often identified as the Hip Star or Thigh Star. In her fieldwork, Marshall (1986) discovered that the !Kung San see Canopus and Capella as “horns of *tshxum*,” an identity, perhaps a magical rain bull, centered on the Pleiades. Predawn observation of *tshxum* and its horns indicated the coming of spring rains.

Astronomy in Sub-Saharan Africa,

Fig. 4 San rock painting of bolide-like object near Bethlehem, South Africa (Thackeray, 1988)



In Khoisan mythology human ancestor spirits inhabit the night. They are accompanied by spirits of terrestrial animals including lions, elands, gemboks, hartebeests, steenboks, porcupines, hedgehogs, and giraffes. The starry sky becomes a great canvas for hunting stories, of which ≠Gao N!a, or G≠kao N!a'an, is often the leading man. According to a story collected by Marshall (1986), ≠Gao stood on the Large Magellanic Cloud one evening looking for game to hunt. He spotted three zebras, the three stars in Orion's Belt, and shot an arrow at the middle one. The arrow fell short; it is represented by the stars just south of the zebras. After his unsuccessful shot, ≠Gao decided to send the zebras down to earth for the San to hunt. Nineteenth-century Khoikhoi told a similar tale. Their rendition identified the hunter with the star Aldebaran, spurred on by his wives, the Pleiades. Having failed in his hunt, Aldebaran cannot return to his family, and is fixed in his place in the sky. Another story independently documented by Marshall and Biesele (1996), involves the sons of ≠Gao, !Xuma and Kha//an, identified with α and γ Crucis, who went out hunting an eland but themselves were pursued and killed by two lions "the keepers of the west," α and β Centauri. ≠Gao suspected the lions. He hid a pair of magic horns in a tree, and invited the lions to dance under its branches. The horns fell onto the celebrating lions, killing them. ≠Gao then resurrected his sons. Celestial players reenact the story on October evenings when the

stars of Crux, representing the two boys, set or "die" on the southwestern horizon; they are followed by α and β Centauri, the lions tricked into death. As viewed from San locations in the Kalahari Desert, where Crux is not quite circumpolar, α and γ Crucis rise again later in the night; the boys are visually resurrected.

Meteors have an important place in Khoisan folklore. These "shooting stars" are interpreted in various ways, but they are generally considered to signify creatures having supernatural powers. Some say meteors are antlions falling to earth in search of food; for others they are porcupines or hedgehogs. Hence a porcupine-skin bag is called a star skin, and hedgehog fat is a chief ingredient for amulets worn in curing dances (Traill, 1994). Through dance a shaman enters a trance state in which, it is believed, he is able to traverse the sky as a meteor, obtaining supernatural potency from the ancestors. Such potency is supposed to give him the mastery over disease as well as control of game animals and the spring rains. The meteoric trance experience is very probably illustrated in rock art. Although only a few rock art images suggestive of meteoric trance have been recorded, the territory in which these images have been found stretches from Zambia to Lesotho (Thackeray, 1988). One extraordinary rock painting in South Africa portrays a shamanistic dance; a bolide-like object appears to zoom over the dancers' heads and burst into two fragments (Fig. 4).

See Also

► Namoratunga

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Astronomy in the Argentinian Chaco

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The Chaco Region

The Great Chaco region is located in central South America. It partially covers the south of

Bolivia, Paraguay, and northwest Argentina. The Argentinean portion of this region includes the provinces of Chaco and Formosa, the oriental portion of the provinces of Salta and Santiago del Estero, and the north portion of Santa Fe.

The Argentinean Chaco was inhabited by various aboriginal groups and a complex non-aboriginal population. Before the arrival of the Spaniards, the social organization of the Argentinean Chaco aboriginal groups was based on small bands. Originally most of them were hunters and gatherers. The three most prominent linguistic groups were and still are the Guaycurú, Mataco-Mataguayo, and Guaraní.

These aboriginal people underwent several changes during colonial times and had complex relationships with the colonial society. Despite the fact that they were politically independent from the colonial government, many types of exchanges between these aboriginal groups and the Creole and European population existed from trade to military conflicts.

Between the eighteenth and nineteenth centuries, numerous religious actors arrived in the area, like the Jesuits and later on the Protestant missionaries. These presences played a key role in new Indian resignifications of Christian practices and cosmologies (López, 2014a, b).

Nowadays, a population of around 133,000 original people survive by working as rural laborers and by developing a variable amount of hunting and gathering (INDEC. *Encuesta Complementaria de Pueblos Indígenas (ECPI) 2004–2005*).

Specific Groups

We will focus on two specific aboriginal groups in the region to exemplify some of the main characteristics concerning their conceptions of the sky. In the examples selected we analyze notions that are key to a large variety of Chaco groups, which indicates the relevance of exchanges in South American cosmologies, both in pre- and post-Columbian times (López, 2014a, b).

Toba of Western Formosa

The Toba (Guaycurú linguistic group) who settle in the west of the province of Formosa (Argentina) specifically reside in the Bermejo Department. Both among the Toba and other Chaco groups, the celestial sphere is mythically related to the female domain. The mythical origin of women is the sky, from which they descended. Stars are also considered to be female beings. Hence, there are well-defined links between the sky and the female world. An example of this is the relationship established with the moon. In the narrative level Moon is a masculine entity which conducts the mythological conformation of the Toba woman. Rafael Karsten's 1912 ethnography of the Bolivian Toba also suggests that they thought that menstruation was caused or influenced by the moon (Karsten, 1923, p. 26). The myth about sexual relationships between the moon and women who have had their first period can still be heard among the Toba. The moon is still thought of as a masculine entity which is responsible for the mythological conformation of Toba women. In the words of a Toba, "Moon is the first man of every woman." When their first period appears, mothers still say to their young daughters that the "Moon is to blame." Therefore, in this context mothers utter things such as "It is as if the moon had raped my daughter." As we have already said, according to Toba oral tradition, the moon is responsible for the mythical formation of femininity. Thus, the moon plays the role of the primordial hero "the fox," who let the primeval men in mythical times have sexual intercourse with women who had just descended from their celestial abode. Indeed, as the moon had his first sexual intercourse with the girls and thus helped them get married, the fox had his first sexual intercourse with the celestial women and helped them have their teeth removed from the vaginas and thus become the wives of men. Likewise, the lunar imaginary is used to measure diverse temporal cycles. The Toba explanation about the moon refers to a group of organic ideas which evoke youth, maturity, and death of a living agent (Gómez, 2014b).

Among the Toba of Western Formosa, political leadership is associated with the asterism known as *Dapi'chi*, which is represented by the Pleiades. This asterism controls cold in general. Its appearance also announces the arrival of a new bountiful period starting around December, when the bush abounds in algarroba, and they say that the asterism seems to "vanish" from the sky. According to the evidence gathered, *Dapi'chi* is "a very important man" wearing a red crown that can only be noticed when he first becomes visible, that is, when coming up in the east before dawn, in winter, during his heliacal rising. Just like the Toba leader, *Dapi'chi* is the "leader" because he knows all those under his control: the other stars. *Dapi'chi* is also reinterpreted concurrently with the changes in the blurred political leadership figures among the western Toba Indians (Gómez, 2014a; 2011). On the other hand, this asterism has been critical in accounting for the beginning of a new annual cycle.

Mocoví

The Moqoit or Mocoví belong to the Guaycurú linguistic group. They inhabit the southern area of the Chaco region, in the Argentinean provinces of Chaco and Santa Fe. We will underline two main components of their rich astronomy that are also present in other Chaco groups.

The Milky Way and the *Nayic* as a Conceptual Structure

For the Moqoit, the Milky Way holds many articulated meanings, which are highlighted according to the circumstances or the narrator. A common element throughout these meanings, however, is the structuring role that is played by the Milky Way in Moqoit cosmology (Giménez, López, & Granada, 2002).

Star brightness is related for the Moqoit people to the notion of the brightness of powerful beings. In this sense, the Milky Way and its myriad of stars make up a space seen as

extremely powerful. The different positions of the Milky Way are used for finding the way in woodland at night and as a temporal marker. Beyond these, the Milky Way is seen by Moqoit as a path, a tree, and simultaneously a whirlwind that gives structure and maintains the communication between the different levels of the cosmos. But it is not simply a naive picture: tree, whirlwind, and path act as true models to think about key aspects of the fundamental dynamics and structure of reality as the Moqoit people experience it.

The Moqoit word *nayic* means “path,” and it is related to the idea of going deep into nonhuman space. One such space is the forest, along which a sequence of markers unfolds, each one commemorating a pact with the ruling powers of the world. The notion of “path” is a general Moqoit conception to organize reality: a tale, the life of a human being, the community memory, and the universe itself. The Milky Way is seen as the path followed by the mythic Rhea, the Mañic, as it flees to the sky haunted by the ancestors of the Moqoit. Stories about these events make up a kind of serial narrative linked to the history of the “hunting of Mañic” and are “strung” by means of the Milky Way. In this sense, the representation of the Milky Way as a “path” structures the Mocoví’s oral narrative about stars.

But this path in the sky is also seen as the road of the celestial powerful beings that descends to the Earth and the way in which the *pi’xonaq* or shamans obtain power. The *pi’xonaq*, the specialists of the sacred, have a capacity to see this structure of the universe. Their healing capacity is based on their capacity to travel around the world and build alliances with the entities governing it.

Iron Meteorites, Power, and Colonialism

Given the sediment composition of the Chaco plains, it is very rare to find rocky or metallic objects. The area inhabited by several Moqoit communities is dotted with pieces of this kind related to the sky – iron meteorite fragments making up the strewn field of Campo del Cielo

(Giménez Benítez, López, & Granada, 2004). These pieces are seen as manifestations of the celestial presence on Earth. It is believed that, after falling from the sky and getting buried in the ground, meteorites start to come up to the surface and appear to those people they were designed for, bringing them luck, wealth, and health. The contact between humans and meteorites may cause rainfall, and only shamans are capable of manipulating them with no risk. To the Moqoit, the wealth-generating capacity of meteorite fragments is a manifestation of the power they confer as agents of the “powerful” of the sky.

In this context, the Moqoit believe that the inequality, violence, and exploitation they suffer from the non-aboriginal society are ultimately due to the way in which the latter has monopolized access to the cosmic sources of power. For these reasons, through texts (Martínez, 2006) and public actions, Juan Carlos Martínez and other young Moqoit leaders have demonstrated the connection that the Moqoit see between their notions about the cosmos and their land and cultural claims (López, 2011). In doing so they have emphasized the importance of the relationships between humans and powerful nonhuman beings in shaping Moqoit notions of territory and way of life. They used the Campo del Cielo crater field as a symbol of those relationships. The successful Moqoit resistance to the transportation of the largest meteorite found to Germany for the dOCUMENTA13 art exhibition should be understood in this context (López, 2014c).

Conclusions

The notions that the Chaco aboriginal groups have about the sky are not a whimsical set of quaint and naive fantastic stories. On the contrary, they are part of complex considerations about the world and the humans which involve the use of sophisticated metaphors and elaborate ideas of such notions as identity, personhood, body, causality, and power. Thus, structures are used both to organize the sky around the Milky Way and to shape the account of a person’s life.

Just like the ideas of any human group about the world, these aboriginal conceptions of the sky are not static but change over time. Furthermore, they are related to the life of the societies that generate them, albeit not necessarily being their reflection. In this sense, the intense relations among the various groups in the region, even if belonging to different linguistic groups, are reflected in the multiple interactions between their astronomies. On the other hand and regarding the groups in question, the sky is strongly tied to abundance and power on Earth, so that all considerations about the sky are regarded as major political issues. As these societies are not hierarchical and many social actors vie for leadership, we are faced with a variety of competing versions of the sky and its inhabitants and of how humans can relate to them.

In the groups analyzed, the process of developing ideas about the sky and the competing interpretations thereof are in full force and are not merely a curious thing of the past. Their views of the celestial sphere play a major role in the current struggle for their cultural, territorial, and health-care rights.

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Astronomy in the Indo-Malay Archipelago

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All societies have their own systems of knowledge through which they seek to understand the natural environment and their relationship to it. Thus we may be better able to understand a society by going beyond the categories of Western science and begin to consider the interrelationship of a society with its environment from the viewpoint of the members of that society. It is this attempt to understand how members of a society, themselves, conceive of their

environment that has come to be known as ethnoecology (Casiño, 1967). Ethnoastronomy, the subject of this article, may be seen as a branch of ethnoecology wherein the interrelationship of human populations with their celestial environment is the focus of interest.

The modern nation states of Indonesia and Malaysia have a combined population of approximately 260 million and encompass the homelands of well over 500 distinct ethno-linguistic groups whose cultures and languages form part of a common Austronesian heritage, a heritage they share with the majority of the peoples of the Philippines, Polynesia, and Micronesia, among others (In addition, there are at least 100 Papuan languages spoken in the Indonesian province of West Papua on the western half of the island of New Guinea.). Inhabiting mountainsides, river valleys, and coastal plains and faced with a somewhat unpredictable tropical monsoon climate, the peoples of Island Southeast Asia have developed diverse systems of agriculture that include both inundated rice farming and the shifting cultivation of rice and other food crops. Spread across an archipelago of over 17,000 islands (at least 6,000 inhabited), they have also developed sophisticated systems of navigation. These indigenous agricultural and navigational practices have been informed by an astronomical tradition that is, at once, unique to this cultural area and richly diverse in its local variation. This article describes several of the many techniques of astronomical observation that are known to have been employed by the peoples of Indonesia and Malaysia to help regulate their agricultural cycles and navigate their ships.

The Celestial Landscape

The passage of time is mirrored in all of nature: in the light and warmth of day and the dark and coolness of night, in the flowering of plants, in the mating and migratory behavior of animals, in the changes in weather, in the ebb and flood of the tides, and in the recurring cycles within cycles of the sun, moon, planets, and stars as they transit the celestial sphere. Of these cycles, perhaps the

most obvious is the diurnal rising and setting of the sun, moon, planets, and stars, as well as the synodic or cyclic changes in the phase of the moon and in the time of day that it rises and sets. More subtle than these might be the annual changes in the sun and stars: the north-south shift in the path of the sun across the sky (including its rising and setting points and its relative distance above the horizon at noon) and the appearance, disappearance, and reappearance of familiar patterns of stars at various times of night. To the trained eye, nature is replete with signs of diurnal and seasonal change. As an integral part of the natural landscape, these recurring celestial phenomena have long provided farmers and sailors worldwide with dependable markers against which operations, agricultural as well as navigational, can be timed.

Likewise, orientation in space and the art of wayfinding have often relied upon knowledge of these same celestial phenomena, the English term “orient,” itself, having been derived from the Latin for “rise” and later associated with the East as the direction in which the sun appears at dawn. Although the times that individual stars rise and set shift gradually throughout the year, as viewed from a given latitude, the azimuths at which a star rises and sets varies only slightly over a lifetime, thereby providing a reliable “star compass” by which to determine direction. So, too, the sun, moon, and planets rise and set generally [▶ east and west](#), depending upon their individual cycles, affording additional guides by that people are able to orient themselves on the land as well as on the sea.

Agricultural Time Keeping

Many traditional, sedentary desert and plains cultures have used the shift in the rising and/or setting points of the sun along the horizon to both mark important dates and seasons and to commemorate the passage of years. Desert and plains environments are conducive to the development and use of these horizon-based solar calendars: a permanent location from which to make sightings, a series of permanent distant horizon

markers, either natural or manufactured, and a clear view are all that is needed for such a calendar. England's Stonehenge and Wyoming's Big Horn Medicine Wheel provide striking examples. Such conditions, however, are not common across much insular Southeast Asia. Here the landscape may consist of anything from a nearby or distant mountain to, more often, nearby trees; the horizon is, therefore, a rather undependable device against which to sight and measure the rising and setting positions of the sun. But in cultivated areas of the region, even from swidens located deep within the rainforest, one can usually find a field or home site from which much of the sky is visible.

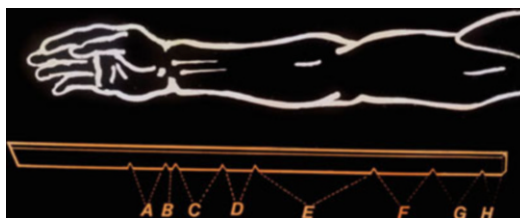
There are several types of observations of annually recurring celestial phenomena that can be made where permanent, distant horizon markers are not commonly available. These include cyclic changes in the phases of the moon, the annual changes in the apparitions of familiar groups of stars, and the annual changes in the altitude of the sun at noon. Here I present variations of these types of observations that we know have been practiced among traditional farmers of Indonesia. For the sake of clarity, they are grouped using Western astronomical categories as follows: solar gnomons, apparitions of stars at dawn and dusk, and lunar-solar and sidereal-lunar observations.

Solar Gnomons. Most often seen on sundials in western cultures, a solar gnomon is simply a vertical pole or other similar device that is used to cast a shadow. The altitude of the sun above the horizon varies not only through the day, however, but through the year as well. By measuring the relative length of this shadow each day at local solar noon, one can observe and more or less accurately measure the changing altitude of the sun above the horizon (or, reciprocally, from the zenith) through the year and, thereby, determine the approximate date.

Two distinct types of solar gnomons have been reported in the region. Both measure the altitude of the sun at local solar noon to determine the date. One type has been attributed to various groups of the Kenyah of the Apo Kayan of Kalimantan and may still be in use (Fig. 1).

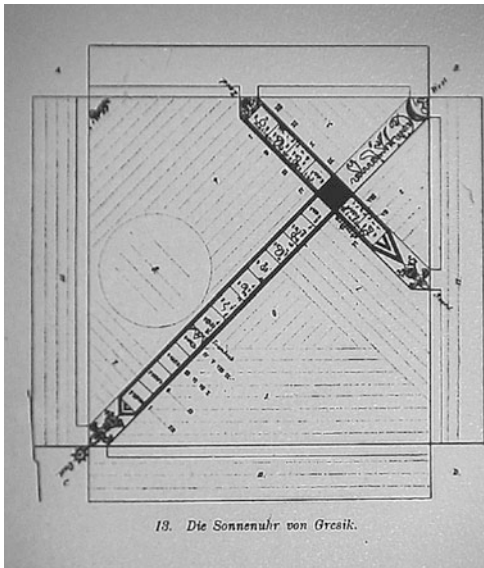


Astronomy in the Indo-Malay Archipelago,
Fig. 1 Kenyah *tukar do* or solar gnomon (From Hose & McDougall, 1912)



Astronomy in the Indo-Malay Archipelago,
Fig. 2 Kenyah *aso do* or base of solar gnomon (Adapted from Hose, 1905)

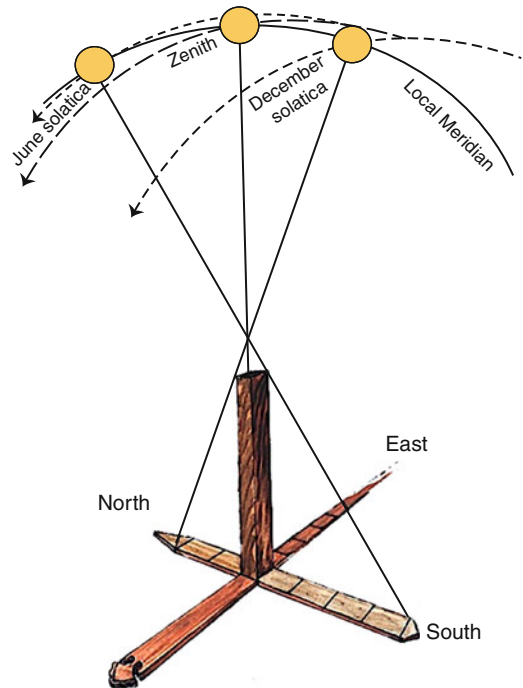
It consists of a precisely measured (=span of maker's outstretched arms + span from tip of thumb to tip of first finger), permanently secured, plumbed, and decorated vertical hardwood pole (*tukar do*) and a neatly worked, flat measuring stick (*aso do*), marked with two sets of notches (Fig. 2). The first set corresponds to specific parts of the maker's arm and ornaments worn upon it, measured by laying the stick along the radial side of the arm, the butt end against the inside of the armpit.



Astronomy in the Indo-Malay Archipelago, Fig. 3 The base of the *bencet* or solar gnomon showing the grid used to measure the length of the sun's shadow (Maass, 1924)

To mark the date, the measuring stick is placed at the base of the vertical pole, butt end against the pole and extending southward. This is done at the time of day that the shadows are shortest, local solar noon. On the day that the pole's noon-time shadow is longest (the June solstice), a notch is carved on the other edge of the stick to mark the extent of the shadow made by the pole. This observation indicates that the agricultural season is at hand. From then on, the extent of the noon-day shadow is recorded every 3 days as a record-keeping device. Dates, both favorable and unfavorable, for various operations in rice cultivation, such as clearing, burning, and planting, are determined by the length of the shadow relative to the marks on the stick that correspond to parts of the arm and to the marks made every 3 days (Hose, 1905; Hose & McDougall, 1912).

On Java a highly accurate gnomon, called a *bencet*, was in use from about AD 1600 until 1855 (Figs. 3 and 4) (Maass, 1924; see also Ammarell, 1996, 1998; Aveni, 1981; van den Bosch, 1980). A smaller, more portable device than that employed by the Kayan and Kenyah, the *bencet* divides the year into 12 unequal periods,



Astronomy in the Indo-Malay Archipelago, Fig. 4 Javanese *bencet* and the annual motion of the sun (Adapted from Aveni, 1981)

called *mangsa*, two of which begin on the days of the zenith sun, when the sun casts no shadow at local solar noon, and another two of which begin on the two solstices, when the sun casts its longest mid-day shadows.

At the latitude of Central Java, 7° south, a unique condition exists which is reflected in the *bencet*. As the illustration shows, when, on the June solstice, the sun stands on the meridian (that is, at local solar noon) and to the north of the zenith, the shadow length, measured to the south of the base of the vertical pole, is precisely double the length of the shadow, measured to the north, which is cast when the sun, on the December solstice, stands on the meridian (at noon) south of the zenith. By simply halving the shorter segment and quartering the longer, the Javanese produced a calendar with 12 divisions, divisions that are spatially equal but which range in duration from 23 to 43 days. The 12 *mangsa* with their starting dates and numbers of days are shown on Table 1.

Astronomy in the Indo-Malay Archipelago,
Table 1 The Pranatamangsa calendar (Adapted from
 van den Bosch, p. 250)

Ordinal number	Name(s) of <i>mangsa</i>	Duration (days)	First day(s) civil calendar
<i>Ka - 1</i>	<i>Kasa</i>	41	22 (21) June
<i>Ka - 2</i>	<i>Karo, Kalih</i>	23	2 (1) August
<i>Ka - 3</i>	<i>Katelu, Katiga</i>	24	25 (24) August
<i>Ka - 4</i>	<i>Kapat, Kasakawan</i>	25	18 (17) September
<i>Ka - 5</i>	<i>Kalima, Gangsal</i>	27	13 (12) October
<i>Ka - 6</i>	<i>Kanem</i>	43	9 (8) November
<i>Ka - 7</i>	<i>Kapitu</i>	43	22 (21) December
<i>Ka - 8</i>	<i>Kawolu</i>	26 (27)	3 (2) February
<i>Ka - 9</i>	<i>Kasanga</i>	25	1 March (ult. February)
<i>Ka - 10</i>	<i>Kasepuluh, Kasadasa</i>	24	26 (25) March
<i>Ka - 11</i>	<i>Desta</i>	23	19 (18) April
<i>Ka - 12</i>	<i>Sada</i>	41	12 (11) May

Apparitions of Stars at Dawn and Dusk. The second category of observational techniques regularly employed by traditional farmers of the region include all of those which involve apparitions of commonly recognized stars or groups of stars (which are herein referred to as “asterisms”) at last gleam at dawn or first gleam at dusk (I use the term “asterism” to refer to a commonly recognized patterned grouping of stars. While these groupings are often referred to generically as “constellations,” I reserve the latter term to refer to the 88 bounded regions of the sky generally accepted by international scientific astronomers, these regions often named for asterisms found within their borders. Note, however, in Western starlore, there may be two or more asterisms within one constellation (e.g., the “Big Dipper” and the “Great Bear” in Ursa Majoris).). Because of the earth’s orbital motion about the sun, it can be observed that each star rises and sets approximately 4 min earlier each night. Similarly, each star appears to have moved about 1° west, when viewed at the same time, each night. As a result, around the time of its conjunction with the sun, any given star becomes lost in the sun’s glare and is, therefore, not visible for approximately

1 month each year. It also means that the altitudes of stars above the horizon vary as a function of both the time of night and the day of the year, such that a certain star or group of stars, when observed at the same time each night (in this case near dusk or dawn) will appear at a given altitude above the eastern or western horizon on one and only one night of the year. Hence the use of any technique or device to measure the altitude of a star or group of stars as it appears at first or last gleam can provide the observer with the approximate date.

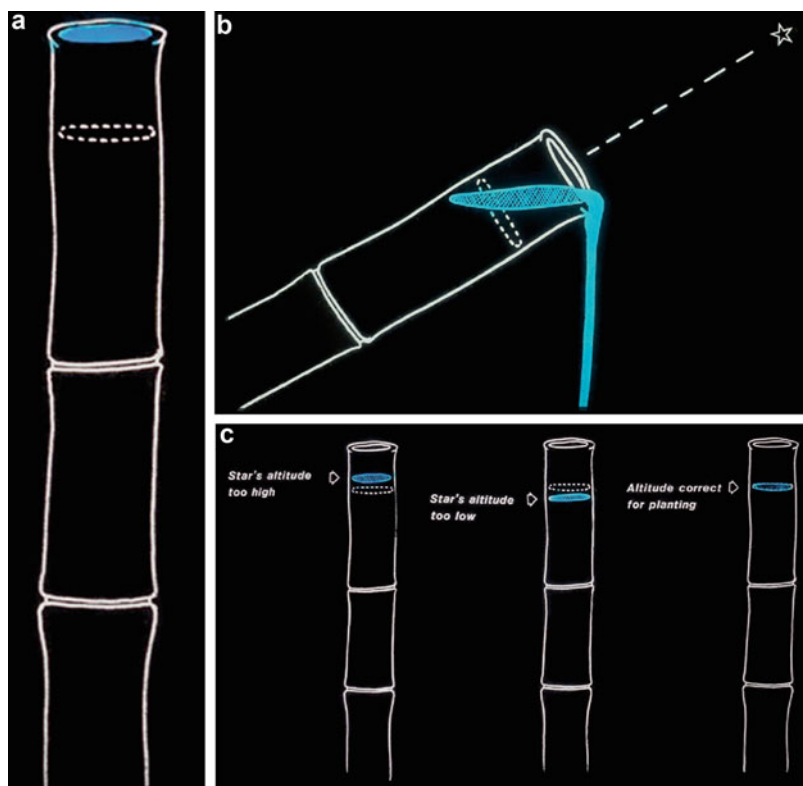
I use the term “acronical” to refer to any stellar apparition that occurs at first gleam while “cosmical” is used to describe stars at last gleam. A subset of these, “heliacal” (Greek *helios*: “sun”) apparitions of stars are those that occur just prior to and shortly after conjunction with the sun. The heliacal setting of a star or group of stars occurs on the date that the star or stars are last observed before conjunction, just above the western horizon at dusk. Likewise, the heliacal rising of a star or group of stars occurs on the date that the star or stars are first observed above the eastern horizon at dawn after several weeks’ absence.

Just about 3 months after its heliacal rising, the star, now about 90° west of the sun, appears on the meridian at first gleam, an event that may be termed a “cosmical culmination” of the star. Two months later, the star is nearing opposition with the sun and undergoes an “acronical rising” in the east at first gleam. In less than 1 month, after opposition, the “cosmical setting” of the star is seen in the western sky. After 2 more months the star may be seen on the meridian at first gleam, accomplishing its “acronical culmination.” Finally, about 3 months later, the star undergoes “heliacal setting” as the sun once again outshines it.

I would like to emphasize that these categories are taken from what is often referred to as the “exact science” of Western mathematical astronomy and are used here as a way of organizing and presenting this material to the Western scholar. The reader is cautioned that the actual observations made by indigenous farmers may not always be as precise as their assigned astronomical categories might imply. The demand for such

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Fig. 5 Bamboo device used by Kenyah-Kayan to measure the altitude of a star (Adapted from Hose & McDougall, 1912)



precision varies greatly between and within cultures and with local environmental conditions. Here it would not be unusual to find a local farmer, for example, first noting the heliacal rising of the star cluster known in the West as the Pleiades at dawn several days or more after its mathematically calculated reappearance. Note that for convenience, I refer in this article to stars and asterisms by their accepted international scientific names. Where I know the name of a star or asterism in the indigenous language, I will note it as well.

The apparitions of stars at first and last gleam have been systematically observed by traditional cultures worldwide. From island Southeast Asia there are references in the literature, too numerous to describe in detail here, to the calendrical use at both dusk and dawn of the stars known internationally as the Pleiades, Orion and, to a lesser extent, Antares, Scorpius, and Crux (for more Indo-Malay examples, see Ammarell, 1988, 1996; for examples from the Philippines, see Ambrosia, 1996). Culminations at both first

and last gleam of the Pleiades, Orion, and Sirius are noted in the literature. Interestingly, the observation for calendrical purposes of such culminations seems to be unique to peoples of this culture area.

A small Dayak group related to the Kenyah-Kayan complex mentioned earlier practiced the first example in this category. Like their neighbors, they were ►swidden rice farmers. But unlike their neighbors who tracked the sun, they depended upon the stars to fix the date of planting. To do so, they nightly poured water into the end of a vertical piece of ►bamboo in which a line had been inscribed at a certain distance from the open end (Fig. 5a). The bamboo pole was then tilted until it pointed toward a certain star (unrecorded) at a certain time of night (also unrecorded), causing some of the water to pour out (Fig. 5b). It was then made vertical again and the level of the remaining water noted (Fig. 5c). When the level coincided with the mark, it was time to plant (Hose & McDougall, 1912).

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Fig. 6 Javanese ritual specialist holding rice in open palm at dusk, pointing toward the rising *bintang weluku* “plough stars” (Orionis)



A

Near Yogyakarta, Central Java, a ritual practitioner was observed raising his hand toward the East in the direction of *bintang weluku* “plough stars” (Orionis) each day at dusk, rice seed in his open palm (Fig. 6). On the night it reached the altitude such that kernels of rice rolled off his palm (angle of repose), it was time to sow seed in the nursery (van den Bosch, 1980). Using a planetarium star projector, the author has determined the date of this event to be about 4 January (Ammarell, 1996).

Lunar Calendars. Lunar calendars comprise the third category. These calendars are based upon the 29.5-day synodic period, usually measured from new moon to new moon and often subdivided by phase. Because there is not an even number of lunar months in a solar year and because agricultural cycles are, after all, tied to the solar year, simple lunar calendars alone are of little use in farming. But when they are somehow pegged to the solar year by reference to the apparent annual changes in the positions of the sun or stars or to other phenomena in nature that regularly recur on an annual basis, a lunar calendar can be of use to the farmer.

Indigenous lunar calendars fall into two general categories: lunar-solar and sidereal-lunar. Examples of the lunar-solar calendar include the Balinese ceremonial calendar, still in use, and the old Javanese *Saka* calendar, used from the eighth

to the sixteenth centuries. Both are apparently of a common Hindu origin and are primarily lunar; both employ complex mathematical techniques to provide the intercalary days that periodically synchronize the lunar with the solar year (Covarrubias, 1937; van den Bosch, 1980).

A second type of lunar calendar, best described as sidereal-lunar, uses the apparitions at dusk and dawn of stars and asterisms as well as the appearance of other signs in nature (such as winds, birds and flowers) to determine which month is current. In these cases, it is only important to know which month it is for a few months each year (that is, during the agricultural season), thereby obviating the need for codified schemes for realigning the lunar with the solar/stellar year. Such “short” lunar calendars are found spread throughout the region (see Ammarell, 1988). The Iban calendar provides a good example.

The Iban Calendar

Freeman (1970) describes the Iban as a riverine people practicing shifting agriculture in the vicinity of their longhouses, situated in low hills of Sarawak and West Kalimantan. The stars have played a central role in Iban mythology and agricultural practices. Several Iban stories tell how their knowledge of the stars was handed down to

them by their deities and according to one village headman, “If there were no stars we Iban would be lost, not knowing when to plant; we live by the stars” (Freeman, 1970, p. 171). The Iban lunar calendar was annually adjusted to the cosmical apparitions of two groups of stars: the Pleiades and the three stars of Orion’s belt.

The first observation was probably the most difficult. It was the reappearance of the Pleiades on the eastern horizon just before dawn after 2 month’s absence from the night sky. This heliacal sighting, around 5 June of the civil calendar, informed the observer that the month, taken from new moon to new moon, that is current is, by convention, the fifth lunar month. It is during this month that two members of the longhouse went into the forest to seek favorable omens so that the land selected would yield a good crop. This may have taken from 2 days to a month, but once the omens appeared, they returned to the longhouse and work clearing the forest began. If it took so long for the omens to appear that Orion’s belt rose before daybreak (heliacal rising around 25 June), the people had to “make every effort to regain lost time or the crop will be poor” (Freeman, 1970, p. 171). This reappearance of Orion at dawn occurred during the next or sixth lunar month, the time to begin clearing the land.

The remaining observations of the stars were more easily accomplished. They are all cosmical culminations, occurring “overhead” at last gleam, and could be seen to be approaching for several weeks. When the Pleiades underwent its cosmical culmination (3 September) and the stars of Orion’s belt were about to do so (26–30 September), it was the eighth month and time to burn and plant. For good yields the burn should have occurred between the time that the two asterisms culminated at first gleam, usually when the two were in balance or equidistant from the meridian (16 September). Rice seed sown after the star Sirius had completed its cosmical culmination (October 15) would not have matured properly. It was okay for planting to carry into the tenth lunar month (October/November), but it had to be completed before the moon was full or the crop would fail. At this point the lunar calendar ended: only months five

through ten were numbered and fixed while the remaining months varied according to how quickly the crop matured (e.g., *bulan mantun*, the “weeding month”). The lunar months from November to April were simply not numbered; it was difficult to see the stars during the rainy season and unimportant in any case.

Celestial Navigation

As we have just seen, the rice farmers of Indonesia have long noted correlations between celestial and terrestrial cycles and incorporated periodic changes in the sky into their agricultural calendars. Meanwhile, neighboring seafaring societies have used many of these same phenomena to orient themselves in both space and time for the purpose of navigation. Of these societies, the Bugis of South Sulawesi are perhaps the best known. Maintaining a tradition of seafaring and trade that spans at least four centuries, the Bugis are reputed to have established and periodically dominated strategic trade routes across Southeast Asia, stretching northeast from North Sumatra to Cambodia, north to Sulu and Ternate, and east to Aru and Timor. Their maritime prowess notwithstanding, Bugis systems of navigational knowledge and practice have only recently come under study (Ammarell, 1995, 1999).

Bugis navigators still employ a system of dead reckoning that depends upon the knowledge of a variety of features of the natural environment to negotiate the seas in their tall ships. Although these features include land forms, sea marks, currents, tides, wave patterns and shapes, and the habits of birds and fish, navigators rely most heavily upon the prevailing wind directions, guide stars, waves, swells, and, increasingly, the magnetic compass.

Winds and Directions. The major wind patterns across island Southeast Asia are governed by the monsoons. In the Java and Flores Seas, from approximately May through October, winds from the east and southeast bring generally fair weather and steady breezes; from November through April, the west monsoon brings first calm air, then rain and squalls to the region.

For the Bugis as well as a number of other regional ethnic groups whose languages share a common Austronesian heritage, these winds are of such fundamental importance that their names are synonymous with the local prevailing wind directions. Thus for the Bugis, both the monsoons and their prevailing directions in the vicinity of their homeland of South Sulawesi are: *bare* ‘west’ and *timo* ‘east.’ (For an exceptionally thorough historical and comparative discussion of concepts of orientation is several South Sulawesi languages, see Liebner (2005).)

For the Bugis of the small coral islet of Balobaloang, located midway between Makassar on Sulawesi and Bima on Sumbawa, trade routes are generally north and south across the Flores Sea. In principle, this allows them to take advantage of both easterly and westerly winds by reaching in either direction, although storms and heavy seas usually confined them, in the past, to port during the west monsoon. Formerly voyages were undertaken during the west monsoon only if the captain was hard pressed financially. Now, with motorization and larger ships, the voyaging season has been increasingly extended such that confinement to port is restricted to brief periods of severe weather, usually lasting no more than a week or two at a time.

Stars and Asterisms. Bugis navigators have long relied upon the stars and star patterns to set and maintain course. Although most sailors seem to know a few star patterns and their use, the navigators have been found to know many more. These star patterns, or asterisms, are known to rise, stand, and/or set above certain islands or ports when viewed from others and thereby pinpoint the direction of one’s destination forming a “star compass.” For example, in late July and early August *bintoéng balué* “Alpha&Beta Centauri” (Asterism A, Fig. 7) is known to make its nightly appearance at dusk in the direction of Bima as viewed from Balobaloang, that is, to the south.

As the night passes and a given asterism is no longer positioned over the point of destination, the navigator’s thorough Gestalt-like familiarity with the sky allows him mentally to adjust to the new conditions: he can derive through

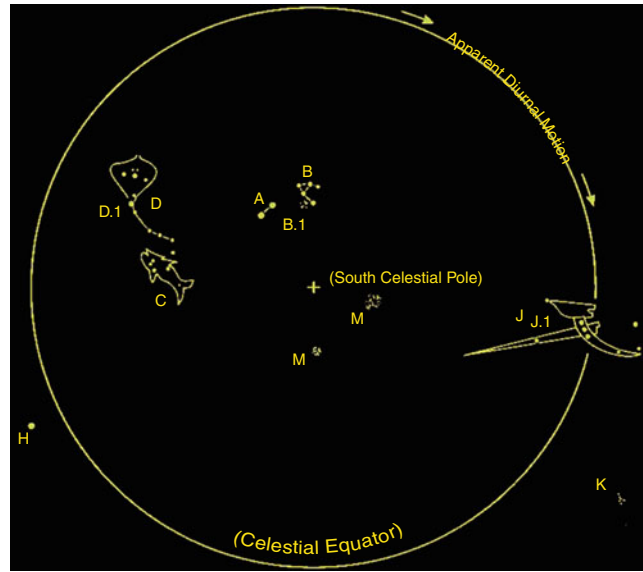
visualization the points on the horizon at which the stars rise or set relative to wherever they currently appear. When a certain asterism simply is not visible, other associated but unnamed stars may be used to remind the navigator where the original asterism set or is about to rise or they may be used instead of the missing asterism. This, by the way, appears to be analogous to the “star path, the succession of rising or setting guiding stars down which one steers” described by Lewis for several cultures in Polynesia and Micronesia (1972, pp. 46–47). The stars identified by Bugis navigators are listed in Table 2 and illustrated in Figs. 7 and 8; those which are most relied upon will now be described.

Perhaps the most frequently used asterism among the Bugis of Balobaloang is that *bintoéng balué*, mentioned above. These two bright stars are used to locate Balobaloang from Makassar and Bima from Makassar or Balobaloang. With regard to their rise/set points, navigators observe that they appear “in the south” at dusk during toward the middle of the east monsoon, the peak period for sailing; they further note that they rise “southeast” and set “southwest.” Their brightness makes them visible even through clouds. The name *balué* is derived from *balu* that means “widow from death of the betrothed before marriage” with the affix *é* forming the definite article. Hence: “the one widowed before marriage.” No graphical figure is attributed to this asterism.

Just to the west of “Alpha&Beta Centauri” is *bintoéng bola képpang* (Crux), visualized as an “incomplete house of which one post is shorter than the other and, therefore, appears to be limping” (B in Fig. 7). Crux is used in conjunction with Alpha and Beta Centauri to navigate along southerly routes; like Alpha and Beta Centauri, it is known to set “southwest.” Interestingly, it was emphasized that Crux is also used to help in predicting the weather. This asterism is located in the Milky Way that is known to the Bugis as *bintoéng nagaé* “the dragon,” whose head is in the south and whose tail wraps all around the sky. As such, a bright haze of starlight surrounds Crux. On the eastern side of the house, however, there is a small dark patch totally devoid of light which is seen as a *bembé* ‘goat’

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Fig. 7 Bugis navigational stars: southern sky



Astronomy in the Indo-Malay Archipelago, Table 2 Bugis stars and asterisms familiar to navigators

Asterism	Bugis name ^a	English gloss	International designation
A	<i>bintoéng balué</i>	Widow-before-marriage	Alpha and Beta Centauri
B	<i>bintoéng bola képpang</i>	Incomplete house	Alpha-Delta, Mu Crucis
B.1	<i>bembé</i>	Goat	Coal Sack Nebula in Crux
C	<i>bintoéng balé mangngiweng</i>	Shark	Scorpius (south)
D	<i>bintoéng lambarué</i>	Ray fish, skate	Scorpius (north)
D.1	(Identified w/o name)	Lost Pleiad	Alpha Scorpii (Antares)
E	<i>bintoéng kappala`é</i>	Ship	Alpha-Eta Ursa Majoris
F	<i>bintoéng kappala`é</i>	Ship	Alpha-Eta Ursa Majoris; Beta, Gamma Ursa Minoris
G	<i>bintoéng balu Mandara`</i>	Mandar widow	Alpha, Beta Ursa Majoris
H	<i>bintoéng timo` or bintoéng timoro` (Mak)^b</i>	Eastern star	Alpha Aquilae (Altair)
J	<i>pajjékoé (Mak.)^b or bintoéng rakkalaé</i>	Plough stars	Alpha-Eta Orionis
J.1	<i>tanra tellué</i>	Sign of three	Delta, Epsilon, Zeta Orionis
K	<i>worong-poronggé bintoéng pitu</i>	Cluster seven stars	M45 in Taurus (Pleiades)
M	<i>tanra Bajoé</i>	Sign of the Bajau	Large and small magellanic clouds
□	<i>wari-warié</i>	(No gloss)	Venus: morning
□	<i>bintoéng bawi</i>	Pig star	Venus: evening
□	<i>bintoéng nagaé</i>	Dragon stars	Milky way

^aThe Bugis term for “star(s)” is *bintoéng*; the suffix *é* may be translated as the definite article “the” in English

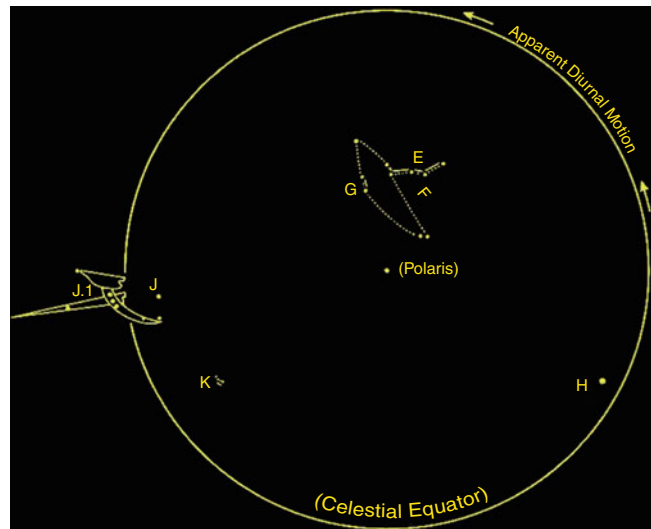
^bAlthough *timoro`* and *pajjékoé* are Makassar terms, they are more commonly used than the Bugis terms on Balobaloang

(B.1 in Fig. 7). Between the squall clouds of the rainy season the goat in the sky may be seen standing, as goats are wont to do, outside the house trying to get in out of the rain. There are

nights, however, when the goat is gone from the protection of the house. Hidden by haze, the missing goat portends a period of calm air and little rain.

Astronomy in the Indo-Malay Archipelago,

Fig. 8 Bugis navigational stars: northern sky



A

In the northern sky the asterism that figures most prominently in Bugis navigation is known as *bintoé ng kappala'é*, “the ship stars” in the international constellation of Ursa Majoris (two versions, E and F, in Fig. 8). The “ship” is used when traveling north and is known to rise “northeast” and sets “northwest” over Kalimantan from the port city of Makassar and from Balobaloang. Associations of this group of stars with the hull of a boat or ship appear to be common throughout the region.

The two stars of *balu Mandara* “widow of the Mandar” (G in Fig. 8) adjoin the “ship” and are likewise used to navigate northward. These two stars, Alpha and Beta Ursa Majoris, remind the Bugis of Alpha and Beta Centauri (thus the name *balu*), while “Mandar” recalls their northern seafaring neighbors.

Several asterisms and a planet are used for sailing ► east and west. They include: *timoro* (Makassar) or *bintoéng timor* (Bugis) “eastern star” (Altair; H in Fig. 8); *pajjékoé* (Makassar) or *bintoéng rakkalaé* (Bugis) “the plough stars” (Alpha-Eta Orionis; J in Figs. 7 and 8); *tanra tellué* “the sign of three” (Delta, Epsilon, Zeta Orionis; J.1 in Figs. 7 and 8); *wari-warié* [no gloss] or *bintoéng élé* “morning star” (Venus in predawn sky); and *bintoéng bawi* “pig star” (Venus in evening sky), so named since it is believed that wild pigs will enter and destroy a garden or orchard when this object shines

brightly in the west. Both the “pig star” and the “plough,” by the way, speak to an agrarian lifestyle not practiced by Bugis seafarers but culturally shared with their kin who farm the lands of South Sulawesi as well as other islands of the archipelago. See Pelras (1987) for the astronomical knowledge of Bugis rice farmers.

Although the stars are useful guides, they are not always visible. Because it is possible to see landfall during the day, navigators appear to plan their voyages so as to maximize its usage. On a voyage from Balobaloang to Bima, the captain scheduled the departure for mid-afternoon allowing him to back-sight on Balobaloang and other islands of the atoll and observed the sun as it set in the west until dusk when Alpha and Beta Centauri appeared in the sky. There was, in fact, a period of about 30 min where both the receding island and the stars could be seen, providing a good opportunity to maintain course as attention was shifted from land forms to the stars.

Except during the height of the west monsoon, it is uncommon to experience extended periods of totally overcast skies. Should, however, the primary guiding asterism may be concealed by clouds, the navigator depends upon his knowledge of other asterisms or unnamed stars to fix his direction. If it is very cloudy, day or night, the navigator turns to wave directions and the magnetic compass to maintain course.

Although the more experienced navigators say that they could do without it and rely on wind, waves, and stars, the magnetic compass plays a central role in contemporary Bugis navigation and their presence should be of no surprise. Magnetic compasses, Liebner (2005) points out, have been used aboard the larger inter-island ships since the eighteenth century. On frequently sailed routes the helmsman knows from experience or from the navigator's instructions the proper compass bearing which will guide the boat toward its objective. At night under mostly clear skies, the helmsman points the ship's bow toward a succession of guide stars whose own azimuths change as the night passes. To compensate for this change, he checks the compass about once per hour, sometimes after several minutes of calling to a sleepy crew member for a flashlight or match by which to see it. On cloudy nights, when few or no stars are to be seen, the helmsman's job is much harder. Complicated by an often-unsteady helm, the helmsman is forced to check the compass every minute or so with a flashlight whose batteries are soon run down through constant use. By day the compass is generally observed more often regardless of the weather, although the sun, when low in the sky, is used as a reference.

Courses are committed to memory in terms of destinations and their required compass headings under various winds. That is, certain points of the compass are associated with certain destinations from various ports. For example, it is known that to sail from Balobaloang to Bima during the east monsoon, one must head due south, while during the west monsoon one heads south-southwest to southwest, depending on the strength of the wind and current. Likewise, to reach Makassar from the island during the east monsoon one travels somewhat east of north, while during the west monsoon a heading to the north-northwest is preferred. This difference, as navigators are quick to point out, takes into account drift from wind and currents, while true directions are also known. Practiced navigators have many of these bearings committed to memory and will refer to the experience of others as well as to charts and maps when they wish to travel to new or infrequent destinations.

On the author's initial voyage aboard a Bugis ship, the route traveled was well known to the seafarers of Balobaloang: Makassar to Bima via the island, a distance of about 212 nautical miles. Over the course of 4 days and 5 nights at sea without an auxiliary engine – and on later voyages after an engine had been installed – only occasionally were the helmsman or captain seen referring to the compass, and rarely at night or when in sight of land. When asked about this, both agreed that the compass could be used through the night, but to do so one would have to light the flashlight “so why not just use the stars?” Even if the compass were thrown overboard, we were assured the navigator could find his way.

Summary and Conclusion

This article has presented several examples of indigenous Indonesian calendrical and navigational systems and describes the celestial observations upon which they are based. It has also attempted to provide categories, drawn from international scientific astronomy, into which these observations may be placed.

With regard to the study of indigenous astronomical systems worldwide, there appear in regional agricultural calendars two types of celestial observations that may be unique to this cultural region. They are (1) observations of “cosmical” and “acronical” culminations – meridian transits at last and first gleam – of groups of stars and (2) observations of the lunar month for a limited number of months each year, creating discontinuous sidereal-lunar calendars. The use of stars by the Bugis navigators of South Sulawesi likewise appears represent a system that, along with its transformations used by Oceanic mariners, appears to be unique to the Austronesian world.

Implicit in the discussion of agricultural calendrical and navigation systems is the understanding that celestial observations do not stand alone. That is, many other environmental markers – changes in wind and weather and the appearances of flora and fauna also inform agricultural and

navigational decision-making. It is suggested that by noting more carefully these and other signs in nature to which members of non-Western societies attend, we may gain a deeper appreciation of the true richness of human knowledge across cultures.

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Astronomy in the Islamic World

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From the ninth to the fifteenth century, Muslim scholars excelled in every branch of scientific knowledge; their contributions in astronomy and mathematics are particularly impressive. Even though there are an estimated 10,000 Islamic astronomical manuscripts and close to 1,000 Islamic astronomical instruments preserved in libraries and museums, and even if all of them were properly catalogued and indexed, the picture that we could reconstruct of Islamic astronomy, especially for the eighth, ninth, and tenth centuries, would still be quite deficient. Most of the available manuscripts and instruments date from the later period of Islamic astronomy, i.e., from the fifteenth to the nineteenth century, and although some of these are based or modeled on earlier works, many of the early works are extant in unique copies and others have been lost almost without trace; i.e., we know only of their titles. The thirteenth century Syrian scientific biographer Ibn al-Qifā relates that the eleventh century Egyptian astronomer Ibn al-Sanbadī heard that the manuscripts in the library in Cairo were being catalogued and so he went to have a look at the works relating to his field. He found 6,500 manuscripts relating to astronomy, mathematics, and philosophy. Not one of these survives amongst the 2,500 scientific manuscripts preserved in Cairo today.

The surviving manuscripts thus constitute but a small fraction of those that were actually copied; nevertheless they preserve a substantial part of the Islamic scientific heritage, certainly enough of it for us to judge its level of sophistication. Only in the past few decades has the scope of the activity and achievements of Muslim scientists become apparent, and the days are long past when they were regarded merely as transmitters of superior ancient knowledge to ignorant but eager Europeans. Islamic astronomy is to be viewed on its own terms. The fact that only a small part of the available material, mainly Greek and Indian material in Arabic garb, was indeed transmitted to Europe is to be viewed as an accident of Islamic history. There is no need to apologize for using the expression “Islamic astronomy.” Within a few decades of the death of the Prophet Muḥammad in the year 632, the Muslims had established a commonwealth stretching from Spain to Central Asia and India. They brought with them their own folk astronomy, which was then mingled with local traditions, and they discovered the mathematical traditions of the Indians, Persians, and Greeks, which they mastered and adapted to their needs. Early Islamic astronomy was thus a pot-pourri of pre-Islamic Arabian starlore and Indian, Persian, and Hellenistic astronomy, but by the tenth century Islamic astronomy had acquired very distinctive characteristics of its own. Sabra (1987) labels this process “appropriation and naturalization.”

Astronomy flourished in Islamic society on two different levels: folk astronomy, devoid of theory and based solely on what one could see in the sky, and mathematical astronomy, involving systematic observations and mathematical calculations and predictions. Folk astronomy was favored by the scholars of the sacred law (*fuqahā*), not least because of various religious obligations that demanded a basic knowledge of the subject; these legal scholars generally had no time (or need) for mathematical astronomy. That discipline was fostered by a select group of scholars, most of whose activities and pronouncements were, except in the case of astrological predictions, of little interest to society at large.

The astronomers also played their part in applying their discipline to certain aspects of Islamic religious practice. It was not Islam that encouraged the development of astronomy but the richness of Islamic society, a highly literate, tolerant, multiracial society with a predominant cultural language, Arabic: but neither did Islam, the religion, stand in the way of scientific progress. The Prophet had said: “Seek knowledge, even as far as China.” To be sure, overzealous orthodox rulers occasionally pursued, killed, or otherwise attacked “scientists” or destroyed or burnt their libraries, but these were exceptions. The scholars of the religious law, who saw themselves as the representatives of Islam, generally ignored the pronouncements of the scientists, even on matters relating to religious practice. Astronomy was the most important of the Islamic sciences, as we can judge by the volume of the associated textual tradition, but a discussion of it in the broader context of the various branches of knowledge, which has been attempted several times elsewhere, is beyond the scope of this essay.

Arab Starlore

The Arabs of the Arabian peninsula before Islam possessed a simple yet developed astronomical folklore of a practical nature. This involved a knowledge of the risings and settings of the stars, associated in particular with the acronychal settings of groups of stars and simultaneous heliacal risings of others, which marked the beginning of periods called *naw*’, plural *anwā*’. These *anwā*’ eventually became associated with the 28 lunar mansions, a concept apparently of Indian origin. A knowledge of the passage of the sun through the 12 signs of the zodiac, associated meteorological and agricultural phenomena, the phases of the moon, as well as simple time-reckoning using shadows by day and the lunar mansions by night, formed the basis of later Islamic folk astronomy.

More than 20 compilations on the pre-Islamic Arabian knowledge of celestial and meteorological phenomena as found in the earliest Arabic

sources of folklore, poetry, and literature are known to have been compiled during the first four centuries of Islam. The best known is that of ► [Ibn Qutayba](#), written in Baghdad about the year 860. Almanacs enumerating agricultural, meteorological, and astronomical events of significance to local farmers were also compiled; several examples of these survive from the medieval Islamic period, one such being for Cordoba in the year 961. The Yemen possessed a particularly rich tradition of folk astronomy, and numerous almanacs were compiled there.

Since the sun, moon, and stars are mentioned in the *Qurʾān*, an extensive literature dealing with what may well be labeled Islamic folk cosmology arose. This was inevitably unrelated to the more “scientific” Islamic tradition based first on Indian sources and then predominantly on Greek ones. Since it is also stated in the *Qurʾān* that man should use these celestial bodies to guide him, the scholars of the religious law occupied themselves with folk astronomy.

Persian and Indian Sources

The earliest astronomical texts in Arabic seem to have been written in Sind and Afghanistan, areas already conquered by the Muslims in the seventh century. Our knowledge of these early works is based entirely on citations from them in later works. They consisted of texts and tables and were labeled ► [zīj](#) after a Persian word meaning “cord” or “thread” and by extension “the warp of a fabric,” which the tables vaguely resemble. The Sasanian *Shahriyārān Zīj* in the version of Yazdigird III was translated from Pahlavi into Arabic as the *Shāh Zīj*, and the astronomers of al-Manṣūr chose an auspicious moment to find his new capital Baghdad using probably an earlier Pahlavi version of this *zīj*. The various horoscopes computed by Māshāʾallāh (Baghdad, ca. 800) in his astrological world history are based on it.

Significant for the subsequent influence of Indian astronomy in the Islamic tradition was the arrival of an embassy sent to the court of the Caliph al-Manṣūr from Sind ca. 772. This

embassy included an Indian well versed in astronomy and bearing a Sanskrit astronomical text apparently entitled the *Māhasiddhānta* and based partly on the *Brāhmasphuṭasiddhānta*. The Caliph ordered al-Fazārī to translate this text into Arabic with the help of the Indian. The resulting *Zīj al-Sindhind al-kabīr* was the basis of a series of *zīj*es by such astronomers as al-Fazārī, ► [Yaʿqūb ibn ṭāriq](#), ► [al-Khwārizmī](#), and others, all prepared in Iraq before the end of the tenth century. The *Sindhind* tradition flourished in Andalusia, mainly through the influence there of the *Zīj* of al-Khwārizmī (see below). As a result, the influence of Indian astronomy is attested from Morocco to England in the late Middle Ages.

Greek Sources

The *Almagest* of Ptolemy (Alexandria, ca. 125) was translated at least five times in the late eighth and ninth centuries. The first was a translation into Syriac and the others were into Arabic, the first two under ► [al-Maʾmūn](#) in the middle of the first half of the ninth century, and the other two (the second being an improvement of the first) towards the end of that century. All of these were still available in the twelfth century, when they were used by Ibn al-ṣalāḥ for his critique of Ptolemy’s star catalogue. The translations gave rise to a series of commentaries on the whole text or parts of it, many of them critical, and one, by Ibn al-Haytham (ca. 1025), actually entitled *al-Shukūk fī Baṭlamīyūs* (Doubts about Ptolemy). The most commonly used version in the later period was the recension of the late ninth century version by the polymath ► [Naṣīr al-Dīn al-Ṭūsī](#) in the mid-thirteenth century. Various other works by Ptolemy, notably the *Planetary Hypotheses* and the *Planisphaerium*, and other Greek works, including the short treatises by Autolycos, Aristarchos, Hypsicles, and Theodosios, and works on the construction known as the analemma for reducing problems in three dimensions to a plane, were also translated into Arabic; most of these too were later edited by al-Ṭūsī. In this way Greek planetary

models, uranometry, and mathematical methods came to the attention of the Muslims. Their redactions of the *Almagest* not only reformulated and paraphrased its contents, but also corrected, completed, criticized, and brought the contents up to date both theoretically and practically.

Theoretical Astronomy

The geometrical structure of the universe conceived by Muslim astronomers of the early Islamic period (ca. 800–1050) is more or less that expounded in Ptolemy's *Almagest*, with the system of eight spheres being regarded essentially as mathematical models. However, in Ptolemy's *Planetary Hypotheses* these models are already taken as representing physical reality; this text also became available in Arabic. Several early Muslim scholars wrote on the sizes and relative distances of the planets, and one who proposed a physical model for the universe was Ibn al-Haytham (fl. Cairo, ca. 1025). In order to separate the two motions of the eighth sphere, the motion of the fixed stars due to the precession of the equinoxes, and the motion of the fixed stars due to the apparent daily rotation, he proposed a ninth sphere to impress the apparent daily rotation on the others.

Of considerable historical interest are various Arabic treatises on the notion of the trepidation of the equinoxes. This theory, developed from Greek sources, found followers who believed that it corresponded better to the observed phenomena than a simple theory of uniform precession. The mathematical models proposed were complex and have only recently been studied properly (notably those of Pseudo-Thābit (date unknown) and ► [Ibn al-Zarqāllu](#) (Andalusia, ca. 1070), who seems to have relied on his predecessor Šā'id al-Andalusī). The theory of trepidation continued to occupy certain Muslim scholars (in the late period mainly in the Maghrib), as it did European scholars well into the Renaissance.

Other significant Islamic modifications to Ptolemaic planetary models, devised to overcome the philosophical objections to the notion

of an equant and the problem of the variation in lunar distance inherent in Ptolemy's lunar model, belong to the later period of Islamic astronomy. There were two main schools, one of which reached its fullest expression in Maragha in northwestern Iran in the thirteenth century (notably with al-Ṭūsī and his colleagues) and Damascus in the fourteenth (with Ibn al-Shāṭir), and the other developed in Andalusia in the late twelfth century (with al-Bīṭrūjī). The latter tradition was doomed from the outset by a slavish adherence to (false) Aristotelian tenets and by mathematical incompetence. The former was based on sophisticated modifications to Ptolemy's models, partly inspired by new observations; Ptolemy himself would have been impressed by it, as have been modern investigators, for the tradition has been rediscovered and studied only in the latter half of this century. In the 1950s Kennedy discovered that the solar, lunar, and planetary models proposed by Ibn al-Shāṭir in his book *Nihāyat al-su'l* (the Final Quest Concerning the Rectification of Principles) were different from those of Ptolemy; indeed they were mathematically identical to those of Copernicus some 150 years later. In this work Ibn al-Shāṭir laid down the details of what he considered to be a true theoretical formulation of a set of planetary models describing planetary motions, and actually intended as alternatives to the Ptolemaic models. He maintained the geocentric system, whereas Copernicus proposed a hypothesis, which he was unable to prove, that the sun was at the center of things. Nevertheless this important discovery raised the interesting question of whether Copernicus might have known of the works of the Damascene astronomer. Since the 1950s we have progressed to a new stage of inquiry: we now know that there was a succession of Muslim astronomers from the eleventh to the sixteenth century who concerned themselves with models different from those of Ptolemy, all designed to overcome what were seen as flaws in them. The question we may now ask is: was Copernicus influenced by any of these Muslim works? The answer is unsatisfactory, namely, that he must have been; definitive proof is, however, still lacking.

Mathematical Astronomy: The Tradition of the *Zijes*

The Islamic *zīj*es constitute an important category of astronomical literature for the historian of science, by virtue of the diversity of the topics dealt with, and the information that can be obtained from the tables. Kennedy (1956) published a survey of about 125 Islamic *zīj*es. We now know of close to 200, and material is available for a revised version of Kennedy's *zīj* survey. To be sure, many of these works are lost, and many of the extant ones are derived from other *zīj*es by modification, borrowing, or outright plagiarism. Nevertheless, there are enough *zīj*es available in manuscript form to reconstruct a reasonably accurate picture of Muslim activity in this field.

Most *zīj*es consist of several hundred pages of text and tables; the treatment of the material presented may vary considerably from one *zīj* to another. The following topics are handled in a typical *zīj*:

1. Chronology
2. Trigonometry
3. Spherical astronomy
4. Solar, lunar, and planetary mean motions
5. Solar, lunar, and planetary equations
6. Lunar and planetary latitudes
7. Planetary stations
8. Parallax
9. Solar and lunar eclipses
10. Lunar and planetary visibility
11. Mathematical geography (lists of cities with geographical coordinates), determination of the direction of Mecca
12. Uranometry (tables of fixed stars with coordinates)
13. Mathematical astrology

As noted above, by the eighth century a number of Arabic *zīj*es had been compiled in India and Afghanistan. These earliest examples, based on Indian and Sasanian works, are lost, as are the earliest examples compiled at Baghdad in the eighth century. With the *zīj*es compiled in Baghdad and Damascus in the early ninth century under the patronage of the Caliph *al-Ma'mūn*,

we are on somewhat firmer ground. These follow either the tradition of Ptolemy's *Almagest* and *Handy Tables* or the Indian tradition. Manuscripts exist of the *Mumtaḥan Zīj* of *Yaḥyā ibn Abī Maṣṣūr* and the Damascus *Zīj* of Ḥabash, each of which was based on essentially Ptolemaic theory rather than Indian. The *Zīj* of *al-Khwārizmī*, based mainly on the Persian and Indian traditions, has survived only in a Latin translation of an Andalusian recension. Amongst the most important and influential later works of this genre are: the *ṣābi' Zīj* of *al-Battānī* of Raqqa, ca. 910; the *ḥākīmī Zīj* of Ibn Yūnus, compiled in Cairo at the end of the tenth century; the *zīj* called *al-Qānūn al-Maṣ'ūdī* by al-Bīrūnī, compiled in Ghazna about 1025; the *Zīj* of Ibn Ishāq, compiled in Tunis, ca. 1195; the *I lkhānī Zīj* of *Naṣīr al-Dīn al-Ṭūsī*, prepared in Maragha in northwestern Persia in the mid-thirteenth century; and the *Sulṭānī Zīj* of Ulugh Beg from early fifteenth century Samarkand.

Although the *zīj*es are amongst the most important sources for our knowledge of Islamic mathematical astronomy, it is important to observe that they generally contain extensive tables and explanatory text relating to mathematical astrology as well. Islamic astrological texts form an independent corpus of literature, mainly untouched by modern scholarship. Often highly sophisticated mathematical procedures are involved. It should also be pointed out that in spite of the fact that astrology was anathema to Muslim orthodoxy, it has always been (and still is) widely practiced in Islamic society.

All early Islamic astronomical tables have entries written in Arabic alphanumerical notation (*abjad*) and expressed sexagesimally, i.e., to base 60. A number written in letters equivalent to "23 30 17 s" (Ulugh Beg's value for the obliquity) stands for $23 + 30/60 + 17/3,600$, i.e., $23^\circ 30' 17''$. In sexagesimal arithmetic, more so than in decimal arithmetic, it is useful to have a multiplication table at hand, and such tables, with 3,600 or even 216,000 entries, were available.

Already in the early ninth century Muslim astronomers had restyled the cumbersome Indian sine function using the Greek base 60 (which the Greeks had used for their even more cumbersome

chord function). Likewise the Indian shadow functions, unknown in Greek astronomy, were adopted with different bases (12, 6, $6\frac{1}{2}$, and 7, and also 60, and occasionally 1). Most *zīj*es contain tables of the sine and (co)tangent function for each whole, or half, or quarter degree of arc. Entries are generally given to three sexagesimal digits, corresponding roughly to five decimal digits. However, certain Muslim scholars compiled more extensive sets of trigonometric tables that were not included in *zīj*es. In the early tenth century al-Samarqandī prepared a set of tables of the tangent function with entries to three sexagesimal digits for each minute of arc. Later in the same century Ibn Yūnus tabulated the sine function to five sexagesimal digits, equivalent to about nine decimal digits, for each minute of arc, also giving the differences for each second. He also tabulated the tangent function for each minute of arc, and the solar declination for each minute of solar longitude. His trigonometric tables were not sufficiently accurate to warrant this number of significant figures, and indeed over four centuries were to elapse before the compilation in Samarqand of the magnificent trigonometric tables in the *Sulṭānī* ► *Zīj* of Ulugh Beg, which display the values of the sine and tangent to five sexagesimal digits for each minute of argument and are generally accurate in the last digit.

Planetary Tables and Ephemerides

Given the Ptolemaic models and tables of the mean motion and equations of the sun, moon, and planets were available to Muslim astronomers in the *Almagest* and *Handy Tables*, or the corresponding tables based on Indian models that exemplify the *Sindhind* tradition, Muslim astronomers from the ninth to the sixteenth century sought to improve the numerical parameters on which these tables were based. Most of the leading Muslim astronomers of the early period made solar observations and computed new solar equation tables. Ibn Yūnus is the only astronomer from the first four centuries of Islam known to have compiled a new set of lunar equation tables. The majority of Islamic planetary

equation tables are Ptolemaic, and where exceptions do occur, such as in the tables of Ibn al-Aʿlām and Ibn Yūnus for Mercury, we find that they are based on a Sasanian parameter rather than on any new observations.

Ptolemy used the same data as Hipparchus for his determination of the solar apogee and hence obtained the same result. The Muslims thus inherited the notion that the solar apogee is fixed with respect to the fixed stars (although the planetary apogees move with the motion of precession), and it is to their credit that their earliest observations established that the solar apogee had moved about 15° since the time of Hipparchus. Most early Muslim astronomers accepted the *Mumtaḥan* value of 1° in 66 Persian years (actually a parameter attested in earlier Persian sources) for both precession and the motion of the apogees. Ibn Yūnus possessed all the necessary data that could be used to demonstrate that the motion of the solar apogee is not the same as the motion due to precession, but he chose to use the same value for both, 1° in $70\frac{1}{4}$ Persian years, which happens to be remarkably close to the actual rate of precession. ► *Al-Bīrūnī* (Central Asia, ca. 1025) seems to have been the first to distinguish the proper motion of the solar apogee from the motion of precession (this discovery is sometimes erroneously attributed to al-Battānī). It was ► *Ibn al-Zarqāllu* (Andalusia, ca. 1070) who was the first to assign a numerical value to both motions, although he also subscribed to the theory of trepidation.

All Islamic *zīj*es contained tables of mean motions and equations for computing solar, lunar, and planetary positions for a given time. Some of the equation tables are arranged in a form more convenient for the user (so that one simply has to enter the mean motions, and calculations are avoided). Auxiliary tables were sometimes available for generating ephemerides without the tedious computation of daily positions from mean-motion and equation tables. From the ninth to the nineteenth centuries Muslim astronomers compiled ephemerides displaying solar, lunar, and planetary positions of each day of the year, as well as information on the new moons and astrological predictions resulting from the

position of the moon relative to the planets. Al-Bīrūnī described in detail how to compile ephemerides in his astronomical and astrological handbook *al-Taḥḥīm fī ṣināʿat al-tanjīm* (Instruction in the Art of Astrology). Manuscripts of ephemerides had a high rate of attrition since the tables could be dispensed with at the end of the year: the earliest complete extant examples are from fourteenth century Yemen, discovered in Cairo in the 1970s and still unpublished; on the other hand, literally hundreds of ephemerides survive from the late Ottoman period.

Stellar Coordinates and Uranography

Most *zīj*es contain lists of stellar coordinates in either the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course) or the equatorial systems, or occasionally in both. A survey of the stellar coordinates in Islamic *zīj*es would be a valuable contribution to the history of Islamic astronomy, and could help to determine the extent to which original observations were made by Muslim astronomers. An impressive amount of research on Arabic star names and their later influence in Europe has been conducted in the last few years by Paul Kunitzsch.

In his *ṣuwar al-kawākib* (Book of Constellation Figures) the tenth century Shiraz astronomer ► al-Šūfī presented lists of stellar coordinates as well as illustrations of the constellation figures from the Hellenistic tradition and also information on the lunar mansions following the Arab tradition. Later Islamic works on uranography are mostly restricted to Persian and Turkish translations of al-Šūfī, although some astrological works also contain illustrations of the constellations that have recently attracted the attention of historians of Islamic art.

Spherical Astronomy and Spherical Trigonometry

Most *zīj*es contain, in their introductory text, the solutions of the standard problems of spherical

astronomy, such as, to give only one example, the determination of time from solar and stellar altitude. Rarely any explanation given of how the formulae outlined in words in the text were derived. There were two main traditions. In the first, the problems relating to the celestial sphere are reduced to geometric or trigonometric problems on a plane. The construction known as the analemma was a singularly powerful tool for solutions of this kind. In the second, the problems are solved by applications of rules of spherical trigonometry. Both techniques are ultimately of Greek origin, and Muslim scholars made substantial contributions to each.

There is some confusion about these contributions in the modern literature. It has been assumed by modern writers that when a medieval writer used a medieval formula that is mathematically equivalent to the modern formula derived by a specific rule of spherical trigonometry, the medieval scholar must have known the equivalent of the modern rule of spherical trigonometry. In fact, however, the medieval formula may have been derived without using spherical trigonometry at all. The first known Islamic treatise dealing with spherical trigonometry independently of astronomy is by the eleventh century Andalusian Ibn Muʿādh. The contributions to spherical astronomy by scholars such as Thābit ibn Qurra, ► al-Nayrīzī, Abu'l-Wafā' al-Būzajānī, ► al-Khujandī, Kūshyār ibn Labbān, ► al-Sijzī, and Abū Naṣr are outlined in the recently rediscovered *Maqālīd fī 'ilm al-hay'a* (Keys to Astronomy) of ► al-Bīrūnī, also from the eleventh century.

Already in the work of Ḥabash in the mid-ninth century we find a Muslim astronomer at ease with both spherical trigonometrical methods and analemma constructions for solving problems of spherical astronomy. In the *Zīj*es of scholars of the caliber of Ibn Yūnus and al-Bīrūnī we find various methods for solving each of the standard problems of medieval spherical astronomy. The auxiliary trigonometric tables compiled by such scholars as Ḥabash, Abū Naṣr (Khwarizm, ca. 1000), and al-Khalīlī (Damascus, ca. 1360) for solving all of the problems of spherical astronomy for any latitude are a remarkable testimony to their mastery of the subject.

Observation Programs and Regional Schools of Astronomy: Al-Ma'mūn's Circle

In the early ninth century the Abbasid Caliph ► al-Ma'mūn patronized observations first in Baghdad and then in Damascus, gathering the best available astronomers to conduct observations of the sun and moon. Some of the results were incorporated into a ► zīj called *al-Mumtaḥan*, "tested," although the details of the activities at the two observation posts are somewhat confusing. The *Mumtaḥan Zīj* was apparently compiled in Baghdad by ► Yahyā ibn Abī Maṣṣūr, but upon his death, according to Ḥabash, the Caliph ordered his colleague Khālīd al-Marwarrūdhī to prepare some new instruments and conduct a 1-year program of solar and lunar observations in Damascus in order to compile a new zīj. According to Ḥabash this was done, but no such zīj is otherwise known to have been prepared before Ḥabash's own *Damascus Zīj*. Also simultaneous observations of a lunar eclipse were conducted at Baghdad and Mecca, and the longitude difference used together with the newly measured latitudes of the two localities to find the *qibla* at Baghdad.

These observations, like later ones, were mainly directed towards determining the local latitude and current value of the obliquity, and towards deriving improved parameters for the Ptolemaic planetary models and more accurate star positions. The armillary sphere, the meridian quadrant, and the parallactic ruler were known to the Muslims from the *Almagest*, and they added new scales and other modifications, often building larger instruments even when smaller ones would have sufficed. Our knowledge of the instruments used by al-Ma'mūn's astronomers is meager. An armillary sphere used by Yahyā in Baghdad was said to display markings for each 10 min of arc, but even contemporary astronomers were not impressed by the precision of the results obtained using it. A mural quadrant made of marble with a radius of about 5 m was used in Damascus, as well as a vertical gnomon made of iron standing about 5 m high. Al-Ma'mūn also patronized measurements of the longitude

difference between Baghdad and Mecca in order to establish the *qibla* at Baghdad properly, as well as measurements of the length of 1° of terrestrial latitude.

Other Observational Programs

Besides the officially sponsored observations conducted in Baghdad and Damascus in the early ninth century, there are numerous instances of other series of observations conducted in different parts of the Muslim world.

The two brothers called ► Banū Mūsā made observations in their own house in Baghdad and also in nearby Samarra about 30 years after the *Mumtaḥan* observations. They also arranged for simultaneous observations of a lunar eclipse in Samarra and Nishapur in order to determine the difference in longitude between the two cities. In view of their proficiency in mathematics, it is most unfortunate that neither of the two zījes compiled by them has survived.

► Al-Battānī carried out observations during the period 887–918 in Raqqa in northern Syria. He appears to have financed his observational activity himself, and although we have no description of the site where he made his observations, the instruments mentioned in the zīj based on his observations include an armillary sphere and mural quadrant, as well as a parallactic ruler, an astrolabe, a gnomon, and a horizontal sundial.

The observational activities of the Baghdad family known as the Banū Amājūr were almost contemporaneous with those of al-Battānī in Raqqa. Father and two sons, and also a freed family slave, all made observations and each compiled a ► zīj, none of which survives. In the accounts of their ► eclipse observations recorded by Ibn Yūnus it appears that the place where they conducted their observations had some kind of a balcony fitted with slits for observation, but the details are obscure. A particularly interesting account of a solar eclipse in the year 928 that they observed by reflection in water includes a remark that the altitude of the sun was measured on an instrument marked for each third of a degree.

A large mural quadrant was erected at Rayy (near modern Tehran) about the year 950, but we have information only on its use to establish the local latitude and obliquity of the ecliptic. In Shiraz not long thereafter, ► [al-Šūfī](#) used an armillary sphere with a diameter of about 5 m to derive the same parameters and to “observe” equinoxes and solstices. Al-Šūfī is best known for his work on the fixed stars, but it seems that this was based more on “observation,” looking at the heavens with the naked eye, than on “measurement,” looking at the heavens with precision instruments and making estimates of positions. Another contemporary astronomer who conducted observations on which we have no information other than the main parameters of his *zīj* was Ibn al-A‘lam.

In the late tenth century the distinguished mathematician and astronomer Abu’l-Wafā’ al-Būzajānī made observations in Baghdad. Most of these appear to have been directed towards the determination of the solar parameters, and the obliquity of the ecliptic and the latitude of Baghdad, although Abu’l-Wafā’ also collaborated with ► [al-Bīrūnī](#) in Khwārizm (modern Khiva in Turkmenistan) on the simultaneous observation of a lunar eclipse in the year 997. We have no information on the nature of the site where Abu’l-Wafā’ made his observations, other than its location in a specific quarter of Baghdad.

Contemporaneous with the activity of Abu’l-Wafā’ was the establishment in 988 of an observatory in the garden of the Baghdad residence of the Buwayhid ruler Sharaf al-Dawla. The organization of a building and program of observations was entrusted to Abū Sahl al-Qūhī, a mathematician of considerable standing. We know from contemporary historical records that a special building was erected for the observations, which in turn were witnessed by “judges, scientists and scholars of note, astronomers, and engineers.” In view of the favorable conditions under which this observatory was established, and the competence of its director, it is somewhat surprising that the two recorded “observations” that were witnessed by so many dignitaries were the entry of the sun into Cancer and Libra in the year 988. Al-Bīrūnī

describes the main instrument that was constructed as a hemisphere of radius 12.5 m on which the solar image was projected through an aperture at the center of the hemisphere. Activity at the observatory stopped in 989 with the death of Sharaf al-Dawla, so that the institution lasted not much more than a year.

In 994 Abū Maḥmūd ► [al-Khujandī](#) made a measurement of the obliquity using a meridian sextant of about 20 m radius. This instrument was erected in Rayy, but al-Khujandī confessed to al-Bīrūnī that it was so large that the center of the sextant had become displaced from its intended position.

The Egyptian astronomer Ibn Yūnus made a series of observations of eclipses, conjunctions, and occultations, as well as equinoctial and solstitial observations. We are extremely fortunate to have not only his reports of these observations, but also his citations of earlier observations of the same kind made by individuals such as Ḥabash and the Banū Amājūr. Ibn Yūnus’ purposed in making these observations and recording them in the introduction to his ► [Zīj](#) is somewhat obscured by the fact that he does not list those observations or present those calculations with which he derived his new solar, lunar, and planetary parameters. Neither does he mention any locations for his observations other than his grandfather’s house in Fustat and a nearby mosque in al-Qarāfa. The popular association of Ibn Yūnus with an observatory on the Muqāṭṭam Hills outside Cairo is, as Aydm Sayili has shown, a myth. Nevertheless, Ibn Yūnus mentions at least one instrument, probably a meridian ring, that was provided by the Fatimid Caliphs al-‘Azīz and al-ḥākīm. In a later medieval Egyptian source Ibn Yūnus is reported to have received 100 dinars a day from al-ḥākīm, and it may be that such extremely high payments were made to Ibn Yūnus when he was making satisfactory astrological predictions for the Caliph. Al-ḥākīm made an abortive attempt to find an observatory in Cairo, but this was after the death of Ibn Yūnus in 1009. At some time during his reign there was an armillary sphere in Cairo with nine rings, each large enough that a man could ride through them on horseback.

The observations of ► *al-Bīrūnī* were conducted between 990 and ca. 1025 in several localities between Khwārizm and Kabul. His recorded observations include determinations of equinoxes and solstices, eclipses, and determinations of the obliquity and local latitude.

The corpus of tables known as the *Toledan Tables* was compiled in the eleventh century, based on observations directed by Ṣāʿid al-Andalusī and continued by ► *Ibn al-Zarqāllu*. Only the mean motion tables in this corpus of tables are original; most of the remains were lifted from the *zīj*es of ► *al-Khwārizmī* and ► *al-Battānī*.

In the thirteenth century there was a substantial observational program at Maragha. The results are impressive only in so far as theoretical astronomy is concerned. Otherwise the trigonometric and planetary tables in the major production of the Maragha astronomers were modified or lifted in toto from earlier sources. This is not a happy outcome for a generously endowed observatory fitted with the latest observational instruments, known to us from texts. In the early fifteenth century the scene had moved to Samarkand in Central Asia: there, a group of astronomers, directed by the astronomer-prince Ulugh Beg, did impressive work. Only the 40-m meridian sextant survives from the observatory. These men produced a set of tables which it would be foolish to judge before they have been properly studied. The same is true for the short-lived observatory in Istanbul under the direction of Taqīʿl-Dīn (1577).

Regional Schools of Astronomy

After the tenth century they developed regional schools of astronomy in the Islamic world, with different interests and concentrations. They also had different authorities (for example, in the furthest East *al-Bīrūnī* and *al-Tūsī*, and in Egypt *Ibn Yūnus*). The main regions were Iraq, Iran and Central Asia, Muslim Spain, Egypt and Syria, the Yemen, the Maghrib, and later also the Ottoman lands. Only recently have the complex tradition of Muslim Spain (tenth to

fourteenth centuries), the colorful tradition of Mamluk Egypt and Syria (thirteenth to early sixteenth centuries), the distinctive tradition of Rasulid Yemen (thirteenth to sixteenth centuries), and the staid tradition of the Maghrib (twelfth to nineteenth centuries) has been studied. The traditions of Ottoman Turkey and Mogul India are currently being researched.

Transmission to Europe

The Europeans learned of Islamic astronomy mainly through Spain, a region where, because of political problems and the difficulty of communications, the most up-to-date writings were not always available. This explains, for example, how it came to pass that the Europeans came across two major works of Muslim astronomers from the East, *al-Khwārizmī* and *al-Battānī*, at a time when these works were no longer widely used in the Islamic East. It also explains why so few Eastern Islamic works became known in Europe. None of the Eastern Islamic developments to Ptolemy's planetary theory was known in Andalusia or in medieval Europe. *Al-Bīrūnī*'s unhappy attempt to develop planetary models confused Europeans for several centuries; he must be worth reading, they naively thought, because he was trying to reconcile Ptolemy with Aristotle. As far as astronomical timekeeping was concerned, this does not seem to have been of much concern to the Muslims in Spain; hence nothing of consequence was transmitted.

On the other hand, some early Eastern Islamic contributions, later forgotten in the Islamic East, were transmitted to Spain and thence to Europe; they have been considered European developments because evidence to the contrary has seemed to be lacking. A good example is the horary quadrant with movable cursor (the so-called *quadrans vetus*), which was invented in Baghdad in the ninth century and (at least in the version with the cursor) virtually forgotten in the Islamic East thereafter; it came to be the favorite quadrant in medieval Europe. What, if any, astronomical knowledge was transmitted through Islamic Sicily remains a mystery, and

nothing of consequence is known to have been learned about the subject by the Crusaders.

In the European Renaissance there was no access to the latest Islamic works. So the Europeans contented themselves with new editions of the ancient Greek works, with occasional, almost nostalgic, references to Albategnius ► (al-Battānī), Azarquiel (al-Zarqāllu), Alpetragius ► (al-Bīṭrījī), and the like. A few technical terms derived from the Arabic, such as alidade, azimuth, almucantar, nadir, saphea, and zenith, and a few star names such as Aldebaran, Algol, Al-tair, and Vega, survived. When the Europeans did come to learn of some of the major Islamic works and to try to come to terms with them it was as orientalists and historians of astronomy, for by this time the Islamic materials other than observation accounts were of historical rather than scientific interest. Thanks to orientalists like the Sédillots in Paris, works that had been completely unknown to Europeans and mainly forgotten by Muslims were published, translated, and analyzed. Islamic astronomy was highly respected by such scholars and others, like the historian of astronomy Delambre, who, innocent of Arabic, took the trouble to read what his colleagues had written about the subject. However, Islamic astronomy, indeed Islamic science in general, received a blow below the belt from Duhem, a physicist and philosopher ignorant of Arabic who simply ignored what scholars like the Sédillots had written. His thesis, that the Arabs were incapable of scientific thought and that whatever merits their science may have had were due to the intellectually superior Greeks, still has many followers, but only amongst those ignorant of the research of the past 150 years.

In the period after ca. 1500 Islamic astronomy declined. All of the problems had been solved, some many times over. Much of the innovative activity had led into a cul-de-sac, from which it would not emerge until modern times, thanks to investigations of manuscripts and instruments. Not that interest in astronomy died out. From Morocco to India the same old texts were copied and studied, recopied, and restudied, usually different texts in each of the main regions, but there was no new input or output of any consequence. Astronomy continued to be used as the handmaiden of astrology, and for the regulation of

the calendar and the prayer times. Where there was innovation – such as, for example, in the remarkable device made in Isfahan ca. 1700 that correctly displays the direction and distance of Mecca for any locality – one must suspect the existence of an earlier tradition. However, the old traditions died hard, and Muslim astronomers for several centuries spent more time copying old treatises and tables than compiling new ones.

During the millennium beginning ca. 750 and especially in the period up to ca. 1050, although also in the period up to ca. 1500, Muslim astronomers did first-rate work, most of which was not known in medieval Europe at all. Those few Islamic works from the early period that were transmitted, notably the *zīj*es of ► al-Khwārizmī and al-Battānī (especially through the *Toledan Tables*) and the banal summary of the *Almagest* by ► al-Farghānī, convey only an impression of classical astronomy in Arabic garb. However, they were in no way representative of contemporary Islamic astronomy in the East, and whilst the Europeans labored for centuries to come to terms with them, Muslim astronomers were making substantial contributions to their subject that have only been revealed by modern scholarship.

There is a wealth of material relating to this subject that remains untouched. Very few Islamic astronomical works have been published or have received the attention they merit. Three out of close to 200 Islamic *zīj*es have been published in the optimum way (text, translation, and commentary). We have no published edition of the Arabic versions of the *Almagest* (except for the star catalogue), or of any Arabic recensions or commentaries. Many of the published Arabic scientific texts were printed in Hyderabad, most with no critical apparatus. Likewise most of the historically important Islamic astronomical instruments are still unpublished, although the catalogue currently in preparation in Frankfurt promises to make them better known.

In 1845 Sédillot, whose privilege it was to have access to the rich collection of Arabic and Persian scientific manuscripts in the Bibliothèque Nationale in Paris, wrote: “Each day brings some new discovery and illustrates the extreme importance of a thorough study of the manuscripts of

the East.” Sédillot also realized the importance of Islamic astronomical instruments. Given the vast number of manuscripts and instruments now available in libraries and museums elsewhere in Europe, the United States, and the Near East, and the rather small number of people currently working in this field, Sédillot’s statement is no less true today than it was a century and a half ago.

See Also

- al-Battānī
- al-Bīrūnī
- al-Biṭrūjī
- al-Khwārizmī
- *Almagest: Its Reception and Transmission in the Islamic World*
- al-Ma’mūn
- al-Šūfī
- Armillary Spheres in India
- Astrology in Islam
- Astronomical Instruments in the Islamic World
- Ibn Al-Haytham (Alhazen)
- Ibn Al-Zarqāllu
- Ibn Mu‘adh
- Ibn Qutayba
- Lunar Mansions in Islam
- Marāgha
- Māshā’allāh
- Naṣīr al-Dīn al-Ṭūsī
- Observatories in the Islamic World
- Precession of the Equinoxes
- Qusṭā ibn Lūqā
- Religion and Science in Islam I: Technical and Practical Aspects
- Šā‘id al-Andalusī
- Stars in Arabic-Islamic Science
- Time
- Ulugh Bēg
- Zīj

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Astronomy in Tibet

Yukio Ōhashi

Tibetan astronomy is a living form of traditional astronomy, and is the basis of the Tibetan calendar which is used in Tibet and in Tibetan communities in India, and other places in the world.

There are four branches of Tibetan astronomical science (*rtsis*). The most important branch is *skar-rtsis* (star calculation) which is based on the *Kālacakra* astronomy of India. Another branch is *dbyanis-'char* which is based on Indian divination, *svarodaya*. Another is *nag-rtsis* (black calculation), based on Chinese astrology and natural philosophy, and the last branch is *rgya-rtsis* (Chinese calculation), based on the Shixian calendar of China.

Indo-Tibetan Astronomy

The Tibetan *Tripitaka* is a collection of Tibetan translations of Buddhist works, some of which include astronomical information. There is a Tibetan translation of the *Śārdūlakarṇa-avadāna*, which is a Buddhist work in which early Indian astronomy and astrology of the Vedāṅga period, the post-Vedic period before Greek influence, are mentioned. There is also a Tibetan translation of an early Indian astrological text ascribed to Sage Garga. Astronomical knowledge in these texts is from an early period, and not of *skar-rtsis*. The most important texts from an astronomical point of view are the Tibetan translation of the *Kālacakra-tantra* and its commentary, *Vimalaprabhā*.

Kālacakra-yāna Buddhism is the last stage of Esoteric Buddhism in India. Its most fundamental text is the *Kālacakra-tantra*. It is not known when and where it was composed. Some people say it was introduced into Tibet in AD 1027, and was introduced into India from Central Asia 60 years before. I believe that it was composed in the eleventh century, because the year 1027 is used as the beginning of the 60-year cycle (*br̥haspaticakra*) in the text itself. I also believe that it was composed in India, because it adopts the Hindu system of astronomy without any apparent influence of Chinese or other astronomy.

According to the commentary *Vimalaprabhā*, there was the original text or *Mūla-tantra*, where the *Siddhānta* system of astronomy was explained, and the text on which it comments is the abridged text or *Laghu-tantra*, where the *Karaṇa* system of astronomy is explained. The *Mūla-tantra* is not extant, and it is difficult to say whether it actually existed as a whole or not, but some fragments are quoted in the *Vimalaprabhā*. The *Siddhānta* system of astronomy is called *grub-rtsis* in Tibetan, and the *Karaṇa* system is called *byed-rtsis*. In Tibetan astronomy, these two systems are basically the same, and only the length of a year and a month are different. In the *Siddhānta* system, one sidereal year = 365.270645 days and one synodic month = 29.530587 days. In the *Karaṇa* system,

a sidereal year = 365.258675 days, while a synodic month = 29.530556 days.

In the Tibetan calendar, there are 2 intercalary months for 65 ordinary months. This is harmonious with the *Siddhānta* system, but not with the *Karaṇa* system. The *grub-rtsis* is usually followed now.

Since about the twelfth century, the *Kālacakra* calendar has been followed in Tibet. In the fourteenth century, a comprehensive treatise of *Kālacakra* astronomy entitled *mKhas-pa-dga'-byed* (AD 1326) was composed by an encyclopaedic scholar Bu-ston Rin-chen-grub (1290–1364). After Bu-ston, lHun-grub-rgya-mtsho wrote the *Pad-dkar-ḡal-luṅ* (AD 1447), and his system was developed as the Phug school. The most famous work of this school is the *Vaidūrya dkar-po* (AD 1683) written by Saṅs-rgyas-rgya-mtsho, who was the regent of the fifth Dalai Lama. Another famous work is the *Ñin-byed-snañ-ba* (AD 1714) of Dharmaśīr.

There is another school, mTshur-phu, whose fundamental text is the *Ñer-mkho-bum-bzan* (AD 1732) written by Karma Ñes-legs-bstan-'dzin.

Let us use astronomical calculation in the *mKhas-pa-dga'-byed* as a case study. It is one of the earliest treatises of the *skar-rtsis* branch of Tibetan astronomy and will give a general idea of *skar-rtsis*. As *skar-rtsis* is based on *Kālacakra* astronomy, it is similar to Hindu astronomy. First, mean motions of the planets are calculated, and then the equation of the center and the epicyclic correction are applied. The operation of the equation of the center (Sanskrit: *manda-karman*) is called *dal-ba'i-las* in Tibetan, and the operation of the epicyclic correction (Sanskrit: *śīghra-karman*) is called *myur-ba'i-las*.

Three kinds of days are used. They are *ñin-ḡag* (Sanskrit: *sāvana-dina*), *tshes-ḡag* (Sanskrit: *tithi*), and *khyim-ḡag* (Sanskrit: *saura-dina*). A *ñin-ḡag* is a civil day measured from sunrise to sunrise. A mean *tshes-ḡag* is a 13th part of a synodic month. The equation of the center of the sun and moon are applied so as to make a *tshes-ḡag* correspond to the change of 12° of the longitudinal difference between the sun and moon. A mean *khyim-ḡag* is a 360th part of 1 year.

The ecliptic is divided into 12 *khyim* (Sanskrit: *rāśi*) or zodiacal signs, and also into 27 *rgyu-skar* (Sanskrit: *nakṣatra*) or lunar mansions. Each day as well as *rgyu-skar* is divided into 60 *chu-tshod* (Sanskrit: *nāḡḡ*). One *chu-tshod* is further divided into 60 *chu-srañ* (Sanskrit: *vināḡḡ*). One *chu-srañ* is divided into six *dbugs* (Sanskrit: *prāṇa*).

The mean motion of the sun and moon is calculated from the following simple formulae, which correspond to the *grub-rtsis* system:

$$\text{Length of a } khyim-ḡag = \text{length of a } tshes-ḡag \times \left(1 + \frac{2}{65}\right)$$

$$\text{Length of a } tshes-ḡag = \text{length of a } ñin-ḡag \times \left(1 + \frac{1 + \frac{1}{707}}{64}\right)$$

The equation of the center of the sun is given for each zodiacal sign. Twelve zodiacal signs are divided into four quadrants. Then 6/135, 4/135, and 1/135 of the mean daily motion of the sun are subtracted from or added to the mean daily motion of the sun in each sign. The variables 6, 4, and 1 are called *dal-rkañ* (slow step). The ecliptic is divided into the first half (*rim-pa*) and the second half (*rim-min*). The first as well as the second half is further divided into the first part (*sña-rkañ*) and the second part (*phyi-rkañ*). So, one part consists of three signs. The first point of the first half is the apogee.

This *dal-rkañ* is, in fact, the difference between the mean motion and the true motion of the sun during one zodiacal sign's movement of the mean sun in terms of *chu-tshod*. Hence, the maximum equation is the total of the variables, that is 11 *chu-tshod* or 2°26'40". The solar apogee is located at the first point of Cancer in this system.

One anomalistic month is roughly considered as 28 *tshes-ḡag*, and a correction is applied to the length of each *tshes-ḡag*. This correction is called *zla-ba'i-myur-rkañ* (fast step of the moon). The word *myur* (fast) shows that it was considered to be the epicyclic correction rather than the equation of center. Since the period of 28 *tshes-ḡag* is a

little longer than the actual anomalistic month, a special correction is also applied so as to diminish the period of 28 *tshes-žag* at the rate of one *tshes-žag* per 3,780 *tshes-žag*. So, one anomalistic month becomes about 27.55459 civil days.

One anomalistic month is divided into four quadrants, each of which consists of seven *tshes-žag*. Then 5, 5, 5, 4, 3, 2, and 1 *chu-tshod* are added to or subtracted from the length of each *tshes-žag*. These values were probably originally meant to be the difference between the mean motion and the true motion of the moon during one *tshes-žag* in terms of *chu-tshod*. Since the time interval during which the moon moves the arc of one *chu-tshod* is about 1.01 *chu-tshod*, this was considered to be one *chu-tshod*, and the same value was used for the correction of the length of a *tshes-žag*. The maximum equation is the total of the variables, that is 25 *chu-tshod* or $5^{\circ}23'20''$.

Five planets are divided into *ži-ba'i-gza'* which corresponds to inner planets, and *drag-gza'* which corresponds to outer planets. The sidereal period (*dkyil-'khor*) of each planet is given as follows:

Mercury (*lhag-pa*): 87 days 58 *chu-tshod* 12 *chu-srai*

Venus (*pa-saṅs*): 224 days 42 *chu-tshod*

Mars (*mig-dmar*): 687 days

Jupiter (*phur-bu*): 4,332 days

Saturn (*spen-pa*): 10,766 days

Just as in the case of the sun, *dal-rkañ* (slow step) for each zodiacal sign is given for each planet. The mean daily motion of each planet in the case of outer planets, or of the sun in the case of inner planets, is corrected as follows.

Corrected daily motion = $A \mp A(d/135)$, where A is the mean daily motion, and d is *dal-rkañ*. The value of *dal-rkañ* for each planet is:

Mars: 25, 18, and 7

Mercury: 10, 7, and 3

Jupiter: 11, 9, and 3

Venus: 5, 4, and 1

Saturn: 22, 15, and 6

The total of the value of *dal-rkañ* is the maximum equation in terms of *chu-tshod*. The maximum equation of each planet is:

Mars: 50 *chu-tshod* or $11^{\circ}6'40''$

Mercury: 20 *chu-tshod* or $4^{\circ}26'40''$

Jupiter: 23 *chu-tshod* or $5^{\circ}6'40''$

Venus: 10 *chu-tshod* or $2^{\circ}13'20''$

Saturn: 43 *chu-tshod* or $9^{\circ}33'20''$

The longitude of the apogee of each planet in this system is Mars: $126^{\circ}40'$, Mercury: 220° , Jupiter: 160° , Venus: 80° , and Saturn: 240° .

The “parameter of step” (*rkañ-'dzin*) is used to count steps of epicyclic correction. The period of 60 *chu-tshod*’s change of the “parameter of step” is considered one step. Sixty *chu-tshod* correspond to 1 lunar mansion, and there are 27 lunar mansions, so 1 cycle consists of 1,620 *chu-tshod*. One cycle is divided into 2 halves, and each consists of 14 steps. The 14 step of the first half and the first step of the second half consist of 30 *chu-tshod* only.

In the case of the outer planets, daily motion of the “parameter of step” is the mean daily motion of the sun minus the daily motion of the planet which has been corrected by its equation of center. In the case of the inner planets, the daily motion of the “parameter of step” is the daily motion of “parameter of fast step” (*myur-rkañ-'dzin*) minus the true daily motion of the sun. The “parameter of fast step” is, in fact, the daily motion of the planet’s revolution, because it is defined as the quotient of 1,620 *chu-tshod* divided by the planet’s sidereal period. The variable of the epicycle correction is given as *myur-rkañ* (fast step) for each step.

The method of the correction is as follows: let M be the true daily motion of the planet, D the daily motion of the planet in the case of an outer planet and the daily motion of the sun in the case of an inner planet, both of which have been corrected by the equation of center of the planet itself, K the daily motion of the “parameter of step,” and m the *myur-rkañ*. Then, for the steps from the first step to the 13 step of the first half and from the second step to the 14 step of the

second half, the following equation gives the true daily motion of the planet

$$M = D \pm K \frac{m}{60}.$$

For the 14 step of the first half and the first step of the second half, the following equation is used

$$M = D \pm K \frac{m}{30}.$$

The first half (*rim-pa*) as well as the second half (*rim-min*) are further divided into the first part (*sña-rkañ*) and the second part (*phyi-rkañ*). The correction is plus in the first part of the first half and the second part of the second half, and minus in the second part of the first half and the first part of the second half.

The values of *myur-rkañ* for each planet are shown in Table 1. The values are arranged for the first half. In the second half, the same value is used in reverse order.

The total of the value of *myur-rkañ* in one part is the maximum epicyclic correction in terms of *chu-tshod*. The maximum correction of each planet is:

Mars: 182 *chu-tshod* or 40°26'40"

Mercury: 97 *chu-tshod* or 21°33'20"

Jupiter: 52 *chu-tshod* or 11°33'20"

Venus: 208 *chu-tshod* or 46°13'20"

Saturn: 28 *chu-tshod* or 6°13'20"

In a paper written in 1986, I compared the astronomical constants used by Bu-ston with those of some schools of Hindu astronomy, and pointed out that they are close to those of the Ārdharātriśa school of Hindu astronomy.

Sino-Tibetan Astronomical Science

The *nag-rtsis* is said to have been introduced into Tibet from China in the seventh century. It is based on Chinese astrology and natural philosophy. According to the *Zla-ba'i-'od-zer* (AD 1684) of Dharmasrī, a popular work of *nag-rtsis*, the most fundamental elements of the *nag-rtsis* are as follows.

Astronomy in Tibet, Table 1 The values of *myur-rkañ* for each planet

Planet	First part	Second part
Mars	24, 23, 23, 23, 21, 21, 18, 15, 11, and 3	11, 38, 80, and 53
Mercury	16, 16, 15, 14, 13, 11, 7, 5, and 0	4, 11, 20, 28, and 34
Jupiter	10, 10, 9, 8, 6, 6, 2, and 1	3, 6, 9, 11, 16, and 7
Venus	25, 25, 25, 24, 24, 22, 22, 18, 15, and 8	6, 30, 99, and 73
Saturn	6, 5, 5, 4, 4, 2, 2, and 0	2, 4, 5, 6, 8, and 3

1. *Khams* (also called '*byui-ba*'), which are the five elements of Chinese natural philosophy: wood, fire, earth, metal, and water.
2. *Lo-'gros*, which are 12 animals used to name each year of a 12-year cycle: rat, ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, bird, dog, and boar. This 12-year system is the Chinese system, which is widely used in East Asia. The combination of the *khams* and *lo-'gros* is used to name each year of a 60-year cycle. This is also the Chinese system.
3. *Sme-ba*, which is the Chinese "nine stars" used for astrological purposes.
4. *sPar-kha*, which is eight symbols of Chinese natural philosophy, of which the most fundamental text is the famous Yijing (I Ching, Book of Changes).
5. *Zla-ba*, which is 12 months for each of which 12 animals are attributed. The first month of spring is a tiger, and so on.
6. *Tshes*, which is the date of the month.
7. *Dus-tshod*, which is a 12th part of a day, for each of which 12 animals are attributed. The midnight is rat, and so on.
8. *gZa'*, which is eight planets: the sun, moon, five planets, and *rāhu*. The *rāhu* (dragon's head, or the ascending node of the lunar orbit) is not Chinese, but of Indian origin.
9. *sKar-ma*, which is the Chinese 28 lunar mansions or lodges.

The *rgya-rtsis* is based on the Tibetan version (AD 1725) of the Mongolian translation (AD 1711) of the Chinese astronomical work

Xiyang xinfu suanshu (AD 1669) compiled in the Qing dynasty, which is the theoretical text on the Shixian calendar. The Shixian calendar is the last luni-solar calendar in China.

The traditional Tibetan calendar, which is based on the Phug school of *skar-rtsis*, is still used by Tibetan people. Also, several Tibetan astronomical texts are extant, and the process of astronomical calculation is explained in detail in these texts. More extensive study of Tibetan astronomy by historians of astronomy will be fruitful. In 1987, Chinese scholars Huang Mingxin and Chen Jiujin published a *skar-rtsis* text of epoch AD 1827, the *Rigs-ldan-sñin-thig* of Phyag-mdzod gsuñ-rab, with Chinese translation and astronomical commentary. This is a good introduction to Tibetan astronomy.

See Also

- ▶ [Lunar Lodges in Chinese Astronomy](#)
- ▶ [Mean Motions in Indian Astronomy](#)

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Astronomy of the Australian Aboriginal People

Roslynn D. Haynes

The Australian Aborigines were almost certainly the world's first astronomers. Their complex systems of knowledge and beliefs about the heavenly bodies have been handed down through song, dance, and ritual for some 40,000 years, predating by many millennia those of the Babylonians, the ancient Greeks, the Chinese, or the Incas. The legends which have survived, until very recently, within a virtually unchanged cultural context, show how natural phenomena, including celestial bodies and events, were assimilated by the Australian Aborigines into a holistic value system which was predicated on the close relationship of the individual with the whole natural world: It is significant, in this regard, that theirs was the only known culture with no myth of alienation from Nature, such as the expulsion from Eden of the Judeo-Christian tradition. On the contrary they believed that through their Great Ancestors of the Dreaming they, too, were continuing co-creators of the natural world. Hence they used their knowledge of the stars not only to predict and explain natural occurrences but also to provide celestial parallels with tribal experiences and behavioral codes.

The Aborigines' knowledge of the "crowded" southern sky was probably the most precise possible for people dependent on naked-eye astronomy. They made accurate observations, not only of first- and second-order stars, but also of the more inconspicuous fourth-magnitude stars. Pattern was apparently more important in recognition than brightness, for the Aborigines often identified a small cluster of relatively obscure stars while ignoring more conspicuous single stars in the vicinity. Thus the people of Groote Eylandt named as *Unwala* (the Crab) the small cluster of relatively insignificant (average magnitude 4.4) stars Sigma, Delta, Rho, Zeta and Eta

Hydrae, while disregarding the adjacent bright stars Procyon (α Canis Minoris) and Regulus (α Leonis) (magnitude 0.36 and 1.35, respectively) which are not part of an obvious group. Members of the Boorong tribe of the Mallee District of Victoria limited their identification procedures to linear patterns of three or more stars. Unlike the familiar Greek designations, based on a join-the-dot pictorial image, the Aborigines identified a group of stars with the whole cast of characters in a story, the relationship being conceptual rather than visual. Color was also an important factor in the aboriginal designation of stars. The Aranda tribes of Central Australia distinguish red stars from white, blue, and yellow stars. They classify the bright star Antares (α Scorpii) as *tataka indora* (very red) while the stars of the V-shaped Hyades cluster are divided into a *tataka* (red) group and a *tjilkera* (white) group. The former are said to be the daughters of the conspicuously red star Aldebaran (α Tauri).

The Aborigines also differentiated between the nightly movement of the stars from east to west and the more gradual annual shift of the constellations. From this latter displacement they devised a complex seasonal calendar based on the location of constellations in the sky, particularly at sunrise or sunset. The Aranda and Luritja tribes around Hermannsburg in Central Australia knew that certain stars lying to the south, namely *Iritjinga* and the Pointers of the Southern Cross, are visible throughout the year, although their position in the sky varies. This amounts to a realization that stars within a certain distance of the South Celestial Pole never fall below the horizon.

Yet what the Aborigines did with their astronomical knowledge was fundamentally different from the procedures of Western science. Tribal Aborigines paid no attention to two of the most basic concepts of western science, numeracy and temporality; they made no measurements of space or time, nor did they engage in even the most elementary mathematical calculations. Their observations of the stars were conducted for essentially pragmatic reasons. Either they were an attempt to discover predictive correlations between the position of the stars and other

natural events important to the survival of the tribe – the availability of specific foods or the onset of particular weather conditions, or they provided a system of moral guidance and education in tribal lore – a function regarded as equally necessary to the continuation of tribal identity.

As hunter – gatherers, dependent for their survival on a foreknowledge of environmental changes, the Aborigines noted the correlation between the movements and patterns of stars and changes in the weather or other events related to the seasonal supply of food. Thus the significance attributed to these sidereal occurrences varied with the diet and lifestyle of different tribes. On Groote Eylandt the appearance in the evening sky toward the end of April of Upsilon and Lambda Scorpii indicated that the wet season had ended and that the dry south-easterly wind or *marimariga* would begin to blow, causing changes in climate and animal behavior. At nearby Yirrkalla the appearance of Scorpio in the morning sky in early December heralded the arrival of the Malay fishermen who came in their canoes to collect trepang or *bêche de mer* which they sold to the Chinese. In winter, the most spectacular individual stars in the southern sky are Arcturus (α Bootis) and Vega (α Lyrae). When Arcturus could be seen in the eastern sky at sunrise, the Aborigines of Arnhem Land knew that it was time to harvest the spike-rush or *rakia*, a reed valuable for making fish traps and baskets for carrying food, and a local legend about Arcturus served as an annual reminder of this. On the other hand, amongst the *Boorong* tribe of the Mallee district of western Victoria, Arcturus was personified as *Marpeankurrk* the tribal hero who showed them where to find *bittur*, the pupa of the wood ant, a staple item of diet during August and September. The constellation Lyra represented the spirit of *Neilloan*, or the Mallee-hen who taught the tribe how to find its eggs, an important source of food in October. Other notable events, like the ripening of tubers and bulbs and the appearance of migratory birds and animals, were correlated with specific positions of Orion, the Pleiades and the Southern Cross at different seasons of the year. For the Pitjantjatjara tribe in the Western Desert, the appearance of the

Pleiades in the dawn sky in autumn was the sign that the annual dingo-breeding season had begun. Fertility ceremonies were performed for the dingoes, or native dogs, and some weeks later the tribe raided the lairs, culling and feasting on the young pups. The legends ensured that these nutritional associations were not forgotten and stressed their importance for the continuing survival of the race.

Equally important to the preservation of the tribe was its sense of identity, involving tribal beliefs orally transmitted across generations. These myths outlined the role of the Ancestors of the Dreaming in the scheme of the universe and the behavior appropriate to their descendants. Explanations of natural events which emphasized pattern, order, and laws, rather than unpredictable effects, reinforced the sense of an organic relationship between natural phenomena and social behavior. Many of these legends involved the constellations, so that the night sky provided a periodic reminder of the moral lessons enshrined in the myths.

Like all explanatory systems, including Western science, these legends represented attempts to understand, predict, and hence to obtain some control over the natural world. However, unlike the essentially analytical, materialistic, and particularizing approach of Western science, the underlying premise of all the aboriginal myths was a belief in the close spiritual unity of human beings, not only with other species, but also with inanimate objects. Astronomy was an integral part of the Aborigines' total philosophy about the natural world, so the legends emphasized the parallels between the personified heavenly bodies and their earthly counterparts, humanizing and integrating natural phenomena with tribal institutions and customs.

The meaning which a tribe attributed to the celestial bodies was conceptual rather than perceptual. It could not be understood by personal experience or by the intellect, but only through initiation into tribal lore which stressed the intimate, causal association between physical events and the human dramas of good and evil. Lessons about compassion, brotherhood, and respect for the land as Mother, the prohibition of incest and

adultery, and taboos on killing or eating totemic animals were nightly reinforced by being enacted in the sky world which thereby established the universal validity of the tribe's ethical laws.

The many and diverse aboriginal myths associated with the heavenly bodies include stories about the Sun, the Moon, the Milky Way, the Magellanic Clouds, Mars, Venus, and the several constellations which form distinctive patterns in the southern sky – notably the Southern Cross and its pointers, the Pleiades, Orion's Belt, Scorpio, Gemini, and Aldebaran. The following are a representative selection of these myths.

In most of the Aboriginal creation stories, the Sun is the life-giving spirit. Amongst the Murray River tribes the origin of the Sun is linked to the tossing of a giant emu egg into the sky where it struck a heap of dry wood and burst into flame, bringing light to the hitherto dark world. Thereupon, the Great Spirit *Baiaime*, seeing how much the world was improved by sunlight, decided to rekindle the woodpile each day.

In contrast to the ancient Greeks, the Amerind Indians and the Quechua Indians of Peru, all of whom designated the Sun as male and the Moon as female, whereas the Australian Aborigines represented the Sun as female and the Moon as male. In most areas, the Sun is regarded as a woman who daily awakes in her camp in the east and lights a fire to kindle the bark torch she will carry across the sky, thus providing the first light of dawn. She decorates herself with powder made from crushed red ochre, coloring the clouds red in the process. At evening she renews her powder in the western sky before beginning her long passage underground back to her camp in the east. It was probably this underground journey which was instrumental in the classification of the Sun as female, for her torch is thought to bring warmth and fertility to the interior of the Earth, causing the plants to grow. However, in Arnhem Land, where the Sun sets in the sea, she is thought to become a great fish, swimming under the Earth to return in the east next morning while the Moon becomes a fish, passing beneath the earth during the day.

The Moon, being male, is generally accorded greater status, and in many areas powers of death

and fertility are accorded to him. An eclipse of the Sun is interpreted as indicating that the Moon Man is uniting with the Sun Woman. Several legends have evolved to account for the Moon's cycles. In coastal areas the correlation between the phases of the Moon and the tides was noted. In Arnhem Land and Groote Eylandt, where high tides occur when the new or full Moon sets at sunset or sunrise, respectively, and low tides when the moon is in the zenith at sunrise or sunset, the local Aborigines believe that the high tides, running into the Moon as it sets into the sea, make it fat and round. (Although the new Moon may appear thin, they deduce from the faint outline of the full circle that it too is round and full of water.) Conversely, when the tides are low, the water pours from the full Moon into the sea below and the moon consequently becomes thin.

In most areas the Moon was regarded as more mysterious, and hence more dangerous, than the Sun. Because of the association of the lunar cycle with the menstrual cycle, the Moon was linked with fertility and young girls were warned against gazing at the Moon unless they wished to become pregnant.

The Milky Way was regarded by the Aborigines as a river in the Sky World, the large bright stars being fish and the smaller stars water-lily bulbs. Central Australian tribes believed that the Milky Way divided the sky people into two tribes and thus it served as a perpetual reminder that a similar equitable division of lands should be observed between neighboring tribes. Various legends regarding taboo marriages, adultery, and reminders to celebrate tribal heroes, many of them involving a moral lesson, have evolved in different areas to account for the formation of the Milky Way and the dark region, known to Europeans as the "Coal Sack."

A Queensland version of the origin of the Milky Way associates it with *Priepriggie*, an Orpheus-like hero, as famed for his songs and dances as for his hunting. When he disappeared, his people tried unsuccessfully to perform his dance until they heard singing in the sky. Then the stars, hitherto randomly dispersed, arranged themselves to the rhythm of *Priepriggie's* song.

Thus the Milky Way serves as a reminder that the tribal hero should be celebrated with traditional songs and dancing.

Because of its diagrammatic shape, the Southern Cross features in association with various characteristic objects in different areas. Around Caledon Bay on the east coast of Arnhem Land, it is taken to represent a stingray being pursued by a shark – the Pointers. On Groote Eylandt, where fish is the staple diet, the four stars of the Cross represent two brothers, the *Wanamoumitja* (Alpha and Beta Crucis), and their respective camp fires (Delta and Gamma Crucis) where they cook a large black fish (the Coal Sack) which they have caught in the Milky Way. The Pointers are their two friends, the *Meirindilja*, who have just returned from hunting. Desert tribes, on the other hand, see in the kite shape of the Cross the footprint of the wedge-tailed eagle *Waluwara* while the pointers represent his throwing stick and the Coal Sack his nest.

Venus, the Morning Star, was an important sign to the Aborigines, who arose at early dawn to hunt. It, too, was personified and frequently associated with death. Arnhem Land legends identify the home of the morning star, *Barnumbir*, as Bralgu, the Island of the Dead. Afraid of drowning, *Barnumbir* could be persuaded to light her friends across the sea at night only if she were held on a long string by two old women, who at dawn would pull her back to Bralgu and keep her during the day in a basket. Because of this connection, the morning star ceremony is important in the local rituals for the dead since a dead person's spirit is believed to be conducted by the star to *Bralgu*.

One of the most widespread Aboriginal myth cycles concerns the constellations of Orion and the Pleiades and these bear a striking similarity to the Greek story of the seven daughters of Atlas who, when pursued by Orion, flew into the sky as doves to form the constellation of the Pleiades. All identify them with a group of seven young women and nearly all portray them as fleeing from the amorous hunter Orion who, in some versions, is castrated as a punishment and warning to other potential wrongdoers. The whole cluster of Pleiades stories therefore forms part

of a much larger group of myths of sexual conquest and submission.

Amongst the Pitjantjatjara tribe, the practical connection between the dingo-breeding season and the appearance of the Pleiades in the dawn sky in autumn is preserved in a local legend. The *Kungkarungkara* or ancestral women kept dingoes to protect them from a man *Njiru* (Orion), but he succeeded in raping one of the girls, the obscure Pleiad, who died. Even though the women assumed their totemic form of birds and flew into the sky to escape from him, he defies their dingoes and follows the women across the sky, armed with a spear (the stars of Orion's Belt) which has ritual phallic significance. Like the Greek Orion, *Njiru* was also a hunter, and pairs of smaller stars which arise near the constellation of Orion are said to represent his footsteps as he pursues the *Kungkarungkara*.

At Yirrkalla on the coast of Arnhem Land, the constellation of Orion is regarded as a group of fisherman arriving from the east in a canoe with a turtle they have caught, while the Pleiades represent their wives in another canoe with two large fish. As they approached the shore a heavy storm capsized the canoes, drowning the people. All the representative stars are visible in the sky during the wet season – a warning against the dangers of fishing when storms are imminent. In north-eastern Arnhem Land the story carries the added moral that the fishermen drowned as a punishment for catching catfish, forbidden to this tribe by totemic law.

Although relatively insignificant to the naked eye, the Large and Small Magellanic Clouds feature in many aboriginal legends as the camps of sky people. On Groote Eylandt they are believed to be the camps of an old couple, the *Jukara*, grown too feeble to catch their own food. Other star people catch fish and lily bulbs for them in the Milky Way and bring them to the *Jukara* to cook on their fires. The space between the Clouds is their cooking fire, while the bright star Achernar (Alpha Eridani, magnitude 0.49) represents their meal. This story suggests a celestial model of compassion for the aged. At Yirrkalla the Magellanic Clouds are said to be the homes of two sisters. During the middle of the dry season

the elder sister (Large Cloud) leaves her younger sister (Small Cloud), but during the wet season she returns so that they can collect yams together. This story reflects the observed fact that at this latitude (12° S) only the Small Cloud is visible during most of the dry season (April to September), whereas both Magellanic Clouds can be seen during the wet season.

Meteors have been variously interpreted by different aboriginal tribes. In north-eastern Arnhem Land, because of their speed and unpredictability, they are believed to be spirit canoes carrying the souls of the dead to their spirit home in the sky. To the Tiwi tribe of Bathurst and Melville Islands, each is the single eye of the one-eyed spirit men, the *Papinjuwari*, who steal bodies and suck the blood of their victims, and their evil eyes are seen blazing as they streak across the sky looking for their prey. In other legends, meteors are associated with fire and linked to the waratah plant, *Telopea speciosissima*, a member of the Protea family, which is resistant to fire and whose brilliant red flowers seemed to the Aborigines like sparks from a fire. This was why, in the early years of white settlement, some Aborigines brought waratahs to the European blacksmiths: they identified the sparks from the anvil with the sparks from meteors and hence with the waratahs.

From this selection of star legends, it will be apparent that, with the possible exception of meteors (and even they can be regarded as recurrent events), the Aborigines' concern was not with extraordinary occurrences, but with the regular patterns of natural phenomena. The star legends served the purpose of integrating a potentially alien universe into the moral and social order of the tribe – by “humanizing” species and natural objects and ascribing to them behavior patterns and motivations which accorded with those of the tribal unit.

Such a philosophy serves a number of important social functions. In the first place it engenders a level of confidence about Man's place in the universe, not as a superior being but as an equal partner; in this it fulfils a role comparable to that of technology which also offers a level of some control over the environment. Secondly,

this philosophy cultivates respect for the inanimate world as well as the animate since, through the indwelling power of the Ancestors, all creatures and things partake of the same spiritual identity as Man himself. Thirdly, the legends provide a justification for the customs, rites, and morality of the tribe, since these are reflected and enacted in the Sky-world.

The aboriginal myths are not fatalistic as astrology purports to be. Although they link certain natural events with a seasonal configuration of the sky, they make no deterministic predictions about individual lives; the moral values enshrined in the legends are held to be true for the *whole* tribe.

The most radical difference between the vitalistic beliefs which underlie these myths and the materialistic philosophy of western science concerns the relationship of the observer to the observed. In Newtonian science, the observer is assumed to be independent of, and distinct from, the object observed, which, in turn, is regarded as uninfluenced by the observer. Hence, the relationship between physical objects can be validly expressed in mathematical terms which remain true irrespective of the observer. The Aborigines, on the other hand, did not conceive of themselves as observers separated from an objectified Nature, but rather as an integral part of that Nature. The meaning of the celestial bodies, as of everything else in the environment, was neither self-evident nor independent of the observer; rather it depended on the degree of initiation into tribal lore which elucidated the links between tribal customs and natural phenomena. Without this knowledge the individual was disoriented and powerless in an alien universe.

See Also

► [Environment and Nature: Australian Aboriginal People](#)

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Astronomy of the Hebrews

Y. Tzvi Langermann

The Hebrew astronomical tradition that shall be surveyed in this essay is that tradition recorded in the Hebrew alphabet dealing with the motions of the heavenly bodies and the structure of the heavens. These writings utilize principally the Hebrew language, but include texts in languages such as Aramaic and Arabic that can be written out in Hebrew script. Topics of specifically Jewish interest, such as calendar computations and doctrinal matters, occupy only a minor portion of this literature. For the most part, the Hebrew astronomical tradition differs little from contemporary writings belonging to the traditions with which Jews found themselves in immediate contact at any given age and place. To the extent that these other traditions may be classified as non-Western, the Hebrew tradition may be by and large considered such.

The earliest substantive materials are found in the Talmud and Midrash. Most of the discussions center upon the structure and physics of the heavens. Of particular interest are several notices of disagreement between Jewish and non-Jewish experts, for example, on the question of whether it is the star itself, or the spherical shell within which the star was thought to be embedded, which moves around the earth.

In other words, we have clear evidence that even at this early date Jewish scholars identified themselves with particular conceptions of the heavens. *Pirquei di-Rebbe Eliezer*, *Baraita di-Mazalot*, and *Baraita di-Shmuel* are three post-Talmudic writings whose precise dating is problematic but which certainly precede the flowering of the sciences under the Abbasids. The latter two are the earliest texts which preserve any mathematical astronomy, e.g., a computational scheme for shadows. In addition, al-Khwārizmī's treatise on the Jewish calendar, which belongs to the Arabic tradition but is almost certainly based on Jewish sources, exhibits positional data for the epoch of the Temple. All of this indicates that a Hebrew tradition, drawing upon Indian, Hellenistic, and other sources, had developed by the eighth century.

Without doubt the years spanning the ninth through sixteenth centuries were the most fecund for the Hebrew tradition. During this period, which is more or less commensurate with what Western historians have long called the medieval age, interest in astronomy was especially stimulated in Arabic speaking lands from Spain to Iraq. Contemporary Jewish writings consist for the most part of exposés or translations of the fruits of Arab science. Dozens of works were written, surviving in hundreds of manuscripts; only a few can be surveyed here. Abraham bar Hiyya created a Hebrew astronomical vocabulary that endured side by side with that developed by the Tibbons, the famous family of translators of Arabic literature. Abraham ibn Ezra's astrological writings were immensely popular both in the Hebrew original and in Latin translation. Both Abrahams utilize more ancient sources that are no longer extant. Isaac Israeli's *Yesod 'Olam* is a thorough analysis of all of the astronomical and historical questions connected with the Jewish calendar; his book, written in 1310 in a polished Hebrew style, may be considered the pinnacle of the Spanish Hebrew tradition. All the same, Hispano-Jewish authors continued to produce treatises in Hebrew and Judeo-Arabic through the end of the fifteenth century. For instance, the work of Abraham Zacuto, so important for the Portuguese

explorers, appeared around the time of the expulsion of Jews from Spain.

Southern France, Italy, and Byzantium were the other major centers of astronomical activity during this period. Emmanuel ben Jacob, Jacob Anatoli, and Mordecai Comtino are, respectively, perhaps the most important representatives of the Hebrew tradition in those lands. In those areas in particular, Jews drew upon Latin, Romance, and other literatures, as well as Arabic materials.

The two outstanding philosophers of this period, ► [Moses Maimonides](#) and Levi Gersonides, participated strongly in the Hebrew astronomical tradition. Maimonides' wrote a small work on the calendar, and he included in his great law code, the *Mishneh Torah*, a detailed scheme for computing the first visibility of the lunar crescent. However, Maimonides' weightiest contribution is the very high value which he placed on the study of astronomy within the context of his religious philosophy, something which encouraged many Jews to acquaint themselves with, at the very least, non-technical resums of astronomical knowledge.

Levi Gersonides was without doubt the most creative representative of the Hebrew tradition, indeed one of the greatest scientists of his epoch. He too developed his astronomical views within the framework of a finely tuned and very comprehensive religious philosophy. Levi was both an observer and a theoretician, and, most notable, one of the rare breed who attempted to fit his own original theory, which had to answer to certain philosophical constraints, to his own observations. Among his other major achievements, Levi invented the Jacob's staff, a simple but accurate instrument for measuring the angular distances between stars; studied the errors involved in instrumental measurements; and arrived at a much greater (and hence more realistic) value for the distances of the stars than those accepted by his contemporaries.

Jews living in Islamic lands, most especially the Yemen, continued to study the ancient and medieval texts well into the twentieth century. In those countries the Hebrew tradition was maintained chiefly through the copying of manuscripts, often transcriptions of Arabic texts into

the Hebrew alphabet. In European countries the study of Latin texts in Hebrew translation seems to have accelerated in the fifteenth and sixteenth centuries. Some three Hebrew translations of Georg Peurbach's *Theorica* were executed, and several Hebrew commentaries were written, *inter alia* by Moses Isserles of Cracow and Moses Almosnino of Salonika, both of whom were leading rabbis of their times.

There is little in the Hebrew tradition that reflects the great advances associated with the European scientific revolution. Joseph Delmedigo, a widely traveled Cretan who studied under Galileo, published the only lengthy and detailed Hebrew exposition of the new science. Other publications, such as Tuviah Cohen's *Maaseh Tuvia* (Tuvia's Opus), present the new science in somewhat abbreviated form; and yet other writings, such as Solomon Maimon's exposé of Newton's work, remain in manuscript. The Hebrew tradition revived during the nineteenth century, particularly due to the efforts of the *maskilim*, advocates for widening the intellectual horizons of Judaism, who published Hebrew scientific texts in a number of fields. With the re-establishment in the State of Israel of a native Hebrew speaking population, and, no less importantly, institutions interested in teaching and writing about astronomy in the Hebrew language, the quantity and scope of the Hebrew tradition have dramatically increased.

See Also

- [Abraham Bar Ḥiyya \(Savasorda\)](#)
- [Abraham ibn Ezra](#)
- [Al-Khwārizmī](#)
- [Levi ben Gerson](#)
- [Zacut, Abraham](#)

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Astronomy: Indian Astronomy in China

Yukio Ōhashi

Chinese astronomy and Indian astronomy were originally independent. Both of them already had developed when Indian astronomy was introduced into China along with Buddhism. The exact date of the introduction of Buddhism into China is not known, but it can be said that Buddhism was gradually introduced at the beginning of the Later Han (Eastern Han) dynasty (AD 25–220) or so. According to my study, the earliest information on Indian astronomy reached China at the time of the Later Han.

During the Sanguo (Three Kingdoms) period (AD 220–265), some Buddhist works, where information of Indian astronomy was included, were translated into Chinese. At the time of the Tang dynasty (AD 618–907), some detailed monographs of Indian astronomy and astrology were composed in China. There were some astronomers who were well versed in both Chinese and Indian astronomy. Yixing was one of them.

It is not known whether Chinese astronomy was introduced into pre-modern India or not.

Indian Astronomy in the Later Han Dynasty

At the time of the Former Han (Western Han) dynasty (206 BCE–AD 23), there was no apparent foreign influence on Chinese astronomy. As Buddhism was already known at the time of the Later Han dynasty, there was a possibility that certain aspects of Indian culture, including astronomy, were also introduced into China.

According to my research, some fragments of information about the Indian calendar reached China at the time of the Later Han dynasty (Ōhashi, 1999). There are three reasons for my view:

1. When the Later Han *Sifen* calendar was compiled in AD 85, its first month was proposed to be large, although that was finally rejected. In the Chinese traditional calendar, the first month was small, because the first new moon occurs at the initial point of time, and the second new moon is included in the first day of the next month. To the contrary, the first month of the Indian traditional calendar was large, because the first new moon occurs at the initial point of time, and the second new moon is included in the last day of the same month. I suspect that the rejected proposal of the Later Han *Sifen* calendar might have been influenced by the Indian method.
2. The Later Han *Sifen* calendar has special days called *mori* and *mieri*, which did not exist in the Former Han dynasty. If 1 year is divided into 360 parts and 1 day is included within a part, the day is called *mori*. If the end of a day coincides with the boundaries of the parts, the day is called *mieri*. These days are of no use in Chinese traditional calendars, but they are similar to certain concepts of Indian traditional calendars, such as the method of intercalation in the *Arthaśāstra* (see the section on Yixing below; for details, see Ōhashi, 2001).
3. In Chinese traditional calendars, midnight is considered the beginning of a day. However, when the date of the half moon and full moon was calculated in the Later Han *Sifen* calendar, daybreak was considered to be the beginning of a day. In Indian traditional calendars,

sunrise is usually the beginning of a day. Therefore, the Chinese use of daybreak might have a connection with the Indian method.

From these three reasons, I suspect that certain information about the Indian calendar reached China. However, the information must have been fragmental, and did not influence the Chinese calendar very much.

Indian Astronomy in Chinese Buddhist Texts

The *Madengqie-jing*

At the time of the Sanguo (Three Kingdoms) period (mid-third century AD), a Buddhist text called *Śārdūlakarṇa-avadāna* in Sanskrit was translated into Chinese by Zhu Lüyan and Zhi Qian as the *Madengqie-jing*. This is the first Chinese text where Indian astronomy and astrology are explicitly mentioned. This text explains lunar mansions and the astrology based on them at length and also mentions some calendrical information.

The astronomical system of the *Śārdūlakarṇa-avadāna* is similar to *Vedāṅga* astronomy, which is one of the six branches of auxiliary learning for the *Veda*. According to my research, *Vedāṅga* astronomy was produced in North India sometime between the sixth and the fourth centuries BCE (Ōhashi, 1993). The description of astrology in the *Śārdūlakarṇa-avadāna* is also based on the Indian traditional system.

The original Sanskrit version of the *Śārdūlakarṇa-avadāna* has a description of the annual variation of the gnomon shadow, which is similar to that in *Vedāṅga* astronomy. The Chinese version, *Madengqie-jing*, also has a description of the annual variation of the gnomon shadow, but it is different from the Sanskrit original. Shinzō Shinjō, a pioneer of the study of the history of Eastern astronomy, pointed out that the description of the *Madengqie-jing* is based on the data around 43°N, and that the data might have been incorporated in Central Asia (Shinjō, 1928: pp., 217–218).

The *Śārdūlakarṇa-avadāna* was also translated into Chinese as the *Shetoujian-taizi ershiba-xiu jing* by Zhu Fahu at the time of Xi-Jin (Western Jin) dynasty (AD 265–316).

The *Daji-jing*

The *Daji-jing* (or *Dafangdeng-dajijing*) is a collection of *Mahāyāna* texts in Chinese. The *Yuecang-fen* (one text in the *Daji-jing*), which was translated by Narendrayaśa in AD 566, is the earliest Chinese text where zodiacal signs are mentioned.

The *Ricang-fen* (another text in the *Daji-jing*), which was translated by Narendrayaśa in AD 586, also mentions zodiacal signs. It is interesting to note that the annual variation of the length of daytime and that of the gnomon shadow, which are similar to those of the *Vedāṅga* astronomy, are mentioned there, but the position of the sun corresponding to their data is given with reference to zodiacal signs. This means that the system of *Vedāṅga* astronomy was still in use when Greek horoscopy reached India. *Vedāṅga* astronomy was widely used in India from sometime between the sixth and the fourth centuries BCE to sometime during the second and fourth centuries AD, and was mixed with the system of zodiacal signs which was introduced into India along with Greek horoscopy in the second or third century AD (Ōhashi, 2002).

The *Ricang-fen* of the *Daji-jing* is, therefore, an important source for studying the history of Indian astronomy. It says that the length of daytime and nighttime is 15 *shi* (which corresponds to Indian *muhūrta* or 1/30 of a day) in the months of Scorpio and Taurus, and that daytime is 12 *shi* (minimum) and nighttime is 18 *shi* (maximum) in the month of Aquarius, and daytime is 18 *shi* and nighttime is 12 *shi* in the month of Leo. The length of daytime and nighttime changes linearly. The above-mentioned data look strange at first sight. The relationship between the length of daytime and nighttime and the sign of zodiac differs by one. For example, the above data tell that the vernal equinox occurs in the month of Taurus, and not in the month of Aries. The only possible explanation of this difference is that the data of the length of daytime and nighttime is for the

beginning of the month, and the sign of the zodiac is for the end of the month. The linear function of the length of daytime and nighttime is the same in *Vedāṅga* astronomy. My studies reveal that this function is not the result of interpolation from the observational data around the solstices, but the result of extrapolation from the observational data around the equinoxes in North India. The *Ricang-fen* also gives the length of the midday gnomon shadow, which is basically the same as in *Vedāṅga* astronomy, which is also based on observational data from North India. Here, we can see that *Vedāṅga* astronomy was still widely used even after Greek horoscopy was introduced into India (Ōhashi 2002).

Indian Astronomy During the Tang Dynasty

The *Jiuzhi-li*

One system of Hindu Classical Astronomy was introduced into China. It was recorded in Chinese as the *Jiuzhi-li* (AD 718) of Qutan Xida, which is included in his (*Da-*)*Tang Kaiyuan-zhanjing*. The author, Qutan Xida (probably a Chinese transliteration of his Indian name Gotama Siddha), belonged to a family of Indian astronomers in China and was the director of the national observatory. In the title *Jiuzhi-li*, *jiuzhi* corresponds to the Sanskrit word *navagraha* ["nine planets", i.e. sun (Ravi or Sūrya), moon (Candra), five planets – Mars (Maṅgala), Mercury (Budha), Jupiter (Bṛhaspati or Guru), Venus (Śukra) and Saturn (Śani), Rāhu (ascending node of the lunar orbit) and Ketu (usually considered to be the descending node of the lunar orbit)]; *li* means calendar. This work explains the method for calculating the sun's longitude, the moon's longitude, and solar and lunar eclipses, etc. This text also contains a sine table. The work also says that Indian numerals are mentioned, but the actual shape of the figure has not come down in extant texts.

Kiyosi Yabuuti pointed out that some astronomical constants of the *Jiuzhi-li* are similar to the *Sūryasiddhānta*, which was summarized in the *Pañcasiddhāntikā* of Varāhamihira (sixth century AD). This is a text of the *Ārdharātri*

school of Classical Hindu Astronomy (Yabuuti, 1944/1989, 1979; also see Yano, 1979).

It is interesting to note that the traditional calendars of mainland Southeast Asia (except for Vietnam) and also the classical astronomy of Tibet are related to the *Ārdharātri* school. It may be that the *Ārdharātri* school was quite popular among Buddhists. The *Jiuzhi-li* has never been used as an official calendar in China, because the tradition of Chinese original astronomy was so strong.

Yixing

There was also a famous monk, astronomer Yixing (AD 683–727), who knew about Indian astronomy. For example, he mentioned the Indian zodiac in his *Dayan* calendar. However, he made his *Dayan* calendar in a Chinese traditional way. There is only one thing which I suspect shows Indian influence in his *Dayan* calendar. It is the change of the meaning of *mieri*.

Yixing explained the method to calculate the *mieri* as follows:

If the *xiaoyu* (time in terms of 1/3,040 day) of the mean new moon is less than *shuoxufen* (=1,427), subtract the *xiaoyu* from the *tongfa* (=3,040), and multiply the result by 30, and subtract the result from *miefu* (=91,200). Divide the result by *shuoxufen*. The result is the number of days. Count the days from the mean new moon day and take the day after the resultant day. It is the *mieri*.

The meaning of this *mieri* is as follows. Let a synodic month be divided into 30 parts. Then, sometimes a part is included within a day. This kind of day is the *mieri* defined by Yixing. This *mieri* is similar to the "omitted *tithi*" in Indian calendars. In *Vedāṅga* astronomy, a *tithi* was a 1/30 part of a synodic month, where the equation of centre was not known. In Hindu Classical Astronomy, a *tithi* is a period of time during which the longitudinal difference of the sun and moon changes by 12°. If a *tithi* is included within a day, the *tithi* is called "omitted *tithi*". In Hindu traditional calendars, the name of a civil day is determined by the number of *tithi* at the beginning (sunrise) of the day. Therefore, the number of an omitted *tithi*, which does not include any sunrise, actually disappears from the calendar.

The significance of Yixing's definition is that when the sum of the *mori* (a day which is included within a segment of 1/360 of a tropical year) and *mieri* grows to 30, one intercalary

month is produced. This way of thinking is similar to certain descriptions in Indian classics, such as the *Arthaśāstra*. A similar description is also found in a Chinese version of the Buddhist text *Lishi-apitan-lun*, translated by Zhendi at the middle of the sixth century AD.

I suspect that Yixing knew this Indian method, and changed the meaning of the *mieri* in order to make it meaningful in Indian calendrical context (Ōhashi, 2001).

Other Texts in the Tang Dynasty

In addition to the above-mentioned texts, the *Suyao-jing* is also famous. In the title, *su* means lunar mansions, *yao* means planets and *jing* means canonical scripture. It is an astrological work which was compiled by Amoghavajra in the middle of the eighth century AD. It is based on Indian horoscopic astrology.

There is also an astrological work with planetary ephemerides entitled *Qiyao-rangzaijue*, compiled by Jin Juzha, who is said to have been a Brahman priest from Western India, in the early ninth century or so. In the title, *qiyao* means seven planets, and *rangzaijue* means formulae to avoid disasters (caused by planets). This work is a kind of mixture of Indian astrology and Chinese astronomy. It includes the ephemerides of the five planets, Rāhu, Ketu and the sun. In Indian astronomy, Ketu usually means the descending node, or comets. However, Ketu in the *Qiyao-rangzaijue* is, according to Michio Yano's study, the apogee of the lunar orbit. This is a special feature of this work (Yano, 1986).

We have seen some records of Indian astronomy in Chinese sources. We have to keep in mind that Indian influence on Chinese astronomy was very small. The tradition of Chinese original astronomy was very strong, and it seldom accepted foreign influence. However, we can find some exceptional influences in Chinese sources, and these exceptions draw attention to researchers.

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Atomism in Islamic Thought

Alnoor Dhanani

Atomism, the view that there are discrete irreducible elements of finite spatial or temporal space, played a significant role in Islamic intellectual history. It was upheld by most practitioners of the uniquely Islamic discipline of *kalām*. However, some practitioners of *kalām* (i.e., *mutakallimūn*) as well as all but one of the practitioners of *falsafa* (i.e., *falāsifa* – those engaged in the Neoplatonized Peripatetic philosophy of medieval Islam) were antiatomists. There was thus a lively debate between atomists and antiatomists, regarding not only matter theory,

but also other areas of natural philosophy and cosmology, particularly theories of space, time, void, motion, and causality.

Kalām has no counterpart in the Western tradition. Even though primarily theological in orientation, it is not equivalent to theology. The subject matter of *kalām* includes not only theological topics, e.g., the nature and attributes of God, prophecy, and revelation, but also philosophical problems of cosmology, logic, anthropology, psychology, etc. The origins of *kalām* are obscure and a subject of debate. Suffice it to say that *kalām* arose in the mid-eighth century, and that during the later half of that century, questions about the nature and attributes of objects were being discussed. In their discussion of such questions among themselves and with others from the various religious and intellectual traditions of the Hellenized Near East, the *mutakallimūn* had access to views and theories propounded by the intellectual, doctrinal, and sectarian movements of Late Antiquity: Neoplatonism, Stoicism, Manicheanism, Dualism, Bārdaišānism, etc. Little is known about the *mutakallimūn*'s manner of access to these views. It was probably oral and through personal contact. Such a transmission is in sharp contrast with the large-scale translation of Greek philosophical and scientific texts during the late eighth and ninth centuries which gave rise to *falsafa*.

The *mutakallimūn* of the late eighth century held three theories of matter and its attributes. In the first, bodies are the only constituents of the world. All secondary qualities like sound, taste, color, etc. are thus corporeal. It follows that perceptible objects consist of several interpenetrating bodies. This view, whose origins are Stoic, was held by some Dualists. Its early *kalām* subscribers were ḥishām ibn al-ḥakam (d. ca. 795), and al-Aṣamm (d. 815). Later, the antiatomist Ibrāhīm ibn Sayyār al-NaẒẒām (d. 835–845) advocated it, albeit holding that motion was the sole accident.

In the second theory, unextended accidents are the only constituents of the world. Extended bodies result from a combination of accidents, namely, color, taste, hot/cold, rough/smooth. The origins of this view lie in Neoplatonism and

Christian theology. Its *kalām* subscribers were ḍirār ibn 'Amr (d. 815), ḥaḥṣ al-Fard (fl. 810), and ḥusayn al-Najjār (d. ca. 835–845).

The third theory holds that accidents and bodies constitute the world, and that bodies are constituted from atoms. This view had its partisans among the Dualists and the Bārdaišānites. It was appropriated into *kalām* by Abū al-Hudhayl al-'Allāf (d. 841) of the Basrian Mu'tazilī school of *kalām*; the Baghdadī Mu'tazilī Bishr ibn al-Mu'tamir (d. 825–840); and Mu'ammār al-'Abbād al-Sulamī (d. 830). Towards the mid-ninth century, the atomic theory displaced its rivals to become the dominant physical theory of *kalām*. Atomism was upheld by the Ash'arī *kalām* school formed in the tenth century in opposition to Mu'tazilīs, particularly regarding questions of man's free will and God's absolute power. However, atomism was attacked by the *falāsifa* who upheld Aristotelian arguments. In the eleventh century, the Basrian Mu'tazilī Abū al-ḥusayn al-Baṣrī (d. 1044) embraced *falsafa* physical theory and abandoned atomism. Atomism declined further in the twelfth and later centuries with the growing influence of Ibn Sīnā's (d. 1037) philosophy. Even though atomism was never actually abandoned, it was no longer central to post-twelfth century *kalām*.

As none of the writings on physical theory of the eighth and ninth century *mutakallimūn* has survived, their theories must be reconstructed from extant fragments. The principal source has been the doxography, *Maqālāt al-islāmīyīn* (The Doctrines of Muslims) by the former Mu'tazilī and founder of Ash'arī *kalām*, Abū al-ḥasan al-Ash'arī (d. 935). The following account of early atomism may be drawn: early *kalām* atomists distinguished between the atom (denoted by *jawhar* (atom), *juz'* (part), *al-juz'alladhī lā yatajazza'* (the indivisible part)) and the body. The body has length, breadth, and depth, while the atom lacks these dimensions (however al-ṣāliḥī [fl. end of ninth/early tenth century] held that the atom was a body). Rather, they believed that dimensions are produced by combinations of atoms. Hence, a minimal length arises when two atoms combine (or, in the formulation of the *mutakallimūn*, a line is formed by

the combination of two atoms). There were different views on the minimal number of atoms which constitute a body having length, breadth, and depth: Abū al-Hudhayl held that it was six; Mu‘ammar held that eight were required; and Abū al-Qāsim al-Balkhī (d. 931) held that four sufficed.

There are obvious parallels between *kalām* and Greek atomism regarding proofs for the existence of atoms, as well as terms which denote the atom. Yet the concept of dimensionless atoms combining to form bodies with dimension is unique to *kalām*. New light has been shed on this puzzling view, and on *kalām* physical theory in general, by the rediscovery of eleventh century sources. Of particular importance are the Basrian Mu‘tazilī texts of Ibn Mattawayh and Abū Rashīd al-Nīsābūrī (both fl. first half of eleventh century), as well as Ash‘arī texts by Abū al-Ma‘ālī al-Juwaynī (d. 1085) and Ibn Fūrak (d. 1015). These sources reveal that, in his reformulation of *kalām*, the Basrian Mu‘tazilī Abū Hāshim al-Jubbā‘ī (d. 933) had redefined the atom as “that which occupies space (*mutaḥayyiz*),” a designation which was also applied to the body. From this designation, as well as arguments advanced in support of the theses that the atom has magnitude (*miṣāḥa*) and its shape resembles a cube, it is clear that the atom must somehow be extended (the Ash‘arī *mutakallim* Abū Bakr al-Fūrakī (d. 1085) states: the atom is the smallest of what is small with respect to volume). Paradoxically, these *mutakallimūn* insisted that despite its magnitude the atom lacked length, breadth, and depth. Like their earlier colleagues, they continued to hold that dimensions were produced by combinations of atoms. Moreover, they considered any difference between their view of the atom and the earlier view as marginal; it was partially conceptual but partially a result of the manner of expression.

These texts suggest the interpretation that a geometry of discrete space underlies *kalām* atomism (as in Epicurean atomism). In ancient and medieval thought, any distinction between geometrical and physical space was inconceivable. If physical space was continuous, then so was geometrical space. Likewise, discrete physical

space meant discrete geometrical space. Hence, *kalām* formulations of “indivisible,” “dimension,” “magnitude,” and “body” need to be analyzed within discrete geometry. Here, a point, which is defined as that which has no parts, is equivalent to the indivisible magnitude (i.e., atom). Next, a line, which is terminated by two end points, must consist of at least two indivisibles. It follows that two indivisibles constitute the least line and are the least to constitute the dimension of length. The *kalām* atom cannot, thus, have length, breadth, or depth, but it has magnitude for it is an indivisible of discrete (and not continuous) geometry. The combination of atoms to form linear dimensions is no longer problematical; unlike points of continuous geometry which lack both dimension and magnitude, atoms/indivisibles of discrete geometry have minimal magnitude yet lack dimension. Such atoms combine to form objects with larger magnitudes and dimension. In a discrete geometry whose indivisibles are square-shaped (as seen from a continuous geometry, for the *mutakallimūn* state that the atom *resembles* a square; having no dimensions it cannot be a square!), one may configure minimal bodies from four, six, or eight atoms.

In his critique of atomism, Aristotle argued that atomism entails indivisible parts of space, time, and motion. Accordingly, most eighth and ninth century atomist *mutakallimūn*, and many later *mutakallimūn* upheld the minimal parts of space, time, and motion. In the tenth century, Abū Hāshim al-Jubbā‘ī abandoned the minimal parts of space (and consequently minimal parts of time and motion) in response to difficulties raised by antiatomists. His successors did not all adopt this view; some continued to say that space, time, motion, and matter were constituted out of indivisibles. We may also note that the atomist *mutakallimūn* upheld the existence of void spaces.

Atomism posed several conceptual and geometrical difficulties, some of which are traceable to Aristotelian arguments against atomism. It may be relevant to mention some Islamic contributions. One argument formulated by Abū al-Hudhayl, which is based on Zeno’s dichotomy

paradox, was the ant and sandal argument. Imagine an ant creeping over a sandal. In order to traverse the sandal, the ant must first traverse half the sandal; but to traverse half, the ant must first traverse half of this, and so on. Hence the traversal cannot commence unless the division terminates at an indivisible (i.e., atom). Abū al-Hudhayl's student, the antiatomist al-Naẓẓām, responded with his theory of leap (*tafra*), saying the ant does not traverse through all points on the path of traversal, but it traverses through some and leaps over others. Hence, al-Naẓẓām claimed, one may traverse from one location to another without traversing all intervening points. The theory of leaps played an important role in discussions of physical theory, if only to illustrate the absurdity of the actually infinite division of matter which was attributed to al-Naẓẓām. Al-Naẓẓām also formulated a clever argument against atomism. Imagine a rotating millstone. Since both an inner circle and the millstone's circumference must complete a rotation in equal time, when an inner circle is ten atoms in length, and the circumference is a hundred atoms, for each unit of space traversed by an atom on the inner circle, an atom on the circumference would have to traverse ten units. Explaining this, al-Naẓẓām resorted to his theory of leaps: when an atom on the inner circle moves one unit, an atom on the circumference moves one unit and leaps nine units. Abū al-Hudhayl, however, responded that the atom on the inner circle moves for one time unit and rests for nine units, while the atom on the circumference moves for all ten units. Al-Naẓẓām objected that this entails that particles of a solid body cannot adhere to each other but must be set loose to allow for such moments of motion and rest. Hence, a rotating solid body must disintegrate (*tafakkuk*) and its internal configuration of atoms be modified. The atomist *mutakallimūn*, unable to answer al-Naẓẓām's challenge, accepted the internal disintegration of a rotating body. However, they considered it to be analogous to a salt shaker where salt particles move freely within the confines of the shaker.

Why did the *mutakallimūn* embrace atomism? This question has puzzled researchers,

particularly given the difficulties atomism raised. The thesis that atomism was theologically more acceptable than the continuously divisible matter theory of the *falāsifa* has been widely accepted. Continuous divisibility raises problems of infinity, and the *mutakallimūn* were mindful of the relationship between ending infinite regress in the argument for the temporal creation of the world and the argument for the divisibility of matter. Yet the question still remains as to why three theories of matter were considered theologically sound in early kalām, and why early atomists did not claim that their theory was, theologically, the most sound. The assertion that antiatomists were heretics is only found after the tenth century when atomism had triumphed. The question of the affinity of atomism to occasionalism has also been raised, but this needs to be reexamined in the light of new sources.

Atomism was also upheld by the famous physician and *faylasūf* Abū Bakr Muḥammad ibn Zakariyā' ► *al-Rāzī* (d. 925). However, surviving accounts are scanty. We only know that his atoms were extended (like Democritus' atoms). Atomism is part of al-Rāzī's cosmology of the five eternal: God, Soul, Space, Time, and Matter upheld by the ṣābiāns of ḥarrān. Some of al-Rāzī's views may derive from Irānshahrī (fl. late ninth century) about whom very little is known.

See Also

- *al-Rāzī*
- *Ibn Sīnā (Avicenna)*

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Ātreya

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Ātreya or Punarvasu Ātreya was probably the physician of an ancient king of Gāndhāra. The name Ātreya implies that he was either a descendant or a disciple of Atri, a sage mentioned in the *Veda*. The date of Ātreya may be fixed before the grammarian ► [Pāṇini](#) (seventh century BCE) and after the *Atharvaveda* (1200 BCE), ca. 1000 BCE.

On the basis of his teachings, six of his disciples composed medical treatises. One of them, Agniveśa, wrote the *Agniveśatantra* or ‘System of Agniveśa’, which became known as the *Carakasamhitā* after its revision by ► [Caraka](#). Another disciple, Bhela, wrote the *Bhelasamhitā*, which has fragmentarily been preserved in a single manuscript. Unfortunately, the text is mutilated and full of scribe’s errors. Some scholars are of the opinion that the *Bhelasamhitā* may be older than the *Carakasamhitā*. The *Hārītasamhitā* is ascribed to a third disciple, also called *Ātreyasamhitā*. But the text that has come down to us is regarded as a relatively late work of an apocryphal nature, though parts of it might be old.

As to the treatises composed by the other three disciples of Ātreya, they have not been preserved. But quotations from their works occur in many commentaries. Two other Ātreya, Kṛṣṇātreya and Bhikṣu Ātreya, are mentioned in the *Carakasamhitā*. According to the *Mahābhārata*, the ‘Great Epic of India’, Kṛṣṇātreya was the founder of a medical school. There is mention of another Ātreya connected with the Buddhist University of Takṣaśilā. He was the teacher of a contemporary of Buddha (fifth century BCE), the famous surgeon Jīvaka to whom tradition attributes extraordinary operations.

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Aztec Science

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The name Aztec most commonly refers to Nahuatl-speaking people who dominated the Basin of Mexico, and indeed much of central and southern Mexico, in the fifteenth and early sixteenth centuries. The most prominent of these people called themselves Mexica. They settled their island city of Tenochtitlan (today Mexico City) in AD 1325, in the midst of a large number

of well-established cities. The Mexica, as hunter and gatherer immigrants from the northern Mexican deserts, were latecomers to the Basin of Mexico and combined their nomadic-style culture with the ways of life of long-settled villagers and urban dwellers. In the fifteenth and early sixteenth centuries, numerous different ethnic groups coexisted in the Basin of Mexico; these groups were politically organized in city-states and exhibited visible emblems of their specific cultural identities (such as patron gods, clothing styles, and distinctive languages and dialects). Three of these groups, the Mexica of Tenochtitlan, the Acolhua of Texcoco, and the Tepaneca of Tlacopan, joined in a military alliance in AD 1430, creating the Aztec empire which subsequently conquered much of Mexico. The empire was short-lived; Tenochtitlan was conquered in AD 1521 by Spanish forces.

The Mexica were the last of a long succession of complex states and civilizations in pre-Hispanic central Mexico. As such, they inherited many cultural traditions from prior civilizations, including much in the scientific realm. The Mexica were devout admirers of their predecessors, the Toltecs (ca. AD 950–1150), to whom they attributed much of their scientific knowledge. This included medicine, geology and mining, astronomy and calendrics, architecture, and fine technical arts (especially feather-working, metal-working, and stone-working). While the Mexica honored the Toltecs with these inventions, most of these skills and surely much of this knowledge clearly predated the rise of the Toltec civilization in central Mexico.

Mexica society was hierarchical and highly specialized. In general, pronounced distinctions between nobles and commoners, between different occupational specialists, and between members of different ethnic groups also meant differences in access to certain scientific knowledge and specialized training. Noble boys were educated in priestly schools where the curriculum included literacy skills, astronomically based calendrics, and the learning of histories, orations, and songs. Some highly placed individuals actively pursued scientific knowledge and were renowned as great thinkers or philosophers.

Medicinal knowledge and skills were in the hands of highly trained physicians, who appear in the documents as men or women skilled in herbal remedies and treatments of injuries and afflictions. Midwives also applied their extensive medical knowledge to the curing enterprise. Specific forms of scientific knowledge, embedded in industrial arts such as stone- or feather-working, were typically the province of exclusive occupational (and sometimes ethnic) groups, who passed on their craft from parent to child. Engineering and architecture (manifest, for instance, in the construction of buildings, dikes, and elaborate irrigation works) would have required special training, perhaps in an apprentice-style setting. Unfortunately, the documents are silent on this. Much knowledge of agronomics, as in genetic engineering of food crops, was probably developed by farmers themselves, who slowly but persistently developed increasingly productive strains of maize and other crops. While documentary evidence is uneven and inconclusive, it appears that some scientific knowledge was developed and passed on in a formal, literary context while other knowledge (such as seed selection and midwifery) was maintained in a more informal folk realm.

Mexica scientific understandings were empirically based, but also closely linked to religious beliefs. To the Mexica and their neighbors, the natural and supernatural worlds shaded into one another, and their practical scientific inquiries cannot be understood apart from their religious concepts and abstract symbolism. So, for example, empirical astronomy was intertwined with astrology and predictions of human fates. The involved system of calendrics was largely based on prolonged astronomical observations, but the calendars themselves were applied to godly demands and ritual as well as practical ends. Medicine combined pragmatic remedies with shamanism, divination, and magical cures. Glyphic writing, sculpture, architecture, and the luxury crafts of stone-, feather-, and metal-working all relied on sophisticated and well-honed practical technologies; the resulting works served secular goals and/or displayed essentials of Aztec religious symbolism. Animals

and plants resided in the everyday, visible natural world, but also carried a heavy load of abstract meaning in the less tangible world of mythology and cosmic forces. To the Mexica and their neighbors, then, an empirical, scientific realm of understanding and inquiry was intricately intertwined with a more abstract, religious realm.

Mexica scientific concepts and knowledge are understood only imperfectly today, mainly due to the paucity of primary source materials on the subject. The ancient peoples of central Mexico, including the Mexica, maintained extensive libraries of pictorial books (codices), but almost all of these were destroyed during or shortly after the Spanish conquest in 1521. An Aztec exception is the *Matrícula de Tributos* (1980) which contains numerous illustrations of plants and animals embedded in place name glyphs, as well as indications of geographical sources of certain raw materials (such as jaguar pelts, precious stones, gold, woods, birds, and feathers). Some of the information contained in pre-Columbian books (such as the *Matrícula* and others now lost) was reproduced or reconstructed following the Spanish conquest and set down in written and/or pictorial form, usually under the supervision of Spanish friars. The most famous of these, and one which includes considerable textual and pictorial information on astronomical knowledge, natural history, and medicinal practices, is *Historia general de las cosas de Nueva España* [General History of the Things of New Spain (Florentine Codex)]. This compendium relied on native informants and was compiled in the Nahuatl (Aztec) language by the Franciscan friar Bernardino de Sahagún (1950–1982).

Additional early colonial codices contain interesting scientific details, such as the images of plants and animals in place name glyphs and a star-gazing priest in the Codex Mendoza (Berdan & Anawalt, 1992) or the several herbal remedies pictured and described in the Cruz-Badiano herbal (Bye & Linares, 2013). Also available, and providing variable enlightenment on native scientific concepts, are Spanish-language histories and descriptions of the Mexica and their neighbors by Spanish secular and

religious officials. Among the most revealing of these are the natural histories of Francisco Hernández (1959) and Gonzalo Fernández de Oviedo y Valdés (1959), although the latter focuses primarily on areas to the south and east of the Aztec imperial domain. These postconquest sources blend native concepts and information with European understandings and conventions and must be read in that light.

Written sources are augmented by the material remains of the people themselves, discovered and interpreted archaeologically. The remains of structures provide clues to architectural and engineering skills; urban layouts suggest detailed understandings of the movements of celestial bodies; artifacts in metal, stone, and feathers (and the tools that produced them) reveal sophisticated industrial technologies; and ancient food remnants, such as corncobs, demonstrate a steady enhancement of crop productivity through hybridization and selective breeding. In addition, human physical remains have left clues to Aztec health, nutrition, and medical practices.

A closer look at astronomy, natural history, and medicine is presented below to illustrate the nature, extent, and goals of Mexica scientific inquiry.

Cosmology, Astronomy, and Astrology

Like their forebears and contemporary neighbors, the Mexica were sophisticated observers of astronomical phenomena. Systematic celestial observations and studies were reportedly the domain of the elite. Imperial rulers such as Motecuhzoma Xocoyotzin (r. Tenochtitlan 1502–1520) had duties which included observing star groups in the night sky, as well as carefully following the morning star, Venus. Nezahualpilli, early sixteenth-century ruler of neighboring Texcoco, spent endless nocturnal hours observing and recording the movements of celestial bodies from the roof of his royal palace. This “observatory” was structured so a man could lie down and contemplate the night sky through small perforations through which were placed lances with

cotton spheres atop. While this description of observing techniques is vague and not entirely clear, it does indicate that careful, rigorous, naked-eye techniques were employed to follow changes in the celestial realm.

Although rulers may have spent some of their nighttime hours studying the heavens, this activity was more commonly performed by priests, who spent many waking hours at night. The *Codex Mendoza* shows one such priest engaged in observing the heavens for the purpose of marking the passage of time. Some temples may have served as “sighting stations” or observatories, from which pairs of crossed sticks were aligned to gain accurate lines-of-sight to celestial phenomena. Lines-of-sight were also established between temples and recognizable points on the horizon and between specific urban structures. The passage of the sun through the seasons could be readily charted in this fashion, with solstices and equinoxes especially marked. For instance, in Tenochtitlan the spring equinox was marked by the passage of the sun directly through an opening between the twin shrines of the Great Temple. This was extremely important to the Mexica; reportedly the emperor Motecuhzoma, micro-managing new construction of the temple, ordered imprecise work torn down and rebuilt to assure the temple conformed to its spring equinox alignment (Motolinia, 1971). This emphasis on precision, along with the various observational devices and techniques, also allowed the ancient Mexicans to track the phases of the moon, record the arrangements of star groups (constellations), follow the movements of the Pleiades, calculate the revolution of Venus, and predict eclipses. They also attended to other celestial phenomena such as meteor showers and comets. Their eyes and minds were glued to the heavens (Aveni, 2001, 2012).

The movements of the sun, stars, moon, and planets had important practical and ritual applications for the Mexica and their neighbors. They were especially concerned with the passage of time and developed complex and accurate calendars of 365 and 260 days. The former was a solar calendar especially used in seasonal agricultural

and state-ceremonial planning; the latter, approximating periods of human gestation and the agricultural cycle, was the basis for divination and astrological determinations. Combined, these two calendars yielded a 52-year cycle which carried a heavy load of complex symbolism and obligatory rituals. To the Mexica, time was cyclical and repetitive, and much as the individual seasons and years came and went with marked similarity, so also did the 52-year “centuries.” The fate-oriented Mexica also saw cycles in the creation and destruction of the universe. Legends told of four prior worlds and their destructions, with the Mexica living in the “fifth sun.” A great deal of carefully prescribed ritual and human sacrifice was required of the central Mexicans to assure the maintenance of this world, whose continuance was especially vulnerable at the closing of each 52-year unit. Thus, a great deal of cultural interpretation was lent to the systematic visual astronomical observations of priests and rulers.

The Mexica conception of the universe and its heavenly bodies was a combination of scientific observations and ideological constructs. Celestial and terrestrial space was united in a hierarchical scheme containing thirteen heavenly layers and nine layers of the underworld. Heavens and underworld were linked by the earth’s surface, which was counted in each. The world above the earth combined visible phenomena with invisible gods and goddesses; for instance, the moon occupied the layer above the earth, followed by the clouds in the next tier, then the sun, Venus, and the Fire Sticks constellation (possibly the belt and sword of Orion) in successive levels. It should be kept in mind that certain celestial bodies, especially the sun, moon, and Venus, were not only visible phenomena but were also accorded divine status. Heavenly layers contained invisible deities, with the male/female creator god at the apex. This whole, integrated arrangement is quite different from the heliocentric (sun-centered) and geocentric (earth-centered) concepts developed in the Eastern Hemisphere.

The linking of heavens and earth is manifest in much of central Mexico’s urban planning. Some scholarly arguments favor the position that cities

and temples conform to astronomically significant alignments. The orientation of Teotihuacan (ca. AD 1–650/750), for instance, may have been associated with the movements of the Pleiades (Aveni, 2012), and we have already seen the spring equinox orientation of Tenochtitlan's Great Temple. At least some astronomically based alignments directed city planning, although its extent is currently debated (see Smith, 2008). In those cases where the ancient Mexicans oriented their centers and temples along astronomically meaningful lines, the human, sacred, and scientific were meshed into a single cultural realm.

Natural History and Ecology

Like the celestial bodies above the earth, the natural phenomena on and in the earth were viewed both scientifically and symbolically. In this close perceived link between natural and supernatural, the creatures of the earth performed a variety of functions in both visible and invisible cultural realms. Birds and beasts were valued as providers of food, fur, and feathers, but were also frequent subjects of metaphors and players in myths and legends. The concrete and abstract were linked: the roles that creatures played in myths, the meanings they carried in the ritual calendar, and the messages they conveyed in metaphors were based on empirical observations of behavior, life cycles, and anatomy (see Berdan, 2014). For example, a human fugitive was likened to a fleet deer, the patting of tortillas compared to the flapping wings of a butterfly, and an eavesdropper described as the little mouse that inhabited every nook and cranny of a house. Close, systematic observations also led to an understanding of the transformations of the hummingbird, which seemingly died during nighttime or winter months and came to life in the warmth of day or springtime. Not surprisingly, hummingbirds were associated with human life-death transformations.

Much of the study of wild creatures undoubtedly took place in the animals' natural habitat, so that, for instance, the wily hunting techniques of

the bobcat, the reproduction of locusts underground, and the nesting of certain birds in "inaccessible places" are recorded. However, the Mexica also maintained a large zoo and aviary in the city of Tenochtitlan, and such a setting would have provided ample opportunity for some degree of observation and study. This was particularly significant for understanding birds and beasts from distant parts of the empire; these were especially valued for their fine feathers or precious pelts.

Habitats of various creatures were meticulously recorded, surely from direct attention to nature: the gray fox was a cave dweller, the tadpole lived in freshwater among algae and water lilies, the raccoon preferred forests and crags, and so on. The many parts of nature were perceived as interconnected: the American Bittern's enthusiastic nighttime singing predicted heavy rains and abundant lacustrine fish; the Ruddy Duck's evening antics signaled rain at dawn; the song of yet another bird heralded the onset of frost.

The Mexica readily understood relationships among the various creatures themselves, including humans. Human involvement in ecological dynamics at times had significant consequences. The Mexica were aware of the rarity of certain creatures, such as the wood ibis or certain serpents; indeed, they considered it a bad omen to catch the wood ibis, a cultural constraint which would have served to preserve this rare avian. In another example, the Mexica king Ahuitzotl (r. 1486–1502) was reportedly responsible for bringing great-tailed grackles to Tenochtitlan from eastern lands and ordering their protection. Unexpectedly, these birds thrived to such an extent that they became an ecological burden, understandably losing their popularity. In these examples, the Mexica were active participants in a continuous ecological drama, engineering changes with often-unanticipated consequences.

Medicine and Health

The Mexica were scientific and empirical in their discovery and use of medical cures for a large

number of illnesses and injuries. The specialized doctor, or *ticitl*, used practical approaches to his/her profession, examining and diagnosing physical problems and prescribing appropriate cures. Physicians could call upon a large pharmacopoeia derived from herbs, roots, animals, and minerals to relieve symptoms, heal injuries, and restore health. They were skilled in soothing burns, setting broken bones, and suturing lacerations, many of these latter injuries undoubtedly suffered in the frequent battles fought in this militaristic society. Midwives also entered the curative arena, being skilled in herbal remedies as well as childbirth processes.

Medical procedures could be multi-staged and quite complicated. Broken bones, for instance, were first set and then splinted with poultices of specified ground roots or herbs. There was some variety in these usages, as the curative ground roots or herbs could be spread on the injury, drunk with pulque, or enjoyed in a bath. A bitten tongue was first subjected to a mixture of chili cooked with salt, followed by a more comforting application of bee or maguey honey. The Mexica considered at least 132 herbs to have curative properties, and these were applied to at least 40 ailments other than injuries. Curable ailments included nosebleed, pimples, headache, diarrhea, fatigue, coughs, chest pains, nausea, difficult childbirth, and many fevers and infections. Other medical issues (some more serious than others) included compromised mental states, arthritis, tuberculosis, insomnia, and hair loss. Some individual infirmities could be served by a variety of cures – for instance, 45 different herbs could be used to relieve fevers and 18 could be applied to festering skin. On the other hand, some remedies had multiple uses – one herb, for instance, could reportedly slow bleeding, inhibit vomiting, relieve side and chest pains, and in general restore a person's strength. The effectiveness of some of these natural remedies has been verified scientifically. In one study, of 118 plants used by the Mexica for curing, 85 % were shown to contain medicinal components recognized in the twentieth century (Bye & Linares, 1999, p. 5). For instance, the Mexica used the sap of maguey leaves to heal

festering wounds; today's studies indicate that the same sap inhibits the growth of various bacteria associated with wounds. In another example, the Mexica used white sapote as an effective sleep aid, and modern medicine reveals that the seeds of this fruit indeed contain sedative components (de Montellano, Bernard 1990, pp. 182–185).

There was some geographic variation in the incidence of medical problems: respiratory and gastrointestinal afflictions were especially prevalent in the highlands, while parasites were particularly problematic in lowland settings. Age was also a factor: rheumatism and arthritis troubled people over the age of 30–35, young children most often suffered from diarrhea and dysentery, and some children also experienced iron-deficiency anemia (Berdan, 2014, pp. 247, 250).

Medicinal aids were often mixed into complex curative potions. Additionally, cures were at times combined with other types of remedies. One of the most popular of these adjuncts was the sweatbath, often recommended as helpful in childbirth problems, skin festering, and traumas. Practical remedies were also at times joined with divinatory and magical cures; magic and divination were used in both diagnosis and curing of certain illnesses. The Mexica believed that some illnesses could have supernatural causes; these included soul loss and the intrusion of unpleasant supernatural substances.

A preventive element is also evident in Mexica medicine. A generally adequate diet contributed to relatively low incidences of chronic diseases such as cancer and heart disease (de Montellano, Bernard, 1990, p. 121). The Mexica also put a premium on hygiene, although a good diet and/or hygiene was not always followed; malnutrition and illnesses have been detected in some skeletal and dental remains of both children and adults (Berdan, 2014, p. 250). Some specific behaviors and natural materials were earmarked for illness prevention and the maintenance of good health. For instance, one designated herb was said to aid digestion and prevent fevers, a nursing mother could prevent diarrhea in her infant by shunning avocados, hair loss could be arrested by avocado seeds, and

stammering or lisping could be avoided by weaning children at a young age. In another vein, some illnesses required adherence to strict taboos: a patient with a fever was not to eat hot tortillas or chilies, and one with a head wound was to refrain from eating fish or meat. Thus, medicine and the maintenance of health in Mexica society were complex matters, relying on a blending of scientific knowledge, behavioral conventions, and strong religious beliefs.

Applications of Mexica Science

What did the Mexica do with the vast amount of knowledge they and their forebears had acquired about the world around them? What was the purpose of the many systematic and rigorous studies they made of the heavens and the earth?

While some priests and rulers may have enjoyed the process of discovery for its own sake, it is clear that scientific knowledge among the Mexica was preeminently geared toward practical and religious applications. Long-term, rigorous observations of the heavens, and the recording of celestial movements, furnished the Mexica with temporal order. These scientific inquiries provided the basis for a sophisticated calendrical system, the ability to make appropriate seasonal preparations, and the capacity to predict and prepare for extraordinary and sometimes fearful events (such as eclipses).

The Mexica were hunter-gatherers long before they entered the Basin of Mexico and adopted a well-developed agrarian lifestyle. Bolstered by both of these traditions, the Mexica were keen observers of nature and its processes. They understood the anatomy, behavior, life cycles, and ecology of wild plants and animals. They also had a sophisticated knowledge of cultigens and drew on a long agrarian tradition of seed selection, agricultural technology, and even the ability to predict certain pertinent weather conditions from animal behavior. They applied this extensive and varied knowledge first and foremost to increase and protect their food supply.

However, natural resources also enhanced their life conditions by providing fibers, furs, and feathers for clothing and adornment; building materials for domestic and godly shelter; and precious stones and metals for ostentatious displays of social status.

Nature also provided a wealth of medicinal cures, discovered, combined, and applied successfully by specialized physicians. Administering the proper remedy to the specific ailment undoubtedly required considerable experimentation, but unfortunately the documents are silent on this process.

We therefore have quite a bit of information on the Mexica's scientific results, but little understanding of their methods. Those methods, such as rigorous naked-eye astronomy, repeated observations of earthly phenomena, and centuries-long seed selection, yielded a significant body of sophisticated scientific knowledge, applied by the Mexica to practical ends. The Mexica also consistently linked the scientific realm to the religious and utilized empirical discoveries to enhance and embellish their everyday lives on more abstract and supernatural levels.

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B

Bakhshālī Manuscript

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The Bakhshālī Manuscript is the name given to the oldest extant manuscript in Indian mathematics. It is so called because it was discovered by a peasant in 1881 at a small village called Bakhshālī, about 80 km northeast of Peshawar (now in Pakistan). It is preserved in the Bodleian Library at Oxford University.

The extant portion of the manuscript consists of 70 fragmentary leaves of birchbark. The original size of a leaf is estimated to be about 17 cm wide and 13.5 cm high. The original order of the leaves can only be conjectured on the bases of rather unsound criteria, such as the logical sequence of contents; order of the leaves in which they reached A. F. R. Hoernle, who did the first research on the manuscript; physical appearance such as the size, shape, degree of damage, and knots; and partially preserved serial numbers of mathematical rules (9–11, 13–29, and 50–58).

The script is the earlier type of the Śāradā script, which was in use in the northwestern part of India, namely, in Kashmir and the neighboring districts, from the eighth to the twelfth centuries. G. R. Kaye, who succeeded Hoernle,

has shown that the writing of the manuscript can be classified into at least two styles, one of which covers about one-fifth of the work. There is, however, no definitive reason to think that the present manuscript consists of two different works.

The information contained in the manuscript, the title of which is not known, is a loose compilation of mathematical rules and examples collected from different works. It consists of versified rules; examples, most of which are versified; and prose commentaries on the examples. A rule is followed by an example or examples, and under each one the commentary gives a “statement,” “computation,” and a “verification” or verifications. The statement is a tabular presentation of the numerical information given in the example, and the computation works out the problem by following, and often citing, the rule step by step.

Thus, the most typical pattern of exposition in the Bakhshālī Manuscript is:

1. Rule (*sūtra*)
2. Example (*udāharaṇa*)
 - Statement (*nyāsa/sthāpanā*)
 - Computation (*karaṇa*)
 - Verification(s) (*pratyaya/pratyāyanā*)

A decimal place-value notation of numerals with zero (expressed by a dot) is employed in

the Bakhshālī Manuscript. The terms for mathematical operations are often abbreviated, especially in tabular presentations of computations. Thus we have *yu* for *yuta* (increased), *gu* for *guṇa* or *guṇita* (multiplied), *bhā* for *bhājita* (divided) or *bhāgahāra* (divisor or division), *che* for *cheda* (divisor), and *mū* for *mūla* (square root). For subtraction, the Bakhshālī Manuscript puts the symbol, + (similar to the modern symbol for addition), next (right) to the number to be affected. It was originally the initial letter of the word *ṛṇa*, meaning a debt or a negative quantity in the Kuṣāṇa or the Gupta script (employed in the second to the sixth centuries). But the initial *ṛ* of the Śāradā script has a different form. This means that that abbreviation in the Kuṣāṇa or the Gupta script became a true symbol for negative numbers in the Śāradā literature. The same symbol is also used in an old anonymous commentary on Śrīdhara's *Pāṭīgaṇita*, which is uniquely written in the later type of the Śāradā script (after the thirteenth century). Most works on mathematics, on the other hand, put a dot above a negative number.

The problems treated in the extant portion of the Bakhshālī work involve five kinds of equations, namely, (1) simple equations with one unknown (15 types of problems), (2) systems of linear equations with more than one unknown (14 types), (3) quadratic equations (two types, both of which involve an arithmetical progression), (4) indeterminate systems of linear equations (three types, including the so-called hundred fowls problem, in which somebody is to buy 100 fowls of several kinds for 100 monetary units), and (5) indeterminate equations of the second degree (two types: $\sqrt{x+a} = u$ and $\sqrt{x-b} = v$, where u and v are rational numbers, and $xy = ax + by$).

The rules of the Bakhshālī work may be classified as follows:

1. Fundamental operations, such as addition and subtraction of negative quantities; addition, multiplication, and division of fractions; reduction of measures; and a root-approximation formula:

$$\sqrt{a^2 + r} \approx a + \frac{r}{2a} - \frac{(r/2a)^2}{2(a + r/2a)}$$

2. General rules applicable to different kinds of problems: *regula falsi*, rule of inversion, rule of three, proportional distribution, and partial addition and subtraction
3. Rules for purely numerical problems: simple equations with one unknown, systems of linear equations with more than one unknown, indeterminate equations, and period of an arithmetical progression
4. Rules for problems of money: equations of properties, wages, earnings, donations, etc., consumption of income and savings, buying and selling, purchase in proportion, purchase of the same number of articles, price of a jewel, prices of living creatures, mutual exchange of commodities, installments, a sales tax paid both in cash and in kind, and a bill of exchange
5. Rules for problems of travelers: equations of journeys, meeting of two travelers, and a chariot and horses
6. Rules for problems of impurities of gold
7. Rules for geometrical problems: volume of an irregular solid and proportionate division of a triangle

All the rules of the first category, namely, the fundamental operations, occur only as quotations in the computations of examples. Many of the other rules could belong to either *miśraka-vyavahāra* (on mixture) or *śreḍhī* (on series) in a book of *pāṭī* (algorithms) such as Śrīdhara's *Pāṭīgaṇita* and *Triśatikā* (eighth century), etc., but they have not been arranged according to the ordinary categories of *vyavahāra*.

We apparently owe the present manuscript to four types of persons: the authors of the original rules and examples, the compiler, the commentator, and the scribe. Possibly, however, the commentator was the compiler himself, and "the son of Chajaka" (his name is unknown), by whom the Bakhshālī Manuscript, or at least part of it, was "written," was the commentator or one of the commentators. The colophon to the section that

deals exclusively with the *trairāśika* (rule of three) reads:

This has been written by the son of Chajaka, a brāhmaṇa and king of mathematicians, for the sake of Hasika, son of Vasiṣṭha, in order that it may be used (also) by his descendants.

Immediately before this statement occurs a fragmentary word *rtikāvati*, which is probably the same as the country of Mārtikāvata mentioned by Varāhamihira (ca. AD 550) among other localities of northwestern India such as Takṣaśilā (Taxila), Gandhāra, etc. (*Bṛhatsaṃhitā* 16.25). It may be the place where the Bakhshālī work was composed.

A style of exposition similar to that of the Bakhshālī work (“statement,” etc.) is found in Bhāskara I’s commentary (AD 629) on the second chapter called *gaṇita* (mathematics) of the *Āryabhaṭīya* (AD 499). Both Bhāskara I’s commentary and the Bakhshālī work attach much importance to the verification; it became obsolete in later times. The unusual word *yāva* (*yāvakaraṇa* in Bhāskara I’s commentary), meaning the square power, and the apparently contradictory meanings of the word *karaṇī*, the square number and the square root, occur in both works.

Bhāskara I does not use the symbol *yā* (the initial letter of *yāvattāvat* or “as much as”) for unknown numbers in algebraic equations even when it is naturally expected, while he employs the original word *yāvattāvat* itself in the sense of unknown quantities (in his commentary on *Āryabhaṭīya* 2.30). This probably implies that he did not know the symbol. The symbol is, on the other hand, utilized once in the Bakhshālī work in order to reduce the conditions given in an example to a form to which the prescribed rule is easily applicable; after the reduction, the symbol is discarded and the rule is, so to speak, applied mechanically (fol. 54^v). This restricted usage of the symbol seems to indicate that the work belongs to a period when the symbol was already invented, but not very popular yet.

There has been quite a bit of dispute over the dates of the manuscript. Hoernle assigned the work to the third or the fourth century AD, Kaye to the twelfth century, Datta to “the early

centuries of the Christian era,” and Ayyangar and Pingree to the eighth or the ninth century. The above points suggest that the Bakhshālī work (commentary) was composed not much later than Bhāskara I (the seventh century).

See Also

- [Bhāskara I](#)
- [Śrīdhara](#)
- [Zero](#)

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Balkhī School of Arab Geographers

Gerald R. Tibbetts

The Balkhī School refers to a group of four authors who recognize the fact that their geographic work is interlinked. It is also known to scholars as the Classical School of Arab Geography or the Islamatlas. Abū Zaid Aḥmad ► [ibn Sahl](#) al-Balkhī (d. 322/834), who wrote *Ṣuwar al-aqālīm*, is the earliest of them and presumably the originator. The other three authors are Abū Ishāq Ibrāhīm ibn Muḥammad al-Iṣṭakhrī (ca. AD 950) (*Al-masālik wa'l-mamālik*), Muḥammad ► [ibn Ḥawqal](#) (d. between 350/861 and 360/972) (*Ṣūrat al-arḍ*) and Abu 'Abdallāh Muḥammad ibn Aḥmad ► [al-Muqaddasī](#) (d. ca. 390/1000) (*Aḥsān al-taqāsīm*).

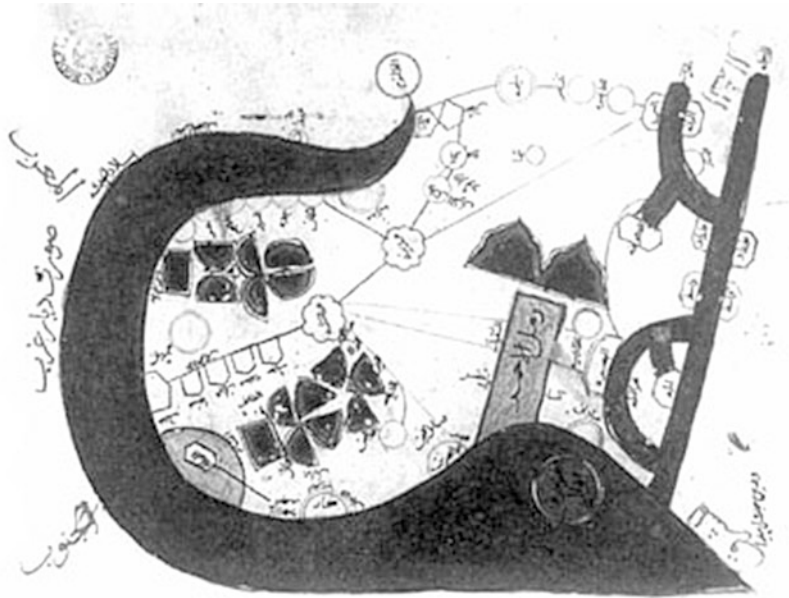
Their work is based on a series of maps covering the Islamic Empire together with a text which consists mainly of notes on the maps. Many copies of these works survive; the earliest surviving manuscript being a version by Ibn Ḥawqal dated AH 479/AD 1086. This is the

earliest Arabic manuscript to contain a map. Yet, copies of al-Iṣṭakhrī's book were still being produced as recently as the middle of the nineteenth century AD. There is so much material available that scholars have identified two separate editions 3ns of al- Iṣṭakhrī, three of Ibn Ḥawqal and two of al-Muqaddasī, although one of the versions of Ibn Ḥawqal does not contain maps. These different texts can be associated with similar sets of maps, and these maps can be compared and relationships established which enable us to trace the development of "Balkhī" cartography. The standard set of maps consists of a world map, two oceans (Indian and Mediterranean), four Roman provinces (i.e., areas which were originally Byzantine) and 14 Persian provinces ([Fig. 1](#)).

It is obvious that the maps are conceived as a set covering the Muslim Empire with reasonable detail, and there is no attempt to cover non-Islamic areas in the same way. It has been suggested that this policy of including only Islamic regions is deliberate. Each map is given a page or so of textual description, and each of these descriptions is planned in such a way that lists of routes, towns, mountains, rivers, etc., are given for each province. Thus they bear a certain

Balkhī School of Arab Geographers,

Fig. 1 Map of Arabia from al-Iṣṭakhrī's *Ṣuwar al-buldān*. From the Bodleian Library, Oxford. MS Ouseley 373, folio 9v (Used with permission of the library)



resemblance to the work of ► [Ibn Khurdādhbih](#), although the latter's work was not accompanied by maps nor did he limit himself only to the Dar al-Islam. There is a likelihood that the Balkhī School material and the work of Ibn Khurdādhbih are based on Persian (Sassanid) materials which survived the Islamicization of the Persian home areas.

The Balkhi maps cannot be connected together like the sectional maps of ► [al-Idrīsī](#) to form one large map of the known world. Al-Iṣṭakhrī and Ibn Ḥawqal show no interest in projection, scale, or mathematical geography and do not mention latitudes and longitudes at all. The only form of measurement given is that of days, journeys (*marḥala*). The maps are very geometrical in design. Lines are straight or arced, rivers are parallel lines, lakes often perfect circles. Towns can be circles, squares, four pointed stars or something similar. Stopping places on routes resemble small tents or caravanserais.

al-Muqaddasī's text is based on the same principles but is a considerable improvement over that of his predecessors. He also includes a section on astronomical geography and geodesy including a note on the Greek system of climates. Both ► [Ibn Ḥawqal](#) and al-Muqaddasī are more up-to-date and are more at home in Europe and North Africa, having a preference for the western part of the Empire rather than the Persian speaking areas. al-Muqaddasī's maps however have a closer affinity with those of al-Iṣṭakhrī, whereas we would expect, from the nature of his text, something much more advanced. He has however a different selection of maps, there being no world map nor one of the Caspian Sea and a completely new map of the Arabian desert.

The works of these authors were reproduced continually throughout the centuries not only in Arabic but also in Persian or Turkish translation. Other writers occasionally borrow a selection of the maps or an individual map. Some of the later versions are very corrupt and hardly recognizable. A world map derived from this school appears regularly in the works of Ibn al-Wardī and often in texts of al-Qazwīnī's cosmography showing how popular these maps were in the Muslim world.

See Also

- [al-Idrīsī](#)
- [al-Muqaddasī](#)
- [Ibn Ḥawqal](#)
- [Ibn Khurdādhbih](#)
- [Maps and Mapmaking: Islamic World Maps Centered on Mecca](#)

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Bamboo

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Few other plants or materials have been so pleasing to the eye, have inspired so many artists, poets, and philosophers, or have contributed so materially to the development of civilization as have bamboos. Bamboo (*Arundinaria*) is a grass that grows with great rapidity in a wide range of climates with over 1,500 species around the world. It is both immensely strong and very light. It is easily worked with simple tools and is

strikingly beautiful both in the economy of its natural form and in its finished state. Yet not only has its key role in the development of science and technology been largely overlooked by Western historians of science, but its contemporary uses tend to be contemptuously undervalued as simple and traditional. It was dismissed as "poor man's timber."

The reality is that bamboo has been one of the prime nutrients of Asian culture and may yet turn out to have a significant role to play in civilizations around the world. The applications and powers of bamboo are almost limitless from the purely aesthetic to merely practical. The earliest boats were made of bamboo. Through inspiring poetry, metaphysics, painting, and geometry while simultaneously being the material for its production, bamboo has both created and preserved knowledge, wisdom and art. Bamboo has not only sustained life by providing housing, food, and medicine, it has been used to make a profusion of tools and domestic and industrial essentials from baskets to scaffolding, cables, and steel reinforcing, from musical instruments to windmills, bridges, and airplanes.

It was a raw material for papermaking that bamboo made its greatest contribution in the past, while also having the capacity to revolutionize paper production in the future. Bamboo is a super producer yielding two to six times more cellulose per acre than pine and can be cropped annually, but its capacity to provide paper pulp has gone largely unrecognized outside India, China, Thailand, and Brazil. Fifty percent of the world's timber is used to make paper, while in India two-thirds of the paper is made from bamboo with more than 40 factories making 600,000 tons of paper annually. If this use of bamboo were extended worldwide, the saving of old growth forest currently used in wood chip production would be greatly reduced.

In Colombia and Costa Rica, bamboo, when coated with concrete in a form of lath and plaster construction, has proved to be a cheap and effective way of building earthquake-proof housing. Similar techniques are under development in the

Philippines and Hawaii to use bamboo in cyclone-proof buildings. Bamboo has proved extremely effective in stabilizing soil and preventing erosion. As a "mop crop" it also has a great capacity to extract nitrates and phosphates from effluent. These characteristics make it an ideal plant for handling two of the world's most significant problems, soil degradation and water quality. It is the ultimate renewable resource and if it is employed in either or both these ways it can become a cheap and sustainable feed stock for making paper, houses, furniture, flooring, a profusion of decorative items as well as food and medicine.

However, it is in this transition from being virtually a free good to being a valued resource that potential problems lie. Demand is already exceeding supply in India, and while government economists in Delhi argue that bamboo can become a cash crop that will improve the lot of the poor, it is possible that the landless peasants will end up being unable to afford even poor man's timber. As Western civilization gradually overtakes the developing world, research on the more industrial uses has begun, and it is being widely used in making parquet flooring and laminated beams. It is to be hoped that, as it becomes a first world resource, it does not become just another opportunity for exploitation. If the developing economies leave the knowledge of its uses and the control of production in the hands of the local people, bamboo has the capacity to benefit all of us.

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Banū Mūsā

Donald R. Hill

The Banū Mūsā were three brothers, Muḥammad, Aḥmad, and al-ḥasan, who were amongst the most important figures in the intellectual life of Baghdad in the ninth century. We do not know their dates of birth, but Muḥammad died in 873 and could hardly then have been less than 70-years old, because the youngest brother al-ḥasan was already a brilliant geometrician in the reign of ► [al-Ma'mūn](#) (813–833). Their father, Mūsā ibn Shākir, was a noted astronomer and a close companion of al-Ma'mūn when the latter was residing at Marw in Khurasan before he became caliph. When Mūsā died, al-Ma'mūn became the guardian of his sons, who were given a good education in Baghdad, becoming skilled in geometry, mechanics, music, mathematics, and astronomy.

Under the successors of al-Ma'mūn, the brothers became rich and influential. They devoted much of their wealth and energy to the quest for the works of their predecessors, especially in Greek and Syriac, and sent missions to the lands of the Byzantine Empire to seek out manuscripts and bring them to Baghdad. Muḥammad is said to have made a journey to Byzantium in person. The brothers acted as sponsors to a group of scientists and translators, to whom they paid about 500 *dinars* a month. The most outstanding of these scholars were Thābit ibn Qurra and Hunayn ibn Ishāq, who rendered numerous works, many of which would otherwise have been lost, from Greek and Syriac into Arabic. Muḥammad was on friendly terms with this group of scholars, particularly with Hunayn, who translated and composed books at the request of his patron. The brothers therefore played a leading role in the transmission of Greek works into Arabic, and in the foundation of the long and important contribution of the

Islamic world to the sciences. Some 20 works are attributed to the Banū Mūsā, of which 3 have survived. The best-known and most important of the brothers, books, which were largely the work of Aḥmad, is their *Kitāb al-ḥiyal* (Book of Ingenious Devices). The work comprises descriptions of some 100 small machines, including alternating fountains, self-filling and self-trimming lamps, and a clamshell grab. About 80 of the devices, however, are trick vessels of various kinds that exhibit an astonishing mastery of automatic controls. The inspiration for Aḥmad's work is undoubtedly to be found in the machine treatises of the Hellenistic writers, particularly the *Pneumatics* of Philo of Byzantium (mid-third century BCE) and the *Pneumatics* of Hero of Alexandria (f l. ca. AD 60). The *Kitāb al-ḥiyal*, although some of the devices in it come directly from Philo or Hero, goes well beyond its Greek predecessors, particularly in the use of small pressure variations and conical valves and other components in automatic controls. Indeed, the work of the Banū Mūsā in the variety and ingenuity of their control systems was unsurpassed until quite recent times. There may have been some didactic intention in their writing, but most of their constructions are quite trivial to our eyes. Nevertheless, many of the ideas, techniques, and components that they used were to be of considerable importance in the development of machine technology.

See Also

- [al-Ma'mūn](#)
- [Thābit ibn Qurra](#)

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Barrow in China

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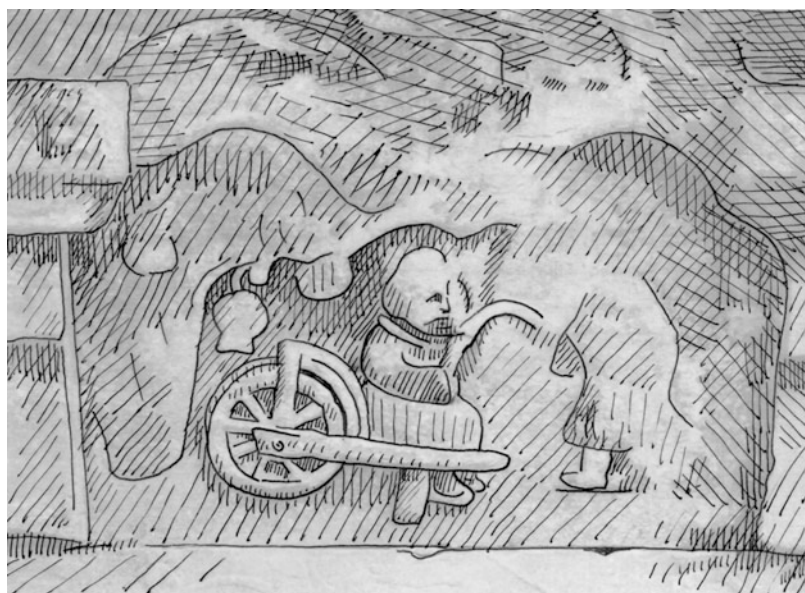
The wheelbarrow as a simple means for transporting goods has been used across much of Eurasia. The vehicle usually consists of a relatively small wheel that is mounted beneath a frame for the load. The wheel is usually placed in front or under the front part of the frame, which extends into two handles by which the barrow is

lifted up and pushed. On the basis of pictorial evidence from medieval Europe, it is assumed that the wheelbarrow was developed as a labor-saving device in which one of two men needed for carrying a carrying load was replaced by a wheel (Matties, 1991). Due to the fact that the workman had to lift part of the weight of the load, the wheelbarrow was typically restricted to short distances.

In China, the wheelbarrow is documented in pictorial sources from the first century BCE. The wheelbarrow of the Han period (206 BCE–221 CE) appears in short-distance urban transport. The vehicle has a small solid or spoked wheel that is mounted under the front third of the frame, which raises over the wheel. With the center of gravity set low, little above the wheel's axle, the tilt angle of the barrow was relatively high, reducing the weight that the barrowman had to lift while pushing. Wheelbarrows of this construction remained in use throughout the plains and lowlands of Shaanxi in the northwest across Sichuan and Hunan into Southern China (Figs. 1, 2, and 3).

From the eleventh century, a one-wheeled vehicle of a different construction appears in written and pictorial sources of Eastern China. This wheelbarrow had a large spoked wheel of

Barrow in China,
Fig. 1 Early pictorial representation of a wheelbarrow on a relief stele in northern Sichuan, illustrating a story of a good son who pushed his old father by wheelbarrow. Eastern Han, ca. first century CE (Drawing by the author, 2014)



Barrow in China,
Fig. 2 Peasants with
 wheelbarrows near
 Chengdu, Sichuan
 (Photograph by Franck
 (1925) plate opposite
 p. 561)



Barrow in China,
Fig. 3 Train of
 wheelbarrows transporting
 tong oil in Hunan. The
 barrows have an additional
 small front wheel for
 negotiating steps
 (Photograph by Franck
 (1925) plate opposite
 p. 633)



the size of a cartwheel, probably not much less than 1 m in diameter. A wooden frame was built over the top half of the wheel with platforms for the load on both sides. The outside beams of these frames extend into two handlebars for the barrowman to work the vehicle and for attaching a sling that ran over his shoulders to take the weight off his arms. The load was usually divided into two and evenly distributed on the two platforms, though bulky goods could be strapped over the top of the housing (Fig. 4).

The constructional difference from the ordinary wheelbarrow is the position of the wheel under the load. The barrowman had to balance and push the vehicle, but he no longer needed to lift part of the weight of the barrow and the load. The housed wheelbarrow constituted a gain in efficiency in carrying capacity and range. The large wheel brought reduced friction and better stability compared to the ordinary wheelbarrow, and the balanced load enabled barrowmen to work full days, making the vehicle widely employed in long-distance transport (Fig. 5).

Barrow in China,

Fig. 4 A housed wheelbarrow in a farmyard in northern Jiangxi (Drawing after Hommel (1937), plate 483)

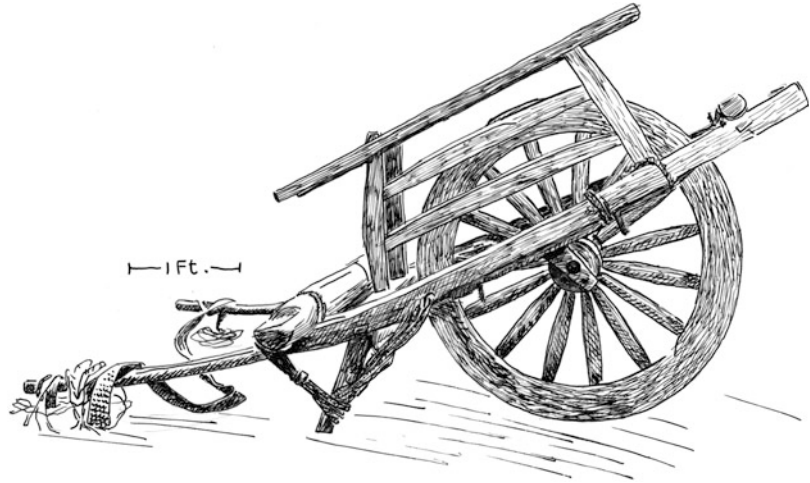
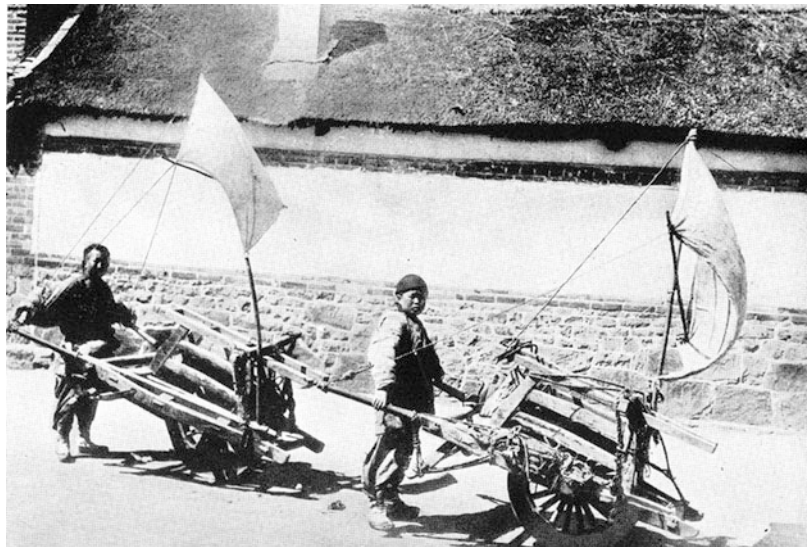
**Barrow in China,**

Fig. 5 Wheelbarrows with small sails, no location (From Wegener, 1930, plate 15)



The technical difficulty with wheelbarrows is the wheel. In two-wheeled vehicles the wheels are subjected to torque, mainly in turns and to a lesser degree on uneven ground. In a wheelbarrow, by contrast, the wheel has to withstand considerable torque almost permanently, the impact being reduced only when the barrow runs smoothly and with good balance. The technical challenge was met by using either small and simple wheels, usually a solid disk, or alternatively by particularly strong spoked

wheels. André Wegener Sleeswyk argued that the early development of highly stable yet light spoked wheels in China, which was certainly in place by the Han period, was instrumental in the development of the housed wheelbarrow (Wegener Sleeswyk, 1982). For this reason, a transition from the ordinary to the housed wheelbarrow appears unlikely, as it would involve a gradual increase in wheel size and a shift from the front to the center of the vehicle. More probably, the housed wheelbarrow was an

Barrow in China,

Fig. 6 Recent photo of a wheelbarrow wheel, showing the segmented rim, the massive hub, and the square hole for fitting the axle



B

adaptation of the cart for crowded streets and narrow paths.

While the wheels of housed wheelbarrows are similar to those of carts in size and general appearance, their construction is simpler. Instead of turning on an axle, barrow wheels have short, fixed axles protruding from the hub. These turn in the holes of two short beams that form the basis of the frame. Wheelbarrow wheels required only a single piece of metal; they were usually fitted with an iron rim. The disadvantage of the structure was that both friction and wear in the fixed wooden axle turning in a hole were high. At the same time, the simplicity kept cost low and maintenance easy; the axle was the only piece of hardwood, and the beams to both sides of the wheel could be easily exchanged when the hole began to wear out (Fig. 6).

Through the Ming and Qing periods, the housed wheelbarrow became a widespread means of transport throughout the North China Plain and the lowlands along the middle and lower Yangzi. *Tiangong kaiwu*, a technological encyclopedia of the early seventeenth century, differentiated between a larger northern form and a smaller southern form. On the basis of this and other sources, it appears that the northern form carried some 200–250 kg and was worked by two men, for heavy loads using a donkey,

possibly even two animals. In addition, sails were mounted in windy plains for additional traction. The smaller southern form usually carried about 120 kg and was worked by a single man. In the middle and lower Yangzi region, the housed wheelbarrow became the only form of wheeled transport. In densely inhabited areas where roads served as links between waterways, the wheelbarrow was particularly well adapted, as it was suitable to narrow paths and needed no animal power that had become rare in an economic system of extremely intensive land use (Figs. 7, 8, and 9).

Housed wheelbarrows were used in goods as well as passenger transport. Passengers usually sat on the two platforms as if they were narrow benches, with a foot supported by a sling, though a riding position with the passenger sitting on top of the frame is also documented. Although rarely mentioned, it seems that housed wheelbarrows served as a common means of transport for passengers who could not afford carts, sedan chairs, or horses. It would appear that they were especially popular with women, as in Northern China foot-binding had spread almost throughout the rural population, and women consequently were poor walkers. A variant form used had a somewhat smaller wheel and a flat frame mounted on a slightly smaller wheel. The vehicle



Barrow in China, Fig. 7 The northern and southern types of the housed wheelbarrow in *Tiangong kaiwu*, 1637, *juan* 9. The accompanying description corroborates

the fact that the northern barrow commonly was larger and traction often augmented by an additional man or a donkey or horse

Barrow in China, Fig. 8 Infrastructure adapted to pedestrian and one-wheeled transport: a wheelbarrow, pedestrians, and a porter carrying tree trunks on a paved path between rice paddies in central Jiangxi (Photograph Georg Wegener 1906 (1926), plate 43)



Barrow in China,

Fig. 9 Two ladies and a toddler on an outing to a temple in the vicinity of Shanghai.

Photolithographic reproduction of an ink drawing by Wu Youru, circa 1880s (Reproduced in Sun 孫繼林, 1996, no pagination)



was used in urban transport as a mobile tabletop for itinerant trade and for short-distance transport in building sites. Wheelbarrows remained in use until bicycles replaced them in the twentieth century (Kim, 2008).

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Basketry in Africa

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The term *basketry* covers a wide range of material culture usually made out of vegetable fibers from both wild and domesticated plants. However other materials such as leather, wool, metal, and plastic may be incorporated into baskets, and baskets made of plastic-coated telephone wire are now produced in southern Africa (Cunningham & Terry, 2006; Sentence, 2001; Wendrich, 1991). Vegetable fibers are made into a great diversity of objects: baskets, bags, mats, fish traps, sieves, strainers, hats, jewelry, and more. Baskets are containers made by basketry techniques.



Basketry in Africa, Fig. 1 Mafa women making coiled baskets, Gousda, Cameroon, 2002 (Photograph: J. Sterner)

They are carried on the head or back or in the hand. They are used for storing small things and as granaries taller than a human. Mats, flat but made by basketry techniques, are used as covers for pots or baskets, to sit or sleep on, or as components of walls, roofs, and fences. Such architectural basketry also includes roof caps and related forms. All these varied objects are made by three primary techniques, coiling, plaiting, and stake and strand, all of which include variations. Definition of these techniques is based on identification of the active and passive elements that make up the basic structure of the basketry item (Wendrich, 1991, 1999). The first technique, coiling, involves a passive element such as a tubular bundle of grass that is held in place by the active element, perhaps strips of palm frond (Fig. 1). In plaiting there is no passive element but three or more active elements, often groups of grass stems (Fig. 2). The stake and strand technique combines a number of relatively rigid passive elements and more flexible active ones.



Basketry in Africa, Fig. 2 Sukur man having completed plaited basket body prepares to add frame. Note the plaited wall mat on right-hand side. Sukur, Nigeria, 1992 (Photograph: N. David)

Weaving, waling, twining, and randing are sub-categories of this technique.

Unlike inorganic materials such as rocks, metals, ceramics and mineral-rich bone and antler, organic materials used to make baskets or textiles are, unless preserved in bogs, deserts or ice, poorly represented in the archaeological record. However, Trigger (1989, p. 276) remarks that, even when basketry is found in excavations, it does not receive the same attention from archaeologists as other domains of material culture (Wendrich, 1999, p. 1). Some of the earliest dated basketry specimens (*ca.* 5900–4000 BCE) were excavated in Egypt and archaeological evidence of basketry production is sometimes found as impressions in fired clay that allow identification of manufacturing techniques (Derefaka, 1980; Mayor, 2011). In the absence of dated archaeological evidence of basketry production, Cunningham and Terry (2006, pp. 25–29) have suggested that the earliest basketry in southern Africa was made by hunter-gatherers, comprising fish traps and open-twined mats that served both as platters and as sieves to retrieve roasted seeds and larvae. Herders subsequently made mats for covering shelters, and with farmers came the proliferation of a wide variety of basketry containers and other objects. Hurcombe (2008a, 2008b) has

exploited contemporary craft production and experimental archaeological methods to study the use-wear on stone tools that may have been used for cutting plant materials for use in basket making. Museum collections, photographic archives and ethnographies are other sources of basketry documentation and history (Cunningham & Terry, 2006; Sieber, 1980; Sterner, 2012). But few published sources focus on this ancient and often archaeologically invisible craft in historic and cultural context. A notable exception is Wendrich's (1999) study of archaeological and contemporary basketry in Egypt. She documents gathering and preparation of raw materials, techniques employed, genders of producers and users, specialization and much more.

Baskets may have more than utilitarian functions. They are sometimes associated specifically with women's rites of passage. A Somali wedding basket represents the bride (McMahon, 1988; Talle, 1993); in Harar City, Ethiopia, basket-making skills and proper display of baskets were an integral part of becoming a woman (Silverman, 1999; Tarsitani, 2009). And in the Aghem-Fungom area of Cameroon, a woman's grave was marked by a basket (Geary, 1987). In the nineteenth-century southern African Zulu kingdom, waterproof baskets (in addition to calabashes) for storing and serving liquids and fiber mats for serving meat were used by commoners, whereas pottery and wooden containers were the prerogative of the royal family and associates (Leibhammer, 2005).

The study of basketry has benefited from the relatively recent development of archaeological approaches to gender, craft production, and technology. This is best exemplified in the work of Hurcombe (2007) and Miller (2007). Hurcombe examines four categories of materials: organics, stone, clay and glass, and metal. Miller identifies production technologies associated with a similar range. Both authors are concerned with gender and the apparent lack of archaeological attention to women's activities and products. Basketry and other fiber crafts are specifically referenced.

The question of the gender of basket makers and users is informed by research in the Mandara

Mountains of northern Cameroon and northeastern Nigeria, a region where women make pottery and men are engaged in iron working and other crafts. In some ethnic groups, these crafts may be dominated by endogamous (casted) specialists (Sterner, 2012; Sterner & David, 1991) (this survey is based on fieldwork by N. David and J. Sterner (1986, 1989, 1990, 1991, 1992-3, 1996, 2001, 2002, 2004, and 2008) and published and unpublished information on 25 ethnic groups in the Mandara Mountains).

Among the Mafa, the most populous ethnic group in the Cameroonian Mandara, women make coiled baskets in a wide range of sizes. They are used in the household and to carry the harvest from field to granary. Unlike pottery making, basket making is here open to all women. The plant materials are available to all. Basket making takes place in the dry season, a woman working alone at her house or with others and their children beneath a shelter. The only formal tools required are a diminutive iron sickle and an awl, often combined in a single tool made by local blacksmiths. Though some produce items for sale, baskets are primarily for the use of the maker and her family. Elsewhere in the region, young boys make coiled straw hats, and blacksmiths make tightly coiled baskets used both as caps and as cups from which to drink beer. Members of the farmer caste will not drink from the same vessel as a smith.

Among other of the culturally closely related ethnic groups in the region, including the Sukur and Kapsiki, men are the basket makers, using a continuous plaiting technique. Just as elsewhere coiled baskets can be made by any woman, here plaited basketry can be made by any man. There are societies in which both types of basket are made by women and men, respectively. In addition to plaited baskets for carrying the harvest, the wide variety of basketry includes chicken carriers, rain capes, and much architectural basketry: granary caps, roof caps, mat walling, and granaries (Fig. 3). While all men can make the large mats used as walling and roofing, a few specialize in making the baskets used for carrying the harvest. A large iron needle and a sickle or knife are the only tools needed to make such a basket and



Basketry in Africa, Fig. 3 Boy with a sample of plaited basketry from the Sukur Mini-Museum. He wears a rain cape, holding one for a baby in his left hand and a beer filter in his right. In foreground there is a rolled sleeping mat, and behind, from left to right, a basket, a food preparation mat, and a basket for carrying charcoal. Sukur, 2004 (Photograph: Judy Sterner)

related forms. However there are more materials and stages involved in basket construction (plaiting of the body, making and attaching a wicker frame, forming and covering the foot and headrest). The work takes place in the dry season often under a veranda in a courtyard, with other men socializing, making rope, and sometimes assisting. The required raw materials are available to all. The baskets and related products are largely for local consumption, with some sold at regional markets.

Large plaited mats are made here for local use and are sold widely within the region and beyond. In the colonial period, men made mats in order pay taxes and bridewealth, the practice continuing to this day as a source of cash. Unlike metal artifacts and pottery, which embody utilitarian, social, and ritual functions, basketry is largely utilitarian, though granaries are repositories of millets,



Basketry in Africa, Fig. 4 Plaited and coiled baskets outside a Hidé house, Cameroon, 1986 (Photograph: N. David)

groundnuts, and symbolic meaning (Sterner, 2012; van Beek & Avontuur, 2005). In summary, in a region where crafts are often gender specific and endogamous groups monopolize metallurgy and ceramics, both genders make baskets, though by different techniques, and the items produced serve primarily utilitarian functions (Fig. 4). Is this true elsewhere in Africa?

Associations between gender and technique are found elsewhere in Africa, as is revealed in a survey of ethnographies and other sources on 23 societies/ethnic groups containing information on basketry techniques, uses and the gender of producers (Sterner, 2012). Cunningham and Terry's (2006) extensive study of southern Africa covers plant materials, the techniques employed and the uses and changes in basketry use from 1850 to present. There are descriptions of



Basketry in Africa, Fig. 5 Mafa coiled baskets with harvested sorghum ready for transport, Gousda, Cameroon, 2002 (Photograph: J. Sterner)

basketry techniques used by many ethnic groups and excellent photographs (some from archival sources) of men and women engaged in basket making and use. Unfortunately there is little specific reference to gender. Perhaps this was a wise choice as there is some controversy in the literature on Zulu basketry as to whether in the past men or women were the primary basket makers, or whether such rigid gender categories existed among early Zulu basket makers (Krige, 1950; Leibhammer, 2005). A wide range of basketry objects are made, using the three primary techniques of coiling, plaiting and stake and strand. Sometimes it is men who use the coiling technique, at other times women. It is not unusual to find that in a single society both men and women are basket makers, with each using a different technique. For example in Kenya, Kikuyu women make plaited and men coiled baskets (Ocholla-Ayayo, 1980). Conversely among the Goula of Chad, men practice plaiting and stake



Basketry in Africa, Fig. 6 Sukur houses with plaited roof and granary caps, some recently renewed, over thatching, 1991 (Photograph: N. David)

and strand, while women coil (Pairault, 1966). Here basketry is used for transporting items, storage, fishing, architecture, as mats and covers, hats, and more (Fig. 5).

There is great potential to develop new methods that do not rely on organic remains to determine the presence of basketry in archaeological sites. This is important since basketry production systems and the nature of their products do not duplicate variation in other domains of material culture but provide new and different perspectives and insights into society, culture, and the ideational world. In addition, basket makers in Africa and elsewhere make use of a huge range of plant species and have been described as caretakers of biodiversity (Novellino & Füsün Ertug, 2006). It is not surprising that in 2005 the IVth International Conference on Ethnobotany hosted a symposium on basketry. The study of basketry opens windows into both nature and culture (Fig. 6). There is indeed a “world according to basketry” (Wendrich, 1999).

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Basketry in Ancient Egypt

Willeke Wendrich

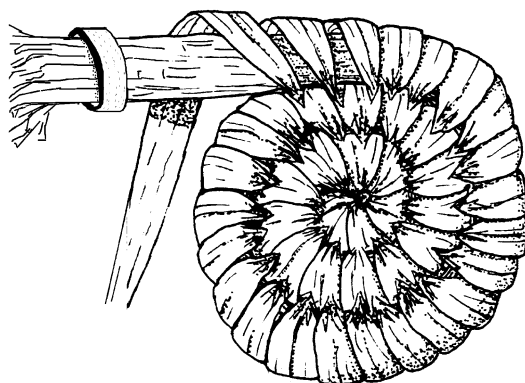
The oldest basketry found in Egypt dates to the Neolithic period (ca. 5900–4000 BCE). In the Fayum Oasis, about 100 km (60 miles) southwest of Cairo, grain storage pits were excavated in the desert floor, lined with coarse straw basketry (Fig. 1).

First discovered in 1926 (Caton-Thompson & Gardner, 1934) and examined in detail for the first time in 2005 after recent excavations (Wendrich & Cappers, 2005), these baskets represent a coiling technique. This entails a bundle of straw fastened into a coil with a number of stems pulled out of the straw bundle at regular intervals. This particular type of coiling went out of use and was replaced by a variation of the

coiling technique, which existed simultaneously. This type of coiling makes use of different materials for the bundle and the winders (Fig. 2).

Near the Neolithic grain storage pits part of an extremely finely coiled basket was found, dated to about 4200 BCE, made of separate bundle and winder materials and decorated with darker winders along the rim (Fig. 3).

These two examples from the Egyptian Neolithic demonstrate that basketry technology was well advanced by that time and must have known a long period of development for which we have no other evidence.



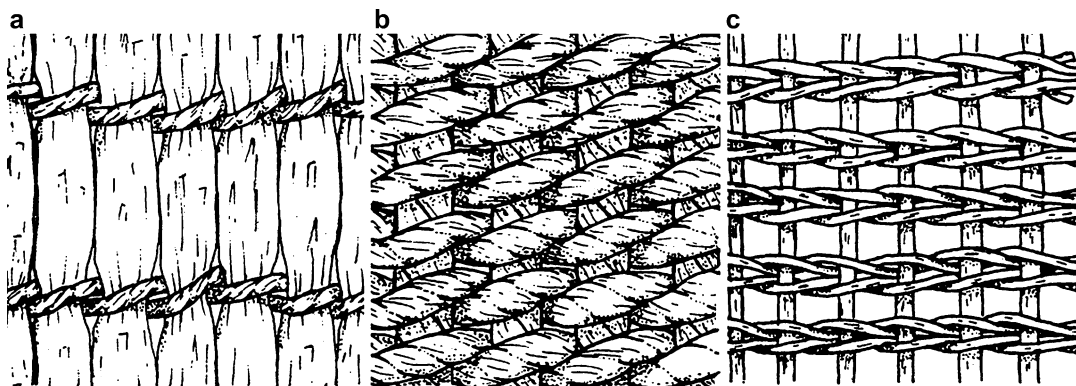
Basketry in Ancient Egypt, Fig. 2 Coiling with separate bundle and winder materials. A bundle of grass is held into place by palm leaf winders



Basketry in Ancient Egypt, Fig. 1 Neolithic grain storage pit lined with coarse coiled straw basketry, excavated in 2005 (Photograph UCLA/RUG Fayum Project)



Basketry in Ancient Egypt, Fig. 3 The Fayum Neolithic produced very fine decorated coiled basketry. This 6,000 year old fragment was found only a few centimeters under the surface (Photograph UCLA/RUG Fayum Project)



Basketry in Ancient Egypt, Fig. 4 Three examples of the many variations used to produce twined basketry: **a** a mat made of bundles of grass, fastened into a fabric with

widely spaced rows of twining; **b** a sturdy mat made of narrowly spaced twined string, and **c** a sieve grid made of open twined strips of palm leaf

The oldest and most frequently used techniques in ancient Egypt were coiling, twining and mat weaving. Coiling was used to produce sturdy baskets, varying in size from 3 to 60 cm in diameter. In Ancient Egypt wood was scarce. Basketry, therefore, had an important function, replacing cupboards as containers for clothing, food, and many other items. The tomb of Tutankhamun contained over 120 baskets (Reeves, 1990, p. 204; Malek). Even coffins and sandals were made in the coiled technique.

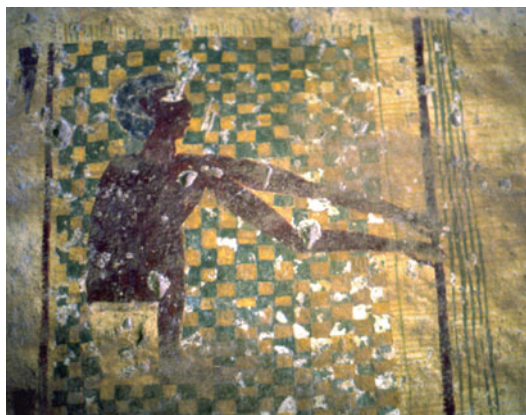
Twining has been attested from the Predynastic period onward. The twining technique consisted of a (passive) warp and a weft of two active strands. These were twisted around the passive warp elements, and each other, in either S or Z orientation. The twining technique was extremely versatile, depending on the materials used and the distance between the weft and warp elements. Figure 4 shows some of the variety.

Matting was used widely as awnings, wind-breaks and doors, but also as mattresses for sleeping and covers to wrap the dead. Egyptian architecture was characterized by many references to the use of mats in the original shrines and temples. The “drum” that was part of the so-called false door represented a rolled up mat, and decorative motifs on tomb and temple walls, such as pillars carved to resemble tied reed bundles, a stylized motif representing the tied off bundles of grass matting (the *kheker* motive) and

other decorative patterns, also referred to mats. The Djoser complex in Sakkara, for instance, displayed many references to the perishable predecessors of its stone architecture (Lehner, 1997, pp. 84–93; Verner, 2002, pp. 108–140).

For mat weaving a simple horizontal ground loom was used, consisting of four wooden pegs in the ground, to which two crossbeams were tied. The warp was kept taut by tightening the strings tying the two beams to the ground pegs. A third beam, with evenly spaced holes, guaranteed the regular spacing of the warp string (in more delicate loom types this part would be called the *reed*). It had a double function, because by slamming the beam into the woven part of the mat, it also served as a beater, creating a tight weave. The mats were mostly made with a warp of grass string, spaced 3–4 cm apart, and a weft of single grass stems, or small bundles of grass. For sleeping mats the grass was laid in with the thicker base side of the stem, while the tip was left to stick out from the warp, forming a more comfortable thick fibrous pad underneath the mat. An early depiction of a mat weaver is found in the tomb of Khety in Beni Hassan and dates to the early Middle Kingdom (ca. 1900 BCE, see Fig. 5).

From approximately the fourth century BCE onward the plaiting technique became increasingly popular in Egypt. Sandals were no longer made of many parallel rows of coiling, but rather plaited with palm leaf. The equivalent of



Basketry in Ancient Egypt, Fig. 5 Tomb painting of a mat weaver (detail), dating to the Middle Kingdom (approximately 1600 BCE). From the tomb of Khety in Beni Hassan, Middle Egypt

our flip-flop was plaited with eight strips of doam palm leaf, each approximately 4 cm wide. More elaborate sandals had several padded layers, of fine and coarse plaiting with different materials: coarse plaits from palm fiber for the outer sole, fine plaited palm leaf fabric for the inner sole. Fans were made of extremely fine plaited matting, using strands of palm leaf of only 2 mm wide. For both mats and baskets a completely new technique was introduced into Egypt, consisting of plaited strips sewn together to form a seemingly ongoing plaited fabric. Depending on the pattern, only twill strips plaited with a particular number of strands (9, 13, 17, 21, etc.) could be used, which created broad edges, with a particular orientation. The edges were pulled inside each other, thus completely hiding the sewing strand. The most commonly used materials for basketry changed slightly over time. In the prehistoric and Predynastic periods the materials attested are papyrus (*Cyperus papyrus*), the stems of the composite *Ceruana pratensis* and wheat or barley straw. In the Pharaonic period tall tough grasses (*Desmostachya bipinnata* and *Imperata cylindrica*) were used for twined and woven matting, as well as for the bundles of coiled basketry. The coils were fastened with winders of papyrus rind or doam palm leaf (*Hyphaene thebaica*). Date palm leaf (*Phoenix dactylifera*) occurred

rarely in the Pharaonic period, but became widely used toward the Late Period and the Greco-Roman period, taking over the significance of both papyrus and doam palm leaf. This probably had an environmental reason; a slight climatic change caused the doam palm to retreat south and at present this species occurs only sparsely south of Luxor and is common only in Sudan. The date palm, on the other hand, was cultivated increasingly in all of Egypt. Similarly, papyrus plants, cultivated for writing material and basketry, withdrew to the south and at present do not occur in a natural habitat in Egypt.

The variety of ancient Egyptian basketry techniques, shapes, and materials reflect the widespread use and functionality of these objects. The tomb paintings and reliefs from all periods of Egyptian history corroborate the information from the archaeological material. Bearers of offerings were shown carrying baskets full of produce and goods, farmers were depicted sowing from twined baskets, loading the harvest in enormous carrying nets and carrying the threshed grain in baskets to the granaries. Perhaps the most telling was the fact that in many of the ostraka (pot sherds and lime stone chips used as scrap paper) from the village of Deir el Medina baskets (of grain) were listed as the standard size for paying wages.

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Basketry in Japan

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Basketmaking in Japan has a long vernacular tradition, using the abundant bamboo for much of the work, this being replaced by creepers, willow, and other materials in the north where forests are coniferous and by palm and other tropical and subtropical materials on the southern islands of Okinawa. There were strong local traditions making functional baskets for the local village and surrounding areas, each being tailored for its use. There was a large range of domestic ware, for steaming, drying, storage of food, and clothing, for cradles, and many other purposes. Animal husbandry also demanded a great many baskets for gathering and carrying foodstuffs, for transport to markets, and for caging. Fishing had a wide and fascinating variety of traps, differently shaped for different species. Fish carriers often put them into water to keep the fish fresh and used scoops for transfer to the cooking pot. Gathering human food also required a wide range of special basket forms. Hip baskets were used for mushroom gathering in the bamboo forests. Back baskets were used in great variety for carrying wood, food, and animal feed when climbing up and down forest hills, leaving hands free for picking and safety. String bags, the equivalent of our plastic ones but very beautiful and well made of local fibrous plants, would also have been used all over the country for many purposes. These stems and roots, which were prepared in a number of ways, were made into cordage then woven in a vast number of different patterns.

In 2005, on a basket research trip to Japan in preparation for the co-curation of a touring exhibition “East Weaves West: Basketmaking from Japan and Britain” 2007, I was lucky to meet one of the best known vernacular basketmakers, Kazuo Hiroshima, in Hinokage, his home village on Kyushu. His work had become well known through the collection formed by the local grocer, Kenji Nakamura, with whom we stayed (Fig. 1). Kazuo Hiroshima had been apprenticed in his teens, making baskets and traveling with his teacher, weaving whatever it was that local farmers needed. He continued this itinerant life, only settling in one place during the Second World War, when he was drafted into a town to make essential containers. He was able to make many designs and became convinced that he should make these to the very best level of his skill, with attention to detail, very fine strips, and good proportions. His examples in the Nakamura Collection show this precision and artistry on these very practical baskets, and they have been exhibited in the USA and the UK as supreme examples of their kind. I was able to talk to him about his material, the bamboo from the local hillside, and hear his passion for it, the qualities of different parts of the pole, where the best gathering was done.

Such trained basketmakers would have been a common sight in rural Japan, providing the populace with the variety of carriers they needed, coming regularly to replace worn items, and able to redesign structures for new uses as country and urban life changed. The basketmaker must be a versatile craftsman, working to customer demand, in order to make a living. In addition many rural residents would have been able to make forms of containers for themselves as they needed them, a range of essential ephemeral containers. The basket was ubiquitous and vital for daily life.

On my trip I also, by pure chance, met an urban basketmaker working not far from Shinjuku Tower, in downtown Tokyo, a very unexpected sight. Shouten Yoshida is an artisan basketmaker working in a small glass lean-to next to his house and selling from a small wooden

Basketry in Japan,
Fig. 1 Kazue Hiroshima
 large backpack



B



Basketry in Japan, Fig. 2 Shouten Yoshida in his workshop

shed on the pavement (Fig. 2). He also makes a wide range of carrying baskets, for animal feed, food, and domestic ware, and a range of bamboo scoops for rice, mushroom sieves, and ladles, but

these are more rapidly made than those of Kazue Hiroshima, with coarse splits of bamboo. We watched him preparing these, first splitting the pole with a 12-bladed tool which is hammered down the pole. The resulting strips are then scraped on the inside to remove the softer central parts and the nodes, making them thin enough to weave, and then they are taken between two precise vertical blades to make the strips a uniform width along their length. His dust scoops, backpacks, and hip baskets were functional and immensely strong. Such urban basketmakers would have been a common sight in all towns, again using whatever material was available locally.

Further north, in Yokote, near Akita, where there is no bamboo, I met an urban basketmaker, Shin-ichi Nakagawara, making only two designs for the local market and with a 5-year waiting list because of their strength and long-lasting qualities (Fig. 3). He learned from his father and is proud to continue the tradition, using vines he gathers in winter from the local mountains, which is hard work for a precious material. It is carefully stored and soaked before use. He works in a corner of the main room in his house; his elderly mother cuts the material to length as she had done for her husband. His wife is also fully involved, completing the baskets with a thick, strong, beautiful rounded border. He makes several sizes of shopping baskets to the same basic



Basketry in Japan, Fig. 3 Baskets by Shin-ichi Nakagawara

plan and small baskets for sweets and fruits. He is proud, with reason, of their quality, each being woven immaculately. I was impressed by the use of every scrap of material, short trimmed ends being packed in to thicken the border; nothing whatever was wasted.

A more formalized way of learning the range of traditional techniques is taught at the Beppu, Kyushu, school for basketry, which has been running in various transformations since 1902 as a technical training support center for artisans. In the 1950s cheap plastic containers replaced many of the simple bamboo wares, so more effort was put into making high-end beautiful things showing the highest levels of craftsmanship. Since 1979 the school has been supported by the government to protect Japanese traditional bamboo arts and crafts and offers a rigorous 3-year training (Fig. 4). The system demands absolute discipline, with a defined program of work, from the



Basketry in Japan, Fig. 4 First-year students at the Beppu bamboo school 2005

simplest open hexagonal plaited dish to individually designed high art baskets by the end of the course. There is a sample room of individually designed furniture and domestic accessories, decorative items, baskets for the tea ceremony, and a multitude of less traditional uses for bamboo. Shono Shounsai, from Beppu, became the first bamboo artist to be made a Living National Treasure, the highest honor for a Japanese craftsman.

Much high art basketry, highly individual and with a specialist clientele from the Imperial Palace and its connections, is made in workshops led by a famous master. This demands a 10-year training with initial emphasis on splitting the bamboo to perfection before using it for personal, often complex designs. Works are destined for

Basketry in Japan,

Fig. 5 High art basket,
Hajime Nakatomi, East
Weaves West: Basketry
from Japan and
Britain 2007



B

traditional activities, flower arranging, and tea ceremonies and as art pieces for exhibition both in Japan and abroad. In the USA, galleries such as the Tai Gallery in Santa Fe specialize in exhibiting the work of particular bamboo artists, work that is highly prized and actively collected. Much of this work is highly sculptural, three-dimensional drawing, with the finest possible skill and exquisite detail. Ties, knots, bindings, and alignment of the node points are all considered, as is the balance and spatial nature of each piece. Leonard Cotsen has a fine extensive collection of this work which is exhibited regularly and catalogued with detailed information, a valuable reference. In 2007 a British Museum exhibition “Crafting Beauty in Modern Japan,” to recognize 50 years of the Japan Arts and Crafts Society exhibitions, brought examples to London to supplement examples already seen in the Victoria and Albert Museum (V&A) and the British Museum’s permanent collections. The exhibitors, many being holders of “intangible cultural properties,” have dedicated their lives to their work, many learning from generations of family or in the master-led workshops which is still largely a male preserve (Fig. 5).

High art basketmakers outside the Japan Arts and Crafts Society cannot become Living National Treasures but make work of the same

caliber and beauty with their own system of awards. Apprenticeship is often family based, passing on skills developed by several generations. I was fortunate to meet Tanabe Chikuunsai III, a third-generation fine art basketmaker and trainer of apprentices, and his wife who is also involved in the running of the workshop. Each day is a disciplined one with an early start in the workshop and formality and quiet for complete concentration on the basketmaking. Their son, Tanabe Shouchiku, trained in part outside the family and also went to art school to gain a degree in sculpture. Bamboo is his passion but his work has two strands, all using his high levels of skill but with different scales and outcomes to the work. During the day he works in the family workshop and makes baskets of his own design but based on the family tradition, using family techniques developed over the generations. Many of these are appreciated and bought directly by collectors or else they go to the US for exhibition. During the evenings he creates his own more personalized, self-expressive weavings, this work going to permanent collections in museums across the world. He is already very well known with his work much sought after (Fig. 6).

Tanabe Shouchiku is one part of the “New Bamboo” contemporary work, based on traditional skills but with a new outlook and free

personal expression. He is also one of a wave of bamboo artists making large-scale installation work of a sculptural nature and often site specific. For “East Weaves West” he brought, ready prepared, strips of bamboo to weave a flower shape with a central vertical section holding the flower form off the ground (Fig. 7). It was a delightful coincidence that Lee Dalby, the UK maker commissioned to make a gallery installation alongside, came up with a closely related

shape, without any prior consultation (Fig. 8). The two works, from east and west, looked very harmonious together.

Ueno Masao has long been well known in this sculptural, installation field with trips abroad to make his sometimes huge, always striking, pieces. He trained as an architect, also learning wood skills and traditional basketmaking. His work involves the manipulation of bamboo to create form and space in a wonderful way and he often describes them in mathematical terms. His installation for the Sainsbury Centre for the Visual Arts, University of East Anglia, UK, for the exhibition “Basketry Making Human Nature” 2011, arrived packed in one moderately sized suitcase, all preplanned and prepared to be assembled on site into the tangents of a huge circle. The effect was magical as the light changed through the very large window where it hung, as appealing from inside as out (Fig. 9). He has worked in a number of European Sculpture Parks and enjoys being alongside others working in a similar way, all highly focused.

In Japan, as in Europe, contemporary basketry has emerged and is thriving. Both stem in part from the work of Ed Rossbach in California, teaching fiber arts to university students in California and having a widening influence across the basketry and textile worlds. A strong fiber arts



Basketry in Japan, Fig. 6 “Connection Bond” Takeo Tanabe

Basketry in Japan, Fig. 7 Takeo Tanabe and his installation, Collins Gallery, Glasgow 2007



Basketry in Japan,

Fig. 8 Lee Dalby and Takeo Tanabe in Lee's installation, Collins Gallery, Glasgow 2007



B



Basketry in Japan, Fig. 9 Reconstructions of baskets from 7,500 to 8,000 years ago

movement with textiles and baskets, made with a rich selection of threads and wires, barks, and tapes, with techniques from round the world, grew steadily from the 1950s onward and

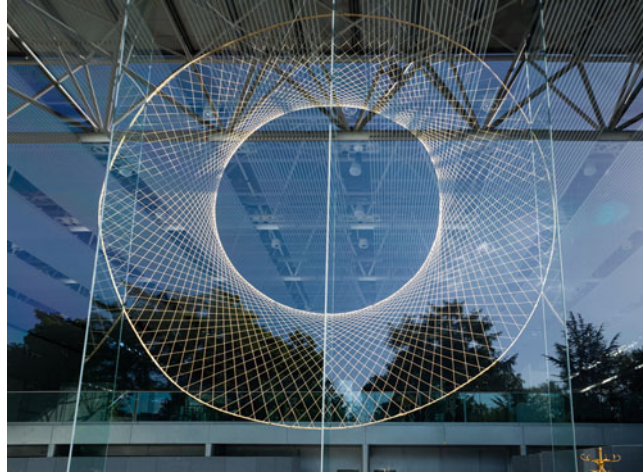


Basketry in Japan, Fig. 10 Hisako Sekijima basket 1990s

changed our perceptions of what these articles could be. Hisako Sekijima spent some time in the USA and became involved with this movement, meeting the makers, working with John McQueen, and developing her own strong practice of contemporary works for exhibition (Fig. 10). On her return to Japan, she started teaching and gathered an enthusiastic, talented group of young makers who were using her ways of thinking and a wide range of techniques and materials and who explored their own pathways. This group has slowly expanded and has exhibited regularly in Tokyo, Kyoto, and

Basketry in Japan,

Fig. 11 Work by Ueno Masao, window at the Sainsbury Centre, University of East Anglia, 2011 Photo Andy Crouch



elsewhere, and they are an influence on more recent work across Europe and the USA. Hisako, calling herself a “basket thinker,” has a shrewd perception of both structural analysis and her natural materials, many of which she grows in her own garden or gathers locally. It is a stimulating scene. In the UK we have been influenced by her ideas as a result of a master class I was asked to organize for her at the V&A, her teaching at Manchester Metropolitan University, and by further visits with “East Weaves West.”

Two members of this contemporary weaving group have recently been involved in the reproduction of archaeological basket remains, analyzing their structures, materials, and final forms. This is painstaking work, with a need of skilled observation and interpretation, only possible with wide existing knowledge. Kazue Honma and Noriko Takamiya worked on the remains of 7,500–8,000-year-old baskets from the late phase of the initial Jomon period. Although squashed, the baskets were in good condition, made of split wood, and had probably been used for acorn storage (Fig. 11). The materials were identified as unlike those used anywhere in Japan more recently. This evidence of the ancient nature and high skill levels of basketmaking in Japan completes the picture of a country weaving diverse containers of many materials and with a wide range of techniques over centuries. Those

makers still keeping these skills alive in variety will provide valuable possibilities for adaptation and development for future changing needs and circumstances.

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Basketry of South America

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The meaning of the word *basketry* includes the skill of making baskets, the making techniques, and the group of finished objects. These objects were made from raw vegetable materials, sometimes without previous preparation process. Baskets are often made with the hands. Basketry fulfilled several needs, including plateaus, spheres, and roofs. However, there are only a few remains of these because they were made from perishable materials.

Techniques

The basket-making techniques can be classified according to the materials used.

Basketry can be classified into three types of techniques: *twining*, *coiling*, and *plaiting*.

In twining, the warp is usually in a vertical position and is a passive element. The weft consists of two or more flexible weaving elements and the folded weft passes in front of and behind the warps acting as an active element. The loom lies horizontally.

In coiling, the active element or stitch is vertical and the passive element or stitch is vertical

and the passive or foundation is passive and horizontal. The stitch is always only one element. It can be defined as the sewing of a horizontal static element called the foundation, moving vertically an element called stitch.

In plaiting, both elements – warp and weft – are active elements and they are usually made from the same material and are both of the same shape.

Antiquity and Permanence of Basketry in South America

Basketry is a very ancient process and it is one of the widest spread crafts in the world as it is in South America. Archaeological research in Patagonia, Argentina, documents the presence of baskets in hunter-gatherer campsites as early as 3,000 years ago (soil layer 3, Campo Moncada 2 site, Chubut, Argentina), and there were also some other baskets dated to 500 years ago (soil layer 3, Piedra Parada 1 site, Chubut). Additionally, there were archaeological remains in sites of the region that demonstrate the existence of raw material suitable for this activity during the entire existence of life on earth. For instance, in Campo Nassif 1 (Onetto, 1986–1987), rock art dated 480 years A.P. $\pm$ 75 (INGEIS665), there was vegetable evidence of camp fires, rough grass beds, sediments from holes, and crafts (little swaps with paint residues, knitting needle of the *Schinus molle* thorn, grass balls, and pieces of brushes). However, now basketry crafts (all the artistic expressions) have disappeared (baskets, plateaus, threads), and there is no record of them in any of the ethnographic researches made in Patagonia during the last century.

This situation is different in the north of Argentina and in the Andina region. In those areas, villages and indigenous cemeteries have been subjects of archaeological research since the end of the nineteenth century. The dry environment of the region and the conditions of the crafts (stone constructions with roofs and doors made of teasel, where they were buried with their grave goods) preserved the crafts that had been

made of perishable materials such as textiles (tissues of animal fiber or basketry and ropes of plant materials).

In the days when European empires conquered America, the weaving industry was the most important local good for export. Basketry and cordage were essential for the delivery service of other goods between both continents. They were parts of the maritime environment of those first years of trade, and they arrived in America at the request of the newcomers or for business needs such as the need for lightweight and unbreakable containers for storing and transport.

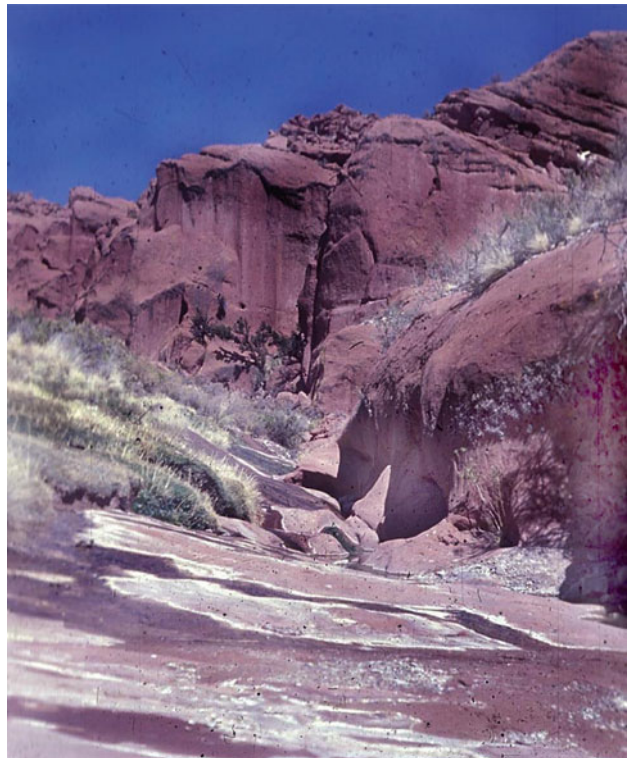
That is the reason that we can find handmade products in every part of America (basketry, woven, or ceramics). Research confirms the presence and use of techniques that were mixed with other techniques provided by Europeans during the days of the colonials. This first contribution was made from the Iberian Peninsula and some centuries later some techniques were brought by immigrant communities in different parts of Europe and Asia, although to a lesser extent.

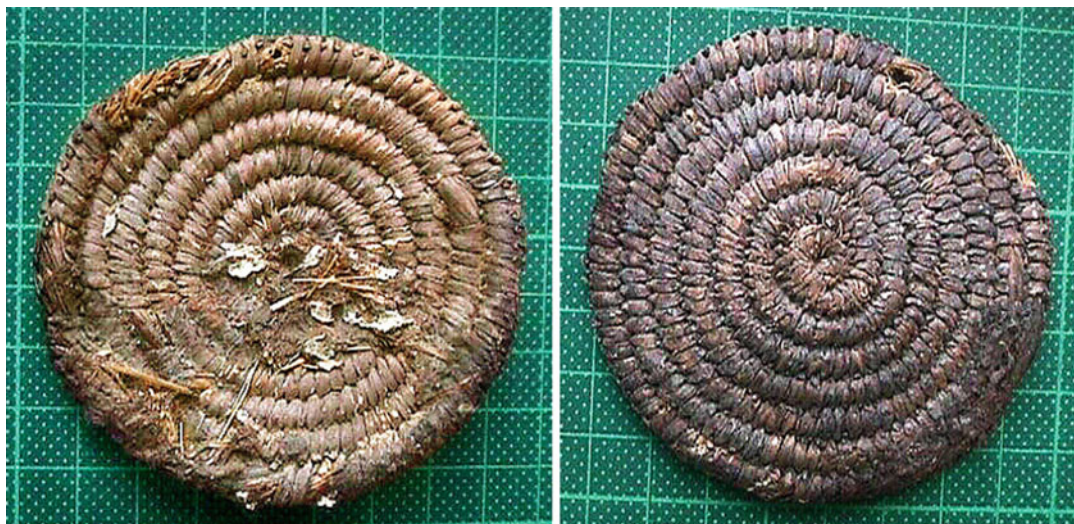
American traditional craft in general and especially in Argentina is the result of the interlinking of techniques, raw materials, and styles that formed a new reality.

Inca Cueva (Inca Cave): First Basketry Vestiges in the North of Argentina

In 1973 Aguerre, Fernandez Distel, and Aschero published their research about the information obtained during the finding and excavation of Inca Cueva site, cave 7, located in Quebrada de Inca in Tucuman province (Fig. 1). It was interesting because of the special location and the size and structure of the soil. There was a deep bore hole 2.30 m high by 3.20 m long and 3 m deep; over 3,860 m were above sea level in a heavily skewed rocky slope of Quebrada de Inca Nueva. In this Quebrada they found evidence of hunter-gatherer early settlements (Inca Cave 1 and Inca Cave 4, for instance) (Boman, 1908; Cigliano, 1965; Fernández, 1968–1971). Recovered

Basketry of South America, Fig. 1 Inca Cueva site (Jujuy)





Basketry of South America, Fig. 2 Front and back side of a plateau basket (a) of Inca Cueva 7 (Jujuy)

remains in IC C7 were settled between quartzitic stones encased in a tightly stuffed straw of 60 cm thickness called soil layer 2. One thing that caught the attention of archaeologists was the variety and quality of the crafts. These findings were not usually observed in other archaeological sites: lytic stone, textiles and basketry, leathers, wooden, stone, and bone devices, pumpkins, and ornaments. All remains were in an excellent state of conservation and many of them were decorated.

These are the remains made with vegetables as raw materials:

Plateau Basket (a). The plateau has a diameter between 74 and 78 mm, slightly concave of 22 m high and 6 m deep. The manufacturing techniques consist of a closed spiral made in a simple stitch without interlocking warps, with a cleft in its foundation. In the last two coils because the stitches are worn out, we can see the foundation and it is a bunch of grass with an “S” shape. There were two spirals per cm, stitches are 3 mm wide, there is no space between them, and there are four stitches per cm, with a “Z” shape that implies that the craft tends to be on the right. It has a standard foundation and it has no edge. It might have been painted or dotted with some product. It has adherent material on its front side (Fig. 2).

Plateau Basket (b). The plateau has a diameter between 77 and 73.5 mm, slightly concave at 9 mm high. The manufacturing techniques are the same as in the before mentioned plateau basket. Three coils per cm can be counted. The simple stitch has a “Z” shape, which means that the craft tends to be on the right as in the previous craft. Stitches are between 2 and 3 mm wide with three stitches / cm. The poor condition of the craft means we have to do more research. Both the foundation and the edge are absent (Fig. 3).

Bunch of Tied Grass. Its size is a square of 45 by 23 mm. The diameter of the bunch varies between 8 and 9 mm. It is strongly tied in the center with a string 2 mm wide above which a cord of 2 mm was placed. It was very well preserved (Fig. 4).

Bunch of Fastened Grass. Its size is 210 mm per 39/19 mm with a depth of 17 mm. It is composed of a whole gramineous plant (it keeps its root, the base of the bush, and the shaft of the leaves), folded on itself in one crease. It is all wrapped up with a juncaceous leaf that surrounds the bunch (Fig. 5).

Bunch of Feathers and Hair. It is 160 mm long, 19 mm high, and 10 mm deep. It is composed of three feathers tied with a strap by the base of the rachis. A hair fleece of a reddish



Basketry of South America, Fig. 3 Front and back side of a plateau basket (b) of Inca Cueva 7 (Jujuy)



Basketry of South America, Fig. 4 Bunch of tied grass of Inca Cueva 7 (Jujuy)

brown camelid is resting on the shaft of the feathers tied up with one juncaceous leaf that surrounds the whole bunch several times (Fig. 6).

Woody Stem Wrapped Up with Flat Basketry. It is 150 mm long and 10/11 mm in diameter. The stem has both sides carved: a blunt one and sharpened one; it is completely surrounded by various parallel rachises, making the warps. They are joined between themselves by a weave composed of two cords that always go over three warps and under, alternatively, four or five warps shaping a spiral. The thread of the weave has an S shape. The first part is a whole lap with simple twined technique. In the second one both elements become one element for the rest of the work of flat technique. The last part is made by

turning several laps over the warps and shaping the weave around itself (Fig. 7).

This combination allowed the authors (Aguerre, Aschero, & Fernández Distel, 1973, p. 229) to date it to the second millennium BC and to connect it with archaeological sites in Argentina and Chile, belonging to the Late Preceramic Period with a high specialization, and to link it to the introduction of cultigens in the Andean foothills and the West Coast Area.

The researches carried out in the Quebrada de Inca Cueva continued until 1979 with the excavation of Inca Cueva 4. The majority of fragments of animal fibers cords and leather cords (120 specimens) and, to a lesser extent, basket fragments (12 made with the twined technique and one with the plaited technique) could be found (Fig. 8). In this site there were no found fragments using the spiral or coiled technique.

Layer 2 of IC c4 had four radiocarbon measurements; the result of the oldest one was 10.620 ± 140 A.P. (LP-137) and the result of the newest was 9.230 ± 70 A.P. (CSIC-498). Meanwhile, IC c7 had two measurements: layer 3b was 4.080 ± 80 A.P. (T-1773) and layer 2: 4.030 ± 80 A.P. (Beta 64938) (García, 1997).

The evidence of these two basketry groups of the Quebrada de Inca Cueva is essential for the study of these techniques during the Argentinean

Basketry of South America, Fig. 5 Bunch of fastened grass of Inca Cueva 7 (Jujuy)



Basketry of South America, Fig. 6 Bunch of feathers and hair of Inca Cueva 7 (Jujuy)

and American prehistory. According to the last one dated, these groups and Daisy Cave basketry in California (USA) belong to the same period of time. These are the oldest crafts founded in these continents, and they belong to one of the first periods of land occupations, during the Paleo-Indian period.

Types of Existing Traditional Basketry

In Belen village (province of Catamarca, Argentina), there is a kind of traditional basketry with symbols (*Pennisetum* sp.). They are similar to the ones found in the north of the province, in los Valles Calchaquies. Economic needs and ship bonds favored the communication and the learning of these manufacturing techniques and the use of natural resources (Figs. 9 and 10).

Different types of vessels (bread basket, baskets, dipper with cover, dresser-basket or wardrobe, trivets, etc.) were made mixing two techniques: plaited or plaiting basketry and twined or twining basketry.

Craftsmen collect the symbol, which grows on the margins of rivers in open lands. That means that the cost of raw materials will depend on the effort and time needed to acquire them and that will depend on the transportation cost. Many of these goods will be held in the fairs that are organized throughout the year across all regions.

In these fairs the visitor can observe the complete manufacturing process and ask craftsmen for some shape, size, and function variants (Fig. 11).

Tracking the “Invisible” Traces of Basketry Production in Argentina, South America

The survival of materials through time is a fundamental condition for archaeological research. Because of its organic nature, basketry requires the combination of certain environmental conditions for proper preservation. Ambient temperature and humidity are key factors. That is the reason that in extremely warm and humid contexts, for instance, this kind of evidence hardly survives. However, in some cases it is possible to gain knowledge of ancient basketry practices from the recovery of the so-called indirect evidence of this material.

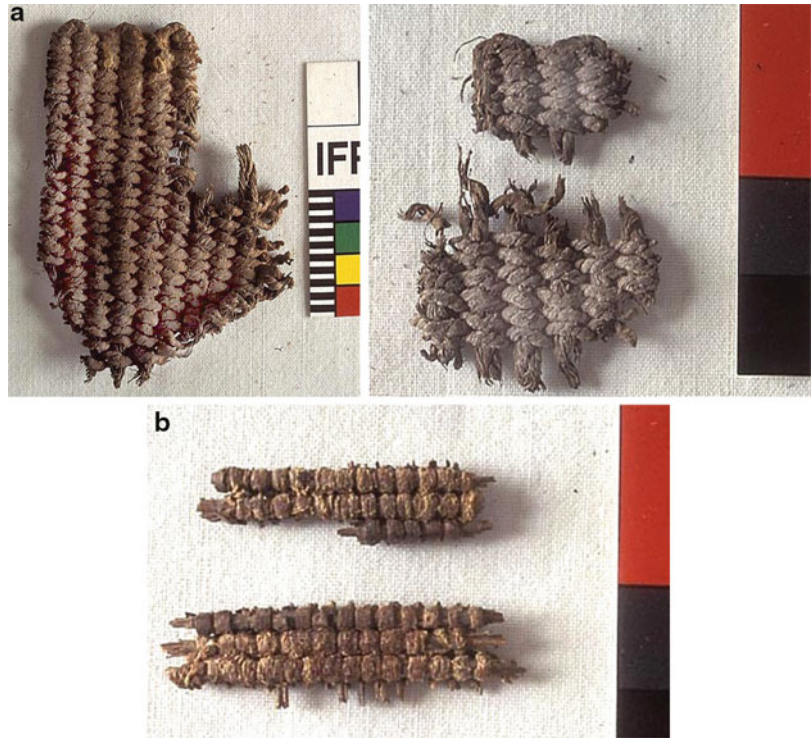
We refer to those situations when the basketry, or just a part of it, has been preserved under special conditions in the form of impressions (or negative imprints) on the surfaces of more long-lasting materials, such as pottery, consolidated sediments, and heat-altered clay or mud (Fig. 12).

These impressions constitute the indirect conservation of basketry structures and may respond to either deliberate actions (related to techniques visual representational and/or productive) or as a result of accidental causes. Records of this kind of findings can be found in western Argentina, in the area known as “The Lowlands” (Chaco-Santiago plains, north of Cordoba, and Misiones, Corrientes, and Entre Ríos provinces), where several archaeological cases have been mentioned (Calo, 2008; Fabra & Laguens, 1999; Gardner, 1919; López Campeny, 2010, 2011; Serrano, 1945; Tarragó & Renard, 2001) (Fig. 13).

Basketry of South America, Fig. 7 Woody stem wrapped up with flat basketry



Basketry of South America, Fig. 8 (a, b) Pieces of the twining basketry of Inca Cueva 4 (Jujuy)



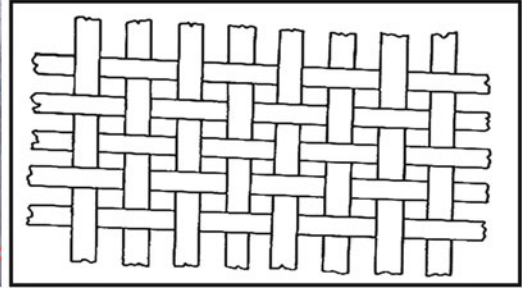
Negatives and Positives: Potential and Constraints of Impression Analysis

Thus, as impressions are negatives of the original structure of the basket, the first step in any analysis should be the production of a cast or “positive” from the negative mold on the pottery. Regarding this methodology, a number of products have been tried (gypsum, clay, epoxy resins, silicone, and dental alginate), all of them having advantages and constraints (for a synthesis, see López Campeny, 2011). Furthermore, strict work protocols were elaborated to recover as much information as possible from the impressions while preserving the archaeological materials and avoiding contaminating the remains with

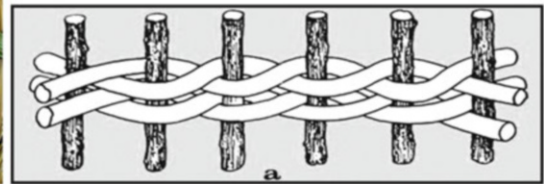
the substance used for the casts (Minar et al., 1999; Rieth, 2004) (Fig. 14).

The second step involves the systematic analysis of the morphological and dimensional attributes in the impressions’ casts. This study gives rise to some interpretative aspects, among which the following are worth mentioning.

Firstly, it is possible to identify the structure impressed on the cast. The structural organization of a piece results from the use of one or more techniques, that is, the set of proceedings used to manipulate the elements. Consequently, it is strongly related to the production process. Hence, recognizing the structure allows us to infer the techniques and instruments used for the manufacture. Conversely, certain properties



Basketry of South America, Fig. 9 Dresser-baskets in plaiting technique and the diagram of a plaiting structure



Basketry of South America, Fig. 10 Foundation of a basket in twining basketry and the diagram of a twining structure

and attributes of the structures (flexibility, resistance, spacing, and thickness) suggest functions associated with basketry (containers, nets, and clothing). In the case of pottery items modeled on complete baskets, it is also possible to reconstruct the containers' form and estimate their size.

Additionally, the overall state of the basket or fragment (damage, missing elements, and wear and tear) may indicate restoration or reuse of pieces which had been previously discarded or recycled from their original function to be later used in the pottery production process (Fig. 15).

The information derived from the fibers, though limited, may indicate its animal or vegetal nature; occasionally, the use of leaves or wood elements can also be distinguished (Fig. 16). An integrated analysis of archaeological evidence, document sources (both historical and ethnographic), and resources available in the area defines a preliminary database of possible raw materials to derive working hypotheses.

Concerning visual perception, patterns defined by color cannot be derived from the impressions. Neither the reverse nor a section view or the borders and finishing are accessible,



Basketry of South America, Fig. 11 Craftsman works symbol and his tools



Basketry of South America, Fig. 12 Baskets' impressions on the bases and walls of pottery surfaces. Maldonado Bruzzone Collection, Archaeology Division, La Plata Museum (hereinafter MLP-DA-Col. M.B.)

Basketry of South America,

Fig. 13 Archaeological sites with testimony of baskets' impressions in Santiago del Estero: analyzed by López Campeny (2011) and bibliographic references



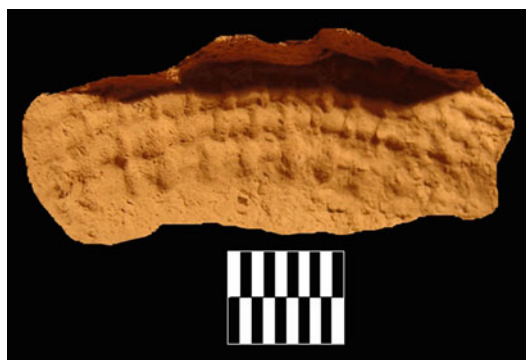
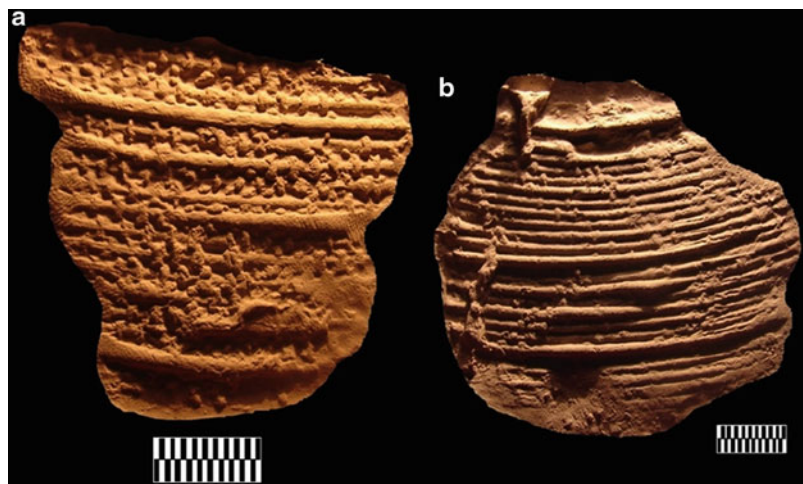
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Basketry of South America, Fig. 14 Ceramic bases with their casts made in modeling clay (MLP-DA-Col. M.B)

Basketry of South

America, Fig. 15 (a) Cast that show damage to the basket structure used as support for pottery and (b) possible repairs



Basketry of South America, Fig. 16 Cast in which the use of woody elements and flexible fibers is observed

except in some exceptional cases. Nevertheless, designs or stylistic patterns may be identified when they respond to different structural effects, such as the use of several raw materials and certain techniques like patterned spacing, divergent stitching, and textural variations (Fig. 17).

Furthermore, the integrated analysis of technological-structural attributes could be used to characterize certain basketry traditions or “production styles,” materialized in learnt manual actions passed down through generations.

Finally, some features of the impressions provide information about certain aspects of basketry (as well as pottery) production. For instance, we can make estimates regarding the production scale (household, specialized craft)

or the preference for specific structures to manufacture certain pieces, reflecting a systematized or standardized production.

From Long Lasting to Perishable: Results of a Study Case

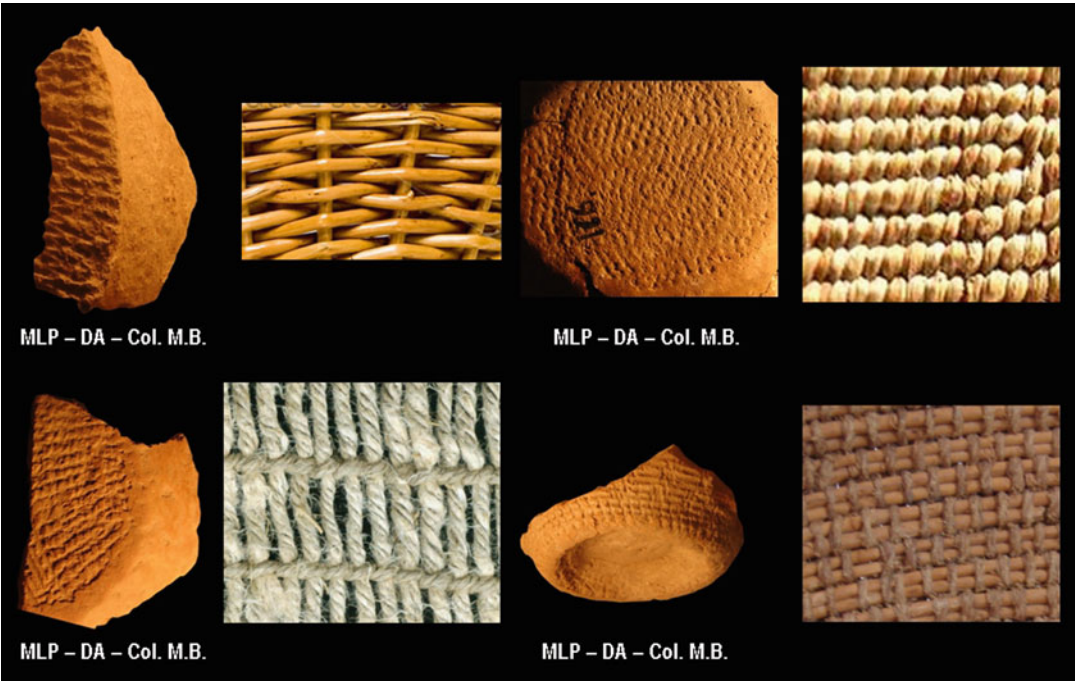
From the actual analysis of basketry impressions preserved on the surface of archaeological pottery, it is possible to figure out aspects related to the practices of the communities who lived during pre-Hispanic times in what is today the Argentinean Western Lowlands (López Campeny, 2011).

First, we identified several basketry structures, performed by the manipulation of vegetal resources with different properties – rigid to semirigid (rods) and flexible (fibers) elements – in areas with limited direct archaeological evidence. Twining structures were dominant, presented in many subtypes such as simple, diagonal or twill, and wrapped twining (Adovasio, 1977; Pérez de Micou, 2005), with different spacing between elements and both twist directions (right and left) (Fig. 18).

The identification of wrapped twining in the materials from Santiago del Estero indicates a connection with other archaeological assemblages, defining a wide dispersion area for this structure (Jujuy, Tucumán, Catamarca, Córdoba and La Rioja provinces) (Figs. 19 and 20).



Basketry of South America, Fig. 17 Divergent stitching and patterned spacing that make zigzag designs or diagonal lines



Basketry of South America, Fig. 18 Examples of some structural types and varieties identified in the sample

This technique would have been used to manufacture some peculiar artifacts; the so-called tipa baskets, which are still crafted in the central-western region of the country, are quite

similar to the archaeological specimens found (Fig. 21).
Based on the record of shared technological practices and traditions, we may think these



Basketry of South America, Fig. 19 Distribution of archaeological finds from basketry with wrapped twining structure on Argentine territory: pottery impressions and baskets

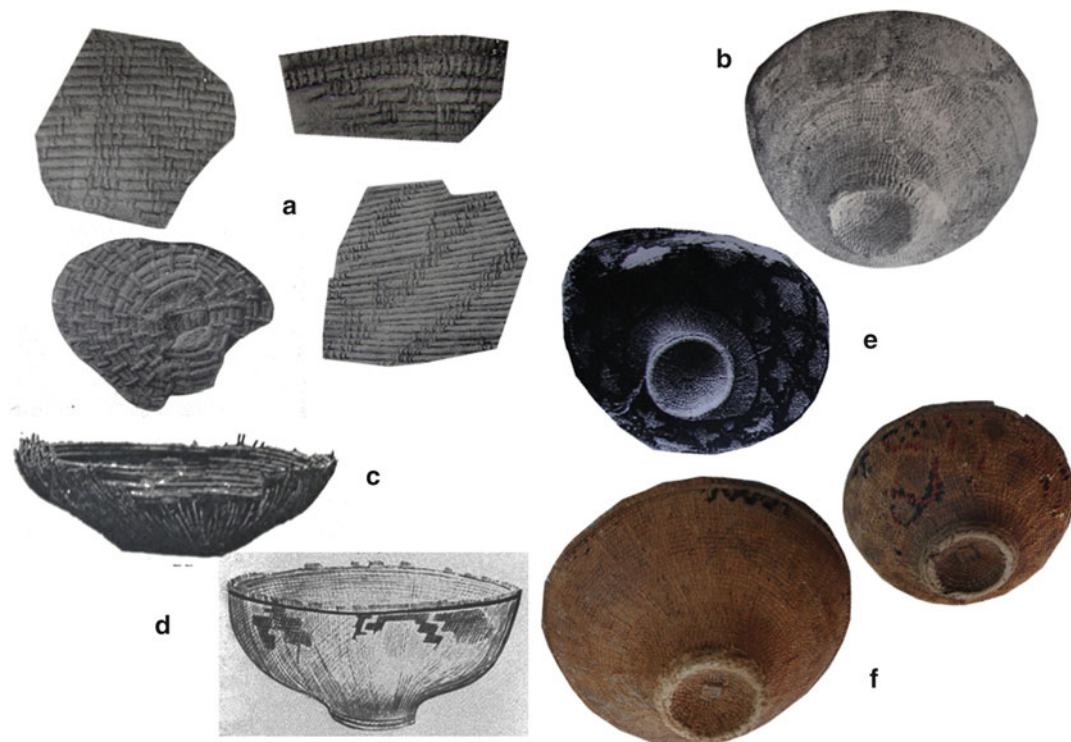
results show interactions among communities occupying a large area and grounded on long-time relationships. It also challenged the idea of a “cultural borderline,” a theoretical construct which has been frequently applied to the role played by the Western Lowlands in the regional processes and links taking place in the Andean area.

Additionally, we propose that basketry would have been integrated into the rest of the technological-production activities of the communities by participating in pottery manufacture (Fig. 22).

Due to a high proportion of impressions on the pot's base, it has been determined that basketry artifacts – most of them with evidence of intense use and damage – could have been used to support the pot during modeling and/or drying. Examples of this practice are found in ethnographic data from northeastern and northwestern Argentina, which depicts the use of textiles by

local indigenous populations as a support during pottery making (Boman, 1908/1991; Gardner, 1919; Outes, 1909). Moreover, the absence of standardization or homogeneity in the constructive attributes of the materials used as the support suggests a household production of both pottery and basketry inside domestic units, as the ones documented earlier (Millán de Palavecino, 1958–1959).

It is interesting to wonder why the impressions are limited to a relatively reduced number of bases in the total assemblage of local pottery. Were they obliterated in the remaining pots? Or was basketry used as a support for some specific pieces, perhaps aimed at concrete functions and/or contexts? In an attempt to find the reason, we suggest that contextual data indicate that the pieces with impressions had a funerary use. They refer to large vessels used as funerary urns or containers and some smaller pieces, such as deep and shallow bowls (pucos and escudillas)



Basketry of South America, Fig. 20 Findings related to the wrapped twining structure on Argentine territory: (a) plasticine casts of basketry imprints in pottery from sites in Córdoba and La Rioja (Serrano, 1945, p. 221); (b) basket printed on a piece of pottery from El Bañado, Quilmes, Tucumán (Boman, 1908/1991, Lámina II, figura 3); (c) basket recovered in a funeral context of Antofagasta de La Sierra, Catamarca (Ambrosetti, 1904, lámina

III); (d) specimen from Quebrada de Las Cañas, Quilmes, Tucumán (Liberani & Hernández, 1877/1950, p. 118); (e) one of the two baskets recovered in Loro Huasi, Tinogasta, Catamarca (Pérez de Micou, 2000, p. 106) y; and (f) pieces recovered at the Medanos site, Tinogasta, Catamarca (Department of Anthropology of the Province of Catamarca)

which were used as lids for the larger containers. In this respect, a link may be postulated between the funerary nature of these vessels and the presence of impressions.

Finally, we pave the way for future research of the esthetic aspects implied by the visual overlapping of both technologies (basketry and pottery) in the production, use, and/or circulation contexts of vessels. In other words, we are interested in the significance of the “overlapping” of both productions, where the basket is missing, but there are evident signs in its print, materialized as an impression on the pot’s surface.

We further highlight the relevance of carrying out the study of any kind of indirect evidence which may provide the information unavoidably lost with the original baskets, particularly in

areas where environmental conditions are not appropriate for the natural survival of organic materials. Thus, despite the impossibility of getting access to direct basketry records because of local weather conditions, lasting elements can greatly enlarge our knowledge about perishable materials.

Basketry of Brazil

So far basketry has not been a well-studied subject in Brazilian anthropology and archaeology. Most archeologists have spent more time trying to understand social variation through stones and pottery. Also Brazilian anthropologists were more interested in shamanic transformations



Basketry of South America, Fig. 21 Baskets (*tipas*) of current manufacture. Collection of the Department of Anthropology of the Province of Catamarca

rituals, for instance, than in objects like baskets. On the other hand, some researchers spent some time discussing the importance of symbols and contemporary baskets in indigenous societies, especially in the Amazon (Reichell-Dolmatoff, 1985; Silva & Gordon, 2011).

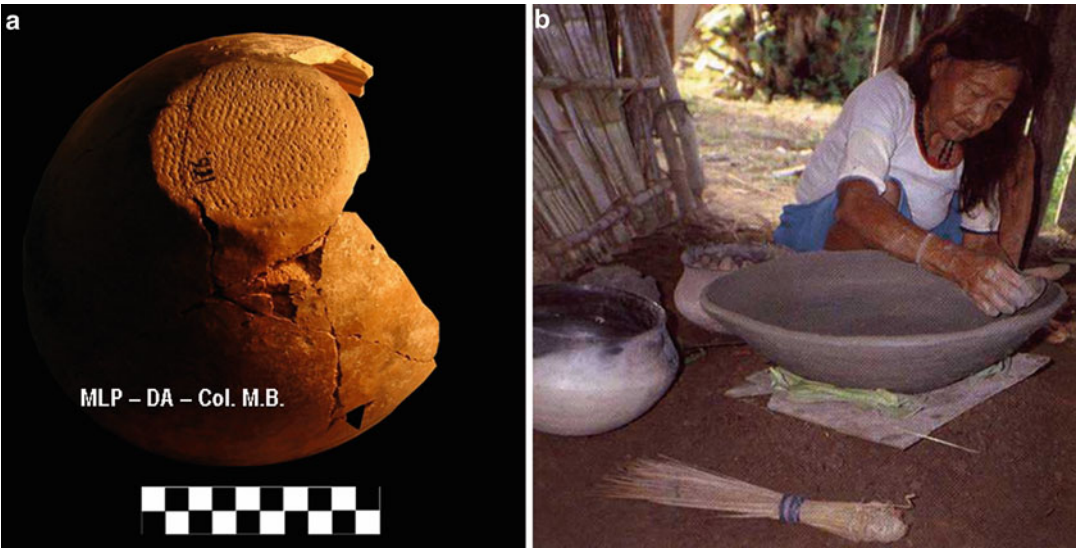
In different places in South America or even around the world, basketry is certainly one of the oldest native technologies. However, weather conditions in Brazil had almost caused the greatest loss of them in archaeological sites.

In the nineteenth century Debret illustrated some kinds of indigenous basketry (Fig. 23).

According to Souza (2010) in *Tratado Descritivo do Brasil* in 1587, in Brazil they found several types of fibers such as “timbós” and “timboranas,” used in handmade baskets and to tie woods that cover huts. Furthermore,

Jean de Lery reported a conical shaped tupinambá basket named “panacu.” “They were large and small baskets carefully woven in small canes, wicker or corn straw.” Panacus were included even in tupinambá imagery as the Jesuit priest Fernão Cardim (2009, p. 175) who wrote his account in the sixteenth century reported:

Sometimes rise up among them (Tupinambá people) some wizards, whom they called “Caraíba”, “Santo” or “Santidade”, and that usually occurred to an Indian with a bad life. He made a couple of witchcrafts, and did weird things to the nature, and was someone who resurrected people who had simulated being dead and other similar things (..) He said others should stop growing their vegetables and provisions, neither dig nor work, so on... Because after he arrived, it became the time that hoes would dig by themselves and also the panacus would go to the farm to bring the provisions by themselves.



Basketry of South America, Fig. 22 (a) Bowl with basketry impression on the base; (b) craftswoman ceramicist from Cañelo-Kitchwa (Ecuador), using a textile as a

support for pottery manufacture (Source: www.minelinks.com/ecuador/kichwa_es.html)



Basketry of South America, Fig. 23 Indigenous basketry illustrated by Debret

In the Handbook of South American Indians, the seminal book edited by Julian Steward, there are a couple of basketry mentions. About Southern Kaiapó, a Gêpeople who lived around

Parnaíba River near of Upper Araguaia, Lowie (1946, p. 519). Steward points out that cotton was neither cultivated nor spun. Textiles included mats and elliptical baskets of buriti fiber. Metraux

(1946a, p. 524), who describes the Purí-Coroado linguistic family, claims that:

The Coroado who raised some crops, had more elaborate cooking techniques and utensils [then purí], such as basketry sifters and various earthenware vessels. Besides, women carried their goods in large baskets.

According to Metraux, Coroado basketry did not differ from the more advanced Tupi tribes. They made rectangular fans to activate the fire, long-carrying baskets with open tops, and other containers of various sizes. About Caingang or Kaingang, Metraux (1946a, p. 457) claims:

[Their] carrying baskets had a hexagonal weave, and, like those of The Tupi, were elongated and rectangular knapsacks open on top and on the outer side. Basketry containers woven from thin strips of split bamboo frequently had stepped designs produced by alternating black and natural color strands.

The Aweikoma (Kaingang from Santa Catarina) “had three main types of baskets: large baskets for transportation of goods; small, impervious water or honey containers of taquaramansa strips coated with wax; and small receptacles, similarly waterproofed, used as cups and dishes” (Metraux, 1946, p. 457).

Currently, Reichell-Dolmatoff’s work shows something else beyond descriptions. He understands that Brazilian basketry has many values. There are material and technological aspects, but there are also certain sets of specific meanings which tend to emphasize spiritual factors above material ones (Reichell-Dolmatoff, 1985, p. 2). Through plaited trays and fishing traps decorations of the Desana people from northwest Amazon, on the Brazil-Columbia border, he shows how specific meanings can be conveyed.

According to Reichel-Dolmatoff their exogamic relationships laws were illustrated on basket decorations, to remind the people that they should never marry a person from the same tribe.

Following Binfordian’s theoretical approaches in an ethnoarchaeological paper, Silva (2011) proposes a situational perspective where the Xikrin people had two different kinds of baskets. There is a simpler one – “expedient” – handy and quickly made, equally

quickly disposed of, that does not carry or convey any symbolic message and can be made by anyone; the other is a more complex kind – “curated” – on which basketmakers spent much time and which is more important symbolically. These are different from Desana baskets, as they had two different categories: one was totally functional and the other was full of meanings. Both of them were made using the same raw materials and the same technique: twill plaited.

Ribeiro (1985, p. 12) noticed among the Kayabí Indians “symbolic representations of their basketry patterns that schematize human pictures like supernatural mythic beings and more significant plants or animals inside these Indians lifecycle.” Van Velthem (2007) demonstrated how several Wayanã and Apalai cosmological elements appeared on basket and mat iconography, crossing Euro-American art, myth, and technology concepts in only one object. The “mirikuit” motifs showed vegetables, animals, and “imaginary beings.” Van Velthen recognized that decoration in body paint is the same as that on basketry.

Ribeiro edited a remarkable inventory where a large part of Amazonian material arts were characterized. The illustrated *Dicionário do Artesanato Indígena* (1988) presents and explains basketry, pottery, cordage, and more work techniques beyond several schematic pictures. It is a fundamental book for those that are researching Brazilian basketry.

Archaeological basketry features are quoted by several authors (Dias junior, 1993; Martin, 2005; Lima, 1984, 1986, e 2012; Oliveira, 2001; Prous, 1992), but none made deep inquiries about this kind of material culture. They mostly noticed the beauty of these artifacts. Costa was the first to dedicate himself to this subject through his doctoral dissertation on development *Palha e Tala: A Tecnológico Trançado entre Grupos Pré-históricos Brasileiros*. Costa chose baskets, mats, and other perishables from four sites where basketry was recovered and where there was at least some information about their contexts. Impressions on pottery were merely considered.

Material from each site has special characteristics, though most of them are associated with

Basketry of South America,

Fig. 24 Fragment of mat from Alcobaça site



B

burial rituals. Costa decided to work with Adovasio's methodology and terminology classifying the artifacts and establishing cultural borders among each particular region or site. As there are still no conclusions to his work, we show some comments for each assemblage. All analyses were conducted in R.L Andrews Basket Center, Mercyhurst Archaeological Institute under Jeff Illingworth's support.

Alcobaça site is a sandstone rock-shelter full of Agreste horizon paintings located in North-eastern Pernambuco. Excavation was carried out from 1996 to 1998. Five fire pits were found there; one of them had remains of basketry dated to 1.118 ± 24 B.P. At least 23 individuals were buried in this area. Seven samples were selected for technological analysis (1977); most of them were open simple twined with Z or S twist (5) and 2 of them were open and simple twined. The raw material was not identified, but probably was caroá (*Neoglaziovia variegata*) or some types of palms like ouricuri (*Scheelea Phalerata*) and babaçu (*Attalea* ssp.) and coconuts. Forms related to these features were almost never identified, except for some of them which were similar to mats (Fig. 24). The Alcobaça site is the only site where basketry remains found were not associated with funeral contexts.

Furna do Estrago is also in the state of Pernambuco, Brejo da Madre de Deus municipality.

This site was occupied during several periods between 11,000 and 1,040 B.P. and it is a 120 square meters rock-shelter. At least 80 individuals were buried there. According to Lima (2012) the site must have been used as a cemetery for about 250 or 300 years. Basketry certainly was present in most burials. Sometimes the person was left above a kind of fiber later replaced by mats. Also they usually put caps on the corpse's skull (Fig. 25). Thirteen fragments have been analyzed including several fragments of knots. Simple plaiting and open twining with Z twisted were the most common techniques used. Raw materials were possibly similar to the Alcobaça ones.

In Minas Gerais State, there are two other sites where basketry remains have been found. Gruta do Gentio is a limestone cave measuring 2.5 km. A mummified toddler was found there. He was wrapped in deer flesh straps and fabrics. Also there were other burials in Gentio (Dias junior, 1993). According to Dias Junior, the researcher who directed all the excavations at this site, all the perishables were found in the first layer dated from 1,000 to 3,500 B.P. The most interesting sample was a 3/3 twill plaiting with a 4 strand braid cord attached to it as a carrying strap. It was constructed by taking two palm fronds and weaving the leaves together. Costa has supposed that it is similar to the one named by Ribeiro (1988) "cestobornaliforme" used until today by the

Basketry of South

America, Fig. 25 Cap on the Furna do Estrago corpse's skull (From: <http://institutoanchietanodepesquisas.blogspot.com/2012/11/pesquisas-antropologia-n-69-furna-do.html>)

**Basketry of South**

America, Fig. 26 Plaited fragments (3/3) from Gruta do Gentio (Gentio Cave). Photos by: Rodrigo Lessa



Xavante people. It could be also a manioc process tool.

The other significant site where perishables were founded is in Minas Gerais State, in "Lapa

do Boquete." Boquete was used as a cemetery, but there were also food storage structures named "silos." Mats and other straw structures were covering and splitting these silos in several

levels. They also found a mummified individual with bones, skin and even hair attached to the bones, and several plant fiber artifacts. It was dated to 560 ± 40 BP, and as the one at Furna do Estrago, the corpse's skull was surrounded by straw like a cap. A large 2/3/2 twill plaited was a very interesting artifact associated with this burial, not just because of technical or decorative elements but because of the context where it was found. Prous and Schlobach (1997) affirmed that this basket was *nécessaire* [necessary] to life after death. Inside the basket there were polished awls, shell tools, a wax ball, a small gourd with a silex flint with red color residues inside, a deer tooth, and three other gourds, one of them with basketry wrap attached, also 2/3/2 twill plaited (Fig. 26).

Studies on Brazilian basketry are just beginning, so we cannot claim what will be the direction of social questions. Some technical points can be quoted. Coiled baskets were not included in Brazilian prehistoric basketmakers' technical set. They preferred weave-plaited objects, though twining appeared especially in Furna do Estrago and Alcobaça, which could denote a regional preference. Also relationships among people who lived in these two sites could be looked into through basketry elements. Decorations were extremely rare, except for red pigment remains on a single-plaited mat from Furna do Estrago. However, it is hard to explain anything about decorations – especially paintings – because of conservation problems that we already mentioned.

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Basketry of the Wabanaki Indians

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The Wabanaki

The Wabanaki (People of the Dawn Land) are living Algonquian-speaking indigenous Native North Americans whose traditional homelands comprise what is today northern New England in the United States as well as Southeastern Quebec and the Canadian maritime provinces of New Brunswick, Nova Scotia, and Prince Edward Island. In the United States, there are five federally recognized Wabanaki tribes, all of which

reside in the state of Maine: the Penobscot Nation (with a reservation in Penobscot County, Maine), the Passamaquoddy Tribe at Pleasant Point or Sipayik (with a reservation in Washington County, Maine), the Passamaquoddy Tribe at Indian Township (also with a reservation in Washington County, Maine), the Houlton Band of Maliseet (in Aroostook County, Maine), and the Aroostook Band of Micmac (also in Aroostook County, Maine). The Wabanaki also own trust lands (property with federal status owned by the tribe or tribal members) and fee lands (taxable property owned by tribal members but for which a tribe regulates use) in other parts of the state of Maine (Fig. 1). As of 2014, there were approximately 8,000 people on the membership rolls of the five Wabanaki tribes in Maine, with a far greater number in Canada.

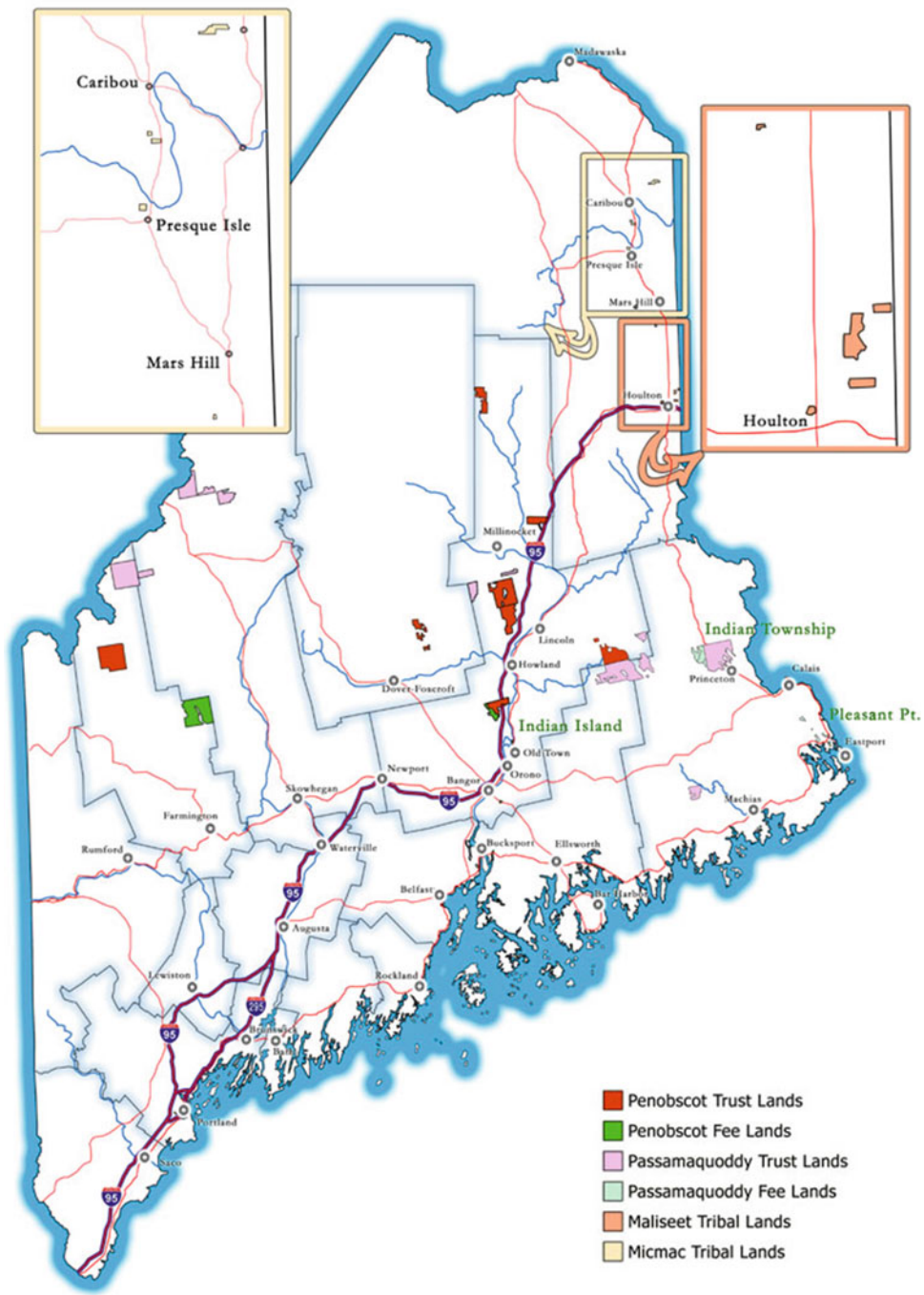
A note here on terminology is important to avoid confusion. Today there are groups of people in Northern New England and Canada called “Abenaki,” historically a part of the larger Wabanaki Confederacy of Algonquian-speaking groups. In discussing basket making, we focus on the five federally recognized Wabanaki tribes now residing in Maine (as well as their kindred in Passamaquoddy, Mi’kmaq, and Malecite communities in Canada), not the US or Canadian Abenaki. Note that all groups have alternate spellings and pronunciations, including those that differ across the US-Canada border (e.g., Micmac or Mi’kmaq, Maliseet or Malecite). We will use Anglicized spellings that are in use and commonly accepted today in Maine. We will also use the terms “Indian,” “Native American,” “Native,” and “indigenous” interchangeably in referring to the Wabanaki people more generally.

History of Wabanaki Basketry

While historically Wabanaki baskets have been made from a variety of materials including birch, basswood, maple, spruce, and cedar, it is brown ash – also known as black ash (*Fraxinus nigra*) (Fig. 2) – that figures most prominently in Wabanaki basketry today. The place of ash basketry in Wabanaki life runs deep, as far into the

past as collective memory can recount the story of how Gloosekap (alternately spelled Glooskap, Gluskabe, Gloosecap, Glooscap, or Klooskap) shot his arrows into the ash trees to create the Wabanaki people. Prior to European contact, the Wabanaki people in Maine were hunters and gatherers, who moved seasonally and utilized bark, wood, and tree roots from the forests along with aromatic sweetgrass and cattails from the coastal wetlands to craft utilitarian bags, boxes, and other containers (McBride & Prins, 1990). The Wabanaki people also utilized types of woven baskets for washing corn, sifting, and carrying supplies. Some evidence suggests that the arrival of Europeans and their roles as trading partners may have accelerated Wabanaki production of splint basketry – that is, baskets produced using thin uniform strips of wood braided or woven together – from forest resources like ash, cedar, spruce, and maple (McBride & Prins, 1990). It is clear that splint basketry – especially that constructed from the versatile brown ash – is central to Wabanaki cultural and spiritual life.

Historically a skill passed down within families, basket making took on new economic, cultural, and social meanings for Wabanaki communities beginning in the eighteenth century, as traders, tourists, museums, and basket makers helped shape a consumer market for Wabanaki baskets (Bourque & Labar, 2009). As non-Native vendors and collectors sought out Wabanaki baskets as consumer goods of artistic value, indigenous basket makers traveled to major cities like Boston, New York, and Philadelphia along the Eastern seaboard to sell their products (Neptune, 2008a). Beginning in the mid-nineteenth century, Wabanaki families set up encampments in well-known resort towns such as Kennebunkport and Bar Harbor on Mt. Desert Island, Maine, to sell their baskets and other crafts to wealthy summer residents and vacationers (McBride & Prins, 2009). New styles of ornamentation and decorative weaves accompanied the introduction in the 1860s of labor-saving commercial aniline dyes, which allowed for a brighter and more varied basket color pallet (Neptune, 2008b; Whitehead, 2004). By the mid-1880s, new technologies



Basketry of the Wabanaki Indians, Fig. 1 Map of Wabanaki territory. Showing tribal reservations, trust, and fee lands in Maine (Courtesy of James Eric Francis, Sr.)

improved the manufacturing of tools like wood splitters, gauges, and blocks for holding a basket's shape, which helped Wabanaki basket

makers create even smaller and fancier decorative baskets (Mundell, 2008). For example, Penobscot men who worked at canoe factories



Basketry of the Wabanaki Indians, Fig. 2 Black ash trees. They can grow 60–70 f. in height and reach a trunk diameter of 8–24 in., producing a small cluster of branches high off the ground (Courtesy of Jennifer Neptune)

in Old Town, Maine, used factory lathes to create new shapes and styles of basket blocks. By the turn of the twentieth century, tribal census data reveal that almost every Passamaquoddy and Penobscot household had at least one member whose primary occupation was basket maker. Making baskets was a communal and intergenerational activity (Figs. 3 and 4). Women would often host sweetgrass braiding parties in their homes, and children could observe the work of adults and sometimes make their own miniature baskets.

During the twentieth century, several historical events profoundly affected Wabanaki basket makers. A decline in tourism due to the Great Depression and the onset of World War II (in which many Wabanaki men and women served) and postwar Wabanaki migration to southern New England (spurred by new job opportunities and the desire to escape racial prejudice back home) led to a decline in the number of Wabanaki basket makers during the middle

part of the twentieth century. From the 1950s to the 1980s, competition from foreign imports and the development of plastic containers, coupled with changes in the potato and fishing industries that led to less demand for Wabanaki utility baskets, promoted further decline in the number of basket makers. Moreover, during this time period, coastal development and changes in land use restricted Wabanaki access to traditional ash and sweetgrass gathering and selling sites. The northern extension of the interstate highway system I-95 during the 1960s diverted traffic away from the Penobscot reservation in Old Town, Maine, taking with it potential customers for basket makers. By the 1990s, it is estimated that there were fewer than one dozen Wabanaki basket makers left under the age of 40 (Neptune, 2008b).

In 1993, Wabanaki basket makers created the nonprofit Maine Indian Basketmakers Alliance (MIBA) to help market their baskets, educate the public about tribal issues, revitalize aspects of traditional Wabanaki languages and cultures, and pass on basket-making skills to younger generations through apprenticeships with elder basket makers. Wabanaki basket makers have written a number of books about Wabanaki basketry, including the styles of Penobscot, Passamaquoddy, Micmac, and Maliseet basket makers (see Sanipass, 1990; Soctomah, 2003; Nichols, Francis, Francis, & Soctomah, 2008). Basket makers display and sell their baskets at a number of venues, including the Abbe Museum in Bar Harbor, Maine, as well as seasonal basket shows at locations around the state of Maine, which also provide opportunities for extended families and friends to socialize (Neuman, 2010). Wabanaki basket makers also have a presence in larger international Native American arts markets, such as Santa Fe Indian Market, with weavers receiving first place and best of show ribbons. Today, museum-quality Wabanaki baskets made by well-known basket makers can fetch as much as a few thousand dollars apiece – a far cry from the pocket change that early twentieth-century tourists would often pay for baskets. For most weavers, basket making provides a modest income and may supplement

Basketry of the Wabanaki Indians,

Fig. 3 Penobscot women and girl weaving outdoors on Indian Island, Maine, early twentieth century (Courtesy of Hudson Museum, the University of Maine)



Basketry of the Wabanaki Indians,

Fig. 4 Penobscot women and boy making baskets in their living room, early twentieth century (Courtesy of Hudson Museum, the University of Maine)



other forms of employment. Moreover, for many Wabanaki people, basket making signifies a process of decolonization, as the production of baskets is inseparable from assertions of tribal/band sovereignty, land use rights, and indigenous identities in twenty-first-century America and Canada (Sockbeson, 2009). However, Wabanaki basket makers face new twenty-first-century threats, including co-optation of their intellectual property rights by non-Wabanaki people, restrictions on access to their traditional brown ash and sweet-grass harvesting sites, and an invasive species of ash-destroying beetle: the Emerald Ash Borer (*Agilus planipennis*) (Fig. 5).

Procuring and Preparing Materials

Brown ash possesses unique characteristics that make it an ideal material for making baskets. Brown ash is strong enough that it can be woven into sturdy utility baskets, yet it is flexible enough to be woven into highly detailed, intricate, and delicate ornamental baskets, known as “fancy” baskets. Its growth rings can be pounded and split into fine splints that are ideal for weaving. However, not all brown ash trees – which tend to grow in wet areas – make good basket trees. Basket makers who harvest brown ash carefully select individual trees based on a set of complex



Basketry of the Wabanaki Indians, Fig. 5 Emerald Ash Borer emerging from an ash tree (Photo by Jennifer Neptune. Courtesy of Maine Indian Basketmakers Alliance)

technical criteria for matching individual trees to their basket-making needs. For example, by notching a small section of the trunk with an axe, a harvester can tell yearly tree ring growth and its suitability for a utility or fancy basket.

Once an ideal basket tree has been identified, it is cut into lengths of 4–12 ft. A spiritual offering may be given at the time a tree is cut. After removing the bark, harvesters use the blunt side of an axe to pound down the length of the log, which separates and releases the growth rings into layers. This produces long straight splints of 4–12 ft in length. As the ash is being pounded, the splints may be split into thinner segments using a splitter (Fig. 6).

Once a growth ring is divided into two parts, it may be split into even finer segments that can be paper thin in some cases. Splitting the ash creates new thinner segments that contain the original rough sides and new smooth surfaces. The rough sides may be smoothed with a knife in a process called scraping. The smooth thinner segments are ideal for delicate fancy baskets. At that point, the splints can be coiled and stored for later or they can be pulled through a sharp-toothed instrument called a gauge (Fig. 7), which cuts them into the desired widths.

Along with brown ash splints, basket makers harvest a highly aromatic marsh-loving grass called sweetgrass, which is integrated into the weave. In addition to being highly prized as a



Basketry of the Wabanaki Indians, Fig. 6 Splitting black ash splints with a wooden tool known as a splitter (Photo by Jennifer Neptune)

weaving material, sweetgrass plays an important role in spiritual and cultural practices (Fig. 8). Sweetgrass became more prominent in fancy baskets during the mid-nineteenth century, as Wabanaki traditional summer village sites on the Maine coast began to overlap with the growth of summer resorts and a new tourist market for baskets.

Weaving Baskets

Now the weaving process begins. Wide splints (called standards) are woven to form the base of the basket, and smaller splints that have been gauged into narrower widths (called weavers) are woven to form the sides and the bottom of the basket. Many basket makers use a wooden form called a block, which is tied to the base to help shape the sides as they are being constructed. After the sides have been woven, the block is then removed. The rim of the basket is then bound by



Basketry of the Wabanaki Indians, Fig. 7 Gauge for cutting splints (Photo by Jennifer Neptune)



Basketry of the Wabanaki Indians, Fig. 8 Picking sweetgrass for weaving (Photo by Jennifer Neptune)

tucking in the standards and finishing the rim's edge with materials, like sweetgrass, that strengthen it and add a decorative touch. Basket makers may weave covers or carve handles for their baskets.

There are two major categories of Wabanaki baskets: utility baskets and fancy baskets. Heavier and sturdier utility baskets are generally

used for gathering, transporting, processing, and storing food and other items. Two of the most recognizable styles of utility basket are the pack basket (often used in canoes) and the potato basket, which was essential for agriculture in Maine. Function, and not ornamentation, governs the production of utility baskets (Fig. 9).

On the other hand, fancy baskets are defined by and sought after for their ornamentation. Weavers will manipulate the ash into curls, twists, and points. Brightly colored and sometimes whimsical fancy baskets in the shapes of foods like blueberries, strawberries, pumpkins, pinecones, and corn are a hallmark of the Wabanaki style of basketry (Fig. 10).

Economic, Environmental, Social, and Cultural Dimensions of Wabanaki Basketry Today

The Maine Indian Basketmakers Alliance has succeeded in bringing together the technical knowledge and specialized skills of various basket makers into one organization dedicated to the preservation of the craft. The MIBA's program of pairing master basket makers with apprentices, with the explicit goal of preserving traditional knowledge (including Wabanaki language) and increasing the number of younger basket weavers, has been extremely successful. Today, there are approximately 200 Wabanaki basket makers in Maine. The MIBA has also been successful in marketing Wabanaki basketry and promoting its status as an art form among collectors; this also has helped raise consumer demand and prices for baskets.

Yet, Wabanaki basket makers in the twenty-first century face several threats. Access to traditional ash and sweetgrass gathering spots has been diminished due to coastal development, changing landowner attitudes concerning access, and new regulations imposed by large-scale landowners such as paper companies. Basket makers also must contend with infringement on their intellectual property rights: some businesses and individuals copy their unique styles and attempt to sell baskets as "Wabanaki" that are not made

Basketry of the Wabanaki Indians,

Fig. 9 Utility baskets by Peter Neptune (Passamaquoddy)
(Courtesy of Maine Indian Basketmakers Alliance)



Basketry of the Wabanaki Indians, Fig. 10 Fancy baskets by Passamaquoddy weavers Clara Keezer and Theresa Gardner (Photo by Jennifer Neptune)

by Penobscot, Passamaquoddy, Micmac, or Maliseet artisans. It is no wonder that many basket makers link their practice of making baskets to cultural survival and decolonization – that is, their continuing struggle against the effects of encroachment on their lands and traditions by outsiders.

However, perhaps the most pressing issue for Wabanaki basket makers today is the environmental threat posed by an invasive insect known as the Emerald Ash Borer. Discovered in 2002 in Michigan, the Emerald Ash Borer is believed to have traveled to North America on shipping pallets from Asia. This small beetle kills all species of ash trees and has destroyed millions of trees

since its arrival. Adult beetles lay their eggs on the bark of the tree, and the hatching larvae bore into the tree to feed on the inner bark. As the larvae feed, they create “S”-shaped galleries, which eventually girdle the tree, effectively killing the tree from the inside out. Infestations can be hard to detect, as symptoms often are not visible for three or more years. The Emerald Ash Borer has rapidly spread from the Great Lakes region of the United States to other areas, moving into the central, southern, and eastern United States as well as the Canadian provinces of Ontario and Quebec. Emerald Ash Borer on its own would spread over the landscape fairly slowly; however, humans have accelerated its spread by transporting infected firewood, logs, and nursery stock hundreds and sometimes thousands of miles. While natural predators help keep the Emerald Ash Borer in check in Asia, it has no natural enemies here. Left unchecked, it threatens to destroy virtually all of the ash trees in North America.

The Future of Wabanaki Basketry

Basket makers have adopted a number of proactive strategies to ensure the future of Wabanaki basketry. Since 2010, Maine has banned the importation and transportation of firewood into Maine from other states. Wabanaki basket makers and Wabanaki scholars testified before

the Maine Legislature and played a major role in the enactment of this legislation. Wabanaki basket makers – along with policymakers, forest service employees, and scholars from around the country – have formed black ash task forces to prepare for the arrival of the beetle, held symposia dedicated to preserving and sharing vital information about ash trees, and collaborated on cross-country field trips to learn how to identify the Emerald Ash Borer, to recognize damage and signs of the beetle, and to share strategies and knowledge about coping with the damage that will be caused by the beetle. Basket makers and conservationists are also saving seeds to preserve the ash trees for future generations.

Cultural knowledge is being preserved as well. Wabanaki ash harvesters are creating filmed records of tree identification, processing, and basket making so that this knowledge can be archived for future generations of Wabanaki basket makers. Some Wabanaki basket makers are also diversifying the materials they are using to craft baskets, returning to other traditional materials like basswood, birch, maple, and cedar, which are protected from the threat of the Emerald Ash Borer. In 2013, the Maine Indian Basketmakers Alliance, the Penobscot Nation, and the Bangor Museum and History Center pooled their resources to purchase a rare woven antique Penobscot basswood bag from an estate auction. Now housed at the Hudson Museum at the University of Maine, this basswood bag has the potential to inspire future generations of Wabanaki basket makers.

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Baudhāyana

R. C. Gupta

India's most ancient written works are the four *Vedas*, namely *R̥gveda*, *Yajur-veda*, *Sāma-veda*, and the *Atharva-veda*. There are different schools which are represented by various *Śaṃhitās* or recensions of the *Vedas*. To assist their proper study, there are six *Vedāṅgas* (limbs or part of the *Veda*), namely *Śikṣā* (phonetics), *Kalpa* (ritualistics), *Vyākaraṇa* (grammar), *Nirukta* (etymology), *Chandas* (prosody and metrics), and *Jyotiṣa* (astronomy, including mathematics and astrology). These auxiliary Vedic works (except the last) are written in *sūtra* or aphoristic style.

The *Kalpa Sūtras* deal with the rules and methods for performing Vedic rituals, sacrifices,

and ceremonies, and are divided into three categories: *Śrauta*, *Grhya*, and *Dharma*. The *Śrauta Sūtras* are more specifically concerned with the sacrificial ritual and allied ecclesiastical matters. They often include tracts which give rules concerning the measurements and constructions of *agnis* (fireplaces), *citis* (mounds or altars), and *vedis* (sacrificial grounds). Such tracts are also found as separate works and are called *Śulba Sūtras* or *Śulbas*. They are the oldest geometrical treatises which represent in coded form the much older and traditional Indian mathematics. The root *śulb* (or *śulv*) means “to measure” or “to mete out”.

The names of about a dozen *Śulba Sūtras* are known. The oldest of them is the *Baudhāyana Śulba Sūtra*. It belongs to the *Taittirīya Samhitā* of the *Black Yajur-veda* and is the 13 *Praśna* or chapter of the *Baudhāyana Śrauta Sūtra*. The title *Baudhāyana Śulba Sūtra* shows that its author or compiler was Baudhāyana, or perhaps more correctly, it belonged to the school of Baudhāyana. Other Vedic works bearing the same name are known. It is more proper to consider these works as belonging to the Baudhāyana school than to regard them as authored by the same person.

Here we are concerned with Baudhāyana the *śulbakāra* that is, the author of the *Baudhāyana Śulba Sūtra* or the *sulbavid* (expert in *sulba* mathematics and constructions). We do not know his biographical details. Georg Bühler believed that he hailed from the Andhra region, but a recent study by Ram Gopal shows that he probably came from northern India. His dates are also uncertain, being any time between 800 and 400 BCE. Taking into account the views of A. B. Keith, W. Caland, David Pingree, and Ram Gopal, he may be placed about 500 BCE or earlier. However, it must be noted that much of the material in *Baudhāyana Śulba Sūtra* is traditional and, thus, still older than its date of compilation and coding.

The *Baudhāyana Śulba Sūtra* is not only the earliest but also the most extensive among the *Śulbas*. The subject matter is presented in a systematic and logical manner. Of course, the language is somewhat archaic, and due to the

aphoristic style, the rules are highly condensed. The *Baudhāyana Śulba Sūtra* was commented on by Dvārakānātha Yajva (ca. seventeenth century). His Sanskrit commentary called the *Śulbadīpikā* was published more than a century ago by Thibaut (1848–1914) in his edition of the *Baudhāyana Śulba Sūtra*. A recent edition (Varanasi 1979) of the *Baudhāyana Śulba Sūtra* also contains the above commentary as well as another called *Bodhāyana śulbamīmāṃsā*, which was written by Vyāṅkateśvara (or Veṅkateśvara) Dīkṣita who lived during the Vijaya-nagaram kingdom (ca. 1600).

The text of the *Baudhāyana Śulba Sūtra* is divided into three chapters which comprise a total of 272 passages or 519 aphorisms. The main subject is the measurement, construction, and transformation of various altars and fireplaces. The forms of the three obligatory *agnis* (whose tradition was older than even the *pgveda*) were square, circle, and semicircle, but those of optional *citis* involved all sorts of plane figures, including the above three and also the rectangle, rhombus, triangle, trapezium, pentagon, and some complicated shapes.

Some mathematical topics covered in the *Baudhāyana Śulba Sūtra* are a fine approximation for the square root of two and the so-called Pythagorean theorem. In the latter, the sides of a right-angled triangle obey the rule $a^2 + b^2 = c^2$.

The *Baudhāyana Śulba Sūtra* also contains formulas for circling a square and squaring a circle, and provides rules for basic simple geometric constructions, such as drawing a perpendicular on a given line or drawing the right bisection of a line. Some other elementary plane figures such as the isosceles triangle, trapezium, and rhombus are also covered for construction.

The *Baudhāyana Śulba Sūtra* deals with the measurements and constructions of a large number of fire-altars (*Kāmya agnis*). These were needed as part of rituals performed to attain certain desired objects according to the religious beliefs of the Vedic people. It was essential that the shape, size, area, and orientation of the relevant altar be according to the prescribed instructions. Otherwise, there was a risk of divine wrath.

The standard forms of some of the optional altars were those which resembled certain birds. The most significant and perhaps the oldest of such altars was the *śyenaciti* (falcon-shaped altar). It was to be constructed when one desired heaven (after death) because “the falcon is the best flyer among the birds.” The spatial dimensions, the number of bricks (of prescribed shapes and sizes), the number of layers, etc., are all given. It is interesting to note that the archaeological remains of this most striking and complicated *śyenaciti* reported to be built in Kausambi in the second century BCE, still survive.

Early Indian geometry developed because of the need for accurate altar constructions and transformations which often required quite advanced mathematical knowledge.

See Also

► [Śulbasūtras](#)

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Beads

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Of the Paleolithic forms of possible symbolic products, beads and pendants seem to tell us the most about the cognition and technology of their users. First, there are the purely technological aspects. To make a bead, one has to be able to drill through an object (or enlarge a natural perforation), thread a string through the hole, and fasten the ends of the string, presumably by knots (Warner & Bednarik, 1996). To persist with such a process of manufacture, one must have a mental construct of the end product and a desire to acquire what is clearly a non-utilitarian artifact. While the bead is such an artifact, the string is not, being utilitarian. It is merely a means of permitting the bead to fulfill its non-utilitarian role. Hence, this is a combination not only of diverse (composite) and interactive artifacts but also a hierarchy of diverse concepts of relating to them. The primary imperative, presumably, is to display the bead to its best advantage; the secondary intent is to find a means of doing so. A piece of, say, ostrich eggshell can be worn on a string without first drilling a hole through it, so why bother with this additional work? It is through such considerations that beads are imbued with the potential of meaning and significance.

Whether they are sewn on apparel or worn on strings, beads, and pendants has symbolic meanings that are far removed from the empiricism of

the interpreting Western anthropologist. For instance, they may be protective, warding off evil spirits or spells, or they can be good luck charms. They can signify status (e.g., availability for marriage, political status, and state of mourning) and convey complex social, economic, emblematic, cultural, ideological, religious, or ethnic meanings or any subtle combinations of them. Their emic meanings can be public or private, but they may be difficult to convey to an alien researcher, and they could never be deduced reliably through archaeology.

Beads have no possible utilitarian function that is not attributable to purely symbolic purposes. Describing them as decorative, for instance, does not amount to any clarification, because it does not tell us why they are “decorative.” All communicative functions of beads are culturally negotiated; the abstract values they communicate to the initiated beholder are crucial to their existence, yet for the early periods of humanity they are entirely inaccessible to the researcher. The outstanding technical perfection of some particularly early specimens has prompted the proposition that these objects expressed concepts of perfection, and it has been demonstrated, via replicative experiments, that such perfection was achieved through a great investment of labor and carefully applied skills (Bednarik, 1997). The intentionality of perfection as well as the various layers of intended cultural meanings of such objects would have been all impossible without the use of a “reflective” communication system of a complexity that does not seem achievable without consciously modulated speech. Hence, beads and pendants constitute key evidence in the quest to clarify the cognitive evolution of humans – not just because they demonstrate the use of symbolisms, but because they demand social, cultural, and cognitive systems of an adequate sophistication to support the complex aggregate of mental abstractions without which such objects simply cannot exist. We have many other indicators of language use several hundred thousand years ago, during the Lower and Middle Paleolithic (e.g., other forms of symbolism or seafaring), but the use of beads and pendants during these earliest phases of

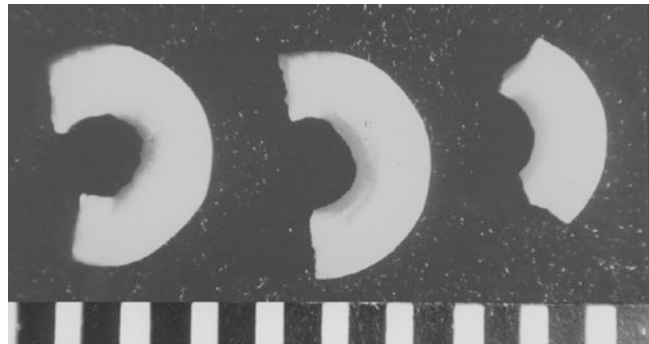
human culture provides one of the most crucial forms of such evidence.

Middle and Lower Paleolithic finds with both artificial and natural perforations are quite common, and many hundreds have been found since the mid-nineteenth century. They demonstrate considerable complexity of human cognition and social structures up to perhaps half a million years ago. The earliest mention of possible beads of the Lower Paleolithic relates to the first Paleolithic tools ever reported, from the very type site of the Acheulian (Boucher de Perthes, 1846). Prestwich (1859, p. 52), who recognized the authenticity of the St. Acheul stone tools Jacques Boucher de Perthes had been collecting for many years, noted that the holes in some of the *Porosphaera globularis* beads he himself collected at French sites had been artificially enlarged. Similarly, many of the 200 Acheulian beads Smith (1894, pp. 272–276) discovered at Bedford, England, showed artificial enlargement of the natural orifice. These, too, were of *Porosphaera globularis* fossil casts, but Smith was not aware of the earlier French finds. His opinion that the globular fossils had been used as beads was confirmed by Keeley (1980, p. 164) who examined some of the Bedford specimens. However, these important finds remained largely ignored until Bednarik, interested in resolving the issue of the earliest beads, conducted a detailed microscopic study of 325 *Porosphaera globularis* specimens held in the Pitt Rivers Museum at Oxford University (Bednarik, 2005). They had all been collected before the early twentieth century, most in England, some in France. In focusing on the best provenanced part of the collection, the Acheulian finds from the Biddenham quarry at Bedford, he found that many specimens bore distinctive artificial flaking around the narrow end of the natural central tunnel. Moreover, many were observed to bear distinctive wear facets around both tunnel openings, which leaves no doubt about their use as beads. They must have been permanently arranged with their tunnels in alignment to acquire this wear – in other words, they must have been on a string and worn in that way for considerable periods, often for years (Fig. 1).

Beads, Fig. 1 Some of the Acheulian stone beads from Bedford, England (Photo by author)



Beads, Fig. 2 The technical perfection of ostrich eggshell beads, such as the El Greifa specimens, illustrates the cultural complexity of the Acheulian period (Photo by author)



Circular, disc-like fossil casts have also been found at Acheulian sites, such as the crinoid columnar segments (*Millericrinus* sp.) from Gesher Benot Ya'aqov, Israel (Goren-Inbar, Lewy, & Kislev, 1991), and in France columnar crinoid segments from a site on the Loire and from Soissons, near Aisne, Picardie (Bednarik, 2005). Several disc beads made from ostrich eggshell have been excavated from substantial Acheulian layers in Libya (Bednarik, 1997). They are from the El Greifa site complex at Wadi el Adjal, near Ubari. The site is located on what was a peninsula of the huge Fezzan Lake in the Pleistocene, which then occupied a large part of southwestern Libya. The U/Th isotopes of the calcareous sediments dated the ostrich eggshell beads from the Late Acheulian of El Greifa site E as being in the order of 200,000 years old. The near-perfect rounded circumference and central perforation of these beads demonstrate that hominins of the Acheulian possessed the

technology of working this fragile medium with confidence and skill. These perfectly made artifacts also imply the existence of the social structures necessary to provide an ideological context for the production and use of body "decoration" (Fig. 2).

Among the earliest objects with human-made perforations we know of are the two perforated pendants from the Repolust Cave in Styria, Austria. One is a wolf incisor, very expertly drilled near its root; the second is a flaked bone point, roughly triangular and perforated near one corner (Bednarik, 1997). Both objects have received little attention since they were first reported (Mottl, 1951). They were excavated with a lithic industry variously described as Levalloisian, Tayacian, and Clactonian, which is in fact an undifferentiated Lower Paleolithic assemblage, clearly free of Mousterian elements. There is no reliable dating evidence available; the currently favored age estimate of around 300,000 years is

Beads, Fig. 3 Perforated wolf incisor, Repolust Cave, Austria, probably of the Lower Paleolithic (Photo by author)



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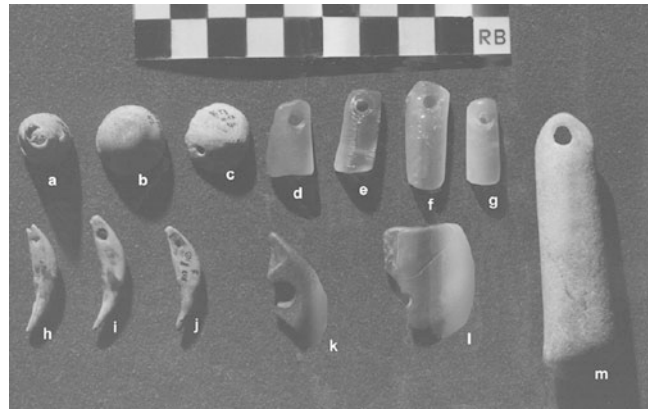
based on the accompanying faunal remains, especially the phylogeny of the bear remains (Fig. 3).

In addition to these Lower Paleolithic beads from three continents, there are numerous perforated objects also from the Middle Paleolithic, and many of them may have served as beads or pendants. The Micoquian has yielded an artificially perforated wolf metapodium as well as a wolf vertebra from the Bocksteinschmiede, Germany (Marshack, 1991; Narr, 1951), while the Micoquian of Prolom 2, Crimea, produced no less than 111 perforated animal phalanges, besides four engraved paleoart objects (Stepanchuk, 1993). The Mousterian of France has yielded a partly perforated fox canine and a perforated reindeer phalange and partly perforated fox canine from La Quina (Marshack, 1991; Martin, 1907–1910), another perforated bone fragment from Pech de l’Azé (Bordes, 1969), and a probable crinoid fossil from Fontmaure (van der Made, 2002). (A crinoid is a type of primitive marine invertebrate animal (echinoderm) with a cup-shaped body and five feathery radiating arms.) Perforated phalanges and perforated cranial fragment from Lezetxiki, Spain, are also of the Mousterian (Baldeon, 1993). Two perforated canines from Bacho Kiro, Bulgaria, too, are of the Middle Paleolithic (Marshack, 1991). The Middle Stone Age of Blombos Cave, South Africa, produced 41 perforated snail shells that are about 75,000 years old. Two slightly older perforated seashells come from Border Cave, also in South Africa (Beaumont, Miller, & Vogel, 1992), as does a centrally perforated ostrich eggshell fragment

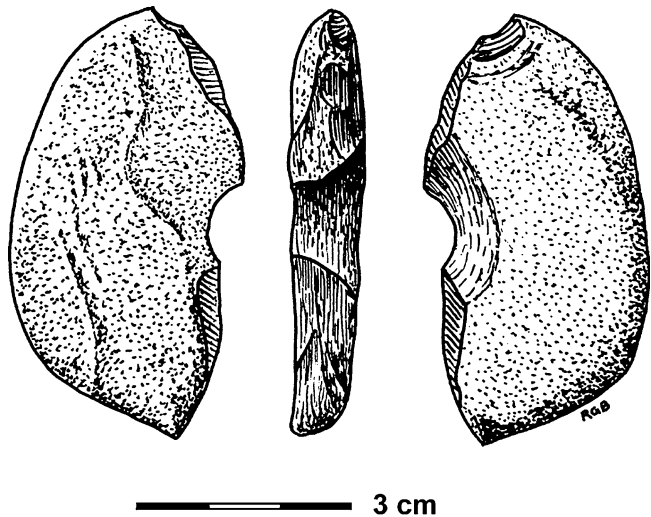
from the same site, about 76,000 years old (Grün and Beaumont, 2001). Of similar age is a broken circular ostrich eggshell pendant from the Cave of Hearths (Grün and Beaumont, 2001; Mason, 1998). Other African finds of the general period are a perforated shell from Oued Djebanna, Algeria; four deliberately drilled quartzite flakes from Debenath, Nigeria; perforated marine shells with traces of red pigment from Grotte des Pigeons, Morocco, about 82,000 years old (Bouzouggar, Barton, & Vanhaeren, 2007); and a bone pendant from Grotte Zouhra, also in Morocco (McBrearty & Brooks, 2000). Toward the end of this technological phase, beads and pendants became increasingly common, and materials of stone began to be drilled, first appearing in Russia and China. Thirteen such specimens from the lower occupation layer of Kostenki 17, found below a volcanic horizon thought to be about 40,000 years old (from the Campanian Ignimbrite eruption in Italy), include not only polar fox canines (Fig. 4) and gastropod shells with perforations, but also stone and fossil cast objects (Bednarik, 1995). From an intermediate Middle to Upper Paleolithic site in China, wenhua Shiyu, comes a broken stone pendant (Bednarik & Yuzhu, 1991; Fig. 5). The oldest beads found in Australia, from Mandu Mandu Creek rock-shelter, are about 32,000 years old and of a stone tool industry of Middle Paleolithic technology (Morse 1993).

With the advent of the Upper Paleolithic in Eurasia, beads became more numerous in various regions. This includes specimens made by the Neanderthals of the Châtelperronian of the

Beads, Fig. 4 Beads and pendants from Kostenki 17, Russia, >40,000 years old. (a–c) are snail shells; (d–g) are silicified, semitranslucent fossils; (h–j) are fox canines; and (k–m) are stone pendants (Photo by author)



Beads, Fig. 5 Fragment of drilled stone pendant, about 28,000 years old, from wenhua Shiyu, China (Drawn by author)

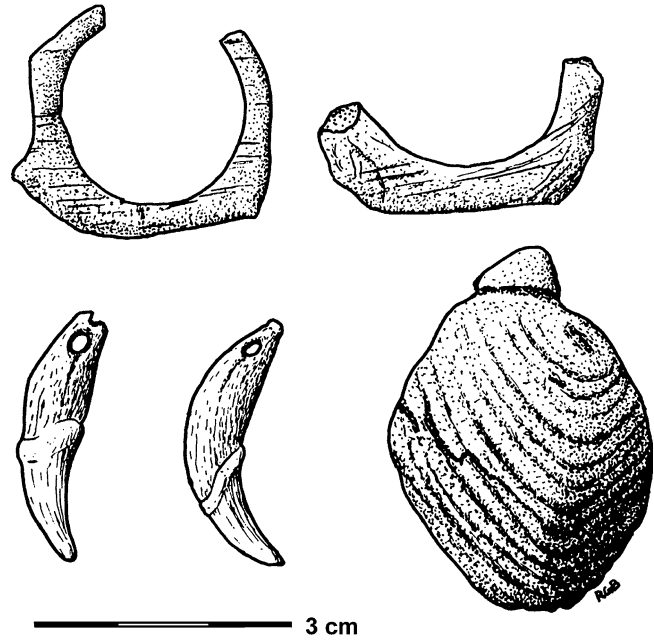


French Upper Paleolithic, among them again a crinoid fossil segment (Leroi-Gourhan, 1965; Fig. 6). Just three graves at the Russian site Sungir – with a stone tool technology that is transitional between Middle and Upper Paleolithic implement types, the Streletsian – contained more beads than have been found in the entire Pleistocene sites of the rest of the world (Bednarik, 1995). They yielded 13,113 small ivory beads and over 250 perforated canine teeth of the polar fox. By this time, perhaps 28,000 years ago, the art of bead making had reached an extraordinary level, in which the results of thousands of hours of labor were lavished on just three burials. In India, we have only a few specimens from the entire Paleolithic:

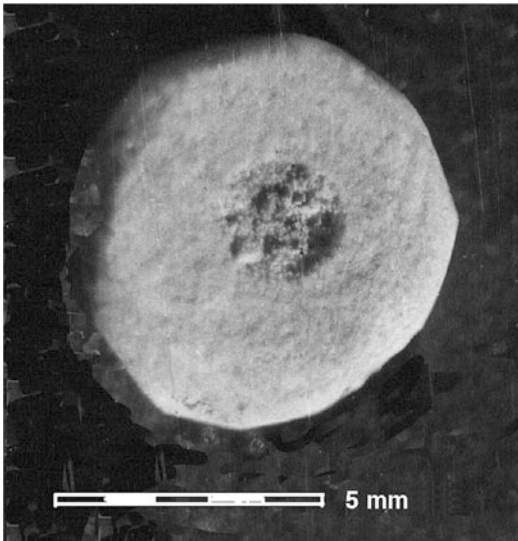
two from Bhimbetka, south of Bhopal, and three from Patne, Maharashtra (Fig. 7). Two of the latter are not perforated, although one is centrally scored (Bednarik, 1997). Other Asian regions producing ostrich eggshell beads include Siberia (Krasnyi Yar, Trans-Baykal), Inner Mongolia (Hutouliang), and the Gobi desert in northern China and Mongolia. The ostrich, now extinct in Asia, was widely distributed to the end of the Pleistocene, occurring in the Arabian Peninsula until well into historical times.

Both southern and northern Africa have yielded countless finds of worked ostrich eggshell (Baur-Röger, 1987, 1988; Camps-Fabrer, 1962, 1966, 1975; Czesla, 1986; Goodwin, 1929; Marmier & Trecolle, 1979; Marshall,

Beads, Fig. 6 Two ivory ring fragments, two perforated animal canines, and a fossil shell with an artificial groove for attachment, made by Neanderthals. Grotte du Renne, Arcy-sur-Cure, France (Drawn by author)



B



Beads, Fig. 7 Ostrich eggshell bead, early Upper Paleolithic, from Bhimbetka, Madhya Pradesh, India (Photo by author)

1976; Sandelowsky, 1971; Woodhouse, 1997). In the far north of Africa, the Caspian, belonging already to the first half of the Holocene, yielded not only numerous figurative and nonfigurative engravings on ostrich eggshell fragments, but also beads of snail shells, teeth, and small stones,

besides those of ostrich eggshell. The southern African sites providing such finds date from the Middle Stone Age right up to recent periods. Ostrich eggshell beads from Bushman Shelter near Ohrigstad, Transvaal, have been suggested to date from somewhere between 12,000 and 47,000 years ago. Beads of this material span a vast age spectrum, still occurring in recent periods in southern Africa. For instance, they are found in the Smithfield B, a tool complex of the subcontinent's interior regions of the fourteenth to seventeenth centuries AD. Indeed, ostrich eggshell beads are among the most enduring symbolic artifacts in human history. Much the same can be said about other forms of beads. For instance, a publication about Palestinian jewelry of the most recent ethnographic past features a photograph of a bead described as a "fossilized sea urchin" (Helmecke, 1990: Pl. 13f), depicting in fact a crinoid fossil cast that closely resembles the crinoids recovered from the Acheulian site Gesher Benot Ya'aqov in the same region, on the River Jordan (Goren-Inbar et al., 1991). Although separated by hundreds of millennia in time, the same materials were used for the same class of symbolic artifacts over an enormous time span – a poignant

reminder that in terms of their humanness, our distant ancestors were a great deal closer to us than many archaeologists are willing to concede.

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Beer Production in Peru

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Fermented beverages, produced from a variety of raw materials, constitute one of the most widely consumed drinks around the world. Indeed, there is tantalizing evidence that indicates that all past civilizations produced and consumed alcohol. Such a pattern continues in contemporary times as these beverages are produced and consumed within almost every culture around the world. Ancient western South America was no exception. First, early accounts left by the Spaniards, such as those of Cieza de León (1962 [1552]), Sarmiento de Gamboa (1999 [1572]), and Father Cobo (1956 [1653]), provide valuable information in regard to the use of fermented beverages within the Inka Empire. These sources note that these drinks were so important to the Inka state that it was directly involved in its production and distribution. Second, archaeological research confirms to a large extent the reports left by the Spaniards and demonstrates that at the time of the Inkas, alcohol was widely used across the Andes (Hastorf, 1991; Morris, 1979). More importantly, archaeological research demonstrates that these drinks were already produced and consumed in the region long before the rise of the Inka Empire (Moore 1989; Shimada, 1994; Gero, 1990; Valdez, 1994, 2006). Finally, ethnographic evidence shows that alcohol continues to be produced and consumed across the Andes (Camino, 1987; Hayashida, 2008, 2009; Jennings, 2005; Valdez, 2012).

As initially observed by the Spaniards for the particular case of the Inka, these beverages are produced from almost any vegetable or fruit but in particular, from maize (*Zea mays*) (Fig. 1), the berries of the molle tree (*Schinus molle* L.) (Fig. 2), the fruit of the algarrobo tree (*Prosopis* sp.) (Fig. 3), quinoa grains (*Chenopodium quinoa*), peanuts (*Arachis hypogaea*), and manioc (*Manihot esculenta*). Native Quechua speakers distinguish each drink type by a name, such as



Beer Production in Peru, Fig. 1 Maize used for maize beer

qora aqa for the one made from maize, *molle aqa* for the one made from molle tree berries, and *masato* (Izaguirre, 1924, p. 72) for the one made from manioc tubers. Currently, all these beverage types are commonly called *chicha*, a name that Spaniards such as Sarmiento de Gamboa (1999 [1572]) and Betanzos (1924 [1551]) had learned elsewhere before their arrival to the Central Andean region and began identifying every type of fermented beverage under this single label. It can be stated, nevertheless, that *chicha* is a name more commonly associated with maize beer (*qora aqa*) than with the other beverages.

In contemporary times, the most commonly produced and consumed beverage type in most of Peru, particularly in the highlands and the western lowlands, is maize beer. This wider acceptance of maize beer appears to be connected with the wider availability of maize in the region. In the central highland region, consumption of maize beer is closely followed by molle beer. Molle trees and therefore molle berries are locally available, especially at elevations below 3,000 m asl. Alcohol produced from quinoa seeds occurs also in the highland region, although more often among the people who inhabit higher elevations, often above 3,000 m asl. Along the western lowlands, alcohol made from the fruits of the algarrobo tree also occurs, along with maize beer. Algarrobo trees are found mainly along the Pacific coast. Finally, on the eastern slopes of the Andes, the most



Beer Production in Peru, Fig. 2 Molle berries (a, immediately after harvest; b, once stepping; c, ready for soaking; d, after soaking)

common types are drinks made from manioc tubers and peanut seeds. Along with the above beverage types, all made from indigenous raw materials, there is one additional alcohol type produced from a nonnative crop, sugar cane (*Saccharum*). In the central highlands and the eastern lowlands, this beverage is called *warapo*.

All these fermented beverages are prepared differently and some are more time-consuming than others. On the one extreme, the one that is

most labor intensive is maize beer. Maize grains must be selected, soaked, malted (Fig. 4), dried, crushed (Fig. 5), boiled, and finally drained in order to ferment. This process is long and it can take a minimum of 18–21 days. As its production is costly and as maize is a highly valued crop because it is also food and can be exchanged for other crops, maize beer is a highly prized drink. Therefore, this is the beverage type that one would expect to find at celebrations such as



Beer Production in Peru, Fig. 3 Algarrobo fruits



Beer Production in Peru, Fig. 4 Malted maize grains

weddings and Andean rituals. On the other extreme, the beverage type that is least labor intensive is molle beer. Indeed, once the molle berries are harvested, the beverage can be ready for consumption in just 3 days. The production involves only soaking the berries in special open-mouth vessels, draining the sweetened liquid, and placing it in narrow-neck ceramic jars for fermentation (Valdez, 2012). Molle beer can be produced on short notice and with the involvement of just two individuals. Since it can be produced quickly and with little effort, molle beer is often consumed at celebrations that involve large gatherings, such as carnival.

Depending on the crop being used, the preparation of these drinks varies. Those produced from maize, manioc, quinoa, and peanuts require boiling, while those made from molle berries and

algarrobo fruits involve only soaking. These differences also imply that their production often requires different equipment. For instance, maize beer and peanut beer production involves the use of grinding stones. In contrast, such tools are not necessary in the production of molle beer or manioc beer. In addition, the production of drinks in general involves the use of various ceramic vessel types. If the production involves boiling, medium-size open-mouth vessels are needed. If the production of a beer type involves soaking, large-sized open-mouth vessels (Fig. 6) are required. Finally, for the purposes of fermentation, large-sized narrow-neck vessels (Fig. 7) are required; an exception is manioc beer because it ferments in hollowed logs. The fermentation process, in almost all the cases, takes only between 2 and 3 days. Unfermented beverage is sweet (Fig. 8); the presence of foam (Fig. 9) emerging at the mouth of the container indicates that the beverage has fermented and is ready for consumption. Storage life is limited; once fermented, the drink becomes undrinkable within just 3 days.

Each beverage type is unique, with a particular flavor, some of which are stronger than others. Such is the difference that each of them leaves a strong aroma in the fermenting vessels. Consequently, vessels used for fermenting one type of beverage (e.g., molle beer) cannot be used for fermenting another beverage type. Therefore, it is common, at least in the central highlands region, that households have several narrow-neck fermenting vessels. The lack of vessels for the purposes of fermenting a particular type of beverage can be solved by borrowing one from a kin.

It is equally important to stress that the vessel types used in the process of producing these drinks, including manioc beer and *warapo*, are the same. These consist of:

1. Medium-sized, open-mouth, round-body vessels called *ollas* or *mankas* (for boiling)
2. Large-sized, open-mouth, round-body vessels called *maqma* (for soaking)
3. Large-sized, narrow-neck, round-body vessels called *urpu* (for fermenting)

Beer Production in Peru,
Fig. 5 Crashing malted
 maize for boiling



Beer Production in Peru, Fig. 6 Open-mouth ceramic
 vessel ideal for soaking molle berries

4. Medium-sized, narrow-neck, round-body vessels called *qipiri* (for transporting)
5. A variety of small-sized cups (for drinking)

As noted elsewhere (Valdez, 2012), the type of vessel used in the production of maize beer and molle beer overlaps and the same can be stated for the other drink types, again the exception



Beer Production in Peru, Fig. 7 Narrow-neck large
 vessel ideal for fermentation

being *masato*. All the other beverages ferment in narrow-neck vessels.

Continuing with the long tradition that predates the Inka Empire, these alcohol types are still produced in most of current Peru, in most cases likely following the same steps as in ancient



Beer Production in Peru, Fig. 8 Unfermented molle beer (upi)



Beer Production in Peru, Fig. 9 Fermented molle beer

times. In regions such as the central highlands, for example, one reason for this continuity is that alcohol plays an important role in the reciprocal obligations that the people of the region maintain. Indeed, communal labor, or any activity that



Beer Production in Peru, Fig. 10 A glass of molle beer ready to drink

brings together a large number of working parties, involves the distribution and consumption of alcohol, in addition to food and coca leaves. The hosting household has the obligation to provide goods that include alcohol. Providing water – instead of alcohol – could be a serious mistake because in the immediate future, it will become nearly impossible to recruit the desired number of working personnel. In a region where inhabitants are closely linked and their activities are carried out collectively, being marginalized could easily make life very challenging.

Finally, fermented beverages are also produced for the market. Indeed, there are households specialized in their production which make them available on a weekly basis. Such households are called *chicherías* (in Spanish) or *aqa wasis* (in Quechua). The most common drink types produced for the market are maize and molle beer (Fig. 10). In urban areas, written signs placed at the entrance of the houses indicate the availability of the fermented beverages. In rural areas, the signs consist of a piece of cloth tied at the end of a stick and placed by the door (like a flag) and indicate maize beer or a bunch of molle leaves tied at the end of a stick and placed by the entrance of the house signals the availability of molle beer.

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Ben Cao Gang Mu

Liao Yuqun

The application of herbal, mineral, animal, and man-made substances in medical therapy has been recorded in China since antiquity. These pharmaceutical compilations are called *Ben Cao*.

In the Ming dynasty, a masterpiece, *Ben Cao Gang Mu* (Compendium of Materia Medica), was published in AD 1590. In China, as well as in other parts of the world, this work is the best known and most respected description of traditional pharmaceuticals. The value of this enormous achievement, written by one person, goes far beyond the scope of a pharmaceutical-medical drug work. In fact, it constitutes an extensive encyclopedia of knowledge concerning nature and the technology required for the medicinal use of nature.

The compilation of *Ben Cao Gang Mu* was based on the *Zheng Lei Ben Cao* (Classified Materia Medica, compiled at the end of the eleventh century AD). ► [Li Shizhen](#), the author, took from it 1,479 drugs. He supplemented these with 39 drugs that had been included in the drug compendia of the Jin Yuan period, as well as with 374 drugs that he himself described for the first time, so that the *Ben Cao Gang Mu* contained a total of 1,892 drugs. This number is confirmed by the table of contents; the actual number should be 1,898. To continue the statistics: the number of drug illustrations is 1,160 and that of the recorded prescriptions is 1,196, of which Li Shizhen collected or newly compiled 161 himself.

The entire work was divided into 2 chapters of illustrations and another 52 chapters containing the

texts. The first four text chapters are of a general nature; chapters 5 through 52 contain the monographs. The total number of drugs was divided into 16 groups, and then 60 subgroups. Thus, for example, the group of herbs was divided into the subgroups of mountain herbs, aromatic herbs, swamp herbs, poisonous herbs, convolvulose herbs, water herbs, stone herbs, moss and lichen herbs, and finally, various herbs.

For each drug the following ten items were discussed. As they were used only when the information was necessary, not all are contained in each monograph:

1. Information concerning a previously false classification of the drug
2. Information on secondary names of the drug, including the sources of these names
3. Collected explanations
4. The pharmaceutical-technological preparation of the drug
5. Explanation of doubtful points
6. Correction of mistakes
7. Information on the thermo-influence and taste of the drug
8. Enumeration of the main indications of the drug
9. Explanations concerning the effects of the drug
10. Enumeration of prescriptions in which the drug is used

As for the author, Li Shizhen was born into a medical practitioner's family. When he was unable to pass the official career exams after three attempts, he was determined to devote himself to the study of medicine. Through 30 years' clinical practice and learning from many experts, he, after innumerable hardships, completed the manuscript in 1578, but the first edition was not finished until after his death.

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Betel Nuts

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Betel leaf and betel/areca nut are important plants in the Asiatic region and are individually masticatory but are generally taken together as *betel quid* or *paan* with other ingredients as catechu, slaked lime, spices, sweeteners, essences, and tobacco. Betel quid chewing is often culturally or socially ritualized, and there are elaborate ceremonies attending its use in various Asian and Pacific cultures though those are stigmatized in the West. The importance of *paan* can be best judged from the English rendering of a Sanskrit sloka [verse], "A mouth devoid of Vedas, the juice of *tambula* and witty sayings, is said to be a mere hole" (Krishnamurthy, 2009; Gode, 1961). The Thais prefer to go without rice or food rather than to deprive themselves of betel (Rooney, 1993).

The areca nut palm (*Areca catechu* L. family Palmaceae) is an unbranching, long plant extending up to 15 m and crowned with 6–9 fronds. The areca nut, botanically a drupe, is the seed found within the egg-sized fruit. The nut may be used fresh or dried and cured before use,

by sun drying, baking, roasting, boiling, and fermenting which change the flavor of the nut and its astringency. The genus *Areca* has two species in India: *A. catechu* L. and *A. nagensis* Griff. of the Naga Hills. There are many cultivated varieties such as *jahaju* (long nut), *manak chandi* (sphere), and so on. In the Pacific islands, betel nut palms are grouped into two cultivars: red and white. It needs a tropical wet climate with evenly distributed rainfall of 1,500–5,000 mm.

The betel vine (*Piper betle* L. family, Piperaceae) is a perennial creeper cultivated for its heart-shaped leaf. It needs fertile soils with proper shade and irrigation and is grown in hotter and damper parts of India. The Rural and Agricultural Glossary offers a number of terms related to betel cultivation and rituals performed during cultivation. Cultivation and plucking is ceremoniously done (Crooke, 1888, 1896; Gupta, 1991; Roy & Vijayalaxmi, 2013). Records on varieties are found in Hular inscription (1077 AD) of Vikramaditya IV and Krishni Gita in Malayalam. The latter provides information on 15 vines and seven nut varieties, their features and uses.

Both plants are cultivated mainly in India, Malaysia, Polynesia, Micronesia, and South Pacific Islands. The origin is likely to be in Southeast Asia where they grow naturally and diversity is greatest with archeological evidences dating back to 10,000 BC (Gorman, 1970). In addition, there is extraordinary diversity of indigenous words for duo in these regions. The Sanskrit word *tambula* for *paan* owes its origin to the Malaysian region and is derived from the term *tembel*.

There is no mention of *tambula* (betel leaf) in the Vedic *Samhitā*, the *Brāhmanas* and *Sūtras*, the *Rāmāyaṇa*, the *Māhābhārata*, and the *Smritis* of Manu. *Tambula* was probably introduced to India from the South Sea Islands such as Java, Sumatra, during the early Gupta period (Gode, 1961). The Mon Khmer-speaking Khasis, one of the earliest tribes to migrate to Assam, are reputed to have brought it in Assam and are the originators of betel chewing (Das, 1992).

Though there was a lot of opposition from religious people, it slowly entered into the social

and religious life of the people as food, medicine, and an item of rituals, and the commodity became a daily necessity. Both became the favorite pastime of elite society and royal persons and were used for royal gifts exchanged between emperors. *Paan* was used in welcoming guests, as a token of honor, pledge, and love. Betel nut chewing is cited as one of the eight enjoyments of royal life in the eleventh-century text called *Manasollasa* or Splendour of Thought. Such travelers as Marco Polo and Ibn Baṭṭūṭa of the thirteenth and fourteenth century mentioned it. As betel nut chewing evolved, so have the accessories used to make *quids* which include fine boxes and seed cutters.

Betel leaf vine and areca nut became important crops in Assam Bengal Hosur, Gadang, Dharwar, Kolhapur and Vijayanagar, South Kanara, Bellary, and Arcot during the eighth and tenth centuries. They also became an important commodity of trade and commerce and earned revenue for the royal treasury (Neog, 1960; Gode, 1961; Swamy, 1973).

The Assamese social, cultural, and religious life is webbed around the two and offers a view of its possible uses in various walks of life. For an Assamese a dream house is one with a courtyard with areca nut trees and betel leaf creepers. Betel chewing is a luxury indulged in by everyone. Khasi etiquette requires exchange of *kwai* as a mark of good breeding, and heaven is a place where one gets betel to one's heart's content. The reception at a social gathering starts with it and ends with it. In the past distance was measured by *khasi*, the number of *kwai* (areca nuts) chewed on the way. Every laborer expects *kwai* in addition to their wages. Khasis place a tamol over a dead body and say, "Farewell, go to the God and chew a tamol with Him." The Ahoms of Assam include tamol in the items offered to the Goddess *Sulichani* and to the almighty. Bodos also do the same in their *Kheral* puja before clearing land (Das, 1992).

Chewing *paan* is not common to the Santhals of Bengal, but they use the two along with many herbs in mouth sores, chest pain, redness and blood in urine, venereal disease (Chancre), hemoptysis, and bronchitis. Roots of *Piper betle*

are used to shut the womb (to stop pregnancy). The stem of *Piper betle* is used in curing madness (Bodding, 2001).

In India, a betel leaf is considered sacred and used to sprinkle holy water at religious ceremonies and offered to Lord Shiva, Lord Vishnu, and other Gods. The betel nut itself is worshipped symbolically as an image of Ganesha. It is customary in Maharashtra to use two betel leaves at all *paan-supari* ceremonies on the occasions of marriage, social functions, and religious festivals (Ahuja & Ahuja, 2011). In Bihar and Awad, the marriage pavilion is prepared with green bamboo and betel leaves, and bundles of seven betels are sent to the boy's father through a barber (Croke, 1888).

The betel is in itself a symbolic language. As rolled betel leaf symbolizes affection, the exchange of *tambula* denotes friendship and restores lost friendship (Ahuja & Ahuja, 2011). Sending a messenger anywhere and offering him a preparation of areca nut is tantamount to saying, "you have my authority" or "you carry my confidence" (Neog, 1960). Used as a simile, betel leaf conveys beauty, shyness, slimness, delicateness, and parts of the body such as lips, while the betel nut conveys the color of the lover. Metaphorically betel quid refers to vanity and worthlessness of place. Symbolically its presentation means affection and love, while socially and in the royal court, it denotes time for departure or time to call off a meeting. The duo has penetrated many Indian languages. Many villages and towns in Assam derive their name from betel, betel nut, or quid: Tamol bari, Pan bari, Chunpura, Chunpora, Tamulinga, and Gauhati. Penang, an island on the northwest coast of Malaysia, derives its name from *Pulau Penang* which means island of the areca nut palm. Houses in Jakarta, Indonesia, are called *Pondok Pinang* (areca nut hut) and *Kehon Sireh* (betel garden). Ko Mak in Thailand and Fua Mulaku in Maldives are also named after the areca nut. Betel is so pervasive that it is part of religion and has penetrated into the vocabularies of Hindi, Gujarati, Assamese, Tamil, Telugu, and other Indian languages. No other post-meal item has attained such an important position except rice.

A number of phrases in these languages are derived from words associated with these two plants. In addition, a number of sayings, proverbs, riddles, folk tales, and songs come from the duo (Ahuja & Ahuja, 2011). It is no wonder that a culture of sayings on suitable time and area of cultivation, planting, spacing, water requirements, time of maturity, and quality of betel leaf and nut also exists (Ahuja & Ahuja, 2012).

In addition to uses in social, personal, and religious ceremonies, the duo is seen in a number of medicinal and ethnobotanical uses (Table 1).

According to the universal classification of food, the areca nut and the betel leaf complement each other and are, therefore, in harmony. Since the areca nut is "hot" and the betel leaf is "cool," they act together to keep the human body in balance. In Āyurveda, betel leaves and betel nuts are both used as medicine in various forms like the leaf juice, the leaf itself, and the betel quid as adjuvant along with other Ayurvedic preparations. Āyurveda regards the nut as heavy for digestion and cooling, as it is dry and astringent in taste. It destroys *pitta* (bile) and *kapha* (phlegm), is intoxicating, and is both a stimulant and a laxative. The raw and unripe nut is poisonous and harmful to the eyesight. The cured hard center is excellent for destroying all three *doshas*. All organisms are sustained by three humors: *pitta* (bile), *kapha* (phlegm), and *vayu* (wind) called *dhatu*s in their equilibrium state. When this equilibrium is disturbed, disease occurs, and in this state they are called *doshas*. Disease occurs either by the aggravation or attenuation of *doshas* (Sadhale & Dave, 2006; Ahuja, Ahuja, Sharma et al., 2007).

In general it can be said that the betel nut is like poison when young, purgative in the middle stage, but an elixir when fully ripe and dry. The nut should therefore be taken only in the third stage. Burnt betel nuts are esteemed as tooth powder. A paste of betel nuts is used as laxative, and mixed with sandalwood it is useful in intrinsic hemorrhage (Sharma, 1996). Areca nut is also used in various cosmetic and aromatic preparations. It was also used to induce flowering in the *Champa* tree. An ointment made with areca nut in

Betel Nuts, Table 1 Ethnobotanical uses of betel nut and betel leaves

State	Tribe	Use
Assam	Miris	Nut and leaves used as vegetable
Bengal	Kols	Leaf used in wound by trident along with other constituents
Meghalaya	Khasi and Jaintia	Leaf juice for optic problems
Bengal	Santhals	Ground leaf with <i>Citrus medica</i> , roots of <i>Randia uliginosa</i> as a drink for colic conditions
		<i>Acacia catechu</i> , <i>Achyranthes aspera</i> , and <i>Randia uliginosa</i> in a betel quid taken for strangulation of the intestine
		Roots of <i>Piper betel</i> used to shut the womb (prevent pregnancy)
		Leaves with nut for hemoptysis and bronchitis
		Betel leaf + 15 other plants for biliary colic
		Betel leaf + roots of <i>Gymnema hirsutum</i> and <i>Nigella indica</i> for venereal disease
Meghalaya	Khasi and Jaintia	Betel leaf juice as indelible ink
	Khasi	Exchange of betel nut is etiquette
		Number of betel nuts chewed on the way is used to measure distance
		Welcoming guest and chance meeting with reciprocal offer of betel nut
		Reception of a social function starts with betel nut
		Exchange of kwai betel nut is correct and accepted way of leave taking at the end of function
Assam		Breaking ice between unknown and welcoming a known person
	Khasi	Betel nut considered as cheap and efficacious mean of hospitality
		Offer in betel nut after a meal in Assam
		First item offered to a visitor at home
Bhutan		Doma zhes “please have betel leaves and areca nut” each time two individuals meet, at the end of a meal and all occasions
		Betel leaf and small piece of areca nut offered to guest at ceremonies, BL and BN in a plate during archery games, official ceremonies, BL and BN passed round after a dinner

sesame oil along with other items is used to cure the swelling of shoulders in cattle (Ayangarya, 2006).

Betel leaves are useful in diseases caused by deranged phlegm (*kapha*) and in control of filarial infection, obesity, and skin diseases (Sharma, 1996). It is also used to relieve cerebral congestion and satyriasis and to allay thirst. *Paan* leaves are used as ready dressing for foul ulcers and with honey are used for coughs. Public singers and criers commonly chew the root to improve their voices. Betel quid chewing promotes health in damp areas (Watt, 1889). Ground leaves of *betel*, along with other plants, are used to cure bloat in cattle and as an antihelminthic for dogs.

According to *Yunani* physicians, betel nut is considered a diuretic; it strengthens the heart and

regulates menstrual flow. It is used for overcoming swollen eyes, mental confusion, chronic urinary distress, and pus formation. It is also a nerve tonic and an aphrodisiac.

Paan chewing with betel nut is popularly believed to prevent tooth decay, but long-term use has been associated with oral submucous fibrosis (OSF), precancerous oral lesions (mouth wounds), and squamous cell carcinoma (cancer). Acute effects of betel chewing include worsening of asthma, low blood pressure, and rapid heart-beat. Harmful effects of areca are roughness in the chest and urinary stones anemia and the appearance of jaundice (Krishnamurthy, 2009). The epidemic proportion of oral cancer in India is due to betel nut chewing (Chaturvedi, 2010). The risk of developing carcinoma of the oral mucosa is 7.7 times higher in betel chewers than in others.

Pharmacology or Drug Action

Betel chewing has been claimed to produce a sense of well-being, euphoria, heightened alertness, sweating, salivation, a hot sensation in the body, and increased capacity to work, but it also leads to habituation, addiction, and withdrawal. However, the mechanisms underlying these effects remain poorly understood. The areca nut kernel contains catechu, tannin, gallic acid, oily matter, gum, and characteristic alkaloids. The main active component, the alkaloid arecoline, has potent cholinergic [neurological] activity and is readily absorbed into the body. Pharmacologically the action of arecoline is a violent stimulant of the parasympathetic nervous system. Arecoline also stimulates salivation and decreases sweating, sweetens the breath, strengthens the gums, and generates a mild exhilaration giving the feeling of a good disposition. In the presence of lime, arecoline and guvacoline in areca nut are hydrolyzed into arecaidine and guvacine, respectively, which are strong inhibitors of GABA uptake. Arecoline hydrobromide is a statutory drug in the Indian, British, German, and French pharmacopoeias. Taenine is a preparation containing areca nut extract, forming a liquid medicine used in veterinary practices against tapeworms (Krishnamurthy, 2009).

The specific burning taste of betel leaf is derived from the presence of volatile oil consisting of phenols (chavibetol, chavicol) and terpenes which stimulate the release of catecholamines in vitro. It exhibits carminative, stimulant, astringent, and aromatic properties. The leaf extract, fractions, and purified compounds play a role in oral hygiene, antidiabetic, cardiovascular, anti-inflammatory/immunomodulatory, antiulcer, hepato-protective and anti-infective, etc. Patents were also awarded for some of its biological activities such as anti-inflammatory, anticancer, and immunomodulatory actions associated with leaf extracts and purified compounds. A number of biologically active compounds have potential for use as medicines, nutraceuticals, and industrial compounds (Kumar et al., 2010).

Betel chewing also increases plasma concentrations of norepinephrine and epinephrine.

These results suggest that betel chewing mainly affects the central and autonomic nervous systems (Chu, 2001). Let the *paan* live the same glorious life as it has in the past. We now know we have to show restraint in eating and avoiding its excessive use.

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Bezoar Stones in Peru

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Precious stones and gems have played a major role in Eastern and Western histories of medicine. One particular kind of stone, the bezoar stone, was especially valued in European medicine in the sixteenth and seventeenth centuries. Bezoar stones are compacted masses or concretions generally formed in the stomach or intestinal tract of animals. They come in a range of sizes, shapes, consistencies, and colors, some reaching the size of a chicken egg. Although the stones are formed in animals everywhere, only those bezoars originating in specific kinds of ruminants from Asia and Peru were believed to have healing virtue.

Europeans learned about bezoars primarily from the writings of two physicians from the Iberian Peninsula. One was the Portuguese physician of Spanish and Jewish origin, Garcia da Orta (ca. 1501–1568), who discussed Asian bezoar stones in his book *Colóquios dos simples e drogas e cousas medicinais da India* (Colloquies on the simples and drugs of India) published in Goa in 1563. Nicolás Monardes (ca. 1493–1588), a noted physician from Seville, included a treatise on the Asian bezoar stone with his first publication in 1565 on New World materia medica, *Dos libros. El uno trata de todas las cosas que traen nuestras Indias occidentales, que sirven al uso de medicina, y como se ha de usar de la rayz del Mechoacan, purga excelentissima. El otro libro, trata de dos medicinas maravillosas que son contra todo veneno, la piedra bezaar, y la yerva escuerçonera. Con la cura de los venenados*. (Two books. One is all things that we have brought from the West Indies which serve the use of medicine. . . . The other book describes two wonderful medicines that are useful against every poison, the bezoar stone, and the yerva escuerçonera.) Monardes later expanded his original presentation of bezoars when he received the first non-Asian stones that were sent to him from Peru by a Spanish soldier. He described these new stones in a second publication on New World medicines, *Segunda parte del libro de las cosas que se traen de nuestras Indias Occidentales, que sirven al uso de medicina* (Second part of the book of the things that have been brought from the West Indies which serve the use of medicine) (1571). He documented their medicinal use and effectiveness in his third and final book on American materia medica: *Primera y segvnda y tercera partes de la Historia medicinal de las cosas que se traen de nuestras Indias Occidentales que siruen en medicina* (Joyfull newes out of the Newe Founde Worlde) (1574). This publication included the first two books as well as new material.

When preparing his treatise on the Asian bezoar stone, Monardes (1565) drew upon his own experience as well as on the writings of famous scholars such as Moses Maimonides

(ca. 1138–1204) and other Persian, Arab, and Jewish philosopher-physicians writing in the ninth through the twelfth centuries who described the physical characteristics of the stones, the kind of animal in which they were found, and the ways that they could be used in medicine. The early sources that Monardes consulted provided two explanations for how the stones were formed inside the animal. According to one description, a rare deer-goat (*cervicabra*) found in the mountains of Asia would seek out and devour poisonous snakes at certain times of the year and then, as the poison heated its body, submerge itself in a cool lake or river. The hot sun would draw the poison from its body, concentrating it in tears that formed and hardened in the corners of the animal's eyes. When the animal came back to the water's edge, the tears would drop off on the shores where they would later be found and collected. According to the second account, after eating the poisonous serpents and taking to the water to cool off its body, the animal would then consume healing plants. These plants and herbs would concentrate the poison in the gut where it subsequently formed a hard ball or stone comprised of layers of poison and healing virtue (Monardes, 1574, pp. 134r–136r).

Considered to be powerful antidotes to many kinds of poisons, bezoars were also thought to be effective remedies for a number of devastating illnesses such as deadly fevers, fainting, melancholy, epilepsy, heart palpitations, vertigo, colic, worms, and poisoned wounds. Treatment called for the stones to be crushed and the resulting powder to be applied directly to a lesion or mixed in a beverage to neutralize any poison that might have been slipped in. In addition to being utilized as a medicinal simple, the stones could be mixed with other ingredients to make a composite medicine such as the costly Gascon's Powder which included bezoar, red coral, black crab claws, and white amber, among other items. Bezoars circulated mainly among European royalty, the nobility, and Church elites, and they were safeguarded in royal pharmacies and in the fashionable cabinets of curiosities in vogue at the time.

Bezoars were treasured and expensive because they were difficult to obtain and the risk that one

had purchased a counterfeit stone was high. Monardes included numerous case examples from his sources that dramatized the stone's healing virtue and priceless value. One such account, from the writings of the Spanish-Moorish physician Abdallah Narach, told of the events that took place when al-Nāṣir, or, as he was referred to by Christians, Miramamolín (amir al-muminin) (O'Callaghan, 1983, p. 244), emir of Cordoba, was saved after having been poisoned because someone gave him a bezoar stone. Miramamolín was so thankful to have had his life spared that he allegedly offered the Royal Alcazar of Cordoba to the man who came to his aid (Monardes, 1574, pp. 138v–139r).

Following its publication in 1565, the first part of Monardes's writings on New World medicines served as a useful manual for people in the New World as well as in Europe. Soldiers in Peru who had read the treatise on the bezoar noticed what looked like an Andean variety of the Asian goat-deer that Monardes had described. After hunting and killing several of these exotic beasts, the soldiers opened them up, and guided by a young boy who was among the Indians accompanying them, they found the precious stones inside the animals' gut. The news of this exciting discovery was published in the second part of the *Historia medicinal* (1571). One of the soldiers involved in the hunt, Pedro de Osma, sent Monardes samples of the stones so that he could experiment with them and write about his findings. Coming across this new source of bezoars was a monumental event for the Spanish because it meant that they could compete with Portugal's lucrative monopoly of Asian stones. It wasn't long before a substantial trade of Peruvian bezoars began circulating throughout the New World and Europe. The Jesuits figured prominently among the protagonists involved in the trade, actively dispatching large quantities of bezoars from the San Pablo Jesuit School in Lima to Rome (Martín, 2001, p. 125).

Although Monardes never named the exotic Peruvian creature found to have bezoars, some of his contemporaries later identified it as the vicuña (*Vicugna vicugna*), one of the two species of undomesticated Andean camelids, along with the guanaco (*Lama guanicoe*). Bezoars found in

vicuñas and guanacos were believed to have the greatest medicinal virtue, although those harvested from the domesticated alpaca (*Vicugna pacos*) and llama (*Lama glama*) were also prized. When word spread that these valuable stones could be found in the two species of wild camelids, soldiers and others began hunting them in great numbers. Consequently, from an ecological standpoint, the discovery of the stones in these animals was a decisive factor in the devastating decline in the vicuña and guanaco populations.

The Spanish learned that bezoar stones also played an important role in Andean indigenous herding communities. Known as *illa* in Quechua and *hayntilla* and *illa* in Aymara, bezoar stones were kept by pastoral families in sacred bundles called *señalu q'epi* along with other ceremonial objects. Anthropologist Denise Arnold studied midwife singers from the herding community of Qaqachaka, Bolivia, and described how the women ritually care for the stones by washing and rewrapping them at the same time that they remember the histories of these *illas* through commemorative songs. By means of these rituals, the stones are symbolically transformed into seeds of renewal that help to ensure the health and reproduction of the family's herd and thus guarantee the future livelihood of the family and the community.

When Spanish inquisitors, or "visitors of idolatries" as they were known in the New World, found these stones in homes and storehouses, they feared that they formed part of the dangerous forces of Satan in the Andes and so they seized and burned as many as possible. Of course, given the stone's value in European medicine, it is likely that many were smuggled out and sold for a handsome profit. For indigenous herding communities, the seizure of the stones from their homes and sacred bundles and the assault on their traditional rituals of commemoration meant that their lives had been turned upside down. The loss of the stones or regenerating seeds signified that their power of regeneration and continuity had been placed at risk. Consequently, the disappearance of the stones represented the beginning of a new era, the primary characteristic of which was hunger due to the threat that the communities' animals might similarly vanish.

By the end of the eighteenth century, medical interest in Asian and Peruvian bezoar stones had largely faded, and today they are of interest primarily for their historical resonance. For Andean indigenous pastoral communities, in contrast, bezoars still hold relevance today as a vital symbol of the regeneration and persistence of Andean knowledge and traditions.

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Bhāskara I

Agathe Tamar Keller

Bhāskara I was a seventh century astronomer, probably from the region that is between the border of modern day Mahārashtra, Gujarat, and Madhya Pradesh in India.

He wrote two treatises in the line of ► **Āryabhaṭa I's** astronomy, the *Mahābhāskariya* (Shukla, 1960) and the *Laghubhāskariya* (Shukla, 1963). Bhāskara did not just restate in an explicit way Āryabhaṭa I's astronomy; he also provided explanations and interpretations of this astronomer's reasoning. Bhāskara I is also the author of a commentary on the *Āryabhaṭīya* (see the entry on Āryabhaṭa). This is the oldest known Sanskrit commentary on this treatise. It is also the oldest known commentary for the whole mathematical and astronomical tradition in Sanskrit. The commentary is called the *Āryabhaṭīyabhāṣya* (Keller, 2006; Shukla, 1976). Bhāskara I himself dates the writing of this text to 628 AD. He is thus a contemporary of ► **Brahmagupta**.

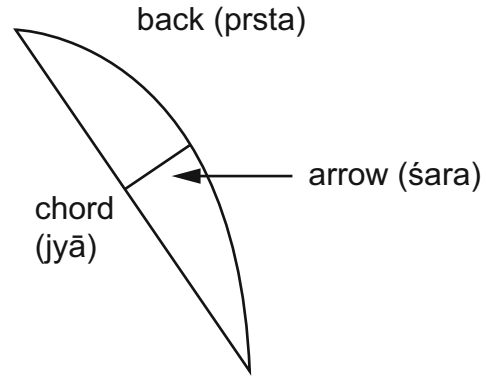
This commentary, not being written in compact *sūtra* verses, can help us reconstruct what astronomy and mathematics were for a seventh century astronomer. It gives us precious insights into how mathematical and astronomical concepts were derived and discussed. Bhāskara, for instance, discusses the relation of mathematics to astronomy, giving several definitions of mathematics in the opening part of his commentary. His idea of *gaṇita* (computation, mathematics) seems to be quite malleable and open. Indeed, if the discipline called *gaṇita* is understood as a set of procedures, general (*samānya*) or specified (*viśeṣa*), then it encompasses astronomy (*jyotiṣa*). But it can also be seen as a set of specialized subjects. In this case, it is quite separate from astronomy. Bhāskara provides us with different proposals as to how one can classify the subjects related to mathematics. He thus states for the first time the classification of

mathematics into eight *vyavahāras*, which were used after him in arithmetical texts (see the entry on arithmetic in India). He also alludes to equations (*bija*) as a way of classifying mathematical subjects, an idea that had a certain posterity in the algebraic tradition in India (see the entry on algebra in India). For Bhāskara I all computations belonged both to arithmetic (*rāśigaṇita*) and to geometry (*kṣetragaṇita*). Thus series (*średdhi*) are seen as both sums of numbers (belonging thus to arithmetic) and piles of objects (belonging thus to geometry).

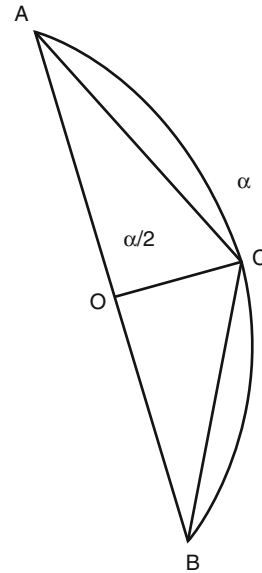
Bhāskara's commentary also testifies to how astronomy and mathematics were practiced in those times. For instance, Bhāskara gives details on the constructions of gnomons (sundials), describing various shapes, styles and schools for this instrument. He also sometimes explains how a mathematician (*gaṇaka*) uses a working surface (probably just the bare ground or a slate) on which numbers are disposed and diagrams drawn. These were then used when solving problems, which involve moving quantities, or seeing a proof in a drawn figure (Keller, 2005).

Bhāskara's commentary on the *Āryabhaṭīya* is an important landmark in understanding the beginning of sine trigonometry. His work shows us that the fundamental diagram of sine trigonometry is a bow field (*dhanuḥkṣetra*). A bow field is composed of a back (*prsthā*), a chord (*vyā*) and an arrow (*śara*). This is illustrated in Fig. 1.

By the time Bhāskara wrote his commentary, it was fairly common to consider something that can be a bit confusing at first, the half-chord of the half-arc. That is, in Fig. 2, the segment AO is the half-chord of $a/2$, and not the half-chord of a . This segment is what we call the sine of arc $a/2$, when in a circle of radius 1. In Bhāskara's mathematics, however, circles are seldom with a unit radius, and so he deals in fact with R sines, e.g., R times the sine. This segment is called *ardhajyā* (lit. half-chord), but slowly as it became a technical term in itself, the word half (*ardha*) was sometimes dropped, until the segment itself was called *jyā*. The innovation constituted by the sine over the chord becomes clear if we look at Fig. 2



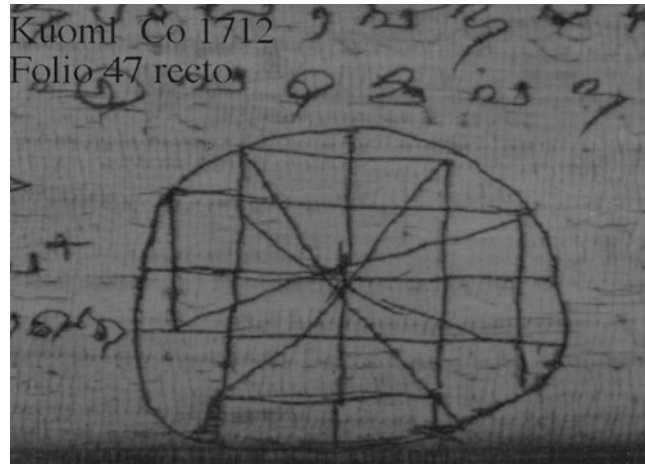
Bhāskara I, Fig. 1 A bow field (Drawing by the author)



Bhāskara I, Fig. 2 The half-chord of the half-arc (Drawing by the author)

again. Indeed, by using this segment, computations using the Pythagorean theorem become possible enabling one to derive lengths of segments quite easily. To explain how to derive tables of sine differences, Bhāskara prescribed the construction of a diagram, which is shown in Fig. 3 (Hayashi & Yano, 1991). It can be seen as an ancestor of our trigonometric circle.

As a mathematician, Bhāskara did not restrict himself to trigonometry but provided his insights on a great range of subjects. For instance he gave a detailed version of different problems solved by

Bhāskara I,**Fig. 3** Bhāskara's diagram for deriving sines

B

a pulverizer (e.g., a method to solve Pell equations, Bag, 1979), all sorts of variations on the Pythagorean theorem, reflections on the concept of quadratic irrationals (Chemla & Keller, 2002; Datta 1980), and many others (Rao, 2006). As a scholar, he often staged intellectual debates and took positions on them, thus letting us have a feel for the oppositions existing between different schools of mathematicians and authors that existed at the time, something that Brahmagupta's work also testifies to.

Bhāskara's legacy has been especially felt in Kerala. If you judge the popularity of an author as being measured by the number of commentaries it has given rise to, we can note that in Kerala, his works were commented upon by Govindasvāmin (ca. 825), Śaṅkaranārāyaṇa (ca. 869) and Parameśvara (ca. 1430). After first being confused with his namesake ► **Bhāskara II** by early nineteenth century scholars (Datta, 1930), his work was slowly brought to light in the early twentieth century (Datta & Singh, 1938). Finally K. S. Shukla took the time to edit his texts and translate his treatises in the 1960s and 1970s.

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Bhāskara II

R. C. Gupta

Undoubtedly, the greatest name in the history of ancient and medieval Indian astronomy and mathematics is that of Bhāskarācārya (b. AD 1114). His *Līlāvātī* is the most popular book of traditional Indian mathematics. He is usually designated as Bhāskara II in order to differentiate him from his earlier namesake who flourished in the early part of the seventh century.

According to Bhāskara's own statement towards the end of his *Golādhyāya*, he was born in Śaka AD 1036 or AD 1114. He also adds that he came from Vijjāḍaviḍa near the Sahya mountain. This place is usually identified with the modern Bijapur in Mysore. S.B. Dikshit is of the opinion that Bhāskara's original home was Pāṭaṇa (in Khandesh), where a relevant inscription was discovered by Bhau Daji in 1865. According to the inscription, Manoratha, Maheśvara, Lakṣmīdhara, and Caṇgadeva were the names of the grandfather, father, son, and grandson, respectively, of Bhāskara. Caṇgadeva was the chief astronomer in the court of the king Siṅghaṇa and had established in AD 1207 a *maṭha* (residential institution) for the study of the works of his grandfather. Bhāskara's father, Maheśvara, was also his teacher.

Bhāskara's *Līlāvātī* (The Beautiful) is a standard work of Hindu mathematics. It belongs to the class of works called *pāṭī* or *pāṭīgaṇita*; that is, elementary mathematics covering arithmetic, algebra, geometry, and mensuration. Its popularity is shown by the fact that it is still used as a textbook in the Sanskrit medium institutions throughout India. It provides the basic mathematics necessary for the study of almost all practical problems, including astronomy. The subject matter is presented through rules and examples in the form of about 270 verses which can be easily remembered. There is a story that the author

named the work to console his daughter Līlāvātī, who could not be married due to some unfortunate circumstances; but the truth of the story cannot be ascertained. Bhāskara addressed the problems to a charming female Līlāvātī, who, according to some scholars was his wife (and not his daughter).

The great popularity of *Līlāvātī* is illustrated by the large number of commentaries written on it since it was composed about AD 1150. Some of the Sanskrit commentators were: Parameśvara (about 1430), Gaṇeśa (1545), Munīśvara (about 1635), and Rāmakṛṣṇa (1687). Only a few of these have been published. Gaḍeśa's gives a good exposition of the text with a demonstration of the rules. However, the best traditional commentary is the *Kriyākramakarī* (ca. 1534), which is a joint work of Śaṅkara Vāriyar and Mahiṣamaṅgala Nārāyaṇa (who completed it after the demise of Śaṅkara).

There are a number of commentaries and versions in regional Indian languages. Quite a few modern scholars have edited, commented on, and translated *Līlāvātī*. At least three Persian translations are known, the earliest being by Abū al-Fayḍ Fayḍī (AD 1587). The English translation by Colebrooke (1817) was based on the original Sanskrit text and commentaries.

Bhāskara's *Bījagaṇita* (Algebra) is a standard treatise on Hindu algebra. It served as a textbook for Sanskrit medium courses in higher mathematics. In it the author included an exposition of the subject based on earlier works. Among the sources named were the algebraic works of ► Śrīdhara and Padmanābha. Besides operations with various types of numbers (positive, negative, zero, and surds), it deals with algebraic, simultaneous, and indeterminate equations. There is a separate chapter on the Indian cyclic method called *cakravāla*. He attributes the method to earlier teachers but does not specify any name. Due to the difficult nature of some of the topics, the *Bījagaṇita* was not as popular as the *Līlāvātī*.

Bhāskara's *Siddhānta-śiromaṇi* (AD 1150) is an equally standard textbook on Hindu

astronomy. It has two sections: *Grahaṇita* (Planetary Mathematics) and the *Golādhyāya* (Spherics). Often these two sections appear as independent works. There is a lucid commentary on the whole work by the author himself. It is called *Mitākṣarā* or *Vāsanābhāṣya*. Other commentators include Lakṣmīdāsa, Nṛsiṃha, Munīśvara (1638/1645), and Rāmakṛṣṇa. The 14th chapter of the *Golādhyāya* is the *Jyotpatti*, which may be regarded as a small tract on Hindu trigonometry.

Usually it is customary to regard *Līlāvātī*, *Bījagaṇita*, *Grahaṇita*, and the *Golādhyāya* as the four parts of the *Siddhānta Śiromaṇi* which make it a comprehensive treatise of Bhāskarācārya's Hindu mathematical sciences. His two other works are the *Karaṇa-kutūhala* (whose epoch is 1183), a handbook of astronomy, and a commentary on Lalla's *Śiṣyadhīvr̥ddhidatāntara* (eighth century AD). Some other works have also been attributed to him, but his authorship of *Bījopānaya* is questionable.

Bhāskara introduced a simple concept of arithmetical infinity through what he calls a *khahara*, which is defined by a positive quantity divided by zero, e.g., $3/0$. His arithmetical and algebraic works are full of recreational problems to provide interesting pedagogical examples.

Perhaps the most important part of Bhāskara's *Algebra* is his exposition of the Indian cyclic method. We now know that the method was already known to Jayadeva (eleventh century AD or earlier). A modern expert, the late Selenius, praised it by remarking that "no European performance in the whole field of algebra at a time much later than Bhāskara II, nay nearly up to our times, equaled the marvelous complexity and ingenuity of cakravāla method." Fermat proposed the equation $61x^2 + 1 = y^2$ in 1657 to Frénicle as a challenge problem. However, by applying the above method, Bhāskara had already solved the problem five centuries earlier. Bhāskara's solution (which he got just in a few lines) in its smallest integers was $x = 226,153,980$, $y = 1,766,319,049$.

The feat was possible not only due to the technique but also because of a well-developed symbolic notation. Colebrook remarks.

Had an earlier translation of Hindu mathematical treatises been made and given to the public, especially to the early mathematicians in Europe, the progress of mathematics would have been much more rapid, since algebraic symbolism would have reached its perfection long before the days of Descartes, Pascal, and Newton.

Another gem from Bhāskara's *Algebra* is a very short proof of the so-called Pythagorean theorem.

The geometrical portion of *Līlāvātī* covers mensuration regarding triangles, quadrilaterals, circles, and spheres. A special rule gives the numerical lengths of the sides of regular polygons (from three to nine sides) in a circle of radius 60,000. The last chapter entitled *Aṅka-pāśa* is devoted to combinatorics.

Bhāskara's *Jyotpatti* contains many trigonometrical novelties which appear in India first in this tract.

Although an equivalent of the differential calculus formula

$$\Delta \sin \theta = \cos \theta \Delta \theta$$

already appeared in Munījla's *Laghumānasa* (AD 932), Bhāskara II gave its geometrical demonstration. He knew that when a variable attains an extremum, its differential vanishes. A crude method of infinitesimal integration is implied in his derivation of the formula for the surface of a sphere. This he gave in the *Vāsanābhāṣya* on the *Golādhyāya* (Chap. III).

Bhāskara's *Siddhānta-śiromaṇi* is one of the most celebrated works of Hindu astronomy. It is a comprehensive work of *Brahma-pakṣa*. He praised ► [Brahmagupta](#), who belonged to the same school, but his own astronomical work became more famous.

Although based on the works of predecessors, rather than on any fresh astronomical observations, the *Siddhānta-śiromaṇi* served as an excellent textbook. Systematic presentation of the

subject matter, lucidity of style, and simple rationales of the formulas made it quite popular. It also contained some improved methods and new examples. For instance, he gave a very ingenious method of finding the altitude of the Sun in any desired direction in his *Golādhyāya* (III, 46). His professional expertise and all-round knowledge made him a truly great and revered *ācārya* (professor) of Hindu astronomy and mathematics for generations.

See Also

- [Combinatorics in Islam](#)
- [Geometry in India](#)
- [Mathematics in India](#)
- [Munīśvara](#)
- [Parameśvara](#)
- [Trigonometry in Indian Mathematics](#)

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Bian Que

Liao Yuqun

Bian Que, one of the most famous medical men in ancient China, lived during the time of the Zhou dynasty, between 500 and 600 BCE. He was good at various subjects in medicine and skilled in diagnosis and treatment, especially in pulse-taking and acupuncture.

Sima Qian (about 145–196 BCE), a well-known historian, wrote a biography of Bian Que in his work *Shi Ji* (Historical Record). In it, he discussed Bian Que's practicing medicine, wandering from town to town and effecting miraculous cures, even bringing the dying back to life. In the end Bian Que was killed by a jealous commissioner of the Imperial Academy of Medicine. Sima Qian says: "Bian Que expounded medicine as the guiding principle of (medical) technique; the later generations followed it and could not change any more." He was regarded as the founder of traditional Chinese medicine, but according to the historical materials in the biography, Bian Que lived and flourished for hundreds of years. That is because its author confused him with another famous medical man, Qin Yueren. Probably Qin Yueren was a follower of Bian Que's teachings.

In the earliest bibliography, *Qi Lue*, written in the first century BCE, Bian Que was assumed to be the author of some medical works such as *Bian Que Nei Jing* (The Internal Classic of Bian Que) and *Bian Que Wai Jing* (The External Classic of Bian Que). Although all of them have been lost, the contents can be partly found in other extant

medical works, which reflect what he contributed to traditional Chinese medicine.

Bian Que said that the blood and *qi* (vital energy) move along the channels of the body, making 50 circuits per day. Some medical historians consider this the first intimation of the circulatory system of the blood; others are more skeptical. This view was constructed on the principle of cyclicism, a very common mode of thought for the Chinese.

It was he, too, who founded the extremely complicated old Chinese system of pulse-taking, according to which a doctor was supposed to be able to diagnose an illness solely by the condition of the pulse. It was not just a question of whether the beat was strong or weak, regular or uneven. Pulses could also be distinguished as “sounding like a sickle, first exuberant then dying away”; “flowing along quietly like flying hair or feathers”; “beating deep and strong like a thrown stone”; “sounding delicate like the string of an instrument”; or “slipping along like a fish or a piece of wood on the waves”. From the above selection of possible pulse beats, it is easy to see with what extraordinarily sharpened sensitivity the Chinese doctor examined his patient. Bian Que also discussed how to diagnose illness by the condition of the complexion. For example, a yellow complexion and nails were an indication of jaundice; red dealt with the heart; and white was always due to the lungs.

As for therapy, Bian Que used the traditional techniques such as acupuncture, ► [moxibustion](#), and drugs to cure various diseases. We do not know who invented those treatments; however, all of them were improved owing to Bian Que’s practice and teaching. Indeed, these are still followed in clinical practice and diagnosis today.

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Bitumen in China

Hans Ulrich Vogel

Reports of bitumen seepages and production concentrate on four provinces: northern Shaanxi and eastern Gansu from the Han period onward, Sichuan from the Ming onward, and Xinjiang which has records of bitumen seepages during the periods of the Northern Dynasties (386–581), the Tang, and the Qing. In addition, during the Ming and Qing periods, minor production sites existed in Guangdong, Taiwan, Zhejiang, Anhui, and Liaoning (Liaodung).

The earliest record of bitumen seepages refers to northern Shaanxi that is the oil fields of Yanchang and Yongping of today. The *Hanshu*, first century AD, states that in Gaonu district (modern-day Yan’an) “there is the Wei River; it can burn.” This statement is elucidated by later sources, which say that on the water of the Wei River “fat” (*fei*) is floating which can burn and which can be taken for greasing cart axles or as fuel for lamps.

Sources from the Song onward provide more details on the locations of Shaanxi petroleum seepages and production methods. In his famous account of about 1070 on using petroleum carbon for ink, Shen Gua (1031–1095) mentions the production of “stone oil” (*shiyou*) in the two prefectures Fu and Yan and of “stone juice” (*shiye*) in Yanchuan. He wrote that stone oil grew in the sand and stones of the waterfront, was mixed with spring water, and, with a view to ink manufacture, was produced inexhaustibly within the earth, in contrast to the limited supply of pine wood. In spring, local people collected it with pheasant tail brushes and put it into pots. The method of collection described by Shen Gua is similar to that described in Agricola’s *De re metallica* of the mid-sixteenth century.

Song and Yuan sources report that near Yan’an bitumen was used to make so-called “stone candles” (*shizhu*). Lu You (1125–1210) says in his *Laouxuean biji* of 1190 that they are

solid like stone and give a very bright light. Moreover, “they also gutter like wax [candles]. Their smoke, however, is thick and may fumigate and defile curtains and clothes. This is why people in the western [part of the empire] do not esteem them.” The stone cave supplying the raw material for the production of the stone candles was, however, closed in 1270 by government order.

Perhaps the first notion of a well intentionally dug for getting bitumen can be found in the *Da Yuan da yitongzhi*, the comprehensive administrative and geographical description of the Yuan period:

South of Yanchang district, at Yinghe, there is a stone oil well which has been cut open. Its oil can burn and also cures itches and ringworms of the six domestic animals. Annually, 110 *jin* [pounds] are handed in. Moreover, in Yongping village, 80 *li* north-west of Yanchuan district, there is another well, which annually procures 400 *jin*. They are handed over to the [Shaanxi] Route (*lu*).

As in many other cases, the output of oil seepages was low. The record also shows that the government was heavily interested in this resource, probably because of its importance for warfare.

The use of bitumen in warfare from the Yumen oil field in western Gansu is reported by an eighth-century source, stating that, in 578, the Emperor Wu of the Northern Zhou, when being besieged by the Turks at Jinquan, took this “fat” and set it afire, thus burning the enemies’ assault weapons. When brought into contact with water, it burnt even more, with the result that Jinquan was saved.

With the development of deep drilling, Sichuan became an important producer of bitumen, being a by-product of the search for brine and, later, natural gas. Sixteenth-century accounts report that the sources of the fire wells of Jiading and Qianwei are all “oily.” Because of its odor, locals call the stone oil “realgar oil” (*xionghuangyou*) and “sulfur oil” (*liuhuangyou*). It was thought that the sources and veins of stone fat, realgar, and sulfur were interconnected. Officials filled ► [bamboo](#) tubes with oil and ignited it for lighting the way. Moreover, special iron

lamps were constructed which fitted the use of bitumen as fuel. An indigenous terminology developed which was based on the colors of bitumen. White bitumen was called “rice-soup oil” (*mitangyou*), green “green-bean oil” (*ludouyou*), yellow “gardenia-nut oil” (*zhiziyou*), and black “black-lacquer oil” (*moqiyou*). Petroleum occurred at depths of 180–220 m, ca. 360 m, and 950–990 m, and there were experts who knew exactly to which depths the hoisting buckets should be sent to have them filled with petroleum exclusively.

The most important application of bitumen in crude and distilled form was certainly in the military field, where it was used for incendiary weapons. The sources do not inform us about details of the processing and distilling methods, but this may be due to the fact that these were treated as military secrets. The second most important use of bitumen was for lighting purposes, for which numerous references, particularly for regions near bitumen seepages or wells, can be found. In Sichuan, bitumen appears to have served sometimes as fuel for the evaporation of brine. Bituminous products were also used for greasing cart axles and the bearings of water power trip-hammers, manufacturing ink, sealing leather wine sacks, covering floors, and tempering iron.

Moreover, bitumen was often applied for medical, pharmaceutical, and alchemical purposes. For instance, Li Shizhen’s *Bencao gangmu*, published in 1596, states that it is smeared on ulcers, ringworms, worms, and scabies, and is used for drugs which heal flesh wounds caused by iron arrows. A source of the seventh century tells us that when swallowing the bitumen of Jiuzi in Xinjiang, fallen out teeth and hair can be induced to grow again. Later sources are less sanguine about internal application and sometimes stress that bitumen is poisonous.

Although, in China, bitumen seepages and deposits were discovered and used from an early period onward, the overall economic, technical, and scientific role of bitumen remained small and did not extend much beyond the limits of the small number of production areas. The only exemption was in the military field, where

testimonies of fire and flame throwers using distilled petroleum are numerous. The revolutionary impact of the Drake Well in mid-nineteenth century Pennsylvania was not due to the depth reached in deep drilling, but to the fact that beforehand a thorough scientific investigation of the properties, refining methods, and possible applications of petroleum had taken place. It was this combination of scientific investigation, technical achievement, establishment of production plants, and creation of a huge demand that was responsible for the rise of the petroleum industry in the West.

See Also

► [Salt in China](#)

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Board Games in Antiquity

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Games in Ancient Egypt and the Near East

Most ancient board games are race games, where the players move pieces from an origin to a goal. The player who finishes the track first wins the game. The rules of the game can vary; they may be agreed upon between both players before a game begins. From their earliest origins, games illustrate the metaphor of armed conflicts. Therefore, fighting and hunting scenes are often present in works of art related to games.

A great variety of dice have been used to determine the movement of the pieces. Among the most ancient types are knucklebones, typically the astragalus bone of a sheep or goat, whose four unique faces meant they could be thrown to give different results. Casting sticks functioned as the principal randomizing agent in Egypt since the Predynastic period, and tetrahedral dice were popular in Mesopotamia from an early date. The origin of cubic dice remains somewhat mysterious and is probably to be found in the Indus Valley.

Game boards have been found in elaborate and humble versions, in materials ranging from gold-inlaid ivory to wood and clay, suggesting that members of all socioeconomic classes play games. Despite their popularity, the original names and rules of some ancient games remain unknown.

The human fascination for games has probably been linked to a desire to control chance since a very early date. Board games often went beyond the playful dimension, to be used for divination. The players' fate depended on the result of dice, reflecting the will of the gods. Funerary archaeology demonstrates that games occupied a specific place in the rite of passage into the hereafter.

The small size of the boards allowed one to travel with them easily. From the second millennium BCE, Egypt and the Near East shared a number of different games. The four most commonly found games in those regions, sometimes closely associated on bifacial boards, will be described here.

Mehen

The oldest known board game is the game of *mehen*, which has been found in Egyptian tombs dating to the Predynastic (3500–3000 BCE) period. Multiple boards from this time period show that it was a board in the shape of a coiled snake, with a segmented body designating the playing area. Sometimes, the form of the serpent is abstracted, particularly in the Second-Dynasty (2890–2686 BCE) examples from the necropolis at Abydos (Amélineau, 1905). The number of spaces represented on the boards varies, and no diagnostic markings have been found on any of the boards designating particular spaces on the boards. Likewise, the first known artistic representation of a board, from the Third-Dynasty (2686–2613 BCE) tomb of Hesy-Re, does not show spaces that appear to be marked in any way (Quibell, 1913). The number of spaces in the game board is not fixed and can vary greatly.

The name *mehen* first appears in an inscription in the Fourth-Dynasty (2613–2498 BCE) tomb of Prince Rahotep (Petrie, 1892). The game shares its name with the Egyptian serpent god Mehen, which, according to different cosmologies, was either an obstacle to be overcome during the soul's journey through the underworld or the protector of the sun god Ra during his daily journey through the underworld. In either case, there was a connection between this game, the serpent god, and the underworld. In the Pyramid Texts, a series of inscriptions on the walls of the Pyramids of Old Kingdom pharaohs, one of the utterances suggests a belief that attainment of the afterlife was achievable by successfully transiting the mehen game board (Piccione, 1990b).

Further connection between the game and ritual activity can be seen on tomb reliefs dating

to the Fifth (2498–2345 BCE) and Sixth Dynasties (2345–2181 BCE). In these depictions, players are shown in contexts of feasting, music, and dancing as part of the celebrations of the goddess Hathor that accompanied the funeral of the deceased. In particular, the mastaba (a type of tomb) of Idu shows the son of the deceased playing mehen against an opponent, with others playing senet around them (Simpson, 1976).

The popularity of mehen in Egypt seems to have waned during the later years of the Old Kingdom, and no boards are known after the end of the second millennium BCE. No known boards have been found dating after the Second Dynasty, though their existence can be inferred from textual references in the Fourth Dynasty and the aforementioned tomb reliefs from the Fifth and Sixth Dynasties. One tomb relief is known from the Twenty-Sixth Dynasty (672–525 BCE) that appears to depict mehen, but it is believed that this relief is a copy of an Old Kingdom original, as were other artifacts dating to that Dynasty (Piccione, 1990b).

There is some evidence that mehen may have been played outside of Egypt. In the Levant and Cyprus, flat stones with depressions arranged in a spiral pattern have been found which could reflect the spread of the game outside of its homeland (Fig. 1). Such stones have been found at Lachish and at Bab edh-Dra (Rast & Schaub, 2003; Tufnell, 1958). The most compelling evidence identifying this type of stone as games has been found in Cyprus, where the game appears on the opposite side of stones displaying three rows of ten depressions (Swiny, 1986), which probably reflects the Egyptian game of senet (see below). In contrast to Egypt, mehen appears to have enjoyed greater longevity, as mehen boards have been found dating to the latter part of the second millennium BCE. In contrast to Egypt, where all the evidence for the play of mehen is related to mortuary ritual, archaeology in Cyprus has shown that mehen was played in domestic contexts at sites such as Sotira *Kaminoudhia* and Marki *Alonia*. Evidence also suggests that mehen was played in communal areas, perhaps at feasting events, on the island.



Board Games in Antiquity, Fig. 1 Mehen game from Episkopi *Phaneromeni* in Cyprus. Late Cypriot I (1700–1450 BCE)

Many senet boards dating to the New Kingdom (1549–1077 BCE) have another game on the opposite side, known as the game of 20 squares. This game has its origins in Mesopotamia and is nearly as old as senet and mehen, though it only appeared in Egypt during the New Kingdom.

Senet

Senet, perhaps the best-known game of the ancient world, has similar origins to mehen in Predynastic Egypt and was indeed one of the longest-lived games in human history, as it is known from archaeological contexts spanning roughly 3,000 years (Fig. 2). Early examples of the game are rare and fragmentary, but it existed in its canonical form (three rows of ten spaces) by the Third Dynasty, where it appears alongside mehen in the tomb painting of Hesy-Re. The appellation “*znt*,” transliterated as senet, first appears in the tomb of Prince Rahotep and is translated as “passing,” most likely due to its strong connotation with the passing of the soul through the underworld to the afterlife, a connection which is more explicit in later periods (Kendall, 1978; Piccione, 1990b).

While senet also appears in the tomb reliefs of the Fifth and Sixth Dynasties, no complete boards are known until the Middle Kingdom (2061–1690 BCE), at which point it appears to have been the most popular game in Egypt. Its popularity increased during the New Kingdom, when it became an essential mortuary accoutrement and was included in the Book of the Dead. It was believed to be a tool in communicating with the dead, and numerous tomb reliefs from the Old Kingdom already show deceased people playing against the living. Its mortuary connotations existed in the Old Kingdom, as it was included in scenes of rituals dedicated to the goddess Hathor: the same scenes are discussed above in relation to that game (Piccione, 2007). Many texts throughout Egyptian history attest to the ability of the game to facilitate the movement of the deceased’s spirit both through the netherworld and back to the world of the living, acting as a connection between life and death (Piccione, 1990a, 2007). During the Late Period (672–332 BCE), the senet board became conceptualized as the netherworld itself, and moving pieces through the spaces actualized the passage of the player/deceased through it (Piccione, 2007, p. 60). By the New Kingdom, it was common to depict the deceased playing senet alone. It is similar to the divination seen in other games, in which the living were attempting to communicate with and influence the supernatural.

In addition to the canonical three rows of ten playing spaces, senet also has distinctive patterns of markings in some of the squares that aid in identification of archaeological examples of this game, typically limited to the final five spaces of the board. These spaces, marked with hieroglyphs indicating danger or good fortune, likely affected the play of senet (Fig. 3).

Much like mehen, senet is also known outside of Egypt from an early date. It can be attested at Early Bronze Age 2 (3000–2700 BCE) Arad in the southern Levant, where 43 boards are known (Sebbanë, 2001). All of them are flat pieces of limestone, but the manner in which the senet pattern is displayed varies: it can either be delineated with etched squares, rows of depressions, or a combination of the two methods. These games

Board Games in Antiquity,

Fig. 2 Facsimile of a painting from the Tomb of Queen Nefertari depicting the deceased playing senet. Valley of the Queens, Egypt, New Kingdom, Dynasty 19, ca. 1279–1213 BCE. Metropolitan Museum of Art, New York. Rogers Fund, 30.4.145



Board Games in Antiquity, Fig. 3 The game of 20 squares with the route of play, in (a) the third-millennium form and (b) the form in the second and first millennia BCE

appear at the site during a period of intense interaction with Egypt but disappear after the Egyptians turn their attentions elsewhere.

In Cyprus, many more senet games are known (Swiny, 1980, 1986). In fact, there are more known senet games from Cyprus (330) than from Egypt (120). Its appearance on the island is later than that of mehen and probably corresponds to more intense involvement of Egypt at the major port of Byblos, on the coast of modern

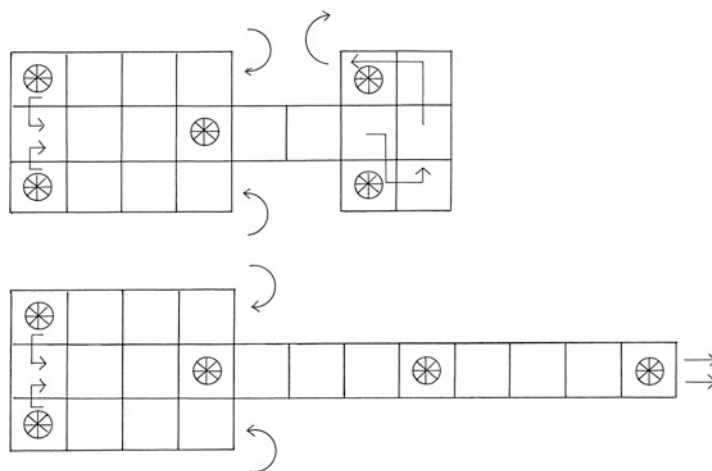
Lebanon. Once the game spread through the island, it became part of everyday life, much as mehen did, with examples found in domestic and in communal settings which may indicate feasting. Senet does seem to have been played in everyday settings in Egypt as well, as it can be found etched into limestone ostraca (a piece of stone broken off from a vase) at the Valley of the Kings, presumably cast aside by workers or artisans building the tombs there, and in pavements of ancient temples throughout Egypt.

The Game of 20 Squares

The game of 20 squares – from the number of playing squares it contains – was certainly one of the most popular games in the ancient Near East. It is also known as the Royal Game of Ur, since its most famous and earliest examples were discovered in elite tombs from the Sumerian city of Ur, in southern Iraq (Woolley, 1934, pp. 274–279, pls. 95–98). Two kinds of dice (four-sided stick dice and tetrahedrons with two marked corners) were associated with the boards at Ur, as well as seven counters for each player. The early version of the 20-square game has also been found in a funerary context, at Shahr-i Sokhta, in

Board Games in

Antiquity, Fig. 4 Senet game inscribed for Amenhotep III, reportedly from Thebes, Egypt, Dynasty 18, ca. 1390–1353 BCE. Brooklyn Museum, Charles Edwin Wilbour Fund, 49.56a-b. Creative Commons-BY



Southeastern Iran (Piperno & Salvatori, 1983). The playing squares are outlined by the coils of a snake, carved in relief on a wooden board forming a block of 4×3 squares joined by a “bridge” of two squares to a smaller block of 2×3 . Both date from the mid-third millennium BCE and attest to the cultural contacts between individuals involved in long-distance trade.

At the turn of the third to the second millennium BCE, the game of 20 squares underwent a slight change in the layout of the board: while the block of 4×3 squares was maintained, the central row now contained 12 squares without a block of 2×3 (Fig. 4). This new variant was first seen in the Kerman region in Iran (Dunn-Vaturi & Schädler, 2006, pp. 2–3, Fig. 1; Madjidzadeh, 2003, pp. 120, 197). There, illicit excavations in ancient cemeteries around Jiroft have brought to light several specimens of zoomorphic gaming boards made of chlorite (Dunn-Vaturi & Schädler, 2006, pp. 4–6, pls. 1, 2a, 3; Madjidzadeh, 2003, pp. 130–136 and 200–201). The boards appear to have never been used for playing, suggesting that they were probably intentionally produced as grave goods. This assumption is corroborated by the choice of the animals: birds of prey, snake, and scorpion. Apart from the fact that these threatening and agile creatures correspond to the competitiveness required in a race game, it seems that an apotropaic (having the power to avert evil influences) and chthonic (relating to the underworld) aspect

characterizes these animals, which also transcend the human sphere, serving as a link between the earth and the underworld (snake, scorpion) and the heavens (bird), respectively.

The same period witnessed the spread of the game westward and was found in a playing context in the form of graffiti on the courtyard pavement of the Amorite palace at Mari in Syria (Parrot, 1958, pp. 13, 46–47, 182, 247, 258). The second millennium BCE was a time of increased intercultural interaction in the Eastern Mediterranean, promoted through the exchange and use of elite artifacts like game boxes manufactured of expensive materials such as ivory and decorated in the International Style. The game of 20 squares was introduced to Egypt during the seventeenth century BCE and is attested there from the Seventeenth to the mid-Twentieth Dynasties. Most of the time, the playing grid is on the upper face of a game box with the Egyptian senet game on the opposite side. While many of these games were found in graves, one example from the artisans’ village at Deir el-Medina demonstrates that it was played by Egyptians and not restricted to a funerary item. The game of 20 squares has a longer history in the Near East than in Egypt. It was in vogue until the mid-first millennium BCE in Syria–Palestine and Mesopotamia, the region to which it was native. More than 100 examples in total are known to date (de Voogt, Dunn-Vaturi, & Eerkens, 2013, p. 1718, Fig. 1, Table 1).



Board Games in Antiquity, Fig. 5 Game box for playing senet and 20 squares, Thebes, el-Asasif, Egypt, Dynasty 17-early Dynasty 18, ca. 1635–1458 BC-E. Metropolitan Museum of Art, New York. Rogers Fund, 1916, 16.10.475a

It is generally assumed that the four squares on each side of the board served as entry squares for the counters. Consequently, the counters of each player met only in the central row where they could be captured and returned to their starting points. The aim of the game seems to have been to move one's counters down that central line to the final square and off the board (Fig. 5). Specially marked squares, found on a number of boards, allow the player certain privileges, like safety from being captured or another throw. These special marks, a cross, a rosette, or an inscription, are placed four squares distant from each other. A late-Babylonian cuneiform tablet dating to 177–176 BCE provides significant detail on how the game proceeds (Finkel, 2007). The game is called “a pack of dogs,” whereas the counters (five on each side) bear the names of birds. They are moved according to the throw of two knucklebones, and special results are needed to enter each of the bird counters into the game. The obverse of the tablet is inscribed with a zodiacal divinatory diagram, and one would be tempted to interpret the five birds of the game and its central row of 12 squares in an astrological context. The foretelling aspect of the game of 20 squares is corroborated by liver-shaped boards from the Levant, which refer to hepatoscopy, divination by the liver of an animal or bird (Becker, 2007; Finkel, 2007, pp. 25–26; Meyer, 1982, pp. 65–69).



Board Games in Antiquity, Fig. 6 Game of Hounds and Jackals, Thebes, el-Asasif, Egypt, Middle Kingdom, Dynasty 12, reign of Amenemhat IV, ca. 1814–1805 BC-E. Metropolitan Museum of Art, New York. Purchase, Edward S. Harkness Gift, 1926, 26.7.1287a-k

The Game of 58 Holes

The modern name of this game refers to two symmetrical circuits of 29 perforations, each one to be completed by a player, thus making a total of 58 holes on the board. Howard Carter named the same game “Hounds contra Jackals” (Carnarvon & Carter, 1912) after a unique ivory set excavated in Thebes in 1910 (Fig. 6). Since its discovery, this particular board has become iconic due not only to its delicate nature but also because it is the only example retaining its pegs: five carved in the form of a hound's head and five with a jackal's head. The most likely route of play starts at the holes next to the palm tree fronds and continues down the center of the board, around the outer edge, and up to the thirtieth and finish hole. The progress of the race was affected by links between the holes and hieroglyphs marking special holes. The links could be shortcuts or penalties, like in the modern game “Snakes and Ladders,” with a playing piece sent forward or backward. From hole 10 onward, every fifth hole is emphasized. It is assumed that the hieroglyph nefer (“good” or “beautiful”), marked on two positions, was beneficial to players that landed on them, similar to square 26 on senet boards. The goal is a larger hole surrounded by the

hieroglyph shen that may have meant “end of the track.” The player who first reached this sign, also interpreted as “eternity,” was possibly believed to have achieved success in his quest for immortality.

Playing accessories, as well as objects imitating games such as pendants, are linked to the deceased’s journey to the afterlife and thus often found among burial goods. The jackal deity Anubis was responsible for the mummification and protection of the dead through the netherworld. His connection to funerary devices in the form of jackal-headed playing pieces is therefore relevant (DuQuesnes, 2002, pp. 157–158, no. 72). Moreover, the choice of animals known for their quickness as playing pieces is appropriate for a race game. Anubis pegs could perform the necessary ritual on the board which would symbolize the deceased’s body. Connections between boards and human representations are made through shapes or anatomical details, such as the eyes, and support the idea of rebirth. Sophie Erdős suggests that the holes on the body-shaped board had to be passed through by the pegs to allow the deceased to be born again (Erdős, 1986, pp. 118–119).

Carl Schuster includes the game of Hounds and Jackals in his “rebirth gaming board” category. Schuster makes the comparison between the paths to complete on our game and the Indian game called “Ladder of Deliverance” (an earlier form of “Snakes and Ladders”), whose compartments symbolize various reincarnations. Furthermore, Schuster compares the shield-shaped boards of 58 holes to a drawing made by the Malekulans of Vanuatu: “The Malekulan artist first punched a framework of dots in the sand, then drew an unbroken, never-ending line around these dots to form a figure identified as, simultaneously, Human Ancestor and Cosmic Turtle. . . . In many ancient and tribal societies, the human body served as a genealogical chart. Joint-marks represented the souls of primary ancestors. To achieve reunion with one’s ancestry (and thereby qualify for rebirth), a continuous line connecting each joint might be drawn to form an image of the First One. Or a sequence could be followed on a gaming board, with peg holes equivalent to the

guide dots of sand drawings. The immediate goal was to ‘re-member the First One’” (Schuster & Carpenter, 1996, pp. 280, 288).

The archaeological evidence for the game points to its origin in Egypt at the turn of the second millennium BCE. In contrast to senet, played for more than 3,000 years, the game of Hounds and Jackals is almost exclusively attested during the Middle Kingdom (2030–1640 BCE) within Egypt. The increasing importance of senet in funerary rituals during the New Kingdom may explain this phenomenon. Military campaigns and trade relations facilitated the game’s spread from Nubia to Central Anatolia very quickly after its invention. The game was popular throughout the Near East, including the Iranian plateau, until the mid-first millennium BCE. There are about 70 known examples of this game (de Voogt et al., 2013, pp. 1718–1719, Fig. 3, Table 2). Other methods were introduced on the playing surface to provide linkage and indicate special holes (size, color, motif). Rosettes on Near Eastern boards are the equivalent of the nefer hieroglyph which brought promotion to the player. During the Iron Age at the turn of the second to the first millennium BCE, Iranian boards (now in the British Museum and the Musée du Louvre) show contrasting links between the holes that cross from side to side. This element changed the nature of the game, which became more complex and increased interaction between the players.

Games in Asia, the Americas, and Africa

Other board games are known in India and China but are less well documented than those from the Eastern Mediterranean. Some of these games differ from those discussed above, as they are not all race games. There is suspicion that the game of 20 squares may have originated in India, based on fragmentary boards found at Lothal (Rao, 1985) and Mohenjo-Daro (Mackay, 1938), dating to the third millennium BCE. Not enough is known about the context of these boards to be able to determine what their roles in divination were, but later references to games in Hindu literature

suggest relationships between games, astronomy, and cosmology in early Hindu belief (Soar, 2007). In China, the game known as liubo is attested from tombs dating to the fourth century BCE (Mackenzie, 2004), but little is known about its role in society.

The game of patolli was known in ancient Mesoamerica from the days of Teotihuacan (possibly as early as 200 BCE) until the time of the Spanish Conquest, when the Spanish chroniclers documented it. Much less is known about this game than those of the Old World antiquity, as there is little reference to it in the extant writings of peoples of Mesoamerica, but it has been found at many sites throughout the region and awaits further study.

Patolli appears in a number of the Aztec codices collected by the Spanish and usually depicts two players around a board but with little other information about the game. The boards depicted in the codices show an "X"-shaped game, with each arc of the X containing two rows of squares which vary in number. These boards differ from the arrangement of spaces in the games which have been found by archaeologists, but nevertheless, it seems most likely that these patterns were indeed some kind of game (Swezey & Bittman, 1983). Most of the examples found consist of a circuit of squares, arranged in a square pattern, with two rows of squares crossing in the middle. There are variations to this pattern, but the variations seem to be merely elaborated versions of the basic pattern, rather than a completely different game (Gallegos Gomora, 1994).

Aside from those depicted in the codices, the patolli boards that have been found have exclusively been engraved into stone pavements or architectural features, commonly among the patio groups and temples known throughout the pre-Columbian Mesoamerica. While these games await further study to determine patterns in when and where they were played, some indications suggest that they were played by those who were observing solar or astronomical events or those who were taking part in other rituals, as evidenced by their appearance on top of the Temple of the Hieroglyphic Stairway at Naranjo in Guatemala (Morales & Fialko, 2010).

In Africa, mancala games are well documented from ethnographic and historic sources, but little is known about the games on the continent from archaeological contexts. This is likely due to the fact that most mancala games are either made of wood or holes scooped out of the dirt (de Voogt, 1997) and thus not preserved archaeologically. In some places, artificial depressions are found in rock outcroppings that could be games, but they are difficult to identify as such and almost impossible to date. These difficulties are also apparent in other regions, where patterns of squares or depressions have been found. The best ways to determine whether a pattern of squares or depressions are a game is if they are arranged in a pattern unique to a certain game (such as 20 squares or 58 holes), if they are accompanied by another known game (such as mehen and senet on Cyprus), or if they can be connected chronologically to a known modern or historical game (such as liubo in China or patolli in Mesoamerica). There were likely more games in the ancient world than are currently known, but knowledge of them is hindered by preservation and identification issues.

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Boats in Goa

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Goa is a small state on the west coast of India with an area of 3,701 km². Its geographic position is marked by 15048'00"N and 14053'54"N Latitude and 74020'13"E and 73040'33"E Longitude. Major rivers, such as Zuari and Mandovi, and minor rivers, such as Sal, Tiracol, and Chapora, flow in Goa. Goa shares its boundary with Maharashtra state in the north, in the South with the northern part of Karnataka, in the east with the Sahyadri mountain range, and in the west with the Arabian Sea. Sandy beaches separated by rocky headlands, cliffs, and broad estuaries have fashioned the coastline of Goa. Such a geography and geomorphology have contributed greatly to the development of a boatbuilding



Boats in Goa, Fig. 1 Boat motifs portrayed on ancient memorial stones found in Goa (Photo: A. S. Gaur, 2007)

industry and distribution of different types of traditional boats.

Traditional folk songs of Goa often mention *Vodem* which means boat. There are boat motifs portrayed on ancient memorial stones (Fig. 1) which suggests that the people of Goa were aware of the art of boatbuilding from ancient times (Gaur & Kerkar, 2007; Kamat, 2008). The people of Goa who have continued their profession of fishing and preserved their traditional knowledge about boatbuilding till today are locally known as “Kharvi” (Fig. 2).

Traditional Boatbuilding

Before we understand how traditional boats in Goa are built, it is important to know the different raw materials required to build boats and the various stages involved in the boatbuilding tradition.

Raw Materials

The availability of raw material defines the flourishing status of the boatbuilding industry. The most used raw material for building traditional boats worldwide is timber.

The boatbuilding industry of Goa, traditionally, is also entirely dependent on timber. Goa, being a part of the Sahyadris and Western Ghats, is covered with forest which provides an excellent source of raw material. Boatbuilders get this timber from local sawmills who procure the wood from local forests.

Apart from timber, other raw materials are used. For fastening and sewing, coir ropes or nylon ropes, wooden pegs (*guddi*) (Fig. 3), copper nails, copper rods, stainless steel nuts and bolts, cotton, and cashew oil (*dig*) are required. For caulking a special type of glue is prepared called *cari* by local boatbuilders using local ingredients (Fig. 4) (see Shaikh, 2009, pp. 27, for ingredients and preparation). In order to make sails a cloth called *cori elephant* (a type of cotton cloth) is used. Nylon or cotton rope (*beed*) is used for tying sails. Stone and iron material is used to make anchors.

Tools like hammers, different sizes of saws, and various types of chisels are used (Fig. 5). All the raw materials and tools are locally available in the market except *cari*.

Stages of Boatbuilding

Traditional boatbuilders generally follow systematic stages for building a complex structure (Rajamanickam, 2004).

The boatbuilding process goes through eight different stages.

Selection of Timber

Selection of timber is the first and most important stage. Boatbuilders never compromise while selecting timber on its quality and size as the entire construction depends on it. There is a saying that “the older the timber is, the best it is for its quality”; hence the old is gold. The oldest and best-quality timber well known for its strength and buoyancy is a preferred choice for most Goan boatbuilders. They mostly prefer mango wood (*Mangifera indica*). Jackfruit



Boats in Goa, Fig. 2 “Kharvis,” a fishing community of Goa (Photo: Z. A. Shaikh)



Boats in Goa, Fig. 3 Wooden pegs used for pegging holes made for sewing (Photo: Z. A. Shaikh)

(*Artocarpus integrifolia*) and *Malti* or *Malat* (*Aganosma caryophyllata*) are other preferred timbers. While selecting timber the size of the tree plays a very important role, especially in the

case of dugouts. The size of timber selection depends upon the size of the boat to be built.

Cutting of Timber

Once the timber is selected, it has to be cut into the required shape to form a boat. Nowadays timbers are brought after cutting from the sawmills but traditionally they were cut by saws on a temporary stand (Fig. 6). The bark is scraped with the help of a chisel (*tasni*) and is given a rough square or rectangular shape. This then helps to cut the required size planks required to build the boat or in the case of a dugout the timber is manually dug with a chisel. To cut timber of the required size or to achieve the same sizes of plank marking to cut planks is done with the help of a thread having a coat of charcoal powder, which leaves an impression. This mark is called “level marking” which helps to cut straight timber of equal size.

Seasoning

Traditional boatbuilders place timber and planks shaped from it in a muddy water or backwater for a week, 15 days, or a month depending upon the quality of the timber in the third stage of boatbuilding, seasoning. This is done, as it is believed by

Boats in Goa, Fig. 4 Cari
a special type of glue
prepared for caulking
(Photo: Z. A. Shaikh)



**Boats in Goa,
Fig. 5** Tools required for
building traditional boats
(Photo: Z. A. Shaikh)



traditional boatbuilders, to increase durability of the timber and to ease the process of bending planks or scooping the timber to build dugout boats. It is also believed that this makes timber stronger and enhances its resistance against wood borers.

After some days of seasoning, when the timber is ready to use, it is removed from the water and cleaned. Care is taken that the timber after seasoning is not exposed to direct sunlight. This stops the timber from drying and developing cracks which would also make it difficult to scoop it to build a dugout boat. Under soggy conditions digging can be done smoothly and helps to give the proper shape required to build a dugout boat or to give a bend or shape to planks.

Bending Process

After seasoning, the timber is ready to be shaped. In order to form the hull of a boat, planks need to

be bent. One can mostly notice such bent planks at stem and stern side of the boat where the curve shape of the boat is highest (Fig. 7). In Goa this is done by trial and error. First, the exact dimensions of planks are cut. Second, oil locally called kadu oil is applied at the portion of the plank where curvature is needed and the plank is placed above the fire on a temporary stand in such a manner that the distance between the plank and fire is maintained in order to avoid burning. Once the plank is heated on both the sides it is placed where it is required to be fixed and is fastened.

Planking

Planking is a process of adding planks to the boat to extend its size. In Goa, most boats are made of dugouts and planks are added to extend them (see Fig. 22). Depending upon the size of the

Boats in Goa,

Fig. 6 Cutting timber on a temporary stand (Photo: Z. A. Shaikh)



B

Boats in Goa,

Fig. 7 Showing the amount of plank bent in order to form the shape of the hull (Photo: Z. A. Shaikh)



boat, one to three planks are added. Planks are joined either edge to edge or by using an L or V or/shape groove. The edge to edge joint is used to join planks one beside the other that form a strake, while the latter is used to join planks one above the other. While joining plank edge to edge, one plank is joined with the other. In V- or

L-shape joints, male V or L or/groove is made on one plank and female V or L or/groove is made on the other plank; they perfectly fit with each other (Fig. 8). Sometime complex joints are used such as shown in Fig. 9. Such joining of planks seems to check seepage of water and give excellent strength to planks against detaching.

Boats in Goa,

Fig. 8 Male and female V groove joining of planks
 (Photo: Z. A. Shaikh)

**Boats in Goa,**

Fig. 9 Joinery method used to join two planks together to form a strake of plank boat (Photo: Z. A. Shaikh)

**Fastening**

There are two ways that boatbuilders of Goa use to fasten boats: sewing and nailing.

Sewing Sewing is a process by which the planks of boats are fastened by sewing mostly with coir or nylon ropes. Two persons undertake the sewing process: one sitting inside and the other outside the boat. The sewing process starts by drilling holes at the edge of the planks. The distance between each hole is approximately 8 cm. The person sitting inside the boat passes the rope through the holes to the person outside, who pulls the rope very tightly with the help of a wooden stick and passes it to the inside person. The stitch appears X shaped from the inner side (Fig. 10) and I I I I pattern from outer side (Fig. 11). After sewing the holes are packed with wooden pegs.

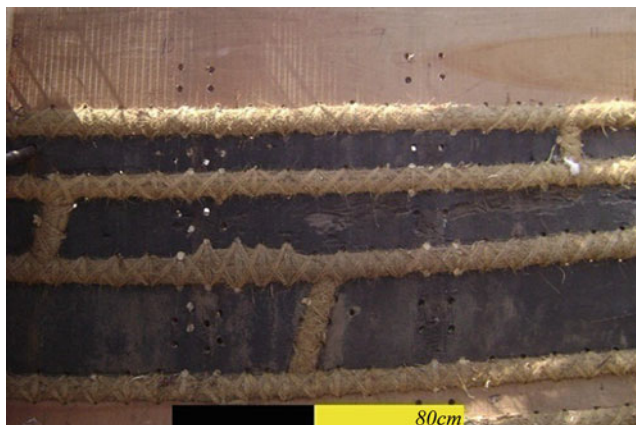
Nailing Nailing is a process by which the planks of boats are fastened by copper or stainless steel nails (Fig. 12). There are very few traditional boats that have been fastened in this way; they are mostly boats that are plank built and are used for river traffic. In this case the planks are joined one above the other by/groove so that two planks meet each other in such a way that they can be fastened together by nailing. The process starts by drilling the hole at the edges of the plank and nailing along the strake with the help of a hammer.

Caulking

Caulking is a process by which boats are made waterproof in order to avoid any leakage. It is done while fastening planks as well as after fastening them. While fastening planks, caulking is

Boats in Goa,

Fig. 10 The inner side of the boat where stitch appears X shaped (Photo: Z. A. Shaikh)



B

Boats in Goa,

Fig. 11 The inner side of the boat where stitch appears I I I I shaped (Photo: Z. A. Shaikh)

**Boats in Goa,**

Fig. 12 Plank boat fastened by copper nails (Photo: Z. A. Shaikh)





Boats in Goa, Fig. 13 Illustrating caulking while fastening or sewing the plank boat (Photo: Z. A. Shaikh)

done with the help of cari or tar and cotton. Before joining the planks, cari is applied on the edges of planks and cotton is placed on top of cari and then the planks are placed against each other, ready for sewing. The gap between the two planks is filled with cotton and secured with the help of tar (*dambar*). This is then covered with dried coir and coir rope and sewn (Fig. 13). Such caulking acts as a barrier for any seepage of water inside the boat through the little space that might have been caused due to any uneven surface at the edges of planks left during joining.

Caulking of planks is also done after fastening planks or once the entire boat is built. This is done by applying cashew oil (*dig*) outside of the boat. If there is any hole or leakage noticed, it is filled with *lambi*. Lambi is a type of glue prepared by local carpenters by mixing cari and *chunnam* (calcium carbonate) together that act as a filler.

Outside Treatment

Outside treatment is given to a boat in order to avoid damage to the timber by wood borers and to increase the longevity of the boat. Such treatment also serves as secondary caulking. It is done by

applying oils such as Kadu oil or cashew oil on the inside as well as the outside of the boat (Fig. 14). This is applied regularly after 15 days or 1 month or 3 months. In Goa November and December are the months preferred for this treatment. Nowadays varnish paint is also applied. Two or three strips of different colors are painted, especially on the bow side. This helps in identifying the owner of the boat. A fiber coat is applied to most of the boats as it remains permanent and prevents damage by borers.

Boat Types and Building Techniques

There are several types of boats which are generally classified on the basis of their construction pattern, size, and shape (McGrail, 1996; Rajamanickam, 2004). Traditional boats in Goa consist of the following types.

Skin Boats (Coracle)

Skin boats are locally called *harigolu*. They (Figs. 15 and 16) are made of bamboo strips or canes. Bamboo stripes are woven together to

Boats in Goa,
Fig. 14 Outside treatment
given to boat by applying
cashew oil (Photo:
Z. A. Shaikh)



B

Boats in Goa,
Fig. 15 Side view of the
skin boat (Photo:
Z. A. Shaikh)



Boats in Goa,
Fig. 16 Inside view of the
skin boat (Photo:
Z. A. Shaikh)



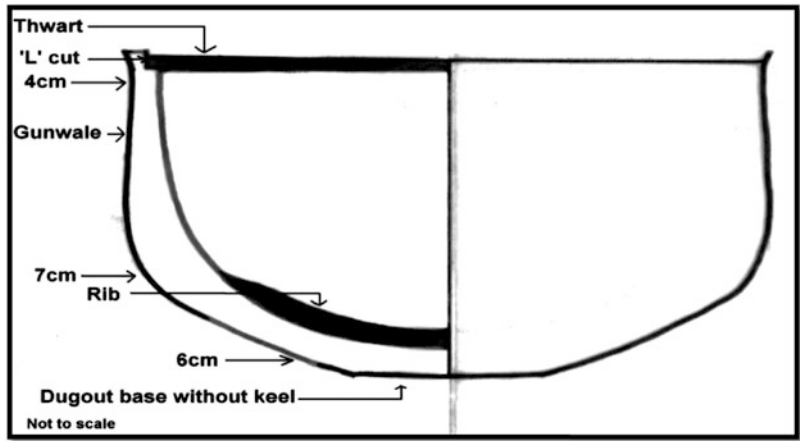
Boats in Goa,

Fig. 17 Dugout without outrigger as seen along the river Mandovi, Goa (Photo: Z. A. Shaikh)



Boats in Goa,

Fig. 18 Diagram illustrating a proportionate thickness maintained along the gunwale in order to maintain the buoyancy of the boat while in water (Illustration: Z. A. Shaikh, 2011)



form a circular shape, and thus they appear like a wide circular basket. Their height varies from 30 to 40 cm and width from 1.5 to 2 m. They are then waterproofed from outside by covering them with plastic or polythene sheets. A coat of tar is applied on top of a sheet which checks water seepage into the coracle. These boats are very flexible and light weight, and as a result they can be carried to other places. They are propelled by paddles. Such boats are mostly used for fishing in calm inland waters.

Dugouts (Logboats)

Dugouts or logboats are locally known as *ponjal*, *ponyao*, or *vodem*. These boats can be subdivided into two types: dugout without outriggers and dugout with outriggers. Outrigger is an additional component provided to enhance balancing.

Dugout Without Outriggers

Dugouts without outriggers (Fig. 17) are built by hollowing a single log of timber with the help of a chisel. They are mostly built of mango timber that is seasoned in the backwater. Once ready, the timber is given a rough shape and hollowed by scooping until the required shape is achieved. While scooping, boatbuilders see to it that there is a proportionate thickness maintained along the gunwale in order to maintain the buoyancy of the boat (Fig. 18).

After scooping, the log is made smooth with adzes and chisels. Sometimes frames are carved while scooping or else added afterwards for strengthening. Thwarts are fixed to gunwales in a groove on the gunwale plank by making L-shape angles on four corners and tying with nylon rope (Fig. 19). These thwarts provide

space for sitting. After completion of construction, cashew oil is applied to the entire boat. To build this type of boat, it takes approximately 20–30 days.

These boats have an elongated look with V-shape vertical cross sections at the bow and stern and U-shape vertical cross sections in the middle. Their bottom is usually flat and thus mostly used in calm waters for inland fishing. Oars propel such boats.



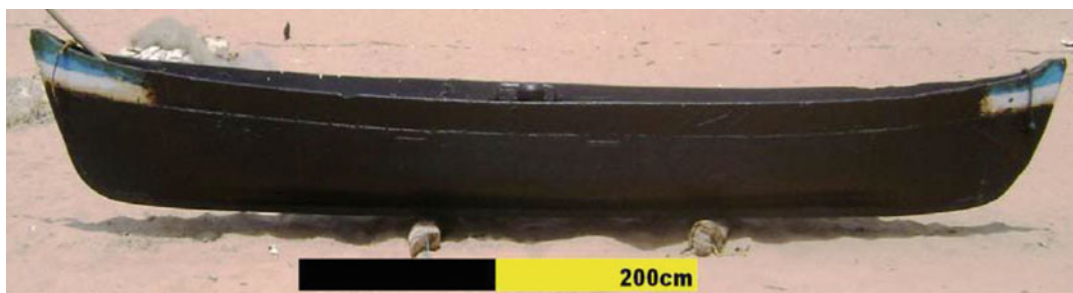
Boats in Goa, Fig. 19 Fixing a thwart on the gunwale by making L-shape joints on four corners of the thwart (Photo: Z. A. Shaikh)

Dugouts with Outriggers

These boats are built in the same way as dugouts without outrigger. There is no difference except that in these boats the outrigger is fixed and sometimes a keel is added. These types of boats make them seaworthy and are mostly used in estuaries or near shore zones with an additional balancing aid provided by an outrigger. The outrigger is made up of a log, shaped as a boat, and attached to the boat with the help of two bamboos (see Fig. 22 where extended boat has outriggers attached).

Extended Dugouts

There are three subtypes of extended dugouts. They are extended dugouts without outriggers with 1 stroke (Figs. 20 and 21), extended dugouts with outriggers having one to three strokes (Figs. 22 and 23), and extended dugout with outriggers having mostly three strokes locally called Rampon boats (Figs. 24 and 25).



Boats in Goa, Fig. 20 Side view of an extended dugout without outrigger with 1 stroke (Photo: Z. A. Shaikh)



Boats in Goa, Fig. 21 Top view of an extended dugout without outrigger with 1 stroke (Photo: Z. A. Shaikh)



Boats in Goa, Fig. 22 Side view of an extended dugout with outrigger having 1 to 3 strakes (Photo: Z. A. Shaikh)



Boats in Goa, Fig. 23 Top view of an extended dugout with outrigger having 1 to 3 strakes (Photo: Z. A. Shaikh)

Extended Dugouts Without and With Outriggers

Extended dugouts without outriggers (Figs. 20 and 21) and with outriggers (Figs. 22 and 23) are locally called *vodem* or *hodi*. These types of boats are built by fixing one or two rows of planks

(strakes) on either side of a dugout boat along the gunwale. They go through the same process as building a dugout. Once the dugout is built, it is extended from both sides by placing one to three strakes.

Strakes are joined along the gunwales by giving a slope shape (/) cut to the upper edge of the gunwale of the dugout and to the lower edge of the plank to be fitted. The planks that form a strake are joined to each other by male and female V grooves. Strakes are mostly fastened by sewing. While planking, caulking is also carried out. This means that while joining the planks *cari* (glue) is applied on the edges of planks and cotton is smeared between the planks to be joined and sewed together.

These boats are sewed together mostly with nylon ropes, but some with coir rope, through the holes, opposite to each other, which are made at a distance of 6–8 cm between two strakes and at a distance of 19–20 cm on each plank, beside each other, along the edges of a strake. Wooden pegs used to fix the holes made for stitching are dipped into cashew oil before pegging.

Once the outer shell of the hull is built, frames of U shape are added with copper rabbet. They are mostly carved and thus made of a single timber. Before the topmost strake is fixed, thwarts (horizontal plank within the hull) are fixed between the topmost strake and the following strake. They provide horizontal support to the



B

Boats in Goa, Fig. 24 Side view of an extended dugout with outrigger having mostly 3 strakes locally called Rampon boat (Photo: Z. A. Shaikh)



Boats in Goa, Fig. 25 Top view of an extended dugout with outrigger having mostly 3 strakes (Photo: Z. A. Shaikh)

hull. Thwarts are basically used for seating by crew members.

Finally the keel is added at the base. The keel is prominent at the base of the dugout; it merges when it reaches the bow and stern. If the keel is made of 2 timbers, it is joined by making male and female V grooves. Once the keel is fixed, cashew oil is applied to the entire boat to protect it from woodborers as an outside treatment. The construction of this boat takes 1 or 2 months depending upon the size of boat.

These boats are mostly used offshore and at very few places along the riverside. They are propelled by oars and sails, but now in some localities motorized engines and rudders are

used, mostly for sea fishing. At some places these are used for bringing firewood from local islands and for ferrying.

Extended Dugouts with Outriggers (Three to Five Strakes) Rampon Boat

The Rampon-type boats (Figs. 24 and 25) are known as *Ramponachem vodem*, and they are differentiated from the above two types not by their construction but by their size, hull shape, and use. These boats are built by extending dugout boats which are much narrower than the dugouts used to build the abovementioned boats. These types of boats are found along every beach of Goa and are only used for fishing locally



Boats in Goa, Fig. 26 Top view of plank-built boat (Photo: Z. A. Shaikh)

called Rampon fishing. The difference between an extended dugout with one to three strakes and a Rampon boat is that the former has an almost U-shape cross section and the latter almost a V shape. That means Rampon boats are narrow at the bottom and wide at the top. This provides extra space to keep huge nets.

The building technique of this boat is similar to that of extended boats. Generally mango wood is used for construction. Once timber is selected, it is seasoned and scooped. The dugouts which are used as a base for these types of boats are narrow. In these boats two to five rows of planks are joined on the dugout. While joining planks, caulking is done on both the inside and outside. The planks are fastened by sewing with coir rope.

Frames, made of two pieces of timber, are fitted at two places where the outrigger posts are fastened. Thwarts are also added and are fastened between the topmost and the following strake. Once the outer hull is ready, a keel made up of three pieces of timber is fitted by making male and female V grooves and sewing them with coir or nylon rope. An outrigger made of bamboo and heavy timber is added to the boat. Dig is applied to the entire boat. These are mostly used for nearshore fishing. These are propelled by oars but sometimes a rudder is attached to them. This boat takes almost 1 or 1½ month for its construction.

Plank-Built Boats

These boats are locally called *Revechem hode* (Figs. 26 and 27). There are two types of plank-built boats: sewn and nailed plank-built boats. These boats are mostly made of Malat timber. Two to four persons are involved in the construction. First, the keel is laid. Three pieces of timber are used which serve as the main keel, bow keel, and stern keel. The stern keel and bow keel joined to the main keel by using a joinery or interlocked method as shown in Fig. 28. Such interlocking helps against the dislodging of bow or stern keel from the main keel.

After laying the keel, six to eight rows of strakes are added to form an outer shell of the hull. These strakes are added in such a way that the vertical section in the middle becomes U shaped whereas the bow and stern become V shaped. Planks are fastened either by sewing or by nailing. Frames are made of three pieces of timber and are joined by using various joineries as shown in Fig. 29. In the middle an iron rod is provided horizontally for strengthening the hull. Frames are fixed at 120 cm distance and fastened with coir rope. Once frames are fastened, thwarts are added with coir ropes at varied intervals. The gap between bow and first thwart is about approximately 332 cm, and the distance between other thwarts to the stern is approximately 120 cm. A platform is created between bow and the first

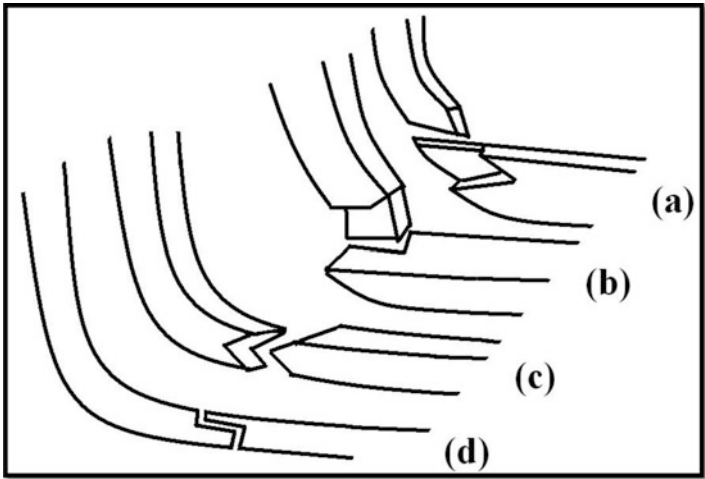


Boats in Goa, Fig. 27 Side view of plank-built boat (Photo: Z. A. Shaikh)

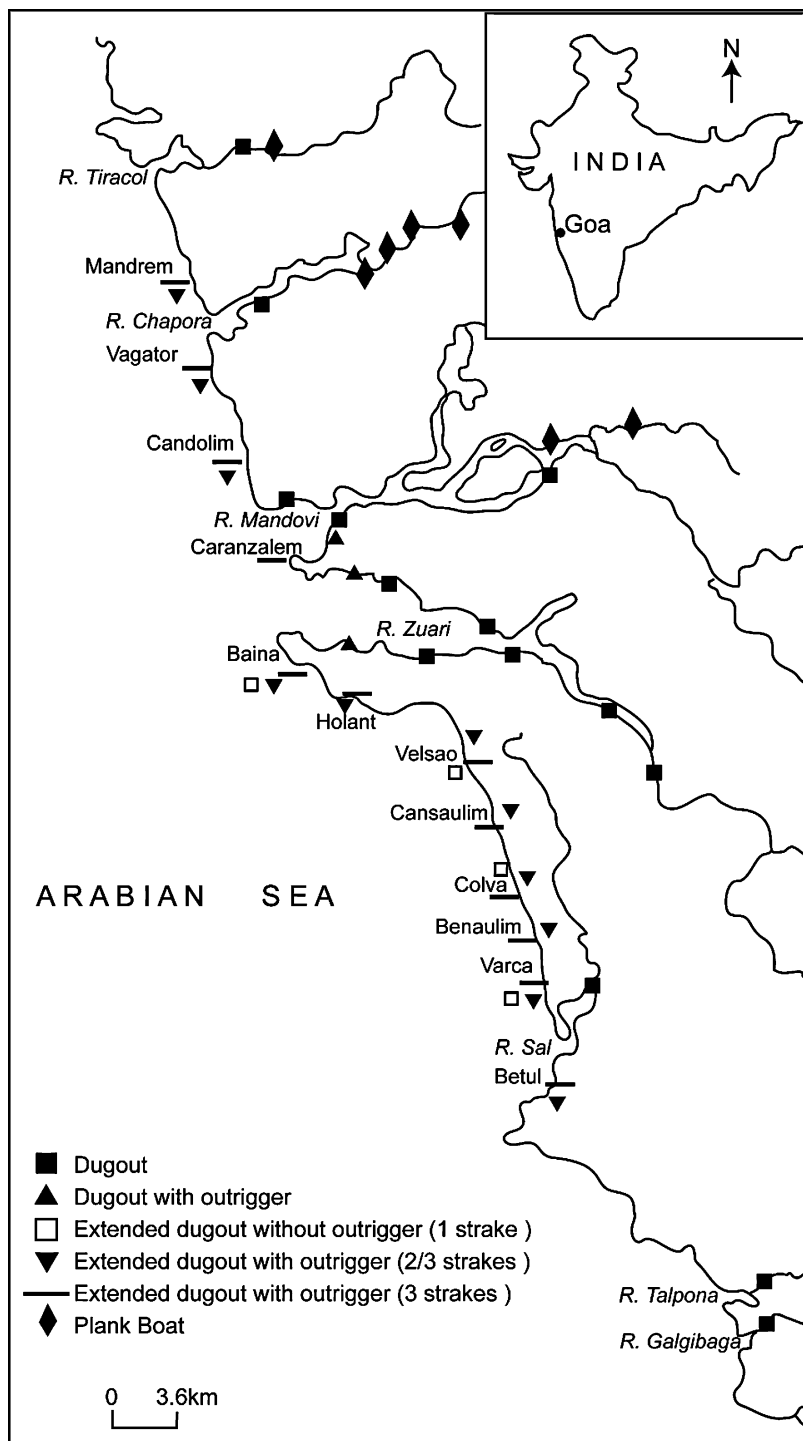
Boats in Goa, Fig. 28 Illustrating a joinery or interlocked method used to join stem and stern keel to the main keel (Photo: Z. A. Shaikh)



Boats in Goa, Fig. 29 Illustrating various joinery methods used to join frames to the plank boats (Photo: Z. A. Shaikh, 2012)



Boats in Goa,
Fig. 30 Illustrating
 distribution of boats in Goa
 (Photo: Z. A. Shaikh, 2011)





Boats in Goa, Fig. 31 Terms used for Different parts of boat (Photo: Z. A. Shaikh)

thwart and the stern and the last thwart where steersmen called *tandel* can sit. Cashew oil is applied to the entire boat.

A rudder is added at the stern of the boat. Since these boats are used only for short distances to carry river sand, they are not operated by oars or machines. Long bamboo sticks are used as poles, and sometimes sails made of plastic sheets are used. It takes almost 1½ or 2 months to build this boat.

Distribution of Traditional Boats of Goa

Geographical features and oceanographic and seabed conditions determine the distribution of traditional crafts (Fig. 30). In Goa the most dominated traditional boat is the Rampon boat. Dugouts without outriggers are found mostly along the major rivers and their tributaries, and dugouts with outriggers are found all along the estuaries, coastline, and in rivers where the water is comparatively rough with high currents. Extended boats without outriggers are found mostly along the beaches of Goa which are engaged in minor fishing. Extended boats with outriggers having two or three (2/3) strakes are found all along the Goa coast and are suitable for long-distance sea fishing. Sewn plank-built boats are found mostly along the rivers.

Different types of traditional boats have been observed along the coast of Goa but Rampon stands as a unique type in the history of boatbuilding technology. The traditional boatbuilding industry is strongly backed by the basic knowledge of local craftsmanship which is passed on from father to son. Boats in Goa, therefore, are a living heritage that can provide an important insight into the ancient boatbuilding technology (Fig. 31).

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Boats in Indonesia

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The presence of boats, or the prahu, in Indonesia is as old as human existence in the archipelago. When early humans inhabited the caves, boats were part of their lives. Some of those caves illustrate prehistoric boats that may have been used by those who painted them or perhaps by their ancestors of several prior generations, the Australo-Melanesians who migrated from Sundaland to Wallacea, the islands beyond, in search of new livelihoods. There is a report of a boat painting in caves of the Little Kei Island in eastern Indonesia. Reproduction of the cave imprint presented by Intan (1998) shows the boat as a dugout with additional structure and projecting bows. This painting resembles the boat painting with pictures of men, animals, and the sun along with pictures of long boats called *kora-kora* found in East Timor reported by Ruy Cinatti in 1963. All those boats were single-bodied dugout canoes without outriggers, although some of them show additional construction for poles and sails or other strengthening structures (Fig. 1).

Outrigger canoes are absent from cave paintings. The outrigger boat technology is associated with the second wave of migration of Austronesians from Taiwan to Indonesia circa 2000 BCE, who brought more advanced technology than the Lapita civilization had in the eastern part of the archipelago. They might have started life in pillared houses above sea level or on their stable boats that roamed the waters before they reached Madagascar in the ninth century and spread to Polynesia until they reached Hawaii and New Zealand in the tenth century.

From the early centuries of the first millennium, the Strait of Malacca, the only passage that connected the West and the East at that time, witnessed the passing of foreign ships. Trading and envoy sending between China and India,



Boats in Indonesia, Fig. 1 A prahu painting on a cave wall in Ohoidertavun Village in Lesser Kei Island (Intan, 1998)

Persia, Arabia, and Rome made the Strait a busy center of traffic. The latest archaeological findings in many places along the Strait of Malacca shipping lanes and Java Sea affirm this. Chinese historians wrote about the sea-going vessels known as *Kunlun-po* in the third century. The ships of the *Kunlun* are described as extending to 200 ft in length and standing out of the water up to 20 ft equipped with up to four obliquely mounted sails. The presence of foreign boat technologies is very influential to the development of indigenous boats in the archipelago even to this day.

The oldest evidence of outrigger boats is preserved on the impressive reliefs of the eighth-century Borobudur Temple. However, the earliest written description is found in the fifteenth-century *La Galigo* cycle, the world's longest epic manuscript written in the royal court of the Bugis-speaking Luwu Kingdom. The boats are described as aristocratic boats used in adventures and wars to conquer neighboring states. A story in the *La Galigo* that narrates the creation process of the mythical boat of the protagonist by "godly creation" indicates that the boat's body consisted only of a large tree that is hollowed out, a dugout boat. Further detailed descriptions say that they were ocean-going outrigger boats with a deckhouse structure, tripod mast, squared sails, and lateral rudder. Borobudur's ocean-going outrigger ships with additional side planks above the outrigger level were certainly dugout boats because only dugout boats with outriggers to balance because of breadth limitation restricted by the diameter of the wood log could have been used. And the side

Boats in Indonesia,

Fig. 2 A relief of a sea-going outriggered ship on the wall of Borobudur Temple



planks formed the upper structure to increase seaworthiness and thus carrying capacity. The tripod mast construction on a La Galigo boat is like the Borobudur ship but with additional technical details such as that their masts recline in the off-sail state. Borobudur reliefs were permanent poles with ladders to climb. This and the addition of the superstructure indicate that Borobudur boats were bigger than the La Galigo boats (Fig. 2).

Interestingly, the kingdom of Majapahit in the book of *Negarakertagama* written by Prapanca in 1364 claimed all known states in Sulawesi as its vassals. There are two possibilities as to what type of boat was used by Gadjahmada, the prime minister and commanding general, in conquering the eastern archipelago. It is not certain whether the fleet utilized the Borobudur boat technology or the plank boat technology which must have already existed. The first possibility is associated with the presence of outrigger boats in the eastern part of the archipelago at nearly the same time or after the conquests. The outrigger boat is still in use today by small-scale fishermen across the archipelago. Hundreds of local names are used all over the country with variations in their appearance and parts. A. C. Haddon and James Hornell documented the outrigger and dugout in their *Canoes of Oceania*. One remarkable type of outrigger is the sailing *sandeq* of Mandar. The *sandeq* has developed in size since the 1970s, and in 1990, its average length was about 7–8 m. At present, the *sandeq* that sails the

open seas for fishing activities is more than 10 m long, and the dimensions would be optimized if the *sandeq* is used for racing. There are at least three variations within the *sandeq* type depending on its usage in fishing. For flying fish fishing there is the *sandeq potanga*; for fishing at *roppong*, which is a fish aggregating device, there is the *sandeq paroppong*; and for daily-short-distance fishing, there is the *sandeq pangoli*. The second possibility is attributed to the story of the origin of Lamaleran. The story goes that local oarsmen (probably the sea nomads) were sent further east and reached the Aru Islands. The small fleet went south round the back route to the west and experienced calamity, and the survivors then occupied the shores in Lembata Island. The current boats of plank technology in Lamalera, which is the remnant of their ancestor's wrecked ships, are very similar to the most basic plank boats in South Sulawesi, the *pajala* hull (Fig. 3).

A common characteristic of traditional plank boat construction in various ship-building centers in the archipelago is the backbone structure. The backbone is a solid structure that bears the longitudinal strength of a boat. The structure comprises the keel, the keel extensions, the stem- and stern-posts, and the strengthening clampers fixed on both sides at a length that covers the joints between the keel and its extensions. The plank pattern is also similar, and thus, the hulls are similar in form. The *pajala* and the *patorani* of Makassar, the *leti-leti* of Madura, the



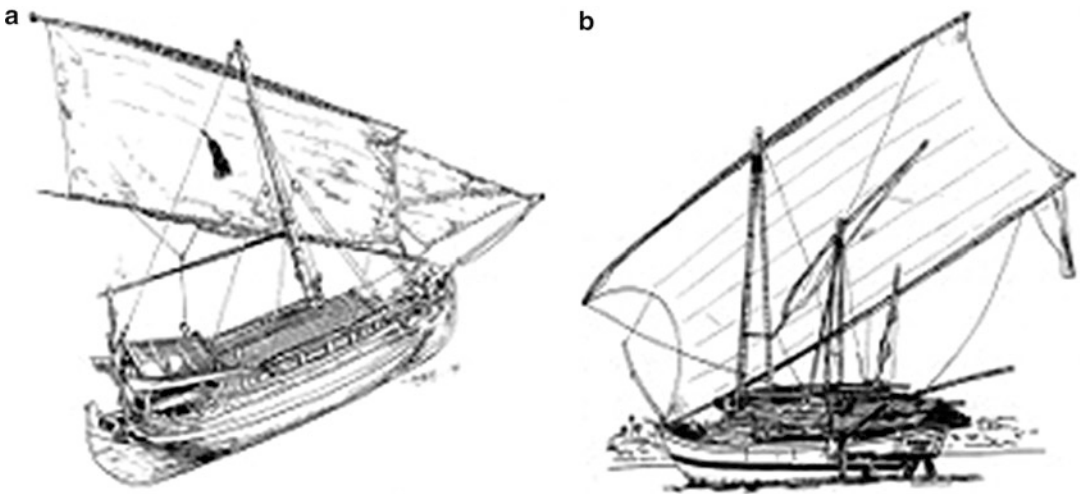
Boats in Indonesia, Fig. 3 A sandeq for fishing

mayang of Sunda Strait, the *baqqoq* of Mandar, the *pencalang* of Java, and the *pledang* of Lamalera all share the basic hull form of what Adrian Horridge called the *pajala* hull. These are the earliest planked boats operated in the archipelago with an open hull structure (without fixed and watertight decks) with smooth curvature seen from any perspective. The plank pattern of the *pajala* hull, as Horridge observed, suggests that it is not far removed from the traditional boats of 1,000 years ago. The stem- and stern-posts are joined end to end with the keel to form a smooth continuous curve, although the bottom is flat with a negligible projecting keel. Bows and sterns are similar in shape, often turning in at a sharp angle because the planks are carved, never bent, to shape.

A Portuguese account written by Tome Pires in 1512 mentions a type of boat called *pangajavas*, which he encountered in Palembang and along the north coast of Java. Pires encountered the Bugis on their “large well-built *pangajavas*” in the port town of Malakka and learned the name *pangajava*, which means “a ship that frequents Java Island.” This nomenclature is common in Sulawesi to name a type of ship based on the place it most frequently visits or the commodity it commonly catches or the fishing gear it uses. Pires then gave the name *pangajava*

to all the planked boats or ships with lateral rudders and square sails, the common characteristics of all native trading ships of Indonesia at that time. Pires might have seen, in the ports of Java, the *pencalang* type, and the “large well-built *pangajavas*” might be the Makassar *biseang* used for overseas fishing and trading in that era. He described the Bugis from “Macaçar Island” as respected traders who frequented many places with their boats to Pahang and Siam and the countries between the two and Malacca, Java, and Borneo (Fig. 4).

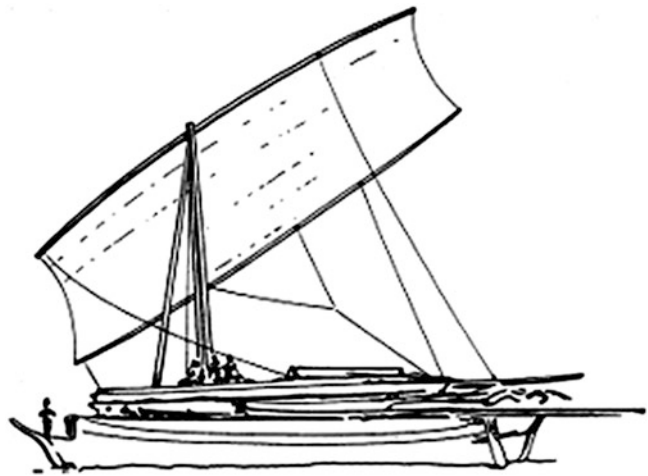
After the conquest of Makassar by Speelman in 1669, he reported in his *Notitie* the existence of the Bajaus in Spermonde Islands who “travel to all islands laying further out to sea, to gather tortoise-shell from them, which they are obliged to deliver to the King of Makassar; and moreover they must always be ready to go with their vessels in any direction they are sent, wherever the King from time to time sees some advantage.” The gathering of trepang and tortoise shell to supply the Chinese market at Makassar continued to the eighteenth and nineteenth centuries, and other ethnic groups joined in as they saw profit in it. They used to go as far as Dewakang Island far south of Makassar when the resources depleted at nearer locations, and they eventually roamed the northern coasts of Australia. Captain



Boats in Indonesia, Fig. 4 A prahu pencalang (a) of the Mid-nineteenth Century (Horridge, 1986) and a Makassa trading prahu (b) (Horridge, 1985)

Boats in Indonesia,

Fig. 5 Drawing made in 1803 by the artist William Westall of a Bugis prahu on the Arnhem Land coast (Horridge, 1985)



Matthew Flinders of H. M. S. Investigator met with a fleet of the *trepangers* (the *paqtaripang*, a specific type of *paqdewakang*) in 1803. In February 1840, Lieut. Owen Stanley on board H.M.S. Britomart sketched praus, which were part of a fleet that annually fished the waters off Arnhem Land for trepang. In 1818, Phillip Parker King, an Australian hydrographer, encountered similar prahus with double tilted sails (Fig. 5).

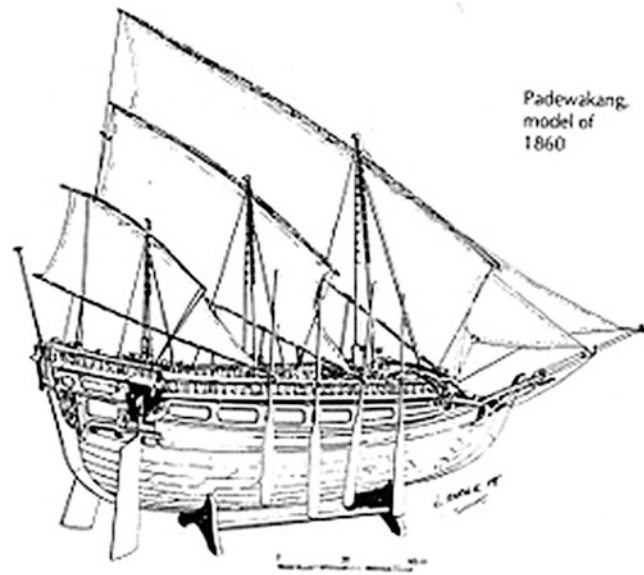
The hull construction of a trading *paqdewakang* is similar to the hull of a *paqtaripang* except that the first is larger in size and it has additional upper structures. This is the

type of boat boarded by Alfred Russel Wallace in his voyage from Makassar to the Aru Islands in 1856. He described the prahu as

It was a vessel of about seventy tons burthen, and shaped something like a Chinese junk. The deck sloped considerably downward to the bows, which are thus the lower part of the ship. There were two large rudders, but instead of being placed astern they were hung on the quarters from strong cross beams, which projected out two or three feet on each side, and to which extent the deck overhung the sides of the vessel amidships. The rudders were not hinged but hung with slings of rattan, the friction of which keeps them in any position in which

Boats in Indonesia,

Fig. 6 Paqewakang model
(Rotterdam 29568) in
Horridge (1985)



they are placed, and thus perhaps facilitates steering. The tillers were not on deck, but entered the vessel through two square openings into a lower or half deck about three feet high, in which sit the two steersmen. In the after part of the vessel was a low poop, about three and a half feet high, which forms the captain's cabin, its furniture consisting of boxes, mats, and pillows. In front of the poop and mainmast was a little thatched house on deck, about four feet high to the ridge; . . .

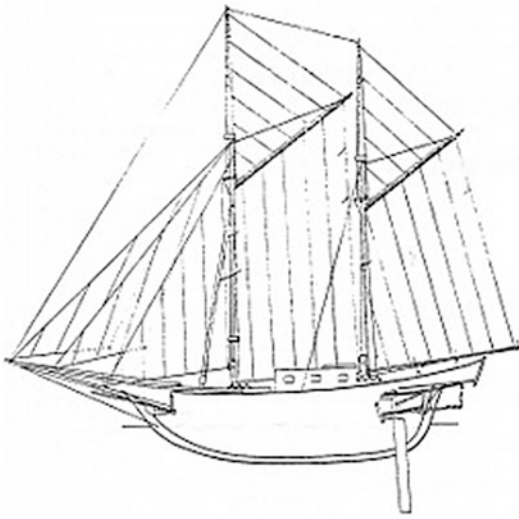
The ship had two masts, which were movable tripods, a system that persisted since its use on the La Galigo boats. The sail carried by this vessel was an oblong shape just like the ones encountered by Captain Flinders half a century earlier. The sail was hung out of the center so that when the short end was hauled down on deck, the long end mounted high in the air. The foresail was of the same shape but smaller. Both were of matting and with two jibs and a fore and aft sail astern of cotton canvas (Fig. 6).

The *paqewakang* type declined in number from the 1860s onward. A new schooner type called *pinisi* emerged. The name resembles the names of European ships: the Netherland *pinas*, the British *pinace*, and the French *peniche*. In 1935, G.E.P. Collins had the local people from Bira village build a *palari*-type schooner which had the initial hull form of a *pinisi*. A change in the hull size and the adoption of a schooner rig

system on a *paqewakang* turned the ship into a *palari*, a name which literally means “runner” or “racer” owing to the improvement of its sail and rigging that makes it speedier. The idea was to increase the carrying capacity of the former trading ship by raising the hull sides and to increase speed by implementing a new schooner sail and rigging system. By raising the hull sides, the main deck became higher than the traditionally maintained stern- and stern-post level. This problem was solved by constructing *ambeng dua kali*, which are double platforms hanging under one another at the stern and at the aft by making the splashboard a wall the height of the main deck (Fig. 7).

A picture of Makassar Port in 1920 reproduced in a photo book (Scarpello & Makhfudz, 2004) from a photograph in KITLV-Leiden shows tens of *palari* at anchor among other ships with Western hulls. This picture suggests that further advancement of the *palari pinisi* into the famous *pinisi* of Bugis-Makassar in its latest form of hull had not yet taken place. The *palari* building by Collins in 1935 and the folk story about the existence of *pinisi* in the early 1940s in Spermonde Archipelago might lead to the conclusion that *pinisi*, the summit of sailing *prahu* evolution in Indonesia, most likely took its last hull shape in the late 1930s. Again, the principal difference

between the new modification and its preceding types was the carrying capacity as was necessitated by the ever-increasing volume of trade. As the hull became bigger and taller, the stem- and stern-post problem could no longer be solved conventionally as in the *palari*. The stem- and stern-posts in a *pinisi* are lengthened up to the deck level, and the upper side planks are extended to be fitted to the posts at the center line. This modification thus eliminates the splashboard



Boats in Indonesia, Fig. 7 The *palari* built by G. E. P. Collins at Bira Village in 1935

and the void space between it and the stem-post and makes the hull a complete round vessel. This requires the stem-post to be a little far away from the points where the upper side planks start to bend sharply inward, resulting in the forward-leaning stem-post of the *pinisi*.

Adrian Horridge describes the *pinisi* in his book *The Prah*. The *pinisi* are partly a copy of a western schooner of the mid-nineteenth century, ranging in size from 120 to 200 t. They are recognized by their tall ketch rig of seven sails, including two topsails, three jibs with bipod or tripod foremast, and fixed gaffs. The enormous, heavy bowsprit with crossbeams and lateral boards is strengthened to support three jibs and a powerful forestay, which runs over both masts. The two lateral rudders are supported on a group of heavy beams, which run right through the stern. The deckhouse and upper part of the stern (*ambeng*) were added over an enlarged *pajala* hull (Fig. 8).

The motorized sailing prahu was the next transformation. The motorized *pinisi* emerged in the 1980s when the traditional *pinisi* fleet, the so-called *pelayaran rakyat* or people's shipping, was encouraged to adopt motorization. The superstructure of a motorized *pinisi* occupies half of the deck length, leaving only the foremast. There are only five sails: a main sail, a topsail, and three jibs. The engine requires a significant

Boats in Indonesia, Fig. 8 A replica of a *pinisi*



Boats in Indonesia,

Fig. 9 Motorized wooden ship now dominates shipping in Indonesia



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adjustment in the aft buttock to accommodate the engine foundation, the propeller and center rudder installations, and the engine room. Moreover, the next development resulted in an entirely new type of wooden ship, the motorized ship. Its hull is entirely of western type, and there are no more sails even for auxiliary power. The mast is now decorated with motor-powered lifting booms for loading and unloading operations (Fig. 9).

Not much is known about the evolutionary development of other boat types in Indonesia except that all types of traditional boats in the 1980s were touched by government programs of motorization. Motorization gave the final blow to the indigenous boats when they were required to adopt the western hull style halfway or totally. The backbone construction of a western hull, as opposed to traditional hulls, consists of straight pieces of wood. Joints are made at clumsy angles, which look to be stiff. The construction is built with three parts: the keel, the stem-post, and the stern-post. To put an engine inside a traditional hull would require some construction reformation, such as a strong structure for the engine foundation, centered propeller and rudder installations, engine rooms, and wheel rooms. The traditional accommodation for the crew inside the hull became inconvenient because of

engine installation, and crew cabins were built on deck behind the wheel room. Now, as the propelling function of the sails is largely replaced by the engine, the number of masts and sails are reduced in certain types and totally dismissed in other types.

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Boats in Vietnam

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The Vietnamese coastline, with long beaches exposed to the surf, deep bays shadowed under high capes, idyllic coves sheltered from the monsoon winds, and numerous river mouths, abounds with an incredible diversity of boats. Stretching

over 3,440 km, from latitude 21°N to latitude 8°N, the environment changes from north to south and so do the people, their sociocultural contexts, their politico-economic history, their maritime activities, and their related boats. Each port, coastal town, and bay had its own fleet of boats, which traditionally differed from one another. Rigging, helm, hull decoration, or hull shapes varied from island to coast, from bay to cove, from fishing town to trading harbor. A few main types that still survive now will be described here to illustrate this diversity and to highlight the skills and originality of Vietnamese boatbuilding, past and present.

Archival material, postcolonial studies, and contemporary research on the boats of Vietnam (Pham, 2015a, b; Pham, Blue, & Palmer, 2010) together provide an excellent boat record to draw upon to characterize the different boat types and the main patterns of construction and to also document some of the technological changes that occurred in boat traditions across time (see Pham, 2013 for a broad historical overview). During the lifetime of the first emperor, Gia Long (1762–1820), a few French-style ships were constructed (Mantienne, 2003), but, overall, the traditional constructions and the wide diversity of traditional boat types were maintained with barely any Western input until the 1940s as shown in the studies of Pietri (1943), Paris (1942), or Poujade (1940). Traditional sailing boats still plied along the coast until the mid-1960s, as attested by the American Blue Books (1962, 1967), but from then on, diversity started to fade. New materials (plastic, nylon, aluminum) and the introduction of small diesel engines were the key elements causing this change. Sails disappeared, but some shapes and features inherited from the traditional sailing boat types are still discernible in present-day boats, such as the generic double-ended shape of the sailing boat hull (Fig. 1) and *oculi* (eyes to guide the boat and scare sea monsters) or some unique features specific to the boats of Vietnam such as the *ngà* (cathead carved and painted embodying the soul of the boat), the sliding bow board (anti-leeway device), and the hulls made out of basketwork.



Boats in Vietnam, Fig. 1 Traditional working wooden boats anchored in the bay of Mui Ne (Binh Thuan province) (© C. Pham 2013–2014)

Since the late 2000s, fewer boats are being constructed in the traditional way. Government regulations (i.e., *chỉ thị 16 năm 2009* and *quyết định 48 năm 2010*), promoting the development of distant seagoing fleets to protect the depleted coastal ecosystems, mark a major change in the practice of fishing and therefore of boat use and construction. Nowadays, vessels using engines over 30 HP are under strict control and soon traditional wooden boats will not be constructed anymore. This is one of the biggest changes in the boatbuilding history of Vietnam and implies in the long term the total loss of traditional boatbuilding.

The Modern-Style Vietnamese Boat

Nowadays, the most noticeable boat style, representative of the contemporary Vietnamese modern boat, is constructed according to a licensed and regulated government-approved plan that completely breaks with traditional boatbuilding.

It is built frame first, based on a heavy keel timber, instead of plank first (Fig. 4). Floor timbers are bolted to the keel, and curved futtocks

are fastened to the floors with bolts and nails. Compared to the slender shapes of the sailing vessels, the modern hull is imposing with a broad beam, almost boxy (the further south, the boxier it gets), a nearly vertical tall stem cuts the water, and ends with a counter stern with a large flat transom. A 250–300 HP engine is located at the heart of the boat, under a large pilot house aft. Aft of the house, the rudder shaft passes through the keel, behind the propeller. Forward of the house, there are large holds for storing fish and ice. The foredeck is long to fit the gear for squid fishing (with many rows of lights in racks on either side and long booms for spreading nets at night) or for hauling large nets (Figs. 2, 3, and 4).

The modern-style boats exist in various sizes that vary between 11 and 30 m but tend to an average of about 14–16 m. They are manned by about 12–20 sailors/fishermen. Crews sometimes spend weeks offshore, at the Paracels and the Spratlys, or several months as far distant as Malaysia.

There is no specific name to identify this kind of boat. They can be referred to simply as *tàu* (ship), *phà*, or *ghe phà* (boat mix) or have regional names, depending on the size, the place



Boats in Vietnam, Fig. 2 Large modern-style boat set up for squid fishing (Khanh Hoa province) (© C. Pham 2013–2014)



Boats in Vietnam, Fig. 3 Medium-sized modern-style boat, manned by 5–7 crew and coming back from a day of fishing 7–8 nautical miles away. Larger boats in that

region fish in the area of Phu Quy and Con Son islands (60–130 nautical miles away) (Binh Thuan province) (© C. Pham 2013–2014)

of origin, or the type of fishing they conduct such as *ghe bò gù* in Phu Yen, *ghe mảnh ghép* in Binh Dinh, or *ghe đà cao*, *ghe lưới rút*, and *ghe chài* in Binh Thuan. None of these names are fixed.

Many of these boats are painted bright blue (sometimes gray or green) with a red trim and white cabin window outlines. In the southern provinces of Ninh Thuan and Binh Thuan,



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Boats in Vietnam, Fig. 4 All the modern boats are now constructed frame first and have a counter stern with transom and an upright stem (Ninh Thuan province) (© C. Pham 2013–2014)

however, they tend to be dark, the natural wood only covered with layers of *dầu rái* (oleoresin), and highlighted with a yellow top wale (Fig. 3). All have at their bow a neatly painted registration number but they do not have the *oculi* of traditional boats. Naturally, a few differences occur regionally, most particularly depending on the type of fishing they conduct, but the regulations are strict and scrupulously followed by the younger generations of boatbuilders.

These characteristics are common to all the modern boats along the coast which can easily be spotted in fleets of hundreds in the main ports and harbors of the country (Fig. 5).

Transition Boat

Among the fleets of modern boats moored in the harbor basins, a smaller boat type with a sharp bow but flat stern can also be noted. This boat, usually called *ca nô* or sometimes *ghe gió lượn* embodies the technological transition between the sailing boat and the modern boat with engine, which seems to have occurred mostly after the American War. The *ca nô* retains some

traditional design elements which were adapted to motor power. The hull shape is still long and slender, with a high overhanging sharp bow directly descended from the traditional sailing boats, but the stern is not pointed and runs to form a flat transom. This is because of the placement of the engine, which was initially fitted aft on the old sailing boats, in a small engine house. The fishing appendages are fitted on the foredeck, where sometimes the remnants of a mast serve to hang up lights for squid fishing or a protective tarpaulin. The bow is decorated with traditional *oculi* and with a *ngà* (cathead). These boats reach a maximum of 15 m and usually fish near the coast staying at sea for a day or two, with a crew of two to five fishermen (Fig. 6).

Traditional Boats: General Characteristics

The wooden working boats that survive in the present day and that descend from the traditional sailing boats can be categorized according to their hull construction. Some hulls in a northern tradition have planks edge-joined by nails, on a



Boats in Vietnam, Fig. 5 Fleet of modern boats (Binh Dinh province) (© C. Pham 2013–2014)

Boats in Vietnam, Fig. 6 *Ca nô* of Phan Ri. Note the small *oculi*, the cathead, and flat transom (Binh Thuan province) (© C. Pham 2013–2014)



keel plank that rises fore and aft and ends with a flat transom. Hull planks in the center and south of Vietnam are edge-joined with dowels and have high sterns and prows overhanging the water. Other hull planks were stitched, and some bamboo rafts were fitted with sails and daggerboards. Yet, the tradition that is the most particular to Vietnam is the bamboo-basket boat tradition. It is a construction technique that is unique although

sometimes compared to *coracles* or *kouffas*, with which the small round basket boats share their shape. The bamboo-basket tradition however is technologically different from these, and above all it stands out for its wide variety. From small round boats to large 15–20 m seagoing surfboats, sizes, shapes, and uses are numerous. Nowadays, these basket boats are still ubiquitous in Vietnam (although not in large sizes anymore).



Boats in Vietnam, Fig. 7 Foot rowing: the rower locks each foot to an oar and faces the direction of the route (Binh Dinh province) (© C. Pham 2013–2014)

Overall, traditional sailing boats in Vietnam, including large sailing basket hulls, were mostly operated along the coast, for trade or fishing. In general the length did not exceed 20 m. The tonnage of the larger class of seagoing sailing vessels ranged from about 20–120 register tons (although some historical references say there were more). Sail types could roughly be differentiated from north to south; however sail type is not a reliable indication of a vessel's origin because sail types can easily be adopted outside their area of origin. Traditionally, the most common shape was a lug sail, rigged on one to three masts that could be lowered even at sea.

In the north, the sails were often of the Chinese junk type, of cotton cloth, with bamboo battens laced to the sail. In the center of Vietnam, the lug sails were quadrilateral and made of woven palm leaves, while in the south, they were closer to triangular. Further southwest, near the Gulf of Siam, their shape was quadrilateral.

Small boats (up to 7 m) were mainly propelled by oars. In Vietnam, north or south, the rower faces forward, whether using crossed oars or one long sculling oar or when rowing with his/her feet which is also a particular Vietnamese technique seen in several provinces (Fig. 7). Steering devices, rudders, fishing gear, color schemes, and decorations also varied regionally.

Today, if large boats tend toward uniformity, diversity still survives in the small boats used as harbor taxis, harbor carriers (ice, water, and other supplies), fish buyers, riverine and inshore coastal fishing boats, and small canoes operated

on the canals and lagoons. From being simple smaller versions of larger boats to having features of their own, they mix various characteristics, exist in various shapes and sizes, and are made from various materials or combinations of materials (wood, bamboo, and nowadays galvanized steel sheets, aluminum, fiberglass, and plastic) (Figs. 8, 9, 10, and 11).

Introduction to Representative Traditional Boat Families

Basket Boats

The basket hulls are composed of a bamboo mat woven with bamboo poles that are split in long laths of about 3 mm thickness (length depends on the shape and size of the boat). First the bamboo mat is woven, and then it is given its shape by being laid into a pit or fitted within a bamboo structure and then clamped within bamboo gunwales (Figs. 12 and 13).

The hull is then covered with a sealing material, inside and out. Traditional recipes include first a layer of buffalo or cow dung and then two or three layers of *dầu rái*, an oleoresin extracted from *Dipterocarpus* trees in central Vietnam. In the north of Vietnam, a lacquer resin was extracted from the *Rhus succedanea* L. tree and mixed with sawdust (Aubaile-Sallenave, 1987). Nowadays, some boatbuilders use tar or cement, the lacquer resin being very expensive and dangerous to use (Burningham, 1994, pp. 233–234). Gunwales, topside wooden planks, thwarts,



Boats in Vietnam, Fig. 8 Small plastic canoe with traditional features (Phu Yen province) (© C. Pham 2013–2014)



Boats in Vietnam, Fig. 9 Small bamboo-basket harbor taxi (Quang Ngai province) (© C. Pham 2013–2014)



Boats in Vietnam, Fig. 10 Small inner lagoon fishing boats with traditional shapes and a particular rudder that folds upwards. Bamboo basket and plastic versions both

have inner bamboo stringers, bamboo frames, and wooden beams. The plastic one also has a small sail (Phu Yen province) (© C. Pham 2013–2014)

futtocks and floor timbers, and stringers of wood or bamboo can then be fitted within the bamboo hull to reinforce the structure (for full construction sequences, see Amos, 1997; Bui & Girard, 2007; Pham, 2012; Tallec, 1997).

The most noticeable and most common basket boats are the small round ones generically called *thuyền thúng* (Fig. 14). Some can be as small as 1 or 1.5 m in diameter, maneuvered only by the sculling movement of a paddle or, even without a



Boats in Vietnam, Fig. 11 Small aluminum canoes retaining the shape of bamboo-basket canoes (Ninh Thuan province) (© C. Pham 2013–2014)



Boats in Vietnam, Fig. 12 Preparation of a bamboo-basket hull. The bamboo mat is laid in a preformed pit. The long green bamboo pole split in two will “sandwich” the rim of the bamboo mat to form the wales (Quang Ninh province) (© C. Pham 2010)

paddle, the boatman moving the boat by thrusting his legs and recovering while holding onto the rim. Some can carry three to four passengers or sometimes many more in calm water in harbors



Boats in Vietnam, Fig. 13 The bamboo gunwales clamp the bamboo mat, which is fastened with fence wire (Quang Ninh province) (© C. Pham 2010)

or near the shore. Some are larger (3 m) and deeper with a long-tail outboard motor engine and operated by one fisherman, who goes one or two nautical miles offshore. Other basket boats, almost round but with a stem and sternpost and fitted with a 24 HP diesel engine, go fishing 10–20 nautical miles offshore and reach about 7 m in length. They are called *thúng xoài* or *xoài máy* because their shape resembles a mango (Fig. 15).



Boats in Vietnam, Fig. 14 A small round bamboo-basket boat, *thuyền thúng*, fitted with a long-tail outboard motor and maneuvered by one fisherman, can go fishing

1 or 2 nautical miles offshore (Phu Yen province) (© C. Pham 2013–2014)

Boats in Vietnam, Fig. 15 A *thúng xoài* or *xoài máy* bamboo boat fitted with sternpost, rudder attached with pintle and gudgeon, a stem, and a decorated *ngà* (cathead). The engine is located under the wooden deck. The hull is reinforced by wooden thwarts, futtocks, floor timbers, and stringers (Binh Thuan province) (© C. Pham 2013–2014)



Basket boats are not just round. They can also be boat shaped, used in the form of small fishing canoes (c. 4 m in length) in inland waterways and harbors, or can be long and narrow (12–15 m) racing canoes used during water festivals (with 20–28 rowers).

The most amazing form of basket boat is the double-ended boat-shaped surf boats well adapted to the surf along the exposed beaches in the provinces of Thanh Hoa, Quang Tri, Thua

Thien-Hue, Binh Dinh, and Phu Yen where they can still be seen gracefully braving the waves. These beautiful basket boats are between 6 and 8.5 m long and 1.3–2.6 m wide and operated by a crew of three to six fishermen (Fig. 16).

The hull is reinforced by topside planks and by an inner structure composed of floor timbers and futtocks. Now, the large boats are all powered with a diesel engine (and a large steering-scuttling oar aft when nearing the

Boats in Vietnam,

Fig. 16 The *xuồng mê* or surfboat of Phu Yen is maneuvered and propelled with a large steering-scuttling oar when near the beach. The engine fitted over a deck and protected by a small engine box is used once the water is deep enough (Phu Yen province) (© C. Pham 2013–2014)

**Boats in Vietnam,**

Fig. 17 A small *ghe véo* or *ghe nan* surfboat in Hue has split bamboo sponsons filled with Styrofoam to keep them afloat in case they are swamped. The surfboats in Hue are steered with a retractable rudder fitted in a slot in the sternpost (Thua Thien-Hue province) (© C. Pham 2013–2014)



beach). They go fishing for the day (Hue) or overnight (Phu Yen), between 15 and 25 nautical miles offshore (Fig. 17). During the turmoil of the “boat people” refugee exodus in the early 1980s, some small 5–7 m versions of these basket boats and even smaller ones sailed as far as Hong Kong.

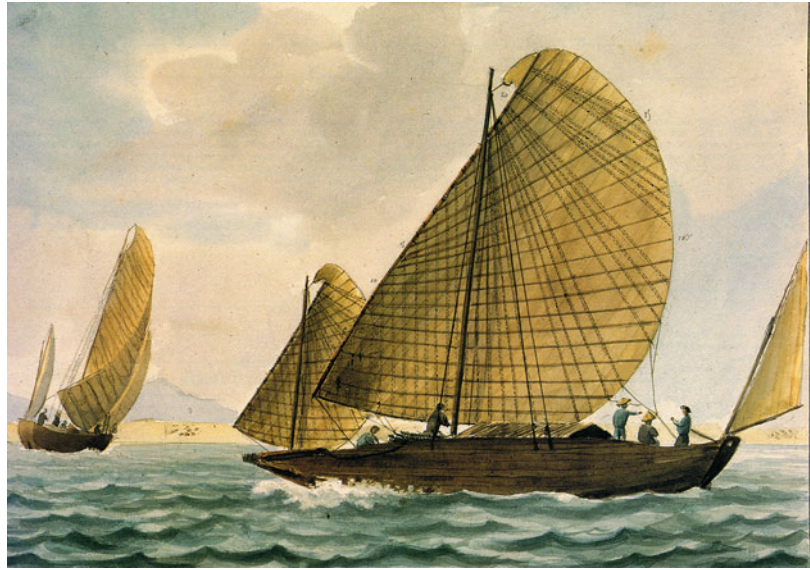
In the past, large sailing basket boats were operated by sail and oar. American Captain John White, on a mission in 1819, noted, “*They possess a great degree of stability, bearing a great press*

of sail, and are most excellent sea boats; they carry from one to three, very well cut, and neatly made lateen sails” (White, 1824, p. 57).

These bamboo-hull sailing vessels could reach 20 m long. They were used traditionally for transporting products such as rice, *nước mắm* (a condiment fish sauce), salt, dried fish, basket-work, or ceramics along the coast between the provinces of central and southern Vietnam. The large ones could also travel to Cambodia and Siam, said to carry as much as 8,000 jars of

Boats in Vietnam,

Fig. 18 Coaster of the Tonkin Gulf entering [the harbor of] Tourane [Da Nang]. “We saw in Tourane a coaster from the Tonkin Gulf, remarkable with its curved sail. . . the sail is solid but heavy, and tacks really well. . . Aft, . . . a rudder with pintle and gudgeon. . . These boats are never painted, . . . they have floor timbers, frames, planking, the maximum width is aft of amidships and they are about 18 m in length and 4 m in width” (Pâris, 1843, pp. 50–51, plate 48)



nước mắm, equivalent to about 120 t (Pietri, 1943, pp. 51, 61) and bringing back rice.

They were commonly called *ghe nang*, *ghe giã*, and *ghe câu* if they went fishing or *ghe bâu* when trading, but these names are generic, since the latter denomination also refers to fully wooden planked coasters.

These large traders have now disappeared, and the small fleets remaining in Thanh Hoa, Quang Tri, Thua Thien-Hue, and Phu Yen are the only descendants of this unique tradition.

Planked Boats from the Southern Border of China to Quang Binh Province

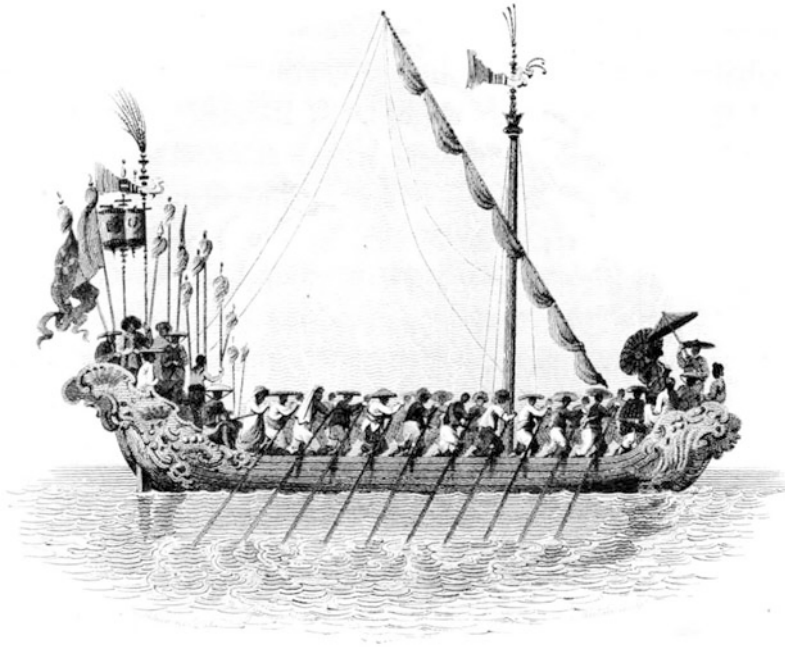
In terms of planked hulls, the boat tradition of the north of Vietnam can clearly be distinguished from the traditions of the center and the south of Vietnam. In the north the boats were constructed with features that can be associated with Chinese boatbuilding, such as battened sails, a high poop, a large beam aft of midships, planking edge-fastened with iron spikes, and bulkheads. Boats nowadays have retained some of these traditional features, but the working fleet is becoming replaced by the same blue and red modern-style vessels, found in hundreds in the ports of Hai Phong or Quang Ninh.

However, the surviving traditional wooden working boats in the Gulf of Tonkin are still

constructed with a flat bottom based on a plank keel that rises fore and aft. The planks are still edge-fastened with iron nails, driven in skewed distinctive triangular recesses. The floor timbers and futtocks that form the frames are bolted to the planking. The hull is partitioned into holds by bulkheads which are structural rather than watertight divisions. As in the Chinese tradition, the greatest beam is aft of amidships. The hull shape clearly shows a bow that is low on water and a high stern that hangs over the water. The boats from northern Vietnam do not have *oculi* or any other particular decoration. During the age of sail, their distinction lay in the Chinese reddish brown battened sails, tanned with *củ nâu* (*Dioscorea cirrhosa* Lour.) and still nowadays seen on the tourist junks, largely for ornamentation (Fig. 18).

The sailing vessels that used to do coastal trading and long journeys down to Siam and up to China were called *ghe mảnh* (and correspond to the *ghe bâu* of central and southern Vietnam described later). They reached 15–25 m in length, 4–5 m in beam, and transported 35–60 t. Fishing junks or river barges were also constructed according to the “northern” tradition.

In the mid-seventeenth century, the navy of the Trinh Lords in northern Vietnam counted over 400 galleys. The war galleys in Tonkin and Cochinchina were long, propelled by about



Boats in Vietnam, Fig. 19 A Cochinchinese galley with ten pair of oars, belonging to the governor of the district of Turon (Staunton, 1797, p. 341, engraving IV). Sir George Staunton, secretary of Ambassador Macartney in 1793, described: “A person of some rank soon arrived at Turon. . . He came in a large decked galley, of a light and sharp construction, formed for quick sailing. The rowers, who were very numerous, rowed in an erect posture, and pushed the oars from them, making short and frequent

strokes. A state cabin was erected, on the middle of the deck, painted in lively colours; each end of the galley was decorated with streamers of different colours and figures. The state cabin was, on the outside, surrounded with spears, and various ensigns of authority. The principal officer, who came in her, was dressed in loose robes of silk, had the polished manners of cultivated society, and was attended by a Chinese interpreter” (Staunton, 1797, p. 331)

40 rowers. The hulls were nicely lacquered or painted, with skillfully carved gilded prows. They sometimes had one mast and were fitted with guns for war. They were often described by travelers who visited the court and witnessed royal pageants (Fig. 19). The navy in Tonkin did not develop much during the subsequent years, but the sailing junks survived until the early 1990s. Now they can only be seen on romantic postcards.

Planked Boats from Quang Nam to Binh Thuan Province

The traditional double-enders in the center and south of Vietnam (Fig. 20) are the true and sole survivors of the past, the remainders of the beautiful sailing vessels of Vietnam praised by foreigners (Paris, 1843; Paris, 1942; Pietri, 1943; Poujade, 1940; Staunton, 1797; White, 1824).

The hull is pointed at both ends. The planks join in the stem and sternpost which both rise high above the water. It has no keel and is constructed plank first. A central plank is laid and joined in the stem and sternpost (Fig. 21). Then the strakes are fitted, dowelled edge to edge. Only when the plank shell has been constructed are the frames fitted. The fastening of planks was until recently done with treenails only, no iron nails used to enter boat construction in the center and south of Vietnam. This is a trait in common with Southeast Asian shipbuilding which differs greatly with the tradition of northern Vietnam and China. Now the planks are still mostly dowelled but a few iron nails are sometimes used for repairs.

These boats do not go far offshore and tend to fish on a daily basis near the shore. Their length varies between 8 and 15 m, and they are usually



Boats in Vietnam, Fig. 20 Traditional double-end. This is one of a very few surviving samples of a traditional boat with a sail, used in the sheltered bay of Xuan Dai (Phu Yen province) (© C. Pham 2013–2014)

Boats in Vietnam, Fig. 21 Traditional shell-first construction (Quang Nam province) (© C. Pham 2013–2014)



operated by a crew of three or four fishermen. Smaller ones can be operated by two people.

The traditional boats, past and present, are decorated with *oculi* on the bow. The *oculi* in the center of Vietnam are long and lanceolate, painted on the sides, distant from the stem or median plank. The painting of the eyes is an important ceremony in the boat construction process. The hulls are usually not painted but protected by layers of *dầu rái* and decorated

with bright-colored wales. Another specific feature of the traditional boats is the *ngà* or *ngà gác neo* (cathead) from which the anchor is dropped and over which the anchor cable rides, but it is also used as the onboard altar and incense burning spot and to repulse the evil spirits. In certain parts of Vietnam, such as the province of Khanh Hoa, the *ngà* is still decorated, carved, and painted, but in many cases, only a simple timber remains (Figs. 22 and 23).



Boats in Vietnam, Fig. 22 Traditional double-ender, with *oculi*, *ngà*, and a gracefully curved and carved retractable rudder that hangs on the sternpost with long iron gudgeons (Phu Yen province) (© C. Pham 2013–2014)

The traditional double-enders in the province of Quang Nam retain another element reminiscent of the age of sail: the bow board or daggerboard that slides in a slot in the stem. This arrangement, like the rudder fitted in a slot in the sternpost, was probably adopted because a daggerboard fitted through the basketry bottom of a traditional boat was problematic. Daggerboards reduce the tendency of a vessel to drift sideways – to make leeway – and thus improve the ability to sail into the wind. It was adapted to wooden hulls too, and although all traditional double-enders are nowadays powered by engine, some still have and use a bow board (Fig. 24).

Described since the eighteenth century, the larger coasters of central and southern Vietnam which conducted long trading journeys as far as China, Siam, and Singapore were called *ghe bâu*. In the records, the “*gai bao [sic] is without contradiction, the most curious type, the most original and also most attractive of the boats of the coast of Annam, and which better characterizes the local construction*” (Audemard, 1971, p. 17) (Fig. 25). Some had a basket hull (Quang Nam, Quang Ngai), and some were completely made of wood (Phu Yen, Phu Quoc island). When fitted for fishing, they were called *ghe câu* and were

similarly built with just a few differences on the upper structure. The large coasters were built and used (and adapted with engine) until the 1980s. The very large sailing *ghe bâu* that could load 300 t of cargo, such as those of Mui Ne described in nineteenth-century records, were long gone by the 1940s (Pietri, 1943, p. 51). The *ghe bâu* could be recognized by a rounded hull that was large amidships but with incurving topside strakes midships (tumble home), said to minimize the harbor dues that were calculated on the beam measured amidships (Ky, 1875, p. 223). In the 19th century, usually of a length between 20 and 30 m, with a tonnage of 60–120 t, hundreds of these boats used to compose the fishing and trading fleets of most of the main harbors in the center and in the south of Vietnam, laden with either fish, salt, *nước mắm*, or rice (Fig. 26). The *ghe cửa* were of similar build but were smaller and operated near the river mouths. Between 1778 and 1819, the Vietnamese court chronicles account for the construction of 235 *ghe bâu* as part of the imperial fleet (Li, 2004, p. 121). The navy of the Nguyen Lords in central Vietnam dramatically developed between the early seventeenth century and the beginning of the nineteenth century. The numbers increased from



Boats in Vietnam, Fig. 23 In southern ports of Phan Rang, Phan Ri, or Phan Thiet, the double-enders are bulkier and have a wider beam and no chine at the turn of the bilge. Their bow and stern rise high but are not as raked as those of the traditional boats from central Vietnam. A less

elegant and simpler square blade that slides in a slot in the sternpost is raised while the boat is anchored. A short carved and painted *ngà* stands abaft the stemhead (Binh Thuan province) (© C. Pham 2013–2014)

Boats in Vietnam, Fig. 24 Traditional double-ender, with bow board, auxiliary sail, and elongated *oculi*. In general, hull shapes in Quang Nam and Quang Ngai appear more slender than in the southern provinces of Khanh Hoa or Binh Thuan (Quang Nam province) (© C. Pham 2013–2014)



100 to 150 war galleys for the first Nguyen Lords in the early seventeenth century to a fleet composed of over 1,500 ships for the first Nguyen emperor *Gia Long*.

Stitched Boats

In the lagoon near the ancient imperial city of Hue survives the unique descendant of another construction technique in which the planks were stitched together. In the early 2000s, and much more in the 1980s, the planks were still stitched,

albeit with modern materials such as nylon rope and small piping. Now, only the shape remains since this kind of boat is constructed of riveted aluminum sheets (Fig. 27).

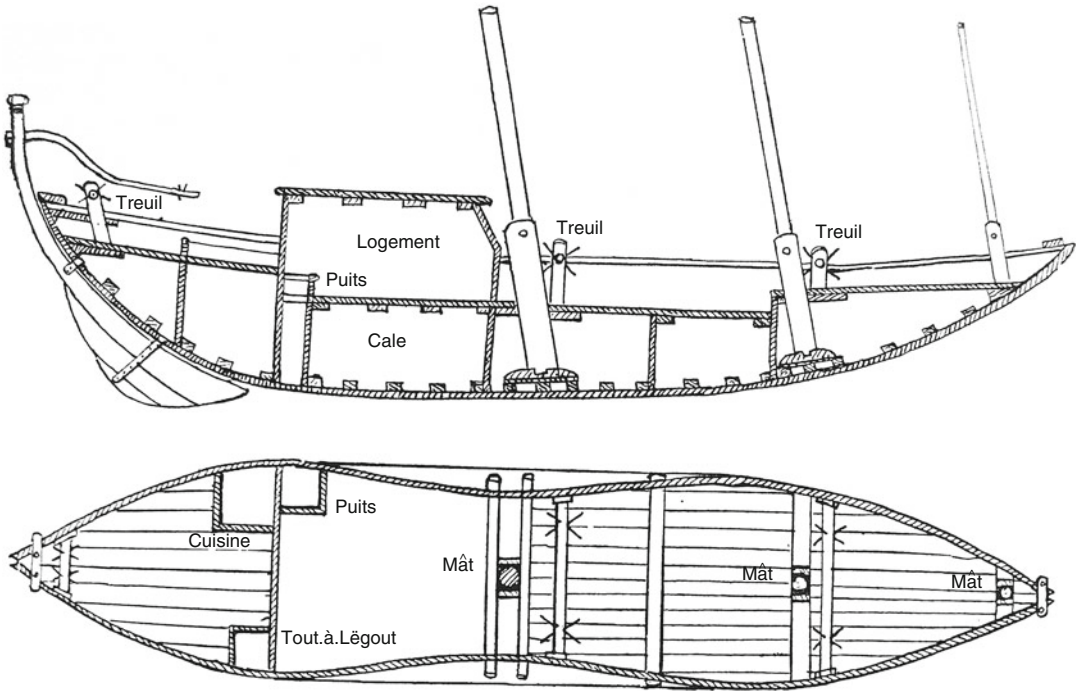
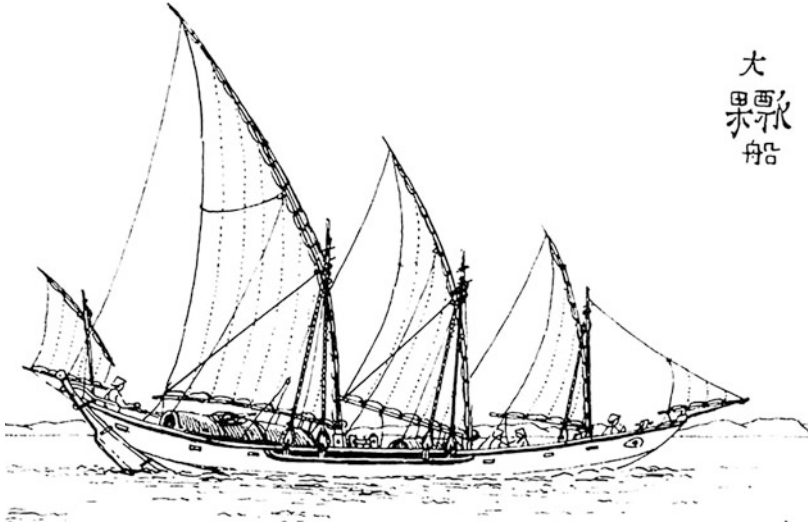
These *ghe nôl* or *ghe nôc* (called as such when they were stitched) or *ghe ðò* (nowadays) were house boats used in the rivers, canals, and lagoons. Made of five long planks, the hulls had a very narrow beam (1.5–2.5 m) with a double chine and reached 15–17 m in length. The bow and stern were particularly

Boats in Vietnam,

Fig. 25 For Commander Louis Theophile Audemard who sailed in Vietnam in the early twentieth century, “amongst the myriad of junks that sail in the China seas, the gai bao [sic] is unique” (Audemard, 1971, p. 16, plate 5, p. 17)

大
果
船

B



Boats in Vietnam, Fig. 26 Plan drawings of a “gai bao” showing the narrowed waist amidships (Audemard, 1971, p. 18, plate 6)

recognizable, the planks reaching quite high above the water and terminating in a flat transom. In the past, they were propelled by cotton sails with battens in the Chinese style, but they have been powered by an inboard engine since the 1980s (Fig. 28).

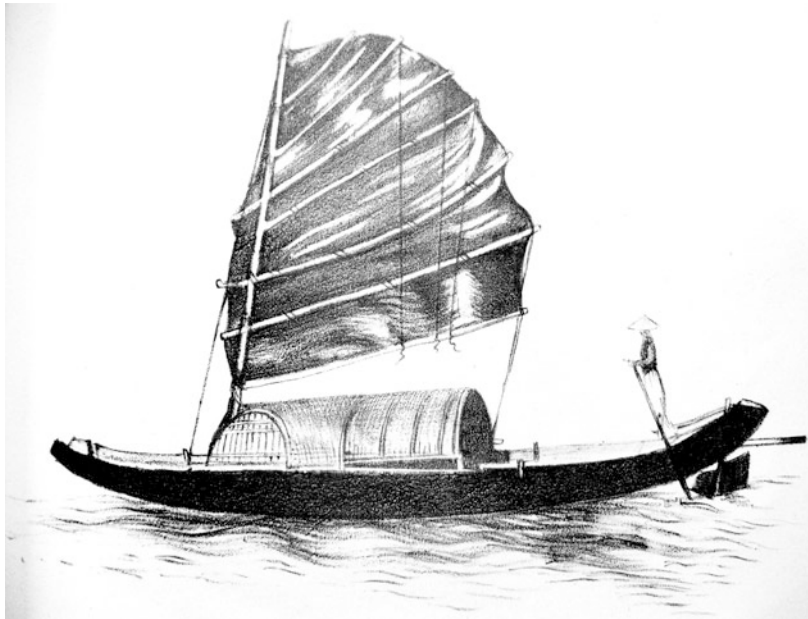
Based on several historical descriptions, it appears that the planks of the *ghe nôc* were stitched together by individual stitches and not sewn (which implies a continuous thread such as in Indian boats). The stitches were not attached to lugs either as seen in archeological material in



Boats in Vietnam, Fig. 27 The hull of the *ghe dô* has retained the shape of the stitched boat, *ghe nôm*, but is made out of tin or aluminum sheets and is powered with an engine. These houseboats still host entire families who

live in the numerous arms of the Perfume River and in the lagoon of Hue. People still remember them being powered by sail (© C. Pham 2013–2014)

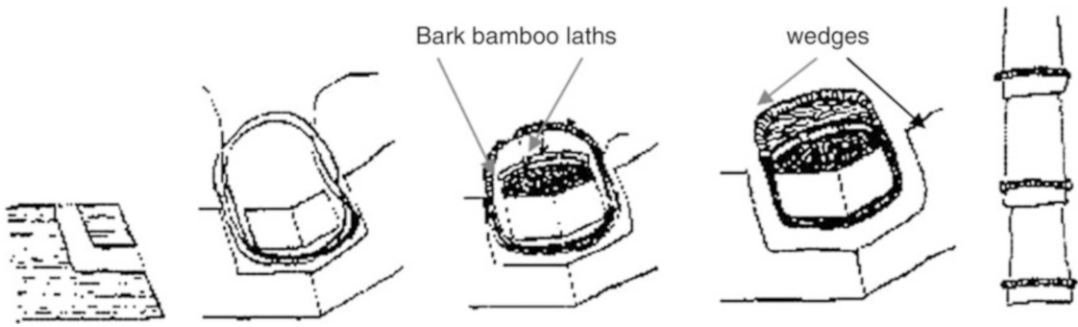
Boats in Vietnam, Fig. 28 *Ghe nôm* drawn by Jean-Baptiste Pietri, inspector for the Directorate of Fisheries in Saigon in the 1940s (Pietri, 1943, plate LI)



Southeast Asia (in the lashed lugs tradition, protruding lugs are left out in the carved planking. The planks are then edge-dowelled and their frames, thwarts, or ribs are lashed down to the lugs). The stitched boats in Vietnam seemed to have been constructed in a different fashion, although as in the lash-lug construction, the fastening was not visible from the outside.

Different techniques are described across time for the stitching of the planks, yet the main principle remains similar. Holes were drilled in the

planks through which threads were inserted to stitch the planks together. The seam was then protected by a wadding of tree bark which was compressed under bamboo laths. The bamboo laths overlapped like tiles, and flat wedges were inserted between them and the stitches in order to tighten the stitching and thus compress the wadding under the stitching (Fig. 29). Any gaps in the seams were then paid with a mix of *tram* tree and coal tar (Pietri, 1943, p. 72) and required constant maintenance.



Boats in Vietnam, Fig. 29 Stitching system of the *ghe nớc* (After Amos, 1998, p. 89)

Boats in Vietnam,
Fig. 30 Mekong freighter
(© C. Pham 2013–2014)



There are many mentions of other larger types of stitched boats in the historical record, from the mid-seventeenth century up to the late nineteenth century (Cadière, 1921). These boats were described as seagoing sailing vessels that could travel from the center of Vietnam as far as Siam or China. Samuel Baron in 1630–1640 wrote that he traveled from Tonkin to Siam aboard this kind of boat in 23 days (Baron, 1808, p. 665). “They have about five hundred other boats called *twinqaes* [sic], which are good and swift to sail, but too weak for war, being only sewn together with rattans; however they serve well enough for transportation of provisions and soldiers. In one of these boats I was forced to go to Siam the last year . . . thanks be to God, we got our passage in twenty-three days to the admiration of all that knew of it.”

The stitched sailing boats seem to have disappeared in the late nineteenth century and,

in the 1940s, were only recorded as small riverine fishing house boats, the *ghe nớc*.

Planked Boats from the Mekong Region

A great traffic of freighters animates the numerous large canals and arms of the rivers in the Mekong Delta. There, the boats are very rounded and run low in the water, with just a few centimeters of freeboard (Fig. 30).

They transport paddy, sand, gravel, bricks, wood, coal, and sugar cane in open holds or have closed holds to transport bagged goods (such as cement, fertilizer, flour, and polished rice) or are live fish carriers with free-flooding fish wells.

The tradition in the southern region seems to blend north and central construction techniques. The boats are double ended, constructed shell first with full-length planks, and the strakes are fastened edge to edge with iron nails.

Boats in Vietnam,
Fig. 31 “Flat red nose” or
ghe chài (© C. Pham
 2013–2014)



Interestingly, they have no stem or sternpost per se, and the planks join at both ends, tapered in the stern and bow so that the hull looks like a mandolin's body. Floor timbers are inserted after the planking is complete. Futtocks support the top-side planking. Transverse partitions or bulkheads reinforce the structure. The beam is wide, ranging from 1/4 to 1/3 of the length of the cargo freighter. These river crafts vary greatly in size, between 15 and 25 m.

Among the variety of boats in the Mekong, there are two main kinds that are easily recognizable, thanks to their particular bows. As the planks run to the bow, they terminate either in a flat horizontal timber that looks like a “flat red nose” as described by the locals (boat called *ghe chài*) or they end on a stem that rises high and looks like an “elongated blue nose” (boat called *ghe cà vom*) (Bogani, 2001, p. 287) (Figs. 31 and 32).

The *oculi* on the bows in the south of Vietnam are rounder than in the center of Vietnam and usually painted very far forward; some are very large in a teardrop shape or very small and round like marbles. For steering, the Mekong riverboats all have centerline rudders that are attached with pintle and gudgeon and are easily retracted, because of the numerous sandbanks and uneven depths of the Mekong, which vary greatly with the tides. In the past, sailing boats with triangular sails made of palm leaves carried on three masts could reach Saigon [Ho Chi Minh City] and the



Boats in Vietnam, Fig. 32 “Elongated blue nose” or
ghe cà vom (© C. Pham 2013–2014)

neighboring ports deep inland to load or unload their cargo. The combination of long oars and of the power of the tide assisted them in sailing up and down the rivers. Chinese junks also operated in the channels of the Mekong due to the long history of the Chinese who settled there since the seventeenth century (Audemard, 1971; Bogani, 2001; Poujade, 1946b). These boats have disappeared in recent years.

Bamboo Sailing Rafts

“Rafts are found everywhere, but rafts worthy of the sailing vessel title are almost impossible to find” (Paris, 1939, p. 14). In Vietnam, however, there used to be sailing rafts fitted with sails and



B

Boats in Vietnam, Fig. 33 Sailing bamboo raft with centerboard and small engine (Thanh Hoa province) (© C. Pham 2009)

daggerboards. They were common in the north, in the provinces from Nam Dinh down to Quang Tri, and are still in use in the area of Thanh Hoa. Fitted with engines, they do not use their sails anymore, but in the mid-1990s, fleets of them could still be seen going about 30 miles offshore (Fig. 33).

The characteristics of the sailing rafts varied according to the region, most specifically in the number of bamboo poles, the mast steps, and the daggerboards. The raft could be composed of 8–24 bamboo poles, to which larger poles were lashed on the sides to form a strengthening framework. Sometimes, they could also be secured to a wooden crossbeam setup on the fore-end of the deck, which piled the poles up vertically, creating as such some sort of pseudo-washboards. They could reach 9–10.5 m in length and 1.6–2.3 m in width, depending on the number of bamboo poles used (Belcher, 2004; Burningham, 1994; Claeys, 1942; Pietri, 1943). Now, the bamboo poles, set in parallel, are braced and lashed together with fence wire or nylon, but in the past, they were fastened with bamboo strips, rattan, or husk.

If in the 1990s sailing fleets could still be seen across the horizon, by the year 2000, they were motored but still using their boomed lugsails once offshore (Belcher, 2004). Styrofoam blocks have been used increasingly since the 1990s to provide the primary buoyancy, and the bamboo is only used for the structure. In the modern bamboo

rafts, the Styrofoam blocks are covered above and below by narrow strips of split bamboo for protection and “quilted” together with the same heavy nylon fishing line that is now universally used to lash the bamboo structure together.

Conclusion

The variety of boats seen nowadays is decreasing dramatically. Some boat types described in the 1940s and in the 1960s are long gone, and surviving traditions will not be renewed. New fishing practices, new regulations, new materials, modern technology, and safer navigation contribute to new seafaring conditions and therefore to the birth of a new fleet.

Yet there is still a lot to learn from boatbuilders today and from the boats that survive from the past. Because a boat is not only the product of function and of environment, a boat also reflects the mind of the boatbuilder and the culture, the socioeconomic contexts, and the history it belongs to. The diversity of boats can reflect changes, adaptations, and cultural affinities across time. For example, it is possible to understand the differences in hull construction as related to the two main cultural spheres that shaped Vietnam’s history: that of the Dai Viet and that of Campa. North Vietnam was under Chinese domination for over 1,000 years and

Boats in Vietnam,

Fig. 34 Fishermen repairing their nets on the beach of Mui Ne (Binh Thuan Province)
(© C. Pham 2013–2014)



the boatbuilding traditions of the Dai Viet included Chinese features. Central and southern Vietnam were Cam lands, and boatbuilding in these regions, albeit progressively controlled by the Nguyen Lords since the sixteenth century, includes features that can be related to other boat traditions in Southeast Asia. This very simplistic explanation shows how a parallel can be made between technology and history. Yet, the intensive waves of migration that occurred in the country since the tenth century up to the latest upheavals of the twentieth century also mean that traditions and craft have been displaced along with people. Some northern-style boats can be found in the south of Vietnam; Chinese boats were constructed in the Mekong region (Poujade, 1946a); the *ghe câu* of Quang Khe (north) was similar to the *ghe câu* of Binh Thuan (south), with the same rudder and even identical *ngà* decoration (Pietri, 1943, p. 80), and bamboo-basket hulls are found everywhere along the coast.

Unfortunately, the poor archeological record does not yet contribute much to the discussion of the origins and the continuity of the different boat types in Vietnam. However, sailing boats, royal galleys, war vessels, and even small fishing junks attracted the eye of foreign travelers who

mentioned them in their journey's accounts or official reports. So other research approaches, such as ethnography and history, participate in this discussion and can help to constitute a wide and detailed record of boat use and construction since at least the seventeenth century. Multiple factors contribute to the design and shape of a boat, some more obvious than others. To discuss with boatbuilders and fishermen today about seafaring, boat use and boat construction can help us to understand elements that are not always related to function and not readable in the archeological or iconographic record. Providing a historical context to these boat types also illustrates a continuity of use and adaptation that can help to understand technological changes. Seafaring, fishing, bird nest collecting, shipwreck salvage, and goods transportation were common to the daily life of the coastal people of Vietnam living at the heart of the great maritime trade routes in Southeast Asia.

In summary, this introduction outlines the main families of boats that could be related to different maritime activities and engagements that occurred across time along the coast of Vietnam. So in a country often described as a long shoulder pole with a rice basket at each end (Mekong and Red River Deltas) and inhabited

by rice farmers and water buffaloes, the study of the boats of Vietnam can provide a complementary perspective to the people along the coast whose life was also shaped by their maritime environment (Fig. 34).

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Boats of the Precolonial Philippines: Butuan Boats

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The Butuan Boats (also known as *balanghai*/*balangay*) refer to the incomplete remains of planked boats excavated from about 2 m of waterlogged alluvial sediments in Barangay Libertad, Butuan City, Philippines (Fig. 1). Reports say that the remains of between 9 and 11 boats have been discovered by looters along what are believed to be the shores of a former river, all within a 1 km radius (Cembrano, 1998; Clark et al., 1993; Ronquillo, 1997; Salcedo, 1998). However, archaeological researchers have only confirmed six sites to date.

The first Butuan Boat was partially unearthed in 1976 by looters searching for buried coffins containing valuable grave goods including Chinese ceramics and gold ornaments. Using long metal rods to probe through the earth for the wooden coffins, they accidentally came upon the timbers of Boat 1. The find was reported to local government officials, who in turn alerted the leadership of the National Museum of the Philippines. Personnel from the Museum's Archaeology Section investigated the boat's remains (Peralta, 1980a).

After several months, looters found the remains of Boats 2 and 3, just over 1 km south of the first boat. Excavations were undertaken on all three sites, though work on Boat 3, described as a smaller vessel, was not completed (Peralta, 1980a). Boats 1 and 2 were subsequently recovered and are displayed in exhibits managed and operated by the National Museum (Fig. 2).

Boat 5 was excavated in 1986 as part of a course on archaeological excavation and conservation organized by the Association of Southeast Asian Nations (ASEAN) and hosted by the



Boats of the Precolonial Philippines: Butuan Boats, Fig. 1 Map of the Philippines showing the location of Butuan City (Map: d-maps.com)

Philippines' National Museum (ASEAN 1986). It was located approximately one kilometer southwest of Boat 1 and less than 400 m northwest of Boats 2 and 3. It was also recovered and its planks are now stored in the Butuan City branch of the National Museum.

The excavation of Boats 4 and 9 commenced in 2012 and is still ongoing. The remains of these two boats were located slightly overlapping each other and just several meters east of the Boat 2 excavation trench.

None of the Butuan Boats were built with any metal fastenings, a characteristic of early South-east Asian plank boat construction that still persists in some areas today.

The most distinctive features of all but one of the excavated Butuan Boats are the rectangular lugs carved on the inner side of their planks. The lugs are drilled with holes to which frames and



Boats of the Precolonial Philippines: Butuan Boats, Fig. 2 Butuan Boat 1 at the Balangay Shrine, Butuan City (Photo: author)

thwarts could be secured with rope or cordage. Such boats are known as lashed-lug boats, used throughout the islands of Southeast Asia and beyond from well before the tenth century until the late nineteenth century. The oldest lashed-lug boat is the Pontian Boat found in Peninsular Malaysia dated to between the third and fifth centuries (Manguin, 1993). Lashed-lug boats were still observed to be in use in remote islands of Indonesia as late as the 1980s (Barnes, 1985).

The Butuan Boats are the oldest archaeological examples of watercraft in the Philippines. Early attempts to date the first three recovered boats in the 1970s and 1980s resulted in disparate radiocarbon ages dating to the fourth century, thirteenth century, and tenth century AD. Accelerator mass spectrometry (AMS) C-14 analysis was conducted in 2014 on seven timber samples collected from five boats,

including the three boats previously dated. The new calibrated results indicate the boat timbers date to between the late eighth and early tenth centuries AD (Lacsina and Van Duivenvoorde, 2014).

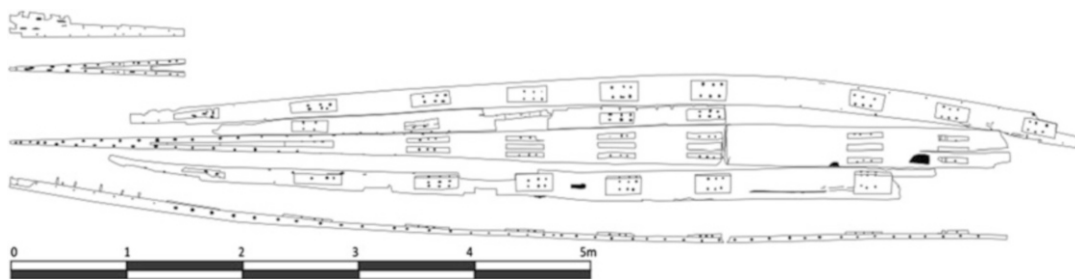
Boat 1

Boat 1 is exhibited at the Balangay Shrine in Butuan City which was erected several meters from where it was discovered.

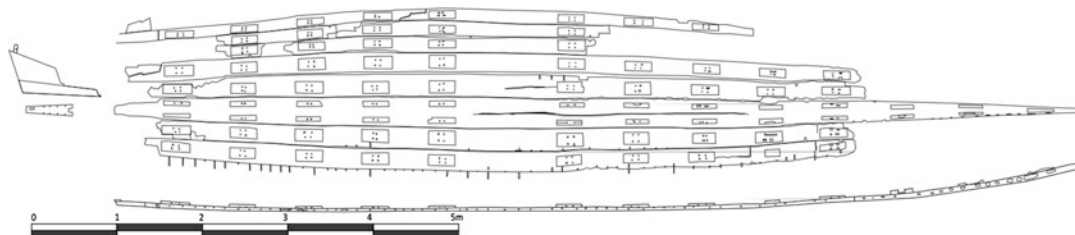
The Boat 1 remains measure 10.2 m in length. It is composed of a keel plank, one strake on one side and two strakes on the other and several plank fragments. As it is displayed (Fig. 3), at least one of the strake fragments may not be in its original position, as its lugs appear to be slightly misaligned with lugs on adjacent strakes. One end of the keel plank is broken off. On the surviving end of the keel plank is a wing end (also referred to as a “wing stem” or “winged stem”) which was used instead of a stem or stern post. It is attached to the keel by dowels. The blade of a quarter rudder, reportedly recovered by looters, is also displayed at the shrine (Peralta, 1980b).

The timbers of Boat 1 were previously said to be of the species *Heritiera littoralis* (Peralta, 1980b). New identification was carried out in 2013 at the Forest Products Research and Development Institute (FPRDI) of the Department of Science and Technology (DOST) in the Philippines (Lacsina, 2013). The timbers of the keel plank, three plank fragments, and the wing end were identified as *Shorea* species. Another plank fragment was identified as *Vatica* species. The remaining plank fragment was identified as *Petersianthus quadrialatus*, as was the one dowel sampled. The quarter rudder was identified as *Eusideroxylon zwageri*.

An unspecified sample from Boat 1 was dated in the late 1970s at Gakushuin University in Japan to $1,630 \pm 110$ BP (GaK-7744) (Manguin, 1993; Peralta, 1980a). In 2014, two samples from the boat were subjected to accelerator mass spectrometry C-14 analysis at the Australian Nuclear Science and Technology



Boats of the Precolonial Philippines: Butuan Boats, Fig. 3 Drawing of Butuan Boat 1 as displayed at the Balangay Shrine, Butuan City (Drawing: author and R. Mitra)



Boats of the Precolonial Philippines: Butuan Boats, Fig. 4 Drawing of Butuan Boat 2 as displayed at the Museum of the Filipino People, Manila (Drawing: A. Peñalosa and author)

Organisation (ANSTO). Sample OZQ841, taken from the keel plank, dated to $1,145 \pm 25$ BP or 904 cal AD. Sample OZQ842 from the wing end dated to $1,130 \pm 30$ BP or 924 cal AD.

Boat 2

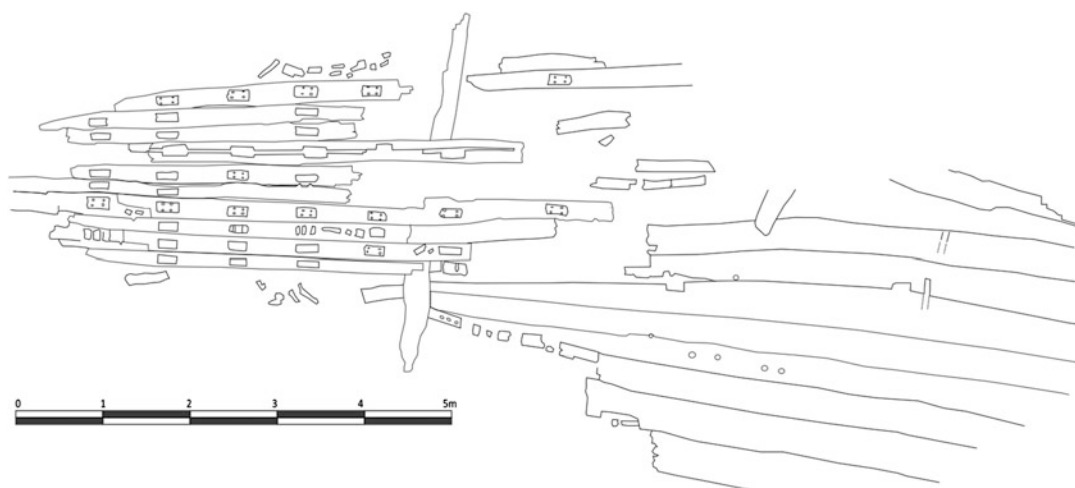
Boat 2 is displayed at the Museum of the Filipino People in Manila. It is 11.3 m long. There are five strakes on one side of the keel plank, and two strakes on the other as displayed (Fig. 4). These were all identified by FPRDI as *Hopea* species. A wing end, identified as *Pterocarpus indicus* was recovered on one end of the boat, attached by dowels and mortise and tenon joins to what may be a fragment of the keel plank, identified as *Hopea*. A portion of a frame still secured to the keel plank and a strake at the time of excavation was not accessed at the time of recording and has yet to be identified. Though not formally identified, the rope used to secure the frame is believed to be from palm fibers (*Arenga pinnata*). As with Boat 1, the timbers of Boat 2 had previously been identified as *Heritiera littoralis* (Scott 1981).

An unspecified sample from the boat was originally dated to 700 ± 90 BP at Gakushuin University (Peralta 1980a). Additional two samples were dated at ANSTO in 2014. The keel plank (OZQ844) was dated to $1,200 \pm 30$ BP or 825 cal AD. The wing end (OZQ845) dated to $1,230 \pm 30$ BP or 787 cal AD.

Boat 4

The remains of Boat 4 include a keel plank, six strakes on one side, and three strakes on the other (Fig. 5). Roughly one half of this boat appears to be missing, with the surviving planks measuring 6–8 m long. As archaeologists have yet to expose either end of Boat 4, it is not clear if a wing end or posts were used on this vessel. FPRDI identified the keel plank and plank timbers as *Vatica* species. Another timber, found underneath Boat 4, atop Boat 9 and roughly perpendicular to both boats' planks, was identified as *Pometia pinnata*.

A keel plank sample taken from Boat 4 (OZQ846) was dated at ANSTO in 2014 to $1,150 \pm 35$ BP or 888 cal AD.



Boats of the Precolonial Philippines: Butuan Boats, Fig. 5 Preliminary excavation drawing of Butuan Boats 4 (left) and 9 (right) produced in 2013 (Courtesy of the National Museum; drawing: J. Santiago and A. Peñalosa)

Boat 5

The degraded and fragmented timbers of Boat 5 are currently stored in Butuan City. Based on the original excavation drawing, the boat is about 11.5 m long. It is composed of a keel plank and seven strakes on one side, eight strakes on the other. Seven frames were also recovered, as was a wing end made up of two segments. The keel strake and ten sampled plank fragments were all identified as *Pistacia chinensis* by FPRDI, confirming earlier findings (Abinon, 1989). Three of the frames were identified as *Vitex parviflora*, while the remaining four frames were identified as *Dimocarpus* species. One dowel was also identified as *Dimocarpus*. Both segments of the wing end were identified as *Pterocarpus indicus*.

In 1988, an unspecified sample from Boat 5 was dated at the Australian National University (ANU) Radiocarbon Dating Laboratory to 960 ± 70 BP (ANU 6193) (Abinon, 1989; Fallon, 2013; Ronquillo, 1997). The keel plank was dated at ANSTO in 2014 to $1,150 \pm 30$ BP or 890 cal AD (OZQ848).

Boat 9

While the archaeologists have not completed the excavation of Boat 9, it appears to be at least

twice the size of any of the other Butuan Boats (Fig. 5). Its timbers are also relatively more degraded than those of the other boats. It is composed of a keel plank, a wing end, and a still undetermined number of strakes, which appear to not have any lugs at all.

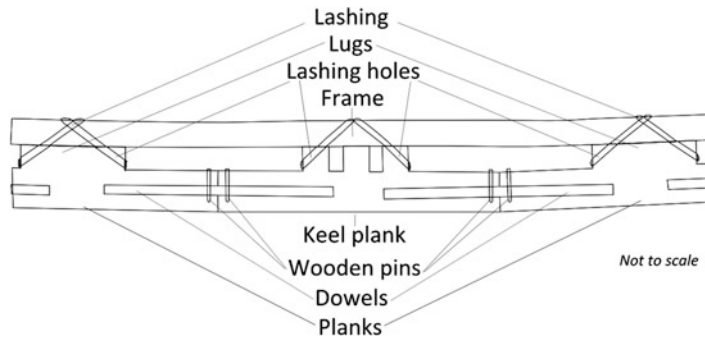
As of this writing, only two samples have been collected from Boat 9 for wood species identification at FPRDI. The keel plank was identified as *Vatica* species. The wing end could not be identified due to its advanced level of deterioration.

The wing end sample collected from Boat 9 dated to $1,160 \pm 30$ BP or 879 cal AD by ANSTO in 2014 (OZQ851).

Construction

Metal fastenings were not used in the construction of any of the Butuan Boats. Their builders edge joined the planks with wooden dowels. The edges of the keel plank and all other planks were drilled with holes through which dowels were inserted to fit tightly. In the cases of Boats 1 and 5, a number of dowels were further locked into place with wooden pins inserted through the planks and into the dowels (Fig. 6).

With one exception, all of the examined boats are lashed-lug boats. A series of protruding rectangular lugs were carved from the inside of each



Boats of the Precolonial Philippines: Butuan Boats,
Fig. 6 Example of plank fastenings based on Butuan Boat 1. Some of the dowels of Boats 1 and 5 were locked

in place with wooden pins inserted through the planks. No such locking mechanism has been observed in other Butuan Boats (Drawing: author)

plank; with the planks assembled, all the lugs are aligned crosswise. Frames and thwarts could then be secured by rope or cordage to the holes drilled through the lugs, adding strength through compression to the boat structure.

Dowelling and lashed lugs are generally considered to be distinctive characteristics of a Southeast Asian boatbuilding tradition. None of the Butuan Boats possess a true keel to cut through water; they were instead designed with a keel plank. The fore and aft ends of any of the Butuan Boats have not been determined.

Lugs and Lashing Holes

Each of the Butuan Boat keel planks is different, particularly in regard to arrangement of the lugs (Fig. 7).

The builders of Boat 1 carved the lugs on the keel plank in sets of three, except for the first two, which are single lugs, and the third, which is a paired set. All but the first lug, which is not drilled, have three pairs of lashing holes. The holes are drilled from either side of the outer lug to the top.

The lugs on the keel plank of Boat 2 were all carved in pairs and drilled with two pairs of lashing holes. As with Boat 1, the lashing holes were drilled diagonally from the outer side of the lugs to the top.

Boat 4's keel plank was carved with single lugs, as well as a continuous raised ridge that runs the length of the keel and through the center of each of the lugs. Two pairs of lashing holes

were drilled through diagonally from either side to the top of each lug.

The keel of Boat 5 stands out from the other keel planks quite distinctly. Instead of lugs, it has a continuous raised ridge, wider than the ridge on Boat 4. The lashing holes are drilled through the ridge, from side to side.

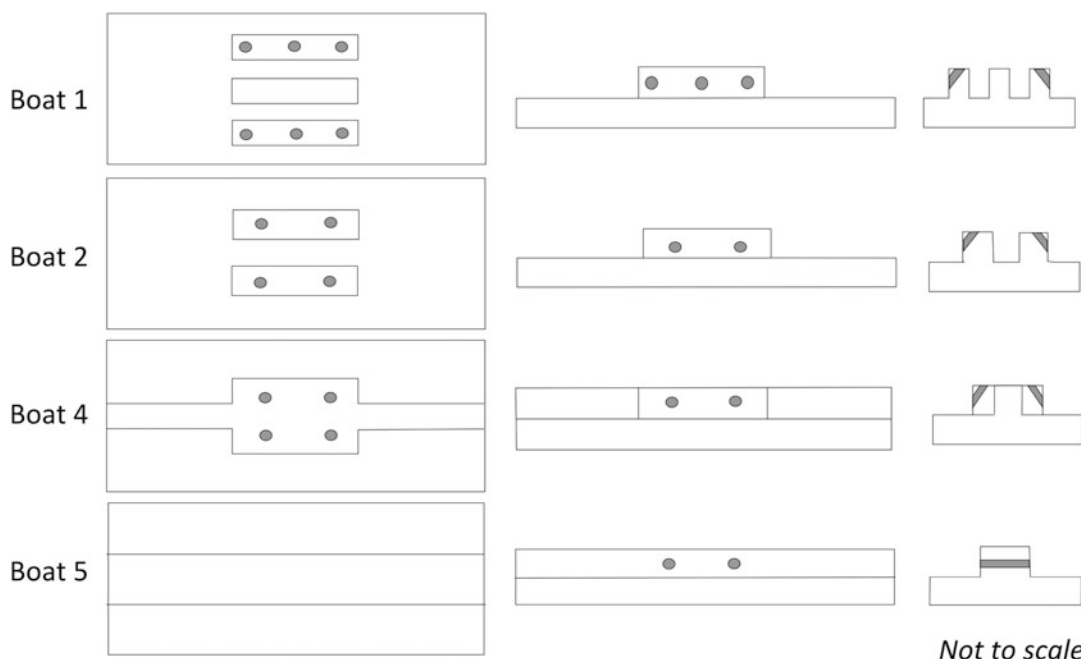
All other planks of each of the Butuan Boats have single lugs which were drilled with the same number and in the same fashion as their respective keel planks' lugs. The lugs on the planks of Boat 1 have three pairs of lashing holes, while Boats 2 and 4 have two pairs of lashing holes all drilled diagonally from side to top. In contrast, the lugs on the planks of Boat 5 have two lashing holes drilled straight through from either side. The design of the lashing holes would affect the manner in which rope and cordage could be secured.

Lug Spacing

A pattern of lug arrangement is evident in the surviving lashed-lug Butuan Boats. Lugs are more or less evenly spaced from either end except for a noticeable gap with an absence of lugs around the widest part of the boat. One end of the boat is invariably longer and more pointed and has more lugs than the other shorter, more rounded end.

Wing End

Only one end of only Boats 1, 2, and 5 survived. Neither end of Boat 4 has yet been uncovered,



Boats of the Precolonial Philippines: Butuan Boats, Fig. 7 Lugs and lashing holes on keel planks of Butuan Boats 1, 2, 4, and 5 (Drawing: author)

while only one end of Boat 9 has been exposed as of this writing. All the surviving ends of the boats show a wing end, rather than a stem or stern post. It is not clear if the opposite ends of the boats were likewise designed to use a wing end.

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Bone Technology in Africa

Alice M. Choyke

Particular cellular structures in the hard tissues of animals provide potential raw materials for manufacturing tools and ornaments. Mammalian bones and teeth provide the bulk of the raw material not only because of their form but also because they were available in the refuse derived from the consumption of meat. Egg and mollusk shell (gastropods and bivalves) were also modified. It is possible that, like ivory in later periods, they might have been sought after for the sake of the shell raw material itself. In parallel, since osseous tissues come from living animals which often had important symbolic significance to the humans exploiting them, their bones may also have had a variety of special significances in traditional tool manufacture. At the beginning, bones were used rather than modified in regular ways, but quite early on humans used a variety of techniques (cutting, scraping, abrasion, and drilling) to produce standardized objects. Until the Late Bronze Age in the second millennium BC, flaked stone tools, rough stone surfaces, and polishing materials were used to manufacture quite sophisticated objects.

As it was the cradle of humankind, it is not surprising that Africa was the scene of the earliest bone working in the world and some of the latest as well, representing almost 2 million years of transforming the hard tissues of animals into tools and ornaments. Furthermore, African bone technology is also distinguished by the use of two special raw materials: ivory and ostrich eggshell. As elsewhere, however, animal bone lay at the

heart of technological processes while antler, a staple material in Europe, was unknown. Shells, riverine or marine, were used as ornaments almost everywhere across the continent and from remarkably early times in the Middle Stone Age to the present.

Outside Africa, until quite recently, the earliest, securely dated worked bones, small split-based projectile points, came from the Central European Szeleta culture at around 35,000 BP, representing the earliest securely dated manufactured objects in Europe, coeval apparently with the arrival of anatomically modern humans in Europe. Worked wooden artifacts from the sites of Clacton and Lehringen as well as three wooden spears found at the 400,000-year old site of Schoeningen in Germany, however, show that Middle Pleistocene European hominids used wood. *Homo erectus* craftspeople could scrape and shave wood so handily that working bone should have presented few problems. There are also examples from this early time period in Europe of large mammalian phalanges, deer antler and diaphysis shaft fragments being used as retouchers for making stone tools. There is even one example from Italy of bifacial tools flaked from an elephant long bone (d'Errico & Backwell, 2001; d'Errico, 2003).

Some of the chronological and spatial gaps in the distribution of these early bone objects from Europe and Africa revolve around the survival of bone on archaeological sites. Very ancient sites are rare everywhere in the world. Furthermore, and importantly, preservation of organic, osseous materials was dependent on the way those objects were used, where they were discarded, and the natural conditions prevailing in those places. Acidic soils destroy bone while root action and animal gnawing can also modify surfaces and shapes. Osseous materials of any kind, compared with stone, will begin to erode and break apart when exposed for more than a month or two in the open air. Thus, both cultural behavior with regard to tool use, location(s) of that use, and traditions of discarding worked bone after they broke compound natural conditions to affect what objects can be found by excavating archaeologists. Bone tools have not often been systematically

researched, perhaps because their study also requires such an intimate knowledge of the biology of the bones they derive from.

The Taphonomy of Worked Osseous Materials

What particularly makes any discussion of African bone tool technologies a challenge is the size of the continent, especially relative to the amount of published research which has gone on there. (Taphonomy is the study of the conditions and processes by which organisms become fossilized or are preserved.) This research has been quite localized in time and space. On the one hand, lands along the great Nile, from Nubia to Egypt have been intensively studied. However, the very grandeur of Egyptian civilization has meant that researchers have concentrated on the grand places, the palaces, temples, and burial monuments and emphasized ceramics and exquisite, special finds. Predynastic settlement has only recently begun to be investigated and even there the bone finds are rarely published in detail. Much less is known of the later prehistory and history of bone technology in the enormous territory of North Africa, best known archaeologically for the great Roman and Medieval Islamic cities whose ruins dot the shores of the continent.

On the other hand, because humankind is infinitely fascinated with its beginnings a great deal of attention has been paid to early hominid sites in South Africa, the Rift Valley and Congo. Over 50 years ago, Raymond Dart, the physical anthropologist famous for his discovery of the baby *Australopithecine* skull from Taung in South Africa (Dart, 1925), later interpreted some of the bone finds from the South African site of Makapansgat as being among the first “natural” tools used by these early hominid populations (Dart, 1949, 1962). Since then there has been debate concerning whether these artifacts were modified or simply used by these early hominids or were the result of nonhuman taphonomic processes such as erosion. However, such tools were never found, or rather they were not evident to the people working on these ancient sites and so the

idea was rejected. It was almost inevitable, given the relatively well-funded research on early human sites, regularly ongoing in Africa, that new finds would emerge to revive Dart’s ideas and even greatly expand them.

The First Humanly Modified Bones in the World—Termite Extraction Tools

Three of the most famous early hominid sites in the world, Swartkrans (Members 1–3, ca. 1.8–1.0 Mya) Sterkfontein (Member 5, 2.0–1.7 Mya), and Drimolen (2.0–1.5 Mya) are located in South Africa. These sites contain the first evidence for the systematic modification and use of long bone shaft fragments and horncores (the boney core within bovid horn sheaths) for tools (d’Errico & Backwell, 2001, 2003). These 68 tools were originally interpreted through microscopic analysis as tools for digging up tubers and working skins (Brain & Shipman, 1993). The bones from these three sites were later reexamined using a multidisciplinary approach that compared wear patterns on pseudobone tools created by known natural processes with the patterns on experimentally used bone tools and with the traces of wear found on the original objects (Backwell & d’Errico, 2005; d’Errico & Backwell).

It was immediately clear that the wear on the artifacts matched that neither on pseudotools nor on artifacts used for digging tubers or preparing hides. Wear traces on the working ends of tools used experimentally to excavate termite mounds most closely fit the wear traces found on these archaeological objects (Backwell & d’Errico, 2001). The bones used as raw material all show signs of weathering prior to use in that they have weathered breakage patterns as opposed to spiral fractures. In addition, compared to other bone fragments found at these sites the 68 modified bone objects stand out as a group since they are made from longer, broader bone fragments showing that they were intentionally selected by these early hominids. The researchers were able to find robust horncores with tips that had been reshaped by grinding.

The presence of such relatively sophisticated shaping suggests that even at this early date, modern human behavior was beginning to emerge, together with the ability to preplan objects according to culturally determined patterns. Although the technology used was far less complex than the completely shaped bone tools found at Middle Stone Age sites such as Blombos cave in southwestern South Africa or regularly encountered in materials from the Late Stone Age to the present day, there is still evidence that the location and direction of the facets produced on the tips represent planned behavior. The makers and users of these termite extraction tools, probably the robust australopithecine, *Paranthropus robustus*, seem to have had a clear understanding of the relationship between the shape of the tip and how the tools were going to be used (d'Errico, 2003; D'Errico et al., 2003). Such complex thinking was always previously associated with anatomically modern humans. The discovery and recognition of these tools have forced scientists dealing with human evolution to change their ideas about what defines modern human behavior.

The earliest specimens of anatomically modern *Homo sapiens* come conclusively from Africa at Omo Kibish in Ethiopia dating to 185,000 BP and Herto in Ethiopia dating to 165,000 BP. However, evidence for planned sophisticated tool making, especially complex techniques for modifying osseous materials for tools and ornaments or even symbolic expression, only appears, at the earliest, 50,000 years later. Students of the development of modern cognitive thought divide into two schools on this issue. One school, led by the scholar Richard Klein (2002), proposes a revolution in mental capabilities beginning around 40,000 years ago in Europe and some 5,000–10,000 years earlier in Africa. This can be seen for example, in the presence of ostrich shell disk beads at the site of Enkapune Ya Muto in Kenya dated to 45,000–50,000 BP. A smaller but growing group of researchers led by Brooks and Henshilwood have argued that technological complexity developed slowly in a piecemeal way along with what may be called modern human behavior (McBrearty & Brooks, 2000). Proofs of

this development may be found in the single-row barbed harpoons from Katanda in the Congo, which have been controversially dated to 90,000 BP (Brooks & Smith, 1987), and more securely in the well-dated finds from Blombos Cave dated to 77,000 BP.

Katanda and the Harpoon in Africa

Barbed harpoons have a special place in the history of bone technology of Africa (Yellen, 1998), demonstrating continuity in their basic form if not in their actual use. At Middle Stone Age Katanda, single-row barbed harpoons were found with remains of giant Nile carp. New dates seem to reconfirm that Katanda was a very early site (McBrearty & Brooks, 2000). The harpoons were dated using thermoluminescence techniques, and there is still debate whether the deposits where the harpoons and fish remains lay can be accurately dated using this method. It has also been suggested that the harpoons themselves may have been washed onto this terrace from later sites. The debate will probably only be resolved if more sites from this early date are found. The manufacturing technique used to produce the Katanda harpoons (D'Errico et al., 2003) was quite different from the technique worked out for the harpoons found at the Later Stone Age lakeshore site of Ishango in Zaire. Ishango is securely dated to around 25,000 BP (Brooks & Smith, 1987). The bone harpoons found there have been interpreted as signs of a fishing industry (Van Noten, 1982; Brooks & Smith).

It no longer seems quite so unreasonable that objects of such sophistication could have been produced so early in the history of modern *Homo sapiens*. Such single- and double-row barbed objects have also been found widely distributed across Africa on sites younger than 10,000 BP (for example, Camps, 1974; Camps-Fabrer, 1961; Haaland, 1992; Petit-Maire et al., 1983). Although the earliest harpoons from Katanda and Ishango in Central Africa are interpreted as having been used in fishing, there is ample ethnographic evidence showing that such barbed objects can also be used for hunting

land mammals, especially in bush land where the prey may not be visible. Mesolithic (Haaland) midden deposits at a lacustrine site from northern Mali dating to ca. 6900 BP contained 200 beautifully carved single- and double-row harpoons as well as fish hooks, long pins and a carved crocodile bone (Petit-Maire et al.).

Single-row harpoons were found at the Sudanese site of Esh Shaheinab in the Nile Valley as well as another late single-sided harpoon made from elephant ivory (Choyke, 1990) from the Middle Bronze Age site of Kerma (ca. 3500 BP), the capital of the Nubian Kingdom of Kush located on the Upper Nile in Sudan. Other, single-row barbed harpoons were discovered at two pre-Iron Age settlements (ca. 3000 BP) at Gajiganna on Lake Chad (Breurig, Neumann, & Van Neer, 1996). Later evidence, from a burial at the site of Daima I (around 2500 BP), also on the shore of Lake Chad, shows a double-row alternating barbed harpoon having been used as a weapon against humans (Connah, 1981). All these complex, fine objects were produced using a variety of techniques depending on the time period and local traditions. Whether used for fish, hunting land mammals or as weapons in human conflict all such objects required a disproportionate amount of time to produce, beyond what would have been practically necessary. Thus, their form has other social implications related to display and identity within and between groups of people.

Ornamentation and Symbolic Reasoning

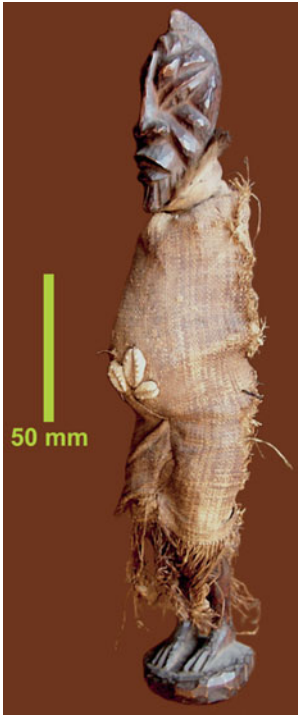
The well-published Middle Stone Age cave shelter of Blombos overlooking the Indian Ocean is securely dated by thermoluminescence to ca. 77,000 BP. It is notable for the 40 standardized bone tools found there including the 3 finely crafted spearheads and 3 projectile points. These points were formed by scraping and then polished to give them “added value” possibly in exchanges designed to facilitate relationships between neighboring groups of people. Other bone points at the same site were used in leather working

(Henshilwood et al., 2003; d’Errico, 2003, p. 192). However, the site is also remarkable for a ruminant mandible fragment with 11 incisions grooved on it with a flint point (d’Errico et al., 2001). Together with pieces of ochre that were ground flat and incised with patterns this represents evidence of symbolic thinking.

Even more sophisticated symbolic thinking is evidenced by the much later incised long bone handle or rod dated to ca. 25,000 from Ishango Cave in Zaire. These repetitive regular groups of notches have been interpreted as representing some kind of mathematical thought (d’Errico, 2003) or as a record of regular events, perhaps associated with female cycles such as menstruation (Brooks & Smith, 1987). This question will probably never really be resolved.

Blombos cave excavations also revealed 19 tiny bivalve shells of *Nassarius kraussianus*, which had been artificially drilled, as evidenced by wear facets around the edges of the holes (d’Errico, 2005). Engraved ostrich shell found at the site of Diepkopf on South Africa’s Western Cape dates to 60,000 BP while ostrich shell beads dated to 70,000 BP came to light at Loiyangalani in Tanzania. Again, it has been argued that such sophisticated objects were designed not only for personal adornment but also for exchange, a social lubricant for acquiring social partners (Yellen & Brooks, 1995; d’Errico, 2003). Fish vertebrae drilled to be made into beads have been reported from Mesolithic sites in Central Sudan (Haaland, 1992).

Beads made of bone and mollusk and bivalves and, in particular, ostrich shell, continue to be made even today (Figs. 1 and 2) everywhere on the continent (Vialou & Vialou, 1981; Breurig et al., 1996; Camps, 1974; Camps-Fabrer, 1966; Connah, 1981; Choyke, 1990; Van Noten, 1982; Petit-Maire et al., 1983). Ostrich shell beads and engraved shells appear regularly on Neolithic sites across North Africa. Cowrie shells, often with their dorsal sides cut off so they lay flat on clothing or on the neck, were certainly used in North Africa by the Neolithic period. Since their form resembles the human vulva it is usually suggested that these shell beads are connected with fertility. In ancient Egypt, there are



Bone Technology in Africa, Fig. 1



Bone Technology in Africa, Fig. 2

depictions of women wearing cowrie shells. As in many other places around the world, they are often imitated in other raw materials like gold, bronze, and bone. All these kinds of bone and shell beads represent a technological tradition of fantastic antiquity which seems to grow sharply in complexity and become widespread about 6,000–7,000 years ago, in North Africa at least, with a variety of incised bones, decorative pins, and a variety of ornamental shapes produced in bone and shell. The Neolithic period in Africa also saw the advent of special tools and ornaments made from human teeth, long bones, and even crania—surely all with special, socially deeply embedded symbolic significance (Camps-Fabrer).

The Use of Ivory

Although drilled and suspended animals' teeth, and in particular canine teeth, are found around the world, the earliest use of ivory still seems to have been at Olduvai Gorge in Tanzania, as reported by Mary Leakey in the Olduvai volume. This material has not been studied as it is difficult to differentiate true and pseudotools made on teeth, but Mary Leakey described them as tools. However, with the extinction of mammoths, African elephant and hippopotamus ivory use became restricted to Africa and the Near East, certainly from the fifth millennium onwards, only reappearing in Celtic continental Europe at the end of the Iron Age and with the coming of the Romans.

In Africa, ivory was traded from Central Africa to the Nile Valley to make prestige goods and beautiful ornaments at least from the predynastic Middle Bronze Age (second millennium BCE). There is now evidence of this trade in the Iron Age from Botswana (Reid & Segobye, 2000). Ivory as a raw material was exported out from Europe through Egypt around the Mediterranean. Roman sites in provincial Europe frequently have objects made from ivory, manufactured elsewhere in the empire.

Manufacturing of ivory seems to have become common rather late compared to other raw materials. From the Kushite site of Kerma comes a



Bone Technology in Africa, Fig. 3

hippo ivory harpoon as well as elaborately carved inlays from elephant ivory (Choyke, 1990). Dynastic Egypt sees an explosion in the use of ivory as decoration for furniture and as beads, buttons, and statuettes, perhaps related to the widespread use of metal in bone and ivory industrial manufacturing. This tradition of ivory working continued into medieval times (for example in Ghana, Stahl & Stahl, 2004) and until recently in sub-Saharan Africa (Figs. 3 and 4).

Bone Tool Production in Later Prehistory

By the Neolithic period, bone working had developed into a multitude of variable industries using different combinations of techniques. Each group had their own standardized way of making tools and these were best made into pointed tools like awls and projectile points. Use was frequently made of ruminant metapodium bones, which can be grooved down the median line with a



Bone Technology in Africa, Fig. 4

pointed flaked stone tool and then easily split. Using one of the epiphyseal ends as a handle the diaphysis was sharpened through some combination of scraping with a flaked stone tool or abrasion with a rough-textured stone. This is an ancient technique, even preserved in a ritual form as a burial offering in the cemetery at Kerma where two new and identical mirror-image sheep metapodial awls from two different bones were deposited with the deceased (Choyke, 1990). Awls were used in leather-working and coiled basket working. Stone tools were the tools of choice in bone working until the end of the second millennium BCE in Egypt when metal tools took over. Stone tools, however, were still important at Kasteelberg, an Iron Age site in South Africa where a combination of hammering off the epiphyseal ends, grooving, splitting, and fine grinding and polishing were used to create beautiful bone projectile points or link-shafts for arrows. These objects have parallels with objects used until recently by San Bushmen (Smith & Poggenpoel, 1988). Simple bone awls based on

the spiral fracture of long bones were also common at Kasteelberg as elsewhere across Africa and the world. Otherwise, there are broad tendencies for bone to continue to be made into objects with beveled edges used as wedges, scrapers, and burnishers, especially for leather working and ceramic production.

It would be impossible here to go into all the different ways bone, ivory, ostrich-egg shell, and mollusk shell have been used in the last 6,000 years in Africa. There is a general tendency for bone objects to be made for increasingly special purposes. Often they were made to be parts of composite objects as fittings, handles, closures, and ornaments. Hopefully, as archaeological work continues in Africa it will be possible to present a more integrated picture of the way this ancient technology developed there.

See Also

- [Beads](#)
- [Fishing in the Stone Age](#)
- [Ishango Bone](#)

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Brahmagupta

R. C. Gupta

“Brahmagupta holds a remarkable place in the history of Eastern civilization” (Sachau, 1971). ► **Bhāskara II** described Brahmagupta as *Gaṇakacakra-cūdāmani*, jewel among the circle of mathematicians.

Brahmagupta was born in AD 598 according to his own statement: “... when 550 years of the Śaka era had elapsed, Brahmagupta, son of Jisṇu, at the age of 30, composed the *Brāhmasphuṭasiddhānta* for the pleasure of good mathematicians and astronomers.” Thus he was 30 years old in Śaka 550 or AD 628 when he wrote the

Brāhmasphuṭasiddhānta. That he was still active in old age is clear from the title epoch of AD 665 used in another of his works called *Khaṇḍa-khādyaka*. Prthūdaka Svāmin, an ancient commentator on Brahmagupta, calls him Bhillamālācārya, which shows that he came from Bhillamāla. This place has been identified with the modern village Bhinmal near Mount Abu close to the Rajasthan-Gujarat border.

We have no knowledge of Brahmagupta's teachers, or of his education, but we know he studied the five traditional *Siddhāntas* on Indian astronomy. His sources also included the works of Āryabhaṭa I, Lāṭadeva, Pradyumna, ► **Varāhamihira**, Siṃha, Śrīṣeṇa, Vijayanandin, and Viṣṇucandra. He was, however, quite critical of most of these authors.

The *Brāhmasphuṭasiddhānta* is Brahmagupta's most important work. It is a standard treatise on ancient Indian astronomy, containing 24 chapters and a total of 1,008 verses in *āryā* meter. The *Brāhmasphuṭasiddhānta* claimed to be an improvement over the ancient work of the *Brahmapakṣa*, which did not yield accurate results. Brahmagupta used a great deal of originality in his revision. He examined and criticized the views of his predecessors, especially ► **Āryabhaṭa I**, and devoted two chapters to mathematics. There have been many commentators on this work. The earliest known was Balabhadra (eighth century AD), but his commentary is not extant.

Chapter 7 is on *Gaṇita* (Mathematics). It deals with elementary arithmetic, algebra, and geometry. The subject is presented under 28 topics of logistics (arithmetical operations) and determinations, including problems related to mixtures, plane figures, shadows, series, piles, and excavations. He wrote in a concise and understandable style, whether dealing with simple mathematics or complex geometry. In the treatment of surds, Brahmagupta is remarkably modern in outlook. The *Brāhmasphuṭasiddhānta* includes formulas for the rationalization of the denominator, as well as a marvelous piece of pure mathematics in the rule for the extraction of the square root of a surd. Still more remarkable algebraic contributions are contained in a chapter entitled

Kuṭṭaka, which is a traditional name for indeterminate analysis of the first degree. The second order indeterminate equation

$$Nx^2 + c = y^2$$

is called *varga-prakṛti* (square nature). An important step towards the integral solutions of such equations is what is called Brahmagupta's Lemma in the history of mathematics. In modern symbology the Lemma is as follows:

If (α, β) is a solution of (1) with $c = k$, and (α', β') is its solution with $c = k'$, then $(\alpha\beta' \pm \alpha'\beta, \beta\beta' \pm N\alpha\alpha')$ will be its solution with $c = kk'$.

This lemma not only helps in finding any number of solutions from just one solution, but it also helps in solving the most popular case of $c = 1$, provided we know a solution for $c = -1$, or ± 2 or ± 4 .

In geometry, Brahmagupta's achievements were equally praiseworthy. He wrote a fine symmetric formula for the area of a cyclic quadrilateral, which appeared for the first time in the history of mathematics. Even more important are his expressions for the diagonals of a cyclic quadrilateral.

Brahmagupta's name has been immortalized by yet another achievement. A "Brahmaguptan quadrilateral" is a cyclic quadrilateral whose sides and diagonals are integral (or rational) and whose diagonals intersect orthogonally. He gave a simple rule for forming such figures in the *Brāhmasphuṭasiddhānta* (Chap. 7, verse 38): If a, b, c and α, β, γ are the sides (integral or rational) of two right-angled triangles (c and γ being hypotenuses), then $\alpha\gamma, b\gamma, c\alpha$, and $c\beta$ are the required sides of a Brahmaguptan quadrilateral.

Prior to Brahmagupta, the usual method for computing the functional value intermediary between tabulated values was that of linear interpolation, which was based on the rule of proportions. He was the first to give second order interpolation formulas for equal as well as unequal tabulated argumental intervals. Mathematically, his rule is equivalent to the modern

Newton-Stirling interpolation formula up to the second order.

The *Khaṇḍa-khādyaka* is a practical manual of Indian astronomy of the *Karaṇa* category. The author claims that it gives results useful in everyday life, birth, marriage, etc. quickly and simply, and is written for the benefit of students. The work consists of two parts called the *Pūrva* and the *Uttara*. The former comprises the first nine chapters and expounds the midnight system. The latter six chapters provide corrections and additions. This work has been studied by a great number of commentators, from Lalla in the eighth century to Āmarāja in the twelfth. It was translated into Arabic first by al-Fazārī (eighth century) and then by ► [al-Bīrūnī](#).

Brahmagupta's genius made use of mathematics (traditional as well as that which he developed) in providing better astronomical methods. He used the theory of quadratic equations to solve problems in astronomy. He knew the sine and cosine rule of trigonometry for both plane and spherical triangles. He supplied standard tables of sines and versed sines.

The historian of science George Sarton called him "one of the greatest scientists of his race and the greatest of his time."

See Also

- [Algebra in India: *Bījagaṇita*](#)
- [Arithmetic in India: *Pāṭiḡaṇita*](#)
- [Astronomy: Indian Astronomy in China](#)
- [Geometry in India](#)

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Bread in Africa

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Bread and Bread-Baking Technologies in Africa

Bread is a dietary staple in North Africa, North-eastern Africa, and the Horn of Africa, and it is important in the diet of many Saharan and sub-Saharan people. African breads are made from the flours of a variety of cereals, tubers, and corms that are baked, steamed, and

sometimes fried to produce pancake, flat bread, leavened or slightly leavened loaves, or cakes using ovens, hearths, griddles, pots, and molds. Technical choice in bread baking is associated with the baking properties of bread ingredients and social group's culinary practices and preferences and does not represent evolutionary stages.

The Bread/Oven Porridge/Pot Bread/Griddle Traditions

Research of Africa's culinary practices includes the history of bread consumption and its associated technologies, an investigation that is far from exhaustive. Several researchers observe a general (but not absolute) culinary divide between bread-based cuisines that use ovens and griddles in North Africa, Northeastern Africa, and the Horn of Africa and porridge-based cuisines cooked in pots in many sub-Saharan societies. These scholars differ in their interpretations of the geographic extent of bread-consuming cultures and the number of associated technologies involved in Africa's culinary divisions. Problematic is the lack of clear definitions for bread and porridge. For instance, many types of African bread are made with a batter that involves boiling some of the fermented dough into thick porridge before baking the bread, especially when using non-gluten-containing ingredients (see below). This process causes the dough to become elastic and starches to gelatinize trapping gas that slightly leavens the bread as it bakes (Lyons & D'Andrea, 2003). Many African porridges are very stiff dough that is used like bread by diners who pull pieces of dough from the mass with their fingers to scoop up sauces served with the meal. Small viscous dough balls (*th'ollo*) are produced in northeastern high-land Ethiopia without boiling the flour in a pot. Instead soaked barley grains are roasted in a griddle and ground, and the flour is sieved and mixed with a liquid and formed into balls eaten with a spicy sauce (Lyons, 2007). Other porridge is gruel and eaten with a spoon or drunk from a bowl. Despite the lack of clear definitions, archaeologists generally apply the term porridge to any flour mixed with liquid and boiled in a pot



Bread in Africa, Fig. 1 Map of place names in the text (Source: Map by Diane Lyons)

regardless of the density of the final product. Bread is a dry food in the form of pancake or flat, molded, or slightly leavened loaves made in ovens, griddles, and pots. It is worth noting that the separation of Africa's starchy staples into bread and porridge traditions glosses over the complexity and variety of its cuisines.

In their interpretation of bread/oven porridge/pot cuisines, Edwards (1996, 2004), Haaland (2007, 2012), and Pope (2014) focus on traditions

in Ancient Egypt and Sudan (see Fig. 1). In Predynastic and Dynastic Egypt, bread was produced with flours of emmer wheat or hulled barley, both Near Eastern cereals that spread from the Levant presumably with the concept of bread baking. Haaland (2007, 2012, p. 330) suggests that the porridge/pot tradition developed in the Middle Nile with pottery and the collection/cultivation of wild sorghum in the early Holocene. It is widely believed that wild sorghum (and other

indigenous grass grains) was eaten for millennia in Northeastern Africa and the Sahara, but timing and location of sorghum domestication is still being determined (Haaland, 2007, 2012, p. 330; Neumann, 2005). Currently, sorghum domestication is firmly dated to 500 BCE in Nubia (Fuller, 2004), but earlier dates in the second millennium BCE are reported from Mahal Teglinos in the Kassala region (Baldados & Constantini, 2011). It is likely however that the porridge/pot tradition has multiple origins. Africa's earliest pottery is dated before 9400 cal BCE at Ounjougou, Mali, in West Africa as well as in the Nile Valley (Huysecom et al., 2009). Huysecom et al. suggest that pottery was developed in the West African Sahel with the reestablishment of grasslands in the early Holocene in order to boil grains of wild grasses rather than to bake bread.

Bread baking is also important in the Nubian region including domestic sorghum bread products baked on griddles (see below). Edwards (1996) suggests that the production of sourdough bread in the Middle Nile (e.g., Nubia) is unique for sub-Saharan African cuisines with the notable exception of *injera* in Ethiopia. In fact, *injera* is the staple pancake bread for the entire Horn of Africa (Ethiopia, Eritrea, Djibouti, and Somalia), a large geographic and culturally diverse zone. Depending on local crops, *injera* and many different types of fermented or unfermented flat or slightly leavened bread are made from flours of indigenous and Near Eastern ingredients baked on griddles. The widespread production of griddle baked bread in the Middle Nile and the Horn of Africa suggests that Africa has at least three culinary traditions based on distinct technologies: porridge/pot, bread/oven, and bread/griddle. Bread is eaten in the Sahara, North, East, southern, and West Africa, and in these societies bread is made of indigenous and nonindigenous grains, corms, and tubers that are baked in hearth ash, earth ovens, and griddles (see below).

Why different technologies? The choice to use griddles, ovens, or molds for bread baking is determined in part by the different performance characteristics of Near Eastern and African foods (Lyons, 2007; Lyons and D'Andrea 2003). Only Near Eastern cereals contain gluten, an elastic

protein formed when their flours are mixed with liquid to produce dough. If yeast is added and ferments, it produces carbon dioxide gas that becomes trapped in the dough's elastic structure causing it to rise. Sourdough leavening is common in Africa. It is produced with residue left in dough mixing containers or by adding dough saved from a previous batch. Barley and many varieties of wheat (e.g., emmer wheat and at least one wild ancestor of wheat) form gluten with poor leavening capacities. These cereal flours still produce viscous dough suitable for shaping by hand, a requirement for baking on oven floors and walls. Light airy bread was possible only after bread wheat, a variety with superior leavening capabilities, was developed in southwest Asia probably during the fourth millennium BCE.

African cereals (sorghum, millets, and *t'ef*) and other indigenous plants (*enset*) do not contain gluten, and their flours are made into fermented or unfermented batter or thick porridge and baked on griddles, trays, or in molds or shallow earth depressions. Only sorghum flours will form viscous dough suitable for baking in ovens, but it is nonelastic and will not rise. Lyons and D'Andrea (2003) suggest that griddle bread baking could be an indigenous technology that developed with the domestication (or use of wild varieties) of African foods. They hypothesize that because griddle technology can incorporate Near Eastern cereals as ingredients in pancake, flat and slightly leavened bread, and Near Eastern oven technology cannot bake bread from African foods with the exception of sorghum, then the domestication of African cereals may precede that of Near Eastern cereals in the Ethiopian highlands. Near Eastern cereals were then adapted to a preexisting African culinary practice. The timing of African cereal domestication (which does not preclude earlier use of wild varieties of these cereals) is gradually unfolding. The paleobotanical record for the first millennium BCE is dominated by Near Eastern cereals (emmer wheat and barley), but domesticated *t'ef* is also firmly dated to the fourth century BCE near Asmara in Eritrea (D'Andrea, Schmidt, & Curtis, 2008). During Aksumite times (third century BCE to 700 CE), crop diversity increased and included a mix of

indigenous and Near Eastern cereals (including sorghum, finger millet, and bread wheat) similar to cropping practices found in the region today (D'Andrea et al., 2008). However, the paleobotanical record may be biased by differential preservation of Near Eastern and indigenous cereals. For instance, different cooking practices favor charring and preservation of Near Eastern cereals but not indigenous ones (D'Andrea, 2008; Lyons & D'Andrea 2003).

Regional Bread History and Technology

Bread baking is ancient in Africa, but some baking practices leave little material evidence. 18,000 years ago wild tubers were made into a fine mush to feed young children in Kabbaniya, Egypt (Hillman, 1989). Pot boiling was unknown at this time, and plants may have been ground and then baked in shallow earth depressions similar to those used by the Tuareg (see below) (Close, 1995). Wild grass grains, including wild sorghum, were collected by nomadic hunter-gatherers-herders in the Sahara and along the Nile during the early and middle Holocene (Neumann, 2005). Foods may have been boiled in early pottery vessels, but ash bread is common with nomadic people and leaves no evidence. For instance, hunter-gatherers in southern Africa make "cakes" from ground corms of the iris family baked in hearth embers (Deacon, 1984, p. 258), and nomadic pastoralists in northern Ethiopia make unleavened bread by inserting a hot stone into wheaten bread dough that is baked in the hearth (Dufton, 1970, pp. 219–220).

Ancient Egypt

Emmer wheat and hulled barley have been grown in the Nile Valley since the sixth millennium BCE and were used to make bread and beer in Dynastic Egypt until free-threshing wheat was adopted after the conquest of Alexander the Great in 332 BCE (Murray, 2000). Bread-baking practices are known from tomb paintings, miniature models of kitchens and bakeries, statuettes,

texts, excavations of bakeries, oven installations, analyses of preserved bread loaves, and experimental studies (Samuel, 2000). Caution is required in interpreting imagery as "photographic" records, as these artistic renderings were intended for elite burials and likely do not provide details or the range of bread-baking practices. Most evidence indicates that grain was pounded in a mortar, ground into flour on a saddle quern, sieved through baskets, and then mixed with water or milk and sometimes dates, honey, eggs, butter, coriander, sesame seeds, or fruit (Samuel, 2000; Wilson, 1988). Bread may or may not have been leavened, and chemical studies of preserved bread indicate that many were not fermented (Samuel, 2000). Bread products were coarsely textured and caused heavy wear on Ancient Egyptian's teeth (Leek, 1972).

During the Old Kingdom (2686–2160 BCE), emmer wheat and barley flours were baked into bread in commercial ovens that used large conical molds called *bedja*. *Bedja* were stacked and preheated, filled with dough or batter, covered, set into depressions in the bakery floor, and banked with hot embers (Lehner, 1997; and the Giza Plateau Mapping Project <https://oi.uchicago.edu/research/pubs/ar/93-94/giza.html>). Bread molds change from large bowl forms that were thick to retain heat and to prevent the bread from burning to long cylinder shapes by the Middle Kingdom (2055–1650 BCE) that baked bread in a shorter time (Samuel, 2000, p. 586). The latter type of molds had to be broken to remove the bread (Jacquet-Gordon, 1981).

Throughout the dynastic period, bread was baked in domestic kitchens in bread molds baked in box ovens, in clay pans set on top of smaller box ovens; hand-formed loaves were baked in hearth ash, on a stone set in the hearth, in small dome-shaped clay ovens; or dough was baked on the outside of clay oven walls (Wilson, 1988).

During the New Kingdom (1550–1069 BC), emmer wheat predominated and bread was baked in tannur-type ovens that became the main domestic and temple bread-baking technology (Samuel, 1999). Tannur first appear in southwest Asia in the late fourth millennium BCE (Van de

Mieroop, 1997, p. 156) and consisted of a clay cylinder, sometimes set into a bench, with wood, cattle dung, or other fuel fed through an opening at the bottom. Dough is inserted through the top and is pressed onto the hot interior walls to bake. Bread molds were used for ritual purposes in the New Kingdom, and a variety of hand-formed bread shapes were baked inside large commercial domed ovens. Some ovens were so large that the baker was held by his feet to avoid falling into the fire as he reached inside to position dough and retrieve baked bread (Wilson, 1988, p. 55). There were 40 different bread types recorded during the New Kingdom, and the Egyptians were the first to make leavened bread. There is evidence that they had developed a form of pure yeast in barm form likely obtained from beer brewing (Weeks, 2004, http://www.thebanmappingproject.com/articles/article_15.4.html; Wilson, 1988, p. 14).

Ancient, Historic, and Contemporary Middle Nile (Nubia) Bread

Ancient Egypt and Nubia had a long history of colonization and commercial interaction in the predynastic and dynastic periods. This resulted in the spread of wheat, barley, and bread-baking technology from Egypt to Nubia. Jacquet-Gordon (1981) developed a typology of conical bread molds found on Egyptian and Sudanese sites dating from the Egyptian predynastic/early dynastic period to the 25th dynasty (747–646 BCD) when Nubian (Kushite) kings briefly ruled Egypt. Bread molds are only found in Sudanese sites of the Kushite Empire, a period subdivided into the Napatan (ninth–fourth centuries BCE) and the Meroitic (fourth century BCE–fifth century CE). There are differences in the distribution of bread molds and bread consumption in Ancient Egypt and Nubia. Bread molds are found in Ancient Egyptian cemeteries, habitation, and temple sites, and bread was eaten by elite and poor alike. In Nubia, bread molds are found almost exclusively with temples dedicated to Amun (Anderson, D'Andrea, Logan, & Ahmed, 2007), although Haaland (2012) suggests that the elite adopted bread consumption as part of the process

of increasing social complexity in the Kushitic period. Bread was offered to the god Amun, who was believed to consume the bread's essence, and later priests and other appropriate people ate the bread (Anderson & Salah El-Din Mohamed Ahmed, 2006a). Large mounds of ash and broken conical molds are found behind these temples and are sometimes associated with ovens (Anderson et al., 2007).

It is assumed that Napatan period bread was made with flours of emmer wheat or barley (Anderson et al., 2007; Edwards, 2004), but a recent study of bread molds and bread-baking equipment excavated from the Meroitic site of Dengeil determined that sorghum rather than wheat was used to make bread (or beer) in these molds (Anderson et al., 2007). By the Meroitic period, sorghum was the dominant crop of the Kushite Empire, and it was symbolically associated with kingship (Anderson et al., 2007). Bread molds were shaped by hand around a wood form and were produced in two sizes: large (c. 100 ml of dough) and small (c. 30 ml of dough) (Anderson & Salah El-Din Mohamed Ahmed, 2006b). There are no ovens found at Dengeil, and the bread molds are not charred by fire. An experiment showed that the molds could be used to shape *aceda* (soft fermented or unfermented sorghum porridge) (Anderson et al., 2007), which today is molded with a bowl, served on a plate, and eaten with a spoon. Notations on a clay sherd found at Dengeil are interpreted as a baker's record of bread batches or a list of bread ingredients.

Sorghum bread products were baked on clay griddles (*doka*) in the Middle Nile for over a millennium, but *doka* are now nearly replaced by the use of a thin iron griddle (*sadj*). Edwards (1996, p. 71) claims that sorghum bread was not made until the middle of the first millennium CE when *doka* first appear in the Kushite ceramic repertoire. Anderson et al. (2007) suggest a slightly earlier date for *doka* based on the representation of round bread in Kushite offering trays at Meroe dated to the second century CE. These loaves are hand molded and are similar in form to five bread loaves recovered from a Ballaña culture cemetery (fourth–sixth century CE) in Lower Nubia. These round loaves may represent bread

Bread in Africa,

Fig 2 Kissra baking

(Source: Photo Diane Lyons)



prepared on *doka* (Anderson & Salah El-Din Mohamed Ahmed, 2006a). *Doka* are common on medieval Nubian sites (ca. 500–1500 CE) when the region converted to Christianity. *Doka* continue into the postmedieval period, which Edwards (2004, p. 385) attributes to new Islamized and Arabized elite influences that include wheat and bread culture.

Many varieties of sorghum and wheaten bread continue to be produced on griddles in the Middle Nile today (see below), and their distribution is determined by cropping patterns. Wheat and barley are grown in the northern part of the Middle Nile, and sorghum predominates in the south. *Kissra* is staple pancake bread made of fermented or unfermented sorghum or finger millet batter on griddles. *Doka/sadj* are balanced on three stones or set into a clay bench over a hearth fueled with animal dung, small pieces of wood, or other dried plant matter (Dirar, 1993, p. 171). In the Delgo region, women make bread (*gerasa* and *sensana*) with fermented or unfermented wheat or barley flour dough although barley is considered inferior for bread making. The *doka/sadj* are wiped with an oily cloth to lubricate the surface before and during baking (see Fig. 2). At least eleven different types of Sudanese sorghum or sorghum-based breads are produced including a thin wafer called *abreh* of fermented sorghum dough that is boiled into a thin porridge before it is spread paper thin on the hot griddle. The resulting wafer bread is made into a beverage, and a spiced and dyed

version (*hulu mur*) is served at Ramadan. Women also make small clay-domed ovens in their kitchens to bake wheaten loaves (see Fig. 3). Commercial bakeries in urban centers have much larger domed ovens made of baked brick for the production of wheaten bread (*aish baladi*, similar to pita bread). These ovens are heated with wood fuel placed on one side of the oven, and flat bread dough rounds are positioned on the other side of the oven using a wooden paddle (see Fig. 4).

Other baking technologies are reported for eastern Sudan. Thick sorghum porridge is baked into small flat bread called *hadib*, on the inner preheated walls of earthenware pots or metal petrol cans similar to tannur (or *mofa*, see below) (Dirar, 1993, p. 220).

Horn of Africa

Bread is a staple food in the Horn of Africa. In northern highland Ethiopia, bread was a dietary staple by Aksumite times (300 BCE to 800 CE) when huge quantities of bread were taxed from rural households (Kobischankov, 1979). No definite bread ovens are known from the highlands, but clay griddle fragments similar to *mogogo* (Tigrinya) or *metad* (Amhara) were found with evidence of domesticated t'ef, emmer wheat, and barley dated to 500 BCE near Lake Tana (Dombrowski, 1971). However, evidence of

Bread in Africa,**Fig. 3** Domestic bread oven (Source: Photo Diane Lyons)

B

Bread in Africa,**Fig. 4** Commercial oven baking aish baladi (Source: Photo Diane Lyons)

mogogo is found only in Aksumite deposits after the sixth century CE (Phillipson, 2012, p. 110). *Mogogo* are found with Black Ware in the Asmara region in Eritrea by the late first millennium CE (Schmidt & Curtis, 2008) and may be associated with the Beja (pastoralists from eastern Sudan) who are hypothesized to have migrated into the Asmara area at that time. Although archaeologists focus on *mogogo* as evidence of bread making, it is not the only griddle used for this purpose. In eastern Tigray Ethiopia, bread is made also on very thin basin griddles (*meklo gundo*, 2–3 mm thick) (Lyons, 2007), which are fragile and may not be preserved (or be recognized as griddles) in archaeological deposits.

In northern highland Ethiopia and Eritrea, contemporary *mogogo* are ca. 60 cm in diameter and are set on top of a firebox of upright, clay-covered stone slabs with an opening to the front for feeding fuel of cattle dung and small branches. In the central and southern highlands, *metad* are balanced on three stones set over a fire. Griddles are lightly lubricated with crushed oily seeds, and removable dome-shaped covers are sometimes used to steam the bread (Lyons & D'Andrea, 2003). Many types of bread are produced. *Injera* is made from flours of *t'ef*, finger millet, wheat, barley, sorghum, pulses, and more recently maize and is served with most meals (Lyons, 2007; Lyons & D'Andrea, 2003) (see Fig. 5). Viscous bread dough made with flours of wheat, barley, or



Bread in Africa, Fig. 5 Injera baking on a mogogo (Source: Photo Diane Lyons)



Bread in Africa, Fig. 6 Bread baking on leaves on a mogogo (Source: Photo Diane Lyons)

sorghum grains is also baked as flat bread or slightly leavened bread on the *mogogo*, including bread made of malted barley or finger millet used in beer brewing. Thick leavened wheaten loaves (2–3 cm) are placed on leaves or succulents that serve to flavor the bread and to prevent the bread from burning (see Fig. 6). Some bread types are steamed by sealing the *mogogo* cover to the griddle using fresh cow dung or clay. Steaming improves the crust and helps leaven the bread. In eastern Tigray, *mogogo* are also set inside special pots (or more recently metal drums) on an interior flange or over stones. Water is poured into the bottom of the pot below the *mogogo* (or metal tray), and the pot is set over a fuel source to steam the bread. In the southern Ethiopian highlands, *injera* and different varieties of flatbread are prepared from the fermented pseudostem of *Ensete* and other tubers (Arthur, 2014; Smeds, 1955, p. 24). Shack (1974) also reports that Harari produce a staple sorghum loaf called *uxat*, but no information is provided on its preparation. Bread ovens are not found in rural kitchens, and the

commercial bakeries that produce European style bread were introduced to Ethiopia and Eritrea in the twentieth century (Pankhurst, 1968, p. 712).

Injera is a dietary staple in Djibouti and is the same as Ethiopian *injera* and made of *t'ef*. Somalia has different types of bread (Abdullahi, 2001, p. 113). In the north, *injera* called *lahoh* is made of sorghum flour batter poured onto a well-oiled griddle. Sweet *injera* and bread made with eggs are also produced. Thick sorghum dough is baked into flat bread on an oiled pan, and “Swahili” sorghum (or maize) flour bread (*muufo*) is baked in a tannur-type oven (possibly a *mofa* oven; see below) along the southern Somalian coast. Indian influences from Somalia’s long participation in the Indian Ocean trade include *roti* bread made in commercial ovens in towns.

Northern Africa

Wheat and barley were grown in North Africa since the mid-first millennium BCE, and sorghum

and pearl millet were introduced into Libya during the early Islamic period (Pelling, 2003). Northern Africa was an important wheat-producing province for Rome, and the analysis of Roman diets in skeletons recovered at Leptimus, Tunisia (Keenleyside, Schwarcz, Stirling, & Lazreg, 2009), indicates that the population's diet was dominated by terrestrial products that would have included bread. One method for bread production in Roman North Africa is a portable clay pot oven (*cilbanus*), the remains of which are found in Roman Tunisian sites (<http://blog.britishmuseum.org/2013/07/19/a-very-versatile-roman-oven/>). Sally Grainger's experimental work demonstrates that the *cilbanus* is an efficient means of cooking many different dishes including bread by placing the food inside the pot and heaping hot coals around and over the lid. Bread can also be baked on the tray part of the *cilbanus* over radiant heat. Today, in large villages in Tunisia, leavened wheaten bread is made in commercial tannur-type ovens, and griddle cakes (*kesra*) are baked in a dish or on a metal plate. Griddle bread and pancake are sometimes stuffed with vegetables, meat and fruit, or a spicy sauce (Balfet, 1975).

In the High Atlas Mountains of Morocco, bread flours are made of wheat, barley, maize, millet, and sometimes acorn (Balfet, 1975; Bruneton, 1975). According to Bruneton (1975), women make ovens (*afarnu*) by piling small stones 50 cm high and 80 cm diameter at the base, and the pile is coated with thick clay. When the clay dries, holes are cut at the top and the base and the stones are removed. The base of the oven is made of flat stones set over rock salt to retain heat. Bread types include leavened wheaten bread for feast days and barley loaves for daily eating. Once the oven is heated, coals are swept to the side, and leavened bread dough is placed on the oven floor. Unleavened dough is baked on a hot stone plate or pottery sherd balanced on two stones over a fire (Bruneton, 1975) or on ceramic plates (griddles) called *makla* that were placed on the hearth (Peña, Peña-Chocarro, Estévez & Urquijo, 2003). Dough is flavored with herbs, oil, garlic, onions, dill, sesame, and aniseed (Balfet, 1975; Bruneton, 1975).

Sahara

Excavation of houses from settlements of the Garamantes Polity (ca. 500 BCE to 500 CE) in the Fezzan region of southern Libya determined the presence of hearths, pottery, grinding stones, and cereals but no evidence of bread baking. Medieval period records of Islamic and North African travelers remarked on Saharan Berber population's bread consumption (Lewicki, 1974). Bread in pancake form or hard biscuit was made from flours of millet, sorghum, tubers, and wild seeds. Bread made of tuber flours was reported as a staple for the Zaghawa, but baking technologies are not described. Today tannur ovens are found in courtyards of historic and contemporary rural houses in the Fezzan region (Mattingly, 2003).

The Tuareg of the Central Sahara are believed to descend from the Garamantes. Wheaten bread is common in the diet of northern Tuareg and is baked in hearth ash, on a metal baking sheet, or on the sides of an inverted metal pot heated over the fire (Nicholaisen, 1963). Tuareg make millet flour bread (*taguella*) that is baked in a preheated shallow depression in the ground. Fine sand and hot coals or a small fire is set over the top to bake the batter through (Gast & Adrian, 1965; Nicholaisen, 1963). Wheaten bread is washed, broken into pieces, served with liquid butter, and eaten with spoons; *taguella* is served with a sauce. *Taguella* may be the bread described by Ibn Baṭṭūṭa as *tekoula*, a hard biscuit used to provision trans-Saharan trade caravans from Timbuktu to North Africa (Lewicki, 1974, p. 160). Tuareg women produce medicinal bread for their own consumption made with millet flour, berry juice, and special plants. These ingredients are mixed with water into a cake and baked like other millet bread (Nicholaisen, 1963). Similarly nomadic pastoralists in Sudan and Egypt use larger earth ovens with floors of heated pebbles or pot sherds to bake sorghum or millet flour dough (Dirar, 1993, p. 218; Hobbs, 1989).

East African Coast

Ovens called *mofa* occur in ninth-century AD houses at Shanga on the Kenyan coast, and the

ovens were used later on Arab dhows (Horton, 1996, pp. 46, 353). *Mofa* consist of clay bowls set in floors that were possibly used to bake bread and boil liquids (Horton, 1996, Plate 21). At the nearby site of Manda, *mofa* were made of clay cylinders of ca. 40 cm in diameter with no base and were constructed inside a pit (Chittick, 1984, p. 153). The cylinder was then surrounded with soil and a fire was lit inside and sorghum or millet flour dough was baked on the hot interior walls. Twelfth-century Chinese traders describe this bread as a dietary staple (Horton, 1996, p. 353). Horton (personal communication, 2005) observes that *mofa* are concentrated in northern Swahili coastal sites where sorghum is consumed and are much less common on southern coastal sites where rice is eaten. Although *mofa* are similar to *tannur*, Horton suggests that this simple technology could be a local invention. This bread type apparently extends geographically to Somalia (see above).

West Africa

McIntosh (1995 pp. 159–160) suggests that bread may have been made at Jenne-Jeno in Mali 2,000 years ago from pearl millet and sorghum flours using earth depressions similar to those of the Tuareg. A millennium later, medieval travelers observed bread consumption in the Central and West African savanna states from Lake Chad to Africa's West Coast (Lewicki, 1974). Medieval Arabic travelers describe pancake and bread made with millets and tubers in Jenne and Gao that were consumed either as luxury items or cheap traveler's fare (Lewicki, 1974, pp. 46–47, 80). Fritters made of fried millet dough were described as common in Bornu (northern Nigeria/Cameroon) as well as in areas farther west. Unfortunately baking technologies are not described. Today round clay griddles with four to six small bowls are used to fry fermented batter of pearl millet flour into small cakes called *masa* or *marsa* in Ghana (Apentiik, 1997) and Mali. Guinea millet is also made into fritters and cakes in northwestern Guinea (National Research Council, 1996, p. 237).

Colonialism and Globalization

European colonization brought wheaten bread to sub-Saharan Africa. Colonial regimes denigrated African culture as inferior to their own, including African culinary practices based on sorghum and millet cereals. In French West Africa, European style bread was introduced by the early twentieth century, wheat was imported, and bakeries were established in coastal centers (Mosley, 2004). As urbanization expanded, indigenous acceptance of bread increased, and it was perceived as modern and more sophisticated than sorghum and millet porridge. Mosley (2004) notes that colonial regimes acted differently. In Spanish Equatorial Guinea, Africans were not allowed to eat European food including bread until they demonstrated a level of cultural assimilation. However, as the demand for bread increased in cities, African colonies and postcolonial nations became entangled in the "wheat trap," a phenomenon in which sub-Saharan nations became dependent upon imported Western wheat at the detriment of indigenous crop production (Kimmage, 1991; Mosley 2004). Food scientists continue to develop methods to produce leavened bread with African cereals as a measure to protect African crop production and reduce reliance on imported wheat (National Research Council, 1996).

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Brewing in Africa

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Beer in Africa has been an important food staple since the Old Kingdom of Egypt (5400–5500 BP), from the site of Hierakonopolis (Geller, 1992; Maksoud, El-Hadidi, & Amer, 1994) and the New Kingdom of Egypt (1550–1070 BCE), to workmen’s village sites at Amarna and Deir el-Medina (Samuel, 1996). In many cultures of Africa, beer provides a substantial part of the diet, with one-eighth to one-third of grain crops being processed and consumed as beer (Platt, 1964). Beer socially binds people together and serves to reinforce social hospitality, usually without aggressive behavior or addiction

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(Mandelbaum, 1965). African societies use beer to indicate wealth and status, as a commodity of reciprocity, hospitality, and communality, as a payment of tribute to leaders, and as a vital food for the redistribution of wealth (Arthur, 2003). In some cases, colonialism has dramatically changed the structure of beer and its ties to society. This paper reviews the importance of beer in Africa based on a number of ethnographic case studies.

Beer Production

The production of beer in Africa is usually under the domain of women. It requires a considerable amount of time-consuming labor. In most societies, producing beer is a multistep process. For the Mabaso women of South Africa or the Maale of southern Ethiopia, beer production can range from 5 to 12 days (Donham, 1999, pp. 153–155; Reusch, 1988, p. 24). First, women let the grain sprout in a damp pot to produce a malt and then mix it with additional grains, and grind on a stone for hours. They bring large quantities of water from up to a mile away to mix with the ground grain and then boil the malt and flour in large pots. After boiling the mixture, women ferment the beer in large gourds or ceramic vessels. In Tanzania, the Haya make a beer using a combination of bananas and sorghum (Carlson, 1990). They use ripe bananas because of their high sugar content, which assists in the fermentation process. The bananas are mashed with the help of dried grass, and then water is added in equal proportion to the banana liquid. After the water is added, dried sorghum is mixed into the water and banana solution and left to ferment for 24 h. In Ethiopia, the Gamo produce beer by two different methods (Arthur, 2000). The highland Gamo produce beer by boiling water in a large ceramic cooking jar and then pouring the water over the wheat and barley flour and stirring it in a large serving bowl, where it is left to cool. It is then poured into a beer jar to ferment for 4 days. The second way to produce beer, which occurs in the lowland areas, is to combine and boil water and flour and then

store this mixture in large beer jars for fermentation (Arthur, 2000, 2002, 2003). In the majority of societies, women produce the beer, but once they produce it, it is used by many segments of society.

The Social Consumption of Beer

In Africa beer is consumed every day as a food product and beer also plays an essential role in the establishment of social obligations. The importance of communal consumption is one of the reasons people process their grains into beer rather than bread (Dietler, 1990). Beer is often considered a food, rather than a beverage, and the consumption of beer adds considerably to their daily calories (Gardiner, 1836, p. 266; Green, 1999, p. 414; Haggblade, 1992, p. 395; Karp, 1980, p. 85; Moore & Vaughan, 1994, p. 192; Richards, 1939, p. 80; Saul, 1981, pp. 746–747). Beer may contribute to increasing caloric intake, but its symbolic role may be more important than its nutritional role. However, de Garine (1996, p. 215) argues that beer “may be richer in vitamins PP and B-12, phosphorous and calcium than sorghum porridge, but it contains only half the calories, one-quarter of the proteins and no glucids” (Adrian & Sayerse, 1954, p. 136; Pele & Le Berre, 1966). For example, among the Koma of northern Cameroon, sorghum beer provides one-third the total energy consumed in a year and bonds age-sets and establishes a hierarchy between each one (de Garine, 1996, p. 210). Among the Tiriki people of Kenya, beer is offered to visitors as a sign of friendship (Sangree, 1962, p. 11), and the Baganda of Uganda use beer as a way to bond two men socially (Robbins, 1979, p. 371). Beer acts as a social lubricant when the Tiriki and the Iteso people of Kenya men sit around communal beer pots everyday to discuss social issues, disputes, and tell stories (Karp, 1980; Sangree, 1962). The Haya of northwest Tanzania pay respect to fathers by offering them a gourd of banana beer, which must be done before others can be served (Carlson, 1990). In addition, the Haya will offer a sacrifice of a gourd of beer to a father at the ancestral altar. The Kofyar of northern Nigeria

conduct all aspects of their daily life around beer (Netting 1964). The Kofyar use beer as an award and as a punishment against not taking part in work parties, verbal or physical violence, disrespect of a clan member, or minor theft.

Beer as a Motivating Ingredient

In order to gather a work party, beer is essential; without beer, it is impossible to bring people together to cooperate on the task at hand. Work feasts are a type of commensal politics (Dietler, 2001; Dietler & Herbich, 2001), where people organize to work on a specific project and in return receive beer for their labor. Beer in work parties provides a social alliance between the work party sponsor and the people involved in the work party. Beer changes the context of the group, by becoming the “social focus” for all of the work party members, but also for people associated with the party members (Donham, 1999, p. 155). Among the Konso of southern Ethiopia, the quality and quantity of beer is a motivational force in gathering people for a work party (Watson, 1998, p. 148). If a person produces a high quality beer in sufficient quantities, then they can expect a range of 20–50 people to help them in the fields. There are a number of different types of Konso work parties, which involve fixed or volunteer groups, costing the sponsor approximately 50–150 Ethiopian birr (US \$7.00–\$21.00) depending on the size of the work party. Feasts also accompany work parties, as in Southern Africa, where leaders and wealthier commoners organize large work parties and then provide an abundance of beer (Crush, 1992). The Pondo of South Africa rate their beer feasts higher than meat feasts, because beer makes the work seem more like a party (Hunter, 1979, pp. 89–90). Among the Kofyar of Nigeria, beer is the primary means for repaying voluntary labor to hoe and harvest agricultural fields and for building corrals and houses (Netting, 1964). These examples demonstrate that beer is a motivating force for labor and beer also has a role to play in the formation of the elite.

The Social Hierarchy of Beer

The payment of tribute with beer indicates its economic and political importance. Although beer in Haya society is a secular refreshment, it has symbolic value since when Haya men make banana beer they must be sexually abstinent while brewing the beer (Carlson, 1990, pp. 298, 303–304). When the Haya produce beer, it is their obligation to pay their leader four or more gallons of banana beer. Beer, along with livestock, barkcloth, and iron products, are presented to leaders as tribute. They present the leader with special gourds of beer that have wrappings of banana fiber covering the gourds which are tied with twigs and leaves from a plant that symbolizes purity and strength. As with the offering of beer to the deceased father, the Haya king also offers a sacrifice to his ancestral altar for the welfare and fertility of his kingdom.

The Chagga leaders of Tanzania opened their houses and gave generous supplies of beer, which fulfilled their redistributive obligations and supported the warriors, who would fight on their behalf (Dietler, 1990, pp. 370–371; Gutmann, 1926, p. 346). The Chagga leaders would collect this beer through either a tax that the people were happy to pay so that they might socialize with the leader or through a work party in which people would help cultivate his millet crop, which was used to make a beer feast. A sign of a good Buganda leader is the redistribution to the people in the form of “beer, meat, and politeness” (Mair, 1934, p. 183). As with the Chagga, the Buganda leaders obtain their beer through a tribute system and beer also is used to settle disputes as fines (Robbins, 1979, p. 371). Thus, the payment of beer forms a social, economic, and political reciprocal bond between commoners and leaders.

Brewing beer in association with slaughtering cattle among the Koma of Cameroon also provides a means to improve an individual’s status (de Garine, 1996, pp. 208–210). The cattle dance ceremony celebrates the hard work and good qualities of a man’s wife as being a good mother to their children. The ceremony in her honor is a redistribution feast that increases the husband’s social status by distributing meat and beer to their

kin and religious leaders. Once the husband has hosted up to seven ceremonies his status increases because he is knowledgeable about the secret rituals and places and can drink beer from his own pot without sharing.

Beer is associated with the wealthy, high-caste Gamo households (Arthur, 2003). The political and religious aspects of Gamo life are under the authority of the *mala* caste. The production and consumption of beer occur at all political and religious ceremonies such as at initiation feasts for ritual-sacrificers (*halakas*), weddings, and at ceremonies celebrating saints' days. The *mala* ritual-sacrificers must demonstrate their generosity through beer feasts. The wealthiest *mala* are "caught" by the other *mala* members to become ritual-sacrificers (*halaka*) (Halperin & Olmstead, 1976). If the people choose a person to become a ritual-sacrificer, his duties are to perform animal and beer sacrifices in which he prays for the health and fertility of his people, crops, and animals. Gamo ritual-sacrificers are always men, who must be circumcised, married, wealthy, and morally respected (Sperber, 1975, p. 215). However, to become a ritual-sacrificer, a person has to perform two beer feasts (*perso oosha*), which include producing enough beer for the people who reside in his political region (*dere*) (Freeman, 1997). This ritual-sacrificer must have enough farmland to provide for producing large amounts of beer and other types of high-status foods. This redistribution of wealth cannot be refused by the chosen ritual-sacrificer (Sperber, 1975). He must organize two different feasts, one at his house and the other in the area of community gatherings (Freeman, 1997). At both feasts, the participants must wait to start drinking until the *halaka*-to-be and the elder-sacrificer pour beer on the ground as an offering for the spirits. Each redistribution feast can comprise up to 300 people and requires 800 kg of wheat for beer production (Halperin & Olmstead, 1976).

Thus, beer in African cultures is more than just a beverage; it is a critical component to the social, economic, and political structure of society (Carlson, 1990; Netting, 1964; Robbins, 1979; Sangree, 1962). People spend a considerable amount of their labor and time processing their

crops into beer rather than bread because of the value of beer in establishing alliances. Beer binds these different groups together by providing a means of establishing reciprocity in the form of labor and social and economic coalitions. Furthermore, the importance of beer in the form of symbolic respect to the living and to ancestors exemplifies its significant role for the well being of societies (Arthur, 2003).

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Bricks in Nineveh

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Nineveh was completely rebuilt, restored, and enlarged when it was elected as the capital city of the Assyrian empire by the king Sennacherib (704–681 BC) in the seventh century BC. He had finally abandoned Dur Sharrukin, the city founded by his father Sargon II (721–705 BC).

Sennacherib deeply changed the aspect of Nineveh. The city was an important urban center since the most ancient period because of the presence of the temple dedicated to the goddess Ishtar. During the Assyrian time, the city always had a significant role because of the Temple of Ishtar, but it finally acquired a new political status when it also hosted the seat of the Assyrian kingship. In the seventh century BC, after Sennacherib, Nineveh kept the role of the Assyrian capital of the empire as it did also during the reigns of Esarhaddon and Assurbanipal. In the last phase of Neo-Assyrian history, Nineveh underwent major works of restoration of old structures and construction of new buildings. The building activities are in fact largely described and registered in detail in the Assyrian royal inscriptions. Precise accounts are given of the building projects by King Sennacherib for the restoration and extension of the defensive walls and urban gates, the

construction of the new royal residence (the so-called Palace without Rivals in the southwestern sector of the citadel of Quyunjiq), and generally the remaking of the whole urban pattern and structure with new roads, bridges, and aqueducts, the control of water sources and rivers, and the realization of botanical gardens (Grayson & Novotny, 2012).

The massive works carried out during Sennacherib's kingdom deeply renewed the aspects of Nineveh. As a consequence, mud bricks were intensively produced to accomplish the transformation of the city during what can be labeled the Assyrian renaissance. They produced technological innovations and knowledge improvements so that the new architectures and visual programs under the reign of Sennacherib were qualified as masterful and artful with no comparisons and rivals (Winter, 2008).

Architectural indications of measurements in the inscriptions refer to the number of bricks used. For the walls of Nineveh, it is said that they were 40 bricks thick and 180/200 brick-courses high; for the construction of Sennacherib's palace, inscriptions say that the height of the mud brick terrace was raised to 180 brick courses. Standard mud brick sizes found during the excavations of Nineveh are about 37 by 37 by 12 cm, and, according to these dimensions, it is possible to reconstruct the original height of the wall of Nineveh (about 22 m with a maximum height of 25 m) and the imposing structure of the terrace of Sennacherib's palace (about 22 m high) (Reade, 2000, pp. 399–400). Bricks were massively produced according to standardized dimensions; there were different types of bricks, particularly for different shapes and decorations. As a consequence, bricks were differently used in the constructions as either part of the elevation of the buildings or the decoration of external façades. In this respect, one of the sides of the bricks was painted and colored with geometrical drawings and representations of humans and animals figures, and, in some special instances, bricks were even molded and decorated with high-relief motifs.

For the technique and manufacture of glazed bricks in Assyria, Assyrian glazed bricks are undoubtedly inferior in quality to the

contemporary and later Babylonian production. Actually, the glaze layer on the Assyrian bricks is in fact so friable (Assyrian bricks in museum collections are characterized by weak colors and they must be handled with great care to preserve the few traces of glaze) that it tends to pulverize readily (Reade, 1987, p. 32). For that reason, in old publications, Assyrian glazed bricks were qualified as painted bricks. However, since glazed bricks were supposed to decorate architectural elements of external façades, it is thus quite possible that the glaze layer was originally adequately created and protected to endure. Indeed, improper restorations made in the past, exposure to the air after excavation, and insufficient protection in museum display surely contributed to the damage of the glaze layer with consequent negative judgments and considerations of the knowledge of the glaze technology by the Assyrians (Reade, 1987, p. 32). Modern analyses and researches on ancient glazed (painted) artifacts can in fact reveal the real technological knowledge of the Assyrians by revealing the existence of ancient varnish to protect the surface of the bas-reliefs, bricks, and tiles that were supposed to be placed on the outside (Verri, Collins, Ambers, Sweek, & Simpson, 2009).

For the nature of the decoration, Assyrian bricks can thus be divided into two main types (Nadali, 2006, 2008): glazed tiles decorated with a complete larger scene on the main face and glazed bricks decorated on either the larger face or the smaller sides with a detail of a scene or a figure (Fig. 1). In this instance, bricks were then assembled and arranged as in a mosaic according to a precise order to finally get the whole image – Aramaic letters on the back of the bricks were used as symbols to guide the correct arrangement (Russell, 1999).

A special category of bricks has been found at Nineveh as part of the original decoration of the Temple of Ishtar on the main hill of Quyunjiq. The glazed tiles, probably dated to the reign of Esarhaddon (681–669 BC), are characterized by high-relief vegetal, animal, and human motifs (Nadali, 2008). The single tiles were thus arranged with one next to/above/below the other accordingly in forming the name of the king Esarhaddon written through the use of the Assyrian system of



Bricks in Nineveh, Fig. 1 Glazed tile of Esarhaddon from Nimrud (Photograph taken by the author; reproduced courtesy of the trustees of the British Museum)

hieroglyphic script. The same hieroglyphic writing had been used by Sargon II on the façade of the Temple of Sin at Dur Sharrukin (Nunn, 1988, pp. 175–182); as the bricks of Nineveh, the tiles of Sargon II had on their surface a detail of a larger figure, but the surface was flat. In the seventh century BC, a new shape was introduced: high-relief bricks probably conveyed the long-lasting tradition of molded bricks of central and southern Mesopotamia since the second millennium BC. Esarhaddon's politics in the South, with special sets of building activities at Babylon, probably influenced the Assyrian way of making bricks, or, conversely, it might be inferred that Babylonian craftsmen worked at Nineveh following their tradition in shaping bricks with high-relief pictures (Nadali, 2008) (Fig. 2).

Mud bricks were the basic material for construction in Assyria, as generally in all regions of the ancient Near East. The numbers of bricks, as referred to in the Assyrian royal accounts, indirectly indicate the dimensions of the buildings, showing how the brick was a kind of standard unit for measurement in building activities.



Bricks in Nineveh, Fig. 2 Glazed high-relief brick of Esarhaddon from Nineveh (Photograph taken by the author; reproduced courtesy of the trustees of the British Museum)

Glazed bricks and tiles were suitably used in particular context of the architecture to highlight architectural elements and decorate external façades of both temples and palaces. The glaze layer gave bricks and tiles a shining appearance, and this probably was the main aim in using these colored and brilliant materials in the constructions. Façades of temples and palaces were immediately recognizable even from a distance; the colors and light of the glazed bricks radiated the power and *melammu* of the gods and kings of Assyria. Temples and palaces were built on high terraces. The palace of Sennacherib at Nineveh stood on a terrace 180 brick-courses high; the Temple of Ishtar at Nineveh was also built on the top of an artificial terrace. Both buildings emerged from the line of the city walls, and colored glazed bricks distinguished the seat of the goddess and the seat of the king from the rest of the public buildings of Nineveh.

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Buddhism and Science

Somparn Promta

Buddhism is normally viewed as an atheist religion. Modern interpretations of the Buddhist teachings made by Buddhist scholars in South-east Asia seem to bring Buddhism close to what is called 'science' in the modern world. That is, Buddhism is explored as a religion teaching that human life, the world, and the universe are the *Dhamma*, a Pali word containing complicated meanings. According to Buddhadasa, the most famous Thai Buddhist thinker, the Dhamma has four meanings (1) natural things, (2) natural laws, (3) human obligations to follow natural laws, and (4) the fruits gained from following the laws of nature. So human life, the world, and the universe, according to Buddhism, are natural things in themselves and they follow the certain laws of nature.

In Buddhist perspective, natural things and natural laws are not created by God or any other supernatural power. They exist naturally, meaning that the concept of creation is not necessary. However, Buddhism does not stress the philosophical arguments concerning the origin of the universe. The view of Buddhism on natural things and natural laws is practical in a sense that knowing what is the world *as we see now* should lead to a happy life. It should be noted that Buddhism believes that religious practice is closely connected to the laws of nature, so the learning of religious teachings in Buddhist perspective is learning the laws of nature.

In Buddhist texts, five laws of nature are mentioned (1) physical law, (2) biological law, (3) psychic law, (4) *kammic* law, and (5) moral law. The first two laws are believed by Buddhist scholars to be the same laws explored in physics, chemistry, and biology in modern Western science. Psychic laws could be partly compared to what are called psychological laws in Western psychology. However, there are some special contents in the Buddhist psychic laws not found in Western psychology. An example of these is the cultivation of the mind through meditation. Kammic laws are the laws concerning human actions. Buddhism believes that what we are is directly the result of what we do. We are born as a free entity to choose our future freely. Philosophically speaking, Buddhism believes that we are born with a free will. In this sense, we are solely responsible for whatever we have done. *Kamma* or Karma in Buddhist teaching, an action with intention and carrying moral value, is a secret power, like the field in physics, which dominates our life. Good Kamma determines a good life; bad Kamma determines a bad life. Moral laws are the laws that govern any events that cannot be classified under the first four laws. For example, Buddhism believes that the unjust or immoral structure of society is a bad thing. It is bad according to moral law. It is possible that individuals in society act well according to the law of Kamma, but they are good people in a bad society. The Buddha is well known as arguing against the caste system in ancient India. For him, it is possible that people of each class act well

according to their class duties, but caste is still a bad thing, judging from moral law.

Looking through the Buddhist five laws of nature, we can see that the belief in nature is wider than the belief in nature found in science. In Western science, the laws of nature as found in physics, chemistry, and biology have nothing to do with social justice, fair distribution, or the violation of human rights. Science within this tradition has become something containing a narrow meaning. Science never questions how we can gain a happy life or a just society. Typical scientists seem to think that such a question should be considered outside the scientific community. It should be part of political science or political philosophy. The above tendency leads to the separation between 'knowledge' and 'value', and between 'nature' and 'human convention'. The Buddhist conception of natural laws does not make the same separation. For Buddhism, physical and biological laws are the beginning laws of nature to be explored. They are looked on as a means leading to some things more valuable.

Between human life and the physical world, Buddhism thinks the former is of more importance. However, as our life can never be separated from the world, the study of the physical world is accepted by Buddhism to be of some value as far as it is undertaken in balance with the study of human life. Furthermore, the study of the physical world must not be run separately from the study of society. If we are allowed to call the activities of exploring nature through the Buddhist five laws 'Buddhist science', what follows is that Buddhist science stresses the balance between three things: human life, society, and physical world.

The confrontation between modern science and Buddhism in the Buddhist countries such as Thailand seems to be best understood in the light of the Buddhist conception of nature as said above. In Thailand, where Theravada Buddhism plays the role of a national religion, the sale of GM food is allowed by law under the condition that the products must be declared to contain GM ingredients. Buddhism in Thailand does not raise moral questions about this, while Islam seems to doubt it. The recent study of the opinions of Buddhists concerning the issues of human

cloning and stem cell research in Thailand declares that the Buddhists, compared to Christians and Muslims, can more easily accept human cloning and the use of stem cell for medical purposes if it is proved safe. This phenomenon can be understood if we are reminded that Buddhism is a religion free from religious dogmas. Like science, Buddhism believes in the natural creation of things. For Buddhism, anything allowed to happen in the world is 'natural'. So, Buddhists do not view human cloning as unnatural. On the contrary, it is 'natural' in a sense that it is allowed by the second law of the five laws. However, it should not be understood that Buddhism has nothing to question about these issues. These arguments essentially stem from the conception of balance between the five laws. Human cloning and stem cell research are viewed as activities run within the second law. So, it is not isolated from other laws.

Finally, Buddhist scientists in Buddhist countries like Thailand seem to feel that Buddhism and science are friendly. This feeling possibly stems from the picture of Buddhism in their minds. Buddhism as taught in the university classroom shares a lot with science. In chapters of high school Buddhism textbooks, the way the Buddha searches for knowledge is usually described in terms of scientific enquiries. The Buddha says that he did not create the truths he found after the process of study. They were naturally given. Anyone, according to the Buddhist perspective, can be a Buddha. The term 'Buddha' means the one who is enlightened. Enlightenment is nothing but the realization of natural laws. Knowledge in the Buddhist view is in the end the same thing as morality. We can easily find the balance between knowledge and value in Buddhist science.

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Building Construction

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It is difficult to talk about the differences in Western and non-Western building technologies, as many approaches used today in this field were also used in Western countries in the past. Some, such as mud technology, are currently being revived in Europe. A more appropriate expression might be indigenous or traditional technology.

Some basic approaches, such as the construction of walls out of stonemasonry, mud, or branches plastered with mud, can be found in many places in the world. It is not surprising that there is not so much basic difference, as the construction materials had to be found in the surroundings. What is amazing is to explore which quality or intelligence is presented in the specific adaptation to the climate and in resistance to disasters.

Traditional Construction Technologies Are Still of Great Value

The fact that we now use other technologies does not mean that traditional knowledge was primitive.

Dealing with local material is more ecological, and these old technologies have no recycling problem.

Traditional technologies went through a long process of evolution, so they are in most cases the very best solution, taking into account what basic materials were available at any given place and time. They are well adapted to the local climate and are rather safe with regard to recurring local hazards. However this is only to the extent that was possible with the available materials and knowledge. The typical empirical way of improving the design could respond only to events with a reasonably short recurring period.

Modern technology has to an extent not yet proved its durability. We face problems, like corrosion in prestressed concrete bridges, whereas stone arch bridges survived for centuries without even regular maintenance or repairs. None of the modern bridges in steel or reinforced concrete would ever have such durability.

Many of these old building technologies still have a potential for improvements, if modern materials and knowledge could be added in a sensible way.

Today traditional building technology is for the poor; it is often the only one they can afford and handle. Unfortunately this gives it a bad image. It has become the technology of the lowest classes, seen as being primitive, in spite of all its values and potential.

Some famous architects have discovered the value of traditions and have gotten inspiration from local buildings. Considerable literature about vernacular architecture has emerged, praising the so-called genius loci (sense of place). An excellent collection which shows how people live is Oliver's *Dwellings* (2003). Unfortunately most literature looks purely at the architectural aspects, so that the engineering experience and the intelligent use of materials including their ecological aspects and their climatic adaptations are left out. This is what this chapter will concentrate on. One should not see the genius loci as something mystical; it is an experience that is presented by traditional buildings, and it is important to document the technology in better detail, so that it does not get lost with the death of the last craftsmen.

Tradition Goes with Esthetics

Transport of nonlocal material was too expensive; this led to a rather great uniformity in a specific region. And as buildings and other constructions are unengineered, there is also not much variation in the structure. As a result, traditional buildings are rather uniform. The limitations given today by town planning regulations with regard to the size and often with the specification of certain exterior materials were more or less imposed by the limited resources for the old construction methods.

Limiting the variations of the buildings has a great esthetic advantage. Total uniformity is boring; too many differences in aspects and the missing of a common idea make the built environment chaotic. This is not surprising; all building was based on the variations of plants, landscape, and textures of the available materials. The grain of a piece of wood never is uniform, but it follows a certain law, a certain pattern. No piece looks like the other, yet we still can say what type of wood it is. A landscape has its character, and a forest has its own appearance and mixture of trees. No person looks exactly like someone else. We are used to such variations generated by certain mechanisms, and we appreciate them.

You can analyze this hypothesis when you visit a medieval town in Europe or if you walk through an old Indian city like the historic part of Ahmedabad or an oasis in the desert. There are prevalent materials and variations of the design, based on traditions, limitations of the structural system, and what the owner could afford. Such an appearance corresponds to the older people's experience with their surroundings, and we find it pleasant. A similar homogeneity is difficult to achieve in today's architecture: normally, styles vary too much, or completely new quarters or towns are too uniform. Today one can find as really bad examples totally uniform quarters at the one end or assemblages of what people think are landmark designs, resulting in chaotic shopping malls at the other end.

Valuable Experience Is Conserved in Traditional Buildings

Our modern design work is to a very large extent based on mathematical models and calculations, which give reasonably reliable results for the dimensions and make nearly every shape possible. The old builders did not have such comfortable design tools. They were lucky if they could cope with the geometrical questions in the case of more complicated buildings. The construction of the building with regard to structural problems and in order to provide an optimal climate under the given conditions and restrictions was based on experience. That means testing at the scale of 1:1 at the real building. However, throughout history, traditional technologies were perfected bit by bit. The choice of material was limited to what could be found locally. So stones, mud, wood, and leaves are prevalent in construction technologies.

A limited range of materials is easier to handle in an improvement process. The results we can see today are quite intelligent and efficient. They represent the experience of hundreds or sometimes even thousands of years. For example, in earthquakes, sometimes traditional buildings behave very well and are most efficiently designed, as one will see further below. What is not surprising, but really remarkable, is the climatic adaptation. If you follow the design criteria for comfort in a certain region, you end up normally with the traditional building layout and detailing (Koenigsberger et al., 1973; Lippsmeier, 1969).

However, there are several problems with traditional construction. As it is not based on theoretical models, average craftsmen and engineers do not really know why it works. So one has to follow the old rules, which get more and more lost. Only a few bright people brought the methods forward in the past. All the others were only followers.

The Major Construction Elements

There are many similarities between traditional construction technologies in non-Western

Building Construction,
Fig. 1 Wattle and
 daub wall



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countries and historical constructions in Europe. Either there was an exchange over wide distances in early times or the availability of material dictated similar solutions. Most likely both were true. However some tropical areas had their own specific solutions, mainly dictated by the different climate and available materials.

Walls

Walls, the most important construction elements, are mainly of the following types:

1. **Wattle and daub.** The basic structure consists of wooden posts, normally directly put into the ground or in a simple foundation. In some regions the ends of the posts to be placed in the earth were slightly burnt until they developed a charcoal surface that made them a bit more resistant to rot. A grid of smaller branches or bamboo, normally bound together by plant fibers, filled the space between the posts. The infill could also be of stronger horizontal branches and vertical hatch or wooden weaving. This wooden core was covered on both sides with mud. Sometimes fibers like short cut straw were added (Figs. 1 and 2).
2. **Mud formed in situ.** Here the mud is mixed with water until it becomes workable. This is often done with the help of an ox walking in the mud. Then the mud pieces are placed one over the other while still wet and made smooth.
3. **Sun-dried mud bricks.** After forming and drying bricks of wet mud, they are joined together with mud mortar.
4. **Rammed earth.** Here only slightly moistened and rather sandy soil is rammed in forms of varying sizes in layers. High buildings up to five stories are built with this method. Well-known examples are the houses in Sanah, Yemen, and the famous mosque in Mopti, Mali. In Europe large and high buildings still exist, made of rammed earth; it used to be a widespread method in Southern France.

This wall type is probably used the most in the world. The method of infill is also used for the typical European timber framework. One can

achieve a very smooth surface if the last layer is reworked over and over without letting it dry until all shrinkage gaps are filled.

There are many variations on this. An interesting one is a framework of vertical wooden columns and thin wooden members as a triangular infill. The space between this wooden structure is filled with stones and mud. This was widely used in Northern Pakistan.

In Afghanistan, one of the historical school buildings has a mixed wall construction, where

Building Construction, Fig. 2 Wattle and daub wall in an old German house, now used for exhibitions (Photo by the author)



Building Construction, Fig. 3 School building in rammed earth in Kabul, Afghanistan (Photo by the author)

the faces of the walls are made of mud bricks and the core of the walls is filled with rammed earth. Corners are made of burnt bricks in mud mortar. This two-story building in the center of Kabul is more than 100 years old, and the walls are still sound (Figs. 3, 4, and 5).

More about mud technologies (as well as their further development with lime or cement

stabilizers) can be found in Doat and Norton (1991), Minke (1999), and Niemeyer (1946).

5. Typical for many tropical hot and humid areas (where day and night temperatures vary only slightly) are light and easily ventilating walls. There the users can benefit from the slightest breeze. These walls are mostly made entirely



Building Construction, Fig. 4 Old castle near Kabul, Afghanistan (with rammed earth) (Photo by the author)

Building Construction, Fig. 5 Detail of the rammed earth blocks (Photo by the author)



of bamboo, but one can also find grass or palm leaves as cladding. Even entire structures of strong grasslike reed existed where this grows close to swampy areas, for example, in the marshes (North of Basra) in Iraq (Thesinger, 1967). They are bound together as in Thor Heyerdahl's famous boat Ra and can form quite sizable arch structures (Fig. 6).

6. A structurally interesting system concerns Chinese temples and other important

historical buildings, where wooden columns (with infill or free standing) carry the roof. Such freestanding columns get their horizontal stiffness against wind mainly due to a high load from the roof. The horizontal load from the wind is related to the height of the structure, and adding vertical loads can increase the horizontal resistance. This is exactly the case, as the tiles of these Chinese roofs are embedded in a thick layer of special mortar. From

Building Construction,
Fig. 6 Thor Heyerdahl's
 boat (exhibition in
 Tenerife, Spain). Similar
 technology is used in the
 swamps of Iraq for
 buildings (Photo by the
 author)



Building Construction,
Fig. 7 Roof structure
 (Dubai) beams, mats, and
 mud as topping (Photo by
 the author)



below it looks like a full wooden roof. Leaving the mortar out would seriously harm the structural integrity. Unfortunately this strategy does not work in the case of earthquakes, as there the horizontal forces are related to the mass. So adding more weight in the roof does not help; old pagodas collapsed during earthquakes.

Slabs

Slabs and flat roofs are normally supported by wooden beams with different infill materials. The major ones are:

1. Stones, which are then covered with mortar or mud. In this case, the beams have to be rather close together. Larger crossbeams can often support small secondary beams. This construction is rather typical for the east African coast with its Arabic influence.
2. Mud, reinforced by wooden branches. The construction usually starts with a mat (bamboo or similar), which prevents the mud from falling down. The branches, being fully embedded in the mud, act as a reinforcement, so that the distance between the beams can be larger up to about 45–60 cm (1.5–2 ft) (Fig. 7).

Building Construction,
Fig. 8 Support of a roof in
 China (Photo by the author)



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3. In Rajasthan, India, ceilings and roofs are made in stone-producing regions by placing a stronger stone as a beam and stone plates between those beams.

Roof Structures

In addition to slab roofs, one can find the following basic roof structures:

1. Wooden beam structures, where besides, the purlin (A purlin or purline is a piece of timber laid horizontally on the principal roof frames support the roofing material. Another design is with common rafters on which the roof covering (then usually tiles) is laid mostly using battens. Those rafters are supported by roof beams and used in inclined roofs and are parallel to the gable) and rafter construction, we can mention some interesting other types. (1) In traditional Chinese roofs, the main load-bearing element consists of wooden beams arranged one on top of the other with small spaces in between. The top beams get shorter to follow the form of the gable. This makes larger spans possible without doing complicated latticework, although at the expense of more timber consumption (Fig. 8). (2) Some communities in Gujarat, India, built conical roofs with small beams without intermediate support, which act like shells (see case study). Others build a wooden dome on a square house using strong branches



Building Construction, Fig. 9 Simple *bungha* roof from the inside (Photo by the author)

(Figs. 9 and 10). (3) In Eastern Africa large roofs were built using tree-type support systems. Now one can find this efficient system being revived in beach resorts at the Mombassa coast (Fig. 11).

Building Construction,
Fig. 10 A simple roof
 structure out of branches
 (Gujarat, India) (Photo by
 the author)



Building Construction,
Fig. 11 Roof structure
 with tree-type supports
 (beach resort in Kenya)
 (Photo by the author)



2. Domes and vaults are often used in desert architecture. Most are made of mud bricks, as they have sufficient strength. The main problem in a dome and vault construction is to counterbalance the horizontal thrust. Heavy and sometimes inclined walls do this. If stones are used for domes, a good overlapping can take a lot of the horizontal tension. This is the case in many old mosques and temples (Fig. 12). Tension belts, which would be the

best technical and scientific response to the problem, are not used to my knowledge. For vaults, only horizontal tension beams lead to an improvement. They can be found, for example, in old Ottoman buildings in the Balkans, where wooden beams carry an intermediate floor under the vault. Removing such a floor with its beams could lead to collapse; even a replacement not respecting the invisible anchoring detail could have this effect.

Building Construction,
Fig. 12 Dome (Jumma
 Mosque, Ahmedabad).
 Ring forces balanced by
 overlapping; joints open
 where there is a little
 overlapping (Photo by the
 author)



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Interesting information on how to build domes and vaults without shuttering can be found in Doat and Norton (1991) and Minke (1999).

The above example as well as the Chinese roof (that stabilizes the wall columns by its weight) demonstrates how dangerous it could be to change traditional construction. One has either to follow the tradition strictly or one must fully understand how it works.

Roofing Material

Roofing material for waterproofing varies a lot.

1. Slab roofs (which are prevalent in dry climates) have mud layers for waterproofing. In some cases they are covered with an additional layer of bricks or clay floor tiles laid to slope. This makes their use as roof terraces more convenient. Normally they are only a mixture of mud and chaff. This cover is in some rare cases also used for sloped roofs.
2. Suitable leaves or grasses are very common covers for sloped roofs. There is the well-known thatch roof using various types of local grasses, some of them are more and some are less resistant. Palm branches are prepared by folding them in half, so that the stalk is one side and the whole piece can be bound to the substructure. This type of roof is called *macuti* in Eastern Africa. The pieces are laid with overlapping shingles. Rounder growing palm leaves are simply overlapped. All these roofs provide good ventilation and heat insulation which make the houses comfortable. However every 3 years or so, thatch type roofing needs to be replaced, which is costly for the owners, and good material gets scarce in some regions.
3. Burnt clay tiles were common in some areas of India and for all official buildings in China, where they are normally glazed. As mentioned, in China, tiles are laid on top of a wooden structure in mortar. In India traditional country tiles were made of short conical pipes that were cut into halves. They are like all traditional tiles laid one on the bottom as a channel and one on top to cover the gap between the two bottom tiles. A more recent type has a U-section as a tapered channel and is laid in the same manner. People who could afford put several layers on the roof for better heat protection. The small gaps in such tiled roofs ensure good ventilation. Predominantly a layer of split bamboo supports the tiles. It is safer than the one batten per tile as we know it. In case an earthquake or high wind moves the tiles, they cannot fall down and cause harm. In some regions of India, one can also find such tiles laid in mud on simple thatched roofs (Figs. 13 and 14).
4. Domes and vaults get a finishing by lime plaster. To make this watertight, the sand used must have different grains and some organic

Building Construction,
Fig. 13 Country tile roof
 (Gujarat, India). Split
 bamboo placed close
 together serves as battens
 (Photo by the author)



Building Construction,
Fig. 14 Country tile roof
 from inside (Photo by the
 author)



material added in order to increase the elasticity.

5. Regions with suitable stone plates have sloped roofs with overlapping stone slabs (Fig. 15).

Earthquake Resistance

In many non-Western regions, earthquakes are a major natural hazard, and all buildings are built to resist their forces.

It is not the earthquake that kills; it is the collapsing building. Traditional constructions have a remarkable earthquake resistance. Problems start when the traditional way of construction is modified. Craftspeople who execute the

works cannot really design for earthquake resistance once traditional design is given up. The strength and the proper dimension of a structure were developed by experience, and this is also reflected in the features that may make a structure more earthquake resistant, even if they are not recognized as structural elements. Even builders might not know why there are certain elements, which users normally consider decoration, which often play a vital role in the buildings' strength.

An earthquake's actions can in a simplified way be understood as horizontal forces acting on the structure. They are more or less proportional to the mass of the structure concerned and are expressed as percentage of the gravity acceleration.

Building Construction,

Fig. 15 Roof with a stone slab (Rajasthan, India)
(Photo by the author)



B

Various strategies deal with earthquake safety. Basically one can have (a) buildings that do not harm people when they collapse; (b) a construction that is light where earthquakes do not induce large forces; and (c) buildings can be strengthened in various ways to withstand earthquakes. Often a combination of those measures is used. One can also have a rather elastic and flexible structure, which reacts by deformation, but that is not the case in traditional buildings.

Traditional Japanese houses consist only of a light wooden structure and a sort of paper filling for the walls. As the structure is light, an earthquake will not introduce many forces, and if it collapses, the walls are not seriously hurting users. This is an intelligent construction using strategies (a) and (b).

All types of thatched roofs (real thatch and covers from palm or banana leaves) always supported by a wooden structure follow the same strategy. They are light and will not cause harm when the roof collapses. Even roof tiles did not result in serious injuries when falling down during earthquakes (or cyclones). As mentioned, in India, there were many pieces of split bamboo lying so close together that tiles could not fall through. However, when modern roof tiles were introduced, this feature was given up, as those new tiles only match well with single straight battens as support. Central Europe, where the design of modern tiles comes from, has not got serious earthquake problems, and there is always

a ceiling under the roof. Introducing the same technology in earthquake-prone areas like northern India, where people normally cannot afford a cladding under the roof, was probably not a good idea. In the great Gujarat earthquake in 2001, falling tiles injured people, but practically nobody was killed. The death toll came mainly from collapsing slabs or slab roofs, especially when their supports failed.

To make the building itself resistant to prevailing earthquakes, following strategy (c) can be achieved in various ways. Rather resistant are wooden structures, filled with either woven mats or similar (which is the usual construction in the real tropics (see section “[Climatic Adaptation](#)”)) or with mud (mostly a wattle and daub type, see wall materials). Some latticework or diagonals increase the horizontal resistance. However, often the traditional joints are a weak point.

You often find this type of approach for the first floor of two-story houses. It has a long tradition in Muslim construction and can still be seen in old Turkish towns as well as in Kabul, Afghanistan. The first floor weight is more essential to the structure, as it contributes more to the internal forces, so it is wise to make it light.

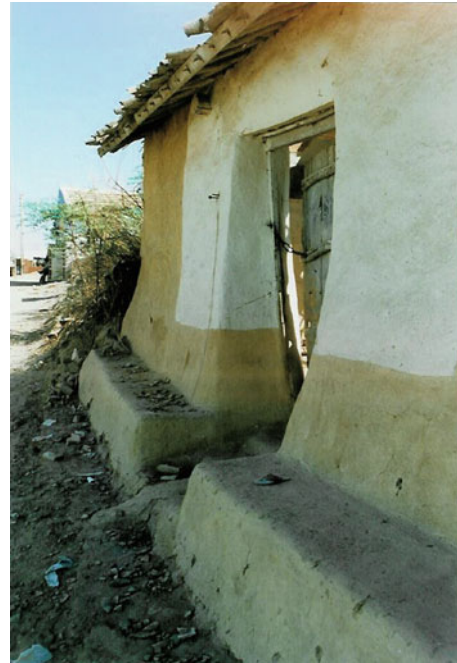
A good way to reinforce masonry buildings against earthquake actions is to use horizontal bands with good tension strength. This is the recommended method for one- and two-story buildings in many modern earthquake-related

building design standards. Today, the bands are normally made of reinforced concrete. You will find similar bands in Turkey and in the Himalayan region of India, etc., where houses are constructed of stones. These bands are however made of wood, a material that is relatively cheap and has good tension strength. There you find one piece of wood on either side of the wall, often interconnected in a form of a ladder by smaller batten type pieces. It looks and acts very similar to modern steel reinforcement in concrete beams. In the Himalayan region, people most likely discovered independently from the Arabic-influenced regions the positive effect of wooden beams in case of earthquakes. You can find buildings, mainly with dry masonry, which have wooden beams incorporated. They look very nice and can be considered as traditional decoration, but basically, they are reinforced against earthquakes.

Wattle and daub walls have also a rather high-tension strength, as the basic structure consists of wood. In addition, the walls are light and do not attract high horizontal forces.

Another way to increase the strength of a structure is to give it a suitable form. If you fold a piece of paper, the load bearing capacity becomes much greater compared to a flat piece. Round forms are very resistant, and this is used in certain types of buildings. In Gujarat, India, such a house type, called *bungha*, withstood the last heavy earthquake amazingly well (see the case study below).

A very simple and basic approach to make a wall itself earthquake resistant is to make it thicker. Assuming that the wall is sufficiently monolithic, one can assume that the resultant of the horizontal earthquake forces acts in the center of gravity of the wall, for a prismatic object that is the middle of the height. If the wall is wide enough in relation to the height, it cannot turn over. This is why huts (with light thatched roofs) and low stonewalls have no problems in earthquakes, even if they are only built with mud mortar. More effective are tapered walls with a wide base in the form of a retention wall or dam. This approach can still be found in earthquake-prone areas (Fig. 16).



Building Construction, Fig. 16 Mud wall in a tapered form to withstand horizontal earthquake forces (Gujarat, India) (Photo by the author)

In general, as one could see, traditional buildings were amazingly well adapted to earthquake hazards and this within a rather limited range of available local materials. Many problems started, when traditions were given up and westernized construction was imitated without designing the buildings for the prevalent hazards.

Climatic Adaptation

For a good adaptation to the climate, the construction of a house plays a major role. Together with the architecture (Koenigsberger et al., 1973; Lippsmeier, 1969; Wilhelm 2000), which should deal with orientation, shadowing, openings, and spatial arrangements, the temperature and the air movement and the type of material used and its dimension also influence major components of comfort.

In desert conditions, thick and heavy walls provide a good phasing (time shifting of the temperature curve between outside and inside the

building) and damping of the temperature. Mud and rubble stonewalls in the range of 30–45 cm (1–1.5 ft) as used in traditional constructions in such regions have a phasing of 12 h or so. This is how people can benefit from cool nights during the daytime. In the night they sleep outside or ventilate the room, if it is too hot from the heat stored during the day. A straw rich mud plaster normally increases the insulation and contributes to the damping effect. So the peak temperatures inside are lower than outside and closer to the average. In the desert environment, the rooms stay within comfortable conditions, whereas a prefabricated concrete building with thin elements as required for structural safety becomes too hot (Fathy, 1986).

In tropical conditions, light walls are traditional, which makes it possible to benefit from the slightest change of temperature. Weavings also let the air through, so that the users get more comfort through the air movement. All traditional houses in hot climates have openings near the roof or a roof that let the air pass through. In thatched or palm leaf roof covers, this advantage is combined with good insulation properties so that the heat is kept out.

Ventilation can be further increased, if the floor is penetrable and put on stilts. Houses on the Southeast Asian islands with bamboo floors follow this strategy. A further improvement of the ventilation can come through a chimney effect. Raised gables in Bali, chimney-type additions on the center of the roof, wind towers in Arabia, and holes on the top of domes are such devices (Fig. 17).

Example 1: Traditional Bungahas in the Semidesert of Kutch, Gujarat, and India

Probably the oldest types of houses in the semidesert of Kutch are called *bungahas*. They look very much like the well-known African round huts. They were considered rather backward and primitive type of construction. The big surprise was their amazingly good performance during the high-magnitude earthquake in January 2001, where nearly 20,000 people died in the region.

Practically none of these buildings collapsed, except for those that were rotten, as the wooden



Building Construction, Fig. 17 Wind catcher tower (Dubai) (Photo by the author)

roof structure and the walls had been weakened by termite attacks. Looking closer into the quality of the bungahas, one finds a very good adaptation to the desert climate with hot days and cool nights.

The bungahas are round structures, standing on platforms for better protection from the rain, which weakens the mud walls, as there are heavy rains from time to time. Several bungahas are placed together on this platform, forming the home of a large family. The houses with mud plaster are often nicely decorated and have furniture made of fiber-reinforced mud with a lot of decorations. The walls are in many cases made of wet mud pieces put in layers. In some cases sun-dried mud bricks are used, fixed together with mud mortar (Figs. 18 and 19).

Another wall type consists of random rubble stone masonry, again fixed together with mud mortar. The fourth wall type found in some areas is the wattle and daub construction.

The wall thickness varies with the material. Wattle and daub is normally about 15 cm. This is

Building Construction,

Fig. 18 Decorated *bungha*
(Gujarat, India) (Photo by
the author)



Building Construction, Fig. 19 Grain storage made of fiber-reinforced mud (Kutch, Gujarat, India) (Photo by the author)

the thickness that results from the material used, and it is rather appropriate to provide a reasonable insulation and damping to cope with the high temperature differences between days and nights.

The filling with branches, together with the mud layers on both sides, has rather good thermal properties. However from the point of view of building physics, a slightly thicker wall would be desirable.

The pure mud walls are about 30 cm thick, which ideally corresponds to the damping and insulation requirements. Mud mortar rubble stonewalls are generally 45 cm or 1.5 ft, which again corresponds ideally to the thermal requirements. The round form gives the walls a great stability, which explains the good performance of the bungha during the earthquake. The conical roofs are made of wooden rafters and covered with thatch. To interconnect the rafters, small branches or the core of palm leaves are used in small bunches that can easily be bent into horizontal rings. From the top, such a roof structure looks like a spider's web: the rafters go in a radial form from the center to the wall, and their interconnections form concentric rings.

Many communities use a king post in the center of the room. They put a heavy beam on top of the wall about 1.80 m high, on which the king post ends. These people are sure that the king post is necessary, but other communities manage without it. They use a corner piece for each rafter to transmit the horizontal thrust of the conical roof to the walls that are acting as a tension ring. This interesting innovation takes

longer to spread to the other communities living in the same region where bungalhas are built (Figs. 20 and 21).

The roof cover is made of thatch, which has good insulation properties and at the same time lets air pass through and provides a good insulation for the buildings. Together with the good

insulation and storage capacity of the walls, the house is kept cool during the day, and it is also comfortable in the cold nights in winter, which can reach zero degrees. Users are well aware of this, and they call it a built-in air-conditioning system. However they would like some improvements like better flooring and longer lasting roof materials.



Building Construction, Fig. 20 Old *bungha* roof (Kutch, Gujarat, India). Large roof without king post and excellent decoration (Photo by the author)

Building Construction, Fig. 21 Detail: corner element in a *bungha* roof (Photo by the author)



Example 2: The Afghan City House

Afghanistan has a harsh climate (hot summers, relatively cold winters and nights), and in addition there are earthquake hazards. Traditional housing is well adapted to those conditions. Whereas in villages, single story mud or stone houses are prevalent, and cities like Kabul have a long tradition of two-story buildings.

The plinth is built in random rubble stone dry masonry. This keeps the moisture from the soil out of the walls. In western technology the damp proof courses were only introduced in the beginning of the last century, normally as bitumen felt layers.

The ground flooring is laid on top of the so-called fox's dens. This is a system of ducts, which ventilate the space under the floor, and is in some cases used as a heating system similar to the Roman hypocausts (hollow floors and in some cases wall ducts, where fire was made for heating). Transverse main ducts connect both exterior plinth walls, so that the air can pass through. From this main duct secondary ducts run in a perpendicular direction. Then a layer of mud follows which

carries the flooring, which is either made of brick or only mud. This construction keeps the floor dry. The ground floor walls are made of sun-dried mud bricks with a wall thickness of at least 30 cm (12 in.).

This corresponds ideally to the climatic requirements, as this wall has a high storage capacity and a phasing of up to 12 h. This room is cool on summer days (as it preserves the night temperature condition). A wooden framework with an infill of sun-dried mud bricks forms the upper floor walls. These upper walls are only about 12 cm (5 in.) thick and have large windows. So the rooms in the upper floors pick up the outside conditions much faster, and one can choose the most comfortable room. The light walls, together with the wooden framework and a sort of batten as bracing against horizontal forces, make the building rather earthquake resistant.

The floor and the roof slab have wooden beams as load-bearing structures at 45–60 cm apart (1.5–2 ft). As described earlier, there is a reinforced mud layer across the beams. To get the roof watertight, a layer of mud mixed with hacked straw is applied, which needs to be replaced every few years.

Some houses of this type are reported to be 200 years old, and the technology is still used today. Those and more modern examples show the potential of mud houses.

Improving the traditional construction systems would be a real benefit for the poor, who mostly have only their labor to invest.

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Building Construction in Africa: Akan

Tarikhu Farrar

The indigenous timber and clay building technology of the Akan peoples of southern Ghana is a later expression of an ancient tradition of timber frame construction. Timber frame building had attained a considerable level of sophistication and beauty by the early nineteenth century as evidenced in the architecture of the Asante kingdom, and especially that of its capital, Kumasi. Such sophistication, in light of the antiquity of timber frame building in the region, should not be surprising. Nor should we be at a loss to account for its origins.

Akan coursed clay construction is less well known than timber frame construction. It was not as widely practiced as timber frame construction in pre-colonial times, particularly in the regions of dense forest. It seems to have been more common in the region occupied by the Northern Akan, the Bono (or Brong), and in parts of the central coastal plain occupied by the Fanti. The product of this type of building is a structure consisting of freestanding, solid clay walls. Coursed clay construction in the Bono region dates to at

least as early as the beginning of the second millennium CE, and perhaps much earlier. See more on this below.

Earlier generations of archaeologists, ancient historians, and architectural historians tended to denigrate or ignore this and similar types of architecture. In the first place, these building traditions did not employ “respectable” building materials (e.g., stone), and, moreover, little evidence could be found of what they considered to be “monumental” architecture. Implicit was the idea that the dwellings, and work and storage structures utilized by non-elite people, was not worthy of serious study.

The architectural traditions of much of Africa, and virtually all of tropical/sub-Saharan, or Black Africa, were not thought to be worthy of serious study; even the designation “architecture” was not assigned. “Huts,” “mud huts,” “thatch huts,” “wattle and daub huts,” etc., were used instead. If the term architecture was used at all, it was qualified. Thus reference was made to “mud architecture,” “wattle and daub architecture,” or more generically, “primitive architecture.” As for “true” architecture, the prerequisite was that it usually had to be effected in stone. If clay architecture were to be considered at all, the clay had to be formed into units of regular size and shape, and kiln-fired. If these two requisites were met, one could refer to “brick,” “red brick,” or “fired brick,” and this type of brick was respectable enough. Clay formed into units of regular size and shape, but not fired, was “mud brick,” and less worthy of serious study.

When African history emerged as a discipline in the second half of the twentieth century, at a time that, not coincidentally, corresponds to era of the struggles for African independence, and the anti-colonial struggles of the “third world” more generally, a growing number of scholars began to pay serious attention to what they termed “African traditional architecture.” Their pioneering research and writing has resulted in a respectable and expanding literature on this subject. Although too much of the old terminology has been slow in changing (we still read of “mud” architecture, for example), a serious, scholarly study of indigenous African architecture has

unfolded which has effectively challenged the older, entrenched stereotypes. Most of this research has focused on the products of the building process rather than the building process itself. In this entry, however, consideration will be given to the latter. (See author’s “Building Technology” entry in the encyclopaedia.)

Timber Frame Building Construction

The Akan peoples of southern Ghana and adjacent parts of Cote d’Ivoire possess two indigenous timber frame architectural forms. One, the *mpapa-dan* structure, is built entirely of plant materials. The other, the *tare-dan* structure, consists of a timber framework with an infilling and final plaster of clay. The former is normally a short-term dwelling, while the latter is expected to have much greater longevity.

Timber frame building construction in southern Ghana is of considerable antiquity. Its antecedents go back to the mid-second millennium BCE. or earlier. It has been firmly associated with the region’s earliest food producing communities of the Kintampo Culture. (For example, see Anquandah, 1976a, p. 92, 1976b, pp. 33–35, 1982, pp. 55–65, 1993, pp. 255–260; Davies, 1967, pp. 115–118; Dombrowski, 1976, pp. 64–71, 1980, pp. 261–262.) The architectural remains associated with the Kintampo Culture are the oldest yet uncovered in West Africa south of the Senegal River, and represent the oldest known timber frame building tradition in tropical Africa outside of the Sudanese Nile valley.

Although mention is made of local architecture in the writings of European mariners dating to as early as the mid-sixteenth century (for example, see Towerson ca. 1555–1557, in Blake, 1942, p. 406), relatively good written documentation of timber frame building for coastal Ghana, known then as the Gold Coast, dates from the mid-seventeenth century. Jean Barbot, resident on the coast from 1678 to 1682, describes one of the local timber building methods:

The *Blacks* generally build their houses on four posts or trunks of trees, drove into the ground, at such a distance as they design the largeness of the

house to be, and about six or seven foot high, to those main corners of the houses they fasten three or four poles athwart at equal distances above one another, and again others across them downwards, from the uppermost to the ground. The houses being thus framed, they lay on a sort of clay or plastering both within and without, about eight inches in thickness; which in a very short time, by the heat of the sun, becomes almost as hard and solid as a stone wall, leaving a few small lights or holes in the wall, and a very low and narrow door, or passage, to go in or out at. Lastly, they for the most part colour the inside of the wall, white and red, or black and yellow, as everyone likes best.

On those mud and timber walls they lay small quarters across both ways for the roof; and instead of tiles, cover them with palm tree, or rice leaves, or bulrushes, as the place they live in affords. In most houses the roof is so contrived, that it opens at the top, to let in air, when the weather is hot.

The ground floor of the house is of the same sort of hard clay, as the walls, and in the midst of it is a hole to hold a pot of palm-wine, when they meet to make merry. (Barbot, 1732, pp. 252–254)

The type of timber framing that Barbot describes is, in fact, one of several types that were practiced locally. A second type, for example, utilized posts and studs. Both posts and studs were planted into the ground, and to these vertical timber elements, the horizontal ones, or laths, were attached. Laths were extended both on the inside and outside of the posts and studs. Posts and studs, and especially posts, were more massive and functioned as structural elements in the building. This was also true of kingposts, ridge-beam, wall plates, eaves supports, and end-girts, and of ceiling girts if used. All of the more massive, structural timber elements were ideally decay and insect resistant hardwood. For posts, studs and ridge-beams this was essential. Akan builders relied on a number of tree species known for their resistance to insects and decay.

By contrast, laths, rafters and thatch-poles were slighter timbers, laths being slightest of all. Often these elements consisted of the midrib of the raphia palm (*ntuntun*, in Twi-Fanti), or that of the oil palm (*mpapa*). In the coastal region, ► **bamboo** was used for these lighter elements of the framework, particularly for laths. In the northern Akan or Bono region, *babadua* was used much in the same way as bamboo in the

coastal region. *Babadua*, when stripped of its foliage resembles bamboo, and is easily mistaken for such.

Barbot mentions different plant materials used for thatching. He also describes how thatch is first attached to a framework – what today Fanti builders call a “roofing sheet” – and how the roofing sheet is then attached to the thatch-poles of the roof framework. In fact, the way that roofing sheets were prepared had everything to do with the material used. Use of palm leaves, and the type of palm leaves used, was characterized by one set of methods. (The coastal Fanti used coconut and raphia palm leaves, while the Asante and other peoples of the dense forest used raphia and oil palm leaves.) Grasses and shrub leaves (these were more common in the Bono region), and, again, several types were used, required a different set of methods. The Fanti even manufactured a kind of “tile” for roofing purposes from bamboo. Stalks of bamboo of considerable girth were split in two lengthwise, and tile-like pieces were cut from these.

In no part of the Akan region did timber frame construction reach a greater degree of sophistication than in the Asante region during the time of Asante ascendancy. Thomas Bowditch, science officer of the first official British mission to Kumasi, the Asante capital, has provided us with a fascinating glimpse, through word and illustration, of Asante architecture at its best in the early nineteenth century. Bowditch’s description of the building of the large, elegant “town houses,” as he dubbed them, of Kumasi is invaluable:

In building a house, a mould was made for receiving the swish of clay, by two rows of stakes and wattle work, placed at a distance equal to the intended thickness of the wall; as two mud walls were raised at convenient distances, to receive the plum pudding stone which formed the walls of the vitrified fortress in Scotland. The interval was then filled up with a gravelly clay, mixed with water, with which the outward surface of the frame or stake work was also thickly plastered, so as to impose the appearance of an entire thick mud wall. The houses had all gable ends, and three thick poles were joined to each; one from the highest point, forming the ridge of the roof, and one on each side, from the base of the triangular

part of the gable; these supported a frame work of bamboo, over which an interwoven thatch of palm leaves was laid, and tied with the runners of trees, first to the large poles running from gable to gable, and afterwards, (within,) the interlacing of the bamboo frame work, which was painted black and polished, so as to look much better than any rude ceiling would, of which they have no idea. . . The pillars, which assist to support the roof, and form the proscenium or open front (which none but the captains are allowed to have to their houses) were thick poles afterwards squared with a plastering of swish. The steps and raised floor of these rooms were clay and stone, with a thick layer of red earth, which abounds in the neighbourhood, and these were washed and painted daily, with an infusion of the same earth in water. . .

A white wash, very frequently renewed, was made from a clay in the neighbourhood. . . The doors were an entire piece of cotton wood, cut with great labour out of the stems or buttress of that tree. . . Where they raised a first floor, the under room was divided into two by an intersecting wall, to support the rafters for the upper room, which were generally covered with a frame work thickly plastered over with red ochre. . . (Bowditch, 1966 [1819], pp. 304–306)

This was Akan timber and clay construction *par excellence*. It was the legacy of more than three millennia of timber and clay building in southern Ghana. As with Barbot's description, we are again exposed to but one of several different forms of timber and clay construction practiced in the region, in this case that which produced the houses of the Asante aristocracy, and the architecture of the kingdom's major political centers.

Aside from size and degree and complexity of surface decoration, the most common type of Asante non-aristocratic dwelling would not have differed greatly from those of the aristocracy. With some differences having to do with the much smaller size of ordinary Asante dwellings, wooden framework construction paralleled that described for Asante "town houses." The most divergent type of timber frame construction involved the building of an *mpapa-dan* structure. But even here, differences were not terribly great. In fact, the most significant difference (besides its smaller size) was the absence of studs and the many fewer laths of an *mpapa-dan* timber framework. (For a more detailed description of the

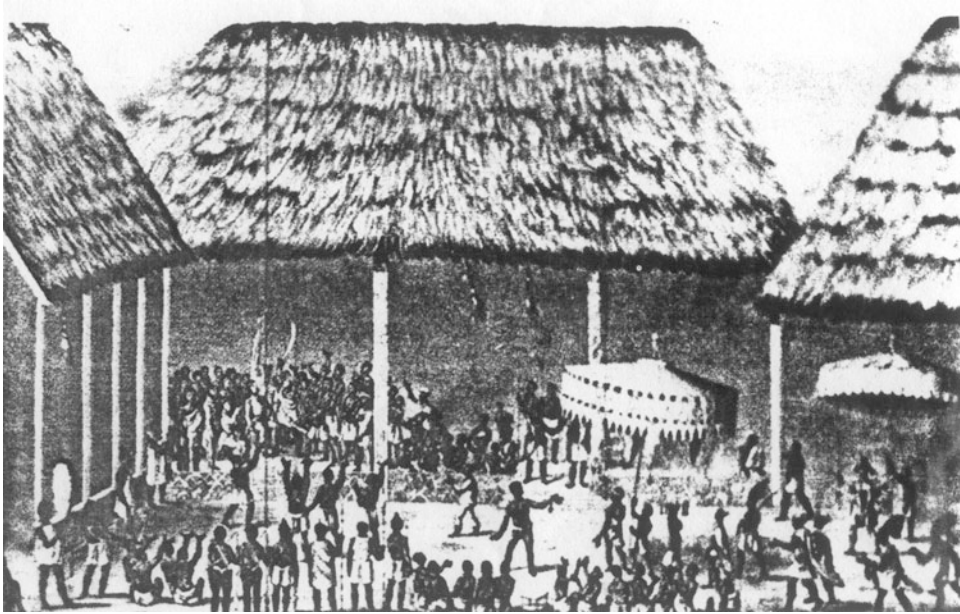
various types and methods of timber frame construction, see Farrar, 1996, pp. 95–151.)

In the far north of the Akan region, among the Bono, local variants of timber frame construction evolved, still part of a broader Akan building tradition, but rooted in local environmental conditions. In the Bono region, however, building in coursed clay was far more common in pre-colonial times than farther south. Archaeology tells us that for the Bono, this tradition goes back for at least a millennium.

Akan Coursed Clay Construction: Some Brief Observations

Despite the fact that the Bono peoples have built in coursed clay for a 1,000 years or more, the Akan peoples in general have not been the most prolific builders in this medium. Their skills in coursed clay construction have certainly been adequate, but their neighbours to the north, east and southeast of them have historically been more adept at it. Some question surrounds the antiquity of coursed clay building in Ghana. The writer has argued elsewhere (Farrar, 1996, pp. 156–168) that coursed clay construction in Ghana may also (that is, along with timber frame construction) date to as early as the Kintampo Culture, as evidenced by the remains of associated structures with stone foundations. Timber frame construction in this part of Africa *never* employs stone foundations, and, as far as we know, never has. Moreover, stone foundations would interfere with the placing of posts and studs, and would do nothing to enhance the strength or longevity of the walls. Some forms of coursed clay construction, on the other hand, do employ stone foundations. Akan builders do not lay stone foundations when building in coursed clay, but neighbouring peoples in southern Ghana (e.g. the Ga and Dangme) do.

There is, perhaps, a tendency to think of coursed clay building as a more complex form of building technology than timber frame construction. But this is not necessarily so. We need only remember that the earliest village agriculturalists of Upper Egypt, the Badarians, built



Building Construction in Africa: Akan, Fig. 1 The great court of the Asantehene's palace (Kumasi From Dupuis, 1824), frontispiece

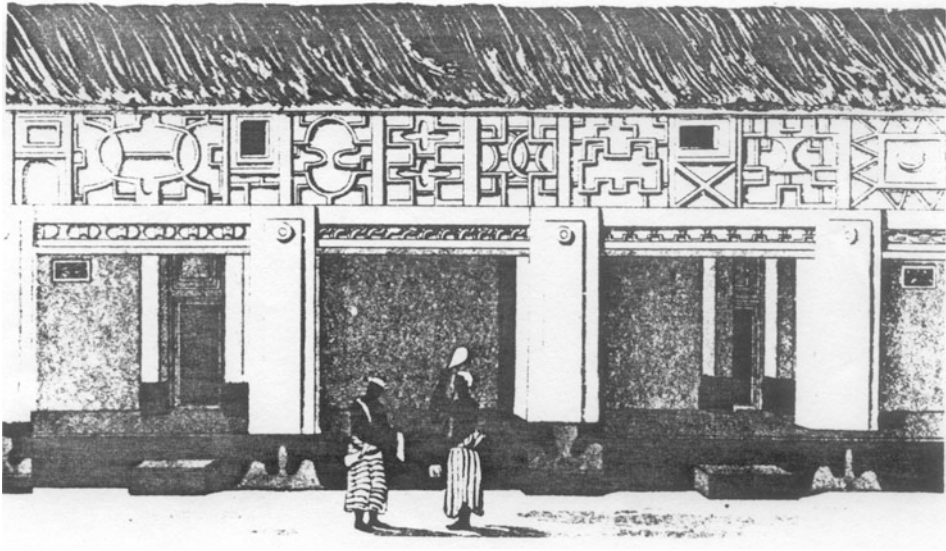
dwelling with solid clay walls. Thus, we should not fall into the trap of dismissing the possibility that coursed clay construction was practiced in West Africa – in Ghana – by local, early food producing communities of 3,500 years ago, on the basis of the dubious assumption that it is too “advanced.” This type of thinking about coursed clay construction is, perhaps, the basis of the suggestion that it must have come later, as an introduction or borrowing from more “advanced” cultures.

Coursed clay construction is related technologically to the building methods known in other parts of the world as *pise*, *tapia*, rammed earth and *tauf*. The product of this method of building is a structure with freestanding, solid clay walls. To achieve this end, certain requirements must be met with respect to the building material that is used, and how it is used. For Akan builders, *ntwuma*, a local, deep red, light clay with high iron content, is the most preferred for the raising of walls. But any earth with a good light to medium clay content can be used. If the clay content is poor, the walls will crack and crumble upon drying. Furthermore, the clay must be of the proper sand-to-clay ratio. If such clay cannot not

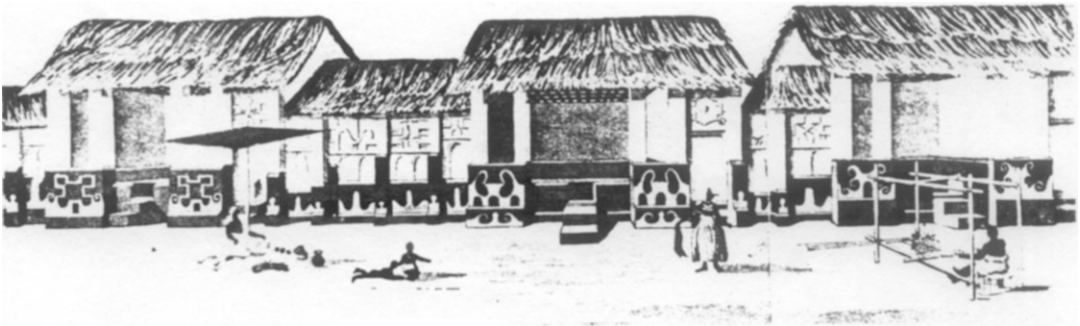
be found in the immediate vicinity of construction by digging far enough below the surface, it must be quarried from elsewhere and brought to the building site. (The same clays, by the way, are used for wall infilling in timber and clay construction, and they are prepared in the exact same manner.)

Clay is prepared by adding water and the mixture is “trodden.” Balls of clay are formed that are about the size of a human head, and these are thrown or rammed into place. Walls are raised in layers, or courses, and each course of the wall is more or less the same height, ca. 50–60 cm. However, each successive course is slightly thinner than the previous one. Thus, the first course, that which constitutes the base of the wall, has an average thickness of 30–45 cm. The final, or top, course averages 20–30 cm in thickness.

Builders explain that the practice of gradually thinning the wall with height is based on a simple structural principle: each successive course must be lighter than the previous one or the latter will crack and possibly crumble under the weight of the former. The same principle is echoed by Se Dangme and Anlo Ewe builders (the writer studied coursed clay building practiced by both



Building Construction in Africa: Akan, Fig. 2 The architecture of early nineteenth century Kumasi, the Asante Capital



Building Construction in Africa: Akan, Fig. 3 Kumasi “town houses” (as Bowditch called them). Dwelling of Kumasi’s political elite

groups), although their method of decreasing the weight of successive wall courses involves reducing the height of each course.

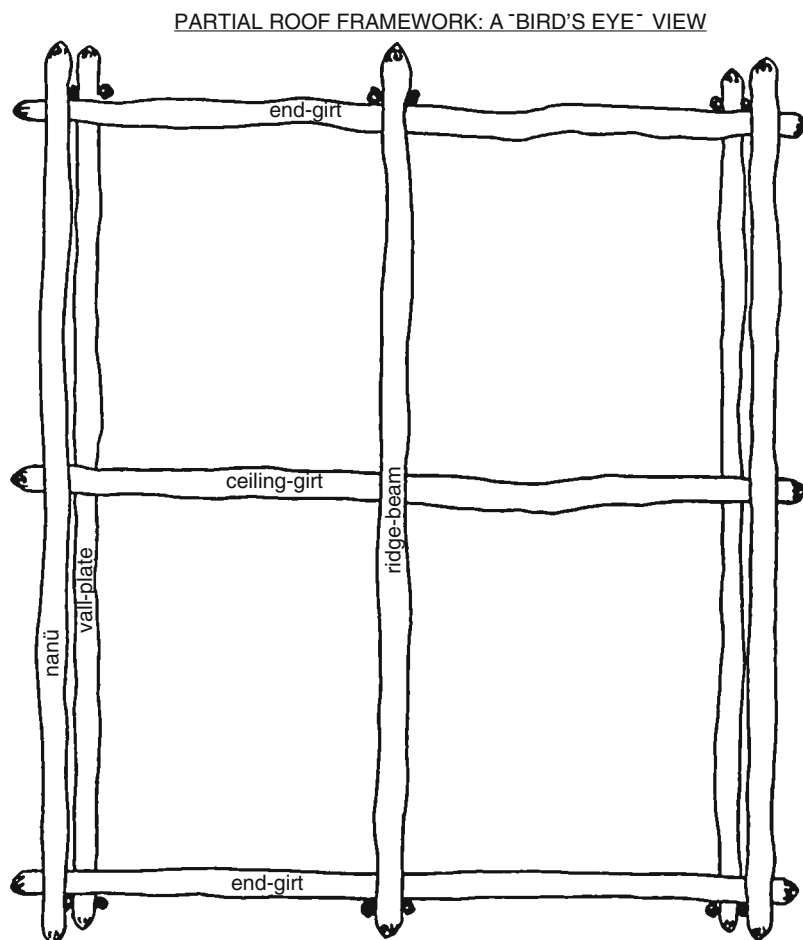
Each wall course must be allowed to dry sufficiently before the next is added. The amount of time for drying obviously varies depending on the season, but at least a week is necessary. If a course has not dried sufficiently, it will crumble under the weight of the addition. The coordinate courses of each of the four walls rise simultaneously as if the shell of the building were “growing” out of the ground. Spaces for doors and windows are left during wall construction as opposed to being cut in later, as is the case in

some coursed clay building traditions. The framework for the roof is constructed entirely of timber, and consists of all of the same timber elements that a roof in a timber frame house has.

This description of coursed clay wall construction comes entirely from ethnoarchaeological research. We have no written accounts of the construction of coursed clay buildings in southern Ghana for the time span extending from the early contact to the later pre-colonial periods, as is the case for timber frame construction. What we know from archaeology, however, is that Northern Akan peoples, the Bono, practiced coursed clay construction in their settlements a

Building Construction in Africa: Akan,

Fig. 4 Elements of Akan timber framework construction

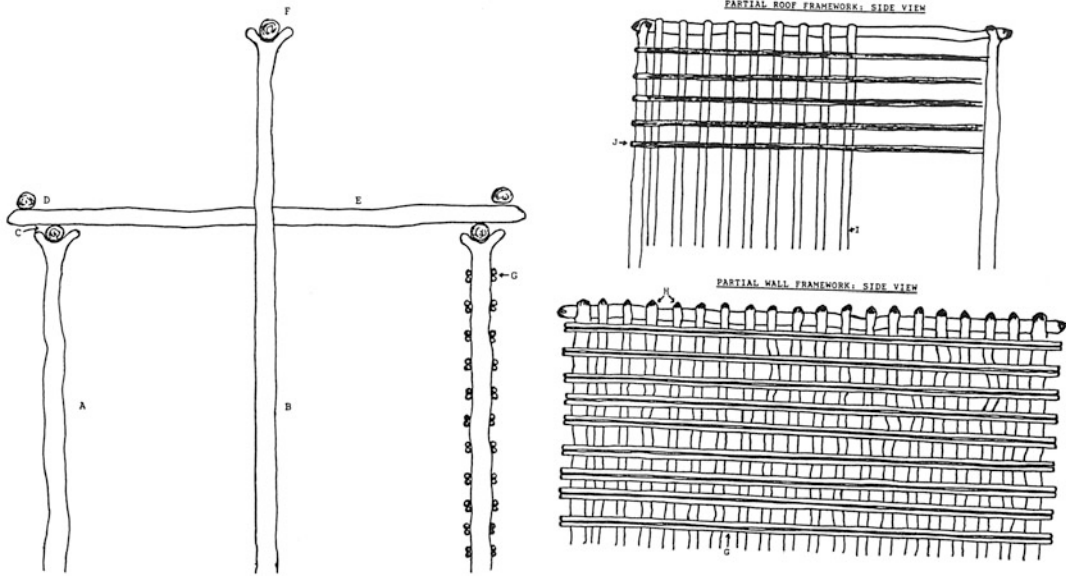


1,000 years ago. Most notable of these settlements, and one that has experienced some archaeological investigation, is the site of the early Akan city of Bono Manso (see, for example, Effah-Gyamfi 1975, 1978, 1979, pp. 173–186). Ethnoarchaeological studies may shed considerable light on the building technology that was practiced at early Akan settlements, so long ago.

In pre-colonial times, impressive structures of timber and clay, large elegant, adorned with beautiful surface decoration, and some of them two storeys high, characterized the major Akan settlements. The best known of these are the Asante “town houses,” so carefully and respectfully described by Thomas Bowditch in the early nineteenth century. In the north of the Akan region, the Bono, too, had their aristocratic town dwellings, but as early as the beginning of the second

millennium CE, these structures were as likely, perhaps more so, to be constructed in coursed clay. Ordinary people throughout the Akan world lived in smaller, less ornate versions of timber and clay and coursed clay dwellings. But the descriptions that we have of these dwellings, mainly from early to mid-nineteenth century sources for the interior, suggest that they were not lacking in beauty, comfort, and durability.

Well before the mid-twentieth century, the larger, two-storeyed timber and clay dwellings were no longer being built. Before century’s end, the practical knowledge of how to build them had disappeared. In the Bono region, large structures of coursed clay continued to be built, but the largest of buildings, now multi-storeyed, were more likely to be constructed in brick, “English style” brick, or *mrikes*, as they are locally called.



Building Construction in Africa: Akan, Fig. 5 The great court of the Asantehene's palace (Kumasi From Dupuis, 1824), frontispiece

Indigenous Akan building construction is still practiced, primarily in rural areas, but it is, seemingly, on the road to extinction. Indigenous architecture, no matter how attractive or well built, carries no prestige. It is thought to be backward, inconsistent with modernity, and thus, undesirable. Extinction may be the destiny for all systems of traditional architecture and building technology. Whether or not this is for the better is a subject for debate. One thing, perhaps, is not so debatable: valuable knowledge can be gained by those who would design and build tropical Africa's architecture of the future, from the study of the architecture and building technology of those who built it in the past (Figs. 1, 2, 3, 4, and 5).

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Cakravala Method

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Let us consider the equations (i) $3x = 6$ and (ii) $5y = 2$ in the two variables x, y . We recognize at once the (integer) solution $x = 2$ for equation (i) and further note that there can be no y in the set $\mathbf{N} := \{1, 2, 3, \dots\}$ of natural numbers which satisfies equation (ii), since the constant term 2 on the right-hand side of equation (ii) is not an integral *multiple* of (i.e., is not divisible by) the coefficient 5 of the variable y therein. Leaving these two simple examples of linear equations in a single variable, let us take up the following linear equation involving two variables x and y :

$$px - qy = m \quad (1)$$

where the coefficients p, q and the constant term m belong to the ring $\mathbf{Z}$ of the usual integers. $\dots -3, -2, -1, 0, 1, 2, 3, \dots$. Clearly, for (Eq. 1) to have a solution $x = a, y = b$ with a, b in $\mathbf{Z}$, it is necessary that any common divisor t of p and q (i.e. any t in $\mathbf{Z}$ dividing both p and q) must be a divisor of m as well. Thus the greatest common divisor (g.c.d. in brief) d of p and q denoted as (p, q) in symbols must also divide m . Now, a well-known algorithm of Euclid's for finding (in finitely many steps) the g.c.d. of any two given integers p, q enables us to write

their g.c.d. d in the form $d = pa + qb$ with suitable a, b in $\mathbf{Z}$, and we are led to the solution for (Eq. 1) in integers $x = am/d, y = -bm/d$. We should not fail to mention that an alternative approach to solving (Eq. 1) is to expand the rational number q/p (for $p \neq 0$) as a simple continued fraction. For example, if $p = 3, q = 11$ in (Eq. 1), then $q/p = 11/3$ has the continued fraction expansion $(3 + 1)/1 + 1/2$ whose "penultimate convergent" $(3 + 1)/(1 + 4/1)$ solves this special case of (Eq. 1) with $x = 4, y = 1$.

Solving linear equations such as (Eq. 1) in two variables or in more variables often opens the door to cracking interesting puzzles or even settling serious problems! A clear description of the method of solving (Eq. 1) is available in *Āryabhaṭīya*, a Sanskrit text of the (fifth or) sixth century AD. (According to Ian Pearce (2002), the mathematical part of *Āryabhaṭīya* covers arithmetic, algebra, plane trigonometry and spherical trigonometry and also contains continued fractions.) As observed by André Weil, this is also "the first ever explicit description" of the general solution in integers for (Eq. 1) from anywhere, except China. In subsequent Sanskrit treatises, this method came to be known as the *kuttaka* (pulveriser) method, but it might not be fair to attribute the same with authority to Greek mathematicians granting the familiarity of Indian astronomers with developments in Greek mathematics until then. It is interesting to learn from Weil how, in utter disregard or (possible) ignorance of the remarkable application of the *kuttaka*

in India and of the connection with the seventh book of Euclid's *Elementa*, Bachet ventured to insert (in the second edition of his book *Problèmes plaisants et délectables*) a strong claim to the *kuttaka* method as his own. Before attempting to say anything about the *cakravāla* method, let us see how the *kuttaka* method is applied.

Equation 1 can be rewritten as an (equivalent) “congruence” relation modulo the integer q , namely as $px \equiv m \pmod{q}$; we might recall here the customary notation, for a, b, c in $\mathbf{Z}$, that $a \equiv b \pmod{c}$ exactly when c divides $a-b$. Whenever d , the g.c.d. of p and q divides m , we can find, by Euclid's algorithm, an integer x such that $px-m$ (equals qy and hence) is divisible by q , i.e., $px \equiv m \pmod{q}$. The *kuttaka* precisely enables one to find the form of the general solution of this congruence (whenever (p, q) divides m). Take, by way of an example, the congruence $3x \equiv 1 \pmod{7}$. Since the g.c.d. $(3, 7)$ equals 1, the congruence is indeed solvable. Now $3 \times (-2) = -6 \equiv 1 \pmod{7}$ and so, on multiplying both sides of the congruence by -2 , we get $-6x \equiv -2 \pmod{7}$ which is the same as $x \equiv 5 \pmod{7}$. The *kuttaka* thus tells us that any integer of the form $7n + 5$ for arbitrary n in $\mathbf{Z}$ satisfies the congruence $3x \equiv 1 \pmod{7}$.

From linear equations in x and y , let us move on to (much more non-trivial) equations of degree 2 in two variables, e.g. $x^2 - Ny^2 = 1$ for N in $\mathbf{N}$. If $N = M^2$ with $M \in \mathbf{Z}$, the solution in integers x, y of this equation can be immediately found by factorising the left hand side and rewriting the equation as $(x + My)(x - My) = 1$ and hence as $(x + My) = (x - My) = \pm 1$. However, if $N = 2$ or any square-free integer (i.e. not divisible by the square of any prime number), then one could ask for all integers y such that $Ny^2 + 1$ is the square of an integer and, in other words, ask for solutions in integers x, y of

$$x^2 - Ny^2 = 1 \quad (2)$$

which indeed looks harder and is known as Pell's equation (ever since Euler attached Pell's name to it by mistake!).

For a while, let the square-free integer $N > 1$ be kept fixed in our general discussion and let, for any given integer m , the given triple $(x, y; m)$ stands for a solution in integers x, y of the more general diophantine equation

$$x^2 - Ny^2 = m \quad (3)$$

We can clearly identify, for any $t \neq 0$ in $\mathbf{Z}$, the triple $(tx, ty; t^2m)$ with $(x, y; m)$.

Under the heading *Vargaprakrti*, (Eq. 3) was investigated by the Indian mathematician ► **Brahmagupta** (seventh century AD) who used his *bhavana* rule to get non-trivial solutions for (Eq. 2) in integers for several cases of N (and, in particular, for $N = 92$ or 83 , solutions given by $(1151)^2 - 92 \times (120)^2 = 1, (82)^2 - 83 \times 9^2 = 1$. The *bhavana* (composition) rule gives, for two given triples $(x, y; m)$ and $(z, t; n)$, their product (or composite) $(x, y; m)(z, t; n)$ by the formula

$$(x, y; m)(z, t; n) := (xz \pm Nyt, xt \pm yz; mn) \quad (4)$$

Written in expanded form, this leads us to the composition formula

$$\begin{aligned} & (x^2 - Ny^2)(z^2 - Nt^2) \\ &= (xz \pm Nyt)^2 - N(xt \pm yz)^2 \end{aligned} \quad (5)$$

expressing, in modern parlance, the multiplicative property of the norm form $x^2 - Ny^2$ in two variables x and y .

The square-free integer N associated with the triple $(x, y; m)$ for (Eq. 3) was referred to as the *gunaka* (or *prakrti*) and the integer m therein as *ksepa* (additive). Brahmagupta knew how composition of a triple $(x, y; m)$ with a triple $(p, q; 1)$ with the same *gunaka* N leads to a triple $(x', y'; m)$, while the product $(x, y; m)(x, y; m)$ is again a triple $((x^2 + Ny^2)/m, 2xy/m; 1)$ provided $(x^2 + Ny^2)/m$ and $2xy/m$ are both in $\mathbf{Z}$. For $m = -1$ or ± 2 , composition of $(p, q; m)$ with itself leads to $(p^2 + Nq^2, 2pq; 1)$ or $((p^2 + Nq^2)/2, pq; 1)$, respectively. While the composition formula (Eq. 5) occurs explicitly in

Brahmagupta's work, special cases of the same for $N = 3$, $z = 5$, $t = 3$ may have been applied by Archimedes to obtain approximations to $\sqrt{3}$ by rational numbers, according to Weil.

We now give an example to see how the *bhavana* rule helps in solving (Eq. 2). Let us take Brahmagupta's investigation of the case $N = 83$ itself. The natural number "closest" to the *vargamoola* (square root) $\sqrt{83}$ of 83 is 9 and the relation $9^2 - 83 \times 1^2 = -2$ is the same as the triple $(9, 1; -2)$ corresponding to the value 83 for N . Composing this triple with itself according to *bhavana* as in (Eq. 4), we note that $((9 \times 9) + (83 \times 1 \times 1))^2 - 83((9 \times 1) + (9 \times 1))^2 = 4$, giving the "square" of $(9, 1; -2)$ as $(164, 18; 4)$. On division throughout by 4, the last-mentioned triple leads exactly to $(82, 9; 1)$ which is a solution (as discovered by Brahmagupta) for (Eq. 2) with $N = 83$. In H. T. Colebrook's book, *Algebra with Arithmetic and Mensuration, from the Sanscrit of Brahmagupta and Bhāscara*, one can find an entire section dealing with Brahmagupta's investigations on *Vargaprakrti*. Brahmagupta could find extremely accurate values for $\sqrt{N}$ using his solutions for (Eq. 2). According to Ian G. Pearce (2002), "this contribution is of huge interest as it is essentially the same method rediscovered and used by Newton and Raphson around 1690, which is known as the Newton-Raphson iterative method".

Despite Brahmagupta's admirable results, the general solution of (Eq. 2) is still not at hand! The brilliant *cakravālā* (cyclic) method for the general solution of (Eq. 2) has been located in the work of Bhaskara much later, around the twelfth century. Almost the same description of the *cakravālā* is provided in a commentary written around the eleventh century by "an otherwise unknown author" Jayadeva, leaving it open (for anyone) to identify the real inventor of the *cakravālā*. We shall now give a brief description of the method and an illustrative example.

The idea of the method is to start from a triple $(p_0, q_0; m_0)$ with "small" m_0 and use the *bhavana* to get a triple $(p_1, q_1; m_1)$ with m_1 "small" again and eventually, in finitely many steps, hit upon a triple $(u, v; r)$ with $r = 1, -1, \pm 2$; for $r = 1$,

(Eq. 2) is solved with $x = u$, $y = v$ but in the three remaining cases of r , composition of $(u, v; r)$ with itself yields a solution for (Eq. 2) as explained earlier (noting that the *gunaka* N is kept fixed all the while). For the triple $(p_0, q_0; m_0)$ at the start, p_0 is chosen such that p_0^2 is the square closest to N and q_0 is taken as 1 so that $m_0 = p_0^2 - N$. Next, the integer x_0 is chosen to satisfy the congruence $x_0 \equiv -p_0 \pmod{m_0}$ besides ensuring at the same time that $x_0^2 - N$ is "small" and in fact, more precisely, least in absolute value among all possible choices for x_0 with $x_0 \equiv -p_0 \pmod{m_0}$. Then the triple $(p_1, q_1; m_1)$ is defined as the composite

$$(p_0, q_0; m_0)(x_0, 1; x_0^2 - N) \\ = \left(\frac{(p_0 x_0 \cdot N)}{m_0}, \frac{(p_0 + x_0)}{m_0}, \frac{(x_0^2 - N)}{m_0} \right)$$

which is a genuine triple due to our congruence condition on x_0 . If we note that $x_0^2 - N = m_0 m_1$, we may see that keeping $N - x_0^2$ "small" helps to keep also m_1 "small". The next step in the *cakravālā* is to find x_1 in $\mathbf{Z}$ so as to enable us to obtain the composite $(p_1, q_1; m_1)(x_1, 1; x_1^2 - N)$ is a genuine triple to be defined as $(p_2, q_2; m_2)$. Actually x_1 is to satisfy the congruence $q_1 x_1 \equiv -p_1 \pmod{m_1}$ as well as the condition that $x_1^2 - N$ is "small" (i.e. least in absolute value among possibilities for x_1 got by using *kuttaka*). Having got the triple $(p_2, q_2; m_2)$, one proceeds to find suitable x_1 (modulo m_2) to move on to a triple $(p_3, q_3; m_3)$ and eventually, as mentioned above to a solution of (Eq. 2).

Example. For $N = 31$, we have $p_0 = 6, q_0 = 1, m_0 = 5$ giving us (in the terminology of Bhaskara) the (corresponding) auxiliary equation $31 \times 1^2 + 5 = 6^2$. Then by Bhaskara's lemma (i.e. indeed composing $(6, 1; 5)$ with $(x_0, 1; x_0^2 - 31)$ so that $x_0 \equiv -6 \pmod{5}$ and further the absolute value of $x_0^2 - 31$ is least (among all integers x_0 congruent to -6 modulo 5), we obtain $x_0 = 4$ and $(p_1, q_1; m_1) = (6, 1; 5)(4, 1, -15) = (11, 2; -3)$. Next with the auxiliary equation $31 \times 2^2 - 3 = 11^2$, *kuttaka* is used to find x_1 with $2x_1 \equiv -11 \pmod{3}$ and $x_1^2 - 31$ least (in absolute value), yielding

$x_1 = 5$ and $(p_2, q_2; m_2) := (p_1, q_1; m_1)(5, 1; -6) = (-39, -7; 2)$. Since $m_2 = 2$, a shortcut via the *bhavana* is to define directly $(p_3, q_3; m_3) := (-39, -7; 2)(-39, -7; 2) = (-1, 520, -273; 1)$, solving $x^2 - 31y^2 = 1$ at once. On the other hand, one could follow the general method indicated in the preceding paragraph to get $x_2 = 5$ and the triples $(-39, -7; 2)(5, 1, -6) = (-206, -37; -3)$, $(-657, -119; 5), (-1, 520, -273; 1)$ in that order. Further iteration of the method not only yields more and more solutions for $s^2 - 31y^2 = 1$ but also reveals a “cyclic” pattern in the *additives* m_i (vindicating the chosen name *cakravāla*). Using familiar notation for periodic simple continued fractions for quadratic irrationalities (e.g. Davenport 1990, pp. 104–105), we write $\sqrt{31} = \langle 5\overline{1, 1, 3, 5, 3, 1, 1, 10} \rangle$ and the relevant *convergent* $\langle 5, 1, 1, 3, 5, 3, s, 1, 1 \rangle = 1520/273$ got by omitting the *partial quotient* 10 from the *very* first period $\overline{1, 1, 3, 5, 3, 1, 1, 10}$ gives the same solution for (Eq. 2) as above. Weil’s own version of the *cakravāla* has the merit of not only totally dispensing with the use of *kuttaka* (in Bhaskara’s exposition of the *cakravāla*) but also making the “cyclic” pattern in the occurrence of the *additives* m_i quite transparent and *in tune with* the phenomenon of *periodicity* in the continued fraction expansion for $\sqrt{N}$. Are not the triples $(1, 766, 319, 049, 226, 153, 980; 1)$ for $N = 61$ and $(48, 842, 5, 967; 1)$ for $N = 67$ discovered and offered to us by Brahmagupta and Bhaskara masterpieces adorning the lustrous history of *cakravāla*?

To be fair though, one should recall Weil’s remarks that a rigorous treatment as explained above for constructing the successive triples $(p_i, q_i; m_i)$ “may have been known to Indian mathematicians only experimentally and there is nothing to indicate whether they had proof for them, or even part of them” and again that “For the Indians, of course, the effectiveness of *cakravāla* could be no more than an experimental fact, based on their treatment of a great many special cases, some of them of considerable complexity and involving (to their delight, no doubt) quite large numbers. Fermat was the first to perceive the need for a general proof and Lagrange the first to publish one. Nevertheless, to have

developed the *cakravāla* and to have applied it successfully to such difficult cases as $N = 61$ or $N = 67$ had been no mean achievement”. Weil is unsparing as well in his critical analysis of Euler’s contribution to the topic of “Pell’s equation” in the form of drawing attention to the periodicity and “palindromic” property of the “partial quotients” in the continued fraction expansion for $\sqrt{N}$ or their use in solving “Pell’s equation” with perhaps merely experimental evidence to back up his assertions. Although the “Cattle Problem of Archimedes” (Davenport 1990) is usually associated with Pell’s equation, one learns from Weil that equations such as (Eq. 2) “do occur in Diophantus. . . , but it is a rational solution that is asked for, even when accidentally a solution in integers is obtained. . . .”. A detailed discussion of Kronecker’s interesting solution (using elliptic functions) for Pell’s equation can be found in Siegel’s section 27.1 (1963).

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Calculus

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The Indian origin of infinite series, found in widely distributed texts, has long been publicly known to Western scholars (Whish, 1832).

Recent research (Raju, 2007) has shown that these Indian developments really did amount to the calculus. (This brings to the forefront various epistemological issues, and the very philosophy of mathematics taken for granted in Western discourse.) This research has also pushed the historical origin of the calculus in India much further back to the fifth century CE Āryabhaṭa and his method of obtaining sine values by numerically solving the corresponding differential equation using a finite difference technique.

The infinite series had originated in India by the fourteenth century. An explicit formula for the sum of an infinite (*anantya*) geometric series is given by the fifteenth and sixteenth centuries Nīlakantha in his *Āryabhaṭīyabhāṣya* (Sastri 1930, commentary on *Gaṇita* 17, p. 142.)

एवं यस्तुल्यच्छेदपरभागपरम्पराया अनन्ताया अपि संयोगः
तस्यानन्तानामपि कल्प्यमानस्य योगस्याद्यावयविनः
परम्परांश्छेदादेकोनच्छेदांशसाम्यं सर्वत्रापि समानमेव ।

which may be translated (cf. Sarma, 1972, p. 17):

The sum of an infinite [*anantya*] series, whose later terms (after the first) are got by dividing the preceding one by the same divisor everywhere, is equal to the first term multiplied by the common divisor and divided by one less than the common divisor.

That is $a + \frac{a}{d} + \frac{a}{d^2} + \dots = \frac{ad}{d-1}$. (It is assumed that the divisor $d > 1$, so that the common ratio is less than 1.) This is obviously the earliest textual source in the world for a formula for a properly infinite sum.

Was this infinite sum based on a “rigorous” notion of limits? In fact, it was based on something superior. Indian mathematicians used a different number system involving what would today be called “non-Archimedean” arithmetic and a different epistemology, which allowed discarding of infinitesimals (see also “► Zeroism”).

In terms of formal mathematics, the Indian approach may be understood as follows. Ever since algebra began (with Brahmagupta), Indian mathematicians referred to polynomials as “unexpressed (*avyakta*) numbers.” This led naturally to “unexpressed fractions,” or what formal

mathematicians would today call the non-Archimedean ordered field of rational functions. (For an elementary construction of this field, see Moise, 1968, Appendix.)

A non-Archimedean field contains a number x such that $x > n$ for every integer n . Such a number may be called infinite. Being a field, it also contains the multiplicative inverse of the number which satisfies $0 < \frac{1}{x} < \frac{1}{n}$ for every integer n , so that $\frac{1}{x}$ may be called infinitesimal. The existence of infinitesimals means that limits are not unique, and one must discard infinitesimals. (“Infinitesimal” does *not* mean the same thing as “imperceptible” or “intangible,” e.g., $\frac{3}{n}$ or $\frac{n}{n^2}$ are infinitesimals.) The traditional Indian process of summing infinite series by discarding of infinitesimals, as used in deriving the above formula, is equivalent to limits by order counting (Raju, 2007, Chapter 3).

Discarding infinitesimals is related to discarding small numbers, but clearly goes a step beyond it. Small numbers were traditionally discarded, from at least 2,500 years ago, since the days of the *śulba sūtra* to provide “approximate” values of $\sqrt{2}$, π , etc. The terms then used were *saviśeṣa* (with something remaining) (Baudhāyana *śulba sūtra*, 2.12 1, Sen & Bag, 1983, p. 169), *anitya* (impermanent) (Apastamba *śulba sūtra*, 3.2, Sen & Bag) in the *śulba sūtra*, and *āsanna* (near value) by Āryabhaṭa (*Gaṇita*, 10, Shukla & Sarma, 1976). This was similar (but not identical) to the way one today has no choice but to discard small numbers in computer (floating point) arithmetic, since a computer cannot physically implement formal “real” numbers obtained as metaphysical limits.

Further, since Āryabhaṭa (fifth century), at least, an algorithm was available for square root extraction, so there was a recursive process of generating an infinite series for, say, $\sqrt{2}$. A recursive series for difficult fractions, similar to continued fractions, was also used since Brahmagupta. (For full details, and for the use of this fraction-series expansion in developing later-day infinite series, see Raju, 2007, Chapter 3.) Summing an infinite series, as Nīlakanṭha did, by discarding infinitesimals, or

order counting, clearly goes beyond the much older process of discarding small quantities by truncation of infinite series or halting those recursive procedures after a finite number of steps.

Further, one should not just assume that metaphysical limits or Western metaphysical ways of handling infinity are automatically superior. Thus, the use of non-Archimedean arithmetic (plus zeroism) leads to a notion of derivative superior to the present-day college-text definitions of the derivative as a limit, for the college-text definition fails with a discrete number system like floating point numbers on a computer, or with discontinuous functions. While the Schwartz theory does allow a discontinuous function to be differentiated, Schwartz distributions cannot be readily multiplied; therefore, that notion of derivative cannot be used for nonlinear differential equations of physics (Raju, 1989).

The whole problem of how to define the derivative or the notion of probability has a natural and very simple resolution using Indian “non-Archimedean” arithmetic and the related philosophy of zeroism, a solution which is better and far simpler than the resolution using nonstandard analysis, as was used earlier (Raju, 2007, Appendix).

Further, it is clearly wrong to assume that the dominant philosophy of formalism, even though globalized by colonialism, represents a universal philosophy of mathematics or is the only correct way to do mathematics. Even the logic underlying mathematical proofs is not universal (Raju, 2001; see also article on “► Logic”). Formalist philosophy hence involves a biased metaphysics (Raju, 2011b).

Calculus can also be taught with a different philosophy which follows its actual historical development and makes it easy to learn. (Thus, over the last few years, “decolonized” courses on “calculus without limits” have been taught with significant success to eight groups in four universities in three countries; Raju, 2011c, 2012.)

Indian mathematicians long knew about *finite* geometric series, which they called *guṇottara sankalitā* or *guṇottara śreḍhī* (multiplicative series), and methods of summing the finite geometric series were a part of the elementary school

curriculum from at least 1,300 years ago and are found in numerous elementary texts such as the *Pāṭi Gaṇita* of Śrīdhara (Śrīdhara, Shukla, 1959, trans. p. 75.) Indeed, summing a finite multiplicative series was a very common commercial problem found in a variety of other sources such as the *Gaṇita Sāra Saṁgraha* of Mahāvīra (Jain, 1963), *Mahā Siddhānta* of Āryabhaṭa II (Dwivedi, 1900), the *Līlāvātī* of Bhaskara II, etc. (rule 126 et. seq; the numbering differs between Colebrooke, 1816 and the critical edition of Sarma, 1975).

In fact, the place value system lends itself naturally to “geometric” (multiplicative) series, and the first such series is found thousands of years earlier in the Yajurveda (17.2), and in the Lalita Vistara Sutra (Chapter 12) where it goes up to large numbers like 10^{53} (named *tallakṣaṇa*).

Of what use were these infinite series? An infinite series expansion for the sine and cosine (today called the “Taylor” series, after a pupil of Newton) was used by Madhava of Sangamagrama (1340 CE) to calculate precise sine and cosine values, by truncating the series to 11th- and 12th-order polynomials. The infinite series expansion is found in two verses stated in various texts, such as the *Tantrasaṁgraha Vyākhyā/Yuktidīpikā* (2.440 – 443) (Sarma, 1977).

निहत्य चापवर्गेण चापं तत्तत्फलानि च ।
हरेत् समूल्युग्वर्गैस्त्रिज्यावर्गहतैः क्रमात् ॥ ४४० ॥
चापं फलानि चाधोऽधो न्यस्योपर्युपरित्यजेत् ।
जीवाप्त्यै, संग्रहोऽस्यैव विद्वान् इत्यदिना क्रितः ॥ ४४१ ॥

This verse may be translated:

Multiply the arc by the square of the arc, and take the result of repeating that [any number of times]. Divide [each of the above numerators] by the squares of successive even numbers increased by that number [lit. the root] and multiplied by the square of the radius. Place the arc and the successive results so obtained one below the other, and subtract each from the one above. These together give the *jīvā*, as collected together in the verse beginning with “*vidvān*” etc.

In present-day mathematical terminology, the above passage says the following. Let r denote the radius of the circle, let s denote the arc, and let t_n denote the n th expression obtained by applying

the rule cited above. The rule requires us to calculate as follows.

1. Numerator: multiply the arc s by its square s^2 , this multiplication being repeated n times to obtain $s \cdot \prod_1^n s^2$.
2. Denominator: multiply the square of the radius, r^2 , by $[(2k)^2 + 2k]$ ("the squares of successive even numbers increased by that number") for successive values of k , repeating this product n times to obtain $\prod_{k=1}^n r^2 [(2k)^2 + 2k]$.

Thus, the n th iterate is obtained by

$$t_n = \frac{s^{2n} \cdot s}{(2^2 + 2) \cdot (4^2 + 4) \cdot \dots \cdot [(2n)^2 + 2n] \cdot r^{2n}}. \quad (1)$$

The rule further says

$$j\bar{iv}\bar{a} = s - t_1 + t_2 - t_3 + t_4 - t_5 + \dots \quad (2)$$

$$= s - \frac{s^3}{r^2 \cdot (2^2 + 2)} + \frac{s^5}{r^4 (2^2 + 2) (4^2 + 4)} - \dots \quad (3)$$

Substituting

- (1) $j\bar{iv}\bar{a} \equiv r \sin \theta$,
- (2) $s = r \theta$, so that $s^{2n+1}/r^{2n} = r \theta^{2n+1}$, and noticing that
- (3) $[(2k)^2 + 2k] = 2k \cdot (2k + 1)$, so that
- (4) $(2^2 + 2) (4^2 + 4) \dots [(2n)^2 + 2n] = (2n + 1)!$, and cancelling r from both sides, we see that this is entirely equivalent to the well-known infinite series

$$\sin \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \dots \quad (4)$$

A similar rule gives another infinite series for $\bar{s}ara$, corresponding to the infinite series for cosine. A similar series was available for the inverse arc-tangent function, and various other infinite series

were developed in the process of accelerating convergence of these series (Raju, 2007, Chapter 3).

The above infinite series was used to devise a numerically efficient formula (Raju, 2007, Chapter 3) which finally leads to the table of 24 sine values accurate to the third sexagesimal minute (*tatparā*) and stated in reverse-sexagesimal *kaṭapayādi* notation. (For a detailed explanation of this *kaṭapayādi* system and the precise accuracy of the values, see Raju, Chapter 3.) The first few and last few lines of the verse are as follows

श्रेष्ठ नाम वरिष्ठाना हिमाद्रिवेदभावनः ।

तपनो भानुसूक्तज्ञो मध्यमं विद्धि दोहनम् ॥

धिगाज्यो नाशनं कष्टं छन्नभोगाशयाम्बिका ।

म्रिगाहारो नरेशोऽयं वीरो रणजयोत्सुकः ॥

...

छायालयो गजो नीलो निर्मलो नास्ति सत्कुले ।

रात्रौ दर्पणमभ्राङ्गं नागस्तुङ्गनखो बली ॥

धीरो युवा कथालोलः पूज्यो नारीजनैर्भगः ।

कन्यागारे नागवल्ली देवो विश्वस्थली भृगुः ॥

तत्परादिकलान्तास्तु महाज्या माधवोदिताः ।

स्वस्वपूर्वविशुद्धे तु शिष्टास्तत्खण्डमौर्विकाः ॥ २.९.५ ॥

This corresponds to the values in Table 1.

The accuracy of these values in decimals is given in Table 2.

The actual calculation requires the value of the number today called π . Madhava had obtained the value accurate to 12 decimal places. This was obtained by accelerating the convergence of various slowly convergent series such as the infinite series today wrongly called "Leibniz series." Nīlakaṇṭha, in his *Āryabhaṭīya Bhaṣya*, in his commentary on *Gaṇita* 10 (Sastri, 1930, p. 56), described the subtle value of π given by Madhava of Sangamagrama as follows:

सङ्गमग्रामजो माधवः पुनरत्यासन्नं परिधिसंख्यामुक्तवान् -

विवुधनेत्रगजाहिहताशनत्रिगुणवेदभवारणबाहवः ।

नवनिखर्वमिते वृत्तिविस्तरे परिधिमानमिदं जगदुर्वुधाः ॥

The numbers in this verse are according to the old *bhūta saṁkhyā* system, which uses word

Calculus, Table 1 Madhava's sine values

No.	Kaṭapayādi	kalā (')	vikalā('')	tatparā('')
1	श्रेष्ठं नाम वरिष्ठानां	224	50	22
2	हिमाद्रिर्वेदभावनः	448	42	58
3	तपनो भानुसूक्तज्ञो	670	40	16
4	मध्यमं विद्धि दोहनम्	889	45	15
...	...	...	...	...
21	धीरो युवा कथालोलः	3,371	41	29
22	पूज्यो नारीजनैर्भगः	3408	20	11
23	कन्यागारे नागवल्ली	3,430	23	11
24	देवो विश्वस्थली भृगुः	3,437	44	48

Calculus, Table 2 Accuracy of Madhava's sine table

No.	Mādhava's sine value	Difference
1	0.0654031452	0.0000000160
2	0.1305262297	0.0000000375
3	0.1950903240	0.0000000020
4	0.2588190035	-0.0000000416
...	...	...
...	...	...
21	0.9807852980	0.0000000176
22	0.9914448967	0.0000000353
23	0.9978589819	0.0000000587
24	1.0000000000	0.0000000000

numerals. Thus, *netra* means 2 because one has two eyes, *veda* = 4, *guṇa* = 3, *tri* = 3, etc. (For more details about the *bhūta saṁkhyā* system, see Datta & Singh, 1935.) The quantity *nikharva* = 10^{11} . Thus, the above verse may be translated:

Mādhava of Saṅgamagrāma spoke the approximate [*āsanna*] number of the circumference of a circle:

vibudha [33] *netra* [2] *gaja* [8] *ahi* [8] *hutāśana* [3] *tri* [3] *guṇa* [3] *veda* [4] *bhavāraṇa* [27] *bāhavaḥ* [28], i.e., [2,827,433,388,233] is the measure of a circle of diameter *nava* [9] *nikharva* [100,000,000,000].

This corresponds to $\pi = 3.141,592,653,5922$..., accurate to 11 places after the decimal point, with the 12th and 13th places (92 respectively) differing slightly from their accurate value (89). The term *nikharva* continues the series, *koṭi*, *arbuda*, *abja*, *kharva*, *nikharva*, then in common use for centuries. (*Pāṭi Gaṇita*, 7. Shukla, 1959.) Parts of this series coming from Vedic times are still in current use, e.g., *koṭi* = crore. (Currently, an *arbuda*, called “arab,” is 100 crores, while a *kharva*, called “kharab,” is 100 arabs.) The more common expression for π stated in the *kaṭapayādi* system, using reverse-sexagesimal notation, gives the radius of a circle with circumference 21,600 (= number of minutes in 360°) as *Devo viśvasthalī bhr̥guḥ*, corresponding (in reverse order) to 3437' 44" 48", which is

substantially more accurate than the seventh-century Bhāskara's figure of $3438'$, or the ninth-century Vateśvara's figure of $3437' 44''$.

As is clear from the above figures, these methods developed gradually over a thousand years, as the requirements of precision gradually increased. These accurate trigonometric values were needed for astronomy used for the practical needs of the calendar and navigation. The calendar was needed for successful monsoon-driven agriculture, in India, while navigation was needed for overseas trade. The whole tradition of computing 24 sine and cosine values, 3.75° apart, was started a thousand years earlier by Āryabhaṭa in the fifth century. He computed 24 sine values and the value of π accurate to the first sexagesimal minute (*kalā*, about 5 decimal places). It is well known that Āryabhaṭa's value of π was quoted by al Khwārizmī, but not so well known that this was still being repeated by sixteenth-century European navigational theorists, such as Simon Stevin (Pannenkoek & Crone, 1961).

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Calculus Transmission

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It has gone unnoticed that Āryabhaṭa's 24 sine values (see “► [Calculus](#)”) involved a striking departure from the earlier geometric tradition and a paradigm shift to numerical techniques. The geometric tradition is useful only in simple situations where high symmetry is present. It cannot be used to calculate the sine of 1° but was earlier used to compute 6 sine values 15° apart.

In a second radical departure, Āryabhaṭa used difference equations, instead of algebraic equations. Indeed, in the tenth *gītikā* (this is called the tenth *gītikā* since the first two are invocations; Shukla & Sarma, 1976), of the *daśgītikā* section, he states only the sine *differences*:

मखि भखि फखि धखि राखि जखि
डखि हस्म स्ककि किषा श्चकि किच्च ।
ब्लकि किग्र हक्व धकि किच
स्ग श्म ड्व क्ल प्त फ छ कलार्धज्या ॥ १२ ॥

The numbers involved here are expressed in Āryabhaṭa's novel numerical notation (see Shukla & Sarma, 1976 or Raju, 2007, Chap. 3). Thus, the verse may be translated:

225, 224, 222, 219, 215, 210, 205, 199, 191, 183, 174,
164, 154, 143, 131, 119, 106, 93, 79, 65, 51, 37, 22,
7—[these are the] sine [lit. half-chord] differences
[for the quadrant divided into as many equal parts,
each part hence being $225'$] [in] minutes.

The method of calculating these differences is explained in Gaṇita 12 as:

प्रथमाच्चापज्यार्धाद्यैरूनं खरिडतं द्वितियार्धम् ।
तत्प्रथमज्यार्धाशैस्तैस्तरूनानि शेषाणि ॥ १२ ॥

This may be translated:

(12) The sine of the first arc divided by itself and diminished gives the second sine difference. That

same first sine, when it divides successive sines gives the remaining [sine differences]. (Trans. by the author, based on the Hindi translation of Rai, 1976, pp. 42–43; cf. Shukla & Sarma, 1976, p. 51)

That is, if the quadrant of the circle is divided into, say, 24 equal parts, where $R_1, R_2, \dots, R_{24}$ are the 24 corresponding sine values; $\delta_1 (= R_1)$, $\delta_2, \dots, \delta_{24}$ are the corresponding sine differences; and $\delta_i = R_i - R_{i-1}$, for $i \geq 2$, then Āryabhaṭa's rule consists of the following two parts:

$$\delta_2 - \delta_1 = -\frac{R_1}{R_1}, \quad (1)$$

$$\delta_{n+1} - \delta_n = -\frac{R_n}{R_1}. \quad (2)$$

This cannot be understood as an algebraic equation, since that would lead to the wrong answers. More precisely, it can be regarded as an algebraic equation for calculating the second difference but not for its proper purpose, which is to calculate sine differences (Raju, 2007).

Āryabhaṭa's technique of solving those difference equations was later modified by Nīlakaṇṭha to make it accurate to thirds. Thus, the above interpretation is also the one given by Nīlakaṇṭha in his *Āryabhaṭīyabhāṣya* (Sastri, 1930), except that Nīlakaṇṭha makes it more precise, by stating it in the form

$$\delta_n^{(2)} = -\left(\frac{R_n}{R_1}\right) (\delta_1 - \delta_2). \quad (3)$$

The difference here is that for Āryabhaṭa, working to the precision of minutes, $\delta_1 - \delta_2 = 225 - 224 = 1$, while this is no longer the case with Nīlakaṇṭha, working to the precision of thirds, who uses the values, $R_1 = [224; 50; 22]$ and $R_2 = [448; 42; 58]$, so that $\delta_2 = [223; 52; 36]$ and $\delta_1 - \delta_2 = [0; 57; 46]$.

Āryabhaṭa's method of solving differential equations by finite differences is today wrongly called “Euler's method” after Euler who studied the relevant Indian texts when he wrote an article on the Indian calendar in 1700. Further, the numerical solution of differential equations (rather than metaphysical existence and

uniqueness theorems) is at the heart of all practical applications of the calculus even today.

Āryabhaṭa's process of setting up and solving differential equations involves only the simple "rule of 3" or what would geometrically be called linear interpolation. However, unlike the geometric notion, the arithmetic process easily extends recursively, and recursive application of this process naturally leads to second- and higher-order differences and thence to the infinite series used by Madhava and others.

Note that Āryabhaṭa himself brought in the *second* difference. Today, we would rewrite the formula as

$$\delta_n^{(2)} \equiv \delta_{n+1} - \delta_n = -\frac{R_n}{R_1}, \quad (4)$$

corresponding to the idea that the second difference/derivative of the sine is proportional to the sine itself. But with finite differences, a little more detail is necessary, and Āryabhaṭa also specifies the constant of proportionality.

Second differences were also used for interpolation, from Brahmagupta onwards, about a century later, and this use was continued subsequently by Vaṭeśvara and Bhāskara II.

Brahmagupta's second-order interpolation formula, nowadays wrongly called "Stirling's formula," is stated as follows (*Uttarakhaṇḍ-akhādyaka*, II.1.4, Chatterjee, 1970, vol. II, p. 177).

गतभोग्यखण्डकान्तरदलविकल वधाच्छतैर्नवभिराप्त्या ।
तद्युतिदलं युतोर्न भोग्यादूनाधिकं भोग्यम् ॥ ४ ॥

This has been translated (using Bhaṭṭotpala's tenth century CE [Saka 888] commentary) as:

Multiply the *Vikalā* by half the difference of the *Gatakhanda* and the *Bhogyakhanda* and divide the product by 900. Add the results to half the sum of the *Gatakhanda* and the *Bhogyakhanda*, if their half sum is less than the *Bhogyakhanda*; subtract, if greater. [The result in each case is the *Sphuṭabhogyakhanda* or correct "tabular" difference.]

Here, the underlying table is that calculated for *khaṇḍajyā*-s or sine differences for intervals that are spaced h apart, where it is assumed that

$h = 15^\circ$ or $900'$. The *gatakhanda* or "past difference" ($= \delta_n$) refers to the interval that has been crossed, and the *vikalā* ($= \theta$) is the amount in minutes by which it has been crossed at the point at which we want to interpolate. The *bhogyakhanda* ($= \delta_{n+1}$) is the one yet to come. Thus, the formula states:

Sphuṭabhogyakhanda

$$= \frac{\delta_n + \delta_{n+1}}{2} \pm \frac{\theta}{h} \frac{\delta_n - \delta_{n+1}}{2} \quad (5)$$

$$\sin(nh + \theta) - \sin nh = \frac{\theta}{h} \times \text{sphuṭabhogyakhanda}. \quad (6)$$

This amounts to

$$\begin{aligned} \sin(nh + \theta) &= \sin nh + \frac{\theta}{h} \frac{\delta_n + \delta_{n+1}}{2} \\ &\quad \pm \frac{\theta^2}{h^2} \frac{\delta_n - \delta_{n+1}}{2}. \end{aligned} \quad (7)$$

Vaṭeśvara (*Siddhānta*, II.1.63 – 82) (in 904 CE) uses backward differences, works with arcs that are only $56' 15''$ apart, and still uses quadratic interpolation, explicitly giving the second of the above formulae, among many others (Shukla, 1976, part I, p. 96, and part II, p. xlv). This enabled him to improve Āryabhaṭa's sine values (accurate to the minute) and achieve accuracy to seconds.

Bhāskara II, while offering a justification for these formulae stated by Vaṭeśvara, brings in the present or instantaneous sine difference as the mean value of the past and future sine difference. This concept of *tātkālika bhogya khanda* or instantaneous difference leads him naturally to the concept of *tātkālika gati* or *instantaneous velocity* of a planet, since it is in that context of planetary motion that these interpolations were typically required (*Siddhānta Śiromaṇi*, *Spaṣṭādhikāra* 36–38, and accompanying autocommentary *Vāsanābhāṣya*, Sastri, 1858, 1929, 1939, 1943; Sengupta, 1932). This notion of derivative used for planetary velocity (*gati*) is not a "precursor" to the Newtonian notion, using

fluxions, but involves an understanding of the derivative which is superior from both a practical and an epistemological perspective, as explained earlier.

The calculus in India was also used to derive accurate formulae for areas and volume – a typical application of present-day integral calculus. The volume of a sphere was first correctly expressed by Śrīdhara in his *Triṣaṭikā* (Dwivedi, 1899; Ramanujachari and Kaye 1912).

Bhāskara II suggests a very interesting pedagogical demonstration, involving a model of the earth made of clay or wood.

He concludes:

This is as I have said in my Arithmetic: (*Lilāvātī*, rule 201; Sarma, 1975) the area of a circle is equal to the product of the circumference by one-fourth of the diameter [πr^2]. That result multiplied by 4 gives the surface of the sphere [$4\pi r^2$], which is like the net surrounding a hand ball; the same (surface of a sphere) when multiplied by the diameter and divided by six [$\frac{4}{3}\pi r^3$] becomes invariably the volume of the sphere.

These correct formulae for the surface area and volume of a sphere are significant, since the correct formulae for the volume of a sphere were not known earlier.

The term “Kerala school,” used by the late K. V. Sarma, has been misused to suggest that calculus originated solely in Kerala. As we have seen, the whole technique of numerically solving differential equations began with Āryabhaṭa who did this work in Kusumpura or Patna. K. V. Sarma, himself, denied that Āryabhaṭa was somehow from Kerala (Sarma, 2001). Further, as the title of Nīlakaṇṭha’s *Āryabhaṭīyabhāṣya* says, Nīlakaṇṭha regarded himself as belonging to the Āryabhaṭa school. This is also significant since Nīlakaṇṭha, as his name “somasūtvān” says, was a Brahmin of the highest caste, while Āryabhaṭa, as his name “bhaṭa” indicates, belonged to a low caste. (“Bhaṭa” meaning slave should not be confounded with “bhaṭṭa” which is the appellation of a learned Brahmin.) The Āryabhaṭa school in Kerala clearly shows that neither the caste divide nor the regional divide was as strong then. The development initiated by Āryabhaṭa was continued by a variety of other mathematicians, from Gujarat, Ujjain, and

Banaras. The first infinite/indefinite series was derived by Brahmagupta, as a technique for approximating difficult fractions, in what this author has called the “fraction series expansion” (*Brāhma Sphuṭa Siddhānta* 12.57, more details in Raju, 2007, Chap. 3).

Even more importantly, a key input in the summation of the series was a general formula given by Nārāyaṇa Paṇḍit of Benares in his *Gaṇita Kaumudī* (Dwivedi, 1942, p. 123) for the *vārasaṅkalitā*. (Since Nārāyaṇa is a very common name in India, some scholars have confounded Nārāyaṇa Paṇḍit with some other Nārāyaṇa in the Kerala school.) This *vārasaṅkalitā* series, involving summation of partial sums, is also mentioned by Bhaskara II, who, however, does not give a general formula for summing it. Some five centuries before Mādhava, Govindasvāmin (ca. 800, *Bhāṣya* on the *Mahā Bhaṣkarīya*, iv.22; Sen, 1966, p. 78) and then Udayadivākara (tenth century, *Sundarī* on the *Laghu Bhāskarīya*, ii.3 – 6; Sen, p. 280), of the Āryabhaṭa school in Kerala, tried to obtain trigonometric values accurate to the thirds (i.e., third sexagesimal minute), but their values were not accurate enough; Mādhava’s trigonometric values are however accurate to the thirds. Hence, it is clear that a key input enabling the computation to thirds is the expression for the sum of the *vārasaṅkalitā* given by Nārāyaṇa Paṇḍit of Benares in his *Gaṇita Kaumudī*. Thus, there is no way that the calculus developments can be localized to any one region or caste in India.

What was the social and practical need for such highly accurate sine values? This is related to the two key sources of wealth in India, namely, agriculture and overseas trade. (For a summary account, see GJH, 2007.) Since agriculture in India was (and still is) mostly monsoon driven, it required a good calendar to get the right time of the monsoons, described in the Indian lunisolar calendar by the months of *sawan* and *bhadon*. There is no such possibility in the Gregorian calendar. The Indian calendar was based on a sophisticated astronomical model, similar, but not identical, to the one attributed to the supposed Greek author of the *Almagest* (Raju, 2014).

In this context, some authors refer to the sine as Rsine and claim that trigonometry was transmitted to Indians from the *Almagest*. However, the actual evidence tells us that trigonometry was transmitted from India to Europe via Arabs. Indeed, the very word “sine” derives from a translation howler during the Toledo mass translations of Arabic texts in 1125 CE. The word derives from the Latin *sinus* or fold, which is a translation of the Arabic *jaib*, meaning pocket, which is a wrong reading of the Arabic *jiba*, from the vernacular *jīvā*, for the Sanskrit *jyā*, meaning chord (as used by Āryabhaṭa).

Indeed, scientific texts are accretive, so that the twelfth-century *Almagest* reflects twelfth-century knowledge which came about by transmission from India. There is no serious evidence for either its existence in its present form in the second century CE or that its author was a Roman-Greek called Claudius Ptolemy. The failure to reform the Julian calendar since the fifth century is counterevidence against this belief (Raju, 2010).

The linguistic error of translation in the term “sine” was accompanied by a conceptual error, as in the very word “trigonometry” where the functions relate to the circle, not the triangle. That error persists to this day in the teaching of “trigonometry” which is stuck in the pre-Āryabhaṭa era. The word “trigonometry” is in quotes, since this geometric method wrongly suggests that the concepts of sine and cosine relate to the triangle, whereas they actually relate to the circle.

Studying the movements of planets on the celestial sphere naturally required calculations with the circular functions sine and cosine. Hence, sine tables are commonly found in Indian astronomy and mathematics texts, starting from the third-century CE *Sūrya Siddhānta*. This requirement of an accurate calendar for successful agriculture still persists. (Specifically, on a number of occasions in the last decade, there has been large-scale crop failure due to mistimed agricultural operations; Raju, 2007, Chap. 4.)

Accurate sine values (and an accurate calendar) were also required for navigation even to determine latitude. At night, latitude could be determined simply by measuring the altitude of

the pole star. This was done using a sophisticated instrument (with harmonic interpolation) which was never earlier understood by Western historians (Raju, 2007, Chap. 5). This instrument was used by the Indian navigator who brought Vasco da Gama to Calicut in India from Melinde in Africa. However, Vasco neither knew nor immediately understood the method. Since the Malayalam word for the pole star (*kau*) also means teeth and the instrument used by the navigator is held between the teeth, Vasco da Gama recorded that “the pilot told the distance by his teeth”!

In daytime, latitude was determined from observations of solar altitude at noon, and longitude was determined by solving the appropriate longitude triangles (Raju, 2007, Chap. 4). A solution to these two problems of latitude and longitude determination is found in many early Indian texts, such as the text of the seventh-century Bhaskara I, a commentator on the fifth-century CE Āryabhaṭa.

The seventh-century Bhaskara I explains (*Laghu Bhāskarīya*, III.2-3, Shukla, 1963, p. 42; Raju, 2007, Chap. 4) how to calculate the local latitude (ϕ) from the equinoctial midday shadow (s) using a gnomon of height g using the formula $\tan \phi = \frac{s}{g}$. Note that this formula is useful only if one has a method of computing the arctangent function (or a method of “arcifying” sines), and this explains the need for the infinite series for the arctangent.

The seventh-century Bhaskara I also explains (*Laghu Bhāskarīya*, III.22 – 23) how to calculate the local latitude from the observation of solar altitude at noon, provided also that the solar declination is known. That requires a good calendar which correctly tells the date of the equinox.

Bhaskara I also gives a method of longitude determination, by solving a longitude triangle, from a knowledge of the departure or distance between two points A and B , and the corresponding difference of latitude (*Mahā Bhāskarīya* II.3 – 4, Shukla, 1960, pp. 49–50). He himself criticized the rule, among other reasons, for neglecting the sphericity of the earth and not using spherical triangles.

This solution of the longitude problem required an accurate knowledge of the size of the earth. Columbus underestimated the size of the earth by about 40 %, and the resulting navigational disasters led to the Portuguese ban of 1500 on carrying globes aboard ships. In contrast, most Indian mathematics and astronomy texts also state an estimate of the radius of the earth. This is stated in *yojanas*, and we do not know *exactly* how much a *yojana* was. Nevertheless, we do know that al Biruni came to India, studied astronomy, and reported on Indian astronomy in his tenth-century *Kitab al Hind*. His estimate was stated in Arabic miles and intended to corroborate Khalifa al Mamun's direct measurement of 1° of arc in the desert. This method of calculating the size of the earth (Raju, 2007, Chap. 4) required very accurate sine and cosine values, and it is also the method implicit in the definition of the Arabic *zam* (from the Sanskrit *yāma*), as the "distance from here to the horizon" (Raju, Chap. 5). Al Biruni's error was 0.25 %, compared to the error of 40 % in Columbus' estimate and the error of 25 % in Newton's first estimate (Rizvi, 1979).

Further, in contrast to Indo-Arabic techniques of celestial navigation, the European technique of navigation involved charts. Hence, apart from the issue of latitude and longitude at sea, a key problem of European navigation was that of loxodromes: because a chart is flat while the surface of the earth is curved, holding a straight course in one direction (using a magnetic compass or a straight line joining two stars) does not result in a straight line on the surface of the earth but a curved line, called a loxodrome. The solution to this problem of loxodromes was provided by the Mercator chart which used an old projection technique of Chinese (Dunhuang) star charts (Needham, 1981, pp. 123–124) to map loxodromes to straight lines. Constructing the Mercator chart required an accurate table of secants or, equivalently, accurate sine values. (The formulae for the Mercator projection are widely available; see, e.g., Raju, 2007, p. 339.) An accurate technique of navigation was the biggest scientific challenge in Europe then. Hence, the Jesuits in Cochin were naturally interested in these Indian

texts with accurate sine values. Their college in Cochin helped procure and translate local Indian texts and sent them back to Europe in a repeat of the Toledo model of mass translation of books. In place of the Mozarabs of Toledo, they then had the support of the local Syrian Christian community in the vicinity of Cochin.

The translated Indian texts would naturally have gone first to the Jesuit general. There is ample circumstantial evidence that did happen. Christopher Clavius, who authored the Gregorian calendar reform, also published in his name a table of sines in 1607. Curiously, these were the so-called Rsines, in that they explicitly involved the radius of the circle. Simon Stevin follows the same practice for his secant tables. Curiously, Clavius used the same large number for the radius as used in Madhava's values (Clavius, 1607). Documentary evidence of a connection comes from Clavius' student Matteo Ricci who visited Cochin just prior to the Gregorian reform to get information about Indian methods of timekeeping (Ricci, 1581). The Indian timekeeping or astronomy texts near Cochin contained detailed accounts of the calculus.

On the epistemic test, those who copy do not fully understand what they copy. This is also evidence of transmission: Clavius got the imported sine values explicitly interpolated to build a larger table but did not know enough trigonometry to calculate the size of the earth. Recall that this size was routinely mentioned in Indian texts and that the size of the earth was a key parameter needed for determining longitudes. (The calendar reform only settled the problem of latitudes.)

There is other circumstantial evidence of transmission of calculus to Europe. Clavius' contemporary, Julius Scaliger, is credited with Julian day-number system which is the same as the Indian *ahargana*. Likewise, another contemporary Tycho Brahe, Royal Astronomer to the Holy Roman Empire, produced the Tychonic astronomical model (in which all planets go round the Sun, which itself goes round the earth) which is just a carbon copy of the astronomical model of Nīlakanṭha, stated in his *Tantrasangraha*. Tycho's masonry instruments

(copied from Ulugh Beg's Samarkand observatory) were not accurate enough to make accurate observations of Mars, such as made by Parameswaran over a 50-year period. Nevertheless, Tycho, in those days of the Inquisition, kept some secret documents with which his assistant Kepler decamped, after Tycho's untimely death or murder. Why did Tycho keep mere observations such a secret from his own assistant? How did Kepler, a nearly blind person, arrive at those super-accurate observations, without appropriate instruments (Broad, 1990; Donahue, 1988)?

Likewise, Fermat's challenge problem to European mathematicians, which remained unsolved for long (and was eventually solved by Euler), is taken from an explicitly solved example in Bhaskara's *Bījagaṇita* (87, Colebrooke, 1816, pp. 176–178). Indeed, Bhaskara himself poses it as a challenge, saying “Declare it friend if the method [of solution] be spread over your mind like a creeper.” Thus, in Feb 1657, Fermat (*Ouvres*, p. 332 et seq.) asked European mathematicians to solve the problem $Nx^2 + 1 = y^2$ for a given (positive, non-square) N . As examples, he listed, for the case $N = 3$, that $x = 1$, $y = 2$ are solutions and $x = 4$, $y = 7$ are also solutions. Then he asked for the smallest integer solutions for the case $N = 61$ and $N = 109$. This is today called “Pell's equation,” and the smallest solutions are the numbers $x = 226153980$, $y = 1766319049$ given by Bhaskara II centuries earlier. Given how large these numbers are, an independent rediscovery would represent a fantastic coincidence.

When the Indian calculus first reached Europe, some people like Fermat and Pascal accepted it enthusiastically, while other people like Leibniz did not fully understand it. (Newton, in his anonymous review of his own report, on behalf of the Royal Society, on Leibniz's charge of plagiarism against him, claimed that Leibniz failed to comprehend the infinite series named after him; Newton, 1714.) Descartes too was unable to comprehend how to sum infinite series. Indeed, Descartes opined that the ratio of curved and straight lines was beyond the capacity of the human mind (Descartes, 1996). In India, children were taught

to measure angles as the length of a curved line (the arc) using a flexible string since the days of the śulba sūtra-s (or aphorisms on the string) (Raju, 2009). They could easily straighten the string to compare the length of a curved line with a straight line (and needed to do so to measure the arc in units of the radius).

On the epistemic test, mistakes are proof of transmission. A charitable interpretation of Descartes' blunder is that he was presumably alluding to the infinite series for π , found in Indian texts from long before Leibniz. He thought an infinite series could only be summed by actually carrying out an infinite number of sums and hence regarded an infinite sum as a supertask. Descartes was not the only person who thought thus. Galileo, whose access to the Jesuit archives is well documented, in his letters to Cavalieri (Mancosu, 1996), agreed with this objection and hence eventually left it to his student Cavalieri to take the credit or discredit for calculus.

Newton, himself, claimed credit only for making the calculus rigorous, not for inventing it (though he did claim credit for the sine series). He thought the calculus could be made rigorous by making time metaphysical. Ironically, that was the precise reason why his physics failed (Raju, 1994). Changing that understanding of time/calculus improves physics including the theory of gravitation (Raju, 2012).

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Calendars and Timekeeping Around the World

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The Origins of Calendars and Timekeeping

The measurement of time catalyzed the development of numbers, mathematics and astronomy, and cosmology, as the first humans began counting days, then hours, then minutes, and seconds of time. The methods of timekeeping vary

by civilization and reflect the belief systems, environment, and mathematics of each culture. A more complete treatment of the entire range of calendars and how they arose from each civilization can be found in Penprase (2010).

Many Native North American groups used changes in vegetation and animal behaviors to set their calendars and named their months based on these annual cycles. Like the Hawaiian and Zuni peoples, observations of the moon, sun, and stars would give the “master clock” to reset the calendar and start a new year. The stellar observations could include noting the position of the Big Dipper (also known as the Plough or Ursa Major) relative to the horizon at the beginning and middle of the night, as is the practice of the Mescalero Apache, who know the Big Dipper as *nahakus* (pivot point) (Farrer 1991, p. 48). The Havasupai tribe began their New Year with the heliacal rising of the stars known as the “the Hoop” (Corona Borealis), which marked the New Year in mid-November. The Maricopa and Cocopa tribes of Arizona believed the stars were literally a hand of the creator, and lines of stars were the imprints of his fingers. These stars also worked like the hands of a clock, indicating seasons when plants such as the cactus are ripe which produce fruit in the summer when the Pleiades (*Xitca'*) appear on the eastern dawn horizon (Miller, 1997, p. 199).

The Chumash tribe from Southern California used a combination of weather indicators, plants, and precise observations of the sun to set their calendar. Each year a multiday solstice ceremony took place near the winter solstice using a portable sun stick that included a carved and decorated stone head that was inclined precisely toward the altitude of the winter solstice sun. A series of solar observatories from Southern California were used to measure the solstice, such as the Burrow Flat Cave, Condor Cave, and Window Cave, where beams of sunlight crossed sun figures painted inside the cave to mark the solstice.

Most cultures realize in their count of days the need to provide a reconciliation between the solar and lunar cycles. Reconciling the number of days

in the lunar month (29.5333) and the number of days in the solar year (365.2422) was a great challenge for ancient civilizations and has been solved independently with many solar/lunar calendars, such as the Babylonian, Hebrew, and Chinese lunar calendars, as well as the Hawaiian and Hopi solar lunar calendars, which are described below.

Mesopotamian Calendars

Mathematical advances in Babylonia allowed them to begin to factor and divide large numbers, which in turn allowed them to ascertain whole number multiples of the lunar months and the solar years, such as the 235 lunar month Metonic cycle, which provides a whole number of lunar months (235) and solar years (19), to enable the lunar and solar calendars to match every 6,940 days.

The Babylonians, like many contemporary civilizations, used sets of 12 and 13 lunar month years to reach the 235-month completion of their cycle. These months were named after the various seasons within the Mesopotamian year, and a month began with the visibility of the first crescent moon. A thirteenth intercalary month was added as needed and usually given the name of “second Ululu” or “second Addaru” since it would follow the month of Ululu or Addaru, respectively, to give a complete set of lunar months to a year. Babylonian numbers were written in sexagesimal (base 60) cuneiform, one of the earliest systems of number notation. We still use such sexagesimal numbers in our notation for time (HH:MM:SS), where the colons denote separation between hours, minutes, and seconds.

The Egyptian Calendar

The Egyptian civilization began with a simple calendar based on the 360 + 5 day Egyptian solar year, and three main seasons, named “Inundation,” “Cultivation,” and “Harvest,” divided the year into three parts of 120 days each. Within

the three seasons were 30-day months, each named after Egyptian gods and goddesses. Night and day were each subdivided into 12 equal parts, giving a 24-“hour” day but with hours of different duration depending on the seasons. The word “hour” itself derives from Egyptian timekeeping, since “hour” comes from the Greek word *hora*, which itself derives from the Egyptian word *hor*, which means “day” or “sun’s path” (Lennox-Boyd, 2005, p. 22).

The calendar year had 360 days with a 5-day festival period to honor the chief gods of the Egyptian pantheon (Osiris, Isis, Seth, Nephthys, and Horus). Without any correction, the Egyptian calendar year (365 days) would drift with respect to the actual period of the solar year (365.2422 days), to give complete rotations of the seasons over the course of the thousands of years of the Egyptian civilization. A solution to this problem came from the stars. By watching the morning twilight for the first appearance of the star Sirius (the heliacal rising), the Egyptians noticed that Sirius’ heliacal rising coincided in time with the flooding of the Nile. By AD 144, an additional month of Thoth was added whenever the heliacal rising of Sirius happened within the last 11 days of the last lunar month (Krupp, 1980). The star Sirius, known in Greek as Sothis, was associated with the goddess Isis, and its heliacal rising coincided with the flood of the Nile, and the Egyptian solar calendar was known as the Sothic year.

Egyptian priests noticed the drift of the Sothic calendar over centuries and were able to improve the match between the days of the year with the motions of the stars by means of the decans system. The decans were a group of 36 sets of stars which could be sighted in the early morning twilight in each interval of 10 days known as a decan. In this way, ancient Egypt had two parallel calendars – one ritual calendar of 365 days subject to some drifting and a more accurate star calendar of the decan stars.

For nearly 2,000 years, the Sothic year was the primary calendar of Egypt and much of the ancient world. However, some attempt to fix the drift of the year was made late in the history

of Egypt, in 286 BC, when the Canopus decree of King Ptolemy III added an additional day every fourth year, predating the leap year of the Julian Calendar.

The Ancient Hebrew Calendar

The development of the Hebrew calendar paralleled that of the Babylonian calendar, perhaps due to the Babylonian exile period between 450 and 419 BC. From the first month of Nissannu in the Babylonian calendar (Nisan in Hebrew) to the last of Addaru (Adar in Hebrew), the Hebrew calendar features month names very similar to the Babylonian and, like the Metonic system, inserts extra lunar months over a 19-year cycle. The Jewish calendar is in fact a hybrid of the earlier Canaanite calendar, which started the year closer to the fall equinox, and the Babylonian, which began the year in spring, soon after the Vernal Equinox. This important difference makes the Jewish calendar 6 months out of phase with the Babylonian calendar (Kelley & Milone, 2005, p. 219) (Table 1).

One additional feature shared by the Hebrew and Babylonian calendars is the 7-day week. The book of Genesis includes a description of a 7-day week, with 6 days of labor in which God created the world and a seventh day of rest known as the Sabbath. The word for Sabbath also shares roots in both Babylonian and Hebrew; in Hebrew the word is Shabbat which means “rest,” while in Babylonian the word is sabattu or “seventh.” For the Babylonians, the sabattu, or seventh day, had ominous associations, as were several other days of the lunar month based on both theology and numerology. For this reason, the seventh day was reserved for rites of purification, and this tradition appears to have been shared by the Greeks and Hebrews (Steele, p. 76).

Like many lunar calendars, the Hebrew calendar relies on sightings of a crescent moon to begin the month. Like the earlier Babylonian calendar, it uses a system of 12 and 13 lunar month years alternating in the 19-year cycle (Rich, 2008), with extra intercalary months added as needed to match the solar year.

Calendars and Timekeeping Around the World, Table 1 Babylonian and Hebrew month names. The Hebrew calendar preserves a snapshot of the Mesopotamian calendar of 430 BC, with very similar month names (but shifted by 6 months), and the same Metonic type lunar calendar as the Babylonian system

	Babylonian		Hebrew		Babylonian		Hebrew
1	Nisannu	7	Nisan	7	Tasritu	1	Tishri
2	Ajjaru	8	Iyyar	8	Arahsamnu	2	Chesvan
3	Simanu	9	Sivan	9	Kislimu	3	Kislev
4	Duzu	10	Tammuz	10	Tebetü	4	Tebeth
5	Abu	11	Ab	11	Sabatu	5	Shebat
6	Ululu	12	Elul	12	Addaru	6	Adar

Additional months in the Hebrew calendar are given the name Adar Shenì or Adar Beit and are added to make for 13-month years, a practice which happens seven times in 19 years. Despite the fact that the main features of the calendar were set in place 2,500 years ago, the first year of the Hebrew calendar is set over 5,700 years ago, in the Gregorian year of 3760 BCE, which is thought by some to be the beginning of the universe as described in Genesis. Each year begins with the first of Tishri, which is the festival of Rosh Hashanah (“head of the year”), to commemorate the creation of the universe and to also observe a time at which the Creator judges the universe. Additional holidays include Yom Kippur, the Day of Atonement, on the tenth day of Tishri, and Hanukah, which always occurs on 25 Kislev in the Hebrew calendar, even though its date will shift each year within the Gregorian calendar. Although the New Year (and universe) is recognized to begin on 1 Tishri, the numbers of the Hebrew months begin with Nisan, as does the Babylonian calendar.

The Islamic Calendar

The Islamic world still sets its sacred holidays with a lunar calendar with 12 lunar synodic months of 29 or 30 days, for a total of 354 days. The beginning of a lunar month is set by the first visibility of the crescent moon, giving rise to the crescent moon as the international symbol of Islam. The beginning of the year is known as Al-Hijra and is the first day of the first month known as Muharram. The Islamic calendar begins its count of years in the year when

Mohammed moved from Mecca to Medina and is called the Hijri calendar after this migration, known as the *hijra*. Year 1 of the Islamic calendar corresponds to the day Friday, July 16, 622 CE, making the year 2010 CE in the Gregorian calendar equal to year 1431 AH.

The gap between the Islamic 12 lunar month calendar (354 days) and the solar year (365.25 days) means that the Islamic New Year shifts 11 days earlier each solar year, causing important dates to rotate through the solar year over time. Unlike many other lunar calendars, the Islamic calendar does not allow extra months to reconcile solar and lunar years, since the extra 13th intercalary month is forbidden by the Qur’ān. All of the Islamic holidays will therefore rotate through the solar year. For example, the Islamic New Year dates for 2009 and subsequent years occur on December 18, 2009, December 07, 2010, November 26, 2011, and November 15, 2012, and continue to rotate through the Gregorian solar calendar 11 days earlier each year.

Islamic holidays include the New Year or Al-Hijra and Laylat al-Qadr (The Night of Power), which is believed to be the day when Mohammed first received his revelation that began the Qur’ān. The Qur’ān was revealed to Mohammed during Ramadan, the ninth month of the Islamic calendar, and so the entire month is observed as a month of fasting during daylight hours. The exact date of Laylat al-Qadr varies by country and ranges between the 21st, 23rd, 25th, 27th, and 29th day of the month. During this night, prayers are made and the Qur’ān is studied. The end of the month of fasting occurs on the first day of the following month of Shawwal and is the holiday known as Eid al-Fitr, celebrated by communal



Calendars and Timekeeping Around the World, Table 2 Major Islamic holidays and their significance along with the Gregorian date in 2010 (later years have dates 11 days earlier each year)

Holiday	Date in Islamic calendar	Meaning	Gregorian date in 2010/2011
Al-Hijra	1 Muharram	Date of Mohammed's migration to Mecca (Hijra)	December 07, 2010
Isra al-Miraj	27 Rajab (7th month)	Ascent of the Prophet Mohammed	June 28, 2011
Ramadan	1 Ramadan (9th month)	Month during which Mohammed received revelation of the Quran	August 01, 2011
Laylat al-Qadr	21–29 Ramadan (varies by country)	"Night of Power" – date when Mohammed received first revelation	August 26, 2011
Eid al-Fitr	1 Shawwal (10th month)	"Breaking of Fasting" and end of the month of Ramadan	August 30, 2011
Eid al-Adha	10 Dhu'l-Hijjah (12th month)	Date of Ibrahim's willingness to sacrifice Isma'il; end of Hajj	November 06, 2011

prayers followed by extensive family gatherings and feasting along with an exchange of gifts.

Other important holidays include Isra al-Mi'raj, which celebrates the Ascent of the Prophet Mohammed and occurs on the 27th day of the seventh month of Rajab, and the Eid al-Adha, which is approximately 70 days after the end of Ramadan, on the 10th day of the 12th month of Dhu'l-Hijjah. The Eid al-Adha is a time of prayer and sacrifice of a lamb or other animal, often a goat, and celebrates the willingness of Ibrahim (Abraham) to sacrifice his son Isma'il. This holiday occurs at the end of the hajj (the pilgrimage to Mecca). A summary of the Islamic holidays with their dates and meanings is given below in Table 2.

The Hawaiian Calendar

The ancient Hawaiians developed an original lunar calendar that made use of the lunar months and the position of the Pleiades star cluster to create a stellar-lunar calendar. The year was known as the *makahiki*, and it was divided into two equal sections for summer and winter. The key for maintaining accuracy of the lunar calendar was the synching effect of the Pleiades star cluster, known to the native Hawaiians as *Makali'i* (Johnson & Mahelona, 1975).

The beginning of the first Hawaiian season and the Hawaiian year is in late October or November

and is marked by the rising of the Pleiades in the east just after sunset, known as *makali'i-hiki*. The first month begins when the crescent moon is first sighted in the evening (the day known as *hilo*), and sets of 30 nights are counted from this point. Each night had particular associations with agriculture (planting of certain crops were best on particular nights) and religion (including worship of specific gods during the *tabu* or holy nights). The second season of summer began in May when the Pleiades were first sighted in the predawn sky (during their heliacal rising). The twelve 30-day lunar months of the Hawaiian calendar, with their 30 named nights, kept track of the year, but occasionally some months would need to be added to reconcile the annual cycle of the Pleiades with the lunar calendar, much as in other lunar calendars.

By coincidence, Captain Cook's final landing in Hawaii in February 1779 came just after the Hawaiian New Year period, and the Hawaiians may have interpreted Cook's arrival to be an inauspicious premature return of the god Lono, which required a ritual sacrifice to return order to the universe (Ruggles, 2005, p. 179).

The Zuni Calendar

The Zuni observed both solar and lunar calendars. Within the culture is the Sayatasha's Night Chant, in which an actor portraying the masked god Sayatasha keeps track of the days and

months. The actor plants prayer sticks every full moon throughout the year until October for 10 lunar months. After the tenth month, he begins counting the days before the beginning of an intense end of year dance known as *Shalako*, by untying a string which contains 49 knots, 1 for each day. At the end of 48 days, Shayatasa's actor begins the long talk, and he and a set of other masked gods (the *kachinas*) participate in the *Shalako* dance until dawn. During the final night, the actor recites the precise poem intoned by hundreds of generations of past Sayatasha impersonators, reciting word for word a Night Chant which describes the motions of the sun and moon, the rituals of the people, and their origins.

The Inuit Calendar

The Inuit developed a set of seasonal star markers for measuring the duration of the long winter night, which can last for months. The stars Altair and Tarazed formed the Inuit constellation known as *Aagjuuk*, and these two stars first became visible in late spring and were used to indicate the end of the long winter night. The two top stars of Orion's "shoulders," Betelgeuse and Bellatrix, were known as *Akuttujuuk* and were used to mark the middle of the winter, known to the Inuit as the "dark period." The Pleiades were used to mark time by many different Arctic groups and had the name *Sakiattiak* among the Igloolik, who also used them for navigation. The bright star Arcturus, known to the Inuit as *Sivullik*, or "leader," is visible in the evening sky, being the first star (or leader) to be sighted in the early evening in the west. For the Inuit of Coronation Gulf, Canada, the transit of Arcturus signaled the beginning of the sealing season (MacDonald, Royal Ontario Museum, et al., 1998, p. 78). The Inuit observed a set of 13 lunar months, and a simple system was used to determine whether a year had 12 or 13 lunar months. If the winter solstice coincided with the first day of the thirteenth month, it was skipped, giving a natural alternating pattern of 12 and 13 lunar months over the years.

The Greek Calendar

The early Greek calendar is described in the "works" section of Hesiod's *Works and Days*, one of the earliest surviving works of Greek culture. Celestial observations included noting the heliacal rising of stars and star clusters such as the Pleiades. The Greek year began in October and continued on through September. The Greek days were numbered from 1 to 30, like the Hawaiian month, and included auspicious days for various activities such as "bringing brides home," "giving birth to boys," "planting," "shearing," and "worshipping gods." The days were set by the phase of the moon, with the month beginning at the first sighting of the crescent moon.

Each of the different Greek city-states had different month names, and separate priests would call the beginning of the lunar month and decide when an extra month was needed based on stellar observations. Year names were set relative to the reign of a particular ruler or relative to key events in local history. One technique used to provide a common reference for year names was the Olympic Games, which all of Greece would recognize and which began in the year 776 BC. Any confusion about the Olympic Game number was fixed by attaching to the date the name of the champion of the most prestigious Olympic event, the footrace known as the *stadium*.

The Roman Calendar

The Roman calendar began before the first glimmerings of the Roman Empire, back on the date of January 1, 4713 BC, which sets the origin of the Julian Day count. The Julian Day is still used in astronomy research where the complexities of orbital periods require the use of a uniform count of days. The origins of Roman timekeeping began not in 4713 BC, but in the period of the Roman monarchy, from approximately 776 BC to 509 BC, when the Roman calendar had ten named lunar months. Each lunar month was divided into named days; the "calends" were the first days of the month, the nones were the 5th days of the

month, and the Ides (Idus) were the 13th day of the month.

The “calends” marked the beginning of both the lunar month and a business cycle, in which debts were to be paid at the beginning of the month, before the “nones,” with the ides marking the middle of the lunar month. The calendar at first counted only those days when business was being done and featured a 10-month year which started at the vernal equinox. The last of the month names (unchanged to this day) were simply their numerical place in Latin corresponding to “fifth” (Quintilis), “sixth” (Sextilis), “seventh” (September), etc. The months in the Roman Republic were of unequal length – Martius, Maius, Quintilis, and October were all of 31 days, and Aprilis, Iunius, Sextilis, September, November, and December were each of 29 days. After the end of the business and agricultural year, near the winter solstice, the early Romans simply stopped counting the days of the year until the month of the vernal equinox, which would signal the beginning of the New Year.

In order to have a complete annual calendar, the Romans later added two additional months (Januarius, with 29 days, and Februarius, with 28 days) in 509 BC to cover the solar year, adding up to 355 days with 12 lunar months. In order for the solar and lunar years to match evenly, the irregular lengths of the lunar months were supplemented with an intercalary month roughly every other year.

Julius Caesar, as part of his duties as emperor and chief pontiff of Rome, discarded the old lunar calendar in 46 BC. To reform the calendar, Caesar added 10 days to the year by lengthening the five shorter 29-day months by 2 extra days, with the exception of February, which was kept at 28 days with an extra “leap day” added every 4 years. By the time of Caesar’s reforms, the calendar had drifted by over 80 days, and so the year 46 BC is known as the “year of confusion” (*annus confusionis*) since it was 445 days long! The result of Caesar’s reforms was the Julian calendar, which includes 365 days, with an extra 0.25 days from leap years to give an average solar year of 365.25 days (Steel, 2000). The Julian calendar, with 365.25 days, provides a close

match with the length of the solar year of 365.2422 days. Caesar’s calendar remained in place for over 1,000 years.

The Julian calendar is still in use today, with the (minor) correction known as the Gregorian reform of 1582 (named after Pope Gregory XIII), which took back 3 of the leap years in centuries not divisible by 4 (1700, 1800, 1900), while retaining leap year in those divisible by 4 (2000, 2400, etc.). The result of the Gregorian reform is to set our modern calendar to have a year of 365.2425 days, which gives an error or “drift” of only 0.0001 days in a year.

The Incan Sidereal Year

For the Inca, time was measured in many ways, from the natural cues of the environment, from the Moon and Milky Way, and from the sightings of stars, planets, and the Pleiades in the night sky.

The motions of the Milky Way in the night sky from 1 month to the next also served as a large “hour hand” of night and provided a similar splitting of the year into four parts. The Inca calendar was also set by heliacal risings of bright stars, star clusters, and dark cloud constellations. The heliacal rising of the brightest star in the Southern Cross (α Cru), associated with *Yutu*, a bird and dark cloud constellation) marked the beginning of the agricultural season, while the rising and superior culmination of the stars α - and β -Centauri (associated with the “eyes of the Llama”) coincided with the birth and mating season of the llama. The positions of star clusters were noted both above in the night sky (at zenith or transit) and below under the feet and crops of the Inca (at nadir or inferior culmination). For example, the appearance of the Pleiades or *collca* at nadir, directly beneath the earth, was thought to be a harbinger of the best time for planting (Urton, 1981).

The Inca religion made use of worship sites rotated through the city to various shrines or *huacas* on a daily cycle, arranged along patterns of space that connected the shrines to the horizon and the stars beyond. The ritual calendar linked

all of the 328 *huacas*, one for each of the named days in the 328-day Inca year.

The somewhat unusual number of days in the Inca year comes from the observation of the Incan lunar month, which is based on a unique lunar/stellar calendar. The 27.3 day Incan month was based on the 27.3-day sidereal period for the moon to return to the same position against the stars, as opposed to the more familiar 29.5-day lunar synodic month of most other cultures. The Inca would carefully watch the location of the moon in the sky relative to the stars to determine the beginning and ending of lunar months. Groups of 12 lunar sidereal months combined to create an Incan year of 328 days, giving the annual calendar, but also leaving behind a group of 37 days which were uncounted (Aveni, 1997).

Calendars of Ancient India

Another culture that made use of the moon's position relative to the stars was ancient India, where the practice of Hindu astrology required the use of moon and star coincidences known as *nakṣatras*. Like the Inca, the early Hindu astrologers would watch the position of the moon against the background of a set of indicator stars, which set the lunar sidereal calendar. For determining auspicious dates of weddings and births, the Hindu astrologer would combine the lunar phase of the date with the lunar sidereal location or *nakṣatra* to get a more precise reading of the sky.

The *nakṣatra* system dates to before 1000 BC, in the era of the *R̥gveda*, a collection of Vedic Sanskrit hymns. A set of 27 stars were chosen near the ecliptic plane as references for gauging the position of the moon as it moves through its 27.3-day lunar sidereal cycle. The stars, their corresponding names in Hindu and European astronomy, and the corresponding constellations are presented below in Table 3.

The Hindu astronomers divided the ecliptic into 27 *nakṣatras* and also divided the sky during any individual day into 27 parts, known as *yogas*. The *yogas* (analogous to hours) were based on the

angular distance along the ecliptic of the sun and moon, which set a reference point on the sky, and from this point divided the sky into 27 regions 13.333° wide. Additional terms and concepts of interest to the Indian astronomers and astrologers include the *tithi*, which is defined as the angular distance between the Sun and moon (something akin to lunar phase), and the *karaṇa*, the time required for the distance between the sun and moon to increase by a distance of half of a *tithi*.

The Hindu solar calendar functioned much like many other calendars, with a New Year beginning with the first lunation after the Vernal Equinox, in April. A set of 12 solar months, or *rashi*, was observed based on the sun's position within the ecliptic. Each of the 12 named solar months included 1 of the 12 named lunar months. The named lunar months include (in order): Chaitra, Vaishākh, Jyāishtha, Āshādhā, Shrāvana, Bhādrapad, Āshwin, Kārtik, Mārgashīrsha Paush, Māgh, and Phālgun. Each lunar month is matched with a solar month, and lunar events determine any corresponding festivals within that month. For example, when the sun is Capricorn, during January, it is the tenth solar month (*rashi*), known as Makar, and the lunar month is known as Paush. A festival (or *mela* in Bengali) in this month in the province would be known as *paush mela*. A summary of the month names within the Indian calendar is shown in below in Table 4.

The Hindu calendar, like many ancient calendars, included a 7-day week. Days of the 7-day week in the Hindu calendar, known as the *vaasara* in Sanskrit, are named after the 7 celestial bodies known to the ancients, in the same order as in the Western calendar. The sequence of days (in order) includes days named after the Sun, Moon, Mars, Mercury, Jupiter, Venus, and Saturn, which in Sanskrit are Ravi, Soma, Mangala, Budha, Guru, Shukra, and Shani, respectively. Therefore the Indian day names are Ravi vasara (Sunday), Soma vasara (Monday), Mangala vasara (Tuesday), Budha vasara (Wednesday), Guru vasara (Thursday), Shukra vasara (Friday), and Shani vasara (Saturday).

Since India as a modern country is very diverse, with 22 officially recognized languages,

Calendars and Timekeeping Around the World, Table 3 Hindu nakṣatras, used to mark the path of the moon through the stars during the 27.3-day lunar sidereal month (Ojha, 1996)

Nakshatra	Location on sky	Shape	Stars
1. Ashwini	and γ Arietis (head of Aries)	Face of horse	3
2. Bharani	35, 39, and 41 Arietis	Yoni	3
3. Krittika	Pleiades + Alcyone	Curved knife	6
4. Rohini	Aldebaran	Cart	5
5. Mrigashira	λ and ρ Orionis	Face of deer	3
6. Ardra	Betelgeuse	Jewel	1
7. Punarvasu	Castor and pollux	House	4
8. Pushya	γ, δ , and τ Cancrui	Arrow	3
9. Ashlesha	δ, ϵ, η , and σ – Hydrae	Circular	5
10. Magha	Regulus	House	5
11. Poorva-phalguni	δ and τ Leonis	Manchaka	2
12. Uttara-phalguni	Denebola	Small cot	2
13. Hasta	Spica	Hand	5
14. Chitra	α to ϵ Corvi	Pearl	1
15. Swati	Arcturus	Coral	1
16. Vishakha	α, β, γ , and ι Librae	Torana	4
17. Anuradha	β, δ , and π Scorpui	Vali	4
18. Jyeshtha	α, σ , and π Antares	Circular earring	4
19. Moola	$\epsilon, \zeta, \eta, \tau, \iota, \kappa, \lambda$ Sco (tail and stinger of Scorpius)	Tail of a lion	3
20. Poorva-shadha	δ and ϵ Sagittari	Tusk of an elephant	11
21. Uttarashadha	ζ and σ Sagittari	Manchaka	2
22. Shravana	α, β , and γ , Aquilae (Altair)	Aeroplane (??)	3
23. Dhanishta	Delphinus	Mridanga	4
24. Shatabhisha	γ Aquarii	Elliptic	100
25. Poorva-bhadra	α and β Pegasi (Markeb)	Manchaka	2
26. Uttara-bhadra	γ Pegasi and α Andromedae	Twins	2
27. Revati	ζ Piscium	Mardala	32

and over a dozen separate historic cultures within its borders, there is a good deal of variation in the names of months, days, and timing of festivals that reflects the linguistic and religious diversity of the country. The effects of precession are causing many of the ritual holidays of India to lose their astronomical underpinnings, such as coincidence with solstice or equinox dates (Aslaksen and Rugulagedda 2001; Nath, 2008).

In the Hindu cosmology, time unfolded in a set of four ages, in a descent from pure order into decay, before destruction and renewal. The first of these ages was known as *kritya* or *satya* and was symbolized by the bull of creation on all four legs. This first age lasted 4800 “divine years,” which corresponded to 1,728,000 of our “human years.” During this first age, the universe was in a state of purity, and the laws of dharma, rules

that are in accord with order, were obeyed. The second age was known as *treta*, and in this age of 3,600 divine years (1,296,000 human years), the first hints of decay are visible, and the cosmic bull is symbolized to have only three legs. The third age was known as *Dvapara* and lasted 2,400 divine years (864,000 human years), and the fourth and final age was the age of *Kali*, which lasted for 1,200 divine years (432,000 human years). After these four ages were complete, there would be a short period of twilight known as *sandhya*, or *sandhyamasha*, before the age would be complete, and a cycle of destruction and recreation would bring the universe back into its pure *kritya* state (Dallapiccola, 2003).

The enormous grouping of this vast expanse of time in the four ages comprised the length of time known as the *mahāyuga*, or “great cycle.” Each

Calendars and Timekeeping Around the World, Table 4 The Hindu and traditional Indian calendar included both solar months and lunar months (source: <http://www.nationmaster.com/encyclopedia/Hindu-calendar#tithi>)

Solar months	Season	Gregorian months	Zodiac
Mesh	Vasant	April/May	Aries
Vrushabh	(Spring)	May/June	Taurus
Mithun	Grishma	June/July	Gemini
Kark	(Summer)	July/August	Cancer
Simha	Varsha	August/September	Leo
Kanya	(Monsoon)	September/October	Virgo
Tula	Sharad	October/November	Libra
Vrishchik	(Autumn)	November/December	Scorpius
Dhanu	Hemant	December/January	Sagittarius
Makar	(Autumn-winter)	January/February	Capricornus
Kumbha	Shishir	February/March	Aquarius
Meen	(Winter-spring)	March/April	Pisces

grouping of four ages amounted to approximately 4,320,000 years and comprised a brief segment of a dream within the sleep of Brahma. One thousand of these cycles created a length of time known as the *kalpa*, which amounts to about 4.3 billion years, close to the current scientific estimate of the age of the earth, the sun and the solar system. This enormous expanse of time was also imagined to be the length of one full day in the life of Brahma.

Chinese Calendars

The Chinese recognized a set of five elements that describe all earthly and celestial phenomena. The five named elements included wood, fire, earth, metal, and water, which had celestial counterparts in the planets Jupiter, Mars, Saturn, Venus, and Mercury, respectively. The solar year was also divided into five seasons, one for each element. The cycles of time and motions of the heavenly objects tied into these numbered elements and connected the essence of these elements to life on earth. Motions of the planets and appearances of “guest stars” and “sweepers” (now known as supernovae and comets) gave a picture of the universe that reflected the heavenly mandate of the emperor on earth.

The Chinese also divided space into systems that included 4, 10, 12, and 28 parts, which arose from both ancient folk traditions and Chinese

philosophy developed over thousands of years. The ancient Chinese believed that each of the four cardinal directions had a symbolic animal and color, much like many Native American peoples.

The Chinese animals and colors include the Black Warrior/Tortoise for North, the Red Bird for South, the Blue Dragon for East, and the White Tiger for West. Early Shang writings refer to “Ten Heavenly Stems” and “Twelve Earthly Branches,” a set of reference stars set the calendar, and the planet Jupiter, respectively. The Heavenly Stems provided a system similar to the decan stars of the Egyptians and helped synchronize the calendar with the seasons. The Earthly Branches were a timekeeping system in which the 24-h day (and the sky) was divided into twelve segments, named after animals from an earlier folk tradition. The motions of the planet Jupiter would circle the sky in a 12-year cycle, the basis of the Chinese Zodiac which assigns 1 of the 12 Earthly Branches (rat, bull, tiger, hare, dragon, serpent, horse, sheep, monkey, rooster, dog, and pig) to each year as Jupiter moves through its 12-year synodic period. The 28 *xiu* or lunar mansions also helped set the Chinese calendar, as they could be observed at dawn or sunset to help set the calendar.

Professional Chinese astronomical records cover over 1,600 years of observations, from approximately 200 BC to 1400 AD and provide rich material for dating ancient astronomical



events. Below are samples of Chinese observations of ancient supernovae, translated from the original records:

“A star appeared to the south of the Ti lunar mansion, east of Ku-Lou and west of Chi-Kuan. At one time it resembled the half moon, shown with pointed rays, and was so bright that objects could be seen by its light” (description of the Supernova of 1006)

“..it was visible by day, like Venus; pointed rays show out from it on all sides; the color was reddish-white. Altogether it was visible in the daytime for 23 days” (description of the Crab Supernova of 1054)

“The star was as big as a peach. . . .” (description of Supernova of 902 AD, which was also visible for a year).

(Kiang, 1969; Shen, 1969)

Maya Timekeeping and Calendars

The interlocking calendars of the Maya contained two short-term calendars, the *tzolkin* and the *haab*, which were based on a 260-day cycle of 13×20 day months, and a $360 + 5$ -day cycle of 12×30 day months. In addition to these two calendars, the Maya kept track of cycles of much larger eras or eons of time, by bundling the days into groups of 20 and 13, into what we would call centuries, millennia, and 10,000-year periods, which the Maya called tuns, katuns, and baktuns.

The Mayan number system was developed to keep track of extremely large numbers from timekeeping and is unique in two aspects: (1) the use of a base-20 number system (common to Mesoamerican people, but perhaps invented by the Maya) and (2) the development, independent of Indian and Arabian mathematicians, of the number zero.

Examples of Mayan numerals are given below and are part of a base-20 number system, as opposed to our base-10 number system (Fig. 1).

By grouping days into bundles of 20 named days, the Maya formed the basis of the “week” in their calendar, which when combined with 13 sacred numbers made a 260-day cycle known as the *tzolkin*. The word *tzolkin* or *tzolk’in* means “count of days” in Yukatek Maya and was the fundamental basis for the Mayan calendar. Each

of 20 named days rounding through a cycle with 13 numbers made a cycle known as the *uinal*, or a Mayan week, in which 20 days were grouped. Each day name would be paired with a number, until the *uinal* was complete. The pairings would continue until every possible pairing of 20-day names and 13 numbers had been made, after 260 days.

The combination of 20-day names and 13 numbers provided the fundamental cycle of time for the Maya. Some have likened the process of pairing names and numbers to interlocking wheels; one wheel would have 13 numbers and would rotate next to a wheel with 20 names. The imaginary assemblage would continue rotating until all 260 pairs had been made.

A period of 260 days does not easily match with lunar months, the solar year, or even the motions of Jupiter. However, many authors have noted that 260 days is roughly half the period of the Venus year – the time Venus spends within either the Eastern or Western sky before disappearing in the glare of the sun. The period between maximum elongations of Venus is 584 days, which divides into two 260-day periods for visibility and two 32-day periods in which Venus crosses either behind or in front of the sun.

Since the Maya needed to maintain crops and time their activities with the stars, a second calendar was needed to fix dates within the solar year. The official count of solar days for the Maya was known as the *haab*, or “vague year,” and took secondary importance to the *tzolkin*. The *haab* operated much like the *tzolkin* but had its basis in 18 named months, with 20 numbered days, and operated somewhat more simply, with its names consisting of 1 of 18 month names, and 20 numbers, progressing along with day names such as “1 Pop,” “2 Pop,” “3 Pop,” etc., until 20 was reached, and then the next month would be used. The 18 named months and 20 numbered days together gave a 360-day period, close to the solar year, known as the *tun*. To keep the calendar from drifting, an extra unnamed (and very unlucky) 5 days were added to the end. The year-ending days were known as the *uayeb* to give a 365-day solar year, much as in the early Egyptian calendar, except the *uayeb* was a time of

0	1	2	3	4	15	16	17	18	19
									
5	6	7	8	9	20	21	22	23	24
									
10	11	12	13	14	25	26	27	28	29
									

Calendars and Timekeeping Around the World, Fig. 1 Examples of Mayan base 20 (or vigesimal) numerals, showing their representation of zero (developed independently from Indian and Arabian mathematicians) and counting with groups of *dots* and *bars*

representing ones and fives, respectively, until reaching 20, the base number for their number system (Source: <http://commons.wikimedia.org/wiki/Image:Maya.jpg>)

dread instead of a time of festivities. Groups of 20 of the haab years formed the grouping known as the *baktun*, which is analogous to a Mayan decade.

The Calendar Round

The combination of a tzolkin date and a haab date gives a unique number name combination that uniquely specified a day within the Mayan calendar cycle. Some basic mathematics will show that the two cycles will both repeat after $73 \times 260 = 18,980$ or $4 \times 13 \times 365 = 18,980$ days, which corresponds to about 52 solar years. The pairing of these two cycles forms the basis of the shortest and most profound of the Mayan cycles of creation and destruction, the Calendar Round. The intermeshing of these two calendars can also be visualized as a set of two imaginary wheels, and when both wheels have turned through all combinations of tzolkin and haab names (after 18,980 days or 52 years), the calendar round would be complete.

The year bearers for the Maya were the days *Kan*, *Muluc*, *Ix*, and **Caucac**, associated with the Chac Gods in the four cardinal directions of East, North, West, and South. The four different types of years required four different New Year ceremonies, soon after the Winter Solstice. During a New Year ceremony, offerings of corn and sacrificial animals would be made, and

a procession would bring a large number of people into town through the appropriate cardinal direction (Sharer & Traxler, 2006, p. 550). Most dreaded were the *Caucac* years, which were associated with dreadful calamities such as swarms of killer ants or flocks of crop-destroying birds. For these years more elaborate ceremonies were performed.

After the completion of the 52-year cycle, the Aztec New Fire Ceremony included observations of the Pleiades to see if it stopped its motion in the middle of the night, signifying the end of the present world. Upon observing that the Pleiades were not frozen on the sky, fires were lit, and chants were sung to help renew the world and preserve order in the cycles of the heavens. The presence of fires atop the mountains could be seen far away, signaling the renewal of a new cycle to the villages below.

Larger groupings of time, analogous to our centuries and millennia, were also of great interest to the Maya. The first of these is the *katun*, mentioned earlier, which is a group of 20 tuns, which amounts to 7,200 kins, or about 20 years or 7,200 days. Of particular interest to the Maya was the ending of each *katun* or 7,200-day period. Mayan monuments provide excellent records of the Mayan kings during the Classic and Late Classic periods and include long count dates (Sharer & Traxler, 2006, p. 546).

Groupings of 20 *katuns* form a *baktun*, which is 144,000 days, or about 394 years. These very

long groupings of days form the basis of a Mayan long count date, which would record in each digit the number of *baktuns*, *katuns*, *uinals*, and days since the beginning of the current age within the long count. By adding together all of the numbers and the corresponding bundles of days, it is possible to place a date exactly relative to the beginning of the current age. A long count date would be completed by including the *tzolkin* and *haab* designation for the date at the end.

As an example, to specify a long count date, one might see the following numbers and names:

9.15.10.0.10 3 Ahau 3 Mol

The long count date specifies in its five (base 20) digits the number of days since the beginning of the current age. The example above would include (starting from the left, which counts the largest grouping of days):

$$9 \times 20 \times 18 \times 20 \times 20 + 15 \times 20 \times 18 \times 20 + 10 \times 20 \times 18 + 0 \times 20 + 10 \text{ days} = 1,407,610 \text{ days}$$

For this example, as we add up the days we include 9 *baktuns* (1,296,000 days) + 15 *katuns* (108,000 days) + 10 *tuns* (3,600 days) + 10 *kin* (10 days) which places the Mayan long count date 9.15.10.0.10 1,407,610 days from the beginning of the universe.

The date also corresponds to a unique date in the two *tzolkin* calendars and can be tied to our Gregorian calendar. For our example, the long count date above, 9.15.10.0.10, is named 3 *Ahau* 3 *Mol* in the Mayan calendar, or June 30, AD 741, in the Gregorian calendar (Sharer, p. 574).

The beginning of the universe, which forms the origin of the Mayan time-based cosmology, corresponds to the Gregorian date of 13 August 3114 BC. On the first day of the age, we would have the long count date of:

0.0.0.0.0. with Mayan day names 4 Ahau 8 Cumku = 13 August 3114 BC

The very ancient date of 3114 BC predates the Mayan civilization, since the oldest known long

count date from Mayan archaeology is from Stela 2 at Chiapa de Corzo, which is listed as approximately 114 BC. Presumably, the beginning of the calendar in August of 3114 BC is simply a result of numerology and mathematics, much like the beginning of many other calendars we have seen. Other calendars with such beginning dates include the Julian dates, which begin in 4713 BC, the Jewish calendar, which begins in 3761 BC, the ancient Greek Olympiad-based calendar, which placed the first Olympics in 776 BC, and the Greek Orthodox calendar, which begins in 5509 BC (Sharer & Traxler, 2006, p. 568).

The last date of the current age is when the leftmost zero (the *baktun* indicator) goes from 12 to 13, which corresponds to the last day of the current age

$$12.19.17.19.19 \rightarrow 13.0.0.0.0 = 23 \text{ December, } 2012 \text{ AD}$$

The time between these dates, which would be the duration of the age we live in, is 13 *baktuns*, 1,872,000 days or 5,200 years! The Mayan astrologers would expect that at this date we would have a complete renewal (and destruction) of our world, but also with the expectation that life and time would begin again, in an endless cycle of recurrent events.

The Long Count and Cycles of the Universe

The largest cycles of days for the Maya come into play in the form of the long count described above, which describes ages of 5,200 years. However in some contexts (such as in monumental carved stoned stelae), long count dates would be specified in an even longer format, with two additional digits beyond the usual five places of the long count. Below is an example.

13.13.13.3.11.8.0.19 5 Imix 9 Kanka

These additional digits refer to even longer units of time, which would be groups of 20×400 years (a *pictun*), $20 \times 20 \times 400$ years

(a *calabtun*), $20 \times 20 \times 20 \times 400$ years (a *kinchiltun*), and $20 \times 20 \times 20 \times 20 \times 400$ years (an *alautun*), corresponding to cycles of 8,000; 160,000; 3,200,000; and 64,000,000 of the Mayan *tuns*. The number of solar years within each of these units of time is slightly less than the number of *tuns*, since a *tun* is 360 days, and the solar year is 365.2422 days. The largest of these time units recognized by the Maya is the *alautun*, which corresponds to about 63,000,000 solar years, or 23 billion days!

To summarize the complete set of Mayan time units we provide the following listing of the many units within their reckoning of time below. Each line in the summary below corresponds to one position in a long count date.

Summary of Mayan units of time
1 kin or 1 day
20 kins = 1 uinal or 20 days
18 uinals = 1 tun or 360 days or ~ 1 solar year
20 tuns = 1 katun or 7,200 days ~ 19.7 solar years
20 katuns = 1 baktun or 144,000 days = 400 tuns ~ 394.24 solar years
20 baktuns = 1 pictun or 2,880,000 days = 8,000 tuns ~ 7885.25 solar years
20 pictuns = 1 calabtun or 57,600,000 days = 160,000 tuns $\sim 157,703$ solar years
20 calabtuns = 1 kinchiltun or 1,152,000,000 days = 3,200,000 tuns $\sim 3,154,000$ solar years
20 kinchiltuns = 1 alautun or 23,040,000,000 days = 64,000,000 tuns $\sim 63,000,000$ solar years

(Sharer & Traxler, 2006)

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Calendars in East Asia

Nakayama Shigeru

Successive attempts to improve a typical luni-solar calendrical system for reconciling two fundamentally incommensurable periods – the tropical year and the synodic month – were made throughout

the history of Chinese and Japanese calendars until their replacement by the Gregorian solar calendar in modern times, the Japanese in 1883 and the Chinese in 1912.

The length of a synodic month varies between 29.0 and 30.1 days. The luni-solar calendar provided for “short” months of 29 days and “long” months of 30 days. Calendrical scientists attempted to arrange short and long months so that the moon’s conjunction would take place on the first day of every month. The day notation of the lunar month represented the phase of the moon; for instance, the 15th day of the month was always a full moon, while the 1st day was a new moon.

In addition, the Chinese had an independent system of solar intervals (*qi*) for indicating seasonal changes, the most important phenomena in the regulation of agriculture. The tropical year was divided into 12 equal intervals of time, the element of a purely solar calendar. The middle point of each interval was called its *zhongqi* or interval center. The synodic month was always slightly shorter than an equal interval, and thus an interval center did not occur in certain months. Such months were designated as intercalary months, and in this way the sequence of synodic months was reconciled with the seasons of the tropical year. The year that included an intercalary month had 30 synodic months. This occurred roughly once every 3 years.

The Chinese calendar calculators were, however, not satisfied with providing a conventional calendar, in which the courses of the sun and moon were reconciled, merely for civil use; they also tried to include the anomalistic motions of the sun and moon.

Prior to the Tang period (roughly seventh to ninth centuries), a mean synodic month of approximately 29.5306 days was used for this purpose. Shortly before the Tang, however, a proposal was made to take anomalistic motions of the sun and moon into consideration in calendar making. Liu Zhuo (AD 544–610) used the term *dingshuo* (true synodic month) as opposed to the older concept of *pingshuo*

(mean synodic month). During the Tang period the idea of the true synodic month was adopted in the official calendar in order to attain better agreement with the actual phases of the moon, and also for convenience in eclipse-prediction calculations.

Liu Zhuo also made the first recorded distinction between *dingqi* and *pingqi*. The former is the period of time for the sun to move through a 30° angle of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), which therefore varies in length in accordance with the anomalistic movement of the sun. The latter is the average length of time to move through a 30° angle. This concept, *dingqi*, however, was not actually adopted in the official calendar until the Qing period (the seventeenth century on).

Daily life is never affected by such small discrepancies in the calendar as those due to the anomalistic motions of the sun and moon. The astronomical attainments of the Chinese calendrical schemes went far beyond the concern of the common people. They included not only luni-solar phenomena but also the periodic motions of the five planets. They were called *li*, which corresponds to “ephemeris” as well as “calendar” in the narrow sense.

In the case of the Julian calendar reform data were doubtless gathered from prior calendars and not from actual observations. One recalls in this connection Lilius’ effort in the Gregorian calendar reform to reduce the toil of observation and computation so as to provide an artificial system independent of astronomical tables and indeed of any link with actual celestial phenomena. The Western calendar was not, in terms of astronomical precision, overwhelmingly rigorous.

The difference of purpose between calendar-making in the West and East is clear. Whereas the Western calendar was divorced from the development of astronomical science, and aimed at schematic convenience for civil and religious proposes, the East Asian calendar, disregarding civil convenience, was an attempt to represent

faithfully the movements of the heavenly bodies. It thus became much more complicated than its practical applications warranted. A sharp separation of scientific astronomy and civil calendar-making did not take place in traditional East Asia. Its scope was confined to the composition of a luni-solar ephemeris which stood or fell on the accuracy with which it could predict eclipses, which is the best way to check the validity of any luni-solar calendar. Analysis of planetary motions was rather ancillary to the main stream of Chinese calendar making.

Cosmological discussions often took place during the Han and Six Dynasties periods (second century BCE to sixth century AD), although they were discontinued soon after. In the Tang period the Chinese astronomers were no longer interested in this particular speculative pursuit. While occasional cosmological debates were found among philosophers, scientific cosmology was long set aside and forgotten in professional calendrical science circles until the time of the Jesuits' impact in the seventeenth century.

Perhaps the most striking thing about the recastings of the civil calendar in China was their frequency. In 2,000 years there were more than 50 revisions of the Chinese calendar, and then of the Japanese calendar, whereas in the West there was only one major reform, the Gregorian. Why were the Chinese so preoccupied with the calendar that they were driven to such repeated efforts? There were two major reasons, one political and the other technical.

Among the ancient Chinese the idea prevailed that a ruler received his mandate from heaven. In the early period, therefore, after important changes within individual reigns and always after important changes of dynasty, the new emperor was prompted to reform key institutions, especially the official calendar, in order to confirm the establishment of a "new order" which a new mandate implied. A new mandate meant a new disposition of celestial influences. The Han Emperor Wu (r. 1480–1487 BCE) was advised by his councilor to revise the calendar and change

the color of ceremonial vestments, in order to make it clear that his rule was based on a true mandate. The result was the imperial edict by which the *Taichu* calendar was adopted.

This notion was responsible for the subsequent course of development of Chinese calendrical science. Calendrical science enjoyed governmental sponsorship throughout its history, and had more prestige than other branches of science; it was China's most genuine contribution to the exact sciences. The history of Chinese and traditional East Asian astronomy is, for the most part, the history of calendar-calculations.

In the course of time, however, the political importance of calendar reform dwindled. The restriction of calendar reform to change of dynasty was not strictly observed by the Northern Wei (fifth century AD) and succeeding northern dynasties. Some rulers unduly took advantage of calendar reform to gain or regain popular support. The calendrical significance and authority of calendar revision were thus largely lost. In the Tang dynasty, the motive for calendar reform became simply to correct disagreements of the calendar with observed celestial phenomena. Hence, reforms were carried out whenever a small error was found. This accounts for the frequent revisions in later phases.

Beyond the concern with timekeeping, the Chinese astronomers dealt mainly with apparent solar and lunar movements and eclipse prediction. The Chinese luni-solar calendar required revision whenever the discrepancy between calculation and observation became noticeable. For this purpose, the government founded the Office of Astronomy, and incumbent astronomers were responsible for the improvement of the calendar. The government enjoyed a monopoly on the regulation of time, which contributed to imperial control of daily life and which strengthened the central power and prestige at a sacrifice of civil convenience. People were forced, in matters of everyday life, to follow a calendar based on a complicated, "astronomically rigorous" and "state-authorized" ephemeris, which, unlike our

solar calendar, could never be prepared by laymen, but depended on the skill of official astronomers.

Despite early recognition that a single perpetually valid calendrical scheme was impossible, the calendar calculators never tired of proposing revisions. Their incentive must be ultimately attributed to the rational desire to conform to the celestial order, a philosophical compulsion to accept the phenomena of the material sky as the most authentic reality. It was because of this orientation that calendar-making maintained its status as an integral part of Chinese science and learning for such a long time.

Modernization and Westernization

As the official calendar was quite an important part of the social system, westernization in modern times was first infiltrated through calendrical science.

Western astronomy had arrived in China with the Jesuits in the sixteenth century. Calendar-making was a vital function of the Chinese bureaucracy, and the Jesuits hoped that by demonstrating the superiority of Western astronomy they would succeed in persuading the bureaucratic elite that Western cultures and Christianity were superior. Astronomy was well suited to their purposes, not only because it was so important to the Chinese bureaucracy but because the phenomena with which it dealt possessed a universality that transcended ► [East and West](#), and the objectivity of celestial phenomena did not permit much human manipulation. Furthermore, it was quantitatively precise. Thus, when the tally sheet was in, Chinese astronomers had to acknowledge that Western astronomy had superior features. All that the Jesuits made available from Western tradition, however, were peripheral data and methods of calculation. The structure, styles, and purposes of Chinese calendrical astronomy remained unchanged. As Xu Guangqi, a high Chinese official who collaborated with the Jesuit Matteo Ricci on several projects, put it, “We melted down their materials and poured them

into the *Datong* (the traditional Chinese calendar then in use) mold.”

In Japan, the eighth Shogun Yoshimune (1644–1751) attempted to use this refurbished Chinese astronomy as the basis for calendrical reform, but he was effectively opposed by conservative court circles in Kyoto. The revision of Horeki that came into effect in 1754 was still modeled upon the traditional *Shoushi* calendar. Yoshimune’s desire was fully realized, however, in the Kansei revision of 1797.

After that, the scientific quality of the traditional luni-solar calendar was improved and perfected, but still the traditional mold was maintained throughout the Tokugawa period (1603–1867).

Despite the earlier recognition of Western superiority in science, a radical change of political institutions in Japan had to precede the official adoption of the Western Gregorian calendar in 1873. The decisive factor in the adoption of the Gregorian calendar was the high value the government placed on westernization. Many Japanese proposed a more reasonable solar calendar at the time of the reform, but the government preferred the Gregorian, despite its obvious shortcomings, because of diplomatic relations with the West.

With the establishment of the Republic of China in 1912, the Chinese luni-solar calendar was officially abolished.

To what extent the Gregorian calendar was observed among the populace is questionable, but after the second World War, it became firmly established in everyday life in East Asia.

See Also

- [Astronomy](#)
- [Time](#)

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Calendars in Egypt

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Otto Neugebauer (1969, 81) described the ancient Egyptian civil calendar as “the only intelligent calendar which ever existed in human history.” His statement can be appreciated by tracing the ancient Egyptians’ gradually developing sense of time from an initial awareness of the day to the full realization that the year had a constant length of 365 days. The introduction of the Egyptian civil calendar, based on solar years as opposed to lunar years, resulted in the development of our present-day Gregorian calendar.

Humans first became conscious of the existence of the day through the regular reappearance of the sun after its disappearance the evening before. Observing the regular change of one crescent moon to the next, they became aware of the longer time unit of the month. The practical demands of temple administration led them to develop their ability to count and calculate and they realized that one lunar month was made up of 29 or 30 days.

With the advent of agriculture in the Nile Valley, the season, rather than the month, gained importance as a subunit of the year. This agricultural calendar was based on a regularly recurring event, the Nile flood, whose return it was desirable to predict with a fair degree of accuracy. The ancient Egyptians must have realized that a purely lunar calendar was not capable of

adequately predicting such annual events. They hit upon another device by which the onset of the inundation could be determined – the heliacal rising of Sothis (Sirius, the brightest star in the sky). They observed that after a 70-day period of invisibility, Sothis could be seen again just before sunrise, and this heliacal appearance of the star was taken to signal the beginning of the new year.

The Egyptians, having reckoned that there was a 365-day span between two successive heliacal risings of Sothis, initially resorted to a luni-stellar calendar which consisted of 12 lunar months totaling 354 days, to which an additional intercalary month was added every few years to make up for the cumulative discrepancy arising from the 11-day difference between the lunar and stellar year. The rule used was that whenever Sothis rose during the last 11 days of the fourth month of the last season, an intercalary month should be added.

Although the luni-stellar calendar could set the time for observance of religious festivals, which were typically agricultural in origin, a more practical calendar was required to meet the demands of the state administrative system. Thus, the Egyptians adopted a 365-day civil calendar which was divided into three seasons, each of four 30-day months. The year consisted of 12 months, each of 30 days, plus “five days upon the year.” Events were officially dated as occurring on the first, second, third . . . day of the first, second, third . . . month of the specific season of a particular year in the reign of the current pharaoh. In New Kingdom documents, the 12 months are often given individual names which originated from the cultic celebrations connected with these months: (1) Thoth, (2) Phasphi, (3) Altyr, (4) Choriak, (5) Tybi, (6) Mechir, (7) Phamenoth, (8) Pharmuthi, (9) Pachon, (10) Payni, (11) Epiphi, and (12) Mesori. These names of months are still preserved in Egyptian folk astronomy and meteorology.

Each of the 30-day months of the civil calendar was divided into three 10-day “weeks” or decans. Thus, there were 36 decans each year [Symons 2007]. The Egyptians defined each decan to begin when a particular star or

constellation appeared on the horizon just before sunrise. In the New Kingdom, the decan hours came to be measured in terms of the local meridian, rather than the horizon (Belmonte 2003). The period of time between the appearance of one decan on the horizon and the next was defined to be an hour. From the surviving “diagonal calendar” examples, it is clear that the night was considered to contain only 12 h rather than the 18 which might have been expected when we consider that we see approximately half the celestial sphere on any given night. The discrepancy seems to arise because the Egyptians did not include the period of twilight or dawn as part of the night. Only the period of totally darkened sky corresponded to the term “night.”

The idea that the day also included 12 h seems to be developed merely in analogy with the night. These hours might be measured on a shadow clock, since the length of shadow cast by any object changes relative to the position of the sun in the heavens. The shadow does not just change over the course of the day, however, but also over the course of the year as the sun travels between the tropics. As a result, these shadow clocks give no more than an approximation of true equal hours. The use of clepsydra (water clocks), in which water escapes from a graduated container at a regular rate, would provide a measurement closer to our modern concept of equal hours.

The Egyptian calendar constructors and time-keepers did not go beyond the hour in measuring time. It is to the Babylonians, with their sexagesimal mathematical system, that we owe our modern concepts of 60 min in an hour and 60 s in a minute.

In time, the Egyptian 365-day calendar became completely out of step with the actual tropical year, since it fell behind the latter by 1 day every 4 years. Thus, in 4×365 years, i.e., in 1,460 years, the civil year would have lost a complete solar year and would again correspond with the seasons. This 1,460-year period is generally referred to as the “Sothic cycle” and reflects the fact that every 1,460 years the so-called heliacal rising of Sothis fell on New Year’s Day and thus marked the onset of a new Sothic period. The Egyptians seem not to have

been concerned by the discrepancy between their civil calendar and the true solar year.

Early attempts to calculate the date of the introduction of the civil calendar based on the period of the Sothic cycle and on the assumption that the civil calendar would have coincided with the luni-stellar cultic calendar when it was first introduced have been discredited by more modern scholarship. At present, there is no satisfactory answer to the question.

In 238 BCE, Ptolemy III proposed to bring the civil calendar into synchronization with the solar year by adding an extra epagomenal day every 4 years. His attempt did not find widespread acceptance. Modification of the ancient calendar only ensued two centuries later when, after Julius Caesar’s conquest of Egypt in 46 BCE, he followed the advice of the famous Alexandrian astronomer, Sosigenes, and adopted a modification of the ancient civil calendar for the Roman Republic. Sosigenes suggested that the length of the year should be 365 and a quarter days, that there should be a 4-year cycle containing 3 years of 365 days and the fourth year containing 366 days, and that the year should begin on the first of January.

See Also

- [Clocks and Watches](#)
- [Sexagesimal System](#)

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This calendar is based on the following imperfect parameters:

- Five sidereal years = 1,830 days
- Sixty two lunations = 1,830 days
- Sixty seven sidereal lunar months = 1,830 days

The star *beta Delphini* indicates the winter solstice (which was indeed the case around 1500 BCE) which is apparently a fixed point. The lunar orbit is divided into 27 equal arcs from *beta Delphini* each equal to 13°20', called *nakṣatra*, the first arc named *Dhaniṣṭhā*. The arcs are named after a prominent star of the division. The theory is that if, in 5 years, two lunations are intercalated, then the lunar year will remain tied with the solar one. This period is called a 5-yearly cycle or *yuga*.

In practice, a cycle begins when the sun and the moon are in conjunction at *beta Delphini* (i.e., from the winter solstice). The first, second and fourth year each contain 12 new moon ending lunations. One lunation is intercalated at the middle of the third year and another at the end of the fifth. The second cycle then again begins from a similar new moon at winter, solstice.

This imperfect calendar was destined to collapse, as the succeeding cycles will begin from new moons shifted by some 4.5 days from the winter solstice at *beta Delphini* per cycle, accumulating to one lunation in six or seven cycles. However, the calendar did not collapse, and so the accumulated lunation was extracalated, but we are not told in the text how this was done. Perhaps the rule is hidden in an obscure part of the text, and so we have to guess it.

A lunation is divided into 30 parts called *tithis*. Accordingly, 30 *tithis* = 1,830/62 days. The excess 30/62 of a *tithi* over a day is called an omitted *tithi*. A month's days are designated by the *tithi* of the day and not by ordinal numbers. The Jainas used this cycle in their calendar with a marginal change: that months were full-moon-ending and a cycle began from a full moon at summer solstice in the middle of the *Āśleṣā* division (180° away from *beta Delphini*).

Calendars in India

A. K. Chakravarty

Calendrical science developed in India in three distinct phases, and each phase influenced the succeeding one. The first phase produced the Vedic calendar, covering a period from an unknown antiquity to the Mauryan emperor Aśoka (ca. 300 BCE); the second had the Greco-Indian calendar for a short period between the post-Aśokan and post-Kuṣāṇa period (ca. AD 300). And the third produced the Siddhāntic calendar from the Gupta period (AD 319) which is still used in India today. All three phases are characterized by formulations of fitting a lunar year into a sidereal solar one by suitably intercalating lunations.

References to calendrical elements like lunation, intercalation, year, and solstice occur even in the earliest part of Vedic literature. A separate calendrical literature, deemed a part of the Vedas, was developed in a small text, *Vedāṅga Jyotiṣa*, but this text has not been fully deciphered yet. There are some astronomical statements in the text, and also in the earliest part of Vedic literature, which do not hold true in the latitude belt and in the time period when the Vedic Aryans are believed to have settled in India.

It is a separate course of study as to how and when the Vedic Indians obtained this calendar, but they adopted it without verifying it.

Kautilya wrote a book entitled *Arthaśāstra* which is believed to reflect the social and administrative conventions of the Mauryan empire. This book, on the subject of measuring time, only reproduced the Jain school of the 5-yearly cycle. We are thus assured of its use until then.

The second phase of the Indian calendar began by the first century BCE after Śaka penetration into northwestern India.

The Śakas, a central Asian people, conquered Bactria in 123 BCE and established an era with epoch at 123 BCE, now called the Old Śaka Era. This epoch has variously been fixed at 88 BCE (Konow) and 110 BCE (Herzfeld), but, as M.N. Saha has shown, 123 BCE fits into all the circumstantial evidence.

The Śakas used the Greek calendar based on the Metonic cycle in their homeland. This was a 19 year cycle at whose beginning and end the sun and moon are in the same relative position to each other. When they reached India they adopted Indian culture and Aryanized or Indianized the Greek calendar, producing a Greco-Indian calendar. It replaced the classical 5-yearly cycle and it circulated in India up to ca. AD 200. The Kuṣāṇas, another Śaka tribe, penetrated further inside India, adopting Indian culture and using this calendar. Kings of the Śaka and Kuṣāṇa dynasties left behind some inscriptions bearing dates. These always refer to an era, as in era of king Kaṇiṣka. Further, they contain a mysterious expression – *etaye purvam* – whose meaning has not been deciphered.

The Indian form of the calendar is that the months are full moon ending; the 19-year cycle begins from a full moon at the autumnal equinox in the month Kārtika; months are assigned Sanskrit or Sanskritized Greek names; and, in special cases, the day is designated by the moon’s *nakṣatra* on that day. The Greek form is that days are designated by ordinal numbers and not by *tithis*, and intercalation is made at the middle of the year in Chaitra.

All these features are fully reflected in the inscriptions of the Kuṣāṇa kings. For example, present researches have shown that Kaṇiṣka established his era in AD 78 after deleting the 100th place in the old Śaka era for that year.

Now, $123 + 78 = 201 = 1$, deleting the hundredth place. Hence, AD 78 = 1 Kaṇiṣka era (current) and 0 Kaṇiṣka era (elapsed).

We interpret *etaye purvam* as elapsed year, and accordingly the Julian equivalent of Kaṇiṣka era in these inscriptions is:

$$AD 78 = 0 \text{ Kaṇiṣka era.}$$

The day of the month can also be identified with the *tithi* with tolerable accuracy. We have seen that the moon gains 12° over the sun per *tithi*. In case of new-moon-ending months, we should expect, on 20th Āṣāḍha:

- Moon – sun = $20 \times 12^\circ = 240^\circ$ (near about)
- Or sun = moon – 240° .

If the moon is near *Uttara Phalguni* (tropical longitude in AD 90 = $144^\circ 46'$), we should have: sun = $144^\circ 46' - 240^\circ = 265^\circ$ (say), so that the sun’s position comes near the winter solstice, which cannot happen in Āṣāḍha. However, if the month is full-moon-ending, then the moon-sun = $5 \times 12^\circ = 60^\circ$, or sun = moon – $60^\circ = 144^\circ 46' - 60^\circ = 85^\circ$ (say), i.e., near the summer solstice, which indeed happens in Āṣāḍha.

If we compute the mean tropical longitude of the sun (L) and mean elongation of the moon in days (D), we get (Table 1):

These lunisolar positions are in complete agreement with the inscriptional dates. We may perhaps identify these dates as Julian equivalents of the inscriptional dates. Using this scale we can decipher all the other dates in the inscriptions of the Kuṣāṇa kings and use the same method to decipher the dates of the old Śaka Era.

This second phase was short-lived, but had far-reaching effects on the later Indian calendar. In fact, this was perhaps the most productive period in Indian calendrical history.

Calendars in India, Table 1 In a period of 4,320,000 years

Date	L	D
June 21, AD 90	$87^\circ.16$	4.81

This Greco-Indian calendar was discontinued after the fall of the Kuṣāṇa empire.

In the third phase, the Indian calendar was thoroughly revised. New calendrical elements were introduced, new techniques in computational works were formulated, and the application of cycles for intercalation was abandoned. The new calendar that emerged is called the Siddhāntic calendar. This calendar was perfected by later Indian astronomers and is still used all over India with some marginal changes in some regions. In this phase the solar zodiac with 12 signs was introduced. The *nakṣatra* division was recast so that the first arc-division, renamed *Aśvinī*, began from the first sign *Meṣa* (Aries). This common point was the vernal equinox. By AD 550, the vernal equinox shifted to *zeta Piscium*, and this star (or a point very close to it) has since been the beginning of the Indian zodiac.

The new technique for computations was that an epoch, *Kaliyuga*, was formulated such that all the luminaries, like the sun, moon, and planets, were assumed to be in conjunction at the initial point of the zodiac at this epoch. Sidereal motions of the luminaries were so assigned that each of them made an integral number of revolutions in a period of 4,320,000 years (see Table 2).

Astronomical parameters in this phase were not uniform in different schools. We cite below some calendrical parameters from the Āryabhaṭian school (AD 476) and the *Sūryasiddhānta* school of the tenth century.

For any day in question, elapsed days from Kali are computed from the above figures, and from the rates of sidereal motion of the luminaries their positions are found in the zodiac. The epoch of *Kali* was computed by Bentley at 18th February, 3102 BCE midnight at Ujjain (longitude 75°45' east). This date has been generally accepted by all astronomers.

► **Āryabhaṭa** formulated corrections of mean motions of the luminaries, but such formulations are not found in earlier works. Our presumption is that only mean motions were considered in the pre-Āryabhaṭian period.

In this revised calendar, the luni-solar year begins from the new moon just preceding the

Calendars in India, Table 2 In a period of 4,320,000 years

	Āryabhaṭa	<i>Sūryasiddhānta</i>
Sidereal revolution of the sun	4,320,000	4,320,000
Sidereal revolution of the moon	57,753,336	57,753,336
Sidereal revolution of Jupiter	364,224	364,220
Total civil days	1,577,917,500	1,577,917,828
Intercalary lunations	1,593,336	1,593,336
Omitted <i>tithis</i>	25,082,580	25,082,252

sun's entry to the initial point in the spring month *Chaitra*. Now, 12 lunations fall short of 10.8 days from a sidereal year, and this accumulates to one lunation in 2 or 3 years. Whenever such an extra lunation forms, it is intercalated in the year; there is no role of any cycle here. This luni-solar year, with days designated by the *tithi* of the day, is used all over India for religious purposes.

A solar year is also devised beginning from the sun's entry into the first sign *Meṣa*, and is divided into 12 solar months, each month being the period the sun stays in a sign. Days of solar months are designated by ordinal numbers. The first month is *Vaiśākha*. Datings are recorded by luni-solar year in some regions, and by solar year elsewhere. The era generally used is the Kaṇiṣka era renamed the Śaka era.

In a year containing 12 lunations, the 12 new moons will, most generally, be distributed over the 12 signs, i.e., each sign will contain a new moon. However, in an intercalary year when 13 lunations are distributed over 12 signs, 2 new moons must occur in 1 sign, and in extreme cases, 1 sign may not contain any new moon at all. Such situations are natural phenomena and are no problem for astronomers.

Out of the 13 lunations occurring in an intercalated year, any one may be earmarked as the extra month. However, metaphysics has taken a toll here. As one sign will contain two new moons, so two lunations, one from each new moon, will occur in that sign. One lunation out of these two has to be selected as the intercalary

one. Volumes of religious literature have been written, perhaps more voluminous than their astronomical counterparts, on which lunation is the proper one and which is the intercalary one. Similarly, when a sign becomes void of a new moon, religious literature is controversial as to which lunation is to be assigned to that sign. Almost every region of India has its own convention on these points.

See Also

- ▶ [Astrology in India](#)
- ▶ [Astronomy](#)
- ▶ [Lunar Mansions in Islam](#)

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Calendars in Islam

Mohammad Ilyas

Even the most ancient peoples considered the day the earliest unit of time-telling. However, the day is not convenient for long intervals of time. Even allowing for a primitive lifespan of 36 years, a person would live some 13,500 days, and it is very easy to lose track of some of those.

It seems natural to turn to the Earth's next most prominent body, the moon, for another unit. Here, the readymade period of the lunar phases provides the natural unit called the *lunar month*. The lunar month is approximately 29.5 days (more exactly 29.5306 or 29:12:2.8). In pre-agricultural times, the month provided a convenient and simple method for measuring moderately long periods of time. A lifetime of something like 400 months is a more convenient figure than 13,500 days. Lunar months united to the seasons, as they would have been initially, would produce some problems for a settled agricultural society, which is not the case for a hunting or herding society of nomads, who could wander more freely in search of grain or grass. Farmers not only had to stay where they were, but also needed to increase their chances of a good harvest by sowing at a proper time to take advantage of seasonal rains and seasonal warmth. Therefore, to keep the lunar months approximately seasonal, an intercalary month needed to be added in 7 of each 19-year cycle (19 solar years = 235 lunar months, i.e. 19 lunar years of 12 months each, +7 lunar months). In due course, the practice of intercalation was gradually perfected; the intercalary months came to be added in the 3rd, 6th, 8th, 11th, 14th, 17th, and 19th year of each cycle, in a popular scheme which transformed the lunar calendar into a seasonal, or lunisolar calendar, in which a month remained in pace with the sun to within 20 days.

The lunisolar calendar practice was adopted by the Hebrews, Greeks, and Romans and remains in use in the Jewish, Hindu, and Chinese calendars of today. The early Christians continued to use the Jewish (lunisolar) calendar tied to the new moon for more than three centuries and established the day of Easter on that basis. On the other hand, the Roman Republic, which had also used a lunisolar calendar for a long period, moved to a purely solar calendar in 46 BCE as a result of abuse of power by Pontiffs in the matter of intercalation.

Julius Caesar decided to put an end to this chaotic situation by introducing the solar calendar system. In this transformation, 46 BCE was allowed to continue for 445 days (!) and came to be known as “The Year of Confusion”, in effect the last one. The adopted solar calendar with a year length of 365.25 days became known as the Julian calendar.

The month, being tied to the moon, begins at a fixed phase in the lunar calendrical system. Since any phase will do, the month can begin at each full moon, the first quarter, etc. However, the obvious way is to begin each month with the new moon – on the evening when the growing crescent first becomes visible immediately after sunset. Practically all lunar calendars began their new months with the new visible crescent. Some modern users of the lunar calendar (the Chinese and Jews) have changed this to the astronomical new moon, i.e. the conjunction, while Muslims maintain the first visible phase of the new crescent as the beginning of a new month.

The Islamic calendar was both a religious as well as a civil calendar, necessary to determine periods of the annual month-long fast, pilgrimages, times of marriage and divorce, years of taxes on wealth for the needy, religious observances, and general and historical timekeeping.

In Arabia, the use of a lunar calendar is known to have existed from very early times. The original practice is believed to have been to use 12 lunar months to a year. On the pre-Islamic Arab calendar, the annual Pilgrimage (*Hajj*) to *Ka'bah* in Mecca was a most significant and

important event. Although the event of the pilgrimage to *Ka'bah* was basically religious, it was also important for trade and business. When the *Hajj* was out of season, it created difficulties in procuring the crops and sacrificial animals for trade and use. To overcome this, the Arabs in Mecca are believed to have introduced a system of intercalation known as *al-Naasi*. A Meccan by the name of Qalmas is reported to be the first person assigned this task who, during each pilgrimage, would announce the dates for the coming years' *Hajj* and inform whether the intercalation was due for the coming *Hajj* season.

In addition to the month of *Dhu'l-Hijjah* (in which the pilgrimage is held), three other months (*Rajab*, *Shawwal*, and *Thu'l Qa'dah*) were sacred to the pre-Islamic Arabs. During these months, certain things, such as wars with opponents, were forbidden. In time, the practice of intercalation was much abused (as with the Roman calendar) thus affecting the sacred months and the related prohibitions by changing a sacred month into a non-sacred one.

The calendar in use in Medina (North of Mecca) remained in the original “twelve months to a year” form. The early Muslims continued to use the Meccan calendar while in Mecca, but shifted to the *Medinan* calendar after the Prophet Muḥammad and his companions migrated to Medina in AD 622. Following the conquest of Mecca in the eighth year of *Hijrah* (December AD 629), the Muslims continued to use the *Medinan* calendar, and the *Meccan* calendar ran parallel.

However, during the Prophet Muḥammad's last pilgrimage in the tenth year of *Hijrah* (AD 632), the Meccan practice of intercalation was abolished through a Quranic injunction, thus reverting the Arab-Islamic calendar to the simple “twelve months to a year” practice.

The Islamic calendar also required that the beginning of a month be based on the first sighting. This was particularly important for religious events like the beginning and end of the fasting month and the date of the pilgrimage to the *Ka'bah*.

There was no commonly accepted permanent calendar in pre-Islamic Arabia. Nevertheless, the custom of counting years was, in one form or another, prevalent among the Arabs and their neighbours. Opinions are divided as to the origin of this practice. According to Ibn al-Jazwī, it dates from the time when the children of the prophet Adam multiplied and spread on earth. In South Arabia, a calendar system originated in 115 or 109 BCE when the Himyarites adopted one using the reigns of the Tubba as the epoch years of their era. The inhabitants of Sanaa (Yemen) also adopted a calendar, using the victory over the Yemen by the Abyssinians, and later, the Persian conquest.

The origin of a chronology of events in North Arabia may be traced as far back as the construction of the *Ka'bah* by the prophet Abraham and his son the prophet Ismail. The northern Arabians are also reported to have their famous battle days as marking epochs of eras. A local calendar is supposed to have existed in Medina also. Al-Masudi maintains that the people of Medina used the dates of their castles and palaces as their local calendar at the time of the prophet Muḥammad's migration, but others reject this, claiming the adoption of an era by the people of Medina to a month or two after the prophet's arrival, which continued until his death in AD 632. According to a widely held view, the *Hijrah* era was set up at the time of Caliph 'Umar ibn al-Khattab in AD 637/638, i.e. about 5 or 6 years after the introduction of the purely lunar calendar. After many consultations, the year of the prophet Muḥammad's *Hijrah* was accepted for the beginning of the Islamic (or *Hijrah*) calendar.

Based on scientific understanding, certain ground rules were laid down which form the part of *sharī'ah* (the Islamic legal system) governing the calendar. Some of these were:

1. The length of a month should be 29 or 30 days.
2. The length of a year should be 354 or 355 days.
3. The maximum number of consecutive 30-day months is 4; the maximum number of consecutive 29-day months is 3.

4. Each new month begins with the first light of the new crescent moon visible on the western horizon after sunset.
5. One should try sighting the new moon on the 29th day of the month, but if it cannot be seen (even due to clouds), complete the month as of 30 days.
6. The visual sighting report must be corroborated by a witness.
7. The persons involved in the reporting must be reliable, adult, truthful, and sane, with good eyesight (implied). They are punished if proved to be purposely misleading.
8. The visual sighting report should not conflict with basic scientific understanding and natural laws. Indeed, professional scientists' involvement is essential to ascertain the reliability of the reported sighting, and the scientific test would include a check on related parameters (e.g. the shape of the crescent, its position and altitude, time of observation, sky conditions).
9. The sighting must be carried out in an organized way every month.

Sharī'ah also allows for the correction of a mistake. If on the 28th day of an Islamic month, the new moon has been sighted, a correction will be made to the beginning of the month, since a month should have only 29 or 30 days. If the month concerned is *Ramaḍan* then an extra fast would have to be completed after Eid celebrations.

Clearly, earliest visibility of the new moon plays a very critical role in Islamic calendar regulation. The Islamic "State" placed special emphasis on astronomy research, and it became a standard element in formal religious and legal education. The early Muslim community, based under the clear skies of Arabia and assisted by State-sponsored research, had no serious problems in following these injunctions to regulate their calendar. Muslims contributed enormously to the development of the science of the new Moon's earliest visibility and its advance prediction for greatly varying geo-environmental situations. In this, they built upon the work of earlier researchers as well (e.g. Babylonians, Hindus,

Jews). Besides the rigorous science, simple schemes were devised to construct long-term calendars especially to interconvert Islamic dates with Christian and other lunisolar calendrical dates. Based on technical information, one of the simple schemes (known as the schematic or *Istalahi* system) involved a cycle of 30 lunar years in which months approximately alternate between 29 and 30 days and 11 years consist of 355 days, the rest 354.

Backed by extensive research, Muslim scientists developed visibility tables and produced many reference works. All were well when astronomy and scientific endeavour were at their zenith in the Muslim lands.

Scientific interest in predicting the time of the first (earliest) new Moon sighting (for a clear sky) goes back to a period at least as early as the Babylonian era. Based on careful observational data, a simple criterion was developed and passed on to the Muslims through the Hindus, apparently with very little further improvement. This problem was thoroughly investigated by the early Muslim astronomers in the eight to tenth centuries AD and included such notable persons as ► [Ḥabash al-Ḥāsib](#) and ► [al-Battānī](#). The physics-based system(s), developed up to the eleventh century, saw very little further development until more recent times, when improvements were made. There has also been a series of simpler criteria involving time difference (lag) between moonset and sunset and the “age” of the moon.

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Calendars in Mesoamerica

Tom Jones

For many reasonably educated persons, the greatest single achievement of ancient Mesoamerica was the Maya calendar. In fact, a calendar was in use throughout Middle America, but it is its Maya form that has captured the world's imagination, the claim often being made that its accuracy exceeded that of the calendar in use in Europe at the time of the Conquest and, by some, even of that which we use today. While most of their neighbors kept account of time with three periods of differing numbers of days, the combinations of which formed a repeating calendar of 18,980 days, the Maya employed a mechanism that synchronized these same periods and others of their own making with a system that tracked cumulative time.

This cumulative record, or ► [Long Count](#), expressed historical dates with five-place numbers that recorded days accumulated from an arbitrary zero-point which has been determined to correspond to August 13, 3114 BCE in our present Gregorian calendar. (The correlation of Maya dates to European are to the no-zero-year Gregorian calendar, employing Thompson's 1935 correlation of 584,285 days.) Accumulating 1-day (*k'in*), 20-day (*winal*), and 360-day (*tun*)

Calendars in Mesoamerica, Fig. 1 The names and values of the Long Count places with their respective glyphs (Drawings by the author)

PLACE	NAME	DAYS	CALC	VALUE	GLYPHS
1	<i>K'in</i>	1 day	(1 X 1)	1 <i>K'in</i>	
2	<i>Winal</i>	20 days	(20 X 1)	20 <i>K'inob</i>	
3	<i>Tun</i>	360 days	(18 X 20)	18 <i>Winalob</i>	
4	<i>K'atun</i>	7200 days	(20 X 360)	20 <i>K'atunob</i>	
5	<i>Bak'tun</i>	144,000 days	(20 X 7200)	20 <i>Bak'tunob</i>	

periods, the Long Count employed a qualified vigesimal (20-base) place-number system – the qualification being an 18-base for the third place. The names and values of the Long Count places, from the unit up, were expressed in the writing system with distinct hieroglyphs for each order of magnitude (Fig. 1).

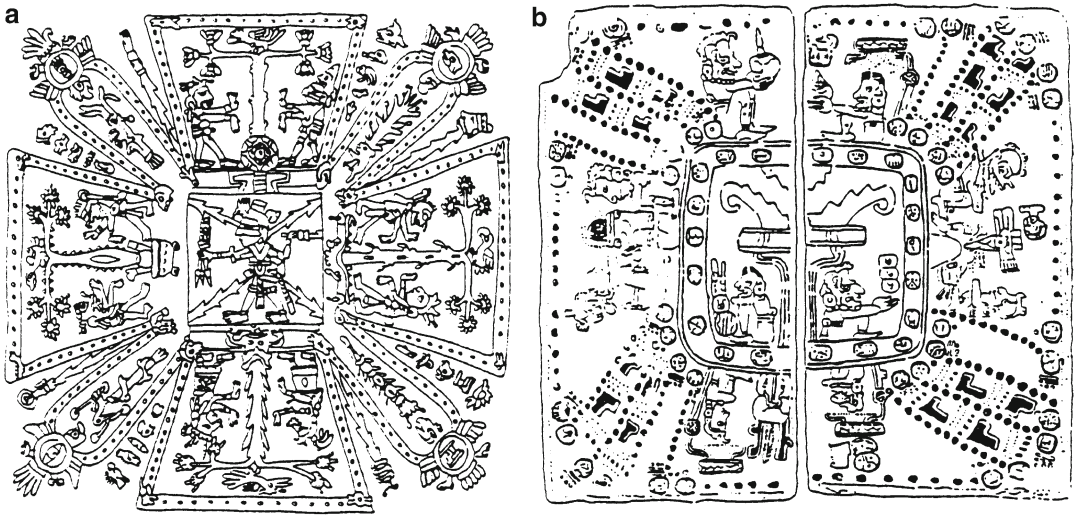
Thus, for example, a Long Count date with the numerical value of 9 *bak'tunob*, 8 *k'atunob*, 9 *tunob*, 13 *winalob*, and 0 *k'inob* records a day that was 1,357,100 days after August 13, 3114 BCE, which is to say March 26, 603. These values were communicated by positioning the numbers as prefixes or superfixes of the glyphs for the periods. The *-ob* inflection of Mayan nouns indicates plural. Because double digits are often required to express decimal equivalents of numbers in the places of the Maya system, Mayanists have adopted the convention of inserting periods between the places of Long Count dates. The above date, for example, is written 9.8.9.13.0. Though Maya historical dates that employed the Long Count were generally limited to five places, the calendrical system itself was open-ended and, when called upon to do so (as to meet mythological needs) could accommodate any number of places and express any full number of days. The greatest known to have survived is recorded at Coba as 13.13.13.13.13.13.13.13.13.13.0.0.0.0, which expressed in our decimal-system amounts to almost 22 quintillion tropical years!

Long Count dates were carved on monuments in the Maya heartland for over 600 years, the earliest known being 8.12.14.8.15 (8 July 292), the latest 10.4.0.0.0. (20 January 909). Moreover, the *Dresden Codex* records the much later date, 10.17.13.12.12 (29 October 1178). Though extensively used by the Maya, the Long Count was probably not their invention. Earlier Long Count dates have survived on several monuments on the southwestern Maya periphery – the earliest, 7.16.3.2.12 (7 December 36 BCE), at Chiapa de Corzo – in what was probably a proto-Zoquean (non-Mayan) speaking area.

The Maya coordinated this cumulative Long Count with the pan-Mesoamerican repeating calendar of 18,980 days. Known generally as the Calendar Round and called the *xiuhmolpilli* by the Aztecs and *hunab* by the Maya, this period consisted of three component cycles of 13, 20, and 365 days. The first two of these were a set of consecutive day-numbers (1–13) and a set of 20 day-names specific to each of some 60 language-groups within Mesoamerica (Fig. 2). The permutations of the 13 numbers and 20 names designated each passing day with a combination that repeated every 260 (13 × 20) days. This resulting 260-day period was termed the *tonalpohualli* by the Aztecs and is called the *tsolk'in* by Mayanists. Mesoamericans visualized this period as a four-sided cosmogram (Fig. 3) that can be described as a “Maltese” cross (the broad arms of which are identified in a counterclockwise order

AZTEC		YUCATEC		AZTEC		YUCATEC	
	1. <i>Cipactli</i>		1. 'Imix		11. <i>Ozomatli</i>		11. <i>Chuwen</i>
	2. <i>Ehecatl</i>		2. 'Ik'		12. <i>Malinalli</i>		12. 'Eb
	3. <i>Calli</i>		3. 'Ak'bal		13. <i>Acatl</i>		13. <i>Ben</i>
	4. <i>Cuetzpallin</i>		4. <i>K'an</i>		14. <i>Ocelotl</i>		14. 'Ix
	5. <i>Coatl</i>		5. <i>Chikchan</i>		15. <i>Quauhtli</i>		15. <i>Men</i>
	6. <i>Mizquitli</i>		6. <i>Kimi'</i>		16. <i>Cozcaquauhtli</i>		16. <i>Kib</i>
	7. <i>Mazatl</i>		7. <i>Manik'</i>		17. <i>Ollin</i>		17. <i>Kaban</i>
	8. <i>Tochtli</i>		8. <i>Lamat</i>		18. <i>Tecpatl</i>		18. 'Ets'nab
	9. <i>Atl</i>		9. <i>Muluk'</i>		19. <i>Quiahuitl</i>		19. <i>Kawak</i>
	10. <i>Itzcuintli</i>		10. 'Ok		20. <i>Xochitl</i>		20. 'Ahaw

Calendars in Mesoamerica, Fig. 2 The 20 Aztec (Nahuatl) and Yucatec (Mayan) day-names and signs (Drawings by the author)



Calendars in Mesoamerica, Fig. 3 The 260-day period as Portrayed by the (a) Aztecs in the *Fejervary-Mayer Codex* and (b) Maya in the *Madrid Codex*

YUCATEC	AZTEC	YUCATEC	AZTEC
1. <i>Pop</i>	1. <i>Tlaxochimaco</i>	10. <i>Yax</i>	10. <i>Izcalli</i>
2. <i>Wo'</i>	2. <i>Xocotlhuetzi</i>	11. <i>Sak</i>	11. <i>Atlcahualo</i>
3. <i>Sip</i>	3. <i>Ochpaniztli</i>	12. <i>Keh</i>	12. <i>Tlacaxipehualiztli</i>
4. <i>Sots</i>	4. <i>Teotléco</i>	13. <i>Mak</i>	13. <i>Tozoztontli</i>
5. <i>Sek</i>	5. <i>Tepeilhuitl</i>	14. <i>K'ank'in</i>	14. <i>Hueytozoztl</i>
6. <i>Xul</i>	6. <i>Quecholli</i>	15. <i>Muwan</i>	15. <i>Toxcatli</i>
7. <i>Yaxk'in</i>	7. <i>Penquetzaliztli</i>	16. <i>Pax</i>	16. <i>Etzalcualiztli</i>
8. <i>Mol</i>	8. <i>Atemoztli</i>	17. <i>K'ayab</i>	17. <i>Tecuilhuitontlii</i>
9. <i>Ch'en</i>	9. <i>Tititl</i>	18. <i>Kumk'uh</i>	18. <i>Hueytecuilhuitl</i>
		<i>Wayeb</i>	<i>Nemontemi</i>

Calendars in Mesoamerica, Fig. 4 The eighteen 20-day periods and final 5 days of the Aztec *xihuitl* and Maya *haab*

as East, North, West, and South) superimposed over a “St. Andrew’s” cross (the narrow arms of which define the diagonal directions Northeast, Northwest, Southeast, and Southwest). The eight projecting arms of this scheme are each comprised of 13 days proceeding out from the center and 13 more returning, with the four outer edges of the “Maltese” arms also each contributing 13 to complete the round of 260 days. This 260-day *tonalpohualli* was the most significant aspect of the calendar for the daily life of the typical Mesoamerican. It formed the basis of numerous rituals, character evaluations, omens, and prognostications, traced out in Aztec, Mixtec, and Maya books.

While the 260-day ritual period seems to have been the result of the combination of a cultural fascination with the number 13 and a vigesimal counting system derived from the number of digits of the hands and feet, the 365-day period – the Maya *haab* or Aztec *xihuitl* – to which we now turn, was an attempt at a full-number approximation of the tropical year (of 365.2422 days, as calculated today). This “vague year” was achieved by a set of 18 named periods of 20 consecutively numbered days each, and five extra consecutively numbered terminal days (*Nemontemi* in Aztec, *Wayeb* in Maya) to total 365 days ($18 \times 20 + 5$) (Fig. 4). Every day, then, could be expressed with a day-number, a day-name and a numbered position in one of the periods of the “vague year.” The workings of this

Calendar Round system are well illustrated by comparing the modes of expressing succeeding dates that include the five terminal days of the vague year in the Aztec *xiuhmolpilli* and Maya *hunab* (Fig. 5). The presence of these 5 days causes the position of any given *tsolk'in* day to drop back by 5 days with each successive vague year. Because 260 and 365 share a common denominator of 5, any specific combination of day-number, day-name, and vague year position repeats every 18,980 days ($260 \times 365 - 5 = 18,980$), or about 13 days short of 52 tropical years. As with the ► [Long Count](#), evidence for the origins of the Calendar Round lies beyond the western pale of the Maya, dating from as early as the sixth century BCE in the Zapotec region.

The *xiuhmolpilli* was of particular importance to the Aztecs, whose mythology claimed that the age in which they lived and in which the current Sun-God, *Tonatiuh*, reigned was preceded by four earlier ages, each with its own sun and each of which had been destroyed in its own way – the first by devouring jaguars, the second by winds, the third by a rain of fire and the fourth by a world-flood. During this fifth era, under *Tonatiuh*, the future seems to have been doled out to the Aztecs one *xiuhmolpilli* at a time. Each successive *xiuhmolpilli* had to be freshly solicited by a great deal of bloodletting and an elaborate “New Fire” ceremony that was carried out during the five *Nemontemi* days of each 52 *xihuitl*. If, following the ceremony, the stars continued on

Calendars in Mesoamerica, Fig. 5 The succession of 25 Calendar Round dates that pass through the five terminal days of the *xihuitl* of the Aztec *xiuhmolpilli* and the *haab* of the Maya *hunab*

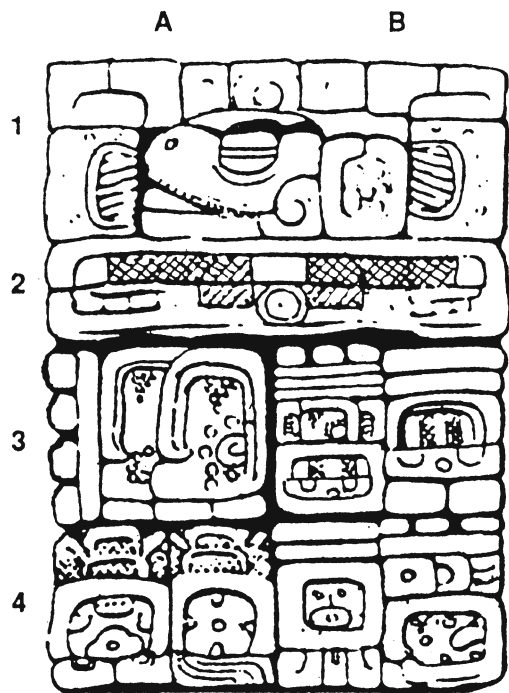
AZTEC		MAYA	
<i>XIUHMOLPILLI</i>		<i>HUNAB</i>	
<i>TONALPOHUALLI</i>	<i>XIHUITL</i>	<i>TSOL K'IN</i>	<i>HAAB</i>
1. 1 <i>Cipactli</i>	14 <i>Huetecuilhuitl</i>	1. 1 'Imix	14 <i>Kumk'u</i>
2. 2 <i>Ehecatl</i>	15 <i>Huetecuilhuitl</i>	2. 2 'Ik'	15 <i>Kumk'u</i>
3. 3 <i>Calli</i>	16 <i>Huetecuilhuitl</i>	3. 3 'Ak'bal	16 <i>Kumk'u</i>
4. 4 <i>Cuetzpallin</i>	17 <i>Huetecuilhuitl</i>	4. 4 K'an	17 <i>Kumk'u</i>
5. 5 <i>Coatl</i>	18 <i>Huetecuilhuitl</i>	5. 5 <i>Chikchan</i>	18 <i>Kumk'u</i>
6. 6 <i>Mizquitli</i>	19 <i>Huetecuilhuitl</i>	6. 6 <i>Kimi</i>	19 <i>Kumk'u</i>
7. 7 <i>Mazatl</i>	20 <i>Huetecuilhuitl</i>	7. 7 <i>Manik'</i>	20 <i>Kumk'u</i> (0 <i>Wayeb</i>)
8. 8 <i>Tochtli</i>	1 <i>Nemontemi</i>	8. 8 <i>Lamat</i>	1 <i>Wayeb</i>
9. 9 <i>Atl</i>	2 <i>Nemontemi</i>	9. 9 <i>Muluk</i>	2 <i>Wayeb</i>
10. 10 <i>Itzcuintli</i>	3 <i>Nemontemi</i>	10. 10 'Ok	3 <i>Wayeb</i>
11. 11 <i>Ozomatli</i>	4 <i>Nemontemi</i>	11. 11 <i>Churwen</i>	4 <i>Wayeb</i>
12. 12 <i>Malinalli</i>	5 <i>Nemontemi</i>	12. 12 'Eb	5 <i>Wayeb</i> (0 <i>Pop</i>)
13. 13 <i>Acatl</i>	1 <i>Tlaxochimaco</i>	13. 13 <i>Ben</i>	1 <i>Pop</i>
14. 1 <i>Ocelotl</i>	2 <i>Tlaxochimaco</i>	14. 1 'Ix	2 <i>Pop</i>
15. 2 <i>Quauhili</i>	3 <i>Tlaxochimaco</i>	15. 2 <i>Men</i>	3 <i>Pop</i>
16. 3 <i>Cozcaquauhli</i>	4 <i>Tlaxochimaco</i>	16. 3 <i>Kib</i>	4 <i>Pop</i>
17. 4 <i>Ollin</i>	5 <i>Tlaxochimaco</i>	17. 4 <i>Kaban</i>	5 <i>Pop</i>
18. 5 <i>Tecpatl</i>	6 <i>Tlaxochimaco</i>	18. 5 'Ets'nab	6 <i>Pop</i>
19. 6 <i>Quiahuitl</i>	7 <i>Tlaxochimaco</i>	19. 6 <i>Kawak</i>	7 <i>Pop</i>
20. 7 <i>Xochitl</i>	8 <i>Tlaxochimaco</i>	20. 7 'Ahaw	8 <i>Pop</i>
21. 8 <i>Cipactli</i>	9 <i>Tlaxochimaco</i>	21. 8 'Imix	9 <i>Pop</i>
22. 9 <i>Ehecatl</i>	10 <i>Tlaxochimaco</i>	22. 9 'Ik'	10 <i>Pop</i>
23. 10 <i>Calli</i>	11 <i>Tlaxochimaco</i>	23. 10 'Ak'bal	11 <i>Pop</i>
24. 11 <i>Cuetzpallin</i>	12 <i>Tlaxochimaco</i>	24. 11 K'an	12 <i>Pop</i>
25. 12 <i>Coatl</i>	13 <i>Tlaxochimaco</i>	25. 12 <i>Chikchan</i>	13 <i>Pop</i>

their steady march across the midnight-sky of the last day of the *xiuhmolpilli* – presumably because the gods had found the ritual to their satisfaction – the people could be assured that another 52 “years” had been granted them.

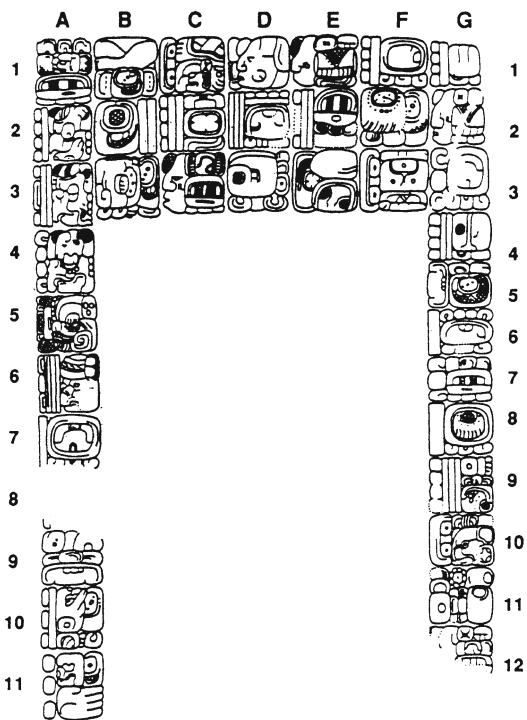
In the Maya region, this endlessly repeating pan-Mesoamerican cycle was synchronized with the accumulated days of the Long Count as the mathematical consequence of the arbitrary assignment of the Calendar Round date 4 'Ahaw 8 *Kumk'u* to the Long Count zero-date (13 August 3114 BCE). Written out in full and preceded by a distinctive hieroglyph that served to introduce them, dates so synchronized stood at the very beginning of the hieroglyphic texts on the carved monuments of Mayadom – whence their designation, Initial Series dates. To take an example, the Initial Series date on Quirigua Stela I (Fig. 6) – which reads in typical Maya fashion, from top-left to bottom-right, two columns at a time – displays a large initial series introductory glyph (ISIG) in the initial position (A1–B2) followed by the Long Count 9.18.10.0.0 (A3–A4) and the Calendar Round 10'Ahaw

8 *Sak* (B4), establishing a date corresponding to August 19, 800. (Glyphs are conventionally located by assigning upper-case letters to the columns of a text, numbers to its rows, and lower-case letters to divisions within the glyph-blocks and designating them in that order, as A3, C2a, F7b, etc. Number-values are dots for 1, bars for 5, and various special symbols for 0).

At times, supplementary to the Long Count and Calendar Round and inserted parenthetically between the *tsolk'in* and *haab* entries, were glyphs that recorded additional cycles of 7 or 9 days duration, as well as certain lunar information. Supplementing the cycles mentioned, the Maya tracked one of 819 days – a product of three basic periods ($7 \times 9 \times 13$) – relating it to a 4-day cycle (which the Aztecs also recognized) that linked each day with one of the four cardinal directions and associated colors (East, red; North, white; West, black; South, white). On Piedras Negras Stela 1 (Fig. 7), for example, the ISIG (A1) is followed by the ► Long Count 9.12.2.0.16 (A2–A6) and the *tsolk'in* position 5 *Kib* (A7), while the *haab* position, 14 *Yaxk'in*,



Calendars in Mesoamerica, Fig. 6 Quirigua, Stela I: hieroglyphic text with Initial Series date (Drawing after Annie Hunter. From *Biologia Centrali-Americana*, by Alfred P. Maudslayi, reprinted in 1974 by Milpatron publishing corp. Used with permission of the publisher)



Calendars in Mesoamerica, Fig. 7 Piedras Negras, Stela 1: hieroglyphic text (Drawing by John Montgomery)

does not appear until eight glyph-blocks later (C2). The intervening blocks include two that record the seventh position of the 9-day cycle (A8–A9), one that records the moon’s age as 8 days (A10), another the moon’s number as third in a set of six (A11), two that name the moon (B1–C1), and one that identifies it as a 31 month (B2). Following *14 Yaxk’in* are four noncalendrical glyphs (B3–E1) describing the event of the Initial Series date (July 7, 674).

When there was a need to record multiple dates, each new one (expressed as a Calendar Round date) was typically linked to its predecessor by what scholars call a Distance Number. The Distance Number employed the same place system as the Long Count, but because the number of days to be recorded usually did not require all five places, they were entered in the reverse order of the Long Count – commencing with *k’inob*

and proceeding only through those higher places necessary to record the distance. Thus on the Piedras Negras stela, following the initial event, come two glyphs that record the Distance Number *15 k’inob*, *9 winalob*, and *12 tunob* (D2–E2), then two more that indicate an advance of that distance forward in time (D3–E3), and finally, two glyphs that record the Calendar Round date, *9 Chuwen 9 K’ank’in*. The calendrical mathematics are:

9.12. 2. 0. 16	5 <i>Kib</i>	14 <i>Yaxk’in</i>	(July 7, 674)
+12. 9. 15			
9. 12. 14. 10. 11	9 <i>Chuwen</i>	9 <i>K’ank’in</i>	(November 16, 686)

After two noncalendrical glyphs (F2–G2) that describe the event of the date so reached, come a second Distance Number, *5 k’inob* (F3), and the resulting third Calendar Round date,

1 Kib 14 K'ank'in (G3–G4). The mathematics are:

9.12. 14. 10. 11	9 Chuwen	9 K'ank'in	(November 16, 686)
+5			
9. 12. 14. 10. 16	1 Kib	14 K'ank'in	(November 21, 686)

This new date is followed by the single glyph that describes the event (G5). Then come the Distance Number, 5 k'inob, 2 winalob, and 1 k'atun (G6–G7), a fourth Calendar Round date, 5 Imix 19 Sak (G8–G9), and fourth event (G10–G12). This final calculation is:

9. 12. 14. 10. 16	Z1 Kib	14 K'ank'in	(November 21, 686)
+1. 0. 2. 5			
9. 13. 14. 13. 1	1 Imix	19 Sak	(September 23, 706)

As was the case for the second of these two monuments, the Maya often accompanied their calendrical entries with lunar data. From this propensity and from the structure of a Lunar Table in the *Dresden Codex*, it is clear that their concern was to anticipate eclipse-possible dates. Because eclipses (both lunar and solar) can only take place during a period of 18 days on either side of node-passage of the Moon over the path of the Sun, which occurs twice during a tropical year, the Maya grouped the months in semesters of six (and for corrective purposes, occasionally of five). In an attempt to approximate the Moon's 29.53059-day synodic period (as calculated today), they ascribed 29 and 30 days, alternately, to successive months, compensating for the gradual accumulation of excess time by introducing an extra 30-day month at predetermined intervals. One result was the *Dresden Codex* Lunar Table with its eclipse-period of 11,960 days, or just over 405 complete lunations. However, that excess time would be allowed to accumulate until after eight repetitions of the period (95,680 days), when the table could be adjusted to correspond more closely to the moon's position by subtracting 1 day. The mathematics behind this adjustment are: $29.53059 \times 405 = 11,959.88895$; $11,960 - 11,959.88895 = 0.11105$; $11,960 \times 8 = 95,680$; $11,959.88895 \times 8 = 95,679.116$;

$95,680 - 95,679.116 = 0.884$, or 21.216 h. To further refine the Lunar Table's use, follow-up adjustments had to be made with succeeding repetitions of the cycle.

Though not central to the calendar itself, the planet Venus was nevertheless also a concern of Maya calendrical savants. Observations and calculations recorded in the inscribed monuments show that the Maya employed a 584-day period to predict culturally important points in the planet's synodic period. Both the Maya and the Aztecs assigned numerological significance to the correspondence between five of these Venus-periods and eight *haabs* ($5 \times 584 = 2,920$; $8 \times 365 = 2,920$). Also, in the *Dresden Codex* is an elaborate table that consists of 13 sets of five periods of 584 days, or 37,960 days. Here again, because of the discrepancy between the full number 584 and the actual synodic period of Venus (583.97 days, by modern measurements) and because of the added cultural requirement that the first heliacal rising of the planet should occur on the *tsolk'in* date 1'Ahaw, an adjustment like that in the Lunar Table had to be made after several runs of the Venus Table.

The Mesoamerican calendar, if by no means invented by the Maya, nevertheless reached its most elaborate form at their hands. Tracking basic periods of 4, 7, 9, 13, 20, 365, and 584 days and greater periods that were the products of various combinations or lowest common multiples thereof – $260(13 \times 20)$, $819(7 \times 9 \times 13)$, $2,920(8 \times 365; 5 \times 584)$, $3,276(4 \times 7 \times 9 \times 13)$, $18,980(13 \times 20 \times 365)$ and $37,960(13 \times 20 \times 365 \times 2 = 13 \times 5 \times 584)$ days – and groupings of months of alternately 29 and 30 days in duration, they synchronized them all with the cumulative and open-ended [► Long Count](#) that recorded every passing day from its original 4'Ahaw 8 Kumk'u zero-point. Where the European calendar intercalated extra days as a device for keeping its dates in close harmony with the seasons (the vernal equinox, for example, occurring always on or about March 22), the Mesoamerican calendar, even in its most refined (Maya) mechanism, simply ground out the 1-day intervals of its several parts, accumulating or repeating them endlessly and without

interruption, all of its components creeping gradually backwards through the seasons. It was thus impossible to identify a position in the tropical year by knowing a Calendar Round date. The first 4 'Ahaw 8 Kumk'u fell on August 13, but the second fell 12 days earlier on August 1 and the third, 12 more on July 19. In the year 265, near the beginning of the Classic Period, after having returned to its original August 13 date 113 times, 4 'Ahaw 8 Kumk'u fell on May 16, and by the close of the Classic in the late ninth century, it had fallen back to December 15.

However skillfully the Maya may have combined their astronomical observations with calendrical calculations to predict lunar and solar eclipse stations, heliacal risings and settings, conjunctions, stationary points, and retrograde motions of the five visible planets, the fact remains that, for all its reputation, the calendar itself was no more accurate than the 365-day calendar the ancient Egyptians adopted around 4250 BCE which was the product of 12 30-day months ($12 \times 30 = 360$), plus – like the Mesoamerican *xihuitl* or *haab* – 5 extra days. Indeed, it was an Egyptian mathematician, Sosigenes, who, recognizing the faults of the rigid 365-day year, persuaded Julius Caesar to adopt his scheme for reforming the Roman calendar in 45 BCE, by intercalating an extra day every fourth year into an otherwise 365-day year. However, it would be unhistorical to judge the Maya calendar by a standard set by the Egyptian, the Julian, or the later Gregorian calendar. The cultural need of the Egyptians was to anticipate (for agricultural reasons) the annual flooding of the Nile. That of the Julian reform was to ensure that the Roman solstitial festival *foris fortuna* would fall regularly on June 22. The Christians, in turn, adopted the Julian calendar in 325 at the Council of Nicaea from a need to establish predictable dates for Easter, which – for religious reasons – had to fall on the first Sunday following the first full moon after the vernal equinox. It was this same need that led Pope Gregory XIII to authorize a further reform of the Julian calendar in 1582.

However, the cultural needs met by the Mesoamerican calendar were of a numerological-astrological nature. Quite apart from the

divinations of the purely numerical *tsolk'in*, the Maya assigned significance to astronomical predictions based upon complex multiples of their several whole-number cycles which were often linked to the actions of remote or fabled ancestors or mythological supernaturals or to multiples of the never whole-numbered synodic periods of the heavenly bodies. Contrived calendrical calculations into the remote past and distant future were made to establish mythological beginnings, regenerations, and calamities to come. Day-to-day events, even to the timing of military attacks or battles among themselves or surrender to the Spanish, seem to have fallen under this numerical spell. However closely the *Dresden Venus Table* may appear to approach a modern astronomical ephemeris of Venus, its purpose was to return the latter's heliacal rising to *I'Ahaw*, the birth date of the mythological Venus-associated hero, *Hunahpu* – irrespective of any temporary losses in accuracy its mechanisms may have produced. If the calendrical efforts of Mesoamericans can be described as an attempt to bring about a marriage between their whole-number numerology and their perceived rhythms of the Sun, Moon, planets, and stars, it was one in which it was the latter who were to love, honor, and obey. However, if the test of a good marriage is its durability, then the Mesoamerican calendar – particularly in its Maya form – was not only mathematically sophisticated, conceptually elegant, and visually beautiful, but a highly successful one as well.

See Also

- Long Count
- Time

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Calendars in South America

R. Tom Zuidema

At the time of the Spanish conquest around the year 1530, the Incas had integrated different cultures, all belonging to Andean civilization, into a large empire, stretching from southern Colombia through Ecuador, Peru, and Bolivia, into northern Chile and Argentina. Much can be learned from the art of the Incas and their predecessors, including architecture, stone sculpture, pottery, and textiles. However, we have no access to written records as defined by western culture; understanding intellectual aspects of this civilization is almost exclusively dependent on what informants from Cuzco, the Inca capital in southern Peru, told the Spanish chroniclers. These were most impressed by Inca statecraft, although they were never present when it was still practiced. Their interpretation of Inca religion was heavily influenced by Christian opinions. Religion to them included memories of the Inca past and of state and private rituals related to, for instance, the calendrical organization of agriculture and llama husbandry. As Inca history is discussed in the article on [► Knowledge Systems of the Incas](#), this one concentrates on the calendar as it functioned in Cuzco.

Most of our information on the Inca calendar and related astronomical practices derives from only a few chroniclers: Juan de Betanzos [1551] (In case of an old text, square brackets indicate

the date of writing or first publication), a soldier and the first chronicler to write on this subject in the context of a full account of Inca culture; an anonymous author [ca. 1565] with precise information on the integration of astronomical observations into the calendar; Cristóbal de Molina [1574], a priest with great knowledge of Inca rituals but excluding those for one-third of the year; and Bernabé Cobo [1653], a late Jesuit author who gave our most comprehensive description of Inca culture including the calendar for the whole year. His information probably derives from a now lost account by Juan Polo de Ondegardo [1559], whose own description of the calendar only survives in a much revised short version [1585] for use by Catholic priests. Later chroniclers and dictionaries mostly follow Polo's version and add little information toward a reconstruction of the original Inca calendar. This reconstruction provides very different results from the general picture that the chroniclers present us with.

All chroniclers conceive the Inca calendar as consisting of 12 months. Notwithstanding this agreement, there is much confusion about the nature of the months, their order, and their correspondence to Christian months. Some of this confusion may derive from much local variation among calendars in the empire, but most of the blame is due to Spanish misreporting on the Cuzco calendar itself. Betanzos, Polo, and Cobo describe a system of 12 “months” with a fixed position in the solar year. Molina speaks of “months” and “moons” and refers to rituals according to the phases of the moon for three times of the year, roughly corresponding to June, September, and January. Some modern scholars therefore argue that the whole calendar was lunar, but this was not the case (Ziólkowski and Sadowski, 1992). On each of the three occasions important lunar rituals were celebrated after an independent solar observation had been made for that time of the year. We have no information on lunar rituals in Cuzco for other times of the year; we can only conclude that the integration of solar and lunar rituals in Peru was done in a way different from Western (Christian, Jewish) presuppositions in this respect.

There are various difficulties in accepting the Inca organization of months according to the Polo version of 1585. For instance, two names are taken together for 1 month that in other versions refer to separate months; in other calendars a name may be used as an alternative for either one or a next month. In some versions, a month name is suppressed for no apparent reason at all; months were said to be of rather different lengths, either longer or shorter than 30 or 31 days. And the anonymous chronicler mentions for two double-months that the moon observed in 1 month (either the first or the second) would always reach the other, leaving us to conclude that the fixed double-month was shorter than two movable synodic (lunar) months $2 \times 29\frac{1}{2} = 59$ days. Comparing the various descriptions of the Inca year, it becomes clear that originally it contained 13 and not 12 months and that each version suppressed one or another month name to accommodate this calendar to the Spanish one. It may have been a goal of Catholic missionaries fighting against "pagan" rituals, but there was also Inca consent, realizing the advantages of combining Inca and Catholic celebrations, first openly and later secretly.

From indications by Molina and Cobo we can conclude that the Inca calendar placed 1 month around the June solstice (21 June), celebrating *Inti Raymi* (feast of the sun), and 2 months, *Capac Raymi* (royal feast) and *Capac Raymi Camay Quilla* (royal feast, feast of the moon) around the December solstice, which honored the fact that in the southern hemisphere the sun is strongest then. For practical reasons, *Inti Raymi* may have been celebrated not on the days of the June solstice but within its month during the full moon either before or after in a given year. People took advantage of the dry season's clear skies when the moon shone the whole night.

During *Capac Raymi*, considerations were different. While the June solstice marked the middle of a month, the December solstice, six and a half Inca months apart, marked the date separating the 2 months of *Capac Raymi*. Moreover, these months fell in the middle of the rainy season when normally no good observations of the sun and the moon could be made. The month

of *Capac Raymi Camay Quilla* was celebrated, first awaiting the new moon with some celebrations. The major celebrations came with the next full moon and took some 7 days. If the new moon arrived early after the solstice (December 21), all celebrations took some 22 (15 + 7) days; but if it was late, they could take up some 52 (30 + 15 + 7) days. Then the full moon celebrations would not occur in *Camay Quilla* but extend into the next month. Although after those days the moon would still be visible late at night, no more attention would be paid. However, the day after these 52 days (February 13) was important for another reason. Then the sun in Cuzco – this city being $13\frac{1}{2}^{\circ}$ south of the equator and within the tropics – passes the zenith point in the sky at noon. Although the chroniclers were only vaguely aware of the importance of this event, Polo indicates that then a new year began, with people preparing for the coming harvest. The sun also passes the zenith 53 days before the December solstice, and we can assume that a similar calendrical calculation was made for this period. The anonymous chronicler considered it as one in which the moon of 1 month would always reach the other. Its beginning was celebrated with a feast, the *Itu*, which only Inca nobility could attend, and the last 6 days before the December solstice were also important for celebration. These days could begin with a full moon if the new moon had arrived late in this 53 day-period.

Apparently, the Incas divided the time from the first to the second passage of the sun through the zenith (107 days) into 4 months, of which the central ones of *Capac Raymi* were most important. The average length of the 13 months was about 28 days and as the connection to the length of a synodic month (29 days) was lost, there is no reason that the months could not be of various lengths as reported by the chroniclers. Having established the framework of the Inca calendar, an outline can be given of its ritual organization serving various, often contrasting, social needs.

The calendar organized, first, a multitude of sacrifices (llamas, guinea-pigs, birds, sometimes children) and offerings (mostly cultivated plants). The months were organized according to four seasons of 3 months and an independent

month after the sun's second zenith passage. Sacrifices and offerings expressed the different seasonal concerns.

A quite different organization of the months attended more political interests in terms of tribute due by Inca and non-Inca subjects and of the large feasts of state presented by the king, queen, and high nobility. In this organization, months were brought together in groups of two and then of four. This organization cross cut the seasonal one but kept the same independent month. Our first chroniclers mention how tribute was brought to Cuzco every 4 months and how non-Inca nobles accompanying these deliveries stayed for the same time in town. Betanzos adds to this that services of labor and distribution of food, especially meat and cloth, followed the same schedule. At first, the colonial administration showed interest in adopting this schedule for its own needs, but after about 1570 it changed to the European custom of having tribute paid twice a year, around Christmas and St John (24 June), and chroniclers no longer paid attention to the earlier system.

I mentioned above the most important 4 month-period around the December solstice. In between the times of planting and harvest, this was a season when the fields needed less attention and when heavy rainfall made travel difficult. *Capac Raymi* and its preceding month were dedicated to the initiation rituals of noble boys, these being assisted by noble girls who had had their own rituals of first menstruation at other times of the year. In the lunar rituals of *Camay Quilla* and the following month, noble men and women pledged their allegiance to the king, and rains were ritually dismissed awaiting the ripening of the fruits. In the 4 months around planting, land was first prepared for cultivation, ploughed and planted, and then rituals followed to help the budding plants grow and attract rains. Again, the two central months were dedicated to state rituals. First, the king himself helped with the planting. Keen observations were made of sunset throughout the first month to have the various timings for planting and irrigation of different sorts of plants, at lower, warmer and higher, colder places well orchestrated. In the second

month, dedicated to the moon, the queen, and women in general, "evil" and "illnesses" were ritually driven out of town in support of peace among people and of the growth of plants. Finally, the 4 months of harvest included the early harvest, the general harvest around Cuzco, the reception of foreign lords with their presents and the tribute of their people, and storage. Again the most important ceremonies occurred in the central months when first harvest was ritually brought into town and then the Inca himself ploughed, opening a new agricultural year, and ate with all nobles and foreign lords in the plaza.

Good descriptions of Andean rituals were also made for the central provinces around Lima, the vice royal capital in colonial times, and some of these ceremonies can be compared with Incaic ones in Cuzco. But when those other records became available in the early seventeenth century, more than 80 years had already passed after the Spaniards had arrived in the Andes. Much research still has to be carried out making those comparisons fruitful for a reconstruction of pre-Hispanic calendars in general.

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Calendars in Turkey

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As a term, the word *takvim* (calendar) derived from the word “community,” meaning to shape something, can be defined as a document that indicates the place of an event within a timescale that has a particular start point (Akgür, 2010, 487). Calendars are usually arranged in relation to the movements of the two main celestial bodies, the sun and the moon. An Islamic calendar known as the Hijri Calendar was used by the Ottoman Empire from its foundation to its collapse (1299–1923). It was established in the period of Prophet Omer, based on the 36th–37th verses from the Quran's *Surah at-Tawbah*. In the hadiths indicated, it is written that the number of moons under the reign of Allah is 12. In the hadiths, it is indicated that a month lasts 29 or 30 days.

In the Hijri Calendar, the Hijri of Prophet Muhammad marks the beginning of the calendar, and the first day of the first month, Muharram, marks the New Year. This calendar, known as Hijri-lunar, is equal to 1 lunar year, 354 days, 8 h, and 48 min. The lunar year is approximately 11 days less than the solar year that the Gregorian Calendar uses today. Therefore, 33.5 Hijri years are equal to 32.5 Gregorian years. In other words, once every 33.5 years, the Hijri Calendar gets 1 year ahead of the Gregorian Calendar (Akgür, 2010, 489). Along with this inadequacy of the Hijri Calendar, it has another negative feature which is that it fails to comply with the seasons which have great importance in agricultural life (BOA, MV, 199/186; *Tasvir-i Efkâr*, 14 Mart 1329).

In Ottoman fiscal tradition, treasury incomes used to be collected according to the solar year and the expenses were consumed according to the lunar year (Sahillioğlu, 228). This operation continued smoothly in the period when the income-expense balance was kept; the incomes collected were well spent, and the Ottoman army was ruled without spending the treasury income (*Takvimü'l-edvâr*, 52–53). Another phenomenon that reinforced the system was the continuous expansion of the borders and, therefore, the increase in public revenues (Gemici, 55). The day difference problem between the lunar and solar year was solved by skipping 1 year once in every 33 years, and the year skipped was known *sıvış yılı* (Tezâkir, 110; Nevsâl-i Millî, 8).

The dissolution faced in the Ottoman manorial system (*timar sistemi*) disrupted the classical operation. In a period when the number of troops was increasing day by day, the salaries, which were paid four times a year, had become a great burden for the treasury. Moreover, the tax system that depended on real payments had been based on cash since the seventeenth century. Salary payments made in cash constituted 77 % of the government budget in 1630 and 62 % in 1670 (Barkan, 321–325). Delays in the payments led to uprisings initiated by the janissaries, and some of these uprisings occurred in the years following the skip period. In order to keep the income-expense balance, the government looked for

borrowing and devaluation. That meant a new tax and it affected the peasantry most. This chain of problems caused the peasants to leave their homes.

At the instigation of the head of the provincial treasury, Morean Osman Effendi, a new calendar known as the Financial Calendar, based on the Julian Calendar, was established in 1794, in order to solve the problem for the treasury arising from the day difference (Nevsâl-i Millî, 9). Because the name Julian was Greek, they tried to overcome the problem by using the Financial Calendar, also called the Julian Calendar, only in financial transactions after 1794 (Millî Nevsâl, 15–16). The starting date of this calendar, which was based upon the solar year and used in all official fields after 1840, was the Hijri of Muhammad (Ahmet Şakir, 25). The months' names were picked from ones used by the Assyrians and Romans (Gökdoğan, 91). Thus, an interesting calendar whose year digit was determined according to the lunar year, and whose month and day digit was determined in line with the solar year, was established. According to Ahmet Cevdet Pasha, whose studies drew attention to the subject of calendars, such a calendar had never been used by any other nation before 1582 (*Takvimü'l-edvâr*, 54–55). Meanwhile, Continental Europe preferred the Julian rather than the Gregorian Calendar which they had been using since 1582, and it was known as *Efrençî* by the Ottomans (Akgür, 1996, 71). Ottomans were familiar with this calendar from the Orthodox religion (*İkdam*, 18 Kanun-i sani 1332).

The move to start using the Financial Calendar for all official matters from 1840, which previously had been used only for financial transactions, was due to the centralization initiative of the Tanzimat Reform Era. Along with centralization, the number of troops, and through the developing bureaucracy, the number of officers was increased. An extraneous factor influenced bringing the subject of the calendar into question and from then on it never lost its importance. Because of the efforts of the Ottoman Empire, which gained speed after the Treaty of Balta Limani, they signed a compact with the United Kingdom in 1838, for unification with the capitalist world.

Executives of the Tanzimat Reform Era, especially Ali Pasha, took action with a number of pragmatic arrangements to create the prerequisite conditions for a capitalist economy. Hence, they took the European calendar, which had reached a certain standardization after the French Revolution, in exactly the same way, and the Ottomans also adopted the length and weight measuring systems. Ahmet Cevdet Pasha wrote a work entitled *Takvimü'l-edvâr* at the request of government executives, when it was deemed necessary to investigate the problem of how the dates fell. In this work, Pasha drew attention to the fact that the year 1288, which had escaped the attention of the executives and had been forgotten, was the skip year (Ma'rûzât, 206–207; Tezâkir, 109–110). The government bonds due to be issued in 1288 would be invalidated and that would cause trouble for the government and the courts (Şakir Paşa, 25; Islâhü't-takvim, 27). Warnings, especially from Ahmet Cevdet Pasha and the commissions that were working on the same matter, were not taken into account. The tradition was abandoned, and the final solution considered was to remove the sıvış yılı (BOA, YEE.KP, 86-35/3454; Ma'rûzât, 208).

It took time to integrate the Financial Calendar into daily life. In fact, in birth certificate applications brought after the Tanzimat Reform Era, the birth dates of some people were given based upon the Hijri Calendar, while some used the Financial Calendar (BCA, 030.10, 124.886.11; Uluçay, 136). In the year when the Financial Calendar was put into practice, postal services were also made open to the public (Eskin, 16). After almost half a century, in 1901, a small adjustment was made to this calendar by the Ministry of Post and Telegrams. In Europe, the day difference between the Julian and Gregorian Calendars was being discussed (The Times, 21 Oct. 1901). Because of the Ministry of Post's decision, the 1-day shortness in the Financial Calendar was increased to 13 days, which made it 584 years behind and 12 days shorter than the Gregorian Calendar. For postal transactions, it was decided that the months would be indicated by the number that referred to which month of the year it was, but not by its name.

Alongside changing the traditional units of measurement and weight, Tanzimat dignitaries intended to accept a new calendar system just like the Jacobins did in France, in order to make advances towards Europe (Kasaba, 20). However, not only were they unable to touch the calendar phenomenon reinforced by tradition and also the strong effect of religion associated with Hijri, but they were also going against the requests of congregations made in this direction.

Despite this, the Ottomans decided to use the same calendar which had been used in London, Paris, and Rome since 1910 and followed the congresses where the possibility of indicating time on a single scale was being discussed. The emphasis was placed on the positive effect of having only one calendar for the world economy, which would be used worldwide (The Times, 27 Oct. 1926). Wanting to act in unison with Europe, the Ottomans took action to regulate the calendar and the metric and hour system. They called this "putting the basis of amalgamation into practice" (Ergin, 264). The understanding of amalgamation would be taken in hand by the Financial Calendar (Nevsâl-i Millî, 9).

The Party of Union and Progress that steered government policies after the Second Constitutional Period did not have sufficient strength either to procure acceptance of the Hijri Calendar as the calendar for daily life, the Gregorian Calendar being the only calendar used in relations with Europe even unofficially, or to remove the Financial Calendar (Takvimü's-sinîn, XX) which was deemed necessary to abandon by the leading experts. The party sought reformation only, but on 22 September 1911, this was rejected by the Council of State, on the grounds that the attempt to accept it as the beginning of the year would lead to confusion (BOA, MV, 124/66).

The Financial Calendar was criticized, as its origin was the same as the one used by the Slavs who gained their independence following the Balkan Wars. Thus, the Financial Calendar, which was the one used by the enemies, was once again brought onto the agenda in the second year of the First World War. At that time, the Ottoman armies were fighting their enemies in Galicia, Macedonia, and Palestine, and

communication and contact with the allies were gaining importance in order to avoid confusion. When using the main means of communication, telegrams, not only was it necessary to use the same language as the allies but also to indicate the same date they used. Meanwhile, the old enemy but the new ally, the Bulgarians, had accepted the calendar that was used by Western countries (*The Times*, 29 March 1916).

The government's intention was to make up the difference of the 13 days between the Financial and Gregorian Calendars. When the government asked for such a change, it also made clear that the birth of Christ would never be accepted as the beginning point of the calendar (1332–1333..., 358). When the matter was brought to the agenda of the parliament, Mr. Talat, Minister of the Interior and Treasury, who spoke on behalf of the government, reminded them that the Hijri Calendar had not been tampered with. He also said that the government's intention was to make up the difference of 13 days and to take the beginning of the year as January. He finished his speech by stating that the state treasury would make a profit of 180,000 liras after this change, and it would also make a loss at the same rate if the change was not brought about (MMZC, 11 Şubat 1331, 124–145). However, a few days later, the government, unable to obtain what it had asked for from the parliament, announced that it had revoked the law.

As well as the Hijri and Gregorian Calendars, all other calendars take their holy dates as the starting point. The Ottomans went further in that they considered the 1300s sacred. That is to say, when the government raised the question of the calendar once again, it was discussed in parliament whether the year digit would be indicated by the 1300s or 1900s. The problem was resolved with the notion that the 1300s belonged to the Nation of Islam (*Tasvir-i Efkar*, 1 Mart 1333), and for this reason, the 1300s continued to remain on the calendar.

The discussions continued for a year, ending with a law that came into effect on 8 February 1332. The Financial Calendar was abolished and the Gregorian-based Western Calendar started to

be used (BOA, İDUİT, 87/22). By skipping 13 days, 1 March 1333 followed 15 February 1332. The year of 1333/1917 started from 1 March and lasted 10 months, with the next year, 1334/1918, starting as of 1 January (Takvimü's-sinîn, X; *Tasvir-i Efkâr*, 1 Mart 1333). With the new regulations, 2 months and 16 days were missing from the year 1917. In the period when the expenses were increasing during war time, the government budget gained much more importance. The issue of how the gap caused by the period skipped from the year 1917 could be filled was resolved thanks to certain guarantees given (BOA, MV, 205/141; DH.UMVM, 1/53). As such, the government guaranteed that there would be no problem with extracting taxes and rents and with the tax-farming contracts. Also, the regulations did not deeply affect people's daily lives although there were minor inconveniences in the official business of the citizens and the provincial administration had a little difficulty in adopting January as the beginning of the year.

The necessity of determining the equivalents of certain days in the new calendar was raised by a German diplomat's question on whether the sultan's ceremony of accession was changed or not (BOA, DH.İUM, E30/29; DH.UMVM, 124/101). In those days when the press also helped the community, several associations drew attention to their work. For instance, it was important that the Mûdafaa-yı Milliye Cemiyeti had wall calendars prepared based on the Western Calendar. On these new wall calendars, sections indicating the religious dates were included. However, a few years later, as with the wall calendars, it was discovered that the dates indicated in pocket and desk calendars had not been determined correctly by the Office of the Chief Astronomer (Müneccimbaşılik). In the final days of the empire, it was discovered that the Office of the Chief Astronomer had not exercised the necessary controls and, more precisely, had neglected its duty (BOA, DH.İUM, 19-18/1-38).

The reaction against the Western Calendar broke out due to a combination of the Party of Union and Progress (İttihad ve Terakki Cemiyeti) and the resentment felt towards its leaders. At the

beginning of the year 1920, the *Tasvir-i Efkâr* newspaper that had previously written on the issue of procuring society's acceptance of the new calendar now appeared before the society with a quite different discourse. The newspaper reportedly found the calendar change meaningless and strange, made by the Party of Union and Progress hurriedly during the war. The paper also regarded the acceptance of the New Year start date as the product of "wise-guy brains" (*Tasvir-i Efkâr*, 1 Kanun-i sani 1336).

In fact, the newspaper reflected the views of society, whose voice had not been heard until then. British and French hostility increased after the Armistice of Mudros, applying to almost anything that belonged to them, and also for the Gregorian New Year. Therefore, although the new year of the Hijri had not been celebrated in previous years, in the period of armistice, it started to be celebrated with nostalgia, with a religious emphasis added to it. In contrast, the Muharram, the first month of the year of Hijri, reminded the Muslims of the Karbala Incident, during which Hussain, the grandchild of Prophet Muhammad, was murdered (Akçura, 36). In the celebrations of the New Year of Hijri that took place at the end of the war, the longing felt for Islam, the period before the Party of Union and Progress, meant that this historical event was discounted. Thus, the high state officials appeared before the sultan and participated in the official New Year ceremony (*Tasvir-i Efkâr*, 27 Eylül 1335).

With the aim of modernization, the executives of the Turkish Republic, which was founded in 1923, were able to take the radical decision to deal with the Hijri Calendar. The developments occurring outside Turkey were also effective in supporting their cause. The League of Nations wanted to create a global calendar by making a calendar reform by means of commissions it had established (*The Times*, 27 Aug. 1923). As, in the Gregorian Calendar, the number of days in the months were not equal to the quarter and half periods of the year, but for the sake of convenience in commerce, industry, transportation, and communication, it was required to stabilize these periods (*The Times*, 27 Oct. 1926). The attempt of

the League of Nations remained inconclusive, but the Turkish executives, who followed the reform exercises closely, did not hesitate in accepting the Gregorian Calendar.

By enacting a law into practice, dated 26 December 1341/1925, the calendar problem that had persisted since the Ottoman period was resolved. The Calendar of Garbi was revoked by the law specified, and the Gregorian Calendar started to be used under the name "International Calendar" as of 1 January 1926. Usage of the Hijri Calendar was restricted, and its use was approved only when determining the sacred days and months (Üçer, 122). In justifying the decision of the law, it was written that the Western Calendar (Takvim-i Garbî), which did not have any scientific foundation, was erroneous and the sacred days would be determined based on the Gregorian Calendar, in accordance with the technical principles of the observatory (Öztürk, 106–107).

When the law was brought to the agenda of the Turkish Grand National Assembly, some members of the parliament were vocally opposed. However, compared with the strong opposition of the Ottoman Parliament and the members of notables, this group remained a minority. Such opposition seen in the parliament was barely apparent in the press, which supported the "Calendar Revolution" unconditionally. Thanks to this law, a step was taken towards westernization and the new Turkish Republic would proceed on its way by removing a calendar, which was a thing of the past. In the meantime, the Hijri Calendar, which had been identified with the Ottoman Empire, had its share of criticism (*Cumhuriyet*, 1 Kanun-i sani 1926).

The new calendar brought to Turkey the tradition of celebrating the New Year in the European style. New Year celebrations took place on the night between 1926 and 1927, attracting great attention, and the celebrations lasted all night long. Also for the first time, on that night the power administration started the tradition of turning off the city lights in Istanbul for a minute at exactly 12 o'clock (Tuna, 41–49).

The latest development on the matter of the calendar was the alteration of the names of the

months. The process of changing the names of the months was initiated in the course of translating the Constitution of 1924 into Turkish in 1945. The names teşrin-i evvel/birinci teşrin, teşrin-i sani/ikinci teşrin, kanun-i evvel/birinci kanun, and kanun-i sani/ikinci kanun were replaced with Ekim (October), Kasım (November), Aralık (December), and Ocak (January), respectively.

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Caraka

Guy Mazars

Caraka is the editor of a treatise of Āyurveda which bears his name, the *Carakasamhitā* or “Caraka’s Compendium”, a work with which classical Indian medicine really begins. The *Carakasamhitā* is supposed to contain the teaching of the sage ► **Ātreya** Punarvasu, recorded by one of his disciples, Agniveśa, and revised by Caraka. Ātreya and Agniveśa belong to the realm of legend, but Caraka is likely to have been a historical figure. Indeed, according to the Chinese version of a Buddhist text, translated from Sanskrit in the fifth century AD, a physician of the same name was practising at the court of the Scythian king Kaniška. Several scholars place this king at the end of the first or second century AD. Like Aśoka (264–227 BCE) some centuries earlier, Kaniška was well disposed towards Buddhism and protected it. During his reign, Indian culture underwent a great expansion. The redaction of the *Carakasamhitā* thus goes back to this period, if it is indeed the same Caraka.

However, the text which has come down to us is a composite work. It contains more recent portions added at the time of its revision by an author from Kashmir, Dṛḍhabala, who probably lived in the fifth century AD. But the core of its content is much older since Caraka himself had only reconstructed an already existing work, cited under the name of *Agniveśatantra*, the “Book of Agniveśa”. At least one of the redactors of the “Compendium” was familiar with the diets

and habits of peoples from different parts of the world. The *Carakasamhitā* was commented upon before the ninth century by Jejjāṭa, who may have been a Kashmirian or an inhabitant of Sindh. Then, in the eleventh century, Cakrapāṇidatta wrote a commentary called *Āyurvedadīpikā*, which has been preserved and edited. Cakrapāṇidatta was a native of Bengal, himself the author of the *Cikitsāsamgraha*, a well-known manual of therapeutics. He wrote other works, including the *Dravyaguṇasamgraha*, a short treatise of materia medica. According to the Arab bibliographer Ibn an-Nadīm, in his *Kitāb al-Fihrist* (Index of Arabic books, completed in 988 AD), a Persian version of the *Carakasamhitā* had been translated into Arabic by the time of the first ‘Abbāsīd caliphs (eighth century).

In its present form the *Carakasamhitā* consists of 120 chapters which are divided into 8 parts (*sthāna*):

1. Thirty chapters in the *Sūtra* section dealing with various topics, including pharmacology, diet, some diseases and their treatments, physicians and quacks;
2. Eight chapters in the *Nidāna* section dealing with the causes of eight main diseases;
3. Eight chapters in the *Vimāna* section dealing with different topics such as “taste”, logic, vessels, pathology and medical education;
4. Eight chapters in the *Śārīra* section dealing with embryology and anatomy, and on the connection between the body and the mind;
5. Twelve chapters in the *Indriya* section devoted to diagnosis and prognosis;
6. Thirty chapters in the *Cikitsā* section dealing with therapy;
7. Twelve chapters in the *Kalpa* section on pharmacy; and
8. Twelve chapters in the *Siddhi* section devoted to general therapy.

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Cashewnut Processing on the Malabar Coast

K. T. Rammohan

The cashewnut processing industry on the Malabar Coast grew around the port towns of Quilon, Calicut and Mangalore, which had cashew-growing hinterlands. Cashew was not a systematically cultivated tree crop. In earlier days, poor people gathered the nuts, roasted them in mud pans, removed the shells by hand and sold the kernels in nearby markets. From the early decades of the twentieth century, trading companies from the West operating on the coast began to purchase shelled kernels from local people for export. After sun drying, cashew kernels were packed in mango wood cases lined with newspaper and shipped out, mainly to Marseilles and occasionally to London from where these would be re-exported. From the 1930s, with the emergence of the United States as a major buyer, the industry gained substantial momentum. To meet the increased demand, the trading companies resorted to the putting out system of production. The companies bought raw nuts locally (and also imported nuts from East Africa) and distributed these to people, who pan-roasted

and returned the shelled kernels to the company. The kernels were dried, peeled, graded and packed at the company premises. Later, as the putting out system gave way to direct production by firms, factories where all the operations were undertaken emerged. The factories employed women and children of lower castes and outcastes who were paid very low wages. Over 90 % of the workers were women. Men, again drawn from lower and depressed castes, were engaged primarily in roasting.

Cashewnut processing involved five principal operations: roasting, shelling, peeling, grading and packing. In the early factories roasting of nuts was done in the open air in iron pans. From 1932, iron pan roasting was replaced by drum roasting. Under the new method, an open-ended drum (rotary cylinder) was placed over a fire in a tilted position. Raw nuts were fed from one end, and roasted nuts were collected from the other. Each cylinder needed six persons to operate: the first person attended to the furnace, the second and third fed the raw nuts, the fourth rotated the cylinder, the fifth removed the roasted nuts, and the sixth sprayed water on the roasted nuts. The workers wrapped themselves in gunny bags to protect themselves from burns. By the mid-1930s, hot oil roasting replaced drum roasting. Here, raw nuts were roasted in a bath of cashew shell oil maintained at about 200 °C. Due to the high temperature, the oil cells of the nuts broke, releasing their contents; and the nuts were then roasted to the desired degree. Cashewnut processing yields a by-product – cashewnut shell oil that has industrial and strategic uses. This could be extracted in full only in oil-bath plants. All these methods used cashewnut shells as fuel.

After roasting the nuts were shelled. This was the most arduous operation and had to be done in an uncomfortable squatting posture. Nuts were placed on a flat stone and were gently hammered with the help of small wooden mallets, to remove the shells. A high degree of skill was required to ensure that the kernels did not break. Peeling the skin off kernels was also a dexterous, repetitive and loathsome task. The kernels were then graded and packed.

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Cave Architecture of India

Pia Brancaccio

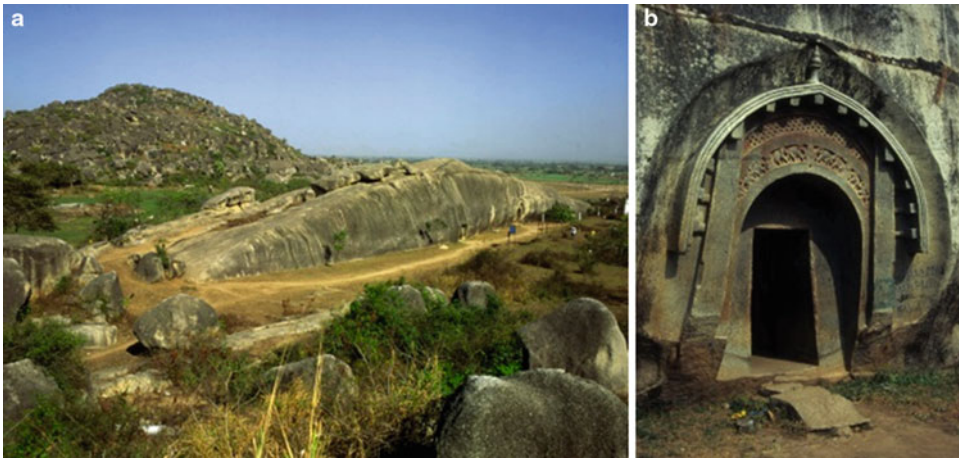
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Caves in ancient India were places of special relevance. Aside from offering natural shelter, they were regarded as *loci* of supernatural powers and spiritual enhancement. Located at the *nexi* of sacred geographies and often associated with local deities, caves were favored abodes by hermits and renouncers. Elaborate rock-cut architectural structures were created for ascetics to use during the Maurya period (322–185 BCE) with King Ashoka (304–232 BCE) being the first to endow man-made caves to the Ajivika ascetics at Barabar Hill (Falk 2006). The four Barabar caves located in a rocky outcrop in the Gaya district of

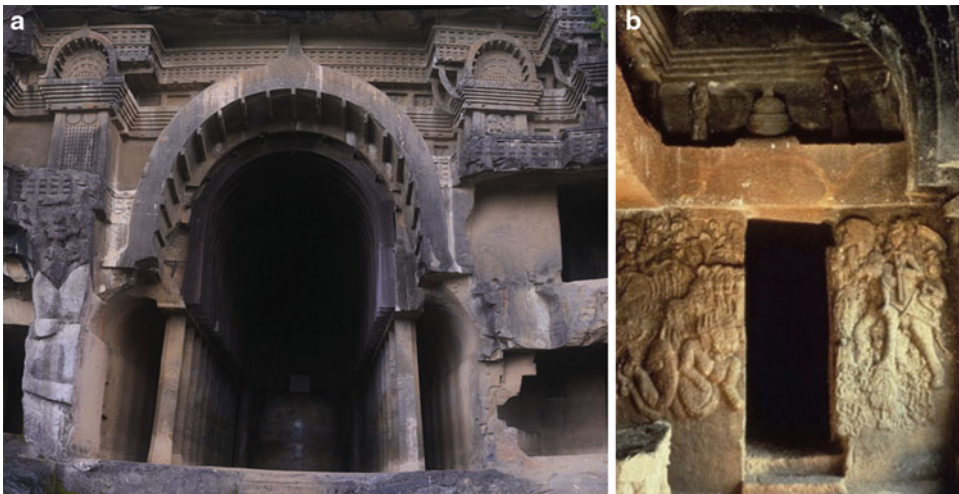
Bihar preserve distinctive plans with rectangular spaces attached to a circular, hut-shaped room at one end. The cave interiors are plain and flawlessly polished in a manner that alters light and sound. The only decoration appears at the entrance of the so-called Lomas Rishi cave where a portal motif with an architrave embellished by elephants and *stupas* is engraved in the living rock (Fig. 1).

During the second and first centuries BCE, rock-cut structures for ascetics were also created in Orissa in the Udayagiri and Khandagiri hills (Mitra 1975). These caves consist of simple series of cells with decorations above the entrances representing trees, elephants, and figures reminiscent of types seen in Shunga terracotta plaques. The Hathigumpha cave at Udayagiri carries a famous inscription by the local king Kharavela. From this time onwards, simple rock-cut complexes also began to develop in Gujarat, in a prosperous area involved in long-distance trade where both Jain and Buddhist religions thrived. The early caves at Junagadh, among others, include simple cells opening on porches with minimal ornamentation that takes the form of auspicious emblems (Soundara Rajan 1985).

Between the second century BCE and the second century CE, a surge in Buddhist patronage led to the establishment of many Buddhist rock-cut sites in Maharashtra along the western edge of the Deccan Plateau (Dehejia 1972; Dhavalikar 1984). These excavations were large and elaborate and typically included monastic residential caves along with an apsidal hall destined for worship (Burgess and Fergusson 1988). Called *chaitya-griha* or *chaitya* hall in the votive inscriptions, this sacred space presents a row of columns running parallel to the walls and a rock-cut stupa placed at its end. The caves at Bhaja were among the earliest in western Deccan (second to first c. BCE): the *chaitya* hall was finished with wooden elements such as beams inserted in the rock vault and a wooden façade now missing, and rock-cut images of arches and balustrades with *mithunas* or couples frame the entrance. The monastic residences at Bhaja consist of series of cells equipped with stone beds;



Cave Architecture of India, Fig. 1 (a) Lomas Rishi cave, general view and (b) entrance to the cave (By Harry Falk)



Cave Architecture of India, Fig. 2 (a) Bhaja, *chaitya* hall, and (b) cave 18

they open on small rectangular porches, generally undecorated, with the exception of cave 19 where carved in low relief are royal figures riding an elephant and a horse-pulled chariot, previously identified as the Vedic gods Indra and Surya (DeCarolis 2000). Buddha images do not appear in the early caves of western Deccan (second c. BCE–second c. CE) generally associated with the Hinayana tradition, and the figural decorations in this phase consist mostly of images of *mithuna* or couples such as those at Bhaja or guardian *yakshas* like those at Pitalkhora (Figs. 2, 3, and 4) (Deshpande 1959).

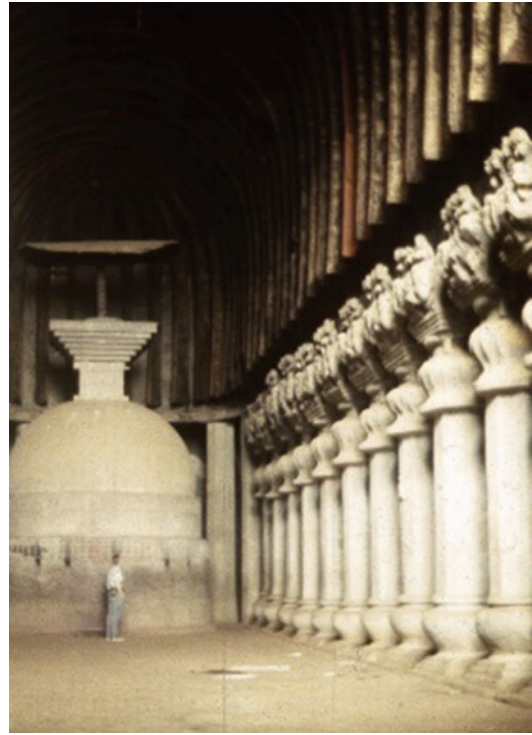
Buddhist cave architecture in western Deccan soon emancipated itself from the use of wood, and most *chaitya* halls came to be entirely carved out of living rock. The *chaitya* hall at Karle has an ornate stone façade and an interior with elaborate pillar bases and capitals, while the Ajanta *chaitya* hall no. 10 was embellished by vivid paintings (Schlingloff 1987). Sometime during the first century CE, well-planned monasteries, with rock-cut cells aligned along three sides of a square court, were introduced in Buddhist cave architecture; caves 3 and 10 at Nasik bearing inscriptions of the Kshatrapa king Nahapana and



Cave Architecture of India, Fig. 3 Pitalkhora, Yaksha

the Satavahana rulers constitute excellent examples of such square *vihara* cave types (Fig. 5) (Bhandare 2006; Rees 2009).

Buddhist rock-cut monasteries in western Deccan were often supported by gifts of traders and craftsmen, as suggested by in situ votive inscriptions (Burgess and Indrajī 1976), and the sites benefited from the wealth brought to the area by thriving Indian Ocean trade (Ray 1981). The caves, called *lena* in the inscriptions, grew in clusters around important passes along the edges of the plateau (Sahyadri Range), near trading routes (Chakraborti 2005; Lahiri 1992), not too far from urban centers, and often in areas where agricultural land was readily available (Brancaccio 2010). The Buddhist caves at Bhaja, Karle, and Bedsa were grouped along the

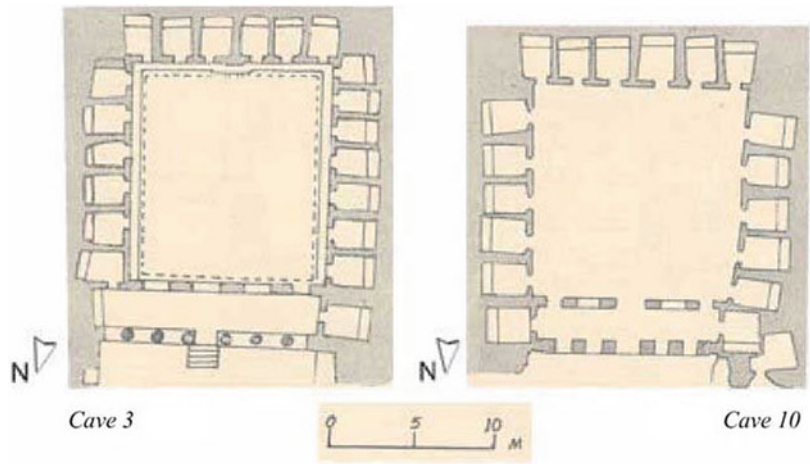


Cave Architecture of India, Fig. 4 Karle, *chaitya* hall

Bor Ghat pass; the large four clusters of caves at Junnar (Tuljalena, Manmodi, Shivneri, and Lenyadri) overlooking fertile land were also situated in proximity of the Nanaghat pass. The caves at Pitalkhora, Ajanta, and Aurangabad were strategically located along major internal trade routes, while in coastal Konkan flourished the Kondivte, Kuda, and Kanheri caves. The latter, located near the ancient port of Kalyan, experienced an unusually long period of activity (Ghokale 1991; Ray 1994). Stylistically related to the earliest Buddhist sites in western Deccan are also the caves at Guntupalli in Andhra Pradesh (ca. second c. BCE) that include a round *chaitya* hall similar to the one from Kondivte in Maharashtra (Brancaccio 2013).

The fifth century marked a renewed interest in patronage of rock-cut architecture in northwestern India. Most relevant are the Vaishnava caves at Udayagiri in Madhya Pradesh realized under the Gupta dynasty (Willis 2009) and the major

Cave Architecture of India, Fig. 5 Nasik, caves 3 and 10, plans after Gethin Rees, <http://www.ancient-asia-journal.com/article/view/aa.10209/47>

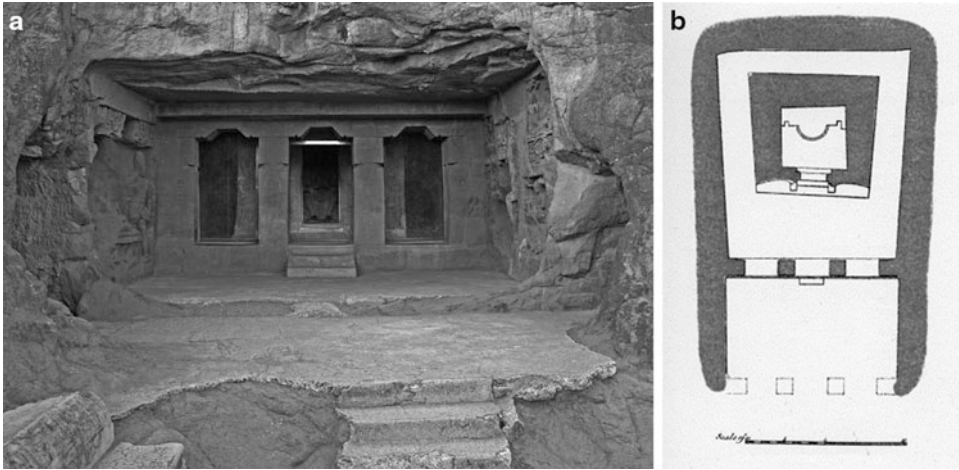


Cave Architecture of India, Fig. 6 (a) Ajanta, *chaitya* hall 26, and (b) cave lower 6 (By Nicholas Morrissey)

expansion of the Buddhist caves at Ajanta undertaken by the Vakataka king Harishena and his entourage (Spink 2007-14). At Ajanta two more *chaitya* halls and 20 additional *viharas* (monasteries) were created at the end of the fifth century, and they were all embellished by elaborate paintings of *jatakas*, *avadanas*, and other Buddhist images that survive only in part (Schlingloff 1988; Jamkhedkar 2009; <http://www.ajantastudygroup.com/>). By this time the Buddha image had become the focus of worship at Ajanta: aside from sculptures on *chaitya* halls stupas, each *vihara* at the site included a cell with

a larger than life sculpture of the Buddha seated on a throne placed on axis with the entrance (Schopen 1997). Buddhist patronage continued well into the sixth century at the nearby site of Aurangabad where new architectural layouts were developed. Smaller caves were created, with or without side cells, that included a square central shrine with a Buddha image surrounded by a corridor for circumambulation as in caves no. 2, 5, 7, and 8 (Figs. 6 and 7) (Brancaccio 2010).

Buddhist caves in western Deccan experienced a slow decline beginning in the sixth



Cave Architecture of India, Fig. 7 (a) Aurangabad cave 2, view and (b) plan



Cave Architecture of India, Fig. 8 Sadashiva at Elephanta



Cave Architecture of India, Fig. 9 Ellora, cave 29, Dhumarlina

century, as patronage in the region shifted to the creation of Shaiva rock-cut temples (Tarr 1969; Soundara Rajan 1981) – most notably the ones at Elephanta in Konkan and at Ellora in the Aurangabad district. The unfinished great cave or cave 1 on the Elephanta Island took rock-cut architecture to monumental proportions with its huge, rectangular hall including colossal pillars, multiple points of access, as well as *linga* shrines (Spink 1982; Michell 2002; Dhavalikar 2005). Elephanta cave 1 is best known for the monumental relief of a three-headed Shiva (usually labeled as Sadashiva) dominating the south wall (Fig. 8) and for the large tableaux depicting other forms and feats of the god carved on the

remaining rock walls (Collins 1988). It is also during the early sixth century that a first group of caves dedicated to the god Shiva was established at Ellora (<http://elloracaves.org/>). These excavations are stylistically linked to the

Elephanta cave as exemplified by cave 29 also known as Dhumar Lena (Spink 1967). It is not until the eight century, after more Buddhist caves had been cut on the southernmost edge of the



Cave Architecture of India, Fig. 10 Ellora, cave 17, Kailash temple (By Lisa Owen)

Ellora cliff (caves 2–12) (Malandra 1993), that the spectacular rock-cut Kailash temple (cave 16) was created under the Rashtrakuta king Krishna I (Dhavalikar 2005). This rock-cut structure is covered by elaborate carvings and echoes the shape of Shiva's mountainous abode (Brancaccio 2013); it stands completely free from the rock cliff, where multistoried pillared halls and rectangular chapels are excavated all around. In the ninth century Ellora was also occupied by the Jains who cut a few more elaborate caves (caves 30–34) on the northern edge end of the site (Figs. 9 and 10) (Owen 2012).

The Deccan was the heartland of cave architecture, and the Chalukya kings continued the tradition of rock-cut temples at Badami and Aihole in Karnataka, where caves were cut between the end of the sixth and the eighth century (Srinivasan 1964). The four Badami caves, three Hindu and one Jain (no. 4), have simple layouts that include a shrine, a rectangular pillared hall embellished with sculptures, and a porch or *mandapa*. They seem to be stylistically related to the earliest Hindu caves at Ellora; in particular, Badami cave 3 dated by an inscription to 578 is akin to cave 21 at Ellora (also called Rameshvara (Tarr 1970)) (Fig. 11). The small Ravana Phadi cave dedicated to Shiva at Aihole seems to bridge, in terms of style and design, the

Cave Architecture of India, Fig. 11 Badami, cave 3, porch



Cave Architecture of India,

Fig. 12 Mahabalipuram, Arjuna, and Draupadi Rathas



rock-cut tradition of the Deccan with that of Tamil Nadu.

Under the Pallava dynasty cave architecture blossomed in Tamil Nadu, along the southeast coast of India. The most impressive are the Hindu caves and monolithic rock-cut temples at Mahabalipuram dating to the seventh century CE (Nagaswami 2011). The caves are many and modest in size; they generally include a shrine that opens directly onto a small porch embellished by sculptures of Hindu gods. The most remarkable are the so-called Varaha, Trimurti, and Mahishasuramardini caves. Among the nine freestanding monolithic temples, five are clustered together and are known today as the five Rathas. These unfinished monuments replicate different building types in the living rock, and the four that appear to be aligned (the so-called Draupadi, Arjuna, Bhima, and Dharmaraja) were originally carved out of a single boulder. Each temple, dedicated to a different Hindu god, is intricately carved on the outside and is associated with a sculpted *vahana* or divine animal; the interiors are barely roughed out or simply unfinished (Fig. 12) (Dehejia and Davis 2010).

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Celestial Vault and Sphere

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The celestial vault is the apparent surface of the sky – both the night sky against which the stars appear to be placed and the blue expanse of the daytime sky. This surface may be assumed to be either imaginary or real and in the latter case is commonly referred to as the *firmament*.

The idea that the celestial vault, and particularly the daytime sky, is a physical cover of some kind is found in the cosmologies and myths of many cultures. In sub-Saharan Africa, a widespread belief is that the daytime sky is a solid blue vault resting on the earth, on which the sun moves. During the night, the sun is thought to return to the east by passing either under the earth (e.g., the Luyia of Kenya) or behind the solid sky (e.g., the Zulus of South Africa); in the latter case, it also produces the stars by shining through small holes in the vault. The idea that the sky is a solid surface was also commonly accepted in China, India, among American Indians, and Australian aborigines. Ethnic groups in northern Eurasia thought of the sky as a roof to protect the earth and life and often described it as resting on a central pillar. In the hero tales of the Yakuts, the sky was said to be hemispherical, resting on the outer edge of the world. In the mythologies of Finland, Lapland, and neighboring regions, the celestial pole or the pole star was described as the “nail of the sky” which supports the celestial vault and around which it revolves. The Lapps, Finns, Yakuts, Japanese, and Hebrews sometimes described the sky more specifically as a tent roof. The most popular conception of the sky in ancient Egypt was that of a blue-water surface, a continuation of the sea or the Nile. Similar ideas were applied to the night sky. The Milky Way appeared to some as a stitched seam, and the stars as tiny holes in the fabric of the celestial vault.

The large amount of attention given to the nature of the celestial vault in cultures all over the world seems to stem mainly from its perceived function as a substratum on which the celestial bodies are situated or upon which they move. The celestial bodies and their movements, and to a lesser extent the celestial vault itself, were of absorbing interest to people in all cultures for a variety of reasons, both practical (e.g., as a basis for the calendar and agricultural practices), magical (e.g., predicting future events), social (regulating social events), and religious (e.g., believing the celestial vault, or the space behind it, to be the home of the gods). Among many native tribes in Colombia, for example, “the sky is seen as an enormous blueprint of everything that did, does, or will happen on the earth; a map replete with information on every aspect of biological and cultural behaviour” (Reichel-Dolmatoff, 1982, p. 165). This information is thought to have provided the people with a measure of security. Furthermore, the diurnal cycle of the celestial vault, coupled with the regular appearance and disappearance of the sun and stars, may have instilled by similarity belief in rebirth and the transcendence of death (Belmonte, 2010).

Although the perceived solidity of the celestial vault implied a fixed form for the sky, that form was seldom clearly defined. There was some debate among early astronomers in China on whether the celestial vault might be strongly flattened, perhaps even a plane parallel to the earth’s surface. For example, the astronomical chapters of the official history of the Chin dynasty (265–420 AD), written in the seventh century under the supervision of Emperor T’ai Tsung, contain a discussion by the scholar Ge Hong (previously spelled Ko Hung [283–343]) of the theory that the sun cannot be seen at night because it moves a great distance away from the earth. Ge Hong argued (Ho, 1966, p. 57): “If it is said that the sun can no longer be seen because it has gone a very great distance from us, then when the sun sets, on its way towards the north, its size should diminish. But, on the contrary, the sun becomes larger at sunset.” This refutation of the flattened vault theory did not originate in China. It was stated in similar words by the Greek

astronomer Claudius Ptolemy in the *Almagest* (Book 1, chapter 3), written around 142 AD. The similarity of the wording leaves little doubt that intellectual contacts existed between China and the Middle East at the time.

The idea that the celestial vault is actually flattened has been ascribed to Empedocles, a Greek philosopher of the fifth century BC. Ptolemy’s refutation of the theory was later transmitted to Islamic scholars as part of the *Almagest* and was slightly elaborated by the astronomer al-Farghānī in the ninth century. However, by this time, most astronomers had accepted that the celestial vault represents the upper half of an imaginary (or sometimes real) spherical surface (or a set of concentric surfaces), called the celestial sphere, which carries the stars. The other half of this sphere is below the horizon. Celestial spheres were key elements in the cosmological models of Aristotle, Plato, Ptolemy, Copernicus, and others. These authors saw the stars and planets as being embedded in rotating, concentric, transparent spheres. Others regarded all the celestial bodies as moving on the same sphere, with the exception of meteors. Arab philosophers regarded meteors as occurring in the terrestrial environment rather than on the celestial sphere.

Irrespective of the assumed shape of the celestial vault, the apparent positions, sizes, and movements of the sun, moon, planets, comets, and stars have often been described as if these bodies are situated on a real surface. Estimates of the sizes and separations between the celestial bodies were therefore expressed as lengths or distances on the celestial vault rather than in terms of angles. For example, Chinese observations of comets from the second century BC to the nineteenth century were expressed in terms of the *zhi*, a length standardized as 311 mm in the ninth century. The *zhi* appears to have corresponded to an angle of a little less than 1°. Similarly, the Babylonian *ammāt* (about 524 mm) represented either 2° or 2.5° at different times. And the Islamic *fitr* and *shibr* (spans later standardized as 152 and 178 mm, respectively) were equivalent to about 0.6° and 0.8°, respectively, in the astronomical work of Ibn Yūnūs during the eleventh century.

These lengths and angles seem to imply that the astronomers in each of the three cultures assumed that the celestial sphere had a radius of only some tens of meters. Numerous estimates of the perceived sizes of the sun and moon (usually seen as some 200–300 mm across) from classical to modern times in Europe support the same conclusion: there exists a universal tendency to describe perceived sizes and distances on the celestial vault as if the height of the sky is only a few tens of meters.

Although astronomers had long rejected the idea that the celestial bodies move along flattened trajectories, the Islamic physicist Ibn al-Haytham pointed out in the eleventh century that the sky usually *appears* flattened. He explained this as an illusion created by our perception of distant objects toward the horizon and the lack of such indicators of distance toward the sky. He furthermore used the flattened appearance of the celestial vault to explain the illusion that the sun and moon are enlarged near the horizon – an explanation that was transmitted to Western Europe during the thirteenth century and survived well into the twentieth century. Its importance lies in the fact that, for the first time, the perceived flattening of the celestial vault and the perceived enlargement of the horizon sun and moon were described as perceptual illusions (now studied by psychologists) rather than measurable phenomena to be studied by astronomers.

See Also

- Al-Farghānī
- *Almagest: Its Reception and Transmission in the Islamic World*
- Astronomy
- Ibn Al-Haytham (Alhazen)
- Ibn Yūnus

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Ceramics in Africa

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Pottery making is a very ancient craft in Africa, as some of the oldest pottery remains known in the world were discovered on this continent. Dating from around 10,000 BCE – i.e., one or two millennia after the inception of the Jomon pottery in Japan – they were excavated in the Aïr Region of Niger (West Africa) (Haour, 2003).

Throughout history, the craft has endured important changes in relation to the shape, function, and decoration of the products, as well as manufacturing techniques, scale of production, or the social status of the potters. The last decades have proved particularly significant in that

regard, due to the massive introduction of plastic and metal containers, social and economic transformations, the development of tourism and urban lifestyle, and the spatial extension of social networks. In most places, ancient pottery functions such as cooking, handling, and serving have been abandoned, while new categories of products such as decorative or commemorative items, flowerpots, tiles, braziers, or incense burners have boomed. Water jars, however, continue to be massively produced in some parts of the continent, as they provide the cheaper and most efficient way of keeping cool water in rural areas.

Social Background

A comparison of several hundred ethnographic sources (Information examined in this article comes from two bodies of data. Since 1990, members of the *Ceramic & Society Project* developed at the University of Brussels and its research associates have conducted fieldwork in Senegal, Gambia, Mali, Niger, Burkina Faso, Togo, Benin, Nigeria, Cameroon, Chad, and D.R. Congo, collecting information about some 1,000 potters in nearly 100 linguistic groups. The second body of data comes from a systematic perusal of the ethnographic and ethnoarchaeological literature devoted to pottery making in sub-Saharan Africa. These sources are of varying relevance and accuracy as they range from large-scale and detailed studies to more local/regional observations, or mentions in ethnographic monographs, administrative reports, and religious publications. Altogether, more than 900 sources have been processed, which relate to some 650 linguistic groups.) indicates that at last four-fifths of the African potters working today are women, which confirms the usual description of pottery making in Africa as a “female activity.” But male potters are also encountered in several regions of the continent, where they either specialize in the making of particular vessels (big water jars, elite ware, bottles) while women produce the largest part of the repertoire, or produce the whole range of vessels in contexts where women are excluded from the

craft, or work together with female relatives, carrying out specific operations such as clay extraction and transport, clay preparation, firing, and, above all, plastic decoration (Schildkrout & Keim, 1990).

The scale of production is highly variable, ranging from part-time, isolated artisans, whose products are essentially consumed locally, to full-time specialists working in workshops, whose vessels are distributed by middlemen in a 100–200 km radius. If men tend to be more frequently associated with the latter category, female potters may also be involved in mass production, especially in West Africa.

In many instances, pottery making is open to anyone. All one has to find is someone who is willing to serve as a teacher. This means, in practice, having a close relative, friend, or neighbor who engages in pottery making and does not mind spending time with someone who may subsequently become a competitor. But restrictions are also observed throughout the continent, which pertain to age, gender, geographical origin, and, above all, socio-professional affiliation. For example, in many Sahelian societies, potters belong to caste-like subgroups such as blacksmiths, bards, tanners, weavers, woodcarvers, hunters, or jewelers (Drost, 1968; Frank, 1998; Gallay et al., 1998; Gosselain, 2001; Haaland, 1978; Lyons & Freeman, 2009; Sterner & David, 1991, 2003; Tamari, 1997). The members of these endogamous specialist groups are associated with specific activities and duties and distinguished from the remaining population. They are regarded with a mix of awe and contempt by nonspecialists, who often consider them dirty and impure and fear being harmed by their power. Due to recent economic changes, however, caste-like structures may become permeable to other social groups in specific places.

Manufacturing Process

There are seven main stages in the pottery manufacturing process: (1) clay extraction, (2) clay processing, (3) shaping, (4) decoration, (5) drying, (6) firing, and (7) postfiring. While

most of these stages are mandatory, some – such as decoration and postfiring – are optional, although widely recorded across the continent (previous surveys of pottery manufacturing processes in Africa include Devisse, 1984; Drost, 1967; Gosselain, 2002; Krause, 1997; Livingstone–Smith, 2007).

Clay Extraction

Available data indicate that most African potters collect their clay within a 3-km radius from the place where they live and/or practice the craft (see Gosselain, 2002, pp. 40–41). Those who exploit sources beyond this threshold generally use animals, cars, trucks, or canoes to carry the clay. They also tend to make stocks that last from several weeks to the whole potting season.

Four categories of extracting techniques are observed in Africa: surface collection, pit extraction, underground gallery, and underwater extraction.

In surface collection, clay is extracted on or just below the surface, either on the ground (plain, fields, dried ponds, or riverbeds), a hill, or the wall of a slope or an embankment. After having eliminated the superficial organic and mineral layer, the potter extracts clay without really digging underground. The operation may be described as “peeling” a clay bed.

In pit extraction, potters dig vertically or diagonally into the ground, until an appropriate layer is reached. Most pits are some 1 or 2 m deep and 2 or 3 m in diameter. Due to repeated and intensive exploitation, they may take the form of a quarry, as in southeastern Nigeria (Nicklin, 1979, p. 349). Variations are observed in the way potters exploit and manage these structures. For instance, some use a pit until the clay layer is completely exhausted, while others abandon it when a specific depth is reached or as soon as it shows risks of collapsing.

Raw materials may also be extracted from galleries. This type of structure generally starts with the excavation of a vertical shaft. When the access shaft reaches the clay bed, the structure is extended horizontally (Livingstone Smith, 2007; Nwafor, 1980; Schneider, 1993). Galleries, like

pits, are generally abandoned at the end of the potting season, but some may be used several years in a row, the access shaft being re-excavated each year.

Finally, a rather uncommon technique consists in extracting clay from the bed of an active river, as among Tikar of Cameroon and Punu of Gabon (Gosselain, 2002, pp. 52–53). Here, artisans build two small dams in the river, bail out the water contained between the dams, and extract clay before the upstream dam gives way.

It is usually in the course of other activities, and especially activities which force them to dig into the ground (e.g., tending fields, building houses, digging wells) or to frequent places such as riverbeds or swamps, that potters, members of their family, or any of their acquaintances may discover a new source and get the process leading to its possible exploitation under way. This involves assessing both the intrinsic qualities of the material (which often includes firing test vessels) and the compatibility of the site with other imperatives.

A first requirement is that the clay must have the right physical properties, i.e., its plasticity, texture, color, and even taste and odor must fit with a potter’s personal requirements (see also Barbour, 1989; Brown, 1989; Frank, 1998; Trowell, 1941, p. 61; Woods, 1984, p. 305). If newly discovered clay is judged suitable, a second requirement is that it must be located nearby the potter’s main occupational areas and/or working place. Since pottery making is often subordinated to other activities – such as farming and domestic tasks – potters tend to restrict their investment in time and energy or, at least, avoid scheduling conflicts when practicing the craft. Sources located nearby living or working sites, fields, rivers frequented for fishing, roads, or tracks are therefore more likely than others to be selected and subjected to long-term exploitation. In fact, about 90 % of the hundreds of sources that we visited in sub-Saharan Africa were situated nearby or within sites used primarily for other activities. Such a situation has an obvious impact on clay exploitation strategies. More importantly, it shows that clay extraction sites are not distributed randomly or according to

a craft-specific logic but are fully integrated in the territory frequented by both potters and non-potters.

Finally, rituals and taboos often surround the selection and exploitation of clay sources (Barley, 1994; Berns, 1993; Drost, 1964; Gosselain, 1999; Herbert, 1993; Pinçon, 1993). For instance, certain persons are systematically kept aside from extraction sites or places where clay is stored and processed: men when the craft is in the hands of women, women in opposite situations, uninitiated people, members of distinct social groups from the potters, little girls or boys, pregnant women, menstruating women, twins, warriors, etc. Likewise, artisans must avoid doing particular things on the eve of extraction or when engaging in clay collection: having sexual intercourse, talking, singing, swearing, urinating, manipulating certain objects, eating particular food, etc. Rituals and sacrifices (e.g., prayers, food offerings) may also be performed at the extraction site.

Clay Processing

As in most places around the world, African potters never use clays in their raw state. Processing operations may be grouped into four main categories: pretreatment, removal of nonplastics, addition of nonplastics, and homogenization.

Pretreatments usually consist in leaving the raw materials to dry, soak, or sour for hours, days, weeks, or even months. Soaking is usually done in a pit, an old jar, or a plastic container and used when clay is extracted in a dry state. It aims at allowing the material to regain its plasticity. If clay is already wet, the aim may be to obtain a better workability through increasing the amount and distribution of water between particles and pores. A long soaking time may also help in increasing plasticity through pH alteration and the subsequent flocculation of clay particles, but such souring process is quite rare among African potters.

When clay is sufficiently dry or wet, undesirable nonplastics may be removed through a series of techniques. The most common one is hand sorting, as potters usually remove coarse

impurities such as pebbles, roots, or leaves when manipulating clay. But there are several other ways of controlling clay composition and texture. For example, potters may pound the clay on a stone or in a wooden mortar or grind it with lower and upper grinding stones. Finally, nonplastics may be removed by sieving with baskets, pierced calabashes, or imported nylon meshes. Potters may also remove the coarser fraction of nonplastics by shaking the crushed raw materials in a calabash or by winnowing it with a winnowing basket or a calabash. A last technique, levigation, is quite rare in Africa. Here, the material is mixed with water until reaching a colloidal state. After having removed the larger, heavier particles on the bottom of the container, water is left to evaporate and the finer fraction is retrieved (David, 1983; Gally & Sauvain-Dugerdil, 1981).

Generally called “tempering,” the addition of plastic or nonplastic elements to the clay matrix involves a large variety of materials: other clays, dust, mud, termite heap clay, sand, gravel, rocks (calcareous rocks, gneiss, schist, and asbestos), iron stone, grog (crushed, grounded, and/or sieved potsherds; Fig. 1 – by far the most common material), fired earth, ash, straw, cereal husks, grass, stems, bark, dung (horse, cow, goat, or donkey), shells, calcareous solution (grounded and sieved calcareous rock mixed with a large amount of water; Sall, 2005), or bark decoction.

The last processing step usually consists in a thorough homogenization of the material. Such operation is mandatory in clay processing and has a determinant impact on clay workability. It may be done in different ways: kneading with the hands, trampling with the foot, or pounding with various kinds of tools and supports (the most common ones are mortars and pestles, lower and upper grinding stones, and handles of diverse farming tools). Due to the frequent combinations of the four categories of treatments, as well as the diversity of tools, gestures, and materials involved, there exist hundreds of technical variants across the African continent. Such diversity sometimes leads processing techniques to become cultural markers at local or regional

Ceramics in Africa,

Fig. 1 Pounding sherds in wooden mortars for obtaining grog, the most common temper in Africa. Note the use of tools and postures identical to those used in food processing



scales (Corniquet, 2011; Gosselain, 2008; Livingstone Smith, 2000).

Potters often explain that they act the way they do because of tradition (i.e., because of the way they have been trained), but also because using other processing recipes would lead vessels to break during drying, firing, or utilization. Such a conception may justify the use of different processing techniques in relation to the intended function of vessels or vessel parts. Among Koma-Gimbe of Cameroon, for example, potters simply pound the clay when making small vessels but add sand when making large beer brewing jars. They explain that jars would crack when drying if they did not do so (Livingstone Smith, 2000). Others examples of the use of different processing recipes for different uses have also been collected in other areas (Gallay & Sauvain-Dugerdil, 1981; Herbich & Dietler, 1991; Nicholson, 1929; Tobert, 1984; Trowell, 1941). Most commonly, however, potters use a single processing technique, irrespectively of the intended function of the vessels.

Another factor that explains the use of specific processing techniques is the relationship with techniques used in other realms of activity, such as food processing and agriculture. For instance, staple foods and clay may be prepared with similar tools and gestures and according to similar recipes. In the Bariba village of Tourou (Benin), for example, potters pound the clay in a wooden

mortar and separate the fine and coarse fraction by shaking the material in a calabash. Then, they pound the coarse fraction a second time, and let it soak in a jar placed in the sun. When the liquid is sufficiently thick, it is sieved through a pierced tin can and mixed with the fine fraction of the raw material. Potters explain that this mixture acts as cement and that the best millet porridge is obtained in a similar way. Similarly, the clay desalinization technique observed among certain Jola Kasa potters of Casamance echoes agricultural practices in mangrove zones (Sall, 2005).

Symbolic or religious concerns may also influence clay-processing strategies (see examples in Gosselain, 1999). For instance, some Boko potters of Benin take great care in extracting all rootlets from the raw material. This is because rootlets are used to prepare a medication that prevents potters from “swelling” when fashioning vessels. Some West African potters often recycle archaeological sherds into grog, as they consider this material to possess particular qualities because “ancestors knew how to make stronger pots” or because “what has lain underground is stronger than what lies on the ground” (Livingstone Smith, 2007). Another example comes from Tukolor potters of Senegal who stop adding dung to the clay when they settle in Soninke communities, where dung is considered impure (Gelbert, 2001).

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Fig. 2 Shaping a vessel with the diverging pounding technique, on a concave wooden anvil, with a clay tamper (Photo by Olivier Gosselain)



Shaping

In most instances, the shaping process must be separated into two specific operations, according both to their purpose and the set of tools and gestures involved: (1) roughing out and (2) preforming. During roughing out, potters transform a lump of clay and/or joint pieces of clay together in order to constitute a hollow volume – the rough shape – whose form, often cylindrical, is not that of the finished product. During preforming, potters give the hollow volume its final geometric characteristics through scraping and smoothing operations.

Wheel throwing – not considered here – is only documented in North Africa, where male potters have used it for centuries. South of the Sahara, only passing references are made to the use of wheel throwing by a few male potters in the Lower Congo area. The Portuguese could have introduced the technique in the late seventeenth century (Vincentelli, 2003, p. 44), yet due to a lack of ethnographical information, it is impossible to know whether it is still used as such by Kongo potters.

Roughing Out

Techniques used in sub-Saharan Africa belong to seven main categories: (1) pounding in a concave form, (2) drawing of a ring-shaped lump, (3) superimposing and drawing of large rings, (4) molding (on concave or convex molds), (5) pinching, (6) drawing of a lump, and (7) coiling. As the last three techniques are

widely documented outside Africa, only the first three will be considered here.

The pounding technique – also called “tamper and concave anvil technique” – consists in placing a lump or a pancake of clay on a mat-covered depression or a concave anvil (wood, clay, or stone) and pounding it with the fist, a wooden pestle, or, more generally, a stone or clay tamper (Fig. 2). Progressing with rhythmic beating, the potter rapidly obtains a concave form that he/she turns continuously on the anvil or the depression while shaping it. This technique is used throughout the Sahel, from Mali to Egypt (Drost, 1967; Gosselain, 2001; Huysecom, 1992; Sterner & David, 2003). Two main variants have been identified so far, whose spatial distribution across the continent could correspond to distinct historical processes (Gosselain, 2010): (1) *converging pounding*, in which potters pound the clay from the edge of the lump toward its center, and (2) *diverging pounding*, in which they progress from the center toward the edge. In the drawing of a ring-shaped lump, the potter fashions a ring of 20–60 cm in diameter with one or several slab(s) of clay and pulls its wall up with the help of the fingers (Krause, 1985; Lawton, 1967; Livingstone Smith, 2007; Roy, 1989). In most cases, the lower part of the vessel is fashioned later with coils or a pancake of clay, after the upper part has been preformed and is sufficiently dry to be upturned. A variant observed in western Cameroon consists in fashioning the bottom part before the upper one (Nyst, 1996).

The superimposing and drawing of large rings is similar to the previous technique, except that the initial volume is obtained by superposing a series of crown-shaped rings of clay which are then carefully joined. So far, the technique has only been recorded in the southeastern part of Central Africa (Lorenz & Plesner, 1989; de Maret & Bulckens, 1978; Livingstone Smith, 2010; Woods, 1984).

The seven techniques mentioned above are seldom used as such by African potters. The shaping of medium to large vessels usually involves the combination of the last two of these techniques, with the consequence that a detailed comparison of actual shaping processes allows one to identify more than 50 variants across the continent.

In comparison with clay extraction and processing, the most striking aspect about the roughing out process is that it mainly relies on hand gestures. While techniques such as molding and pounding require specific tools and devices, it is especially the artisan's hands and fingers that act during the major part of the shaping process. Gestures associated with the roughing out process also stand apart because of their relatively specialized character. Few relations exist with other activities at this level and only body postures (e.g., working while bending over the rough out or sitting on the ground with legs wide apart) may find an echo in other domains than pottery making.

The reliance on specialized gestures has been identified as a crucial factor for explaining the frequent stability of shaping technique through time and space, as well as the possible coincidence between techniques and major social boundaries such as language, socio-professional groupings, or political units (Fowler, 2008; Gosselain, 2000, 2002). Their mastery involves a close interaction between two individuals and a training period that may span over several years, so that motor habits would be more resistant to change than other stages of the manufacturing process. Recent studies have showed, however, that borrowing processes may also affect the shaping stage (Gelbert, 2001; Gosselain, 2008; Sterner & David, 2003).

Another explanation could be that since potters frequently view shaping techniques as an inheritance and an index of their social affiliation, they develop a conservative attitude in regard to the transmission of technical practice at this level of the manufacturing process. This is the case among female potters of the Songhay blacksmith group in Niger, who have acquired the molding technique from their Bella neighbors (considered as former slaves) but have chosen to pass on their own pounding technique ("the true Songhay technique") to their daughters.

Preforming

Carried out in continuation of the roughing out operations, this stage aims at giving the vessel its desired shape. To this end, potters scrape and smooth the wall with a series of tools, exercising gradual pressures in order to deform the clay material.

To round off the body and make it bulge, potters scrape the outside and inside walls while supporting the wall with the other hand. The tools used for scraping the inside surface have a rounded or spherical form: rounded off pottery sherds, pieces of calabash, pods, large seeds, nuts, shells, or spoons. Moved horizontally or obliquely, they do not generate much displacement of clay since internal scraping aims essentially at modifying the shape of the body. Outside scraping and smoothing operations, on the other hand, allow the potter to mask irregularities and to heighten the vessel through the displacement of a rather large amount of clay. Such operations are typically carried with flat and oblong tools, such as flat sticks, spatulas, bones, blades, pods, shells, or corncobs.

Forming the neck may be achieved with different techniques, either in continuation of preforming the body or after having added one or several coil(s). A first technique consists in bending the upper part of the wall through horizontal smoothing of the inside wall. In this case, the potter exercises an increasing pressure on the smoothing tool, while supporting the wall with the other hand, until the appropriate shape is obtained. Another technique consists in smoothing the outside wall of the vessel horizontally

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Fig. 3 Forming the neck and the lip of a vessel with the fingers. A constant pressure is exerted on the wall while the vessel is rotated slowly with the other hand (Photo by Olivier Gosselain)



with a tool whose curvature corresponds to that of the neck. Rounded off sherds or calabash pieces are typically used to that aim. A last technique consists in pinching the rim between the fingers (directly or with the help of a leaf, a rag, or a piece of leather) and rotating the vessel slowly with the other hand while exerting a constant pressure on the rim and progressively tipping up the hand toward the exterior (Fig. 3).

Finally, some potters form the lip of the vessel through constant pressure between fingers – or with the help of any supple material – as in the neck-forming method described above. Depending on the position of fingers, the pressure exerted, and the materials used, lips may acquire a rounded or sharp profile or bear a groove. The rim may also be shaped through smoothing with a flat or slightly concave tool such as a spatula, a stick, a bone, or the nervure of a large leaf. Here also, the potter usually rotates the vessel while exerting a constant pressure on the tool or, alternatively, moves the tool itself on the rim. A last method consists in adding one or several coil(s) above the rim or on its side and smoothing it with fingers or a supple material.

The individual dimension of preforming operations must be stressed. While frequently sharing a pottery tradition with a larger group of people, individual potters often develop idiosyncrasies at this level of the manufacturing process, through the specific ordering of operations and the way tools or fingers are used (Kaneko, 2007). Minute variations in profiles – neck, lip, handle, or

base – are also likened to “signatures,” which can be recognized as readily by eye as by touch (Gosselain, 2002, pp. 113, 115).

Another striking characteristic of the preforming stage is its permeability to innovation. Starting from simple and common forms, artisans are able to innovate in order to meet new demands (e.g., flowerpots, moneyboxes, stills, or incense holders) or to modernize the aspect of their products (Argenti, 1999). This explains the current appearance of a new generation of flat-bottomed pots fitted with handles, which are faithful copies of the aluminum pans produced in urban environments. The production of such vessels may also allow individuals to position themselves as experts and agents of modernity within their community.

Decoration

Decoration occurs either after shaping, while the paste is still wet, or after drying or even firing. In the first case, the techniques used belong to four large categories: (1) grooving, (2) incising, (3) impressing, and (4) appliqué.

Grooving consists in tracing lines or figures on the surface of the vessel with the fingers or a tool with a rounded or sharp extremity: sticks, stalks, thorns, ends of calabash scrapers, sharp stones, bones, shells, nails, bicycle spokes, bracelets (drawn on the surface), bundles of stalks or thorns held between finger or driven into a clay ball (Fig. 4), hair combs, and indented pieces of calabash.

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Fig. 4 Decorating a vessel with a comb-like device
(Photo by Olivier Gosselain)



Incising is similar to grooving, except that the tools used have a sharp cutting edge so that clay surfaces are actually incised. Such tools include knives, spearheads, or scraps of metal.

Impressing is done with distinct tools and methods. The simplest is to press any kind of device or material (fingers, natural objects, sticks, combs, or carefully designed wooden or iron stamps, as those used in the Inland Niger Delta; Gallay, Huysecom, & Mayor, 1998), in order to make a single impression that may be subsequently repeated on the surface. Another method consists of pressing and rocking convex devices such as blades or indented combs and bracelets on the surface and obtaining zigzag-like rows of impressions. Rouletting is a third technique, in which natural objects (corncobs, shells, fish vertebrae, plant parts) or roulettes (made by carving wood or twisting, knotting, braiding, coiling, or wrapping fibers) are rolled on the vessel's surface to obtain regular patterns (Haour et al., 2010).

Appliqué corresponds to any kind of clay elements added to the vessel surface, e.g., coils, buttons, spikes, and human or animal figures.

Decoration made on dry and hard surfaces comprises painting and specific surface treatments. The most usual ones consist of applying a slip made of iron-rich clays, crushed beforehand on a stone or in a mortar, and subsequently sieved and diluted in water. The application is made with the hand or a rag. In many instances, slipped surfaces are then carefully polished with

round stones or strings of seeds (mostly from baobabs) or cowries. The resulting effect, after firing, is a dark-red and shiny surface. Polishing may also be done on unslipped surfaces or with graphite, as among several South African populations (Bell & Calder, 1998; Fowler, 2008; Lawton, 1967).

Painting occurs either before or after firing. In the first case, by far the most common, it is done with various mineral pigments diluted in water and occasionally mixed with gum arabic, salt, or sugar, all elements that are said to favor adherence on vessel walls. Pigments are applied with a feather, a millet ear, a stalk, or a stick with a crushed or rag-wrapped end. In southwestern Niger, Bella and Zarma potters use a blade for drawing thin lines and motifs (Fig. 5). Postfiring painting is essentially observed in South Africa or in modern contexts, where vessels are aimed at tourist or city markets. Potters then use industrial paints and inks.

Regardless of the techniques, tools, or materials, a striking feature of decoration is the casual way in which most potters talk about it. Decoration would essentially be a matter of "simple embellishment," "like a hairstyle or clothes," the main function of which is to "attract the customer's eye." In some cases, even the aesthetic function of decoration is questioned, as when potters explain that roulette impressions are simply a matter of modifying wall texture to prevent pots from slipping when manipulated (Bredwa-Mensah, 1996; Priddy, 1971).

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Fig. 5 Applying a mineral paint with the help of a blade (Photo by Olivier Gosselain)



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This does not mean that artisans proceed randomly, outside rules, or reference frameworks. On the one hand, pottery decoration is but an ornamental manifestation among others in a given context. Aesthetic choices may be influenced or even channeled by practices unrelated to pottery making. For example, there exist numerous parallels between vessel ornamentation and tattooing or scarification (Barley, 1994; David, Sterner, & Gavua, 1988; Ritz, 1989), as well as architecture or other elements of material culture (baskets, gourds, aluminum pots). On the other hand, if decoration is obviously open to innovation (e.g., the current vogue of painted inscriptions in West Africa), change mostly affects the components of the decors, rather than their organization or “grammars.” Interestingly, the latter could be related to the symbolic function of decoration or the expression of collective identities (David et al., 1988).

Drying

There exists a broad palette of practices and attitudes in regard to drying. Some potters deem it necessary to place the wares in the sun during the early stage of drying, while others take great care to shelter them during the first hours, the first days, or even the whole drying process. Similarly, some may wait several weeks or several months before firing the vessels, while others do it after 2 or 3 days. While drying periods are often shorter in dry areas than in tropical areas,

variations seem essentially related to personal conceptions and schedules, rather than climatic variations or the chemical and physical characteristics of raw materials. Thus, potters who make vessels on demand or frequent weekly markets generally resort to short drying periods. If necessary, wares cracked from too fast a drying are simply repaired with fresh clay.

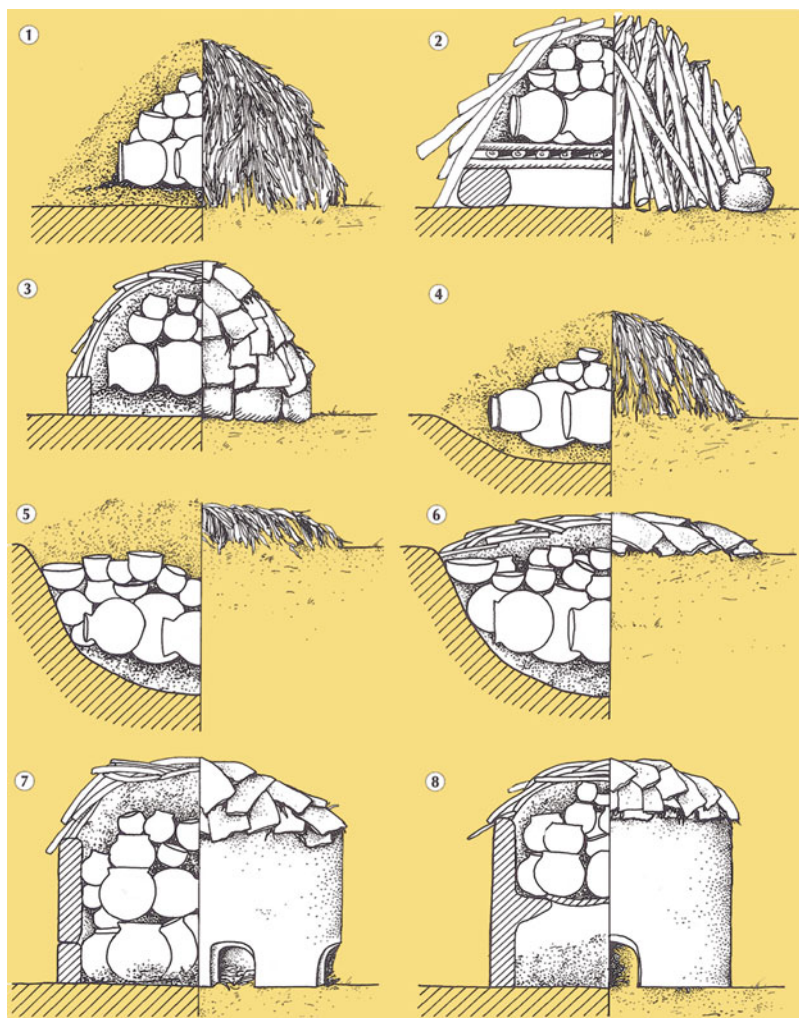
Such flexibility in drying procedures is due, in part, to the accommodating nature of the raw materials used in Africa. But it may be reinforced through the use of preheating techniques that allow the gradual evaporation of residual water. For instance, pots may be placed around or above a cooking earth (Gosselain, 2002, pp. 145–146; Priddy, 1971; Woods, 1984), on glowing embers (Kanimba & Bellomo, 1990; Mercader, García-Hera, & Gonzalez-Alvarez, 2000), or on a rack-like structure below which a fire is kept going, as among several Kongo groups from Central Africa (de Maret, 1974; Mpika, 1986).

Firing

Although the emphasis will be put here on fuels and structures, several other aspects of firing may be taken into consideration, including the scheduling of firing events, the location of firing structures, the way vessels and fuel are positioned within the structure, the overall firing schedule (duration, refueling, way of assessing the degree of firing of the wares), or the identity of people taking part in the operation.

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Fig. 6 Firing structures used in Africa: (1) bonfire, (2) elevated bonfire, (3) bonfire with isolation, (4) depression, (5) pit, (6) pit with isolation, (7) oven, and (8) updraft kiln (Drawing by Yvette Paquay)



Fuel

As summarized by Livingstone Smith (2001, p. 993), almost all categories of combustible materials are used for firing pottery in Africa, from sawdust to rubber tires. Used independently or combined in various proportions, they may be grouped into three main categories, corresponding roughly to those made by the artisans themselves when asked about their conception of “appropriate” and “inappropriate” fuels: (1) manure of cows, donkeys, camels, or horses; (2) light materials (dry grass or cereal stalks, cereal chaff, palm fronds, leaves, twigs, barks, or roots); and (3) heavy materials (branches and logs from dozens of tree species).

Neither the firing structure nor the firing conditions possibly sought by potters seem to impose restrictions on the selection of fuel materials. With the notable exception of manure, whose combustion is slower, all the fuels used throughout Africa allow potters to obtain similar firing schedules and temperatures.

Structure

Eight firing structures are documented in Africa (see details in Drost, 1967; Gosselain, 2002, pp. 153–162): (1) bonfire, (2) elevated bonfire, (3) bonfire with isolation, (4) depression, (5) pit, (6) pit with isolation, (7) oven, and (8) updraft kiln (Fig. 6).

Bonfires are the most commonly used structures in Africa. Pots are placed on a bed of fuel, at ground level, and covered with another layer of fuel. Such structures vary tremendously in size (50–250 cm in height and 50–700 cm in diameter), firing duration (from 20 min to several hours), as well as the number of vessels fired at once (from 1 to 500). The number pieces may depend on the stock available at the time of firing but also personal conceptions. For example, some Gbaya potters from Cameroon deem it impossible to fire more than one to three vessels at once. They thus multiply firing sessions or construct several bonfires side by side.

So far, elevated bonfires have only been observed in the Great Lakes region, among the Twa of Burundi and Rwanda and the Konjo of Uganda (Célis & Nzikobanyanka, 1984). The technique consists in placing vessels on elevated rack-like layers of branches placed on four or five big stones and covering them with fuel. During firing, they fall gently on the ground as the branches gradually burn down.

Bonfires with isolation differ from simple bonfires in that a layer of fireproof materials – sherds, enamel wares, sheets metal – is placed either between the vessels and the upper layer of fuel or upon the whole structure. In the first case, the aim is to avoid color variations caused by contacts between fuel and vessel surfaces. In the second, the aim is to shelter the structure from the wind.

Depressions are shallow structures dug in the ground (between 20 and 40 cm depth) in which vessels stand partly above the ground when having been placed on the fuel bed. Their shape is circular, oval, or rectangular, with diameters (or sides) ranging from 100 to 500 cm. As for bonfires, important variations are observed in the number of wares fired at once and the duration of the firing. Variations also exist in the way vessels are positioned within the structure. For instance, while most potters place them horizontally or vertically, some place them upside down on the bed of fuel, in order to obtain a dark and shiny internal surface, as among the Zaghawa of Sudan (Tobert, 1984) or Hausa and Kanuri of Niger.

What differentiates pits from depressions is that, in the former structure, vessels remain below the ground surface after having been placed on the fuel bed. Their depth always exceeds 50 cm and may reach as much as 100–150 cm, for a diameter ranging from 50 to 400 cm. Another difference pertains to the duration of the firing, which is often several hours long. In a variant observed among Bamileke Fe'fe' from western Cameroon (Gosselain, 2002) and Kongo Manyanga from Congo (Mpika, 1986), the wares are placed on a rack-like wooden structure standing above the pit and gently tipped in the hole in the course of firing.

Pits with isolation resemble bonfires with isolation in that a layer of fireproof materials is placed either on the vessels or on the upper layer of fuel. This technique is commonly used in southern Africa (Krause, 1985; Lawton, 1967) and throughout the Sahel area, from Senegal to Sudan. Here, the firing usually lasts a whole night, even though the fire actually burns for a few hours.

Ovens are wall-enclosed structures within which vessels are not separated from the fuel. Such structures have only been documented in West Africa. They are made of mud, with a height of 50–180 cm and a diameter of 100–400 cm. The base of the wall has one or several hole(s), through which fuel (usually stalks or grasses) is charged during firing. 20–200 vessels may be fired at once in such structure. They are piled and subsequently covered with fuel and/or a layer of sherds. A simpler oven technique, observed among some Yoruba of Nigeria (Fatunsin, 1992, pp. 39–40) and Bariba of Benin, consists of firing vessels in a bottomless jar placed on mud bricks upon a small fire. Such technique is only used for small pieces.

Updraft kilns are particularly rare in sub-Saharan Africa. So far, they only have been observed in western Nigeria, among the Nupe of Bida (Nicholson, 1934; Vernon-Jackson, 1960) and the Yoruba of Abeokuta (Fatunsin, 1992). While such firing structure is constituted of a circular mud wall – as ovens – fuel is placed in a distinct chamber and separated from the

vessel with sherds or a perforated clay plate. They are in fact strongly reminiscent of the fish dryers used along the River Niger, within and to the north of the Nupe area.

Measurements made in the field show a considerable homogeneity in firing conditions, despite the variety of fuels and structure used throughout the continent. Whether in regard to temperature rise, maximum temperatures, or the time of exposure to specific temperature thresholds, each technique allows for similar results (Livingstone Smith, 2001). Such homogeneity echoes the way in which potters determine the completion of the firing process: in most instances, they retrieve the vessels or stop refueling when vessels' walls become incandescent.

There exist multiple relationships between firing techniques and techniques used in the realm of food processing (Gosselain, 2002, p. 165). But not with metallurgy, even in societies where male blacksmiths and female potters belong to the same endogamous subgroup. The fact that both activities are respectively practiced by different genders and in different circumstances would seem to hamper technical transfer. As other stages of the manufacturing process, firing is also surrounded by a series of prescriptions and prohibitions. Yet, they are both less numerous and less influential in technical terms, as they aim essentially at avoiding "evil" or "impure" individuals.

This worry stems from the public and collective character of the firing process. In many regions of Africa, artisans associate with relatives, friends, or neighbors for firing their wares. Such associations do not only help in alleviating their work but also meeting scheduling constraints (e.g., the existence of weekly markets) when only a few firing locations are available. Interestingly, communal firings often give rise to micro potting communities when artisans start to regroup on a regular basis. Operating within broader communities, they are characterized by the existence of close social bonds between members and the development of specific technical practices not necessarily limited to the firing process (Corniquet, 2011).

Postfiring

In many regions of Africa, vessels are subjected to various treatments after firing, either when retrieved red hot from the fire or after having cooled off. Aiming at improving the physical characteristics and/or appearance of vessels, postfiring treatments may be grouped into five categories: (1) organic coating, (2) resin application, (3) smearing, (4) smoking, and (5) water sprinkling or soaking.

Organic coating is by far the most common treatment. It consists of coating the surface with an organic mixture made from parts (bark, fruits, leaves, branches, roots) of several dozen tree species, the most common of which are *Bridelia ferruginea*, *Bridelia micrantha*, *Parkia biglobosa*, *Parkia filicoidea*, *Diospyros mespiliformis*, *Ximenia americana*, *Pterocarpus angolensis*, and several *Acacia* and *Syzygium* subspecies (see details in Drost, 1967, pp. 174–182; Gosselain, 2002, pp. 184–190). After having been crushed, the material is boiled in water (decoction), put into hot water (infusion), or soaked at ambient temperature (maceration). Application is done by immersing hot vessels in the mixture, sprinkling it on the walls, or smearing the surface with the help of a series of brushlike tools. Alternatively, cooled off vessels are coated with the help of a rag. Besides having a decorative purpose, organic coatings are said to have strengthening and waterproofing effects.

Resin application is solely aimed at waterproofing the vessels. In this case, the inside surface is coated with resin extracted from several tree species – e.g., *Canarium schweinfurthii*, *Copaifera demeusei* or *mildbraedii*, various *Acacia* species, *Euphorbia candelabrum*, *Dodonea viscosa*, and *Guizotia abyssinica* – either by melting it directly in the vessel or pouring it in after melting. The vessel is then rotated rapidly for ensuring a homogeneous surface coating.

Organic materials may also be smeared on the surface or cooked in the vessel in order to strengthen or waterproofing them: leaves of *Ricinus communis* or *Sida rhombifolia*, oil or sap from *Raphia vinifera* or *Elaeis guineensis*, fruits, fibers, roots, cereal husks, milk, porridge,

or cow dung (see examples and details in Gosselain, 2002, pp. 191–192).

Smoking aims at covering the vessel surface with wood tar in order to give it a black shiny aspect – and according to several potters, improving their strength and waterproofing. To that aim, vessels retrieved red hot from the fire are usually buried in organic materials such as grass, cereal husk or chaff, animal manure, fruit pods, and bark or wood shavings (see examples in Gosselain, 2002, pp. 192–193). Another technique, observed in the Great Lakes region and South Africa, consists in maintaining vessels above a small fire (Armstrong, Whitelaw, & Reusch, 2008; Fowler, 2008; Trowell, 1941).

Lastly, vessels may be immersed in, or sprinkled with, freshwater or boiling water (see examples in Gosselain, 2002, p. 193). Here again, the aim is to waterproof and strengthen the wares.

As with clay processing or firing, artisans often emit strong views about the choice of ingredients, preparation recipes, or application techniques. As diverse – and even antagonistic – as they are, they seem to follow similar logics. For instance, sub-Saharan potters use at least 50 different plant species for making organic coatings, but few of them know about the existence of other plants than the ones they use, and most believe that there is simply no alternative to their choice. The same applies to the preparation of the plant parts or the application technique. Seen from a comparative and analytical perspective, however, all choices are perfectly justified from a technical or aesthetical point of view. The chromatographic analysis of various fruits and barks used in sub-Saharan Africa indeed reveals the presence of a specific category of tannins, the procyanidins, with excellent coloring and waterproofing properties (Dialo, Vanhaelen, & Gosselain, 1995).

The most striking aspect of the postfiring stage is its connection with many other domains of activity. For example, most of the plant species exploited by potters are also used as food, dyes, basketry materials, waterproofing materials for wall and pavements, and, above all, pharmacopoeia. This last domain reveals interesting ties, as the illnesses and injuries treated with the help of

preparations similar to those used by potters are mostly characterized by discharges (Gosselain, 1999, 2002, pp. 197–198, pp. 210–211): wounds, diarrhea, gonorrhea, hemorrhage, menorrhagia, ulcers, etc. Pots are thus treated as human bodies, and reversely. Similarly, postfiring treatments are often connected to birth and circumcision rites. What is at work, here, is the materialization of an extremely widespread association between pottery making and human beings (Armstrong et al., 2008; Barley, 1994; David et al., 1988; Gosselain, 1999; Ritz, 1989) that seems to channel potters' behavior in relation to the choice of ingredients as well as processing and application techniques.

This fact illustrates perfectly why a *chaîne opératoire* cannot be reduced to mere actions on matter. As stressed by Lemonier (1991) and many other scholars, techniques do not solely aim at transforming materials or acting upon the material world. They also respond to a series of social, political, economical, and symbolic concerns, whose echo may be found at any level of the manufacturing process as we have seen throughout this article.

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Ceramics in Burma

Myo Thant Tyn

Kyeemyindine Township, Yangon Region,
Myanmar Ceramic Society (MCS), Yangon,
Yangon Region, Burma (Myanmar)

Prehistoric Earthen Wares

Late Palaeolithic Age: The prehistoric tradition of Myanmar (Burma) earthenware could be traced back as far as $13,400 \pm 200$ years before the present (BP) with some simple cord-marked potsherds, an earliest Hoabinhian culture or earlier than the Spirit Cave (Thailand), from the excavation of Padah-Lin caves in the Ywa-ngan Township (Shan State) in January 1969. The late Anyathian (12000–6000 BP) culture site in Myanmar belongs to the late Palaeolithic Age (75000–9500 BP).

Neolithic Age: The corded earthenware culture of the Neolithic Age (6000–4000 BP) was discovered at various places within the great basin where the Chindwin and Ayeyawady rivers flow from Kani down to Letpanchebaw and Thegone. Red-painted pottery from Halin and Twintaung are also included in this culture.

Other prehistoric earthen pottery has been found, mostly by excavation, in Taungthaman (late Neolithic) (Fig. 1), and Nyaunggan (1500–300 BC) (Fig. 2).

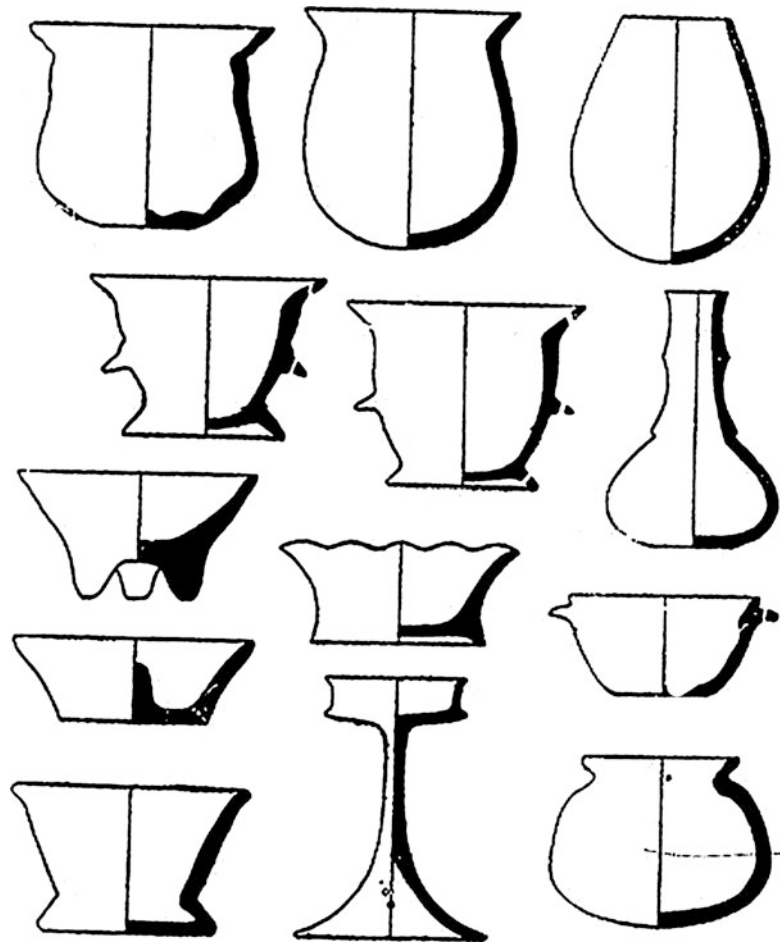
Forming Technique: Much of the pottery recovered was plain and undecorated, being formed by coiling and paddling (without wheel) fine-grained clay tempered with sand which had turned a buff colour on firing. The turning wheel was supposed to be invented from about 5000 BP and found in continued use in about 950 BC (excavated finding at Nyaunggan). Forms comprise a variety of bowls with inverted, everted, and perforated rims and rounded, ringed, and tripod bases. A few have perforated lugs on the body while others are set on flaring foot-rims.

Uses: Such bowls probably served as oil lamps and receptacles for food, water and flour for both domestic and ritual purposes. In Nyaunggan, Bronze Age artifacts, including earthenware pottery has been excavated; among these some interesting sets of pots that might possibly have been used for distillation for alcohol or fragrance were found (Fig. 3). Consequently, small cylindrical pots something like beer cans were also found in an excavated site at Samon Valley (Bronze-Iron Transition Age) could be regarded as a distillate container for generating evaporated cooling effect. Ceramic earthenware in various forms also played a very important part in the lives of Myanmar people. From the late Palaeolithic period to historic times earthenware had been used for storing and cooking food, for ceremonial and religious purposes, and also for building and decorating houses, palaces, shrines and city walls. From birth to death, earthenware had a significant role in Myanmar. In many cases in ancient times, earthenware was buried in the grave so as to accompany the dead to other existences.

Decoration/Design: Although simple cord-marks are possibly the earliest design decorated on pottery surfaces since late Anyathian culture in Myanmar, better techniques and varieties of decoration or design seemed to appear in about 9000 BP. The technique for decorating earthenware changed and diversified in Myanmar since that time and falls mainly into two groups, incised

Ceramics in Burma,

Fig. 1 Neolithic earthenware from the west bank of Lake Taungthaman (Amarapura) (Than Tun "Pottery in Burma, 1972")

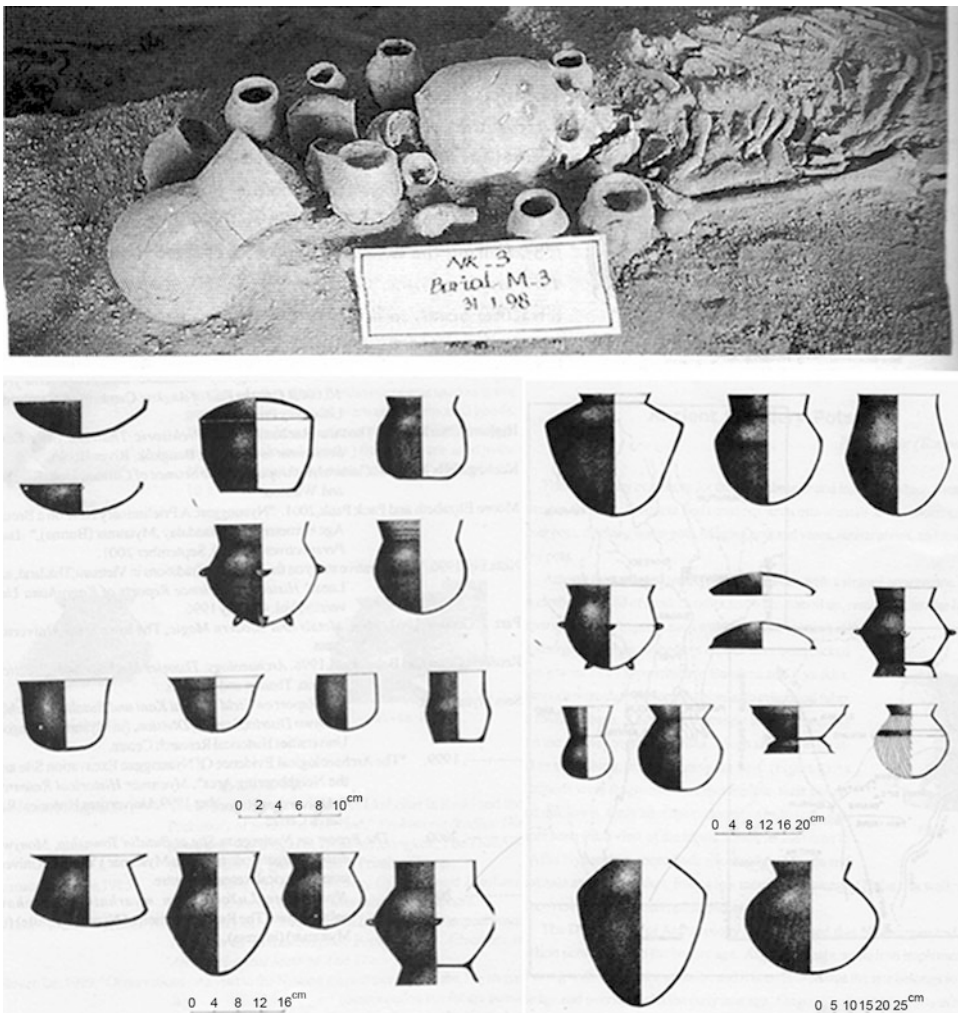


and impressed. The incised technique used a sharp or pointed tool, a comb or a shell to cut or punctuate the required pattern on the clay surface. In the impressed technique, the pattern was impressed into the surface of clay rather than cut or appliquéd. The incised technique was normally used for lines and curving patterns whereas the impressed technique was used for the rest. Different tools and different methods were used in the impressed technique. A paddle wrapped with cord, basket, net or fabric was used to make impressions on the clay surface and such products are called cord-marked, basket-marked, net-marked or fabric-marked pottery. The other type of paddle impressed method was carved-paddle-impressed where patterns were carved on the surface of the paddle and made impressions on clay surface layer by beating with the

paddle. The other one was the stamped-impressed method where the stamp with pattern was pressed onto the clay surface. The roulette method was another impressed technique where a roller with patterns (called roulette) was pressed and rolled on the clay surface.

Protohistoric and Transition Period Earthenware

Analysis Through Design: Comprehensive study of design from the assemblage of 3,000 potshards from Taungthaman, Beikthano, Halin, Tagaung, Bago, Mrauk-U, Amarapura and Twante reported by various scholars was conducted. Although these designs look simple enough as individuals, when studied collectively in large numbers some



Ceramics in Burma, Fig. 2 Earthenware excavated from Nyaunggan in association with burials containing bronze weapons (Ni Ni Myint, 1998; Sein, 2003)

cultural link can be deduced for a better understanding of the prehistoric and protohistoric culture of Myanmar.

Neem-Leaf Design: Analysis of the Neem-leaf design is an example for deduction. Through close analysis referring to the above technique the design could be classified into two categories, geometric and zoomorphic decorations. In the geometric group carved-paddle-impressed Neem-leaf design was used the most (about 50 %). Out of Neem-leaf pattern shards the majority was collected from Delta (Tawnte and Bago) (Fig. 4). Only a few were observed in

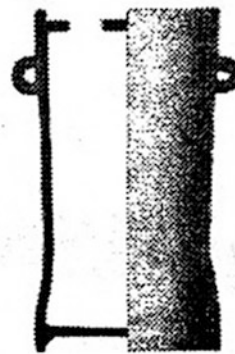
upper Myanmar. This was also found to be a missing link for the migration of carved-paddle-impressed (Neem-leaf pattern) pottery tradition into island Southeast Asia proposed by the eminent scholar Dr. Solheim II. He said that, “the movement of carved-paddle-impressed tradition was towards the east from India by the way of Burma as early as 2000 years ago so it may have spread through the Malay maritime world from India or Burma”. Now it is clear that Twante could be the link in solving the migration problem of this tradition from India to island South-east Asia through via Myanmar. Moreover it

Ceramics in Burma,

Fig. 3 Earthenware distillation unit excavated from Nyaunggan



Earthen Distillery Unit



Earthen Beer Can



Plate 2



Plate 3



Try pod Lid in Detail

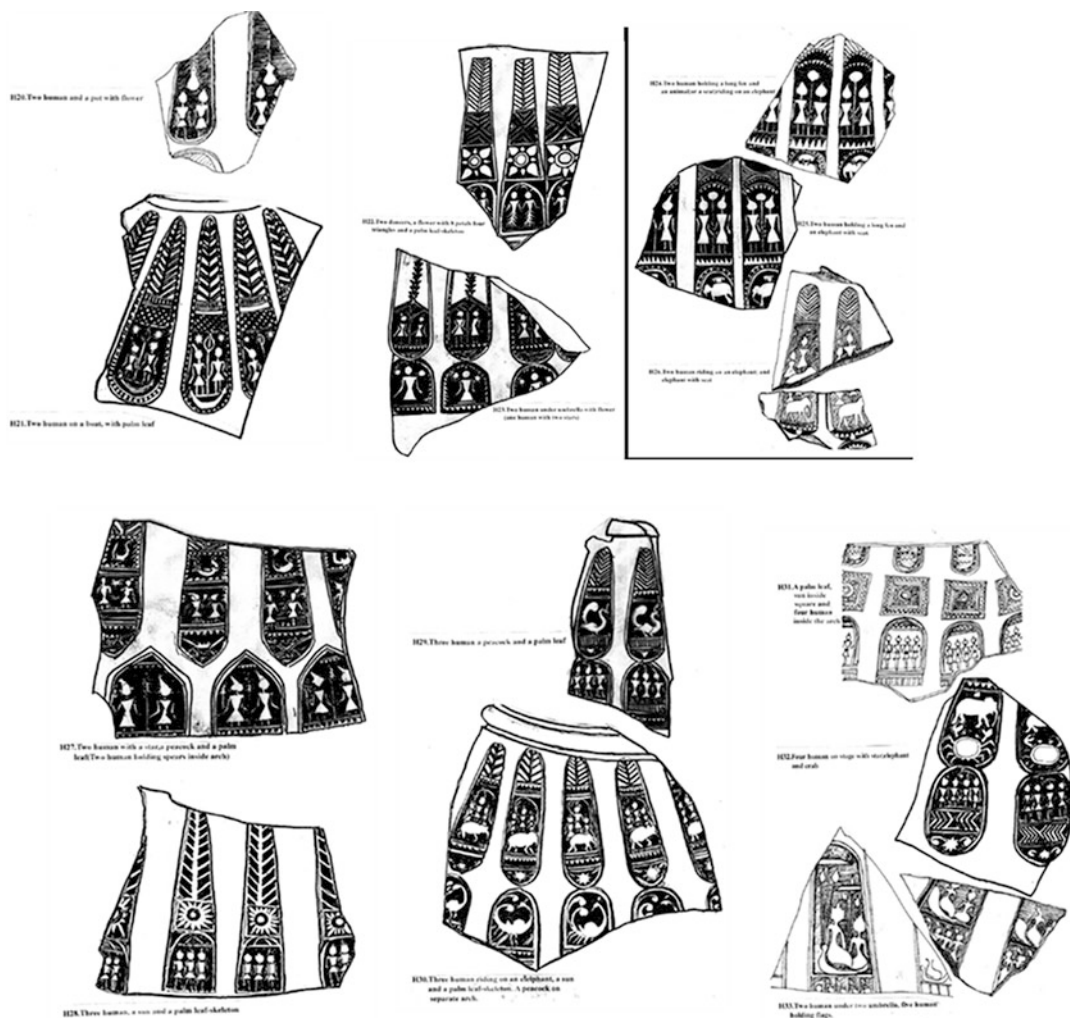
could also infer that Neem leaf type pottery tradition started in Twante as early as 2000 BP and then migrated to upper Myanmar.

Historic Earthenware and Glaze Ware: Pyu Period

The Pyu period is the transition from the prehistoric to the historic civilization of Myanmar; it flourished from about third Century BC to about ninth Century AD. During a millennium Pyu people were able to accomplish indigenous development of Pyu towns and cities such as Samon Valley (fifth Century BC-first Century AD), Beikthano (second Century BC-fifth Century AD)

(Fig. 5), Tagaung (earlier than first Century AD), Halin (second Century AD-ninth Century AD) (Fig. 6), Sriksetra (third Century AD to ninth Century AD) and Pinle (Mai-mau) (fifth Century AD) from small prehistoric villages in a way that was not previously possible in Southeast Asia. There were also numbers of self-regulating villages and towns of Pyu people outside the cities area. These Pyu people left an impressive record of their lives and deaths in the archaeological evidence.

Excavation of Pyu Cities: A series of excavations was conducted at important Pyu cities by the Archaeological Department at Beikthano (since 1958), Halin (since 1963) and Sriksetra (initially in 1907 and since 1963). They collected a considerable amount of information on ceramic

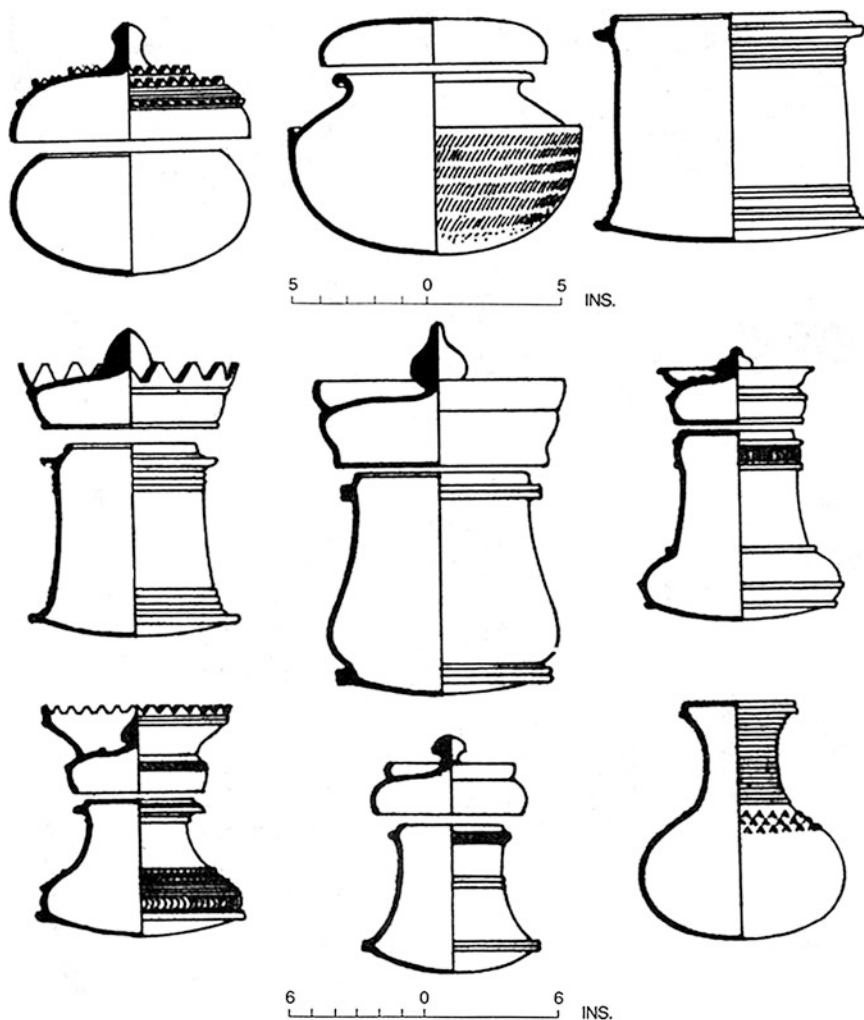


Ceramics in Burma, Fig. 4 Neem leaf (carved-paddle-impressed tradition) design on earthenware pottery shards from Twante

artifacts. As these artifacts are specifically related to the Pyu culture, they are being employed as an allegoric tool for tracking ancient Pyu. Earthen artifacts such as burial urns, bricks with marks/finger-scratches (Fig. 7), potter marks/Pyu-alphabet (Fig. 8), earthen and glass beads, earthen votive tablets and earthen seals obtained from the archaeological excavations are unique tools for identification.

Glazed Ceramics in Pyu Period: Although many earthenware objects emerged from excavations glazedware is still missing and has not shown up as archaeological evidence in any of these Pyu

sites. However evidence for the existence of glazed ceramics tradition in Pyu period is now in hand. The direct eyewitness is the Ngakywe-Nadaung pagoda (eighth to ninth Century AD) on which tin-lead glazed bricks were inlaid (Fig. 9). From logical deduction based on the evidence [potter marks of Pyu, seventh Century AD stone inscription mentioning Kalathapura (City of Pots) and fifth Century AD dated Buddha bronze image being covered with green glaze], a hypothesis was proposed that Pyu potters might have been the first to employ glazed ceramic technology (possibly low temperature

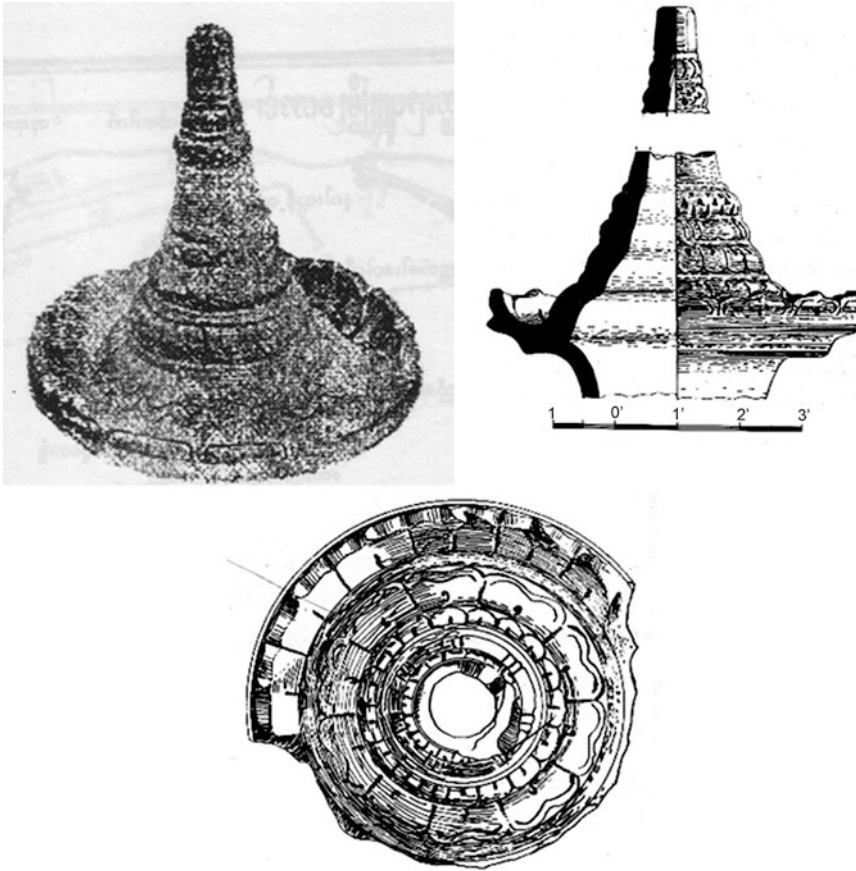


Ceramics in Burma, Fig. 5 Earthenware excavated from Beikthano (Vishnupura)

lead glaze) in Myanmar at about fifth Century AD or earlier.

Revelation of Glazed Ceramic History in Myanmar: The history of Myanmar glazed ceramics has just emerged from its obscured existence. Although there was a long tradition of Martaban jars most of the ceramic historians were less enthusiastic about including Myanmar into their study because of the scarcity of ancient production sites. This dormant period stretched along until 1984 when some mysterious green-and-white glazed wares popped up in the Tak and Omkai areas near the Thai-Myanmar border (Figs. 10 and 11). While beautiful green-and-

white ware was popular in antique markets the controversy of its origins triggered the enthusiasm of ceramic historians. Being passionate lovers of Asian ceramics, the Japanese brought large amounts of green-and-white wares back home and identified that their origin is Myanmar through lead isotope ratio analysis. These findings aroused the interest of ceramic historians in such a way that the Myanmar Glazed Ceramics tradition suddenly became quite important. Ceramic historians and local enthusiasts joined forces to reveal the ancient Myanmar glazed ceramic tradition so as to elucidate the ambiguity of green-and-white wares.



Ceramics in Burma, Fig. 6 Earthenware excavated from Halin

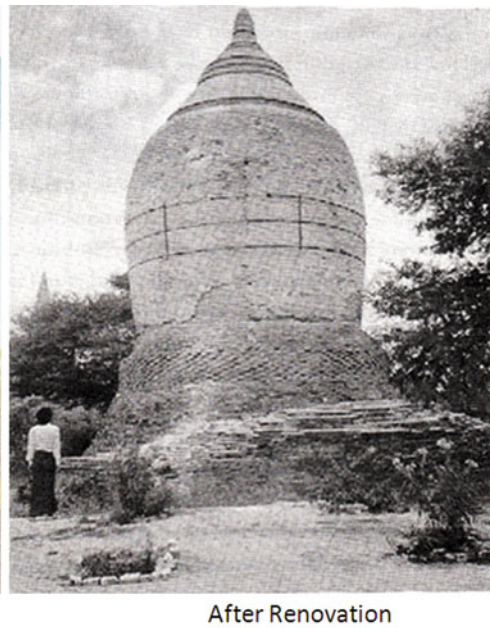
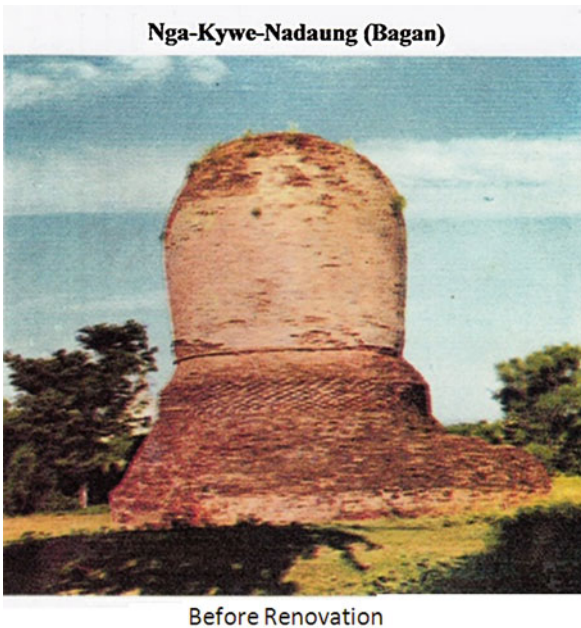
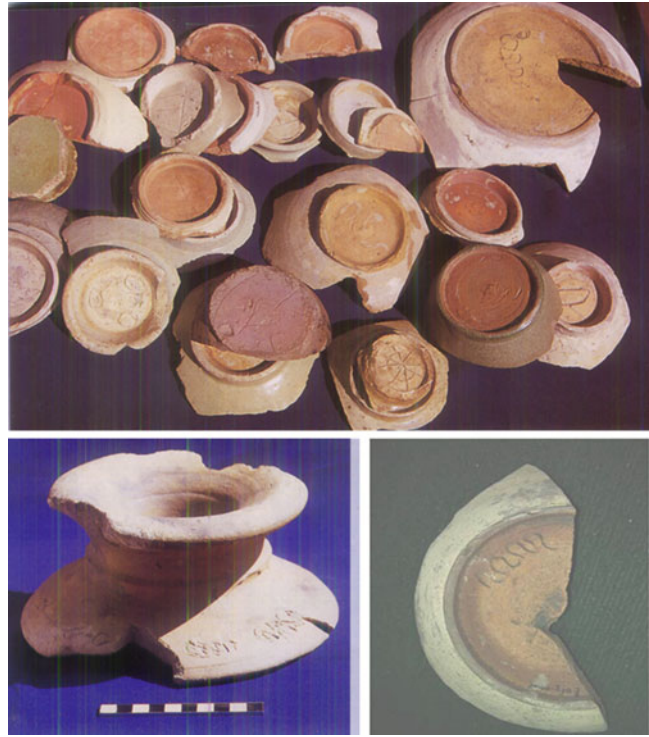


Ceramics in Burma, Fig. 7 Earthenware bricks with marks and finger-scratches

Due to this collective effort about a hundred production sites consisting of nearly 2,000 kilns were discovered in different places such as Lagumbyee (Yangon-Bago Regions); Pathein,

Old-Myaungmya and Ngaputaw (Ayeyawady Region); Twante (Yangon Region); Bagan and Inn-Wa (Mandalay Region); Honar (Shan State); and Mrauk-U (Rakhine State). Some

Ceramics in Burma,
Fig. 8 Potters marks on
pottery



Ceramics in Burma, Fig. 9 Ngakywenadaung Padoga with inlaid tin-lead glazed bricks

Ceramics in Burma,

Fig. 10 Tin-lead glazed white ware from Tak-Omki near Thai-Myanmar border

**Ceramics in Burma,**

Fig. 11 Green and white ware from Tak-Omki near Thai-Myanmar border



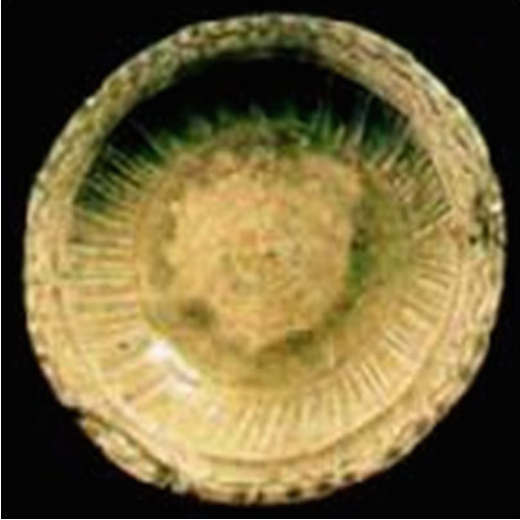
possible sites were identified in Martaban, Donzayit and Mawlamying (Mon State); Hmawbe and Hlègu (Yangon Region); Hinthada, Maubin and Bogalay (Ayeyawady Region); Pakhangyi (Magway Region); Chaung-U, Myin-hmwe, Panpin and Myin-mu (Sagaing Region); Keng Tung (Shan State); Vesali (Rakhine State); Tagung (Sagaing-Mandalay regions) where

many glazed shards, wasters and supports were found.

Out of these listed kilns few low temperature updraft kilns producing alkaline, lead and tin-lead glazewares are situated in Bago, Bagan, Inn-Wa and Myin-Mu along Ayeyarwady River banks in Central Myanmar. The rest are high temperature crossdraft (surface and inground)

kilns capable of producing lead or tin-lead glazeware and high temperature ash glaze (celadon) stoneware (Fig. 12).

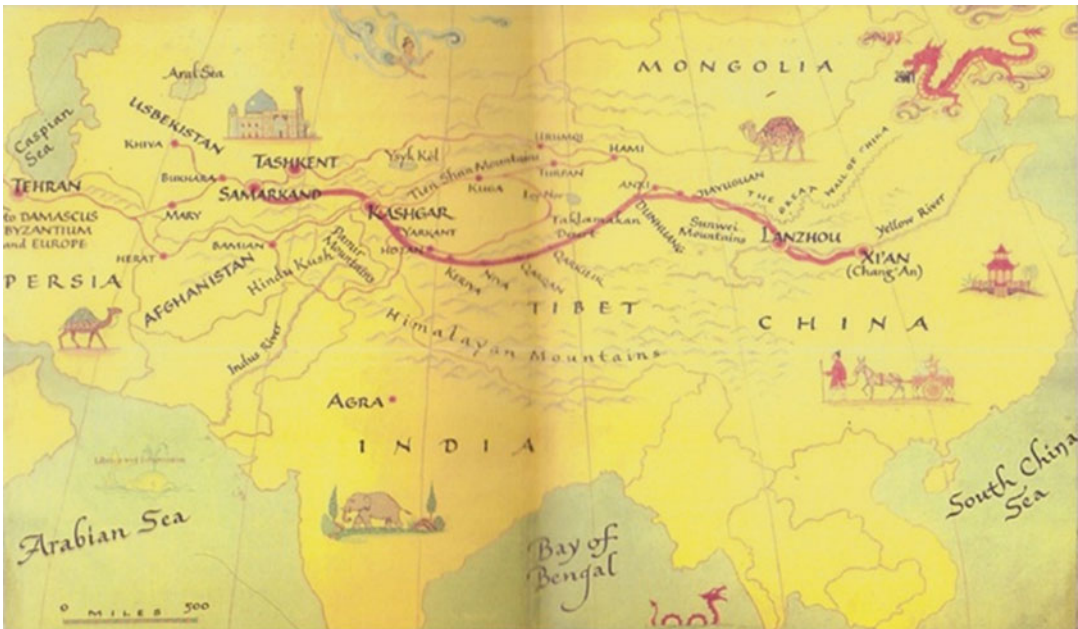
Low Temperature Glaze Tradition: Lead or tin-lead glazeware was fired in an oxidized atmosphere at about 900–1100 °C in updraft kilns. It



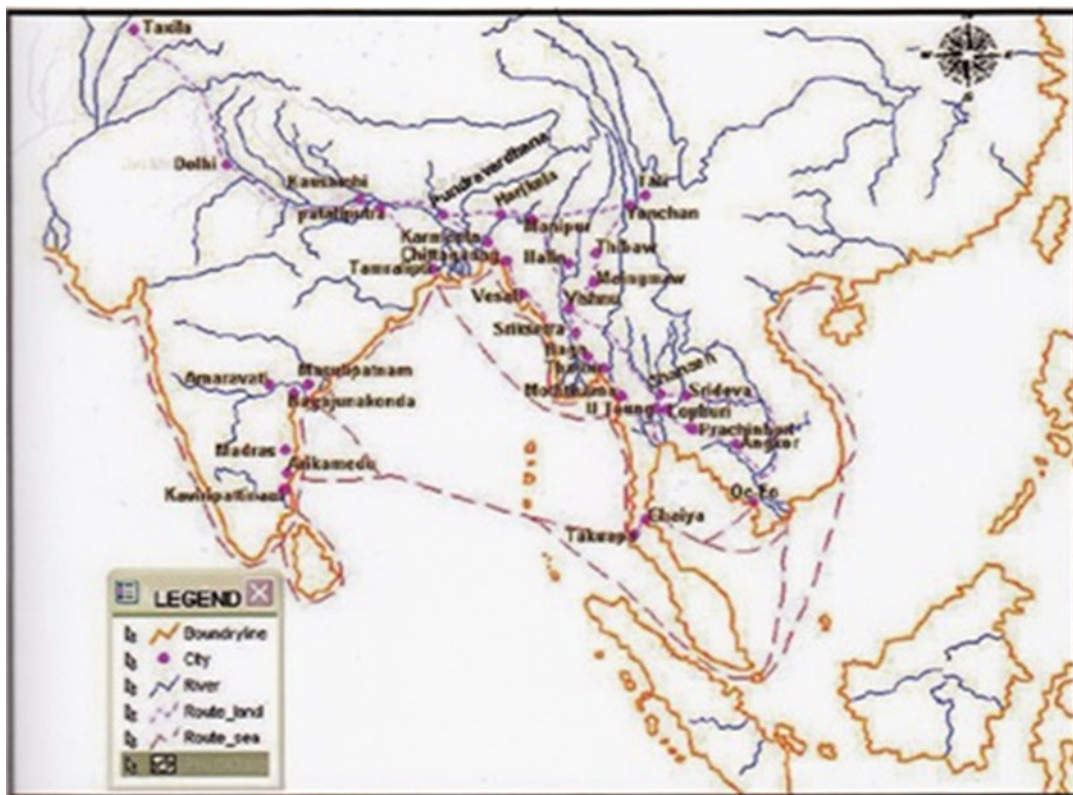
Ceramics in Burma, Fig. 12 Celadon (ash glaze) of Myanmar 15th–16th AD

was generally accepted that low temperature updraft kilns originated in ancient Egypt where low temperature glazes (with lead as flux) were produced in early 4000 BC. The use of tin as an opacifier in lead glaze was also noticed in the Middle East (Persia) since 1100 BC when tin-lead glazed bricks marked with the name of the Assyria king, Tiglath-Pileser, had been found. Therefore it could be deduced that low temperature glaze tradition originated in the Middle East and spread. For East-bound migration, possibly both overland and sea routes of the Silk Roads might have reached Myanmar (Figs. 13 and 14). However since early 109 BC the overland Silk Road had been the conduit for envoys from West (Persia) that might penetrate from India into Myanmar by two routes: one linked to China and the other to Thailand (Dvāravatī), Cambodia (Funan) and Vietnam (Annam). Both routes involved Ayeyawady River which is navigable all the way down to its delta.

Since tin-lead glazewares are hardly known in China, the tin-lead glaze tradition of Myanmar possibly came directly from Persia through the inland Silk Road. The presence of turquoise (alkaline) and opaque (tin-lead) glaze-coated



Ceramics in Burma, Fig. 13 The overland silk road



Ceramics in Burma, Fig. 14 Trade routes among Pyu, China, India and SEA in ancient period (Dr. San Shwe, 2008)

bricks inlaid on the eighth to ninth Century AD dated Pyu-type Ngakywenadaung pagoda and excavated finds of turquoise, green, olive green and brown (alkaline, tin-lead) glaze shards from updraft kiln No.1 of Bagan etc. support the technological connection with Persia although the products were locally made. Based on the ancient Chinese chronicles and practical reasoning, Di Crocco postulated that Pyu city with green glaze brick wall mentioned by eighth Century AD Chinese chronicles was some ancient city in the Bagan area. Chronicles also mentioned Pyu people use tiles of lead and tin, silver coins and traded or battered in glazed jars. Bawzaing mine extracted silver as early as sixth Century AD with lead slag as a by-product containing at least 30 % lead and a bit of tin. Therefore a very large glazed ceramics industry must have existed around that period. Since some time is usually needed to attain such production level it is envisaged that

Pyu potters might have started their industry much earlier, say fifth or sixth century AD.

High Temperature Glaze Tradition: The high-fired stoneware glaze technology was discovered in the Shang-Yin period (1500–1027 BC) as having its origin in China. Wood ash or lime was employed as a flux in combination with silica and feldspar to produce celadon firing in reduced atmosphere at about 1250–1300 °C in crossdraft kilns. It is believed that celadon technology might possibly have come into Myanmar directly from China through East-Northern route although we do not know exactly when. However there is an indication for probable existence of a celadon manufacturing tradition in Myanmar (Bagan) at about eleventh to twelfth Century (Di Crocco, 1990). In recalling the fact that celadon stoneware from Myanmar (Twante) were being exported to Egypt as early as fifteenth Century AD the said indication is quite plausible.

As mentioned earlier there were signs of active updraft kilns in Central Mainland Myanmar at about sixth Century AD it is quite relevant to assume the indigenous evolution of the updraft kiln into the crossdraft kiln. However there is not enough evidence of transitional kilns in hand yet. Until then a provisional assumption of Chinese connection for crossdraft kilns has to be maintained.

While updraft kilns were mostly situated in the central mainland, crossdraft kilns were widely spread along the outward area of the country such as Rakhine State; Ayeyawady, Yangon and Bago Regions; Mon, Kayin and Shan States. Inground kilns were mostly concentrated in the West and West-Southern parts producing lead and tin-lead glaze wares whereas surface kilns in East and East-Southern parts producing ash glaze (celadon) wares. When and why the whole celadon production (except Honar, Shan State) was stopped and why lead glaze tradition was dominated until now are questions still to be answered.

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Ceramics in China

Jiazhi Li, P. L. Leung, K. N. Yu and R. Wu

China was one of the earliest countries that possessed pottery, and was also the country that invented porcelain. She has a unique and sustained history of technique development of 10,000 years. The entire development can be summarized by five milestones and three technological breakthroughs. The outstanding achievements in this development constituted an indispensable contribution to Chinese culture (Table 1 and Map 1).

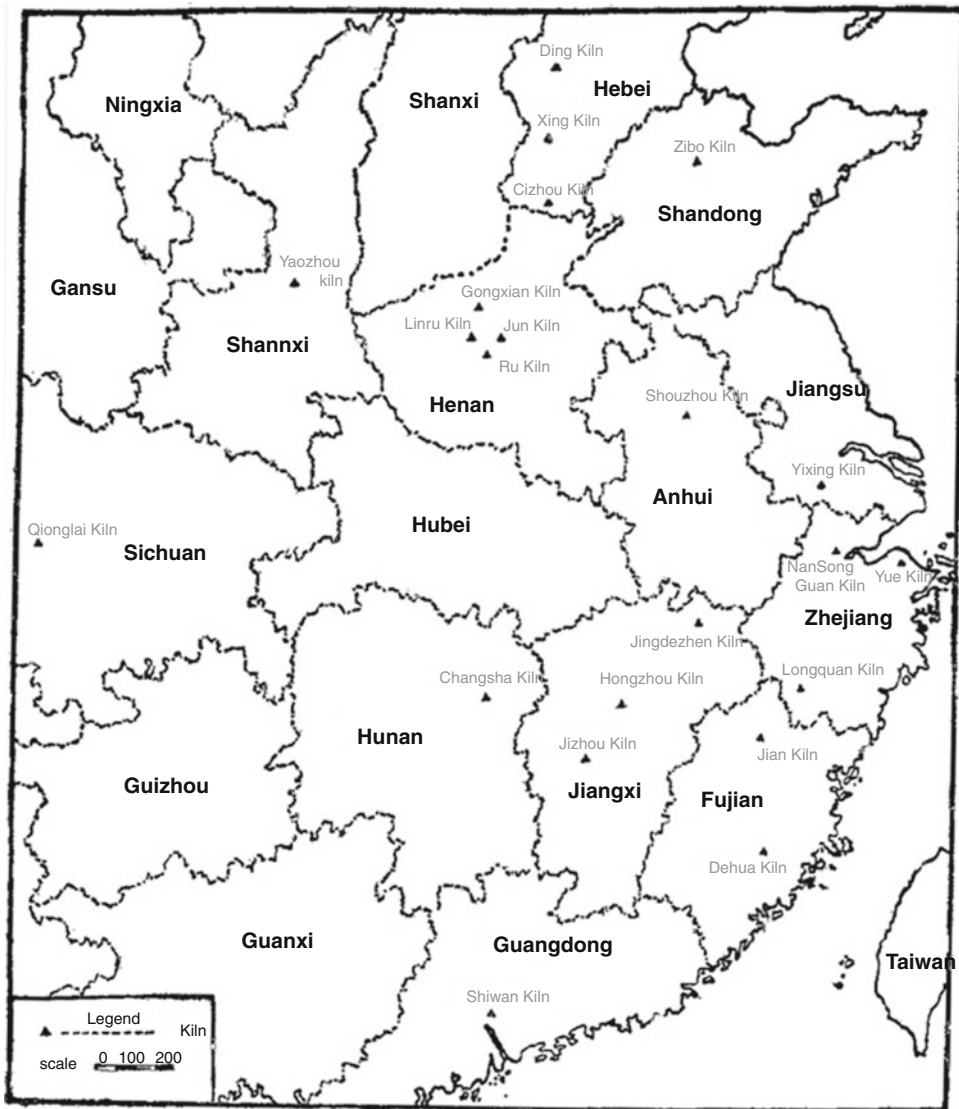
Five Milestones

The First Milestone: Appearance of Pottery in the Early Neolithic Age

According to archeological information, after the discovery of potteries of the Yangshao culture, the following were discovered:

Ceramics in China, Table 1 Chronology of ancient Chinese history

Neolithic period	6500–1700 BCE
Xia	2100–1600 BCE
Shang	1600–1100 BCE
Western Zhou	1100–771 BCE
Spring and autumn annals	770–476 BCE
Warring States	475–221 BCE
Qin	221–206 BCE
Han	206 BCE–AD 220
Three Kingdoms	220–280
Jin	265–420
Southern and northern	420–581
Sui	581–618
Tang	618–907
Five Dynasties and Ten Kingdoms	907–960
Sung	960–1279
Yuan	1279–1368
Ming dynasty	1368–1643
Hongwu	1368–1399
Jianwen	1399–1403
Yongle	1403–1424
Hongxi	1425–1426
Xuande	1426–1435
Zhentong	1436–1450
Jingtai	1450–1457
Tianshun	1457–1465
Chenghua	1465–1487
Hongzhi	1488–1505
Zhengde	1506–1521
Jiajing	1522–1566
Longqing	1567–1572
Wanli	1573–1619
Taichang	1620–1621
Tianqi	1621–1627
Chongzhen	1628–1643
Qing dynasty	1644–1911
Shunzi	1644–1661
Kangxi	1662–1722
Yongzheng	1723–1735
Qianlong	1736–1795
Jiaqing	1796–1820
Daoguang	1821–1850
Xianfeng	1851–1861
Tongzhi	1862–1874
Guangxu	1875–1908
Xuantong	1909–1911

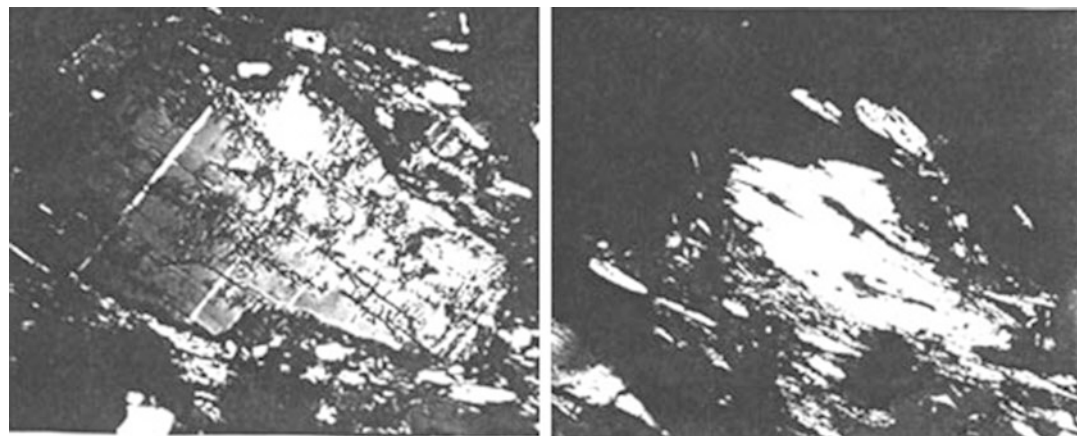


Ceramics in China, Map 1 Map showing the kilns in different provinces in China (Adopted from Chen, 1990)

- Those of the Hemudu culture in Yuyao, Zhejiang Province about 7,000 years ago
- Those of the Cishan culture and the Peiligang culture about 8,000 years ago
- Those of the Pengtoushan culture in Li County, Hunan Province and the Jiahu culture in Wuyang County, Henan Province about 9,000 years ago
- Those at the Yuchanyan site in Dao County, Hunan Province, the Xianrendong site in

Wannian County, Jiangxi Province, and the Nanzhuangtou site in Xushui County, Hebei Province about 10,000 years ago

The raw materials for early pottery were all obtained locally. In particular, a common feature for the pottery of about 10,000 years ago is that they were all coarse sandy pottery with coarse and loose textures, so most of them were only small shards when unearthed, and only very few



Ceramics in China, Fig. 1 Microstructure (70×) of sandy pottery from the Nanzhaungtou site in Xushui County, Hebei Province

Ceramics in China, Fig. 2 Microstructure (350×) of sandy pottery from the Xianrendong site in Wannian County, Jiangxi Province



whole pieces could be restored. Their firing temperatures were about 700 °C. For examples, pottery from the Nanzhuangtou site in Xushui County contained big grains of hornblende and vermiculite (Fig. 1), and pottery from the Xianrendong site in Wannian County contained large grains of quartz, dickite, and muscovite (Fig. 2; Li, Xianqiu, Zequn, et al., 1996). This also explained why the pots from the Nanzhuangton site contained more calcium oxide (lime, CaO) and magnesium oxide

(MgO), and those from the Xianrendong site contained more silicon dioxide (SiO₂) and potassium oxide (K₂O). In this way, the amounts of calcium oxide and silicon dioxide can be used as characteristic constituents to differentiate between pots manufactured in the northern part and those manufactured in the southern part of China. The microstructure of the black pottery including charcoal from the Hemudu culture was rather peculiar (Li, Xianqiu, Zequn, et al., 1978) and is shown in Fig. 3.

Ceramics in China,

Fig. 3 Microstructure (165 $\times$) of black pottery including charcoal of the Hemudu culture in Yuyao, Zhejiang Province



Ceramics in China,

Fig. 4 Microstructure (140 $\times$) of an early proto-porcelain of Western Zhou dynasty from Jiang Shan, Zhejiang Province



The Second Milestone: Successful Firing of Stamped Hard Pottery in the Late Neolithic Age and Appearance of Proto-Porcelain in the Shang-Zhou Dynasty

It is generally accepted that stamped hard pottery first appeared in the late Neolithic age about 4,000 years ago (which could be regarded as the Xia period according to dating results) and that proto-porcelains first appeared in the Shang dynasty. Stamped hard pottery had lower contents of iron oxide (Fe_2O_3) than general potteries. The firing temperature was above 1,000 °C, and the maximum temperature could reach 1,200 °C. Proto-porcelains had even lower iron oxide content; they were in general below 3 %.

The highest firing temperature reached 1,280 °C. There were glaze layers of nonuniform thicknesses on the interior as well as the exterior surfaces of proto-porcelains. The glazed layer could be a green glaze with a grayish green or yellowish green color, or a yellow glaze with a greenish yellow or brownish yellow color. Generally speaking, the glaze was not tightly bonded to the body and could be easily delaminated. The glaze contains relatively high contents of calcium oxide, and is thus called *calcium glaze*. This kind of glaze is a unique high-temperature glaze created in China and is the earliest high-temperature glaze in the world (Fig. 4; Li, Xianqiu, Fukan, et al., 1985).

Ceramics in China,

Fig. 5 Microstructure (405×) of the glaze of a green-glazed porcelain from the Yue Kiln, Xiaoxiantan, Shangkyu, Zhejiang Province



The Third Milestone: Appearance of Green-Glazed Porcelain (Celadon) in Southern China in the Han-Jin Dynasty

The successful firing of the southern green-glaze porcelains, represented by the Yue wares in Zhejiang Province during the late East Han dynasty (AD 25–220), signified another leap in the development of ceramic technique in China. Porcelains first appeared in the world from this period.

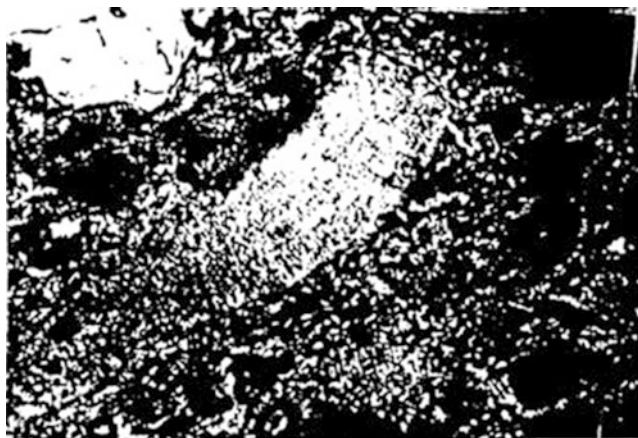
Porcelain differed from pottery in that the porcelain appeared to be stronger and more compact. Most were white; some had a grayish tint. Their cross-sections had a glass-phase luster and the thin layer was slightly translucent. They had relatively high contents of silicon dioxide and aluminum oxide (Al_2O_3) and smaller amounts of fluxing agents; they could be fired at higher temperatures and had higher strength. The porosity as well as the water absorption rate was very small. As regards their microstructure, they contained relatively larger amounts of glass phase as well as a certain amount of Mullite crystals. The quartz remnants were small and rounded. The appearance, chemical composition, physical properties, and the microstructure described above are the characteristics of porcelain. Yingxing Song (a famous scientist in the Ming dynasty) describes them as having the “...appearance of white flesh and jade skeleton” in his publication *Tian Gong Kai Wu* (Exploitation of the Works of Nature).

The success of green-glaze porcelains in southern China was primarily attributed to the rich reserve of China stone in the southern part of China. Since at that time only China stone was used as the raw material for porcelain, this led to the early quartz-muscovite series of porcelains with high silicon and low aluminum contents in southern China. The success of green-glaze porcelains could also be attributed to the techniques derived from extensive experience in firing the stamped hard pottery as well as the proto-porcelains.

We use as an example the shard from a green-glazed stamped *Ci Lei* (porcelain drinking vessel) unearthed from the Yue Kiln in Xiaoxiantan, Shangkyu, Zhejiang Province. The iron oxide and the titanium dioxide (TiO_2) contents in its body and glaze are relatively lower, and the titanium dioxide content in the glaze is particularly low. The firing temperature reached 1,300 °C. The body contains relatively larger proportions of the glass-phase. The quartz remnants are small and uniform, while Mullite crystals are ubiquitous. The glaze layer contains extremely small amounts of bubbles and quartz remnants. The glaze layer is a rather thin transparent glass glaze. The anorthite crystallization layer is common at the body-glaze interface, which strengthened the bonding strength of the body and the glaze (Fig. 5). The water absorption rate of the body is only 0.28 %, and the bending strength is as high as 71 MPa. Its chemical

Ceramics in China,

Fig. 6 Kaolinite remnant in the body of a white-glazed porcelain of the Xing Kiln (350 $\times$)



composition, microstructure, and physical properties perfectly satisfy the requirements for contemporary porcelains (Li et al., 1978).

The Fourth Milestone: Breakthrough of White-Glazed Porcelain in Northern China in the Sui-Tang Dynasty

The breakthrough in white-glazed porcelain in northern China in the Sui-Tang dynasty (AD 589–907) was the result of the rich supplies of high-quality raw materials in northern China as well as experience over a long period of time. Its occurrence was another leap forward in porcelain techniques in China, and made China the first country to possess white-glazed porcelains (Li et al., 1985).

The techniques required by the white-glazed porcelains of Xing, Gong, and Ding Kilns are summarized below.

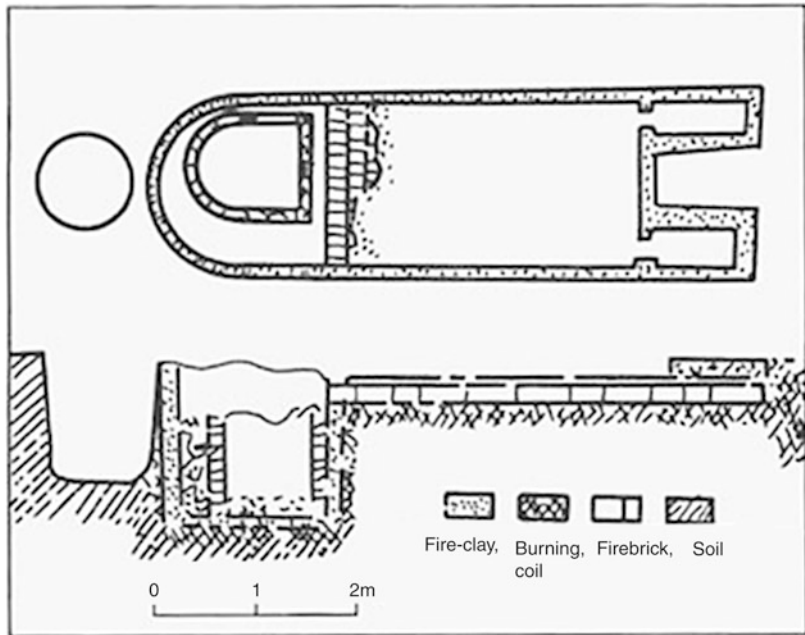
Use of New Materials and Improvements in the Recipes for the Body and Glaze

All the bodies of white-glazed porcelains of the Xing, Gong, and Ding Kilns made use of secondary settled clay with higher contents of kaolinite or kaolin clay, so their bodies contained more than 30 % of aluminum oxide. Figure 6 shows the microstructure of the body of a white-glazed porcelain of the Xing Kiln, in which a kaolinite remnant can be seen. Furthermore, feldspar was found in the recipes of the body of some white-glazed porcelains, and the potassium oxide content in these bodies could be above 5 %.

According to the silicon dioxide contents and α -quartz contents in the microstructure of the bodies, it can be inferred that the kaolin-quartz-feldspar porcelains emerged in the Sui and Tang periods in China. These were not found in the southern green-glazed porcelains. Even when kaolin clay started to be used for the Jingdezhen white-glazed porcelains during the late Song and early Yuan dynasties, these were only kaolin-quartz-muscovite porcelains. These two types of porcelain represented the two major white-glazed porcelain systems in northern and southern China. For some white-glazed porcelains of the Sui dynasty, the potassium oxide content far exceeds that of calcium oxide, the glaze of which is referred to as the alkali-calcium glaze. This is also never seen in the southern early green-glazed porcelains, and only starts to appear in the Jingdezhen sweet white-glazed porcelains during the Yongle period of the Ming dynasty and the Dehua white-glazed porcelains during the Qing dynasty.

Increase in the Firing Temperature and Improvement of the Kilns

The firing temperatures of white-glazed porcelains of the Xing, Gong, and Ding Kilns of the Tang dynasty reached 1,300 °C, and some reached as high as 1,380 °C. The increase of the firing temperature was certainly linked to the improvement of the kilns. The kilns used for the northern white-glazed porcelains in the Sui and Tang periods were up-draught Mantou kilns

Ceramics in China,**Fig. 7** Qichun relics of a Xing Kiln in the late Tang period

(Fig. 7). The improvements included big firing chambers, small kiln chambers, and double chimneys, which increased the drag force to enhance the firing temperature.

Use of Saggars and Improvement in Firing Techniques

The firing of Xing Kiln white-glazed porcelains during the late Sui and early Tang dynasties already made use of saggars (a sagger is a case made of fired clay in which porcelain and similar delicate items are enclosed while they are being fired in the kiln) for assembling and firing. The transition from open firing to firing in saggars was a breakthrough to enhance the quality of porcelains. This kiln was one of earliest ones which employed devices for firing in saggars, and possessed various saggars as well as various techniques according to the different forms of porcelains.

The Fifth Milestone: Time of Monochrome-Glazed, Polychrome-Painted, and Sculpted Porcelain from the Song to Qing Dynasty

All the famous porcelains from the Song dynasty to the Qing dynasty (AD 960–1911), such as the imperial wares, Ge wares, Jun wares, Ru wares,

Yaozhou wares, Linru wares, Cizhou wares, Jizhou wares, Longquan wares, Jian wares, Changsha wares, Qionglai wares, Dehua wares, Yixing wares, and the later Jingdezhen wares, were all world famous for their monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains. These porcelains illustrated the great achievements in the sciences, techniques, and arts needed for Chinese porcelains.

Starting from the late East Han dynasty, the Zhejiang Province had been firing celadon with iron oxide as the colorant. Until the South Song dynasty, the black body celadons manufactured in its imperial kiln and the Longquan kiln were crystallization-phase separation-crackle-glaze porcelains. These porcelains made use of the microcrystals of Anorthite and the immiscible liquid droplet separated from the glaze to enhance the jade-like appearance, and exploited the different expansion coefficients of the body and the glaze to generate cracks with different patterns and to become a unique world famous decoration. On the other hand, the white-body celadons were manufactured in the Longquan kiln in large numbers and were

transported to different places in the world and have been collected by all major museums.

The celadons from the Ru Guan kiln and Linru kiln of Baofeng in Henan Province, as well as those of the Yaozhou kiln of Tongchuan in Shaanxi Province, also used iron oxide as the colorant. These porcelains also enjoyed a very good reputation in the world. The celadons from the Ru Guan kiln were particularly precious due to the short manufacturing periods and their small handed-down number.

Black-glazed porcelains emerged almost at the same time as the celadons. All the famous kilns in north and south China manufactured this kind of black-glazed porcelain from time to time, which used iron oxide as the main colorant. With the arrival of the Song dynasty, the techniques in manufacturing black-glazed porcelains had been significantly improved. The most unusual products included the hare's fur bowl of Jianyang, Fujian Province and the black-glazed bowl of Jizhou, Jiangxi Province. These developments were partially attributed to the habit of drinking tea at that time, and partially to the availability of the extremely complicated technology, which was unique in the world. The "hare's fur" was formed by crystallization and then phase separation (or direct phase separation), and then by recrystallization. Under different environments, products with different colors, such as the golden hare's fur and the silver hare's fur, can be formed (Chen, Shiping, Ruifu, et al., 1983a, 1983b). Among these, the fur streaks of some will display different colors in the optical spectrum, which can interchange with each other when observed from different angles. This product is called *Hao Se Bian Yi* bowl (hare's fur bowl with alterable colors), which is a product of the science and technology that integrated the phase separation and crystallization in physical chemistry and thin-film interference or diffraction grating in physical optics. The Hao Se Bian Yi cup transported to Japan was called the *Yohen Temmoku* and was considered a national treasure.

The glaze of the Jun kiln in Yu County, Henan Province was a new product. It was a red glaze colored by copper compounds, or a multicolor glaze with nonuniform red patterns distributed

on a bluish opalescent glaze surface with different tints. The blue Jun glaze was not colored by cobalt oxide, but was caused by the stronger scattering of the blue light with a shorter wavelength by the liquid droplet phase which fulfilled the size requirement for Rayleigh scattering. (Rayleigh scattering refers to the scattering of light off of the molecules of the air, and can be extended to scattering from particles up to about a tenth of the wavelength of the light. It is Rayleigh scattering off the molecules of the air which gives us the blue sky.) In other words, this was a kind of physical coloration. The copper-colored liquid phase droplets and cuprite formed the red patches, while the purple streaks were formed by the bluish polycrystals of chalcocite (Chen et al., 1983a, 1983b). The phase separation of the Jun kiln glaze was a physicochemical process taking place within a range of chemical compositions and under the actions of the firing temperature, atmosphere, and time. Because of complicated factors, it was difficult to control the formation conditions, so the appearance of the products could not be controlled easily; this was referred to as furnace transmutation.

Starting from the white-glazed porcelain manufactured in the Five Dynasties to the bluish-white-glazed porcelains in the Song dynasty, Jingdezhen has been one of the greatest kiln sites in terms of quality, quantity, and impact. Before the Yuan dynasty and the early Ming dynasty, there had been ground-breaking developments in the techniques required for Jingdezhen porcelains. The white-glazed porcelains of Shu Fu (Center government in Yuan dynasty) and the sweet white-glazed porcelains of the Yongle period were not only superb in terms of the quality and appearance, but also provided sound techniques and physics foundations for the further manufacturing of monochrome-glazed porcelains and polychrome-painted porcelains. Starting from the Yuan dynasty, Jingdezhen started to fire the blue-and-white underglaze colored by cobalt oxide and the red underglaze colored by copper oxide (CuO), as well as the blue-and-red. This started the manufacture of products with polychrome high-temperature underglazed colorants. In particular, the blue-and-white

porcelains were a unique long-lasting product with the largest sales in Jingdezhen. Furthermore, the different colors created by various metal oxides, such as iron, cobalt, copper, manganese, and their combinations, were the basis for the vibrant color-glazed porcelains from Jingdezhen. At the same time, overglazed painted porcelains started to emerge. When it came to the middle of the Ming dynasty, firing of the so-called *doucai* porcelains was successful, which incorporated the underglazed blue-and-white as well as overglazed paint. The best painted porcelains in the Ming dynasty were the *doucai* porcelains in the Cheunghua period, which were famous for their vibrant colors, white and moist appearance of the glaze, vivid patterns, and intricate skill work. They were collected in all major museums as well as by private collectors. In the Qing dynasty, there was another type of low-temperature overglazed painted porcelain called *wucui*. These were most famous during the Kangxi period. The subsequent *fencai* porcelains in the Yongzheng period also received great admiration.

After the Ming and Qing dynasties, major kilns all over China perished or stopped manufacturing, except that Jingdezhen kept firing its own colorful porcelains in large quantities and was able to imitate the products from other major kilns. In this way, Jingdezhen became the porcelain center in China and was nicknamed the “Porcelain City.”

The Dehua kiln in Fujian Province, which was developed some time later than the Jingdezhen, was also world famous for its high-quality white-glazed porcelains and sculpted porcelains. The semitransparent bodies of Dehua white-glazed porcelains, due to the relatively larger proportion of glass and the very thin glaze layer, made the Dehua porcelains uniquely bright.

Before the emergence of the polychrome underglazed painted porcelains in Jingdezhen, the dark brown underglazed painted porcelains colored by iron minerals and those colored by copper materials had already appeared in the Changsha kiln in Hunan Province and the Qionglai kiln in Sichuan Province during the Tang dynasty. These successes had far-reaching influences on the painted porcelains in

later generations. When it came to the Song dynasty, the painted porcelains manufactured by all the kilns in the Cizhou ware type in northern China reached another height. Since these were all folk kilns, the portrayed patterns were all derived from the daily lives of the general public, so the patterns had rich flavors of folk lives, which were in great contrast to those of the imperial wares with many more restrictions. These folk wares also created unique decorations which did not exist in the wares from other kilns.

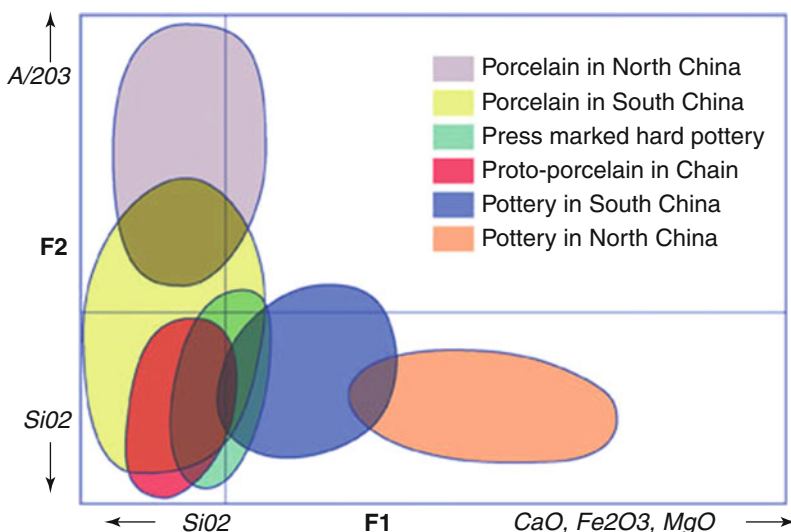
From the proto-porcelains at the second milestone to the monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains at the fifth milestone, porcelains dominated the history of Chinese ceramics. Interestingly, however, in Yixing, Jiangsu Province, which was also known as the *pottery city*, a world famous pottery called *Zisha pottery* (purple stone ware) has been manufactured since the Song dynasty.

Zisha pottery had many unique features. First, it was especially designed for tea drinkers. The most famous as well as the most manufactured products were teapots with various unique and beautiful forms. Second, it was derived from a unique raw material. The Yixing region is extremely rich in different kinds of Zisha minerals, which were used to produce Zisha pots with different colors. Third, most of the Zisha pottery were handmade, and made use of different tools in the manufacturing process, which fully reflected the wisdom and the skills of the pottery masters. Fourth, the decorations of the Zisha pots were unique in that they integrated the form, painting, poems, calligraphy, and seal cutting, and were thus very rich in Chinese culture characteristics. Starting from the Ming dynasty, there were great masters who made long-lasting famous pots. Therefore, Zisha pottery played a role in the fifth milestone.

When Chinese ceramic techniques developed into the fifth milestone, Chinese ceramics no longer referred to a single region or a particular monochrome-glazed porcelain. Instead, they included the monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains from different kilns in both southern and northern China.

Ceramics in China,

Fig. 8 The scatter plot of the F1 and F2 factors for the chemical composition of the bodies of Chinese ancient ceramics



Three Technological Breakthroughs

The five milestones described above relied on continuous breakthroughs in firing techniques. The latter can be summarized as described below (Li, 1978a, 1978b).

Selection and Refinery of Raw Materials

The raw materials of pottery in general, particularly the early ones, came from the local soil. Therefore, the soil around the residences of early people became the raw materials for firing their pots. Since most of these people resided near hills or close to water sources, the collected raw materials were, in general, soils containing different sand grains. Early pottery was mostly sandy, containing different types of sand grains with different sizes. Strictly speaking, these soils were not suitable for firing pots. After a relatively long period of time, the people became aware that some soils might be more suitable for firing, and they started to select these soils for their pots. In other words, the people started to select the soils locally and clay pottery appeared as a result. When the people discovered that using a particular clay could not satisfy the requirements for forming, drying, and firing, they added different sand grains, ashes of vegetation, and shells of corn, as well as ashes of shells, etc., to get pottery including sand, charcoal, or mussel. The black

pottery including charcoal from Hemudu culture was a typical example (Fig. 3).

The raw materials for the stamped hard pottery, proto-porcelains, or even celadons and white-glazed porcelains were still selected locally. However, the people had higher standards for the suitable raw materials. This explained why the stamped hard pottery, proto-porcelains, and celadons were first successfully fired in some regions in southern China, while the white-glazed porcelains were first successfully fired in some regions in northern China. All in all, the raw materials derived from regions which were only suitable for particular types of ceramics.

Differences in raw materials will be reflected by the different chemical compositions of the ceramics. Principal component analyses have been performed on the chemical compositions of the bodies of 700 pieces of ancient ceramics spanning from the Neolithic Age to the Qing dynasty. The cumulative variance explained by the first three principal factors (F1, F2, F3) was more than 80 %. Figure 8 shows the factor loadings of F1 and F2.

From Fig. 8, we can clearly see the changes in the chemical compositions of ceramics in southern China. During the development from the stamped hard pottery to the proto-porcelains and then to porcelains, the silicon dioxide in

Ceramics in China, Table 2 Changes in the firing temperature of ancient ceramics

Product	Sample number	Highest firing temperature (°C)	Average firing temperature (°C)
Pottery	15	1,000	920
Stamped hard pottery	55	1,200	1,080
Proto-porcelain	37	1,280	1,120
Porcelain	146	1,380	1,240

the bodies increased gradually while the fluxing agents calcium oxide, magnesium oxide, and particularly iron oxide decreased. The contents of aluminum oxide did not change much until after the Song dynasty when the aluminum oxide contents increased due to the use of kaolin clay. The chemical compositions of the ceramic bodies had overlaps, which demonstrated their close relationships. However, the ceramics from northern China did not have this pattern. The northern Chinese pottery came from an area with high fluxing agents and low silicon dioxide contents, while the porcelains were in an area with low fluxing agents and high aluminum oxide contents. This is explained by the use of clay which is more readily melted as the raw material for the former and the use of clay with kaolinite as the raw material for the latter. The two regions were well separated, which showed that they had no relationships with each other. The chemical compositions of the small number of stamped hard pottery and proto-porcelain unearthed in northern China did not show any transitional zone between the two regions, so no relationships between their chemical compositions can be inferred. It can be said that the development from pottery to porcelain took a different path in northern China. However, the development from pottery to porcelain together with continuous improvements in their quality was primarily attributed to the selection and refining of raw materials. The raw materials were the fundamental substances for firing the ceramics.

Improvements of Kilns and Increase in Firing Temperatures

According to the vast amount of experimental data obtained for firing temperatures from

ancient ceramic shards, it can be concluded that there were two breakthroughs in firing temperature. The first one was realized for the firing of stamped hard pottery in the Shang and Zhou dynasties. The highest firing temperature of 1,000 °C and the average value of 920 °C for pots were increased to 1,200 and 1,080 °C, respectively. The second one was realized for the firing of white-glazed porcelains in northern China in the Sui and Tong dynasties. The highest firing temperature of 1,280 °C and the average value of 1,120 °C for proto-porcelains were increased to 1,380 and 1,240 °C, respectively, for white-glazed porcelains, the latter being the highest firing temperature for porcelains in the history of China. Table 2 summarizes the statistical data for the experimentally determined firing temperatures for pottery and porcelains.

From the archeological data for kilns, we can conclude that pottery from the early Neolithic Age might be fired without kilns, i.e., firing on the ground. Kilns were found from the Jiahu and Peiligang cultures. Kiln firing might have started later in southern China. After a long period of development and improvement, the dragon kiln and the chamber kiln with chimneys appeared during the Shang period in Zhejiang and Jiangxi Provinces. The stamped hard pottery and the proto-porcelain were fired in such kilns. The upward slope and the length of the dragon kilns, as well as the chimney of the chamber kilns, increased the drag force, thus enabling the rise in the firing temperature. This was the first breakthrough in the kiln structure, which facilitated the first breakthrough in raising the firing temperature.

In the Sui and Tang dynasties, big firing chambers, small kiln chambers, and multiple chimneys



appeared in Hebei Province in northern China. As seen from the above, improvements in the kilns were closely related to the increase in firing temperatures.

Invention and Development of Glaze

The earliest glaze which was transparent, bright, and which did not absorb water was the glaze for the proto-porcelains fired in the Shang dynasty more than 3,000 years ago. Therefore, glaze must have been created before the Shang dynasty.

It is well known that the proto-porcelains and the earliest porcelains were fired in southern China. Recently, a large amount of clay-glazed black pottery prior to the Shang period has been discovered in ancient kilns and tombs, and *Tao Yi* (pottery coat) has been discovered on the surface of colored pottery from the early Neolithic era in southern China. The creation and development of glazes in China can be divided into the following four stages, according to their chemical composition, microstructure, and appearance:

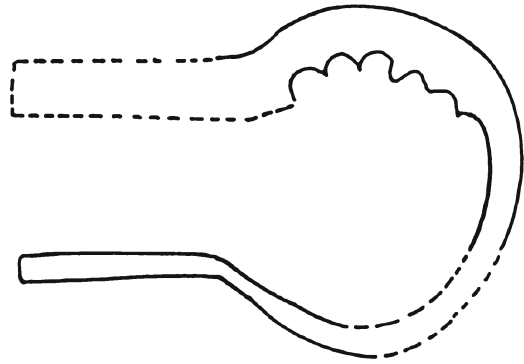
1. Breeding period of glaze – Shang dynasty
2. Formation period of glaze – Shang and Zhou dynasties
3. Mature period of glaze – Han, Jin, Sui, Tang, and Five Dynasties
4. Flourishing period of glaze – from the Song to Qing dynasties (Li, 1983)

Similar to the five milestones, the three technological breakthroughs signified improvements and achievements during the 10,000 years of history from the Neolithic Age to the Qing dynasty.

Contribution to Chinese Culture

Chinese ceramics have a long history, rich technological and arts contents, and are highly acclaimed all over the world. The contribution of ceramics to Chinese culture can be briefly summarized:

1. The early pottery was based on very simple techniques. Pottery techniques were an



Ceramics in China, Fig. 9 Schematic diagram showing the relic pottery kiln T31 in the Peiligang in Xinzheng, Henan Province

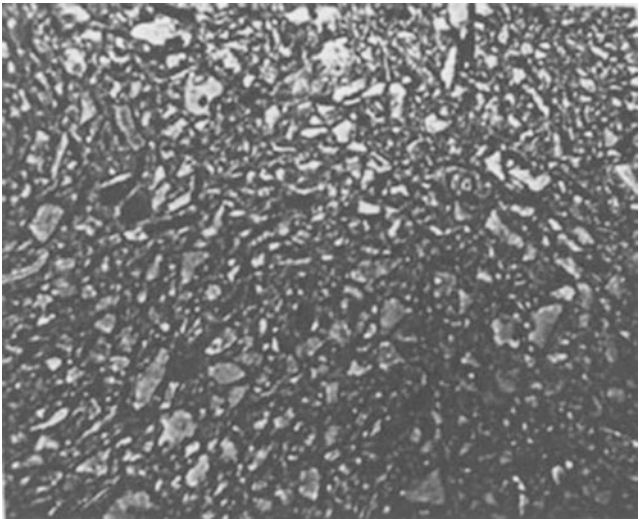
integral part of Chinese culture. These techniques were made up by the three stages of raw material selection, forming of the wares and the firing of the pottery. The basic ideas behind the whole set of techniques developed more than 10,000 years ago; they have been used until now, and have laid the foundations of ceramic industries in later generations. With pottery cooking utensils, the people could enjoy cooked food, which enhanced their quality of life. This is important not only for the Chinese culture, but also for world culture.

2. The Chinese culture is one of the four ancient cultures in the world (China, India, Near East, and Greece) that has been sustained until today, with the development of Chinese ceramics as an example of its sustainability.
3. Pottery kilns appeared in the relics of Peiligang in Xinzheng (Fig. 9) and Jiahu in Wuyang in Henan Province about 8,000–9,000 years ago (Kaifeng Managing Committee of Cultural Relics & Xinzheng Managing Committee of Cultural Relics, 1978; Zhang, 1999). These kilns proved that China was one of the first places to fire pottery in kilns. The appearance of kilns enabled the increase in the firing temperature (Table 3). This greatly enhanced the quality of the Peiligang pottery (Fig. 10) and at the same time enabled the first effective step in the history of high-temperature processes for mankind.

Ceramics in China, Table 3 Firing temperatures of some early porcelains from the Neolithic Age

Sample number	Unearthed site and layer	Firing temperature (°C) ±20
1-64WXT ₅ ④	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (fourth layer)	810
2-62WXT ₃ ③	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (third layer)	740
12-64WXT ₄ ②	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (second layer)	800
15-64WXT ₄ ②		840
6-99WXE ₁₀ N ₁₂ ·2A		780
18-64WXT ₆ ①	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (first layer)	800
13-93WXE ₁ N ₁₂ ·1A		740
	Sandy pottery from Zengpiyan in the Guilin of Guangxi	680
	Sandy pottery from Qingtang in the Yingde of Guangdong	680
EN2	Clay pottery of Peiligang in Xinzheng in the Henan Province	910
EN3	Sandy pottery of Peiligang in Xinzheng in the Henan Province	920
EN4		820

Ceramics in China,
Fig. 10 Microstructure of a clay pottery of Peiligang in Xinzheng, Henan Province (70×)



4. Figure 10
5. Table 3
6. Slow wheel trimming for pottery appeared in the middle of the Yangshao culture, 4,000 years ago. Fast wheel trimming occurred during the Dawenkou culture. The fast wheel is also called the *potter's wheel*, which is the rudiment of the jolley (a mold to produce uniform hollow ware) used today. The fast wheel was a necessary requirement to throw as well as trim, and was instrumental in enhancing both the quality and the quantity of the products. The appearance of the fast wheel reflected the use of wheel shaft machines as well as the effects of inertia in manufacturing pottery, which inspired machining processes in later generations.
7. Early pottery contained certain amounts of sand grains with different sizes. Some of these sand grains occurred naturally in soils,

while others were purposely added. The latter ones were referred to as *Chan He Liao*. For example, the burned vegetation found in Hemudu pottery was purposely added (Fig. 3; Li et al., 1978). These additions were used to mitigate the contraction of clay during drying and firing, which served the same purpose as the clinker (a hard brick used as a paving stone) does today.

8. Pottery can be both containers and tools. Earthen spinning wheels, net weights, pills, and casts have been found in many relic sites of the Neolithic Age, which were tools for textiles, fishing, and pottery manufacturing. Despite the very simple forms, these served as the first examples of using pottery as tools, and demonstrated that pottery was an indispensable material in human lives. In particular, the earthen pills and earthen net weights not only signified the exploitation of elastic stress and gravity machines in the manufacturing process, but they also illustrated that pottery needed chemical reactions, which were unlike stone wares which needed only physical processing. This was pioneering in the chemical industry.
9. Pottery was the earliest product integrating technology and arts. Colored pottery was discovered in Jiahu in Wuyang, Henan Province as well as in Hemudu, Yuyao, Zhejiang Province. Colored pottery and pottery statues were also found for the late Neolithic Age. These not only showed the artistic talents of the people, but also reflected their daily lives. For example, carved symbols were found on pottery from the relic site of Jiahu, which provided information on the emergence of Chinese words. Colored pottery was an ancestor to polychrome-painted porcelains in later generations; pottery statues were ancestors to sculpted porcelains.
10. The crucibles for alloy melting for bronze wares and the pottery moulds for casting illustrate the required skills for techniques. The emergence of pottery kilns and the attainment of higher firing temperatures as a result of the improvements in the kilns facilitated the development of bronze wares and thus the early arrival of the bronze-ware era. The early pottery marked the start of the Neolithic Age, but improvements and extended applications played an indispensable role in marking the end of the Neolithic Age and in marking an unacknowledged ceramic Age.
11. Porcelains are recognized as one of the greatest inventions in China. The manufacturing techniques of porcelain masters in different times were adopted by different countries in Europe and Asia, which had significant influence on the manufacture and the development of porcelains in certain countries in the world.
12. One of the main reasons that the Jingdezhen porcelains could survive and their quality improve was that the recipe contains kaolin clay and its percentage kept increasing. The good quality of the white-glazed porcelains from the Xing Kiln in northern China starting from the Tang dynasty was also attributed to kaolin clay. Firing of hard porcelains in Europe was also successful after the use of kaolin clay. China was the first country to discover kaolin clay. The terms *kaolin clay* and *kaolinite* were translated from Chinese.
13. The famous porcelains manufactured in various areas in China not only satisfied the needs of different people in China, but were also exported in large quantities or used as precious gifts. These exquisite porcelains, as part of Chinese culture, were thus dispersed to different areas in the world. This inspired their techniques and at the same time built the reputation of Chinese porcelains over the world.

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Ceramics in Korea

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Korean ceramics is a culture that has been close to the hearts and minds of Korean people throughout its history. In many parts of the country, one can still touch the centuries-old remnants of everyday bowls and dishes and even artistic masterpieces. For those who seek them out by research or consulting with experts and village elders, waste mounds of shards and dragon kilns are invariably found on sunny mountain slopes with flowing brook water nearby. Such artifacts reveal many details of the forming, designing, and firing methods of traditional Korean ceramics.

Today, Korean ceramics is enjoying an active phase of development. For the first time, all four major types of pottery – *togi*, celadon, *punch'ŏng*, and whiteware – are produced simultaneously in numerous studios. With the continued unearthing of kiln sites in major excavations have come new

theories about the rise and development of Korean ceramics history. The overseas museum space dedicated to exhibiting ceramic art pieces has increased noticeably in the last decade. Special fairs, biennales, and competitions are held in many locations that attract both Korean and international audiences. The World Ceramic Biennale, held in 2005 for the third time in the greater area of Kwangju (near Seoul; this was the center of ceramic activities during the Chosŏn dynasty), is developing as an important event for ceramic arts and crafts.

Coming of Age for Korean Hard-Paste Porcelain

Among countless types of ceramic products that make ceramic culture ubiquitous, the position held by Korean porcelain and stoneware is due to their hard-paste raw material. Korea and China were the first countries to possess the know-how for using this material, readily available in nature, and obtaining the necessary firing power for its proper vitrification (forming a glassy or noncrystalline material). Although the dates are still being debated actively among ceramics scholars, a long tradition of making high-fired unglazed stoneware, called *togi*, enabled Korea to adopt porcelain technology from China sometime between the early ninth and late tenth centuries. The making of refined teabowls must have been a strong motivation for the import of the technology because shards of such bowls are found in abundance in early kiln sites. The Japanese porcelain industry began only after many Korean potters were taken to Japan during the Hideyoshi Invasion (1592–1598), which is also known as the Ceramics War or the Tea Bowl War.

While China and Japan benefited enormously from the export of their porcelain wares to Europe until the technology successfully developed there in the eighteenth century, Korea maintained its unique aesthetics that were appreciated mainly within East Asia. Never developing the overglaze that was so popular in Europe, Korea produced one major type at a time: *togi*

up to the Unified Silla Kingdom (AD 668–935), celadon during the Koryŏ dynasty (AD 918–1392), and *punch'ŏng* and then more commonly whiteware during the Chosŏn dynasty (AD 1392–1910). Although several other types were also produced – including a substantial amount of white teabowls in the initial stages of porcelain technology, a small amount of black temmoku type, and a very small amount of ware known as Chosŏn celadon with white body and celadon-type glaze – the linear sequential development of the four major types is undeniably the predominant feature of Korean ceramics history.

It is not surprising, therefore, that Korean ceramics remained largely unknown in the world, as attested by Bushell's report in his comprehensive 1896 book *Oriental Ceramic Art*. "Korea has been thoroughly explored during the last few years, and it is now known that no artistic pottery is produced there in the present day, and no indisputable evidence of any original skill in former times has been discovered." Within a decade of this report, an enormous amount of porcelain (including thousands of pieces in many shapes and types) was unearthed during the building of railroads. Many accolades were bestowed on Koryŏ *pisaek* celadon as early as the twelfth century. For example, a Song connoisseur, Taipyŏng Noin, said they were the "First Under Heaven," and a famous calligrapher envoy to Korea, Sŏh Keung, referred to the celadon as being very refined with workmanship surpassing that of the Yüeh kiln (in China). The isolation of Korea from development in other parts of the world resulted in the unique characteristics of simplicity and quietness that today are acclaimed as the quintessence of oriental spirit.

Togi Up to the Unified Silla Kingdom

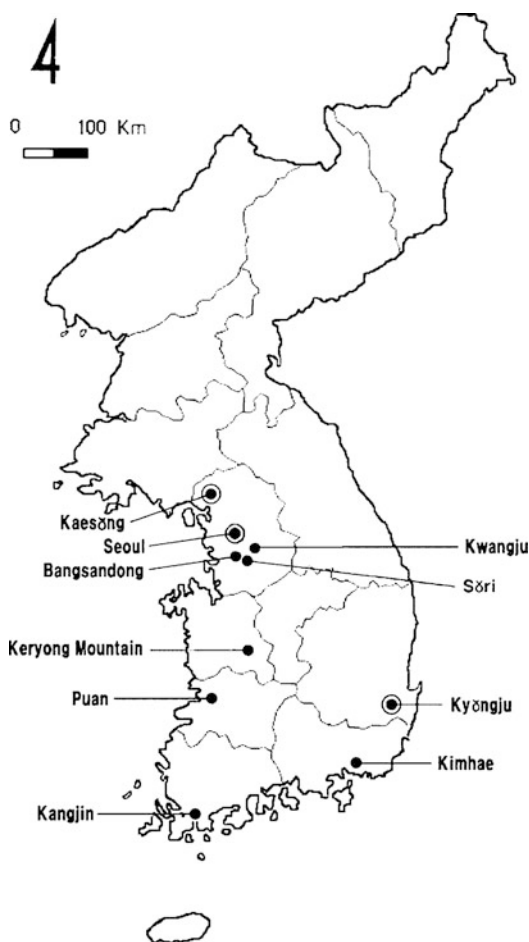
The term *togi*, with a literal meaning of earthenware or clayware, is used inclusively for a wide variety of mostly unglazed earthenware or stoneware produced from the beginning of the Neolithic Age (ca. 6000–1000 BCE) through the Bronze and Iron ages (ca. 1000–0 BCE), the proto-Three Kingdoms period (ca. AD 0–300),



Ceramics in Korea, Fig. 1 Long-necked jar. Black pottery. Excavated at Kijong-dong, Taejeon. Bronze Age. National Museum of Korea, Seoul

the Three Kingdoms period (ca. AD 300–668; Koguryo in the north, Paekche in the southwest, and Silla in the southeast), and much of the Unified Silla Kingdom. On a much smaller scale, the production of *togi* continued during the Koryŏ and Chosŏn dynasties. One of the oldest Korean ceramic wares known today, a reddish comb-patterned jar with a pointed bottom, is carbon dated to 5770 BCE. Red and black (Fig. 1) pottery from the Bronze and Iron ages attests to the high-level technology and aesthetics that the ceramic culture already obtained. These soft-textured wares were painted with iron pigments and burnished and most likely fired in an open pit.

By the end of the proto-Three Kingdoms period around the fourth century, two breakthroughs allowed the technology to become much more sophisticated and efficient. The potter's wheel was introduced, and the knowledge of high firing power, originally developed for bronze and iron casting, was applied to ceramics production. The type of dragon kilns and the method of reduction firing that Korea used continuously throughout its ceramics history were developed at this date. The *togi* fired in this way was highly vitrified and hard textured to the extent that it rings like porcelain when struck with the fingers. These wares were colored usually blue gray or black gray.



Ceramics in Korea, Fig. 2 Map of Korea with historically important kiln sites and capital cities of different dynasties. Kaesŏng is the capital city of the Koryŏ dynasty (AD 918–1392), Kyŏngju that of the Unified Silla Kingdom (AD 668–935), and Seoul that of the Chosŏn dynasty (AD 1392–1910) as well as modern Korea

The first of these grayish stonewares is known as Kimhae ware after the southeastern area where they were first produced (Fig. 2). Kimhae prospered as an independent state known as Kaya until absorbed into Silla in the sixth century, and the highly vitrified *togi* characteristic of this area is also referred to as Kaya *togi*. Such ware became more refined and was produced in such vast amounts during the Three Kingdoms period and Unified Silla Kingdom that they are found in abundance even today.

The forms of the *togi* bowls and jars already possess the elements of beauty that characterize

Korean ceramics in general, especially the slender gracious line of Koryŏ *maep'yŏng* and the voluptuous roundness of Chosŏn whiteware jars. Both of these elements make the Kaya pedestalled jars, usually with lids, very attractive. The tall and short pedestals are basic components in much of the *togi* form. Shaped either as part of the whole ware or separately, they often have beautiful contours.

The naturalistic forms of humans, animals and birds, transportation means, and houses were favored motives both as shapes and as decorations. There were many varieties of warriors mounted on horses or carriages (Fig. 3). A roof-end tile, in spite of its monstrous appearance, stimulates the feeling of warmth that is a hallmark of Korean ceramics (Fig. 4). A handsome inkstone is a forerunner of small equipment for calligraphy, which was made both in the Koryŏ and Chosŏn dynasties (Fig. 5). A Silla long-necked jar is decorated with many symbols of fertility and well-being, such as figurines of a snake, a frog, a bird, a duck, a turtle, a woman playing a *kayakum* (a traditional musical instrument), and a man and a woman engaged in a sexual act.

The Unified Silla wares with lead and tricolored glazes of the Tang style are rare examples of low-firing glazes, because they were discontinued in the following Koryŏ dynasty (Figs. 6 and 7). Why Korea stopped this line of development and never adopted or developed the lead-containing materials for overglaze decoration that became so popular and profitable in China and Japan is one of the most interesting questions concerning the Korean ceramics industry.

Some later *togi* wares were glazed, often only partially, but this occurred due to ash falling on them unintentionally in the process of wood firing. Recent excavation of an eighth- to ninth-century *togi* site at Kurimni in the southwestern area near the important celadon centers of Kangjin and Haenam offered some circumstantial evidence of glaze being intentionally applied. Such a suggestion is a topic of interest, because it raises the possibility that celadon technology might have arisen indigenously within Korea.

Ceramics in Korea,

Fig. 3 Ceremonial vessel in the shape of mounted figures. Excavated at Tomb 127 (the Gold Bell Tomb) in Nodong-dong, Kyŏngju. Three Kingdoms period (Silla). National Museum of Korea, Seoul



Ceramics in Korea, Fig. 4 Round eaves-end tile with goblin-mask design. From Pyŏng-an-do province in north-western Korea. Three Kingdoms period (Koguryŏ). Diameter 18.1 cm. National Museum of Korea, Seoul



Ceramics in Korea, Fig. 5 Covered ink slab with 13 legs (one is lost). Place of discovery unknown. Three Kingdoms period (Paekche). National Museum of Korea, Seoul

Celadon in the Koryŏ Dynasty

The appreciation of Korean ceramic art usually begins with numerous celadon masterpieces in the shape of *maepyŏng* vases, which inherited from the *togi* tradition the graceful elegant contours of the pedestalled jars and other vessels. This type developed widely and artistically with many variations in the shape and styles of decoration. The earlier ones decorated with only incised designs are often *pisaek* and beautiful. Many were decorated with inlaid designs of clouds and cranes (Fig. 8), and some rare pieces were painted with iron-black slip before the

glazing (Fig. 9). The gourd-shaped ewer with decoration of copper red is a variation in shape (Fig. 10).

The love of naturalistic forms of plants, animals, and birds was also inherited from the *togi* tradition. Notable among them are many water droppers, such as a child holding a bottle and a monkey holding a jar as big as itself (Fig. 11). An ewer in the shape of a dragon-headed tortoise seated on a lotus pedestal (Fig. 12) and an incense burner with the lid and feet in the form of lion figures (Fig. 13) are some of the celadon vessels with elaborate naturalistic forms.

Another form that was dominant in the Koryŏ dynasty was the teabowl (Fig. 14), as the act of drinking tea was a highly valued means to clear one's mind for meditation in the Buddhist Koryŏ dynasty. The teabowl shards excavated in the



Ceramics in Korea, Fig. 6 Green-glazed covered bowl containing six small covered bowls (cinerary urn). From Kyōngju area. Middle Unified Silla period. National Museum of Korea, Kyōngju



Ceramics in Korea, Fig. 8 Celadon *maepyeong* with inlaid decoration of cloud and crane. Twelfth century. Height 30 cm. Provenance unknown. National Museum of Korea, Seoul



Ceramics in Korea, Fig. 7 Covered bowl with three-color glaze (cinerary urn). From Kyōngju area. Middle Unified Silla period. National Museum of Korea, Seoul



Ceramics in Korea, Fig. 9 Celadon-glazed iron-black *maepyeong* decorated with floral design in white slip. Mid-twelfth century. Height 27.5 cm. National Museum of Korea, Seoul

earliest porcelain kiln sites have a particular style of wide foot rim that resembles the sun's halo and is called, in Korean, *haemurigup*. The similarity in these foot rim styles, glaze colors, and general shapes of these wares with those found in Yüeh kiln is one of the reasons to believe that the Korean porcelain technology was strongly influenced by the Chinese technology or even that it was directly imported from China (Fig. 15).

Haemurigup teabowls in recent excavations included surprisingly both celadon and whiteware. In particular, a series of excavations in Sōri and Bangsandong in the 1980s and 1990s near Seoul showed that whiteware was just as important as celadon in the earliest stages of



Ceramics in Korea, Fig. 10 Gourd-shaped celadon ewer with stopper and bowl, decorated with overall inlaid design of boys among grapevines. The grapes are painted in underglaze copper red. Second half of the twelfth century. Height 36.1 cm. National Museum of Korea, Seoul



Ceramics in Korea, Fig. 11 Celadon water dropper in the shape of a monkey holding a jar. The eyes are marked with iron spots and the hairy body is executed with incised lines. First half of the twelfth century. Height 7.2 cm. National Museum of Korea, Seoul

porcelain technology in Korea. During the latter part of its two-century-long production, Söri produced only whiteware, and another nearby site of Chungamni also produced mainly whiteware during its entire existence.



Ceramics in Korea, Fig. 12 Celadon ewer in the shape of a dragon-headed tortoise seated on a lotus pedestal. The head, body, and twisted lotus-stem handle are modeled. First half of the twelfth century. Height 17.0 cm. National Museum of Korea, Seoul



Ceramics in Korea, Fig. 13 Celadon incense burner with cover. The vessel has three lion-headed feet and decorated exterior with incised clouds. First half of the twelfth century. Height 17.5 cm. National Museum of Korea, Seoul

Söri, Bangsandong and Chungamni were among some 50 sites located inland in the western midsection of the country, and they are now considered one of two distinct routes of technology transfer from China. The other route consists of a group of sites in the Kangjin area on the southwestern coast. These two different routes show several remarkable differences. Unlike in

the inland kiln sites, only celadon is found in Kangjin. From the beginning, Kangjin kilns were constructed with mud and rock in a similar style to *togi* kilns, while kilns in inland sites were first constructed with bricks as in some Chinese kilns. Only later was the Kangjin-type kiln of mud and rock introduced to some of the longer running inland sites such as Söri. Kangjin fired the wares in two steps – once before and again after glazing – while inland kilns fired wares in one step like the Chinese.



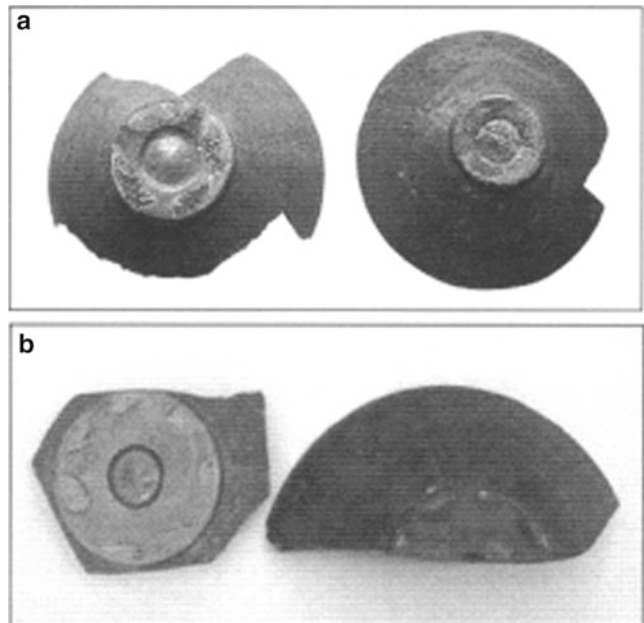
Ceramics in Korea, Fig. 14 Celadon bowl with inlay decoration. Mid-twelfth century. Height 6.4 cm. National Museum of Korea, Seoul

By the middle of the eleventh century, the inland kilns were mostly closed, while another center at Puan about 200 km north of Kangjin was newly established. The founding of Puan and closing of the inland kilns represented a new and indigenous phase of porcelain technology. In the two centers of Kangjin and Puan on the southwestern shore, porcelain production became highly centralized and reached a high technical and aesthetic level. Dedicating their efforts only to celadon rather than producing several styles, Koryŏ potters and their patrons made three original achievements in ceramic arts and crafts: *pisaek* glaze, the decorative technique of white and black inlay, and that of copper red.

Pisaek, represented by two different Chinese characters, mainly appears in a jade color and kingfisher's color (after the bird's blue-green plumage) in Korea and as a secret color in China. In the Koryŏ *pisaek* celadon, the thin glaze blends with the body of the ware, revealing it just enough that the observer yearns to see more. Chung Yangmo, a leading historian of ceramic arts and former director of the Korean National Museum, likened the Korean celadon glaze to clear water flowing through

Ceramics in Korea,

Fig. 15 (a) Whiteware shards with *haemurigup* foot rim, excavated in Söri, Korea. (b) Celadon shards with *haemurigup* foot rim, excavated in Yüeh, China



brooks and streams in the mountains and valleys and to a partition screen made of ramie fabric.

The thin transparent glaze that showed off the celadon body in a harmonious way was ideal for underglaze decorative techniques. Perhaps such a success enabled and motivated Koryŏ and later Chosŏn potters to persist with only underglaze decorations. The first decorative effect was achieved simply by incising figures such as flowers and birds or making them stand out in relief. The second of the three achievements was made when the incised lines were filled with white or red (which turns into black when fired) clay material to contrast with the gray body color. Flying cranes among stylized clouds (Fig. 8), ducks playing underneath plants such as willow trees and reeds, and various renditions of lotus, chrysanthemum, and peony flowers are some of the inlaid designs.

The third original achievement was the use of copper red, and this represented a technical challenge that required a good control of firing atmosphere and schedule. The volatile copper turns green when oxidized to its divalent state of cupric oxide (CuO). By the first half of the twelfth century, the subdued red from the reduced state of cuprous oxide (Cu₂O) and copper metal in colloidal state was used only sparingly in most cases to represent grapes (Fig. 10) and peony sprays (Fig. 16). It was used to outline lotus petals in gourd-shaped ewers and to cover the entire ware (Fig. 17).

Though the predominant wares were glazed gray green or blue green similar to *pisaek* celadon, some unusual glaze and decorative methods were produced. The entire body of *maep'yŏng* (Fig. 9) is first coated with black pigment and decorated by brush painting with white slip before a clear glaze is applied. Another type is colored light brown, most likely to have been fired in an oxidizing atmosphere. Often it is brush painted with iron pigments and resembles Cizhou wares. Even a small amount of porcelain whiteware, in general much more vitrified than the whiteware teabowls of the earliest stage, was produced at Puan (Fig. 18).



Ceramics in Korea, Fig. 16 Celadon *maep'yŏng*, decorated with black and white inlaid peony sprays and chrysanthemum scrolls and underglaze copper red. Mid-twelfth century. Height 34.6 cm. National Museum of Korea, Seoul



Ceramics in Korea, Fig. 17 Celadon cup and stand, decorated entirely in underglaze copper red. First half of the twelfth century. Height 6.7 cm. National Museum of Korea, Seoul

Punch'ŏng and Whiteware in the Chosŏn Dynasty

Punch'ŏng grew directly out of inlaid celadon in the last decades of the Koryŏ dynasty when the government became too weak to keep the ceramic activities supervised and centralized. In the first two centuries of the Chosŏn dynasty, *punch'ŏng* blossomed into a folk craft and art



Ceramics in Korea, Fig. 18 White porcelain *maepyo*, decorated with black and white inlaid floral designs. Mid-twelfth century. Likely to have been made in Puan. Height 28.8 cm. National Museum of Korea, Seoul

that was unique to Korea. Some of the earliest pieces are difficult to differentiate from heavily inlaid celadon. The white slip material was eventually coated or brushed over the entire body surface before any further decoration was applied (Fig. 19). The name *punch'ong* was coined for this type of ware by Koh Yusŏp, a scholar of Korean ceramics in the first decades of the twentieth century, and was adapted from the longer term, *punch'ong* (powder-decorated) *whe-ch'ong* (gray-blue) *sagi* (stoneware). The white slip was first used as a decorative medium easier to apply than white inlay, but eventually it became a means to make the wares appear whiter to meet the demand of royalty and officials who favored heavily the whiteware. The production of *punch'ong* came to an abrupt end after the Ceramics War. With so many potters taken to Japan, only the whiteware production was revived afterward in Korea.

Punch'ong is vigorous in form and decoration modes. Unlike celadon, it was produced in all parts of the country, and different styles reflected the people's daily lives, rooted deeply in the earth and other natural environments. The free-spirited spontaneous flow manifested in *punch'ong* led



Ceramics in Korea, Fig. 19 *Punch'ong* jar with lid. Arabesque design painted in underglaze iron. Sixteenth century. Height 17.2 cm. National Museum of Korea, Seoul

Koh Yusŏp to characterize Korean ceramics as made with “a plan without planning” and “technique without technicalities.”

Celadon inlaying techniques became modified in many ways. The incision of designs was replaced by stamping with engraving tools or even with rope. Instead of filling individual incised lines or surfaces with inlay material, white slip was applied on the whole stamped body. When the body and the slip were leather dried, the surface was scraped off evenly with the stamped areas left with white inlay. In another modified method, all the areas except those of such designs as flowers and plants were scraped off. Sometimes the scraped background was painted with iron-rich clay to contrast with the decorative area.

In more casually made wares, the only decorative element was white slip that was applied freely and unevenly with a large coarse brush. The abstraction of designs is bolder and more freely executed when they are brush painted with iron-rich pigment over white slip (Fig. 19). Those made in such styles in the area of Keryŏng Mountain became particularly popular with the Japanese.

Together with *punch'ong*, white porcelain replaced celadon as the dominant type in the Chosŏn dynasty. Chosŏn potters were able to produce much more vitrified whiteware than Koryŏ counterparts by adopting the two-step

firing method that Kangjin and Puan had developed and used throughout their celadon production history. The adoption of Confucianism and its stern frugality from the Ming dynasty as the guiding principle of the new society to replace the Koryŏ lifestyle of pleasure and luxury provided the crucial force for the ascent of the whiteware technology. The undecorated pure white was preferred, and the decoration was again limited to underglazing. The import of cobalt blue from China to produce white and blue represented the only innovative element in the new Chosŏn technology.

The raw material for Chosŏn whiteware was rediscovered in the area nearby Sŏri and Bangсандong, two centers where Koryŏ whitewares were produced at the beginning stage of porcelain technology centuries earlier. Except for the lower contents of iron and titanium oxide, it is basically the same porcelain stone that is used for celadon. This general area with plentiful raw material, Kwangju near the ruling center in Seoul, was soon established as the official kiln for producing high-quality wares for the use at court. In much the same way as in Kangjin and Puan, the ceramic activity in Kwangju was supervised and centralized by court officials for nearly 500 years. So far some 285 sites have been discovered in this area, where the potters had to move to new sites approximately every 10 years in search of firing wood. Unlike celadon, the production of whiteware, however, was not restricted to this area and was produced all over the country.

The majority of Chosŏn whiteware was undecorated. As mentioned before, the colorful overglaze decoration was never developed, and even the underglaze decoration with cobalt, iron, and copper oxides was sparingly used. However, the various shades of white for body and transparent glaze, combined with beautiful forms, resulted in some of the most appreciated masterpieces. The eighteenth-century jar with globular body is representative of such pure white, imparting the feeling of abundance and warmth (Fig. 20). This particular form is made in diverse modifications and decorated with various designs and colors. The brush painting with cobalt blue



Ceramics in Korea, Fig. 20 White porcelain jar with everted lip and globular body. Late seventeenth century. Height 40.8 cm, National Museum of Korea, Seoul



Ceramics in Korea, Fig. 21 Blue and white jar with cloud and dragon design. Second half of the seventh century to early eighteenth century. Height 35.3 cm. National Museum of Korea, Seoul

on a late seventeenth-century or early eighteenth-century globular jar is executed freely and boldly in the same characteristic manner as *punch'ŏng* wares (Fig. 21).

The cobalt blue decorated wares, made mostly for royal use, are usually refined and restrained. The cobalt pigment, imported and expensive, was usually used sparingly (Fig. 22). When its use became even more difficult after the war with Japan, iron pigment was substituted as the main pigment. It was used more freely and effectively in various styles of brush painting, some refined and some very daring (Fig. 23). The use of copper red, which became more liberal in the eighteenth and nineteenth centuries, produced various styles of jars, bottles, and water droppers that are very



Ceramics in Korea, Fig. 22 Blue and white porcelain angular bottle with orchid design. Second half of the seventeenth century. Height 41.5 cm. National Museum of Korea, Seoul



Ceramics in Korea, Fig. 23 White porcelain bottle coated with underglaze iron. Second half of the eighteenth century. Height 27 cm. National Museum of Korea, Seoul

free spirited (Fig. 24). In some rare pieces, two of the three pigments are used in combination, and very rarely all three pigments are used, always very sparingly.



Ceramics in Korea, Fig. 24 White porcelain water dropper coated with underglaze copper red with molded double crane design. Nineteenth century. Height 5.4 cm. National Museum of Korea, Seoul

This short treatment of 8,000 years of Korean ceramic art and culture, linearly developing *togi*-celadon-*punch'ŏng*-whiteware as distinct phases of creative and original achievements, leaves many important stories untold. Many teabowls of the Koryŏ and Chosŏn dynasty that became national treasures in Japan and the brown pottery known as *onggi*, which ranges from small boilers for herbal medicines to enormously large storage jars, are important examples that have been omitted altogether. The masterpieces and coarse everyday utensils are testimony not only to the availability of diverse materials and technical know-how of Korean potters and their clients but also their creative spirits, their love of nature, and their dreams and ideals.

Scientific Study on Traditional Korean Ceramics

Within Korea the scientific study of Korean traditional porcelain began about 25 years ago in the late 1980s. The first such work was presented internationally in 1992 in the Proceedings of Material Science Society of America. Chinese ceramics had been an academic subject of scientific investigation and analysis for almost a century in several western countries such as Sweden, England, and America and eventually in China itself. Some of the important results culminated in the first proceedings of the international

symposium in 1982 organized by the Shanghai Institute of Ceramics and several volumes of *Ceramics and Civilization*, edited by MIT's W. D. Kingery. Serious analytical works abroad on Korea began in the 1980s by scientists like Pamela Vandiver and Richard Newman in America, Nigel Wood in England, and K. Hangst in Germany.

One of the preparatory aspects of the Korean study was to locate the waste mounds of shards, kiln equipment, and clumps of fired clay left at the original production sites. It was not easy to find them any more, as the kiln sites were erased out of existence to make room for cultivating fields, houses, roads, and dams. After endless inquiries in books and to village elders, one still can be lucky to find them tucked away quietly, along mountain edges with water streams flowing nearby. The spots are invariably sunny and beautiful like the ones that must have been sought after ardently to bury loved ones, as graves are often found close by. The shards chosen as representative ones in such sites were the first ones to be analyzed in the initial stage when various experimental methods were tested and established for the new study.

Soon the community of ceramic historians and archaeologists joined the effort to understand Korea's ceramic heritage from scientific and technological points of view. Well-documented shards from systematic excavations and surface investigations by leading museums and ceramic studio institutes were donated, enabling the analysis work to become systematic with the possibility to connect the results with artistic functional features. For this reason archaeological information and visual features of the shards were recorded meticulously before they were analyzed for their compositional and microstructural characteristics.

The work was initially led and centered at a laboratory in the Department of Scientific Studies of Cultural Heritage in Chung-Ang University but quickly spread to several other centers. Eventually more than 1,500 shards of celadon, punch'ŏng, and whiteware were collected and studied in Chung-Ang University alone, where they are organized by ceramic types, locations,

and periods of their production and stored for further studies. From these studies were worked out the developmental changes of the ceramics from celadon to punch'ŏng, and to whiteware, and these were presented in a series of three papers in English in a Korean journal named *Journal of Conservation Science*.

Body Composition

Regardless of the ceramic types, a predominant proportion of the Korean bodies was formed with a hard-paste clay material called pottery stone or porcelain stone. Such is the case in southern China, too. This material is an intermediary type of clay formed during the disintegration process from igneous rocks of feldspar into kaolinite. In the process, the alkali oxides of Na_2O and K_2O from feldspars are leached out until pure kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) is formed. Feldspars do not have plasticity to be formed into bodies, and plastic kaolinite is so highly refractory that it requires an extremely high firing power to vitrify. However, porcelain stone in the mid-stages contains various minerals in a wide range of concentrations in such a way that they can be used as they are found with only the physical processes of powdering and purification.

In the process of transformation, hydromical clay is formed in such mineral forms as muscovite, illite, and sericite, and even a small amount of primary kaolinite. Hydromical clays are plastic due to the mineral structure of their sheets in a similar fashion to mica; they also have fluxing property from the alkali oxides still retained in them. In addition to the newly formed clays, porcelain stone from the intermediary stages contains the remnant feldspar and the original quartz. These various minerals make the porcelain stone become triaxial, as they contain all three different properties to form and vitrify ceramic bodies. The plasticity of hydromical clays and a small amount of kaolinite allows the clays to be formed into various shapes, the fluxing property of hydromical clays and feldspars makes the bodies to be vitrified, and the refractory quartz retains shapes as the bodies are fired and become molten at high temperatures. Porcelain stone from earlier stages is sometimes referred to as glaze stone

because higher amount of feldspar still retained makes the material have a higher fluxing property and thus make it appropriate as the flux component in making glaze batches. Often glaze stone is found finer grained than porcelain stone.

The porcelain stone and glaze stone are found in abundance in Korea as in southern China. There is a geological dividing line called Nan Shan Quiling that runs in a west–east direction roughly midway between the Yellow River and Yangtze River in China. This line extends up northeast to Korea, and south of this line porcelain stone is found in abundance; in the north there is kaolinite. Therefore, the majority of Korean and southern Chinese wares from such kilns as Yüeh kiln, Jingdezhen, and Dehua are made with porcelain stone. On the other hand, the northern wares from such kilns as Yaozhou, Ding, and Linru are formed with kaolinite and fired at higher temperature around and above 1,300 °C.

Among the Korean ceramic bodies so far analyzed, only shards that may have been formed from kaolinite are the late fifteenth-century whiteware shards from local kilns of Chunghyodong and Yonggye-ri in Jeolla South Province. Chunghyo-dong had been successfully producing punch'öng for half a century before attempting to make whitewares in around the 1450s. Their first whiteware was soft textured, because their firing power was far too low to vitrify the bodies formed of kaolinite clay. Only about 20 years later, it succeeded in vitrifying properly because they added to the kaolinite some glaze stones particularly rich in albite, Na₂O-based feldspar. Adding glaze stone to bring down the firing temperature of kaolinite bodies had occurred more than a century earlier at Jingdezhen in China during Yuan dynasty (1279–1368), but such a practice was not common in the fifteenth century. At present nothing is known about how Chunghyo-dong potters were inspired to use such an innovative material or whether such material was used significantly in whiteware kilns of later times. To date only a limited number of later kilns in rural areas have been excavated, and eighteenth- and nineteenth-century kilns have been excluded from the

collection of 1,500 shards so far analyzed at Chung-Ang University.

The porcelain stones appropriate for different ceramic types contain different levels of iron oxide and titanium oxide. Ideally the material for whiteware should contain as little of Fe₂O₃ as possible, and in Chinese its level was mostly less than 0.5 wt%. Unfortunately, Korea lacked such pure material, and in some whiteware shards, as high as 2 wt% level was often found. In general its level in whiteware ranged between 1 and 2 wt%, in celadon between 2 and 3, and in punch'öng between 2.5 and 4. In the similar way, the level of TiO₂ should be nearly zero for whiteware, but in Korean whiteware as much as 0.4 wt% has been found. In celadon and in punch'öng, the presence of certain amount is needed to make the body fire to gray, and its level was found in the range between 0.5 and 1.0 wt%.

Glaze Composition

Traditional Korean glazes are high-fired glazes formulated by mixing two different types of material, clay and flux component, as was the case with the majority of southern Chinese kilns. Within this system of two components, changes occurred over Koryŏ celadon and Chosŏn whiteware glazes. Although certain punch'öng kilns initiated change that eventually became established as normal whiteware practice, punch'öng wares kept many of the celadon practices well into the newly found Chosŏn dynasty.

Calcium oxide was the chief flux ingredient in all but a few cases, and it was provided in the form of wood ash, burnt limestone, or powdered limestone. The level of phosphorus oxide P₂O₅ in the glaze composition is a good indicator whether and how much wood was involved in the preparation of the flux material. Wood ash was the earliest traditional flux material, and in some Korean porcelain, it is likely to have been added by itself to the clay component. In an extensive compositional analysis study, Sŏri is found to have been such a center. Both celadon and whiteware glazes from Sŏri complex contained P₂O₅ in high levels above 1.5 wt%.

In the majority of Koryŏ glazes, however, P_2O_5 is found in a concentration range between 0.5 and 1.0 wt%. Meanwhile, CaO is found in a high concentration range between 15 and 22 wt%. Such a small ratio of P_2O_5 and CaO implies that burnt limestone and not wood ash was employed as the main flux material. Known as glaze ash, the burnt limestone was an ideal flux material especially for the high-lime glazes with limited level of phosphorus, which were used persistently at Kangjin and Puan, the centers of inlaid celadons. High-lime glaze becomes transparent when fired to high temperature and cooled rapidly, and a moderate amount of bubble created by limited level of P_2O_5 in glaze ash makes the glaze become somewhat translucent. Such glaze shows off the underglaze decorations of incised and inlaid designs quite clearly and at the same time softens the images. The centers of the inlaid celadon of Kangjin and Puan used this high-lime glaze with a limited level of P_2O_5 persistently. Sometimes burnt shells may have been used, too, as they are found easily in these complexes in southwestern coastal areas.

In many cases of celadon, burnt limestone may have been supplemented with wood ash. *punch'ŏng* wares produced from the last decades of the Koryŏ dynasty in fourteenth century until the early decades of the sixteenth century in Chosŏn dynasty continued to employ celadon methods of obtaining flux material by burning wood by itself for wood ash or burning limestone to make glaze ash. However, in making whitewares at the royal complex in Kwangju, such a practice of using wood disappeared, only with a few exceptions of the early fifteenth-century kilns, where a special ceramic type known as Chosŏn celadon was made as one of their regular productions. These wares were made of whiteware bodies but had celadon glazes, whose flux continued to use the celadon tradition of using wood in some capacity. A low level of P_2O_5 around 0.2 wt% was detected in their whitewares, but in kilns of the late fifteenth and early sixteenth centuries, it is no longer detected. By such time the important change of using limestone in its powdered form had occurred.

Another important change accompanied the change to a powdered form of limestone. Less flux was used, making the concentration of CaO decrease to about 15–10 wt% from the range of 15 to 20 in celadon. Instead the concentration of alkali oxides, Na_2O and K_2O , increased. In the scheme of categorizing high-fired glaze types according to the concentration of CaO and alkali oxides into four types of high lime, lime, lime alkali, and acid rock, the Kwangju whiteware glazes ranged between lime and lime alkali, changing from celadon glazes that ranged between high lime and lime. The latest kiln sites of official Kwangju complex Geumsa-ri and Punwŏn Village of the eighteenth and nineteenth centuries where blue and white were produced increasingly in greater quantity used the lime-alkali type. This type had become the favored one at Jingdezhen in China, too, as it is rather viscous and does not diffuse the cobalt decorations as much as glazes with a higher amount of calcium oxide. Geumsa-ri complex is acclaimed for having produced some of the most beautiful whiteware, especially those with snow-white or milk-white glazes. The fine quality of its glaze composition may be in some way due to an unusually high level of MgO around 4 wt%, more than double the usual amount.

As for the clay component in glaze formulation, often slightly different forms of clay like glaze stone instead of the clay used for the body itself was employed. The relative levels of titanium oxide in the glaze and body have been a good guide to decide which. In Yüeh kiln, one of the most influential Chinese kilns to Korean ceramic technology, the TiO_2 content in the glaze was found to be usually about 80 % of that in the body. Such a compositional characteristic resulted from the practice of mixing body clay with flux material in proportions around 8:2. Such a consistent proportional relationship was not found in Korean glazes. In Bangсандong and Sŏri kiln sites, its level in whiteware glaze was slightly higher than that in the body. A similar situation was observed for iron oxide Fe_2O_3 . On the other hand, in Kangjin complexes the level of TiO_2 in the glaze was only about one third of the level in the body.

Clearly such levels of TiO_2 content in Korean glazes could not have been obtained by using the body material itself. It is logical that glaze stone was used in Korean glazes, because it has the same characteristics as porcelain stone, except it has more alkali oxide content and is in general finer grained. What is surprising is that it was employed from the very beginning stages of Korean porcelain, as practiced in the earliest kiln complexes as Bangсандong, Sŏri, and Yongun-ni of Kangjin.

Glaze stone is a versatile material with a wide range of composition, which would depend upon various factors such as the composition of the original mother rock and the particular stage of transformation when it is found. A wide compositional range enabled potters to search for and choose a batch of glaze stone appropriate for their particular wares. There is also a possibility that glaze stone was used together with the body material of porcelain stone in order to bring about the desired effect that the potters were looking for. For their whitewares, Bangсандong and Sŏri potters had to find glaze stone that was almost free of TiO_2 and Fe_2O_3 except in the smallest concentrations of a few tenth of a weight percent. For their celadon glazes, Kangjin potters needed glaze stone with the TiO_2 content around 0.4–0.5 wt%, about half of the level found in celadon body material. Fortunately, such ceramic materials with similar compositional characteristics were available rather easily at close distances, as the Kangjin area had not only an abundance of celadon materials but also mines of porcelain and glaze stone with such low TiO_2 content that they could well have been used to make whitewares. Actually such a mine exists to this day in front of Jŏngsusa, a temple that used to be the spiritual center of celadon potters.

When the new Chosŏn dynasty began, glaze stone as free of TiO_2 and also of Fe_2O_3 as possible was adopted both for whiteware and punch'ŏng. Such a selection is expected for whiteware, but it is quite surprising that even punch'ŏng glazes followed the same change while keeping other characteristics similar to those of celadon. The range of Seger values of SiO_2 and Al_2O_3 and also the levels of P_2O_5 and

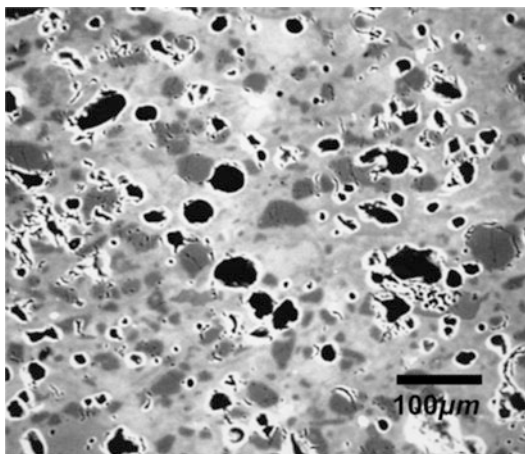
CaO contents in punch'ŏng were similar to those of celadon. The practice of burning limestone and using it as a flux component by itself or in combination with wood ash lasted much longer in making punch'ŏng glazes than in making whiteware glazes, for which limestone was soon powdered.

Another characteristic of the glaze stone adopted for the lime and lime-alkali glazes of the Chosŏn dynasty is its increased content of alkali oxide. Such glaze stone is an earlier product in the process of transformation from the original feldspar state into the final kaolinite state. A pronounced form of early product rich in feldspar content, especially albite, was used at Chunghyo-dong in the middle of the fifteenth century in developing a glaze with a composition close to acid rock. The combined content of Na_2O and K_2O was higher (8.42 wt%) than the content of CaO (7.01 wt%). Such a unique glaze composition was not observed anywhere else in Korea until then, and only at another contemporary kiln nearby at Yonggye-ri. As with the case of innovative Chunghyo-dong bodies, whether such a new type of glaze was used significantly in later kilns is not known at the present time, since eighteenth- and nineteenth-century kilns in rural areas away from Kwangju system are not included in the scientific study.

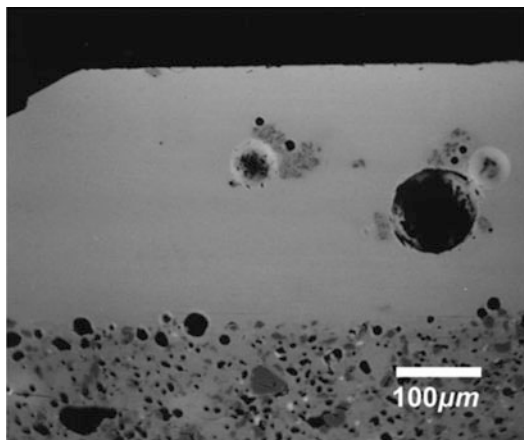
Science of *Pisaek* Celadon

The production parameters of Koryŏ celadon were lost to modern Korea, and the revival of its art and craft in the latter half of the twentieth century was carried out much in trial-and-error efforts. A systematic analysis study dedicated to bisaek celadon is yet to take place, and its compositional and microstructural characteristics are only understood in general terms worked out for celadon. The bodies of celadon considered bisaek appear to be much whiter than common celadon gray bodies, so that their contents of Fe_2O_3 and TiO_2 are suspected to be lower. However, such a systematic difference has not been yet established.

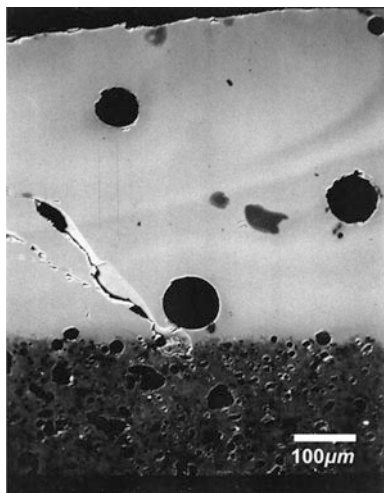
Microstructural images are various features preserved in a frozen state in the process of densification and vitrification when the firing of the



Ceramics in Korea, Fig. 25 A backscattered electron image (BEI) of a celadon body from Sadangni, Kangjin



Ceramics in Korea, Fig. 27 A backscattered electron image (BEI) of a celadon glaze from Sadangni, Kangjin



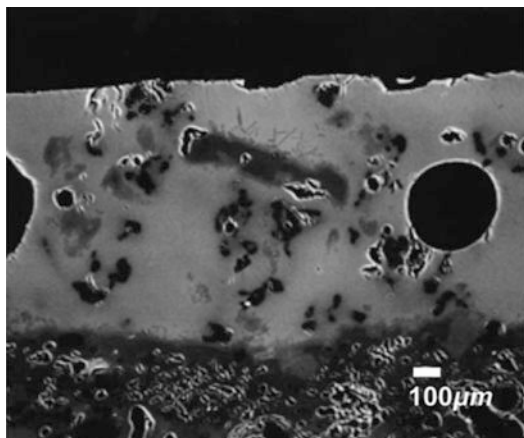
Ceramics in Korea, Fig. 26 A backscattered electron image (BEI) of a celadon glaze from Sadangni, Kangjin. The shard was made in Sadangni Ahredangjeon in mid-fourteenth century

ceramic pieces is stopped. A typical microstructural image of a celadon body (Fig. 25) reflects the various features of the raw material itself. The black holes in various sizes are the resultant pores that have become coalesced from innumerable small pores, and the dark-gray minerals are quartz. The matrix is made of two different phases intermixed together, the lighter ones

from the melting of feldspar and the darker from the melting of the clay component.

Glaze images are shown in Figs. 26, 27, and 28. In Fig. 26 is a rare wavelike image of an unusual result called the schlieren effect. When the glaze batch is not mixed sufficiently to become completely uniform in composition, the inhomogeneous state is caught as a wave of light and dark areas. Light areas are richer in elements of higher atomic weights, and the dark areas in elements of lower atomic weights. Such an effect of inhomogeneity would have disappeared if the firing continued further. It is not clear whether such an effect was sought after intentionally or not by the potters, but the resulting microstructural feature scatters light in such a way to bring a translucent character to the celadon glaze. Bubbles of round black images, quartz minerals, and crackled line in the left lower corner also participate in the scattering of lights.

Often found in celadon glazes, especially in inlaid celadon, are images of clustered grains occurring around and underneath bubbles (Figs. 27 and 28). They are remnants of granophytic intergrowth of quartz and feldspar in glaze stone. The feldspar part is melted and incorporated into the matrix, while the quartz grains remain as dark grains. In Fig. 28 a rare rodlike



Ceramics in Korea, Fig. 28 A backscattered electron image (BEI) of a celadon glaze from Sadangni, Kangjin

image of muscovite mineral, which is only partially melted around its surroundings, from which are grown anorthite needles during the cooling period after the firing was stopped is also shown.

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Ceramics in Pre-Hispanic North America

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By its very nature, a synthesis of pre-Hispanic pottery technology in North America must be general in terms of both cultural areas and specific techniques. Although it is my hope to present here a fair representation of current knowledge, it is by no means meant to be a final discussion of the topic. Rather, it is my intention to provide a starting point for individuals interested in considering the multiple dimensions of indigenous pottery production in North America over time and space.

Earliest Pottery Production by Cultural Region

North America can be divided into ten broad cultural areas: Arctic and sub-Arctic, Northwest Coast, West Coast (including Baja California), Plateau, Great Basin, southwest United States, northern Mexico, the Plains, northeast United States, and southeast United States (Fig. 1). With the exception of the Northwest Coast (where only a few clay pipes and figurines have been found; Ross, 1990), all of these regions developed or adopted pottery in the pre-Hispanic era. When and how pottery production began in each region varies. In the western Arctic region (Anderson, 1980, 1984; Dumond, 1982, 1983, 1984, 1987; McCartney, 1984), pottery production appeared slightly after 3,000 years ago in association with the Norton Tradition; ceramic technology may have been introduced into the region from Siberia based on similarities in both technology and design (Zhushchikhovskaya, 1997). At about 1,500 years ago, pottery production is associated with the Thule Tradition in the Arctic; based on a few sites with apparently transitional pottery types, the Thule pottery tradition

may be related to the earlier Norton Tradition (Dumond, 1984; Griffin, 1969–1970). Pottery production began as early as 2,600 years ago in the eastern sub-Arctic region (Bonnichsen, Keenlyside, & Turnmire, 1991; McGhee, 1978; Meggars, 1987; Tuck, 1999); this sub-Arctic technology is assumed to have been introduced into the region from the northeast United States even though there are few similarities in pottery from these two regions (Wright, 1981). By 2,300 years ago, pottery production spread into the central sub-Arctic region.

Ceramic material is found throughout the West Coast region in the form of pipes, figurines, small balls (possibly for use in slings), and baked clay items that may have functioned as cooking stones. The earliest pottery vessel tradition in this region, called Owens Valley brown ware, developed in central California about 500 years ago and then diffused west (Elsasser, 1978; Spier, 1978). Although there are some reports of pottery vessels in the southern coastal area dating to as early as 2,500 years ago, this technology apparently faded out and was not resumed again until about 300 years ago in the San Diego area. Pottery entered the Great Basin Region approximately 1,500 years ago with the development of the Fremont Culture (Aikens & Madsen, 1986, 1986, 1989; Marwitt, 1986; Talbot, 2000). Production techniques were probably introduced into the Great Basin Region from the southwest United States and then disappeared from the region around 1,500 years ago; the reason for this disappearance is not well understood.

Probably the most extensively studied pre-Hispanic pottery in North America comes from the southwest United States. The earliest pottery in this region dates to over 2,300 years ago and is associated with the Pioneer period of the Hohokam culture (Gladwin & Gladwin, 1933; Gumerman & Haury, 1979). At about the same time, and probably related, is the introduction of pottery production in the Mogollon cultural area (Martin, 1979; Rinaldo & Bluhm, 1956). Pottery in other areas of the southwest United States began somewhat later, with production beginning at around 1,300 years ago in both the ancestral Pueblo (Anasazi) and Patayan culture areas. It is

Ceramics in Pre-Hispanic North America,

Fig. 1 Map of North America showing prehispanic cultural regions (drawn by author).



generally assumed that pottery technology in the southwest United States was introduced into the region, possibly more than once, from what is present-day Mexico.

Dates for the introduction of pottery in northern Mexico vary by cultural area, with a better understanding for some areas than others. There is evidence that plain ware pottery was being produced as early as 2,500 years ago in the northeast Sonoran area; however, this tradition is not well understood (Douglas & Quijada, 2004). Along the Northwest Coast, pottery production began around 1,800 years ago with the production of Tiburón Plain, a thin, particularly well-made pottery type. Probably the best understood pottery sequence comes from the area around the site of Paquimé in Chihuahua, where the production of pottery began at least 2,000 years ago (Brand, 1935; Carey, 1931; DiPeso, Rinaldo, & Fenner, 1974). This technology is believed to have moved into the area along with groups moving up from Central Mexico.

Very little pottery is reported for the Plateau region: some cave sites have revealed brown-gray pottery that date from 500 to 1,500 years ago (Roll & Hackenberger, 1998). The earliest pottery on the Plains dates to approximately 2,500 years ago and is associated with different complexes depending on the cultural area. For example, the earliest pottery on the Northern Plains is associated with the Besant complex, while the earliest pottery on the southern Plains is associated with the Plains Woodland complexes to the east of the region. Depending on the area within the Plains, this early pottery shows influence from the northeast United States, the southwest United States, or both.

The oldest pottery in North America comes from Stallings Islands in Georgia (Claffin, 1932) and is believed to date as far back as 3,800 years ago (Sassaman, 1998). Pottery in northwest Florida is believed to be nearly as old, while pottery in Maryland dates to approximately 3,000 years ago (Manson, 1948). In other portions of the

southeast United States, pottery technology was adopted much later: the technology may have arrived as recently as 800 years ago in central Texas (Hughes, 1989). In the northeast United States, pottery vessels replaced soapstone vessels as early as 3,500 years ago in southern portions of the region, marking the transition between the Archaic and Woodland periods. In other areas of the northeast, pottery was adopted somewhat later: the northern portion of the region did not make ceramic vessels until approximately 2,000 years ago.

Pottery Production Techniques

Pottery production was one of the more complex technologies employed in pre-Hispanic North America. Potters took a geological material (clay) and, after preparing, shaping, and firing created a new material (ceramic). Ceramic production techniques throughout time and across North America were fairly consistent. The process of making raw clay into ceramic vessels includes five production steps: preparation of raw materials, building or shaping the clay into desired vessels forms, finishing vessels, decorating vessels, and firing.

Preparation of Raw Materials

The one required material for making ceramic vessels is clay. Clay can be found in numerous geological contexts throughout North America, from sedimentary clays in riverbeds to veins of primary clays near mesa tops. Clay is a complex geological material that has been defined by particle size, depositional context, chemical structure, and mineralogical composition. A basic definition of clay is that it is a fine-grained material formed by decomposition of high-alumina- and high-silica-bearing rocks, normally of igneous origin. Although such a definition may be useful for North American archaeologists attempting to find sources of clay used by pre-Hispanic potters, these potters used a different definition for selecting their material. The most

important property of clay is that, due to its small particle size, it becomes plastic when wet. This plasticity allows some clay to be worked into desired shapes. It is this workability that would have been the defining characteristic of clays for pre-Hispanic potters. Other important characteristics for potters include shrinkage rate and amount during drying, firing behavior, texture, and impurities.

Once clay is collected from its geological source, it needs to be prepared. Preparation varies depending on the quality of the clay and what type of vessel is to be shaped. Natural or raw clays often need to be ground, cleaned, and seasoned. Although we do not know with certainty how these tasks were performed in the pre-Hispanic era, ethnographic and historical evidence concerning Native American potters provide some clues. Although clays may be soaked in water to break them down, many indigenous potters grind dry clay with either a combination of mortar and pestle or *mano* and *metate* (Shepard, 1956). Clay needs to be cleaned to remove any coarse particles that may cause a vessel to crack during drying or firing. Methods of cleaning clay vary widely, depending on the extent and size of impurities, but include handpicking, screening in baskets, and washing in water. There is no evidence that North American potters ever used levigation [freeing from grit] to clean their clays. Wet clay is then often seasoned, or soured, by storing it in a cool location for weeks or months. Seasoning clay increases its workability through bacteria growth and the complete wetting of all clay minerals through absorption.

Temper is the nonplastic material in clay. Depending on the type of temper, it can affect various attributes of the raw clay or the final ceramic product including workability, shrinkage, strength, and porosity. Some clay has naturally occurring temper, such as sand. However, potters are required to add nonplastic material to many raw types of clay before forming their vessels. Among historic and ethnographic potters, temper is added at different times during the preparation process; dry clay and temper material may be mixed during the initial grinding of the materials or ground temper may be added

to wet clay that has already been well cleaned. Pre-Hispanic potters in North America used a wide variety of material as temper. For example, charcoal and bone were both used in the southeast United States (Wallis, 2011), while shell was sometimes used on the Plains (Henning, 2001). Sand, igneous rock, mica, and grog (crushed ceramic sherd) have all been reported from archaeological ceramic materials in the southwest United States, as well as untempered pottery (Eckert, 2008).

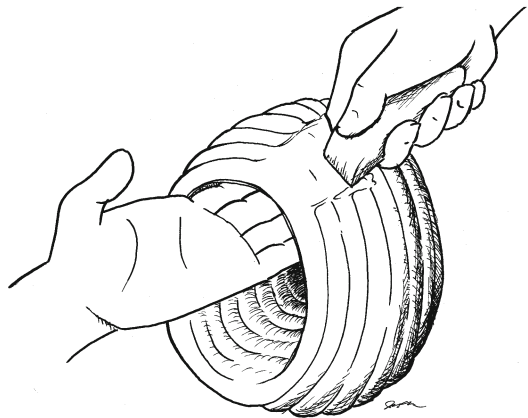
Shaping the Clay into Desired Vessel Forms

Once the clay has been prepared, it needs to be shaped into the desired form. In the pre-Hispanic era, the shape of a vessel was most often determined by its function; in other words, ceramic vessels were utilitarian in nature and not purely artistic. Pottery was used for many purposes, including storage, cooking, and food service. Broken pieces of pottery were often reshaped into jewelry, gaming pieces, or spindle whorls used in weaving. Common pre-Hispanic forms across North America include jars, bowls, platters, dippers (or ladles), pipes, figurines, and effigy vessels. Pre-Hispanic potters in North America never used a potter's wheel to shape their vessels; all vessels were hand built (Fig. 2). The two most common shaping techniques were coil-and-scrape and paddle-and-anvil; however, drawing-and-pinching and molding techniques were not uncommon (Figs. 3 and 4).

The coil-and-scrape technique involves rolling the prepared clay into ropes and then forming the vessel by successively coiling these ropes one on top of another. Alternatively, the ropes may be formed into rings that are then placed one on top of another. Vessels may be free-formed or ropes may be coiled within a preexisting vessel to help support the shape of the newly formed vessel. The joints are often smoothed over to hide the coils and strengthen the vessel walls, which are then thinned by scraping the vessel with a tool. The use of the coil-and-scrape method in pre-Hispanic North



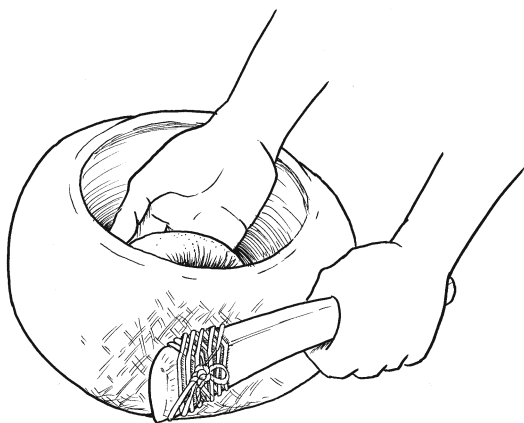
Ceramics in Pre-Hispanic North America, Fig. 2 All Pre-Hispanic pottery in North America was hand built (drawn by Joshua Keene).



Ceramics in Pre-Hispanic North America, Fig. 3 Pottery vessel smoothed and thinned using coil-and-scrape method (drawn by Joshua Keene).

America has been reported specifically on the West Coast, in the southwest and the southeast United States, and on the Plateau, and the Plains.

The paddle-and-anvil technique involves the potter's taking a mass of prepared clay and then drawing pieces of the clay upwards into the desired vessel shape. In order to thin the walls of the vessel, the exterior surface is slapped with a paddle against an anvil held against the interior surface. Paddles were normally made out of



Ceramics in Pre-Hispanic North America, Fig. 4 Pottery vessel smoothed and thinned using paddle-and-anvil method (drawn by Joshua Keene).

wood and often wrapped with cord or a textile. Anvils could be made from a variety of materials, including wood, clay, or stone. The use of the paddle-and-anvil technique by pre-Hispanic potters has been reported for southern Canada, the southwest United States, northern Mexico, the southeast United States, portions of California, and on the Plains.

Drawing-and-pinching is probably the simplest way to shape clay. A lump of clay is placed on a surface, or held in one hand, while the other hand is used to form an indent in the center of the lump. The potter then pulls (draws) and squeezes (pinches) the clay with one or both hands, while turning the lump of clay, to shape the clay into the desired vessel form. Further pulling and squeezing helps to hollow out and thin the vessel walls. The amount of pinching versus drawing depends on the size of the desired vessel. Pinching is used primarily to form small vessels that can be held in the hand, while drawing is used primarily to form larger vessels that sit on a surface. Drawing-and-pinching can also be used to create the base of vessels that will be further formed using other shaping techniques. Evidence for the use of drawing-and-pinching in the pre-Hispanic era has been reported from all regions of North America.

Molding can also be used to form a vessel. Vessels are shaped by pressing clay into premade containers of the desired form. The use of

complex, multiple piece molds was not practiced in pre-Hispanic North America, with the possible exception of northern Mexico. Instead, simple shapes such as pottery vessels or woven baskets appear to have been used as molds, especially on the Plains, and in the southeast and southwest United States. As with drawing-and-pinching, molding may have been used to form the base of vessels that would then be completed using either the coil-and-scrap or paddle-and-anvil technique.

Finishing Vessels

Once a vessel has been shaped, at least one surface of the vessel is usually finished. Depending on the finishing technique, a potter may choose to finish a surface, while the clay is still wet and plastic, or may choose to wait until the vessel has been dried and the clay is leather hard. Finishing techniques serve primarily to improve the quality of a vessel's surface by removing irregularities that may have been created during the forming process. The choice of finishing techniques relies on the intended purpose of the vessel, whether or not the potter intends to decorate it and, if so, the decorating technique to be used. Finishing techniques used by potters throughout pre-Hispanic North America included smoothing, slipping, and polishing, although the popularity of any single technique varied by cultural region.

Smoothing entails evening out the surface of a vessel with the palm of the hand or with a tool such as a smooth pebble, the smooth surface of a potsherd, or a corncob. Smoothing a surface can be accomplished while the clay is still wet, in which case it is often done as part of the forming process. Smoothing can also be accomplished once the clay is leather hard; however, the application of water to the surface intended to be smoothed is usually necessary once the vessel is dry. Either way, smoothing serves to level ridges and fill depressions, resulting in an even surface.

Slipping involves the application of watered-down clay to the vessel surface. Often, the clay chosen as a slip is not the same clay chosen for the forming of the vessel. A vessel may be slipped to

enhance its appearance by creating a uniform surface; if a slip is thick enough, it hides the temper and other inclusions in the clay used to form the vessel. A slip may also be applied to make the vessel surface, or portions of the surface, a specific color. Finally, a slip may be added to a surface to prepare the vessel for further decoration. A slip may be applied by dipping the vessel into the slip, by pouring the slip over the vessel, or by washing it onto the vessel with the palm of the hand or a rag. Once a slip is applied to a vessel, the surface of the vessel may be polished.

Polishing a vessel serves to give the surface a fine luster. Among historic and ethnographic potters in North America, polish is usually achieved by vigorously rubbing the vessel surface with a smooth stone (Shepard, 1956). Polishing can be accomplished when the clay is still moist or when it is leather hard. Although the surface of a vessel can be polished with or without a slip, it must be well smoothed before polishing can begin. If the surface is uneven, depressions will not be polished, resulting in dull spots, while ridges or inclusions may be pulled, resulting in drag lines.

Decorating Vessels

Although not affecting the function of a vessel in any way, many pre-Hispanic potters chose to decorate their products. Decorations may have had social, religious, economic, or personal significance to the potter. The numerous styles of decoration employed by potters represent the greatest diversity to be found in pottery production in pre-Hispanic North America but is not to be elaborated upon here. The techniques of decoration, however, were limited to the use of coils, surface texturing, painting, and appliqué.

When vessels are formed using the coil-and-scrape method, potters are faced with the decision to smooth the coils or to leave the coils visible. Smoothing the coils increases the strength of the vessel, while leaving the coils visible increases the surface area of the vessel. This latter

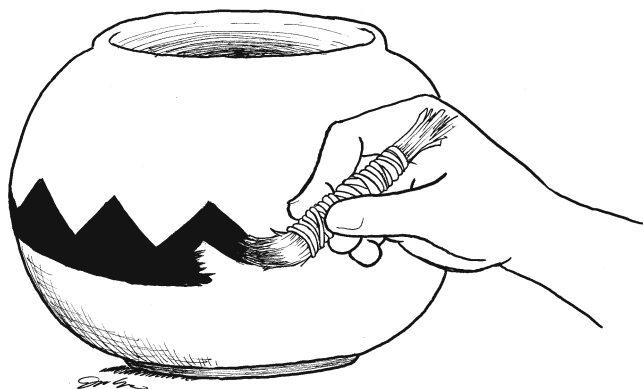
characteristic is desirable in vessels to be used for cooking. If a potter chooses to leave the coils visible, she can decorate the coils with various finger indentations or tooled patterns. She can also vary the width of her coils. This technique of decorating a vessel with the coils was well established in the southwest United States, where the corrugated brown wares of the Mogollon culture were some of the finest vessels made in pre-Hispanic North America (Rinaldo & Bluhm, 1956).

The smoothed surface of a vessel can be decorated with various types of texturing. Pieces of textiles, carved wood, or other textured tools can be used to decorate wet clay through stamping, as was common on decorated pottery produced in the Arctic region (Dumond, 1982). On the Plains and in the northeast United States, many vessels were decorated by the impressions left on the exterior surface of the vessel from the paddle used to form them. Paddles were wrapped in cord, netting, or different textiles to create different surface designs on the vessels. Throughout North America, potters gouged, scored, grooved, carved, and incised various designs on their vessels using their fingers or sharps tools. Depending on place and time, these various designs were created when the vessel was still wet, when it was dried to leather hard and, in some instances, once it had been fired.

Painting a vessel requires the application of a pigment to create a design (Fig. 5). Paint can be applied with a finger, with a soft tool such as animal hair, or with a hard tool such as a smoothed piece of bone. Paint can be applied before firing, during the leather-hard stage of production, or after a vessel is fired. In some ethnographic instances, paint is applied after the first firing, and then the vessel is fired a second time to bind the paint to the surface (Fewkes, 1944). Two common types of paints were used throughout pre-Hispanic North America: carbon paint, which was made from organic material, and mineral paint, which was made from nonorganic material. Carbon paint was only applied if a reducing atmosphere was used during firing; in an oxidizing atmosphere, the carbon would have burned away. Further, in the

Ceramics in Pre-Hispanic North America,

Fig. 5 Paint can be applied in a variety of ways, including using a soft brush made of animal hair or plant fibers (drawn by Joshua Keene).



southwest United States, the technology to create glaze paint was developed.

Appliqué involves attaching pieces of clay to a vessel as decoration; unlike the decorative techniques described above, appliqué results in a three-dimensional effect. Throughout pre-Hispanic North America, appliqué was never a primary decorative technique; however, its use has been reported from archaeological context in most cultural regions. The appliqué was often shaped into animal or human forms but was sometimes added simply as trim. In some instances, the appliqué is painted with details, such as eyes or ears.

Firing

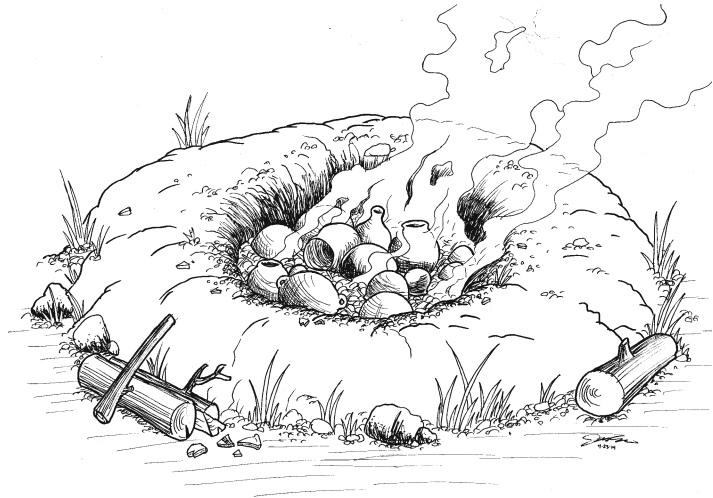
Once a vessel has been formed, decorated, and dried to the leather-hard stage, it is fired. It is during firing that the clay material undergoes the chemical change of vitrification (the point at which a pot loses its porosity during firing) and becomes ceramic material. Ceramic material is harder and more brittle than clay, it is often more porous, and it does not become plastic with the addition of water. Although the use of a formal kiln was rare in pre-Hispanic North America, potters still had the same concerns when firing their products as modern potters do: retention of heat, control of draft, and control of atmosphere.

Retention of heat is important because if a vessel is not fired at a high enough temperature for a long enough period of time, the clay does

not vitrify and become ceramic material. Specific temperatures and length of firing depends upon the properties of individual clays. The most common “kiln” in pre-Hispanic North America was the pit kiln (Fig. 6). Potters would have dug a pit into the ground; a fire would have been built into the pit and the vessels placed upon the charcoal from this fire, with further charcoal being placed around and on top of the vessels. Alternatively, the vessels may have been placed within an unfired pit, and then charcoal would have been stacked around the vessels. Although various types of fuel may have been used – including hard wood, coal, and dung – the main requirement of the fuel was that it smoldered. Pottery may also have been fired above ground, with fuel simply being placed under and around the vessels.

It is important to control air drafts to insure even firing and to avoid surface discolorations that are the result of soot coming into contact with the vessels. Although it is easier to control drafts in formal kilns, pre-Hispanic potters using pit kilns or firing above ground had a number of options. If the fuel and vessels were placed appropriately within a pit kiln or above ground, an updraft could have been created that would allow for more even firing, avoid the problem of sooting, and help control the firing atmosphere. To avoid a cross draft, potters could have fired their vessels in areas that were sheltered from the wind or in seasons that were particularly calm.

Pre-Hispanic potters also needed to control the firing atmosphere within their informal kilns;

Ceramics in Pre-Hispanic North America,**Fig. 6** Example of an open pit kiln.

specifically, they needed to worry about the amount of oxygen that entered into the firing atmosphere. They needed to create an oxidizing atmosphere that was sufficiently hot enough for a long enough period of time to completely burn out all organic material. If organic material remains in a vessel during the vitrification process, the vessel surface may bloat and potentially break. Controlling the amount of air in the firing atmosphere for a long enough period of time requires a well-controlled draft as well as the possible need to add fuel. Alternatively, some pre-Hispanic potters fired their vessels in a reducing atmosphere, one in which no oxygen entered the kiln. This is a much more difficult firing atmosphere to obtain in pit kilns, as the fuel must smolder long enough and hot enough for the clay to vitrify into ceramic material, but at the same time no air can be allowed to enter into the system. A reducing atmosphere, although not as hot as an oxidizing atmosphere, allowed for the creation of specific decorative affects including the use of carbon paints and the creation of white slips.

During the firing process, a potter may have chosen to smudge her vessels. Smudging is the process of blackening the surface of a vessel through the deposition of soot. In other words, rather than avoid the discoloration of sooting, some potters appear to have chosen to do this

intentionally. By bringing the vessel surface into contact with the smoldering fuel, and keeping the vessels in a reducing atmosphere, carbon penetrates into the pores of the vessel and turns it permanently black. Potters of the Mogollon culture of the southwest United States developed particularly fine smudged wares, with the entire interior surfaces of their vessels being a dark, even, glossy black.

Although the timing of the adoption of pottery production varies by region, the knowledge of how to produce pottery throughout North America appears to have been gained through diffusion rather than being independently developed. Vessels throughout the continent were hand built, often through either the coil-and-scrape or paddle-and-anvil technique. Once a vessel was formed, decisions on how to finish and decorate a vessel were limited to a handful of techniques. Firing methods were simple, never proceeding beyond pits or simple kilns. Overall, despite the apparent diversity of pottery types that were produced across pre-Hispanic North America, the methods used to produce these vessels were relatively homogenous.

See Also

► [Ceramics: Mimbres Pottery](#)

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and Vietnam testify that trade contacts between India and Southeast Asia were established by the last century BCE.

Ban Chiang, Udon Thani Province, North-eastern Thailand, is a representative, prehistoric site for the region. Excavations of burials conducted between 1974 and 1986 yielded tons of shards. Various forms of vessels with geometric designs painted in red on a buff-colored body were made using the anvil and paddle technique. The site is dated from BCE 3600 to AD 200.

The prehistoric tradition of making indigenous pottery in Southeast Asia continued into the next period. Thousands of shards unearthed at Angkor Borei, Ta Keo Province, southern Cambodia, are typical pottery of the early historic period, particularly the spouted vessel (*kendi*) with a bulbous body and a spout on the side, which is a ubiquitous form at all early sites in Southeast Asia (Fig. 1).

The earliest transitions from low-fired, unglazed to high-fired glazed ware occurred in Cambodia and Myanmar between the eighth and ninth centuries AD.

Ceramics in Southeast Asia

Dawn F. Rooney

The mainland region of Southeast Asia has a rich, indigenous tradition of ancient ceramic production with centers in the modern nations of Cambodia, Lao People's Democratic Republic (Laos), Myanmar (Burma), Thailand, and Vietnam. The main output was ware for domestic and ritualistic use and regional trade. The insular Southeast Asian region (Brunei, East Timor Indonesia, Malaysia, Philippines, Singapore) made only utilitarian earthenware such as cooking and storage vessels for foods and liquids. It did, though, import trade ceramics from the mainland, China, and Japan beginning in the fourteenth century.

By the second millennium BCE inhabitants of early rice-agriculture settlements in Southeast Asia were making similar types of red-slipped, painted, stamped, and cord-marked pottery. Roulette-made ware from India found in Java

Cambodia

Green-glazed roof tiles from temples of the Angkor Period (AD 802–1432) capital of Hariharalaya (now Roluos), built by King Indravarman I (r. AD 877–889), attest that the Khmers were making glazed stoneware by the late ninth century. Their repertoire expanded to include brown-glazed ware in the eleventh century. Ceramic production in Cambodia continued at least until the end of the thirteenth century. Although the Khmer Empire lasted for another 150 years, ceramics have not yet been positively attributed to the later period.

The first discovery of kilns producing Angkor Period ceramics was in the 1970s in Northeastern Thailand on the Khorat Plateau, an area that was part of the Khmer Empire between the eleventh and the thirteenth centuries. Kilns in Cambodia, however, were not confirmed until 1995.



Ceramics in Southeast Asia, Fig. 1 Spouted vessel (*kendi*). Earthenware. Sisophon, Cambodia. ca. AD sixth century

Groslier proposed the first chronology for Khmer ceramics. He analyzed types of glazes on wares found in excavations in the mid-twentieth century at the Angkor Period Royal Palace compound and in a burial at Srah Srang, the royal bath. Brown published a later refinement of Groslier's chronology (1981).

Two extensive kiln sites have been identified in Buri Ram Province – Ban ("village") Kruat and Ban Baranae. The oval-shape, crossdraft kilns were built of clay slabs with two chambers and a chimney. Both made green- and brown-glazed ware.

Over 12 groups of kilns operating during the Angkor Period in Cambodia have been identified in Siem Reap, Banteay Meanchhey, and Kandal provinces. Anlong Thom, on the southern ridge of Phnom ("Mount") Kulen, 25 mile (40 km) northeast of Angkor, produced high-quality, green-glazed stoneware. The main shapes were architectural fixtures (tiles and finials), covered jars, and bowls (Fig. 2).

The iron-rich body of Khmer stoneware is gray with impurities. Larger vessels were coil-built; smaller ones were thrown on a wheel. The glaze was either brown or green with fine-line cracks. Flaking of the glaze is a common defect. Decoration is always minimal and consists of repetitive geometric patterns encircling the neck, shoulder, or body (Fig. 3).



Ceramics in Southeast Asia, Fig. 2 Green-glazed roof tile. $L = 7.5$ in. (19 cm). Khmer. Tenth century

Some Khmer forms, uncommon in other ceramic traditions of Southeast Asia, may have metal prototypes. Examples are:

- A green-glazed cylindrical covered jar and a bowl with slightly flaring walls and unglazed firing scars around the lower body
- A brown-glazed flattened globular pot with a broad shoulder, a flat base, and a narrow mouth with a rolled rim
- A footed jar with a round body, a flat shoulder, tubular neck, flaring mouth with a flange, and a pedestal base
- Small pots with animal-shape (birds, elephants, rabbits) appendages (Fig. 4)

Laos

Excavations conducted at Sisattanak, near the modern capital of Vientiane in Lao People's Democratic Republic (Laos), in 1970 and 1989 identified a kiln site that operated between the fifteenth and seventeenth centuries based on



Ceramics in Southeast Asia, Fig. 3 Brown-glazed storage jar. *Ht* = 26 in. (66 cm). Khmer. Twelfth century

radiocarbon dating of associated finds. Quantities of unglazed and brown-glazed stoneware shards and wasters were spread over a wide area. The shapes are utilitarian and include bowls, dishes, jars, and pipes (Fig. 5).

Myanmar (Burma)

Architectural plaques and tiles (unglazed and glazed) were used on temples at Bagan (formerly Pagan) in the eleventh century. Geometric tiles are square, round or octagonal and decorated with applied lotus leaves or a lozenge with a blue-green glaze and yellow and white accents. Pictorial plaques portray episodes from the Buddha's former lives (Fig. 6).

Myanmar archaeologists recently discovered hundreds of ancient kilns in Twante district,



Ceramics in Southeast Asia, Fig. 4 Brown-glazed footed jar. *H* = 16 in. (40.6 cm). Khmer. Late eleventh century



Ceramics in Southeast Asia, Fig. 5 Unglazed pipe. Stoneware. *L* = 3.5 in. (8.9 cm). Laotian. Seventeenth Century

approximately 11 mile southwest of the capital, Yangon (formerly Rangoon). They produced only celadon and probably operated between the fifteenth and seventeenth centuries. Previously

Ceramics in Southeast Asia, Fig. 6 Glazed tiles at Naga-yon temple. Bagan, Myanmar. Eleventh Century



Ceramics in Southeast Asia, Fig. 7 Excavated kiln at Twante, Myanmar. Fifteenth to seventeenth centuries



unidentifiable celadon found in burial sites in Indonesia, the Philippines, and Tak and Om Koi are now attributed to Myanmar.

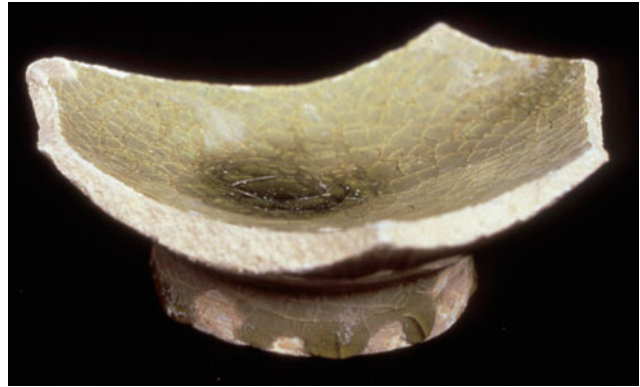
Two kilns were excavated in 1999. The characteristics are (1) oval-shape, (2) crossdraft, and (3) built of clay slabs on a slope with two chambers separated by a low wall and a chimney. An unusual feature of the Twante kilns is the remains of columns in the firing chamber, which were probably used to support a dome-shaped cover. The kiln dimensions are 39×16 ft (11.9×4.9 m). Tubular, clay supports were used to stack the ware. The body contains quartz, other silica, and a high concentration of iron. The characteristics after firing in a reducing atmosphere to a stoneware temperature are: a nonporous body and a wood-ash glaze with iron that produced a transparent, green color. Pooling of the glaze is common. Forms are medium-sized vessels that

were hand-built or thrown on a potter's wheel. Typical shapes are simple bowls, dishes, and plates with minimal geometric decoration (Figs. 7 and 8).

Other known kiln sites in Myanmar include: Lagunbyee, a former Mon center, southwest of Bago (formerly Pegu) where remains of a brick, crossdraft kiln were discovered in 1987 and excavated in 1998–1999; the kiln is 120×70 ft (36.6×21.3 m) and provisionally dated between the eleventh and the thirteenth centuries. Ten kilns and firing supports have been discovered at Myaung-Mya, west of Yangon, near Bassein.

Although kilns have not been found, it is certain that distinctive earthenware with an orange body and an opaque white, vibrant red, or green glaze was made in Myanmar. A variation is a design painted in green under the white glaze (Fig. 9).

Ceramics in Southeast Asia, Fig. 8 Celadon bowl (shard). Twante, Myanmar. Fifteenth to seventeenth centuries



Ceramics in Southeast Asia, Fig. 9 Green and white earthenware shards. Myanmar. Fourteenth to sixteenth centuries



Thailand (Sawankhalok or Si Satchanalai Ware)

Three sources have enabled recent advances in our knowledge of ancient ceramic production in Thailand: underwater archaeology in the Gulf of Thailand where 130 shipwrecks have been reported; excavations of kilns at Sawankhalok and surveys in satellite areas – Phitsanulok, Suphan Buri, and Sing Buri; and ceramic finds in burials at Tak and Om Koi, western Thailand, near the Myanmar border. The quality of ware from the latter is extremely fine and the wide

range includes ceramics from China, Vietnam, Thailand, Cambodia, and Myanmar.

Glazed architectural fixtures were made in the late thirteenth century for the temples of the burgeoning Kingdom of Sukhothai in north-central Thailand (279 mile (449 km) north of the modern capital of Bangkok). As the kingdom expanded, a second city developed at Si Satchanalai, 43 mile (69 km) north of Sukhothai, where kilns producing glazed ceramics were also set up. In the middle of the fourteenth century when Sukhothai became vassalage of the southern Kingdom of Ayutthaya, 49 mile (79 km)

Ceramics in Southeast Asia, Fig. 10 Excavated kiln at Ban Ko Noi. Sawankhalok, Thailand. Fourteenth to fifteenth centuries



inland from the Gulf of Thailand the place name “Si Satchanalai” was changed to “Sawankhalok.” Today, either name is acceptable when referring to the kiln site and the wares. The kilns continued to operate at least through the sixteenth century despite the shift in power.

The dates of operation for the two ceramic centers are not conclusively known. Evidence from shipwrecks carrying ceramics found in the Gulf of Thailand reverses a previously held theory and confirms that the Sukhothai kilns began production later than those at Sawankhalok. During the peak period for the export of ceramics from north-central Thailand (fifteenth and early sixteenth centuries) an estimated 1,000 kilns were operating. Changes in social, economic, and political circumstances of the kingdom most likely impacted on the kilns, causing a gradual decline in ceramic production.

Some 800 kilns have been discovered in the modern village of Ban Ko Noi, 4 mile north of the old city wall on the banks of the Yom River. Ban Pa Yang, a smaller kiln site in the area, produced architectural fixtures, human and animal figures, and brown- and white-glazed trade ware.

Kiln technology at Sawankhalok evolved from a simple bank kiln for firing unglazed, low-fired ware to one constructed of clay slabs that was more sustainable and could hold larger vessels. Finally there was a crossdraft kiln built of prefired bricks. A typical kiln of the latter type is oval shape, crossdraft with a sloping chamber for the wares in the center, a recessed fire-box at one end, and a round chimney at the other. A typical kiln

was 29×11 ft (8.8×3.4 m). For firing, a fixative was applied to the base of a vessel, which was then placed on top of a tubular clay support that was sunk into the sandy floor of the kiln. A black ring on the unglazed base resulted from the fixative of the vessel after firing (Figs. 10 and 11).

Green-Glazed Ware (Celadon)

Sawankhalok celadon is the most widely known product of the ancient Thai kilns. An iron-rich glaze was mixed with ash and fired in a reducing atmosphere. The thick, translucent glaze varies in color from a sea green to olive. Motifs incised in the center of plates and bowls, around the cavetto (a hollow or concave molding in the form of a quadrant) and rim, and on the exterior, drew inspiration from the regional flora, such as lotus and peony. Primary shapes are plates, bowls, bottles, kendis, and jarlets (a small, squat, rounded, or square jar with a small mouth) (Fig. 12).

Brown and White Ware

Sawankhalok kilns produced two other monochrome glazes – brown and white. A typical brown-glazed form is a jar with a tall body, a thick-rolled mouth rim and two handles. A combination of the two glazes on a single piece was a specialty of the export ware made at the Ban Pa Yang kilns (Fig. 13).

Exceptionally large water jars were also made (Fig. 14).

Architectural fixtures, such as tiles, were usually white-glazed (Fig. 15).

Ceramics in Southeast

Asia, Fig. 11 Tubular support for celadon bowl; scar after firing. Sawankhalok, Thailand. Fifteenth century



Ceramics in Southeast Asia, Fig. 12 Celadon plate. Diameter = 11 in. (28 cm). Sawankhalok. Fifteenth century

Quantities of figures (animal and human) were made at Tukatha (Ban Pa Yang kiln site) for the religious and cult needs of the native inhabitants (Fig. 16).

Iron-Decorated Ware

A design was painted on the body with iron oxide; then a transparent clear glaze applied over it. Sometimes a slip was put on the body for a lighter color which created more contrast between the design and the background. Forms include plates, bowls, bottles, kendis, and architectural fixtures. A particular type of round covered box was produced prolifically for export.



Ceramics in Southeast Asia, Fig. 13 Brown-glazed jar. $H = 5$ in. (13 cm). Sawankhalok. Fifteenth century

The body and cover of the box form a continuous line with modeled knob on the cover that is shaped like a lotus bud or in the form of a fruit stem (Fig. 17).



Ceramics in Southeast Asia, Fig. 14 Brown-glazed storage jar. $H = 3$ ft. Sawankhalok. Fifteenth century



Ceramics in Southeast Asia, Fig. 16 Brown-glazed chicken. $L = 3$ in. (7.6 cm). Sawankhalok. Fourteenth century



Ceramics in Southeast Asia, Fig. 15 White-glazed tile. $H = 4$ in. (10 cm). Sawankhalok. Fourteenth century



Ceramics in Southeast Asia, Fig. 17 Underglaze glaze painted box with cover. Diameter = 4 in. (10 cm). Sawankhalok. Fifteenth to sixteenth centuries

Thailand (Sukhothai Ware)

Two clusters of over 50 kilns have been identified at Sukhothai – one near Wat (“temple”) Prah Phai Luang and another north of the city wall. The kiln



Ceramics in Southeast Asia, Fig. 18 Disc firing support. Diameter = 4 in. (10 cm). Sukhothai. Fifteenth century



Ceramics in Southeast Asia, Fig. 19 Painted shard. Sukhothai. Fifteenth century

shape and construction are essentially the same as those at Sawankhalok except the Sukhothai kiln is narrower. The average dimensions are 29×8 ft. Plates and bowls were stacked for firing by placing one on top of the other separated by a disc-shaped clay support with spurs (usually five). A distinctive feature in the center of Sukhothai plates and bowls is five circular scars resulting from separating the disc after firing (Fig. 18).

Sukhothai kilns produced two types of ceramics – painted ware and a white-glazed ware. To achieve the former, a slip was applied to a dark body; next, a design was painted using iron oxide; then a thin, transparent glaze was applied. After firing, the texture of the gray body was coarse with visible white flecks of quartz; the color of the iron pigment varied from gray to olive, brown or black; and the glaze is often opaque, or milky in appearance with fine-line crazing and pin holes. A painted fish plate (average diameter = 10 in. (25 cm)) is characteristic of the Sukhothai kilns. The central motif is a single fish, painted in profile, and encircled by one or more rings. Other designs on plates, bowls, and a few bottles such as a single stemmed flower surrounded by leaves and a solar whorl and architectural forms were made at Sukhothai (Fig. 19).

Thailand (Suphan Buri Ware)

A complex of kilns at Ban Bang Pun in Suphan Buri Province, northwest of Ayutthaya, was discovered in the 1980s. The main output was unglazed stoneware footed jars, which were previously attributed to Sawankhalok or Sukhothai. Distinctive, repetitive bands of a leaf motif were stamped around the base of the neck and outer shoulder. The crossdraft, clay kilns were of a similar design to those at Kalong in northern Thailand.

Thailand (Phitsanulok and Nakorn Thai Ware)

Phitsanulok, a small state east of Sukhothai and controlled by the Sukhothai Kingdom in the thirteenth century, became a provincial capital of the Ayutthaya Kingdom in the fifteenth century. Excavations in 1984 at Ban Tao Hai (“village of the jar kilns”) on the eastern bank of the Nan River, 2.5 mile (4 km) north of the modern town of Phitsanulok, revealed two brick, crossdraft kilns of the type developed at Ban Ko Noi with another estimated 40 kilns in the area. A typical jar is baluster-shaped with a flaring mouth and applied decoration. The kiln structure and the output suggest the site operated in the late fourteenth or early fifteenth century.

Ceramics in Southeast Asia, Fig. 20 Excavated kiln at Sankampaeng. Northern Thailand. Mid-fourteenth to mid-sixteenth centuries



The identification of six kilns at Nakorn Thai, east of Phitsanuloke, indicates that it was also a production center for stoneware jars with dates of operation the same as the Phitsanulok kilns.

Thailand (Northern Thai Ware)

Lan Na, founded by King Mengrai in 1292, with a capital at Chiang Mai in Northern Thailand, was an extensive ceramic center making glazed stoneware for domestic and ritualistic needs between the mid-fourteenth and the mid-sixteenth centuries.

The northern kilns were dug from river banks, or made with clay slabs in-ground, or brick-constructed above ground. General characteristics are: small size, simple construction, and crossdraft with two chambers and a chimney. Plates, dishes, and bowls were stacked in the kilns lip to lip and base to base.

Kalong

Over 200 kilns are mid-way between Chiang Mai and Chiang Rai near the valley of the Lao River. Kalong kilns produced ware painted with iron oxide under the glaze in the style of those from north-central Thailand but with more flamboyant motifs executed with broader brush strokes. Dishes with an abstract leaf and flower design are typical. The Kalong kilns also made a fine, thinly potted ware covered with a soft rain-cloud

gray glaze. Vases, bowls, bottles, and dishes comprise this group.

Sankampaeng, Phayao, Nan

Eighty-three kilns are located by the Ping River valley, approximately 15 mile (24 km) east of Chiang Mai. Average dimensions of a kiln are 10 × 4 ft (3 × 1.2 m). Plates and dishes (either painted or brown-glazed) with a central medallion of two fish are typical Sankampaeng ware. Celadon, painted ware, and two-color jars were also common (Figs. 20 and 21).

Kilns were reported at Phayao, in Cham Pawai district, near the remains of an ancient walled city, in the 1950s. The site is unexcavated but shards of celadon, brown-glaze, and two-glaze wares have been found. Stamped motifs and incising through a slip are distinctive characteristics of Phayao ware.

An extensive kiln site was found at Nan, western Thailand, in 1982. It produced painted ware (underglaze black) with a milky white glaze that was placed in a sagger (a box of baked fireproof clay used to protect pieces during firing) for protection during firing.

Phan

Twenty-seven brick kilns situated between Chiang Rai and Phayao are of the crossdraft type with the average dimensions of 20 × 11 ft (6 × 3.4 m). The Phan kilns only produced celadon. It is more carefully potted and more finely



Ceramics in Southeast Asia, Fig. 21 Brown-glazed plate. Diameter = 9 in. (23 cm). Sankampaeng, Northern Thailand. Mid-fourteenth to mid-sixteenth centuries

finished than other northern wares. The shapes include plates, bowls, jars, oil lamps, miniatures, elephants, and kendis. The sophistication and the narrow range of these wares suggest a slightly later date, perhaps from the mid-fifteenth to the mid-sixteenth century.

Thailand (Lamphun (Haripunjaya) Ware)

Although no kilns have been found, shards litter the area of Lamphun, the old Haripunjaya kingdom, and similar ones were found at Tak and Om Koi. These finds suggest a mid-fourteenth to mid-sixteenth century date. The finely textured body is either orange or brownish black. A typical form is a thinly potted, globular, long-necked bottle with a flat base, inlaid with slip, and either intricate white or black geometric motifs on the neck and body.

Thailand (Sing Buri or Maenam Noi Ware)

Excavations conducted in 1987 in Bang Rachan district of Sing Buri Province at the Tao Maenam Noi kiln site established the provenance of a class of brown-glazed storage jars previously believed



Ceramics in Southeast Asia, Fig. 22 Brown-glazed jar. $H = 18$ in. (45.7 cm). Sing Buri, Thailand. Late sixteenth to early seventeenth centuries

to be Sukhothai. As the kilns are located near a temple, the ware is popularly called Wat (“temple”) Phra Prang Pottery. The oval-shape, crossdraft, brick kiln measures 44 ft (13.4 m) long and is the largest one found so far in Thailand. Both unglazed and glazed ware was made, mostly storage jars but also unglazed kendis. A typical jar is heavily potted, with an ovoid body and a narrow neck with a rolled lip and partially covered with a brown glaze. These jars have been found in the cargo of a number of shipwrecks in the Gulf of Thailand dating to the late sixteenth or early seventeenth centuries (Fig. 22).

Vietnam

The glazed ceramic tradition of Vietnam is unlike any other in Southeast Asia as it was strongly



Ceramics in Southeast Asia, Fig. 23 Green-glazed lime pot. $H = 7$ in. (18 cm). Vietnamese. Fifteenth to sixteenth centuries

influenced throughout history by China, both technically and stylistically. Its development, forms, and motifs, therefore, are parallel approximately that of Chinese ceramics. Extensive excavations of burial grounds in the early twentieth century in Thanh-hoa Province, northern Vietnam, yielded quantities of ceramics dated between the tenth and the thirteenth or fourteenth centuries. Kilns near the modern city of Hanoi, the site of capitals of the Ly (AD 1009–1225) and the Tran (1225–1400) dynasties, were most likely the source of the Thanh-hoa ware. Vietnamese ceramics entered the export market in the fourteenth or early fifteenth century with painted ware in both underglaze blue and black. Despite the Chinese influence, some forms are distinctively Vietnamese. A storage container for lime to use for betel chewing is an example. The squat form has a small opening on the shoulder, a pedestal foot, and a “basket-like” handle with

elaborate decoration. Ritualistic ceramics made in the late sixteenth or seventeenth century at kilns near Hanoi are distinguished by large altar vases and incense burners (Fig. 23).

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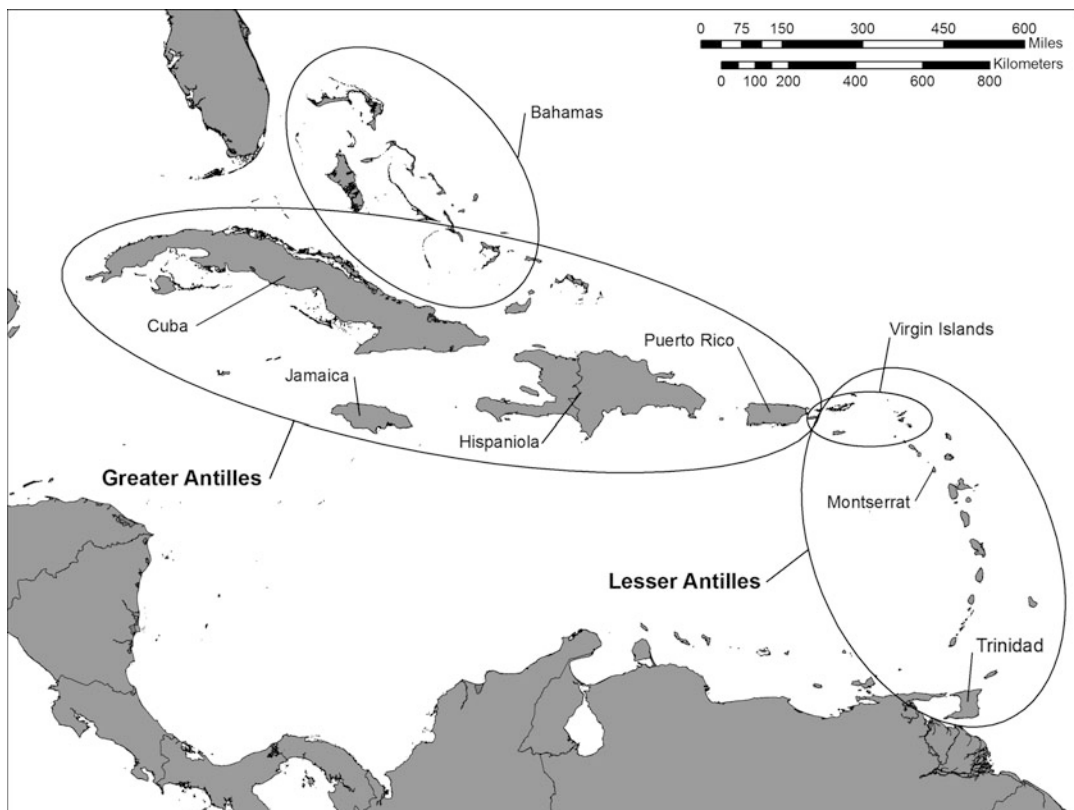
Ceramics in the West Indies

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The West Indies are a series of 28 island nations and over 7,000 islands in the Caribbean Sea and Atlantic Ocean between North and South America (Fig. 1). The islands include the Greater Antilles, which are the more northern and larger islands of Cuba, Hispaniola, Jamaica, and Puerto Rico, and the Lesser Antilles, which are the islands from the United States Virgin Islands south to Trinidad. The West Indies also include the Bahamas, Aruba, Bonaire, and Curacao. The islands vary in size, topography, and proximity to one another, which has had an influence on pre-historic and historic settlement, subsistence, and material culture. Pre-Columbian pottery in the West Indies is very diverse due to the geographical breadth of the region and influences from South and Central America and possibly North America. After European contact, the many islands were colonized by the Spanish, British, French, and Dutch, and the Amerindian populations in the West Indies were quickly decimated on most islands. A plantation economy was soon in place where enslaved Africans worked the sugar, tobacco, spice, coffee, cotton, and indigo plantations.

The West Indies were first settled from South America around 7,000 years ago and from



Ceramics in the West Indies, Fig. 1 Location of West Indies with subregions and islands mentioned in text identified

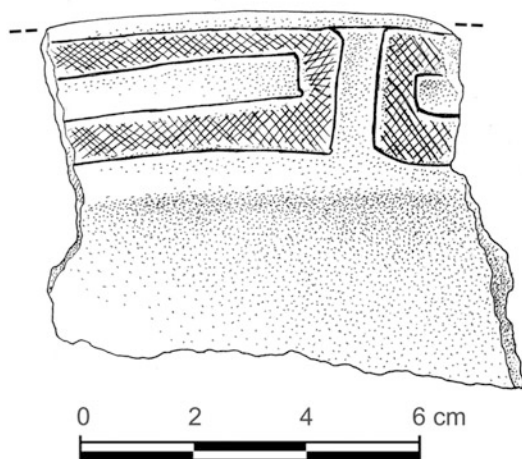
Central America about 6,000 years ago. The first settlers of the West Indies engaged in marine and terrestrial subsistence with material culture of ground stone, coral, and shell tools. The paucity of quality cryptocrystalline stone meant that stone tools were not widely used. Pottery first appears in the West Indies as early as 800 BC during the Saladoid period. The Saladoid takes its name from the type site in the Orinoco valley of Venezuela where it is thought the people who brought ceramics to the West Indies originated. The earliest known Saladoid sites are in Montserrat, St. Martin, Puerto Rico, and the Virgin Islands.

The Saladoid period is marked by horticulture, hunting and fishing, permanent villages, and pottery. The presence of griddles indicates the cultivation of manioc roots as well as other root and vegetable crops. Pottery is the defining feature of the Saladoid period and includes a variety of

plain as well as highly decorated pieces. Early Saladoid pottery is marked by white-on-red painted decorations, modeled-incised adornos, and zone-incised cross-hatching (Fig. 2). After AD 400, Saladoid pottery becomes thicker and heavier and has polychrome decorations with white, red, black, and orange painting, modeled-incised zoomorphic and anthropomorphic adornos [ornamentation on the rims or handles of ceramic pieces] (Fig. 3), incised motifs (Fig. 4), and some zone-incised crosshatched decorations. Barrancoid pottery developed around AD 650 in the southern West Indies and occurred concurrently with Saladoid pottery with influences from South America. Barrancoid pottery has modeled-incised handles, and anthropomorphic and zoomorphic hand, feet, and face adornos.

At the same time as the Saladoid, Huecoid ceramics developed in the northern West Indies

around 800 BC and lasted through AD 200. Researchers believe this pottery has influences from Central America. These ceramics are decorated with curvilinear-incised zones with punctuates and cross-hatching. Huecoid ceramics were not painted, but some included white or red paint or slip rubbed into the incised or hatched patterning. Some pottery was adorned with zoomorphic adornos (Fig. 5) and/or shaped into aquatic animal forms.



Ceramics in the West Indies, Fig. 2 Zone-incised cross-hatching decoration on bowl (Drawn by Eric Carlson after Fig. 61 in Hardy, Meredith Devereaux, Saladoid Economy and Complexity on the Arawakan Frontier. Unpublished Ph.D. dissertation, Department of Anthropology, Florida State University. 2008)

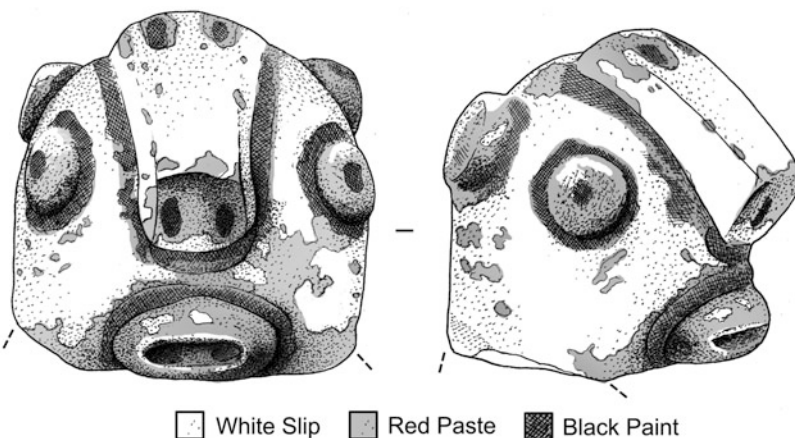
The Casimiroid is a preceramic period that developed independently on Cuba and Hispaniola starting around 4000 BC. Casimiroid pottery developed on Hispaniola during the Courian subperiod between 2630 BC and AD 240 on Hispaniola.

During the post-Saladoid period, a differentiation in pottery series between the Greater Antilles and northern West Indies and the Lesser Antilles appears. In the Greater Antilles, the Ostinoïd series developed from the Saladoid or Casimiroid periods in Cuba, Hispaniola, Jamaica, Puerto Rico, and the Bahamas around AD 600 and continued until AD 1500. The Ostinoïd series is further broken into regional and temporal variations based on pottery decoration and forms with variants often occurring simultaneously on the same island. The Troumassoid series developed in the Lesser Antilles during the same period and is broken into temporal subseries.

In the Greater Antilles, the Elena Ostinoïd dates from around AD 600 to AD 1200 and occurs in eastern Puerto Rico and the Virgin Islands. This pottery series is marked by a reduction in decorative elaboration and overall craftsmanship from the earlier Saladoid but appears to be better suited for utilitarian uses. During the first half of the period, red-painted and plain varieties dominate with smaller numbers of black, negative, and smudged decorations. Bio-morphic modeled, strap, lug, and tubular handles are also found. The second half of the period shows a return to modeled and incised

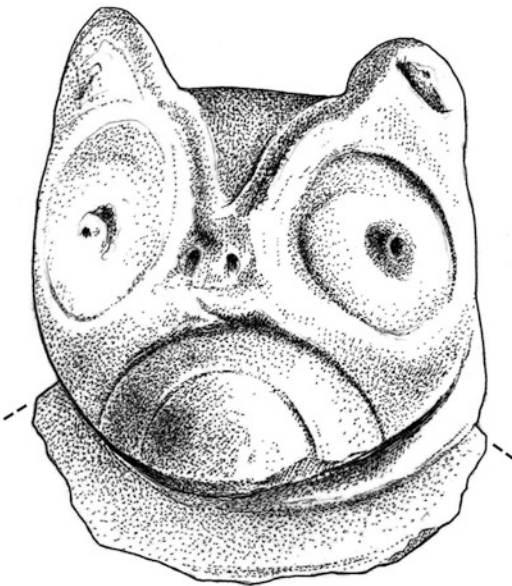
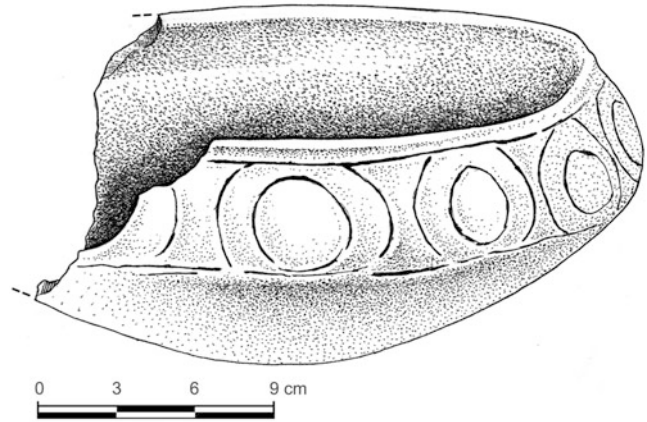
Ceramics in the West Indies,

Fig. 3 Transformational adorno from Barbados (Drawn by Eric Carlson after Fig. 4 in Waldron, Lawrence. Geographic Distributions of Zoomorphic Motifs in Saladoid Ceramics. *Caribbean Connections*. 2011. http://fieldresearchcentre.weebly.com/uploads/1/8/0/7/18079819/waldron_2011.pdf)



Ceramics in the West Indies, Fig. 4

Incised and carinated bowl (Drawn by Eric Carlson after Fig. 61 in Hardy, Meredith Devereaux. *Saladoid Economy and Complexity on the Arawakan Frontier*. Unpublished Ph.D. dissertation, Department of Anthropology, Florida State University. 2008)



Ceramics in the West Indies, Fig. 5 Huecoid screech owl adorno (Drawn by Eric Carlson after Fig. 24 in Waldron, Lawrence. *Geographic Distributions of Zoomorphic Motifs in Saladoid Ceramics*. *Caribbean Connections*. 2011. http://fieldresearchcentre.weebly.com/uploads/1/8/0/7/18079819/waldron_2011.pdf)

decorations, zoomorphic adornment, and an almost absence of painted or slipped decorations.

The Ostionan Ostionoid dates from AD 600–1200 and has been found in western Puerto Rico as well as Jamaica, Hispaniola, and Cuba. There is also a simplification in pottery decoration and styles during the Ostionan, but many Saladoid variations are retained. Red-painted or

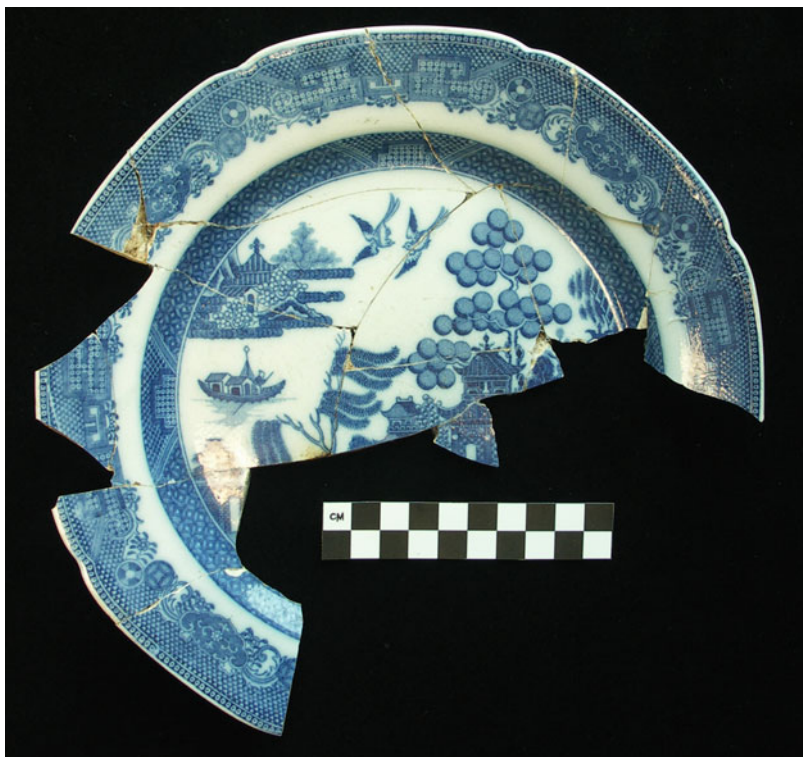
slipped varieties survive along with looped handles and zone painting. Island variation exists with red-, pink-, or lilac-colored painting, incising, and zoomorphic adornments.

The Meillacan Ostionoid was first defined in Hispaniola and is found in Cuba, Jamaica, and parts of the Bahamas and dates from AD 600–1500. There is debate as to whether the Meillacan Ostionoid developed in place from the Casimiroid, developed out of South American influences, or borrowed from the Ostionan Ostionoid, but there do not seem to be many Saladoid influences. The pottery almost is devoid of painting and is generally characterized by rectilinear incising that forms hatching and cross-hatching designs along with punctuates and appliques. Handles are generally straps with geometric or zoomorphic decorations.

The Chican Ostionoid dates from AD 800–1500 but is most common from AD 1200–1500. This pottery is found in the Virgin Islands, Puerto Rico, eastern and southern Hispaniola, eastern Cuba, the Bahamas, and the northern Lesser Antilles. Chican Ostionoid pottery is primarily characterized by bowls with incised shoulders with circles, triangles, parallel dashes, and lines. Painted pottery is almost absent from this series but is found at some sites. Handles include biomorphic, modeled head lugs, and adornos.

The Palmettan Ostionoid is found in the Bahamas and Turks and Caicos islands and dates from AD 600–1500. This pottery series was previously

Ceramics in the West Indies, Fig. 6 British-made blue transfer printed pearlware that dates from 1780 to 1820 (Photo by author)



thought to be unrelated to other West Indian ceramics but is now thought to be related to the Chicano Ostinoid and Meillacan Ostinoid based on similar decorations. The Palmettan Ostinoid has been divided into subseries such as Abaco Redware, Crooked Island ware, and Palmetto ware that does not necessarily correlate with specific geographical areas. There is temporal variation in these subseries with the Abaco and Crooked Island ware occurring before the Palmetto ware.

In the Lesser Antilles, the Troumassoid ceramic series follows the Saladoid series and is divided into two temporal periods: Troumassan and Suazan Troumassoid. The Troumassan Troumassoid immediately follows the Saladoid period and dates from AD 600–1000. This subseries carries forward many Saladoid characteristics, but over time, there is a trend in decreasing decorative and vessel-form complexity. In the northern Leeward Islands, the Troumassan pottery has bicolor and polychrome painting with broad-lined and curvilinear incisions. In the

Windward Islands, the Troumassan Troumassoid is characterized by decreasing complexity in decoration with red, black, and white paints and curvilinear-incised lines dominating. There are many similarities to pottery from South America, including cotton spindle whorls suggestive of cotton cultivation and trade.

The Suazan Troumassoid subseries dates to AD 1000–1500 marks the end of the pre-Columbian pottery production in the Lesser Antilles. This period continues the overall post-Saladoid trend in pottery simplification with thicker walls, rough or scraped surfaces, and finger-indented rims. Utilitarian wares dominate assemblages, but finer wares do appear in smaller amounts and include polychrome and red painting, curvilinear and linear incising, and modeled anthropomorphic and zoomorphic adornments. Utilitarian vessel forms include griddle, incense burners, spindle whorls, and pestles.

The contact period between Amerindians and Europeans shows a continuation of the Ostinoid and Troumassoid series characteristics as well as

Ceramics in the West Indies, Fig. 7 Afro-Caribbean ware bowl from St. Kitts (Photo by author)



a melding of these traditions, influences from South America, and evidence of interactions with Europeans. For instance, the Cayoid pottery series in the central and southern Lesser Antilles dates from AD 1550–1650 and was thought to have formed out of the preceding Suazan Troumassoid. Recent research, however, has shown similarities to Carib pottery from the Guianas, and researchers believe the pottery has direct ties to South America. This idea blends well with Island Carib traditions that state Carib men came from South America and were in regular contact with Amerindian groups throughout the West Indies and South America. Cayoid pottery has decorations with similarities to the Polychrome Tradition of Amazonian vessel forms with decorative motifs related to the Chicoid Ostinoid of the Greater Antilles, and rough-surfaced griddle and bowls like those from the Suazan Troumassoid. A few Cayoid pottery shards found on St. Vincent have European beads embedded in the rims.

Ceramics during the historic period include the full gamut of European wares typical of the colonial period (Fig. 6). In general, the ceramics of each island reflects the national identity of the European colonizing nation. For instance, on



Ceramics in the West Indies, Fig. 8 Afro-Caribbean ware bowl from St. Kitts (Photo by author)

islands like Montserrat and Nevis, the ceramics are distinctively British, but on St. Eustatius, a Dutch island that served as a major port and shopping center, the ceramics are much more diverse and include Dutch, British, French, and Spanish ceramics.

During the historic period, enslaved and freed Africans made and traded pottery called by

Ceramics in the West Indies, Fig. 9 Afro-Caribbean ware rims with iron oxide slip (Photo by author)



archaeologists Afro-Caribbean ware (Figs. 7, 8, and 9). Afro-Caribbean ware is a handmade, low-fired earthenware made by enslaved and freed Africans throughout the West Indies. First identified on Barbados in the 1960s, this pottery has become one of the most studied historic material types on the West Indies because it represents a direct connection to the slaves who made and used the pottery. Analyses have included macroscopic examination of paste characteristics, petrographic study of inclusions and construction methods, and INAA of the chemical composition. These analyses have identified a vibrant production history that hit its height during the late eighteenth and early nineteenth centuries. Researchers have examined the trade networks on Jamaica and found that pottery was likely made in certain production centers and radiated out along known travel routes. Within the Lesser Antilles, intransland trade was extremely important, but some researchers have explored the interisland trade of the pottery. Researchers have used instrumental neutron activation analysis to examine the chemical composition of pottery shards to study this trade and found that

numerous compositional groups occur throughout the islands and that some groups occur on more than one island. For instance, shards likely made on Nevis or St. Kitts occur on those islands as well as St. Eustatius and Antigua. Modern day potters continue to make similar pottery on Nevis, St. Lucia, Antigua, Jamaica, and several other islands.

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Ceramics in West Africa

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Archaeologists, anthropologists, and art historians have studied ceramics in West Africa. These studies have focused on ceramics as markers of identity, the role of ceramics in ritual practice, and the gendered nature of ceramic production. A range of technical and stylistic ceramic forms have been identified throughout West Africa that can be correlated with different historically known ethnolinguistic groups to varying degrees (Mayor, 2010). A number of long-term regional studies in West Africa are focused on filling the gaps in our knowledge of the origins and development of ceramic traditions in the region utilizing archaeological and ethnographic research. These include the Mandara Archaeological Project in Cameroon, Nigeria, and Ghana (David, 1998) and the Mission Archéologique et Ethnoarchéologique Suisse en Afrique de l'Ouest (MAESAO) in Mali (Gallay, Huyssecom, & Mayor, 1998; Mayor, 2010). Both projects trace changes in ceramic technology and style. However, the numerous similarities between decorative styles and vessel forms make it difficult to delineate potting traditions based solely on aesthetics. In this entry, key aspects of the different ceramics, potting techniques, and traditions are highlighted, recognizing that this is by no means an exhaustive summary. As such, only ceramic vessels and not other objects made from fired clay will be addressed.

Definitions and Characteristics

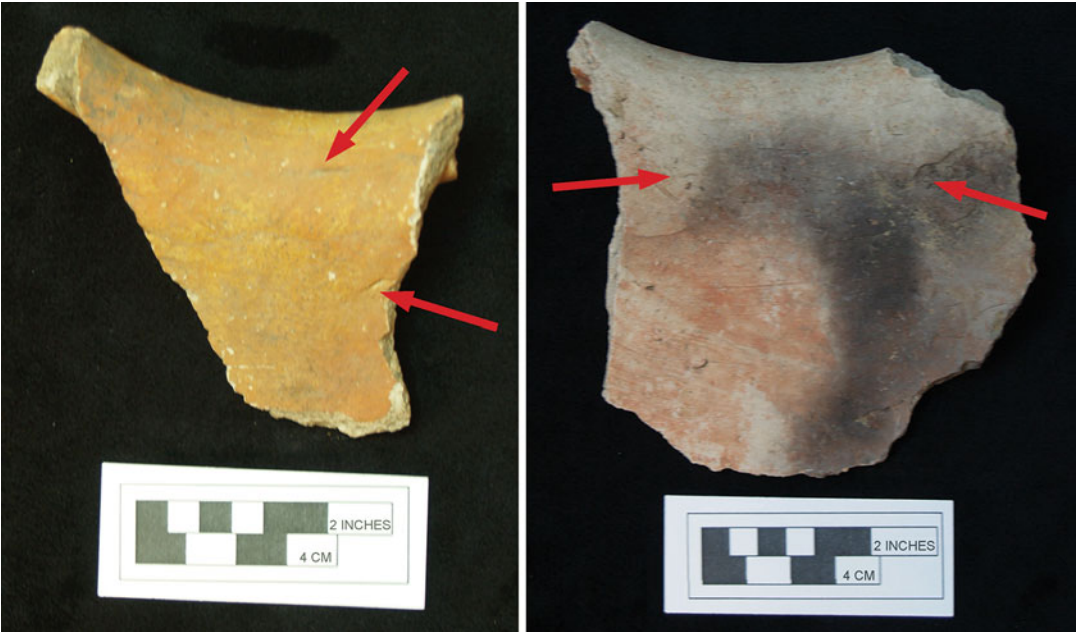
West African ceramics are classified as low-fired earthenware and are typically some form of hollowware vessel serving a range of purposes. Most ceramics function as cooking, serving, and storage containers for water, medicine, oil, or grain.

Ritual ceramics are also produced and may be similar in shape and design to those used for foodways. In the Gambia, restricted hollowware vessels similar to those used for storage would also serve ritual functions. These vessels would be transformed into juju (a ritual charm or amulet) through burial. Archaeological examples include pots containing stone, animal bone, and botanical remains. Ritual ceramics can also be incorporated into shrines or burials. These ceramics are often similar in form to everyday wares and can be identified by their poorer quality (Norman, 2009, p. 196). There are also specialized forms that are produced in areas of Benin and Ghana.

West African ceramics are less refined than wheel-thrown and kiln-fired wares because of the lower firing heat which in turn makes them more porous. The potter builds the vessel by hand using local clays. Clay extraction is carried out in a number of ways including surface collection, pit extraction, gallery extraction, and underwater collection (Gosselain & Smith, 2005, p. 3). Throughout most of West Africa, the local clay requires processing and tempering agents such as chaff, sand, grog (broken ceramic), or shell to survive the firing process. The vessels are created from the processed clay using a range of shaping techniques including but not limited to coiling, slab, or pound molding, molding over an existing pot (convex-form molding), or molding in a convex form. Many potters utilize a combination of these techniques, shaping the body of the pot in one way and adding the rim manufactured in another. Depending on the ability of the potter, the manufacturing technique may be evident in the final product (Figs. 1 and 2).

Once the pots are shaped and smoothed, they are left to dry until they are leather hard. At this stage, various finishing techniques may be used. Finishing techniques include slips, burnishing, smoothing, or painting the surfaces of the vessel. In addition, decorative elements are often impressed or carved into the exterior of the vessel at this time. The most common decorating technique identified throughout West Africa both archaeologically and ethnographically is rouletting. Camps-Fabrer (1966) classified a range of

Ceramics in West Africa,
Fig. 1 The nineteenth-century ceramic rim and body sherd from Berefet, Gambia, with no visible evidence of coiling



Ceramics in West Africa, Fig. 2 The nineteenth-century ceramic rim and body sherds from Berefet, Gambia, exhibiting evidence of coiling manufacturing

roulette decorations based upon the tool used. These could be applied to the ceramics vessel using a braided cord, cord-wrapped stick, or natural plant material. McIntosh (1995) and Galley (1970) have expanded this list to include a greater range of cord-wrapped designs as well as impressions made using various types of shells. Various patterns have been associated with different regional areas and have demonstrated a temporal variation (Haour et al., 2010, pp. 7–9). However, ethnographic work has demonstrated that technical style (i.e., vessel construction techniques) is more closely tied to ethnic affiliation than decorative motifs (Mayor, 2010, p. 15). This is largely attributed to the fact that it is easier to mimic a design than gain access to technical knowledge which requires a period of apprenticeship. The completed pots are piled together and surrounded by fuel. This is an open-air firing process with the vessel in direct contact with the fuel source which can be wood, straw, or palm leaves depending on what is available in the local environment.

Origins and Ceramic Traditions

Ceramic production in Africa is believed to have originated in the Central and Eastern Sahara as well as the Nile Valley between the late tenth and early ninth millennium BC (Jesse, 2003, pp. 40–42), and the technology expanded from the east, including the modern nation of Sudan. The earliest known West African ceramics were found at Mouche at Ounjougou in Mali. These have been dated to the late tenth millennium BC using C14 and OSL techniques (Huysecom et al., 2009, pp. 906, 907). This places the beginning of ceramic production in sub-Saharan Africa as early as production in the Nile Valley. Three ceramics were recovered dating to this period at Mouche. Vessel form could only be determined from one sherd which is a rounded bowl. A second sherd has an impressed decoration (Huysecom et al., 2009 pp. 910). These sherds are clear antecedents to the variety of ceramics manufactured throughout sub-Sahara into the present.

There are distinct differences that have been observed in the archaeological record that persist today between ceramic traditions in the northern Sahel-Sudanic and southern savanna-forest regions. This historical division is first observed in ceramics from Koroukorokalé (Mali) dating between 4240 and 3800 BC. These vessels are described as an offshoot of the northern traditions found in the inland Niger Delta including Djenné-Djeno. It is not until the third millennium AD that distinct ceramic traditions have been identified by archaeologists in Mali that are distinguishable from neighboring areas by both aesthetic and technical style (McIntosh, 1995, pp. 130–215). The phase I ceramics identified at Djenné-Djeno are semi-refined open and closed hollow vessels with a high prevalence of twine impressions and grog-tempered wares (McIntosh, 1995, p. 212). Those from the southern savanna and forest zones are characterized by everted rims and course grog-tempered paste and they are decorated using relief or grooved motifs (Frank, 1998, p. 20).

Production Organization

The primary producers of ceramic vessels in West Africa are overwhelmingly women. Male potters are rare but can be found among the Mossi (Ivory Coast, Burkina Faso, and Nigeria) and Hausa (Nigeria) to name a few examples. While women create ceramic vessels, they are often prohibited from producing other objects from clay. This is seen among the Asante whereby women are not allowed to create pipes or anthropomorphic figures (Rattray, 1927, p. 301). Potters are present in nearly all ethnic groups in the region, with a few exceptions (e.g., the Bozo). In those societies where craft castes are present, potting is restricted to women of particular lineages. They can be members of these lineages either through birth or marriage. For several groups including the Mande, Dogan, Senufo, Mafa, and Dowayo, only the wives of blacksmiths can be potters (Vincentelli, 2004, p. 51). Fulani potters also marry blacksmiths, but they can also be the wives of weavers,

leatherworkers, or woodcarvers (Mayor, 2010, p. 9). For many groups, a potter is viewed as a female blacksmith, and a Dogan legend suggests that pottery originated in the smithy (Barley, 1994, p. 53).

Mande potters in the Kadiolo region of Mali are tied to griot rather than blacksmith lineages. Frank (1993) has convincingly argued that this anomaly to Mande tradition is the result of these women's ancestry as slaves in the region. Precautions are taken in many of these societies to restrict craft production to the proper lineage. For example, the Senufo will not train a potter until after marriage, whereas many Mande women will marry men outside of their village in order to ensure that they are blacksmiths.

In addition to lineage-based restrictions, other taboos surround ceramic manufacture. Much of this is tied to beliefs about the nature of the earth. In many societies, the earth is considered female and a connection is made between various forms of production including potting to fertility and reproduction. These taboos can be specific to a particular vessel that is made, the time when potting can take place or who is able to pot at certain times. Among the Yoruba, red is not worn when near the clay pits because of its association with menstruation. Age restrictions are present in different societies as well. For the Yoruba, post-menopausal women cannot make sieves which are used in grain processing. Kelly and Norman (2006) have noted that production of specific ceramic forms is restricted to different potters in southern Benin. Older Gbe-speaking women in this area control the local industry, and they are the only ones able to produce ritual ceramics. The Bamana presents a further example. For them, girls are not deemed full-fledged potters until they go through an excision ritual. During this, their virginity is checked, and those who do not pass are banned from potting (Herbert, 1993, p. 209).

Ceramic production has declined significantly in West Africa beginning in the mid-twentieth century. This has been correlated to the widespread availability of low-cost metal and enamel

wares. While the production of everyday utilitarian vessels is declining, specialized wares continue to be manufactured. In Benin, the production of ritual vessels continues, though other forms have fallen into decline. An extreme example of this loss of potting traditions is the situation in the Gambia where only a small number of villages have women who continue to produce ceramics (Vincentelli, 2004, pp. 53–54). These include villages in the Foni and Wuuli districts. Regional production is evident in the physical nature of these ceramics despite the fact that the potters are Mande. Both traditions utilize grog temper. The Foni wares are not burnished and have red- to orange-painted decorations. In contrast, those produced in upcountry are highly burnished and have white-painted designs (Fig. 3). The vessels produced by all potters are limited to closed pots, incense burners, large water storage containers, and steamers.

Conclusion and Observations

West African ceramic production is a long-standing practice. As a material class, these are distinguished from imported wares by their coarse texture and lack of glaze. These ceramics were and continue to be a craft or cottage industry rather than being mass produced. Because of the localized production, the ways in which the pots are created as well as decorated at times can signal ethnic affiliations. This correlation has been used to understand past migrations and settlement throughout the region. Ethnographic research has highlighted the engendered nature of production. The majority of West Africans who have in the past and continue to produce ceramic pots are women. The abandonment of ceramic production in different areas of West Africa is primarily the result of cheap and readily available alternatives including metal and plastic wares. Because of this decline, ceramics that are produced today are highly specialized for either domestic or ritual use.

Ceramics in West Africa,

Fig. 3 Ceramics currently available for sale in the Gambia in 2008

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Ceramics: Maya Pottery

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A social analysis of pottery investigates how potters translated into clay the social values and representations of people's lives, simultaneously considering how these objects defined their being in the world (Fig. 1). After decades of studying Maya pottery as a chronological marker of site interactions, ceramicists in the Maya region are researching the life histories of pots and potters under new theoretical paradigms and techniques (Jackson, 2009; LeCount, 2010; López Varela & Dore, 2005; Luke, 2012). Maya pottery studies are ready to begin this new journey, after a long history of using a methodological approach known as the type-variety system. Maya pottery is the result of a high level of technological expertise and knowledge. Each pot was made and used for the daily life activities of people we now called “the Maya.”

Analytical Approaches to the Study of Maya Pottery

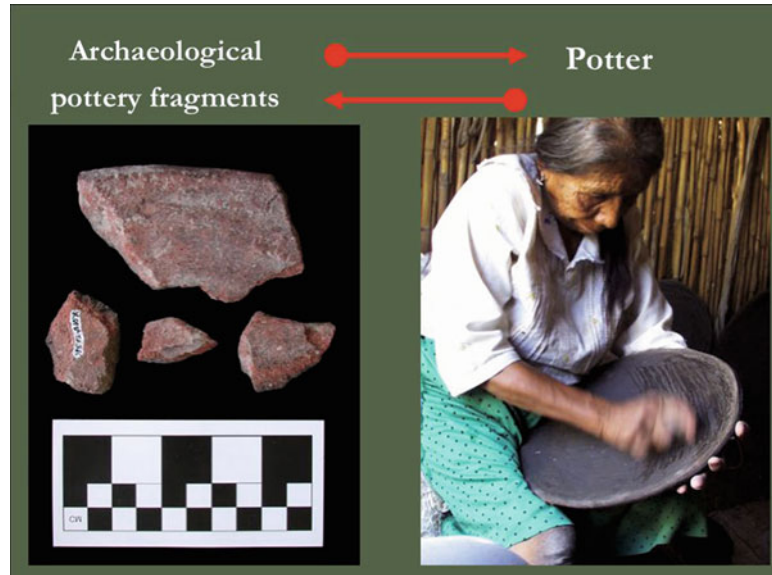
Since the beginning of the twentieth century, archaeologists have studied pottery mostly to order archaeological remains in time and space so they can interpret past cultures. There are many reasons why pottery became the ideal data to reconstruct culture. Basically, pottery fragments can be arranged in a sequence of formal characteristics and styles called attributes. By determining the location of the pottery type in a stratigraphic column, the archaeologist dates a particular time and is able to produce a ceramic sequence. These goals in archaeological research conformed to cultural relativism, a theoretical and methodological approach established by Franz Boas, concerned with documenting culture-historical sequences and influences (Hodder, 2004, p. 23).

Deriving from these goals, the type-variety system was introduced in 1960, as a systematic procedure to describe Maya pottery (Smith, Willey, & Gifford, 1960). To establish a type, the analyst takes into consideration decorative techniques and vessel form. When the analyst notes differences in ware, decorative techniques, vessel form, design, or temper, a variety of a type is established. The ware describes the paste composition (texture, temper, hardness, porosity, and color) and surface finish. When several types share the same ware, they form a ceramic group. Simultaneously, all of the known attributes are indicative of a particular class of pottery produced during a specific time interval known as the ceramic complex (Sabloff & Smith, 1969, p. 77). By 1965, use of the “system,” as colloquially referred to by its users, had created analytical and methodological problems. These were discussed during the Maya Ceramics Conference, held in Guatemala City (Willey, Adams, & Culbert, 1967). The strengths and weaknesses of the type-variety system, assessed mostly in qualitative terms, continue to be discussed and debated (Adams, 2008; Aimers, 2013; Culbert & Rands, 2007).

In 1969, Sabloff and Smith introduced a format to present the type descriptions of the

Ceramics: Maya Pottery,

Fig. 1 Learning how potters translated into clay the social values and representations of people's lives is a challenge for pottery analysis (Illustration by Sandra L. López Varela)



Seibal pottery, used by archaeologists working in the southwest of the United States (Colton & Hargrave, 1937). For many analysts, the format, later extended in the Seibal monograph (Sabloff, 1975), introduced a comparative framework for understanding pottery network distributions and extended the possibility to recognize new pottery attributes, leading to the establishment of new categories (e.g., Adams, 1971; Kosakowsky, 1987; López Varela, 1989; Smith & Gifford, 1966; Valdez, 1987; Varela Torrecilla, 1998). Each resulting monograph, presenting the description of the pottery and chronology, is to Maya pottery analysis the equivalent of any taxonomy book to biology. The analyst learns the taxa by reading the descriptions of the pottery and looking at the illustrations reported in the monograph.

In the field, the “system” may only be qualified as invaluable to the ceramic analyst, studying hundreds of bagged pottery fragments to answer common questions raised by archaeologists regarding the time framework of every excavated context. The type-variety system is used as a quick and reliable method to compare and date pottery (Smith, 1979). The analyst is able to date any context, “good, fast, and cheap,” with the type-variety system. The type-variety system has become a common artificial language for

Maya ceramicists. The system provides artificial identities necessary for archaeologists to state what something is and what it is not; otherwise, there would be no process of communication to interpret their results. However, to study the richness in form and dexterity in the making of every Maya vessel, multiple approaches are needed. The type-variety system is the essential first step.

Early Uses of Science and Technology in Maya Pottery Studies

After World War II, the North American school of archaeology adopted the scientific method (Binford, 1962). This new way of doing science involved the testing of hypotheses, using technology and rigorous methods, such as statistics, to produce a law, model, or theory adequately accounting for cultural phenomena. Archaeology was concerned with objectivity, systematization, and the need to provide explanations of the observed phenomena.

The search for objectivity raised criticism of the failures of taxonomic systems to appraise the meaning of pottery (e.g., Dunnell, 1971). Krieger (1944, p. 272) suggested objectivity could be reached based on demonstrable historical factors, not only on “the inclinations of the analyst or the niceties of descriptive orderliness.” Most of the debates were trapped in an endless circular

discussion of subjectivity versus objectivity, determining how many conditions are necessary for membership in a class.

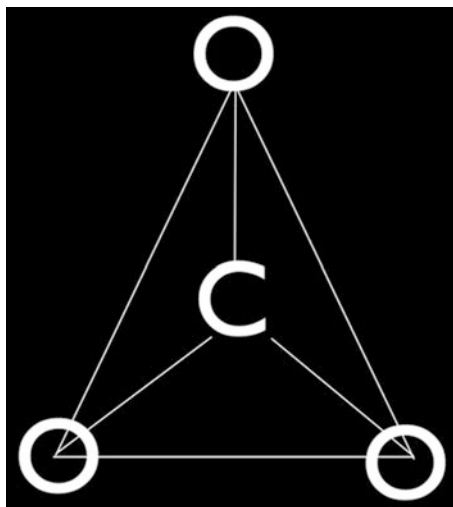
In following this scientific trend, quantitative methods to approach the chronological ordering and distribution of pottery were introduced in Maya pottery studies. Statistical methods, such as seriation, were used to learn about the inherent space and time dimensionalities of Maya pottery (Henderson & Beaudry-Corbett, 1993; López Varela, 1989; Vallo, 2002). Seriation is a relative dating technique considering the chronological ordering of a group of artifacts or assemblages, where the most similar ones are placed adjacent to each other in the series. The seriation method, however, is not an objective means for finding the life span of artifacts, as it orders the number of pottery attributes defined by the type-variety system.

Interest in understanding the craft specialization and technology of Maya pottery required the integration of mineralogical analysis (Ford & Rose 1995; Iceland & Goldberg, 1999; Jones, 1986). Archaeologists use petrography to identify rocks in thin sections precisely, aided by a microscope and careful mapping of rock units. Petrography is primarily concerned with the systematic classification and precise identification of rocks in thin sections, aided by a microscope and careful mapping of rock units. Instrumental techniques, mainly INAA (instrumental neutron activation analysis) and XRF (X-ray diffraction), have been used to investigate the provenience and to determine the concentration of trace and major chemical elements in Maya pottery (Rice, 1976).

The use of instrumental techniques implicitly assumes the results provide us with information about Maya pottery production and distribution. Archaeologists have accepted the resulting data, under the strength of “scientific authority,” without being able to interpret the nature of the data adequately or the problems regarding the analytical sensitivity, precision, and accuracy of physical or chemical techniques, including the preferential use of some laboratories (Bishop,

Canouts, Crown, & De Atley, 1990). Customarily, instrumental techniques are giving us information about the provenance of 13 or 19 chemical elements in “pure” form (Kosakowsky, Estrada Belli, & Neff, 1999; Neff, Bove, Robinson, & Arroyo, 1994; Neff, Cogswell, Kosakowsky, Estrada Belli & Bove, 1999). The given set is integrated by some of the most abundant chemical elements on earth. Absent from INAA results is silicium (Si, silicon in English) and aluminum (Al), the main components of silicate minerals and aluminum oxides, constituting the basis of pottery clay.

The limitations in the use of instrumental techniques is not the failure of a particular laboratory and analysts, but, rather, the limitations of solving an archaeological problem. There is a substantial analytical difference between learning about the technology of pottery making and identifying the chemical elements in a pot. Contrary to Neff’s (2005, p. 210) position, if we were to guide these studies from an anthropological perspective, it would matter if we used chemical or mineralogical approaches to source determination or how many chemical elements of the periodic table need to be measured to learn about the making of pottery. When we look through the microscope, we are observing a substance containing no social information. The analyst considers a chemical compound, such as carbonates, as a triangular structure with a carbon at its center and an oxygen atom on each corner, bearing distinctive density or coloration qualities, except social information (Fig. 2). When the archaeologist wants to extract social meaning from what he has observed under the microscope, this corollary is unintelligible to the chemist. Chemical phenomena occupy a realm largely distinct from social phenomena (Latour, Woolgar, & Salk, 1986, p. 23). In opposition, the construction of knowledge in archaeology reads science as culture. Material sciences are mostly applied to provide precise physical and chemical properties from which an object is constituted to learn about culture or human behavior (Jones, 2002, p. 66).



Ceramics: Maya Pottery, Fig. 2 Chemical elements and minerals contain no social information. Carbonates identify as a triangular structure with a carbon at its center and an oxygen atom on each corner, bearing distinctive density or coloration qualities, except social information (Illustration by Sandra L. López Varela)

New Routes for the Use of Science and Technology in Maya Pottery Studies

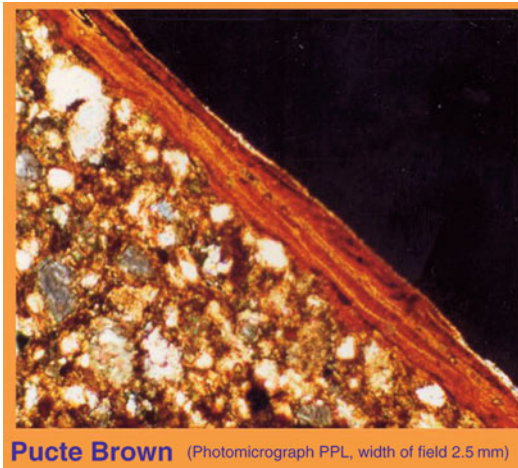
Instrumental techniques are being used to learn about Maya pottery, as a complex mixture of raw materials often from disparate sources with clay and non-clay minerals mixed together in different forms and varying ways to produce a pottery fabric. These increasingly available studies are using technology to learn about the uses of pottery and the choices potters made to produce a pot. These studies are providing the field of Maya pottery with insightful analytical results (García-Heras et al., 2006; Goodall, Hall, Viel & Fredericks, 2009; Fanjat et al., 2013; López Varela, 2005a; Meanwell, Paris, Cruz Alvarado, & Peraza Lope, 2013).

The Maya region is a vast terrain with varying geologies and topographies providing the raw materials for many different recipes to make pots. These raw materials were washed or levigated (made smooth), and non-plastic temper (to create hardness and elasticity) of certain grain sizes was added or mixed with other clays. Maya potters had a thorough knowledge of the

different properties of the available natural resources, including their thermal behavior, to make a functional vessel. Learning about the physical and chemical properties of the clay bodies is important to determine the suitability of a vessel for cooking or storing different kinds of products (López Varela, 2005a). A wide range of techniques deriving from the physical, chemical, and natural sciences is helping archaeologists identify how potters chose to select raw materials and how natural resources were used to make pots to support numerous daily life activities, for everything from cuisine preferences to cave rituals.

Technological and characterization studies provide insightful information about the function of a vessel. Throughout the history of humankind, people have used objects differently from their intended function. When a cooking jar was placed in a burial site or a cave, it extended its meaning beyond the domestic realm into the underworld. With this knowledge, archaeologists may distinguish if a vessel was used for its intended function or if it was used to signify, empower, embody, and/or engender the living spaces of the Maya. Identifying the residues trapped in Maya pots reveal how these were used. Ultra-performance liquid chromatography (UPLC)/MS-MS Analysis has already detected the presence of *capsicum* in excavated Formative pots from Chiapa de Corzo (Powis et al., 2013). This same technique has yielded valuable information about the consumption of cacao through its identified residues in spouted vessels from Colha (Hurst, Tarka, Powis, Valdez, & Hester, 2002). Molecular archaeology, a developing field, has already been used to determine blood residues in Maya pots from Copán (Matheson, Hall, & Viel, 2009).

Raman spectroscopy is commonly used to investigate the mineralogical composition of materials and to investigate the making of paints. In the Maya region, Raman spectroscopy has provided information regarding the surface treatment of vessels from Copán but also, about the firing process of Maya pots (Goodall et al., 2009).



Pucte Brown (Photomicrograph PPL, width of field 2.5 mm)

Ceramics: Maya Pottery, Fig. 3 Microprobe analysis of Pucte Brown pottery (Micrographs by Daszkiewicz et al., 1999, illustration prepared by Sandra L. López Varela)

Basically, this study has successfully identified paint mixtures for each color applied to different ceramic types and estimated the firing techniques through the different phases of iron oxide (Goodall et al., 2009, p. 108). Microprobe analysis is another technique used to determine how Maya potters treated pottery surfaces. At K'axob, potters selected vessels with a calcareous matrix, with rhombohedral carbonates of coarse silt and fine sand fraction, to paint their surfaces. This fine textured fabric yields relatively flat surfaces, easily smoothed with a pebble. The use of microprobe analysis revealed potters used brushes to facilitate the application of several slip coatings (Daszkiewicz, Schneider, & Bobryk, 1999). Preparing the surfaces to display the images on a Saxche Orange Polychrome vessel, required the potter to apply a fine layer of engobe before adding an iron-rich red slip (Fig. 3). Engobe is liquid clay used to decorate a ceramic piece before it has been fired and usually applied before the piece has dried. The black color of Actuncan Orange Polychrome contains both manganese and iron, contrasting with the iron-rich red slip. Black paint on Ixcanrio Orange Polychrome and Saxche Orange Polychrome fragments contained manganese. By controlling the original oxidizing and reducing atmosphere, the potter achieved both a red and a black color. Additionally,

LA-ICP-MS analysis of the chemical composition of the exterior slips, and red and black pigments of vessels originating from the central Petén lakes region of Guatemala suggest the Itza and Kowoj used different pigments for exterior slips and decorative motifs (Cecil & Neff, 2005).

In dating Maya pottery with instrumental techniques, thermoluminescence has not been successful for dating samples with a sedimentary origin (Wagner, Haberman, & Wagner, 1999). Additionally, archaeointensity determinations on Maya incense burners from Palenque, supported by Mössbauer spectroscopy, have estimated their firing temperatures (Fanjat et al., 2013). However, limited comparative data restricts the possibility of establishing a trend of intensity variations in Mesoamerica (Fanjat et al., p. 168).

The availability of portable and noninvasive technologies, such as pXRF spectrometers, is about to change the ways we study Maya pottery in the field. The ability to collect compositional data rapidly from highly specific locations on individual artifacts and its nondestructive capacity, pXRF, is aiding investigations along the Motagua Valley in Guatemala and the Naco Valley and Cacaúlapa Valley in Honduras (McCormick & Wells, 2013).

A Social Analysis of the Making of Maya Pottery

A social approach to the study of Maya pottery is concerned about investigating how material culture expresses the ways we conceptualize the relationships between others and ourselves, and between us as ceramicists and the Maya in the past. In building ceramic sequences through the type-variety system, archaeologists have struggled to define the pottery, characterizing the Terminal Classic and the subsequent post-Classic period. Despite the observed persistence of pottery forms and wares through time, innovation and continuity have to be accommodated to the theories suggesting a foreign population took over Maya Lowlands sites, putting an end to

Maya culture around AD 800 (Adams, 1971; Sabloff, 1973; Sabloff & Willey, 1967). Over the course of new excavations, we have learned fine paste pottery, a considered trait of such population, was not exclusively made during the Terminal Classic; alternative regions were producing the pottery, even during Formative times; and the pottery did not always display militaristic images (Bishop & Rands, 1982; Foias & Bishop, 2005; Lopiparo, Joyce, & Hendon, 2005; López Varela, 2005b; Rands, 1987). Instead of searching for answers as to why new forms were introduced at a time of political turmoil and environmental change, analysts are concerned about fitting innovation and continuity in pottery making as exceptions to the beginning-end cycle ceramic complexes are forced to express. Ceramic sequences are references for the archaeologist to measure time. Classifications are distant from the ways Maya peoples in the past constructed time and experienced meaningful times. These sequences have constructed “Maya” time following a plot (Hodder, 1995, p. 164), having a beginning (Early Classic period), a climax (Late Classic period), and an end (Terminal Classic period). In other words, this literary process has governed the ways analysts analyze pottery data.

Increasingly, archaeologists in the Maya region are becoming interested in learning how social values are communicated through different kinds of objects and their uses (Jackson, 2009; LeCount, 2010; López Varela & Dore, 2005; Luke, 2012). In approaching the ways people have used objects or natural elements for daily life activities (Meskell & Preucel, 2004), there is a genuine interest in learning about how individuals in a society communicate their particular values through objects and natural elements (Buchli, 2004; Hodder, 2004; Hoffman & Dobres, 1999; Pfaffenberger, 1999). At the Institute of Archaeology at Belmopan, there is a distinctive piece of pottery, an orange, nonglazed piece, recovered from Actun Chanona, a cave located at the base of the Sibun Gorge in Belize. This lion effigy bears a remarkable resemblance to those found in the Lion’s Courtyard of the Alhambra in Granada, Spain. These lions

conveyed the Quranic and Biblical images of paradise, a garden associated with four rivers, sprouting from the lions’ mouth. All of these elements – water, plant fertility, directionality, and the transition of humans into a paradisiacal world – were shared concepts with the Maya. Meaning does not reside in the object itself or in its immediate surroundings, but in the way we make sense of the object. The social embedded in material culture communicates its materiality, but only if we are familiar with the meaning objects intend to convey. Within this sense of materiality and agency, it is essential to recognize both elements, the social and the natural, are intertwined, both constructing individuals and the space they live in. Learning about the “social life of things” is a theoretical approach contributing to an understanding of the spatiality of objects, to the ways people organize living spaces and how these objects define their being in the world (Tuan, 1977; Low & Lawrence-Zúñiga, 2003).

The social analysis approach favors the use of material sciences to learn about the physical and chemical characteristics of the object. Analytical techniques address the influence of the chemical and physical properties in the selection of raw materials and preparation of the clay body to achieve specific technological and functional properties. Reconstructing the step-by-step process of a given technology requires a set of interpretative questions surrounding the object of production, examining the data with material science analyses and experimentation. The social analysis of Maya pottery has incorporated the *chaîne opératoire* or operational sequence as central to the study of technologies (López Varela, McAnany, & Berry, 2001). The intrinsic hermeneutics of the operational sequence guides the investigation to reveal the social diversity of humankind by approaching the choices made all the way through it. A social approach to the analysis of Maya pottery, therefore, questions if the ratios of raw materials really influence the physical and chemical properties of the body or if there are other reasons guiding their specific use.

In fact, the concern of using instrumental techniques to define human behavior originates from

analysts doing ethnoarchaeology (Arnold, 1971, 2005). Ethnoarchaeological studies have been crucial in learning about pottery production (Arnold, 1971, 1978, 1991; Deal, 1983, 1998), despite the making of Maya pottery in the past may not be compared easily with a modern context. Indirectly, ethnoarchaeological studies as a comparative procedure to learn about the past from the present suggests people and their social values, concepts, representations, and symbols have remained unchanged (Hodder, 1982, p. 16) throughout their living of historic events. The social logic of our actions, our being in the world, indeed is embedded in history and tradition, so the detachment with the past is not absolute either. However, assuming people can live unaffected for 500 hundred years of historic events entails some naïveté (Thomas, 1996). In the future, ethnoarchaeological studies could dedicate its efforts to address the social changes incited by economic development in the Maya region (Arnold, 2008). Development policies are becoming powerful erasers of social memory and traditions through infrastructure building and welfare policies inviting potters to change the technology of pottery making and restricting the availability of natural resources.

Identifying Maya Potters in the Pots Left Behind

Archaeological research has provided further evidence of pottery making and tools (López Varela et al., 2001; López Varela, van Gijn & Jacobs, 2002). Already, analysts have identified different kinds of firing features, ranging from open hearths to double-chamber kilns (López Varela et al., 2001; Lopiparo et al., 2005; Urban & Schortman, 2004). The seminal work of Anna O. Shepard (1956, 1964) stated the relevance of investigating the technological character of Maya pottery (e.g., Angelini, 1998; Daszkiewicz et al., 1999; López Varela et al., 2002). Results deriving from these studies describe the sequence of steps, transforming natural resources into meaningful and functional objects. The chaîne opératoire (operational sequence) (Leroi-Gourhan, 1943–1945), as an analytical concept, leads to an investigation of the decisions made by the

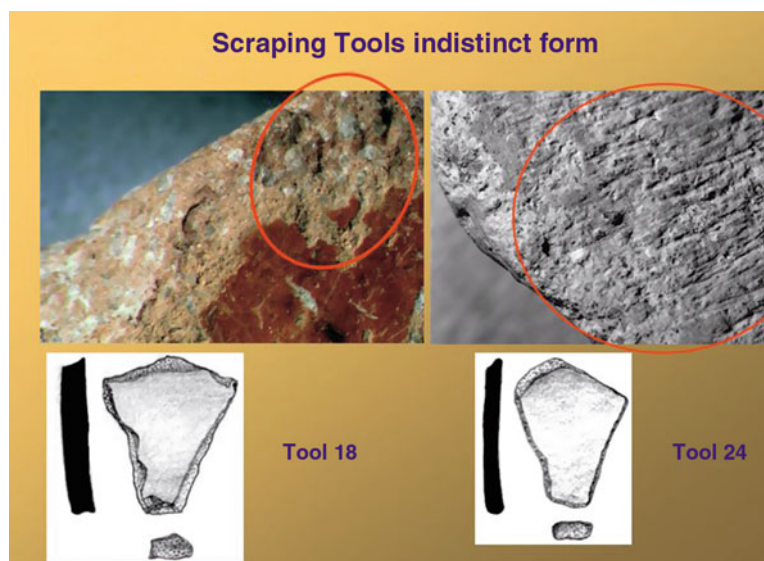
producer, in the use of natural resources to make a particular form. The decisions made by Maya potters encountered recognition in the archaeological record (López Varela et al., 2002). These decisions related to their selection of tools for the making of Late Classic vessels. Basically, potters chose to recycle broken pieces of pottery to make their tools for smoothing, scraping, incising, polishing, and boring. To make ceramic fragments suitable as tools, the edges need to be shaped; otherwise, it would be difficult to hold the piece with the fingers to perform a smoothing or scraping activity. Also, potters worked the edges of the sherds to create particular geometric forms and sizes. Selecting the shape of the pottery tool represents another choice to determine the effectiveness and performance of these implements. In the case of small tools, the angles allow reaching the joints quite easily, facilitating shaping, and retouching of the vessel (López Varela et al., 2002). These shapes adapted to the pottery grammar of simple clean curvatures and preferable angles characteristic of the Late Classic vessel repertoire (Fig. 4).

Not all pottery fragments made useful tools. Potters intentionally selected broken pieces of pottery, considering the characteristics of the fabric over hardness. Still, potters needed tools to perform a particular task. Fragments were selected considering the texture properties of the fabric and the adhesive bond power of particles, as these affect resistance to abrasion (Fig. 5). Tools used for scraping, characterized by a fabric containing angular, coarse, crystalline calcite, and rare grains of quartz, facilitated its use in such activity. Most tools were made from jars with a high frequency distribution. Broken pieces of jars or bowls could be recycled to fabricate the necessary tool fairly quickly, according to our experimental studies (López Varela et al., 2002). Consequently, cost was a factor in the making of Maya pottery.

The chemical and physical properties of the natural resources condition not only form and function but also the objectification of the social. For instance, vessels with a calcareous matrix (a substance containing calcium carbonate), according to chemical analyses, were not used

Ceramics: Maya Pottery,

Fig. 4 Experimental use of a triangular tool (Photographs by Eric Mulder. Illustration by Sandra L. López Varela)



Ceramics: Maya Pottery, Fig. 5 Examples of scraping pottery tools (Photographs by Annelou van Gijn. Illustration by Sandra L. López Varela)

in cooking or in any other activity involving their use in a fire atmosphere. Most pots with a calcareous matrix exhibited appliqué, slip clay, or paint, such as Hillbank Red or Saxche Orange Polychrome. On the contrary, vessels with a noncalcareous matrix and coarse crystalline calcite, added as temper, allowed their exposure to fire (Daszkiewicz et al., 1999). Most striated jars from the Formative to the post-Classic period have a non-calcareous matrix. We learned potters changed their recipes to make pots, as jars of the Encanto Striated type contain aggregates of grog and clay in its noncalcareous matrix. Adding

grog represents another choice the potter had to make either because it was necessary to recycle pottery against the lack of resources or the need for experimentation. There is evidence of the making of new recipes to make jars for post-Classic times, as the body shows large crushed particles of calcite causing the jars of Piste Striated to bloat (Figs. 6 and 7).

To acquire their raw materials, Maya potters did not have to move a long distance. There is evidence potters were quarrying in the surroundings of the pottery workshop found at K'axob (López Varela et al., 2001). In the surroundings of this workshop, 9 roughly rectangular blocks of fine-grained consolidated sediment share physical attributes, such as texture, with Belize Red pottery, easily recognized by its thin walls and fine-grained but gritty paste composition. Their size and shape are ideal for tumpline (a band or strap strung across the forehead or chest to support a backpack) or canoe transport. Samples of Belize Red type, originating from excavations at Barton Ramie, showed the gritty texture of Belize Red was attributable to fragments of pumice and volcanic glass and, to a lesser extent, grains of calcite (Gifford, 1976, p. 255). The analyzed sample from K'axob is characterized by a noncalcareous matrix with grains of quartz and aggregates of

Ceramics: Maya Pottery,

Fig. 6 Examples of Society Hall vessels with a calcareous matrix (Photomicrographs by Daszkiewicz et al. (1999). Illustration by Sandra L. López Varela)

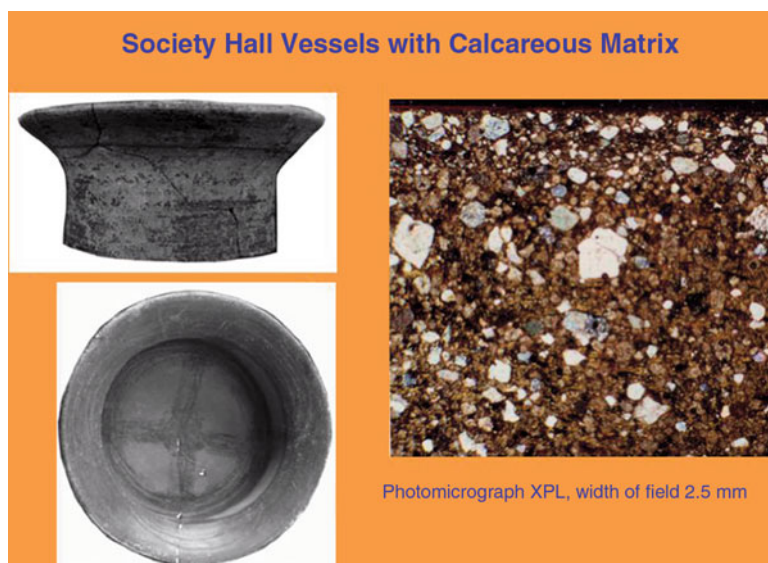
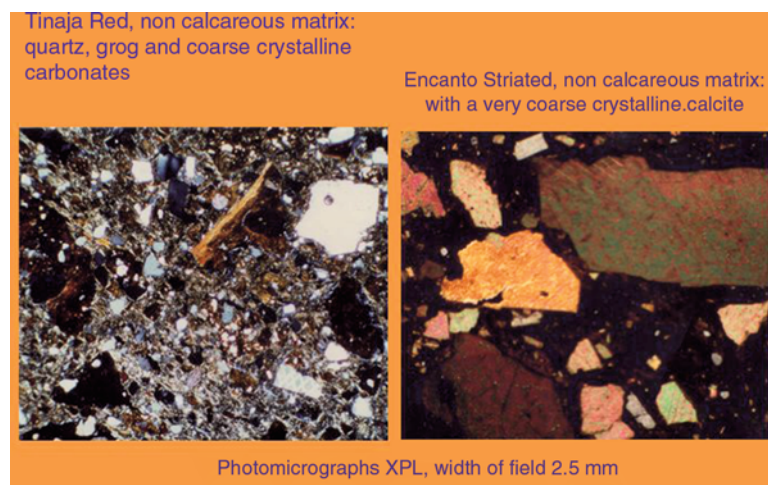
**Ceramics: Maya Pottery,**

Fig. 7 Examples of vessels with a noncalcareous matrix could have withstand fire exposure (Photomicrographs by Daszkiewicz et al. (1999). Photographs and Illustration by Sandra L. López Varela)



cryptocrystalline calcite. The composition is not common in the chemically analyzed samples. The making of Belize Red shows potters accommodated the available natural resources to fulfill social demands (López Varela et al., 2001).

Maya potters received or provided stylistic and form conventions from and to a large-scale sphere of influence includes, at various times, the Peten, the Teotihuacan, the Usumacinta-Pasión regions, and the Yucatan. These pots represented

individuals' thoughts and actions, such as the making of the tripod cylinder vessel of Early Classic times. The vessel form was used as far as Teotihuacan and has appeared in numerous contexts in the Maya region (Varela Torrecilla & Braswell, 2003).

In the Maya region, social identity and power was displayed on painted vessels, such as those of the Saxche Orange Polychrome type. Most painted images are displayed on the outside surfaces of vases or the bottom of a dish.

Preserving the Knowledge of Maya Potters

In writing about the social in the making of Maya pottery, it is of concern to me the reader understands potters in the past had a thorough knowledge of physical and chemical properties. The type-variety system is a valuable tool to the study of the Maya knowledge. However, the use of analytical techniques is the most reliable avenue of research to investigate how pottery was made. The technological knowledge of Maya potters should be investigated and preserved with the use of instrumental techniques, experimental studies, and application of emerging theoretical paradigms.

The word technology could be inadequate to refer to the steps of how pottery was made in the Maya region. Reading the past in the realms of technology simply represents our ways of seeing the world of how potters expressed, materialize, and mediated social relations through the pots they made. My suggestion, now followed by other analysts, to investigate the social aspects of Maya pottery results from the long-time quest in archaeology of providing a human face to the pots and sherds that we excavate.

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Ceramics: Mimbres Pottery

Michelle Hegmon

Mimbres pottery, made primarily in southwestern New Mexico between 750 and 1150 AD, is renowned for its spectacular, often naturalistic, black-on-white designs (Fig. 1). Although painted pottery is common in the archaeological record of the North American Southwest, Mimbres pottery stands out because of its elaborate representational designs, which depict everything from the ubiquitous rabbit to scenes of everyday life and apparently mythical creatures. Because of the pottery's beauty and appeal to collectors, many Mimbres archaeological sites have been destroyed by looters searching for pottery to sell, and irreplaceable information about the past has been lost.

Mimbres, from the Spanish for “willows,” is the name given to a small river in southwest New Mexico. The name came to be applied to the pottery found in archaeological sites along the river, and eventually to the people who made the pottery. However, it is important to keep in mind that these are labels applied (mostly by people of European descent) to pre-Hispanic Native Americans. We do not know what the people called themselves, although we can be sure it was *not* Mimbres. In fact, recent approaches in archaeology have attempted to decouple pottery styles and cultural identity, and have challenged the extent to which the people who made the pottery we call Mimbres were



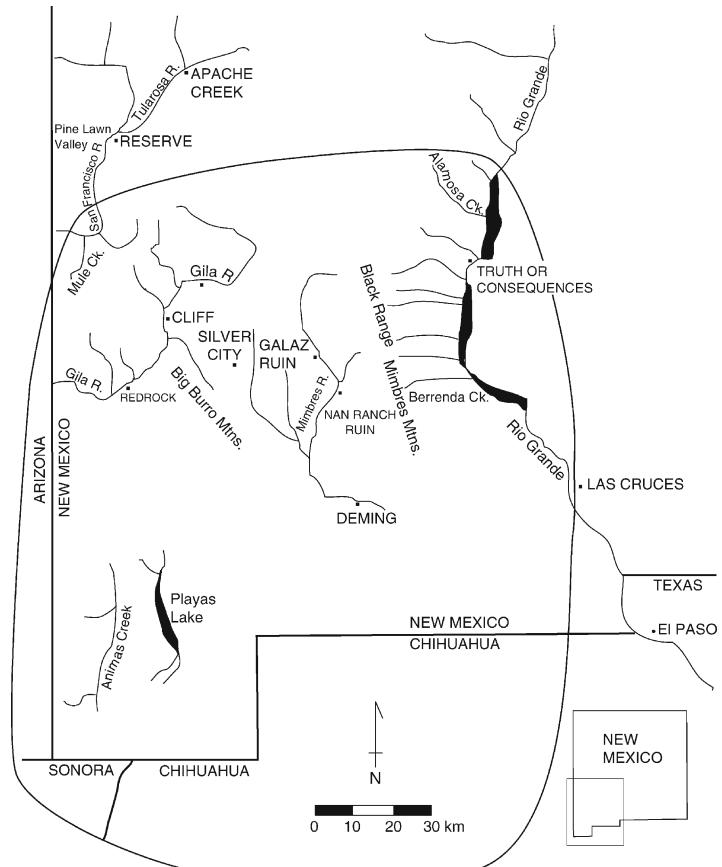
Ceramics: Mimbres Pottery, Fig. 1 Classic Mimbres Black-on-white bowl from Ronnie Pueblo (Nelson, 1999, pp. 96–97). The bowl is part of the permanent collections of the Museum of Anthropology, Arizona State University

united culturally, socially, or politically. They were maize farmers living in fairly simple hamlets and villages that housed from a few households to a few hundred people. They had no writing, draft animals, or metal tools. And while their social organization was elaborate in many ways, they did not have a well-developed political hierarchy or marked social inequalities. Syntheses of Mimbres archaeology include Anyon, Gilman, and LeBlanc (1981), Hegmon (2002), Hegmon et al. (1999), LeBlanc (1983, 1989), and Nelson (1999) and a recent issue of *Archaeology Southwest* (2003). Book-length treatments of Mimbres pottery, especially the designs, include Brody (1977, 2004), Brody, Scott, and LeBlanc (1983), Brody and Swentzell (1996), Fewkes (1989), Kabotie (1982), LeBlanc (2004), Moulard (1984), and O’Bagy Davis (1995). In addition, reports on Mimbres sites include numerous pictures and analyses (e.g., Anyon & LeBlanc, 1984; Cosgrove & Cosgrove, 1932; Shafer, 2003).

Situating the Pottery in Time and Place

The Mimbres region (Fig. 2) is part of the larger Mogollon archaeological culture area, which

Ceramics: Mimbres Pottery, Fig. 2 Map showing the Mimbres region in southwest New Mexico and surrounding states



includes much of southern New Mexico and northern Chihuahua, as well as central Arizona. Mogollon pottery, made with iron-rich volcanic clays, is generally brown or red in color, while pottery made in the northern Southwest (what had been called the Anasazi area but is now more properly known as Ancestral Pueblo) is generally white or gray, sometimes with black designs. Because Mimbres pottery is black-on-white, it was initially thought to be northern in origin. However, it is now well known that Mimbres pottery is indeed a Mogollon brown ware, covered with a thin slip of white clay that provides a backdrop for the black designs. The local development of Mimbres pottery – from plain brown to red-on-brown to red-on-white and finally to black-on-white – is well understood and well dated (see especially Anyon, Gilman, & LeBlanc 1981; Scott, 1983; Shafer & Brewington, 1995; Shafer & Taylor, 1986). Because the

painting style changed fairly rapidly, archaeologists are able to date the pottery quite precisely. For example, Fig. 3 illustrates a bowl with a design that extends all the way to the rim and that has straight-line hachure with framing lines thicker than the hatch lines; these are both relatively early characteristics and together they indicate that this bowl should be classified as Early Style II (ca. AD 880–920; Shafer & Brewington, 1995). Later designs (generally classified as Classic Mimbres Black-on-white or Style III, and illustrated in Figs. 1, 4, 5, 6, and 7) have various kinds of rim framing lines. Scott (1983) illustrates the stylistic changes over time, and Shafer and Brewington (1995) present a detailed microstyle chronology. Mimbres pottery includes various forms including storage and cooking jars as well as bowls. However, most of the painting and virtually all of the representational designs are found on bowls. Painted pottery was most elaborate and



Ceramics: Mimbres Pottery, Fig. 3 Style II Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 12a) (Photo courtesy of the Mimbres Archive [#2963]). The bowl is part of the permanent collections of the University of Minnesota)



Ceramics: Mimbres Pottery, Fig. 4 Jackrabbit depicted on Classic Mimbres Black-on-white bowl from the Swarts Ruin (Photo courtesy of the Mimbres Archive [#2051]). The bowl is part of the permanent collections of the Peabody Museum, Harvard University)

probably most common during the Mimbres Classic Period (1000–1130 AD), and painted bowls at that time had an average volume of 2.2 l (based on data from the Galaz Ruin Anyon & LeBlanc, 1984, p. 169).

Chemical and mineralogical analyses (summarized in Gilman, Canouts, & Bishop, 1994) clearly indicate that Mimbres pottery was made in many locations and villages; it was not centrally produced. The elaborateness of the designs suggests that some may have been produced by specialists, but if this were the case they were likely part-time specialists. Recent calculations (Le Blanc, 2004) suggest that all Mimbres black-on-white vessels could have been made by just a few potters, each making only 50–100 pieces annually. While most pottery makers and painters in the pre-Hispanic Southwest were probably women, several authors have suggested that at least some of the Mimbres designs were painted by men, because they depict rituals probably controlled by men (Brody, 1977) and because the birth scenes are anatomically unusual (Hegmon & Trevathan, 1996). The issue is controversial, and a clear resolution is unlikely.

Mimbres painted pottery is found in many contexts, including in trash middens, on living floors, and in burials, across the Mimbres region. Many burials – in simple pits in middens and under house floors – were interred with a bowl placed over the skull. Most of these bowls had a small hole carefully punched out of the base (see Figs. 3 and 6); these bowls are said to have been “killed,” and some have speculated that the hole allowed the deceased’s spirit to escape. Many of the bowls found in burials have wear patterns that indicated they had been used before they were interred (Bray, 1982). It is possible that most individuals had a bowl that they used for eating and other purposes, and that bowl accompanied them into the grave.

The Designs

Before considering the designs and their analyses, two caveats should be noted. First, although many designs appear to be realistic, in that they accurately portray details such as the topknot on a Gambel’s quail and the black tips on jackrabbit ears (Fig. 4) the corpus of designs as a

whole should not be assumed to reflect Mimbres life accurately. Rather, the pre-Hispanic artists – for various aesthetic, cultural, and social reasons – *chose* to depict certain scenes in certain ways. The designs are representations of what people believed should be portrayed on pottery, and they should be interpreted from this perspective. Second, as Brody (2003) has emphasized, the designs were painted on hemispherical surfaces (i.e., the interior of bowls) that were often placed below the user and viewer's eye level; most reproductions do not convey the designs' three-dimensional aspect or use context.

Mimbres pottery designs have been the focus of much attention, by archaeologists, art historians, and the public (Brody, 1977; Brody et al., 1983; Brody & Swentzell, 1996; Moulard, 1984), and much is known about what they depict. However, there is still a need for comprehensive quantitative analyses of the designs and their distribution, as I noted in my recent review (Hegmon, 2002). Designs with representational elements (Figs. 1, 4, 6, and 7) are less common than those that are purely geometric (Figs. 3 and 5) (221 versus 494 in the Galaz Ruin collection Anyon & LeBlanc, 1984). Most representational designs are depictions of animals native to the Mimbres region, some show scenes that include humans, and others depict apparently mythical creatures. Early Mimbres representational designs are similar to designs on pottery from the Hohokam region in southern Arizona, but by the Classic Period, the Mimbres style was unique.

Interpretations of the meanings of the designs are best made by considering their larger cultural context. Maize was a staple food in the Mimbres region, supplemented by other crops, wild plants, and meat from small animals such as rabbits, as well as occasional larger animals such as deer. In comparison, almost no maize or other plants are depicted on the pottery, and while there are many rabbit paintings (Fig. 4), there are few scenes (possibly only one in the known corpus) of rabbits being trapped or hunted. In contrast, quite a few paintings depict the hunting of larger animals, including bear and elk (Fig. 6). Taken together, these patterns support the argument that the paintings represent what people wanted



Ceramics: Mimbres Pottery, Fig. 5 Geometric design on Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 23E) (Photo courtesy of the Mimbres Archive [#3033]. The bowl is part of the permanent collections of the University of Minnesota)



Ceramics: Mimbres Pottery, Fig. 6 Bear hunt depicted on Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 83E) (Photo courtesy of the Mimbres Archive [#2902]. The bowl is part of the permanent collections of the University of Minnesota)

to emphasize (i.e., hunting), not what they actually ate. One unpublished but widely cited analysis (LeBlanc, 1977) found that bowls depicting certain animals were associated with certain

villages or areas, suggesting the animals were relevant more to social identity (e.g., as clan symbols) than to food.

While many of the animals depicted on the bowls would have been local to the Mimbres region, a number of exotic and probably symbolically important species are also depicted. In many cases, biologists have been able to identify particular species because the Mimbres paintings include relevant details, such as fin and beak shapes. Macaws, particularly their red feathers, have great ritual significance to contemporary Southwestern Native Americans, and a few macaw skeletons have been found in archaeological sites in the Mimbres region and elsewhere in the Southwest, suggesting that this ritual significance extends far back in time. Parrot-like birds are occasionally depicted on Mimbres bowls, and analyses of their traits indicates that most are scarlet macaws, native to the lowlands of southern Mexico and central America, more than 1,000 miles from the Mimbres region (Creel & McKusick, 1994). Similarly, analyses of the fish (and a possible whale) depicted on Mimbres pottery indicate that many are saltwater species, probably from the Gulf of California, approximately 640 km distant (Jett & Moyle, 1986). Thus it is clear that the people who painted the Mimbres designs had knowledge of distant regions, either through travel or trade and interaction.

In the past two decades, archaeologists have devoted significant attention to understanding women and gender relations in the past. Mimbres paintings give particular insights (see Hays-Gilpin, 2002) because some depict men and women engaged in various activities (almost all depictions of humans show them engaged in some activity; there are almost no simple portrait-like treatments). Some humans have clear sexual characteristics (breasts or penis), and inferences about styles of dress and body decoration associated with each sex make it possible to identify the sex or gender of many of the human figures (Munson, 2000). For example, when string aprons (Fig. 7) are depicted on individuals with clear-cut sexual characteristics, they are always associated with females; thus, string aprons



Ceramics: Mimbres Pottery, Fig. 7 Pregnant woman with parrot-like bird (possible macaw) depicted on a Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 76F) (Photo courtesy of the Mimbres Archive [# 2845]. The bowl is part of the permanent collections of the University of Minnesota)

are interpreted as good indicators of gender (i.e., women). Drawing on this and similar analyses, Munson was able to conclude that there was a gendered division of labor in Mimbres society (men are more often associated with hunting, women with child care). However, there is at least one famous scene of a pregnant woman (seemingly triumphant) carrying a hunted antelope; this image graces the cover of a milestone volume on gender and archaeology (Gero & Conkey, 1991). Furthermore, although more men than women are depicted engaged in apparently ceremonial activities, women are consistently shown handling ritually important parrot-like birds (often macaws) (see Fig. 7).

Contemporary artists often state that their art conveys meanings that cannot be put into words, and it is likely that the same applies to art of the past. It is also likely that Mimbres pottery painting – done by perhaps hundreds of artists over approximately four centuries – conveys a range of meanings. However, researchers have gained some insights into the general range of meanings associated with the pottery. Because the bowls are often found in burials, and some

depict scenes from what appears to be the Puebloan World of the Dead, Brody and Swentzell suggest the images refer to “the unity of man and the cosmos, the living and the dead, and of the structures of harmony” (1996, p. 38). Moulard (1984) similarly concluded that the designs symbolize transformations, such as from life to death or childhood to maturity.

Collections

Mimbres pottery – particularly pieces with representational designs – has long had great appeal to collectors. The result has been the destruction and desecration of Mimbres sites. The large site of Old Town is well known for looking like a mine field because it is so full of large holes, many made by backhoes and bulldozers. Galaz Ruin (Anyon & LeBlanc, 1984), one of the largest Mimbres villages, no longer exists; it was completely removed by bulldozing. Much of this activity is illegal (i.e., it is illegal to disturb archaeological remains on public land, and it is illegal to disturb human remains even on private land), but law enforcement cannot always keep pace (Turnbow, 2001). In an attempt to stop the destruction and preserve some of what remained of Mimbres archaeology, Steven LeBlanc formed the Mimbres Foundation in the 1970s, and today the Archaeological Conservancy undertakes similar activities on a much wider scale (Blanc Le, 2003). Also, many responsible authors are today refusing to publish images of looted bowls so as not to increase their value (e.g., the second edition of Brody’s *Mimbres Painted Pottery* 2004), a strategy in line with the ethical guidelines of the Society for American Archaeology. Thus the situation is improving, though destruction continues (Turnbow, 2001).

The problem with collections is not simply private ownership of the remains of past Native American cultures. A more serious issue is that the demand for collections, and the high prices paid for Mimbres pottery on the art market, encourage the illegal looting of sites. And because many bowls are found in burials under

house floors, the search for pottery results in the destruction of architecture and the desecration of burials. People who want to possess privately the beauty of a Mimbres bowl are advised to purchase some of the well-made replicas available from various sources, including Laurel and Paul Thornburg of Sonoita, AZ.

The End of the Mimbres Pottery Tradition

The style, color, and sizes of the pottery we know as Mimbres changed, more and less rapidly, during the entire period of its production, from at least 750 to 1150 AD. It became less common by AD 1150, and it was certainly no longer made by the end of the twelfth century. Instead, people in the Mimbres region began using and making an array of different kinds of pottery. An understanding of the end of this famous style provides insights into how archaeologists understand prehistoric peoples. Again, “Mimbres,” is a Spanish word, a label we have applied to a river and a style of pottery, among other things. But the decline of the pottery does *not* mean the decline of a people. It simply is yet another example of a style change.

We know, through detailed studies of architecture and radiocarbon dates (Nelson & Hegmon, 2001), that people continued to live in the Mimbres region during the time that Mimbres pottery became less common. So why did the style change? Mimbres pottery is unique in the Southwest, and it is reasonable to think that it meant something special to the people who made it. Mimbres villages were among the largest and most densely populated in the Southwest at the time (with the exception of the Hohokam area in southern Arizona). Life in these villages may have been fairly difficult; the Mimbres Classic period was a time of environmental degradation, and eventually drought and subsistence stress (Minnis, 1985). The beauty of the pottery is not an indication of the ease of the artists’ lives. Rather, Mimbres pottery, especially the elaborate Classic period paintings, may have been part of the tradition of living in large villages, including

the hard times. Beginning by 1130 AD, many people left the villages and resettled in small hamlets, a process known as regional reorganization (Hegmon, Nelson, & Ruth, 1998; Nelson, 1999). As people resettled, they developed new social networks and learned about new styles, which they eventually adopted as part of their changing social identities. The new generation chose to make new styles of pottery for new reasons.

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Ceramics: Rethinking Olmec Pottery

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After 1200 BCE (years presented in this entry are uncalibrated), distinctive ceramic vessels – Olmec pottery – appeared at select sites across the vast region that anthropologists refer to as Mesoamerica (southern Mexico, Belize, Guatemala, and eastern Honduras; Fig. 1). While exchange and interaction between regions existed prior to this time, in the case of Olmec pottery, the ceramic vessels display a consistent iconography that often contrasts with local pottery traditions. The iconography exhibited on Olmec pottery may represent developing religious beliefs, cosmology, and ideology, elements of which can be found in subsequent Mesoamerican groups. While features of religion and cosmology existed prior to 1200 BCE, Olmec pottery synthesizes and abstracts these concepts

on durable materials. As such, understanding the origin and spread of Olmec pottery has important implications on the nature of Mesoamerican civilization.

In discussing Olmec pottery, the focus here is only on the earliest Olmec ceramic phase, which corresponds with the ascendance of the site of San Lorenzo from 1200 to 900 BCE – often referred to throughout Mesoamerica as the San Lorenzo Horizon or Early Horizon (see Pool, 2007).

Mesoamerica Prior to 1200 BCE

For millennia after the adoption of agriculture, small villages – marked by very limited political organization and social differentiation – flourished throughout Mesoamerica. In the centuries before 1200 BCE, sociopolitical change began to occur. In the Soconusco region of coastal Chiapas, early chiefdoms of the so-called Mokaya people have been documented (Clark, 1991; Clark & Pye, 2000), where competing leaders vied for prestige and redistributed imported goods, such as obsidian (a volcanic glass). Each Mokaya chiefdom was centered on a main village, such as Paso de la Amada, where leaders lived in what were probably combinations of public structures and elite residences. The importance of and reliance on agriculture in these early villages remains an important debate, with great regional variation. In the Soconusco, for example, maize was a relatively unimportant part of the diet, used primarily as a prestige food (Clark & Pye, 2000).

By 1200 BCE, chiefdoms also appear in the Valley of Oaxaca and the Nochixtlán Valley in modern Oaxaca state. In the Valley of Oaxaca, where most small villages covered only 2–5 ha, the village of San José Mogote had a 20 ha “downtown” area of public structures and higher-status houses which contrasted slightly with normal houses in terms of quality of construction and plaster and the occasional outbuilding or ramada (Flannery & Marcus, 1994). Similar developments occurred to the northwest, where the site of Etlatongo became the head of



Ceramics: Rethinking Olmec Pottery, Fig. 1 Map of Mesoamerica, with modern national boundaries and Mexico City shown for reference. Important San Lorenzo

Horizon sites from which Olmec pottery has been analyzed are indicated

a small chiefdom in the Nochixtlán Valley. Beyond Oaxaca, chiefdoms are evident at the Basin of Mexico sites such as Tlapacoya and Tlatilco.

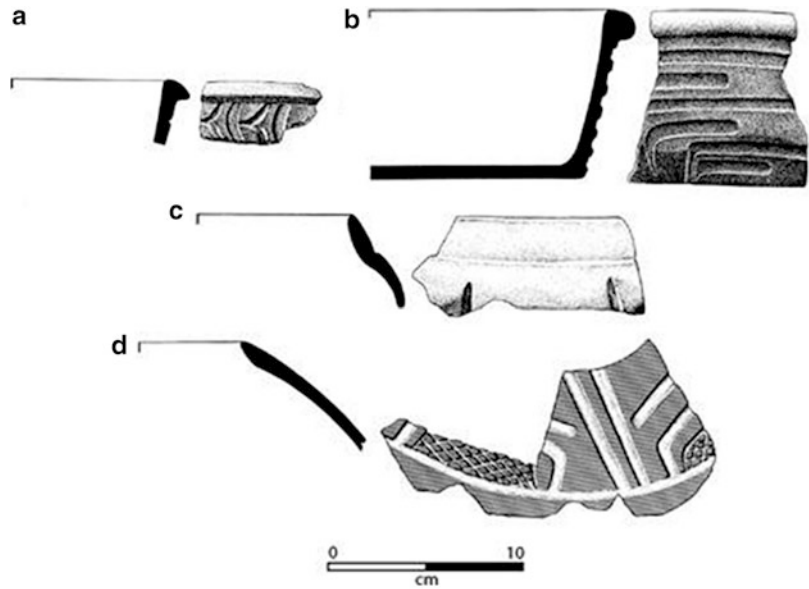
The Olmec and the San Lorenzo Horizon

Around 1200 BCE, all of the villages mentioned above exhibit a distinctive new style of ceramic vessels – Olmec pottery – that contrasts with local pottery traditions, which continued to be produced alongside Olmec pottery. While the origin of this pottery has been highly debated, the name applied to it – Olmec pottery, as well as the associated concept of Olmec style – has been criticized for linking this material with the archaeological Olmec people, who flourished at the Gulf Coast site of San Lorenzo, Veracruz, from 1200 BCE to 900 BCE (Blomster, 1998; Coe, 1968; Diehl, 2004; Grove, 1989; Pool, 2007). In this entry, the terms Olmec style and Olmec pottery are used separate from the Gulf

Coast Olmec, to indicate that the link between Olmec-style material culture scattered across Mesoamerica and the Olmec people of the Gulf Coast is one that must be robustly documented rather than assumed. Much of the problem with the incautious use of the terms “Olmec style” and “Olmec pottery” is that these concepts were created in the first half of the twentieth century by museum curators examining looted objects, lacking provenience, prior to the discovery and exploration of the archaeological Olmec (Blomster, 1998, 2004; Grove, 1996). Thus, many objects that have loosely been labeled “Olmec style” over the past 50 years have no actual correspondence with the Gulf Coast Olmec material culture. To really discuss the Olmec style and Olmec pottery from a Gulf Coast perspective, objects from excavated and well-documented Olmec sites must be employed to define it and then compared with the many disparate objects from throughout Mesoamerica that have been labeled as part of this style (Blomster, 2002; Coe, 1965).

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Fig. 2 Types of Olmec pottery at San Lorenzo, with exterior shown to the right of the profile. (a, b) Calzadas Carved pottery. (c) Xochiltepec White pottery. (d) Conejo Orange-on-White (Adapted from Blomster, Neff, and Glascock (2005, Fig. 2))



The location of San Lorenzo, on an artificially modified salt dome above the surrounding floodplain, seems to have been an important reason for the growth of this center, which Cyphers (1996, 1997, 2012; Symonds, Cyphers, & Lunagómez, 2002) estimates as close to 700 ha – dwarfing all contemporaneous settlements in Mesoamerica. San Lorenzo is almost an island among various streams and rivers, with soils constantly replenished by the Coatzacoalcos River. The San Lorenzo Olmec appear to have exerted a tight control over their immediate hinterland, with secondary sites deployed throughout the landscape for controlling the flow of resources (Symonds, 2000). Some archaeologists believe the Olmec at San Lorenzo represent a more complex form of political organization, perhaps an incipient state, while all other contemporaneous Mesoamerican regions featured chiefdoms. The debate over the sociopolitical organization of the Olmec has implications for their impact on other regions of Mesoamerica (see “[Extra: The Debate on Olmec Interaction](#)”).

Olmec artists created the first monumental art in Mesoamerica, including multiton basalt colossal heads – representing Olmec rulers – and large, rectangular thrones for leaders. The Olmec style is different from other Mesoamerican art styles in

formal qualities of shape, line, and space. This art is sculptural – made both in the round and in relief. In addition to the naturalistic imagery on monumental Olmec art, there is an iconographic or symbolic imagery that abstracts the important concepts of Olmec religion, cosmology, and ideology (Coe, 1965; Cyphers, 2012; De la Fuente, 1992). The sculptural nature of this style is expressed in pottery, where one of the important types (see below) features carved designs and symbols, some of which appear on monumental Olmec art.

Types of Olmec Pottery at San Lorenzo

In terms of Olmec pottery from San Lorenzo, four types have corresponding examples elsewhere in Mesoamerica (Fig. 2): Xochiltepec White, Conejo Orange-on-White, Calzadas Carved, and Limón Incised (Coe & Diehl, 1980).

Xochiltepec White pottery is made of clay so low in iron that it fires pure white. In terms of vessel shape, this type is frequently expressed in effigy vessels that represent squashes, usually without additional decoration. Conejo Orange-on-White represents a related – and even scarcer – type (Coe & Diehl, 1980, p. 179).

It exhibits the same paste as Xochiltepec White but has an orange slip, through which potters sometimes carved designs – contrasting the orange with the underlying white of the paste.

Calzadas Carved pottery exhibits distinctive carved Olmec-style symbols. Many of these stylized images contain elements of possible supernaturals referred to as the fire-serpent and were-jaguar, represented by what has been interpreted as flame eyebrows, crossed bands, opposed lines, and music brackets. Limón Incised pottery (which also includes some carved motifs) represents more abstract designs, which generally occur on the exterior of the vessel. Incised lines form curvilinear designs, emphasizing the *ilhuitl* or opposed volutes motif. Limón Incised pottery is less evident in ceramic assemblages outside of the Gulf Coast compared with Calzadas Carved.

Olmec Pottery in Oaxaca

As my work has focused on Oaxaca state, I discuss primarily the Olmec pottery present in San Lorenzo Horizon villages in the Valleys of Oaxaca (home of the Zapotec people) and Nochixtlán (home of the Mixtec people). Sherds – broken pottery vessel fragments – of Calzadas Carved and Xochiltepec White have been excavated in the large village of San José Mogote (Flannery, 1968), as well as secondary sites such as Tierras Largas (Winter, 1972), in the Valley of Oaxaca. Vessels that feature Olmec designs in Oaxaca, such as Leandro Gray and Delfina Gray (Fig. 3), have been interpreted as locally made without any priority by the Olmec in their creation (Flannery & Marcus, 1994) – an example of a “peer polity” model (see “Extra”). Accumulating evidence from both the Gulf Coast and Oaxaca, however, suggests a more complicated scenario.

Excavations at Etlatongo, in the Nochixtlán Valley (Blomster, 2004), recovered a large sample of Olmec pottery in an area once characterized as peripheral to the Valley of Oaxaca in terms of both sociopolitical complexity and interaction (Marcus, 1989). In addition to examples of



Ceramics: Rethinking Olmec Pottery, Fig. 3 Examples of gray Calzadas Carved pottery from Oaxaca. *Left* from San José Mogote, *right* from Etlatongo (Photo by J. Blomster)



Ceramics: Rethinking Olmec Pottery, Fig. 4 Cylindrical Calzadas Carved bowl excavated at Etlatongo but through compositional analysis determined to be an import from San Lorenzo (Photo by J. Blomster)

Calzadas Carved (Fig. 4) and Xochiltepec White vessels, types of Olmec pottery that have largely not been reported from the Valley of Oaxaca – Limón Incised and Conejo Orange-on-White (Fig. 5) – have also been recovered at Etlatongo. Thus, it appears that Etlatongo has a fuller suite of Olmec pottery types than the large chiefdom centered at San José Mogote.



Ceramics: Rethinking Olmec Pottery, Fig. 5 Conejo Orange-on-White vessel excavated at Etlatongo but through compositional analysis determined to be an import from San Lorenzo (Photo by J. Blomster)

Compositional Approaches to Olmec Pottery

The origin of Olmec pottery proved elusive through primarily stylistic analyses. If the peer polity model or “sister culture” model is correct, Olmec pottery made in Oaxaca should occur readily at San Lorenzo, while sites like San José Mogote should have little imported Olmec pottery. Oaxacan graywares – Leandro and Delfina Grays – have been interpreted as produced in the Valley of Oaxaca and exported to Tlapacoya and San Lorenzo (Flannery & Marcus, 1994).

In order to determine more robustly the origin of Olmec pottery, chemical characterization techniques were used. Approximately 1,000 archaeological pottery and modern clay samples from the Gulf Coast, Oaxaca state, Chiapas, and Central Mexico were subjected to Instrumental Neutron Activation Analysis (INAA) at the University of Missouri Research Reactor. This was a collaborative process, with specialists from both archaeology and compositional analysis contributing to the database and its analysis (Blomster, Hector, & Glascock, 2005; Neff & Glascock, 2002). The INAA process determines the basic chemical composition of a sample through the measurement of various forms of radiation emitted as the radioactive isotopes in an irradiated sample decay. After counts of

concentrations of 32 elements have been performed, the chemical data are then analyzed in order to recognize compositionally homogeneous groups within the sample; these groups represent geographically similar zones. Samples that fall within these groups originate from the same geologic zone and are more similar to each other than samples from other zones.

Through INAA, it was possible to determine the compositional group and region of origin for 726 archaeological samples of Olmec pottery (Table 1). The results fundamentally change the way in which the production and distribution of Olmec pottery is modeled (Blomster et al., 2005).

The San Lorenzo Olmec produced both fine white paste pottery (Xochiltepec White and Conejo Orange-on-White) and decorated Olmec-style pottery (Calzadas Carved and Limón Incised) and exported them to other regional centers across Mesoamerica. Clays collected from various sites around San Lorenzo demonstrate the close chemical relationship between ancient Olmec pottery and modern clays in this region. Some Olmec pottery from other parts of Mesoamerica is in the same compositional group as those manufactured at San Lorenzo. Most regional centers produced local variants of Olmec pottery (Fig. 6), with much variation between regions.

Table 1 documents that the local variants of Olmec pottery were not exchanged between these villages. Of special interest is the data from San Lorenzo itself. A total of 203 archaeological pottery sherds were tested from San Lorenzo, and none of them come from Oaxaca or any other part of Mesoamerica. Calzadas Carved sherds found at San Lorenzo that appeared most similar to “Oaxacan variants” (Flannery & Marcus, 1994) were included in the sample to determine if Oaxacan villagers exported Delfina and Leandro Gray pottery to the Gulf Coast. Contradicting a central tenet of the peer polity model, none of the locally produced Olmec-style pottery in the sample was exported to the Gulf Coast. Instead, pots without Olmec designs, or truly localized renderings of them, may have circulated. One sherd from Etlatongo, in a style more similar to San José Mogote than anything else at Etlatongo (or San

Ceramics: Rethinking Olmec Pottery, Table 1 Regional assignments for San Lorenzo Horizon pottery (Adapted from Blomster et al. (2005, Table 2))

Archaeological context	Region as identified by INAA							Total
	Gulf Coast	Mazatán	Valley of Oaxaca	Nochixtlán Valley	Valley of Mexico	Chiapas Central Depression	Isthmus of Tehuantepec	
San Lorenzo (Gulf Coast)	203	0	0	0	0	0	0	203
Mazatán (various sites)	23	177	0	0	0	0	0	200
Valley of Oaxaca (various sites)	13	0	42	0	0	0	0	55
Etlatongo (Nochixtlán Valley)	35	0	0	26	0	0	0	61
Tlapacoya (Valley of Mexico)	17	0	0	0	87	0	0	104
San Isidro (Chiapas Central Depression)	1	0	0	0	0	41	0	42
Laguna Zope (Isthmus of Tehuantepec)	3	0	0	0	0	0	58	61
								726



Ceramics: Rethinking Olmec Pottery, Fig. 6 Small Calzadas Carved vessel determined through compositional analysis to have been made at Etlatongo, where it was excavated (Photo by J. Blomster)

Lorenzo), has a composition suggestive, but not definitive, of a Valley of Oaxaca origin.

While it is possible that if every sample of Olmec pottery at San Lorenzo could be tested, a few may come from outside of the Gulf Coast,

this does not impact the general findings of this study. The Olmec at San Lorenzo generally did not receive foreign-made variants of Olmec pottery; the Olmec were its primary exporters.

Olmec pottery and associated symbols were valued by elites at the largest chiefly centers in Mesoamerica. While regions outside of the Gulf Coast made their own unique innovations and contributions to local versions of Olmec pottery, it does not appear that these other regions contributed substantially to the assemblage of Olmec-style symbols employed beyond each region. The Olmec appear to have been the primary disseminators of this pottery, which often displays rich iconography. Furthermore, important villages in adjacent regions such as San José Mogote and Etlatongo received pottery from the more distant San Lorenzo rather than from each other. It is also possible that potters, or their practices, moved and linked producers in disparate regions of Mesoamerica.

The Olmec interacted with groups across Mesoamerica that were already chiefdoms; both the Olmec and regional groups had various

interests in this interaction. The symbols exhibited on Olmec pottery suggest the dissemination of elements of Olmec religion and cosmology, which may have been received and utilized in widely different manners based on the interests of regional leaders and negotiations between and within local populations. Indeed, a fascinating aspect of this interaction is local emulation and appropriation of these symbols.

There was no one way in which these pots and symbols were disseminated across Mesoamerica. While some regions had limited, if any, entanglement with these materials and/or practices, at least one site, Canton Corralito in the Soconusco region (close to Paso de la Amada in Fig. 1), evinces the full suite of motifs, as well as vessel forms and angles virtually identical to those at San Lorenzo. Ceramic samples subjected to INAA document clear imports from San Lorenzo. Canton Corralito has been proposed as an Olmec colony or enclave (Cheetham, 2010). While investigators in the Soconusco region propose that this interaction transformed the local population from Mokaya to Olmec (Clark & Pye, 2000), the impact in the Nochixtlán and Oaxaca Valleys appears to be substantially different and less profound. At Etlatongo, both imported and locally made Olmec pottery rarely exceeded 5–10 % of the total ceramic assemblage from discrete contexts (Blomster, 2004). Access to foreign produced versus local imitation may reflect increasing differences in social status within the Etlatongo society. In Central Mexico, the impact also appears limited.

Extra: The Debate on Olmec Interaction

Much of the debate over Olmec interaction revolves around two perspectives. The nuclear-linear or so-called “mother culture” school views the Olmec as a precocious group in terms of social complexity, synthesizing and disseminating traits essential to all Mesoamerican societies. While Covarrubias (1957) proposed the Olmec created Mesoamerican civilization, modern proponents reject this idea, arguing that while the Olmec had achieved a different level of

sociopolitical complexity than their contemporaries, they interacted with groups that already exhibited complexity (Diehl, 2004). Due to the charged nature and contested meanings of the term “mother culture,” scholars who explore Olmec influence in Mesoamerica attempt to move beyond this term by focusing on the actual impact of the Olmec outside of the Gulf Coast (Neff et al., 2006b).

The peer polity model or so-called “sister culture” school views the Gulf Coast Olmec as just one of many groups utilizing a shared symbol set with other regions of Mesoamerica, without any priority in developing these symbols or attainment of a fundamentally greater level of social complexity (Flannery, 1968; Flannery & Marcus, 1994). Proponents of this perspective view the Olmec as a chiefdom, although the ongoing research at San Lorenzo (Symonds et al., 2002) demonstrates the more complex sociopolitical organization of the Olmec relative to contemporaneous groups.

Peer polity supporters (Flannery et al., 2005; Stoltman et al., 2005) contest the results of the INAA of Olmec pottery project, claiming a different approach to analyzing the ancient pottery – thin-section analysis (which looks at specific minerals in sherds) – contradicts the results of the INAA, viewing one method as superior to the other. The reality is these two methods complement each other. The conclusions of the Flannery and Stoltman group lack a substantive sample of local geology around San Lorenzo. Their claim, for example, that the volcanic materials in pottery excavated at San Lorenzo prove they are made in Oaxaca (Stoltman et al., 2005) founders on the fact that volcanic materials are also present in soils around San Lorenzo, as documented by a petrographic analysis from the Cyphers project at San Lorenzo (Neff et al., 2006b). The INAA project (Blomster et al., 2005; Neff et al., 2006a) documents that the Gulf Coast Olmec produced and disseminated Olmec pottery. While this research contributes to a stimulating debate on Olmec interaction and contrasting scientific methods, basic questions about what the Olmec and the various groups received from this exchange await further exploration.

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Chao Yuanfang

Fabrizio Pregadio

Virtually the only known detail of the life of Chao Yuanfang, Chinese physician and medical author, is that he was Medical Erudite (*taiyi boshi*) at the court of the Sui dynasty sometime between 605 and 616. In that position he supervised the compilation of the *Zhubing yuanhou lun* (Treatise on the Origin and Symptoms of Diseases), the first Chinese text comprehensively devoted to etiology and symptomatology. The work, which is integrally preserved, was submitted to the throne in 610.

The 50 chapters of the *Zhubing yuanhou lun* discuss more than 1,700 syndromes, classified into 67 categories of internal and external diseases. The final sections are concerned with gynecology, obstetrics, and pediatrics. A special feature of the text lies in its therapeutic methods. Rather than ingestion of drugs or acupuncture, Chao advocated a therapy based on such practices as diet and *daoyin* (a set of bodily postures, similar in some respects to Indian *hatha yoga*). The ► [Huangdi neijing](#) (Inner Canon of the Yellow Emperor) provides the broad theoretical foundation to Chao's work.

The *Zhubing yuanhou lun* exerted a remarkable influence on the history of Chinese medicine, as reflected for example in the ► [Qianjin yaofang](#), written by ► [Sun Simo](#). It was highly esteemed in Japan as well, where it inspired the classification of diseases in the earliest extant medical compilation, the *Ishinpō*.

See Also

- [Acupuncture](#)
- [Huangdi Neijing](#)
- [Sun Simo](#)

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Chemistry in China

Anthony R. Butler and Christopher Glidewell

Of all the sciences in antiquity chemistry was one of the least understood. Until people had some comprehension of chemical elements, compounds, atoms, molecules, ions, and bonding, they found it difficult to make much sense of the chemical processes occurring naturally. This does not mean that there is no real history of chemistry; it means only that we should assess the early chemical practitioners on the accuracy of their observations rather than that of their interpretations. The modern Chinese term for chemistry is *huaxue*, the study of change, and what the ancient Chinese did well was to note and describe the chemical changes which were observed when substances were mixed, heated, dissolved, or treated in some way. The fact that their interpretation may seem a little abstruse by modern standards does not detract from the worth of their observations.

Before chronicling chemistry in ancient China it is important to understand exactly what had stimulated an interest in chemical processes. The Daoist religion sought to lead its adepts into such a harmonious relationship with the world that they would escape the horrors of disease and the tragedy of death. It was not life after

death but life without death, although the precise notion varied from age to age. Those who had discovered the *dao*, through meditation, study, forms of exercise, appropriate sexual activity, and purity of life, would retire to an isolated mountain retreat and there live in complete harmony with nature. They were called *xian* or “immortals,” nearer to gods than men. The idea of longevity as a reward for the godly life is not unique to Daoism; similar notions occur in Judaism. In the genealogy of the patriarchs we read, “And Enoch walked with God after he begat Methuselah three hundred years and begat sons and daughters” (Gen. 5²²). However, what is special to Daoism is the use of drugs to acquire immortality.

Until the Song dynasty, Chinese drugs were grouped into three classes: superior drugs which allowed one to realize vital powers, medium drugs to enrich one’s nature, and inferior drugs which cure disease. This particular classification is given in *Zhenghe bencao* (Herbal of the Zhenghe Era) and it is the superior drugs that became associated with the attainment of immortality. Initially the drugs were quite crude materials: minerals straight from the ground or dried herbs, but subsequent developments lead to the compounding of these “simples” to give “elixirs of immortality.” It was in the preparation of elixirs that the ancient Chinese made their first chemical observations.

The preparation of elixirs was not an activity associated with a popular or debased version of Daoism and abhorred by the more sophisticated Daoist adepts. Although the importance of elixirs in Daoist practice varied somewhat from dynasty to dynasty it always played some part in the pursuit of the Daoist goal. Several emperors of ancient China expended considerable effort to obtain the elixir of life. Shihuangdi (259–210 B.C.E.), of the Qin dynasty, equipped large expeditions under the command of Xu Fu and others to go abroad to uncover arcane secrets of preparing elixirs. Emperor Wu (156–87 B.C.E.) appointed numerous magic specialists to high positions.

Two prominent components of Daoist elixirs were cinnabar (mercuric sulfide) and gold. The

reasons for this selection are not difficult to appreciate. Cinnabar is bright red, reminiscent of healthy blood, and it was thought that the infusion into the body of extra healthy blood would enhance health and lifespan. The absence of understanding of chemical composition among the ancient Chinese meant that the physical appearance (i.e., the color) had greater significance than the obviously different chemical properties of cinnabar and blood. Gold was probably the most prized component of an elixir because it was obtained from the ground in an uncombined (and thus, uncorrupted) form and in the air it did not tarnish. If these attributes could be acquired by the human body then it would, indeed, last forever. One difficulty recognized by Chinese alchemists was that both cinnabar and gold are insoluble in water and, therefore, unlikely to be absorbed in the body. Much effort, therefore, was expended in devising methods of solubilizing both cinnabar and gold.

A manual in the Daoist Patrology (*Dao Cang*) entitled *Sanshi liu Shui Fa* describes the use of niter (potassium nitrate) in vinegar (dilute ethanoic acid) to bring numerous minerals, including cinnabar, into solution. In some cases there appears to be some confusion between solution and suspension; in other cases solution would occur in any aqueous solvent. However, in a few cases, particularly in the solubilization of cinnabar, some interesting chemistry is involved. A solution of pure niter in pure aqueous ethanoic acid has no effect on cinnabar but solubilization does occur if chloride ion is present as an impurity. This is probable as niter was obtained from marine sources. Thus the fanciful descriptions of Chinese alchemy may have a sound basis in chemistry if allowance is made for probable impurities. The same applies to an account in the *Sanshi liu Shui Fa* for the solubilization of gold where the required contaminant is iodate, a common impurity in crude niter deposits. The fact that these accounts of Chinese alchemical activity can be explained in modern chemical terms is evidence of the accuracy of the original observations.

Gold is not common in China and it was not regularly used as a form of currency. Because of

the shortage of gold, much alchemical activity was directed at making gold from more commonly available materials. This appears, at first sight, to be identical with European alchemical activity but the motivation was completely different. In Europe it was, until fairly late in the thirteenth century, the pursuit of wealth; in China it was from earliest times the pursuit of immortality. Cinnabar was a popular material upon which to work (gold and cinnabar often occur together in the earth) and the *Gui Jia Wen* contains the lines:

The span of life is up to me, not heaven.
The reverted cinnabar becomes gold, and millions of years are mine.

In the most famous alchemical manual (the *Neipian* of the *Bao puzi*) the author, ▶ [Ge Hong](#), gives a recipe for preparing gold from tin by heating with various forms of alum (potassium aluminum sulfate) on a horse dung fire. What was made was tin sulfide or mosaic gold, a yellow material which glitters just like gold. Present-day repetition of the procedure, using an electric furnace rather than a horse dung fire, confirms the production of tin sulfide.

The elixirs made from simples like cinnabar and gold contain, in general, so many components, some of which will contain impurities, that it is difficult to hazard a guess at what chemical changes are occurring. Picturesque titles were given to many elixirs. A mixture of calomel (mercuric chloride), cinnabar, sulfur, and realgar (arsenic sulfide) was known, according to the *Danjing Yaojue* of ▶ [Sun Simo](#) of the Tang dynasty, as Grand Unity Three Envoys Elixir. Needless to say, the elixirs did not have the required effect and their use in Daoist practice gradually died out, leaving only a memory of sustained but flawed chemical activity. There are just a few exceptions to this generalization of futility in Chinese alchemical activity, the most famous of which is the production of ▶ [gunpowder](#), known originally as *huoyao* or “fire drug”. Niter and sulfur are mentioned in early *materia medicas*, including *Shennong Bencao Jing* from the Han. Possibly in pursuit of elixirs, they were mixed and inadvertently

contaminated with carbonaceous materials, giving a material which burned very brightly. Careful adjustment of the proportions gave an explosive, used in China for firearms and civil engineering and for fireworks. The first printed recipe for gunpowder is given in a military manual, *Wujing zongyao* by Zeng Gongliang, printed in A.D. 1044. It was the optimized formula which traveled to Europe and had such a dramatic impact on the conduct of warfare. It is ironic that the most significant achievement of Chinese alchemists in their efforts to make elixirs of immortality was an instrument of warfare.

With a decline in interest in alchemy during the Yuan, Meng, and Qing dynasties, there was no emergence of modern chemistry from alchemical activity as there was in Europe. The advanced state of modern Chinese chemistry (epitomized by the laboratory synthesis of insulin in 1965) is due to the introduction of chemistry from the West during the nineteenth century, partly by missionaries and partly by young Chinese students studying in Europe and America. Among missionaries (although the term is not entirely appropriate) was John Fryer, the son of a poor English clergyman, who worked at the Kiangnan Arsenal translating manuals and textbooks for the Chinese government. Between 1867 and 1897 he acted as focal point for the propagation of western scientific ideas in China. Even during the political upheavals of the first part of this century, there was a general increase in Chinese scientific education, and a number of Western style scientific institutions, like the Peking Union Medical College, were established. In chemical research the dominant figure was Wu Xian. He completed his Ph.D. at Harvard Medical School in 1920 and returned to the Peking Union Medical School. By 1925 he was a full professor and initiated an extensive program of research into blood chemistry. Chemical research started elsewhere and, fueled by the innate talent of the Chinese people, it has grown, in spite of all the political upheavals of the Communist revolution and the downfall of Mao, to make China one of the leading nations in the world for chemical research.

See Also

- ▶ [Alchemy in China](#)
- ▶ [Ge Hong](#)

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Chen Yan

Hong Wuli

Chen Yan, a famous physician of the Southern Song Dynasty in the twelfth century, was born in Qingtian (now in Zhejiang Province), with Wuze as his surname and Hexi as his nickname. He was extraordinarily clever and proficient in prescription and pulse taking, as well as in treatment. It was said that he could prophesy the prognosis of incurable diseases. In 1161, he assembled a six-volume work of prescriptions, *Yi yuan zhi zhi* (Treatment Based on Etiology), with 81 categories which deals with the pulse and diagnosis of diseases, followed by their etiology, and the variorum of the *Canon of Pulsology*, all with relevant recipes. This work was never published.

Chen was especially interested in the study of pathogenesis. He claimed that the causes of all diseases could be divided into three categories; this was based on Zhang Zhongjing's hypothesis. Eventually, he compiled the *San yin ji yi bingzhang zhengfang lun* (Discourses on the Manifestations and Recipes of Diseases of Three Pathogenic

Categories) in 1174, in 18 volumes. He summarized all pathogens into three categories:

1. Endogenous emotional changes, the Seven Emotions (joy, anger, sadness, ratiocination, grief, apprehension, and fear), which originate from the internal viscera and affect the extremities.
2. Exogenous pathogenic factors, the Six Excesses (wind, cold, heat, damp, dry, and fire), which originate from the channels and affect the internal viscera.
3. Causes neither exogenous nor endogenous, which derive from immoderate food and drink, wounds, ulcers, and insect and beast bites. The etiological work exerted some influence on later generations.

Chen also summarized medical science in four Chinese characters, reading “title, substantial property application” claiming that all new commentaries on ancient classics could be categorized under four branches: sphymology, manifestation, disease, and treatment. Hence, all medical students should recognize a disease on the basis of pulsology and make a diagnosis on the basis of manifestations.

In the years 1165–1173, he compiled the *Herbology of Compiled Categories* with subheadings based on the above-mentioned ideas. Though it was an anonymous compilation with a “Preface by Master Hexi,” it was commonly believed to be Chen's.

See Also

- ▶ [Medicine in China](#)
- ▶ [Yinyang](#)
- ▶ [Zhang Ji \(Zhang Zhongjing\)](#)

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Childbirth

Margarita A. Kay

The pelvic changes that evolved when hominids became upright walking creatures resulted ultimately in what is known as the “obstetrical dilemma” for humans. The woman's pelvic bones must not obstruct safe passage of the infant's head, and her soft vaginal tissue must be able to stretch to the maximum. Meanwhile, the baby must be mature enough to survive outside the woman's body but small enough to pass through her narrowed birth canal. Managing childbirth within these parameters developed throughout human history by means of observation, trial, and errors accommodated, however, by high fertility. Obstetrics conducted in hospitals is a recent biomedical specialty, and in the past decades, Western obstetrics has developed still more technologies. However, for non-Western mothers, little has changed in 2,500 years of written record. From that record, we can draw one of two opposing conclusions: first that childbirth customs are appropriate adaptations to biological needs; or, second, that high technology is always better than childbirth in a natural setting.

Some writers portrayed childbirth practices in non-Western societies as ideal, resulting in a quick and painless process. Men who were not allowed to observe births were told about them by informants who themselves also had been excluded from the birth scene. These writers believed that the non-Western woman just goes in the fields, gives birth, and returns to work in a few hours. Later, women anthropologists who observed non-Western births gave very different reports. Management of childbirth anywhere requires attention to the problems of safety, pain, fatigue, protracted labor, malposition of

the fetus, delivery, expulsion of the placenta, and healing. Solutions to problems are mandated by the universal physiology of childbirth. In Western obstetrics, these problems of childbirth are managed with technological equipment; in non-Western societies, the same problems are managed with hands.

Childbirth is not only a biological occurrence; it is also a sociocultural event. Differences in the management of birth reflect different values and beliefs. In some cultures, myth is used to explain pregnancy and birth. Sometimes birthing is a private process, sometimes a communal event. How a society reacts to physiological processes and the extent to which there is contact with other cultures accounts in part for diversity in the ways of managing childbirth. Each birthing system relates to the place women hold in a community, the value given individual children in that community's social structure, how much medical care is available and how it is distributed, and the religious belief system that is in place. Thus childbirth practices develop within the context of each particular society.

Such cultural strictures determine, among other things, how the pregnant woman should behave, who should take care of her, how abnormalities are to be explained and how to prevent them, what, it is believed, causes labor, how it should be stimulated, where the birth should take place with which persons in attendance, and what should be done after birthing for mother and newborn. Descriptions of diverse birthing practices can be found in the writings of George Engelmann and Hermann Ploss, Max Bartels, and Paul Bartels. Birth customs are catalogued in the *Outline of World Cultures*. MacCormack and Kay edited anthologies detailing birth practices in mostly non-Western cultures. Following are illustrations of some of this diversity from East India, Japan, Malaysia, the Navajo Nation, Seriland of the northwest coast of Mexico, Guatemala, Mexico, Ireland, and Ibo and Bariba tribal homelands in Africa.

Many “normal” activities of women are proscribed during pregnancy with the view of preventing childbirth difficulties. Some of these prebirth customs, are considered adaptive by

Western medicine. For example, pregnant American Indian women are urged to keep moving and working during pregnancy and to limit their intake of food. The goal is not to have too large an infant for easy delivery. In West Africa, on the contrary, women are fattened in order to make them desirable for marriage and childbearing. Each custom is beneficial: genetically, American Indian women tend to have very large infants, whereas the babies of African and African-American women are likely to be quite small.

The women themselves explain their customs only as "we have always done it that way." The outsider sees the rationale for many proscriptions deriving from principles of sympathetic magic, like affecting like. Ancient Mexicans and recent Navajo, for example, believe that weaving is dangerous during pregnancy because the umbilical cord will tie up the baby. This belief has a very long history. It is recorded as fact by ancient Greek authorities of Aristotle, Galen, and Soranus. Across Western and non-Western cultures, the woman and sometimes her mate are told to avoid certain foods and actions to prevent problems in birthing or abnormalities in the baby. Conversely, a woman's cravings for exotic foods must be satisfied or the baby will be marked. Some of the rules placed to solve birth problems may be seen in the belief system of the larger culture; for example, the *bidan kampung* (traditional midwives) of Muslim Malaysia consider the humoral system of Islam in selecting a western-facing direction (with modification for days of the week) to align the woman for birthing; west faces Mecca. For Navajo, on the other hand, it is vital that the mother's head *never* face west, for that is their direction for death. Women who are taught that congenital malformations are caused by unnatural phenomena wear amulets to protect the unborn child. Charms include medals, pictures, and prayers that represent their religion, iron filings, and pieces of crystal, coral, or jet. It could be said that magical thinking can also characterize high technological Western cultures, for childbirth outcomes cannot always be predicted. Rituals of testing are enacted to resolve anxiety of the unknown. Childbirth is feared to a certain extent by all people.

Non-Western women are given prenatal massages in many cultures, notably Japan and Mexico. The purpose of the massage is to fix the fetus in a position favorable for delivery. In some societies, the fetal position is also assisted by a belt around the woman's abdomen. The Japanese apply the maternal *obi* in a special ceremony in the fifth month of pregnancy. Mexican women wear a narrow red cord, which shows the ascent of the uterus. Traditional Navajo women maintain their custom of wearing a red belt woven with green figures, 5–6 in. in width, throughout pregnancy. This belt is later used during labor and delivery.

When a woman believes that her childbirth labor is starting, she takes herbal teas. Mexican women drink *té de manzanilla*, camomile tea, believing that if it is false labor, the tea will make the pains go away, and if it is true labor, the pains will come stronger and harder. This belief has pharmacological support. Navajo women use tea from a penstemon for the same purpose, or one from rabbitbrush. Ideally, the birth should be fast. Mexican and Guatemalan women are given the ancient Aztec herb *cihuapatli*, which has strong effects on the uterus. They are permitted little sleep but are encouraged to walk with their contractions to hasten delivery. When in pain they are allowed to scream, unlike West African Bariba and Ibo. The proud Bariba women attempt to deliver alone to conquer their fear. Traditional Navajo women were trained to make no sound in order to preserve the secrecy of the process and today are silent and motionless during labor.

Because childbirth is the obvious result of sex, women in societies that value female purity, innocence, and virginity have particular difficulties. Irish peasants hide their pregnancies as long as possible, and do not publicize births. Hindu women also do not advertise their condition, resulting in little attention to their prenatal health, and distressing labor. Following Biblical injunction, the laboring woman was expected to suffer, until in the mid-nineteenth century, Queen Victoria accepted the newly discovered anesthesia for her birthings.

In non-Western childbirth, a midwife conducts the birth process. She uses many ways to stimulate labor, from placing an amulet on the laboring woman or an axe under her bed, to giving herbal teas or some of the husband's semen for her to swallow. To lubricate the birth canal, she massages with whatever is typically available, such as lard, clarified butter (*ghee*) or cooking oil.

Posture during labor also varies. In many non-Western societies, the laboring woman is encouraged to keep an upright position, utilizing gravity to move the fetus in the birth canal. Anderson and Staugård summarized traditional birth positions of 22 tribes in Africa and found kneeling to be used in 12, squatting in 10, holding rope in 7, lying in 6, and half sitting in 5. These postures may relate to different pelvic dimensions; for example, women of Biafra commonly used the squatting position, which works best for women who have a short pelvic outlet. The 80,000 women who have had traditional genital surgery (female circumcision) present special challenges for safe delivery, because scar tissue does not stretch.

A common practice of American Indians has the woman in either a kneeling or squatting position, with one attendant supporting the woman from behind, pushing on the abdomen above the uterus, while another attendant is in front, pressing from below. The mother might be pulling on a rope during contractions. Or she might pull on a hammock, which is suspended above where she stands, as has been recorded for the Kalopalo Indians of Central Brazil. In the latter case, four attendants help the laboring woman, two pressing down on each shoulder, and two pressing on her feet to direct force during a contraction. Navajo women pull on the special red belt that they wore during pregnancy, looped over a beam in the ceiling. For the Seri, a hunting – gathering people of Sonora, Mexico, two women who are usually close relatives help with the birth. One assistant sits on the ground, her legs spread but her knees doubled under her, to make a lap for the parturient to sit on. The second assistant, also sitting on the ground but facing the laboring woman, holds her hands in position to receive the infant.

The parturient and midwives often wait for hours in the described positions. To speed the labor, the parturient may be given tea from the roots of indigenous plants, or a concoction of alcohol, limes, cinnamon, and aspirin. The women often say that they do not want to marry because childbirth hurts too much. Women of the nearby agricultural Yaquis drink an infusion of the narcotic plant *Datura* for childbirth pain.

For difficult deliveries, Punjabi midwives straddle the chest of the laboring woman, pressing hard on the abdomen with their hands; or they push with the heels of their feet on the pubic bone.

In matrilineal societies such as the Navajo, the attendants are commonly women from the maternal side of the family. Patrilineal societies such as Egyptian or Japanese, where descent is traced through the father's line, require the presence of the husband's kin, to assure continuity of the line. The birthing woman is accompanied by her husband's mother, and goes to her mother-in-law's house to recuperate from the birth.

Delivery of the placenta (afterbirth) is a grave concern in all societies. The medical ethnobotany of every group contains a variety of plants to give the woman whose placenta is slow to separate. According to humoral doctrines which are prevalent in many non-Western cultures including India, China, Middle America, and Latin America, those herbs that acted on the uterus were categorized as "hot" and "dry," and many of the same plant genera are used crossculturally. A retained placenta is a most dreaded complication of birth: "anyone can deliver a baby but it is the placenta which kills" (Bariba). Once the midwife delivers the placenta, she disposes of it according to its meaning in her culture, respect as a spiritual entity or fear of its power. In Malaysia, the placenta is considered to be the fetus's semi-human sibling, and thus is washed and ceremonially buried, which is similarly done by Guatemalans and Seri.

Some of the materials used to act on the uterus, either to bring on menstruation, stimulate labor, hasten birth, or separate the placenta, have been subjected to phytochemical analysis. *Artemisia* species, the botanical name first given by the

Greeks for their goddess of women, and used worldwide in Europe, the Middle East, China, Latin America, North America, and Mexico, contain estrogens, female hormones. *Matricaria*, named since Roman times from the Latin word for womb, relieves painful uterine cramps through its spasmolytic compounds. Analysis of other materials, such as the husband's semen, given to the laboring woman in some African cultures, shows that they are high in prostaglandins, chemical compounds used in biomedicine to initiate labor by causing the mouth of the uterus to begin opening.

Indian peoples of Mexico use plants passed down in oral history from Uto-Aztecan forbearers (such as *yyahautli*, marigold, to stimulate labor, and *toloache*, jimson weed, for labor pain) and also those learned from Europeans who came in the colonial period, coriander and rosemary, for their actions on the uterus. Hindu mothers are given Ayurvedic herbs, while Chinese herbs are used all over eastern Asia. Childbearing women take herbs for prenatal care, labor strength, and postpartum healing. The woman may drink the plant material in teas; it may be applied to her abdomen, inserted in her vagina, inhaled, or she may sit over infusions in vapor baths.

After the baby is born, the umbilical cord must be tied and cut, and again there are many practices to be followed. The cord is cut with a piece of sharp ► **bamboo** in Malaysia, a razor blade or broken glass in Ghana. It may be tied with hair, string, or animal tendon. The variety of dressings include pounded pottery, herbs, salt, ground shells, and ash, materials that can harbor bacilli causing neonatal tetanus. The cord remains may be buried in a place that is associated with the anticipated sex role behavior of the child. For example, a Navajo woman may bury her infant son's cord near the sheep corral and her infant daughter's cord near the weaving room. Mexican, Malaysian, and Japanese mothers kept each child's cord for the child's future welfare.

The immediate postpartum period lasts for 3 days in cultures predominately Christian, and 4 days in American Indian societies, the respective magic numbers for each. After giving birth,

and for a period of time prescribed by the culture, 20 days for many American Indians, 40 days for traditional Jews, Christians, and Muslims, the woman is supposed to be confined to her home. It is believed that the woman is vulnerable, requiring protection during the entire postpartum period. Some Mexican patients still observe *la dieta* during which time baths, walking barefoot, and otherwise being subjected to cold are proscribed. This includes avoiding "cold" foods, foods that are believed to have a quality of chilling the body.

The newly delivered woman is healed with heat in many cultures. The Navajo woman may have heat applied by warming green cedar and holding it to the abdomen with her red sash. She is bathed on the fourth day after delivery, especially if she had a ceremonial Sing during her labor. Her lacerations are treated with a salve of baked cactus, or a fumigant treatment may be prepared by digging a hole and heating stones therein. Soranus described a similar fumigant 2,000 years ago. "Mother roasting," as it is called, is a therapy used by many societies in Southeast Asia, including Malaysian. A fire is maintained beside the delivered woman for a prescribed number of days. This "dries out" the womb. A ritual fire is kept burning in the dwelling of the Seri woman for 4 days following the birth, in this case for the infant's sake. Hot leaves are pressed on the Ibo mother's abdomen, immediately after birth. The *temascal* or sudatory was used by ancient Aztecs after childbirth, as well as by ancient Romans and is used by present day orthodox Jewish women after menstruation as well as after childbirth.

Sexual intercourse is not permitted anywhere until the puerperium, however defined, is over. Mexicans, like so many others, believe that intercourse when there is vaginal bleeding is abhorrent. The Navajo believe that even indirect contact with vaginal blood is very dangerous to the husband and anyone else. In many cultures, contact with blood was considered polluting to the individual and to the community. The woman could now be purified, by bath and by religious ceremony. Leviticus XII, two provides the Laws of Purification and Atonement for Jews,

Christians, and Muslims. The postpartum bath is a Shinto rite of purification in Japan.

Non-Western Birth Today

It is estimated that worldwide, 80 % of births are attended by Traditional Midwives, Traditional Birth Attendants, or simply female relatives. The status of the traditional midwife has varied through time and place. For some non-Western cultures, her status has been very low, for it is women's work, and deals with blood. With many ethnic groups in India, midwifery was looked upon as a most degrading occupation.

The traditional midwife is typically a woman who is respected in her community, nonliterate, postmenopausal, has herself borne children, and learned her craft as an apprentice to another woman. She is often looked down on by the Western medical community. Traditional midwives may get Western training to meet difficult births, although they may not always find such instruction useful. When Western technology is not available, the traditional midwife's birth skills may prove to be superior. It may be hoped that the Certified Nurse Midwives of each culture may bridge the birth customs of the non-Western traditional midwife with the practices of Western biomedicine.

See Also

- [Ethnobotany](#)
- [Magic and Science](#)

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Childbirth in India

Nitin Trasi

Obstetrics in Ancient India

The oldest sources of information about Indian culture are the four *Vedas*, sacred compositions probably compiled over several centuries during the second millennium BCE. The knowledge about Vedic medicine is contained mainly in the fourth and latest Veda, the *Atharva Veda*, and a related later work, the *Kaushika Sūtra*. Later, in the post-Vedic era, the ancient Indian system of medicine acquired the name *Āyurveda* (lit.: knowledge of life). The golden age of Indian medicine lasted almost 2,000 years, from about 1000 BCE to about AD 1000. The most famous works written at this time were the

medical treatises known as the ► *Caraka Saṁhitā* and the *Śuśruta Saṁhitā*.

The art of obstetrics was well advanced in ancient India. Āyurveda had eight branches (*aśtāṅga āyurveda*), one of which was *Kaumārabhr̥tya* – gynecology, midwifery, and pediatrics. This included the classification of diseases of the female genital tract, including menstrual disturbances, and suggestions for treatment. It discussed the clinical course and various stages of labor, difficult labor (*mūḍagarbha*), the management of the puerperium (the period of confinement after labor), and miscarriage (*makkalla*). The different malpositions of the fetus were also known, and methods of treatment by version (the manual turning of the fetus to make delivery easier), embryotomy (an operation to destroy the fetus), forceps delivery, and even cesarean section were described (Keswani & Sharma, 1972). In fact, the first mention of the obstetric forceps in world literature is to be found in the Vedas. It was called the *jugna śankhu*, and consisted of paired, semicircular-ended tongs, such as that used for holding hot utensils. It was probably used for extracting a dead and dismembered fetus from the mother's womb (Das, 1929; Douglas & Stromme, 1988, p. 367).

Caraka, the author of the *Caraka Saṁhitā*, was a famous physician. He is believed to have been the court-physician of the Buddhist king Kaniśka (AD 78–100), and attended on the king's wife as obstetrician during her difficult delivery (Saletore, 1984, pp. 300–301). The *Caraka Saṁhitā* lacked a detailed study of surgery, but was otherwise quite comprehensive.

Śuśruta was the most celebrated surgeon of ancient India. The *Śuśruta Saṁhitā* was originally written probably in the last centuries BCE, although some date it much earlier, even as far back as 1000 BCE. It is especially important from a surgical point of view. Śuśruta mentions as many as 121 instruments of various descriptions, made largely of steel. Alcohol in the form of medicated wines was used as a narcotic during and also after operations, and hot oils, tar, or

caustics were used to stop bleeding. A drug called *Sammohinī* (producer of unconsciousness) was administered before major operations, and another drug, *Sanjīvanī* (restorer of life) was employed to resuscitate the patient after operation (Keswani 1961, 1967).

When delivery was impossible by natural means, the fetus – usually dead by then – was probably extracted using forceps; if necessary after dismemberment by embryotomy. Cesarean section, though mentioned in the literature, was not likely to have been a real choice. It had an extremely poor maternal outcome (almost 100 % mortality) the world over until the twentieth century. In ancient India too, it was probably only performed on rare occasions on a dying mother (or one who had just died) in an attempt to save the baby. Embryotomy, on the other hand, seems to have been a well-known procedure, finding mention even in nonmedical literature. The great monistic philosopher Ādi Śaṅkarācārya (AD 788?–820) refers to it, citing it as an example of human suffering even before life has begun.

If, by chance, the child moves into a transverse position at the time of delivery, it is then turned out (extracted) forcibly, broken into pieces by instruments (*Prabodasudhākara*, v. 10).

Charitable hospitals were established by many rulers, notably Rāhul, the son of the Buddha, and the famous Emperor Aśoka (ca. 273–232 BCE or 265–238 BCE).

The Populace

Although the art of obstetrics was well advanced in ancient India, most people probably had little access to it. Pregnancy and childbirth were generally managed at home, by practices based partly on experience and partly on cultural beliefs. Girls were customarily married off at a very young age, often even before they had attained puberty. Their obstetric career therefore began early, and they continued to bear as many offspring as their health would permit. The pregnant woman was subjected to many restrictions.

The solar and lunar eclipses were believed to be especially inauspicious times for her, and she was forbidden from venturing out into the open at these times.

Childbirth was largely a domestic affair, the parturient woman being attended to by experienced elder ladies from her own and from her neighbors' families. The squatting position or the seated (kneeling) posture was often favored for childbirth, and even today many tribal societies in India prefer these positions. The vaginal canal was lubricated with clarified butter (*ghī*) and *ghī* was also fed to the mother in the belief that it would lubricate the birth canal. A normal delivery did not usually present too many problems, but there was no recourse when complications arose, and in such cases the baby was often lost, and at times the mother too. Unsanitary conditions and lack of proper training and knowledge contributed to a high maternal and fetal mortality. Neonatal tetanus was an important cause of infant mortality. Cow dung was believed to have purifying properties, and was commonly used to "purify" the floor of the house (Saletore, 1943, p. 114). This could have been a contributory factor.

At some time, the system of the traditional birth attendant, the *dāi*, took root. These *dāis* were usually experienced elderly ladies who would provide their services for a modest fee. However, though experienced, the *dāis* had no scientific education or training. Even today, it is estimated that *dāis* conduct over 50 % of births in rural India. However, since 1957, the *dāis* undergo scientific training, and *dāi* training is now an essential part of the maternal and child health program of the Indian government.

The Medieval Ages and Later

With the coming of the Muslim conquerors to India, from the tenth century onward, the golden age of Āyurveda began to decline. Some of the factors leading to the decline were want of

patronage from the rulers, aversion of educated Hindus to contact with blood, pus and diseased persons, and absence of a system of regular education and training for practitioners. In the absence of professional standards, it became difficult to distinguish the genuine practitioners of Āyurveda (the *vaidya*'s) from quacks. Medicine in India during the later medieval period was dominated by Persian and Arabic influences which introduced an amalgam of Greek and Persian medicine, known as the *Unāni system* of medicine.

From the 1800s until 1947, the British ruled over most of India (British India included what are now India, Pakistan, and Bangladesh). By then, both Āyurveda and the *Unāni* systems were unorganized, as they had not kept up with modern discoveries and research. Skills were passed by familial succession and not by institutionalized education, and the practitioners were for the most part uneducated and unwilling to incorporate the new knowledge and discoveries that were pouring in from the West.

The state of public health in India at the time was poor, and women and infants were the most neglected segments of society in matters of medical aid. Maternal mortality (maternal death during childbirth) and infant mortality were very high. Even when modern medical treatment was available, resistance to treatment by male physicians and the strict *purdāh* system prevalent among certain communities often ensured that women got little access to it. There were cases where women preferred to die in childbirth rather than submit to treatment by a male doctor (Kumar, 1998).

Modern Obstetrics in India

The Portuguese first introduced modern Western medicine to India (Royal Hospital, Goa, 1510), but it was largely the British who later established and consolidated both its practice and its study in the subcontinent. Popularization of sound

surgical practice led to great improvements in the health of the population. Specialization was introduced in Indian universities both in education and research, and India was kept abreast of all the major developments taking place in the fields of science and medicine all over the world. All-women managed hospitals were opened for women patients. In Bombay (now Mumbai), several hospitals for women were opened in the late 1800s; among them, the Cama Hospital (1886) and the Allbless Obstetric Hospital (1890) were entirely managed by women staff. Medical education was promoted among girls even at a time when this was not popular in Europe. Anandibai Joshee was the first Indian woman to go abroad for medical education. She obtained an American degree in 1886. Significantly, her MD Dissertation topic was “Obstetrics among the Aryan Hindoos” (Kumar, 1998).

In the early twentieth century, several Indian obstetricians made valuable contributions in the field of obstetrics. Some of the pioneering Indian obstetricians were Dr. N. A. Purandare from Mumbai (1877–1964) and Rão Sāhib Dr. Shivarao Trasi (1881–1954) from southern India. In 1929, Sir Kedarnath Das published his work on the history of the obstetric forceps, which is still considered a classic, and in which he described over 500 varieties of forceps and included over 2,000 references in ten different languages. Dr. V. N. Shirodkar (1899–1971) pioneered several new surgical techniques, the most famous of which was an operation for women suffering from repeated abortions. Other leading obstetricians were Dr. K. M. Masani (1903–1988), Dr. M. K. Krishna Menon (1908–1988), and Dr. B. N. Purandare (1911–1990), among many others.

In India today, women use both traditional and modern techniques, depending on their location and income. In remote rural areas, conditions are similar to what they were a hundred years ago, while women in the city have access to top hospitals and the best of equipment. Mortality statistics are still alarmingly high in certain parts of the country.

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Cities and Towns in Ancient Israel (Bronze and Iron Ages)

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Background

Many cities have been uncovered from Bronze and Iron Age Israel, the vast majority of which were located on *tells* – artificial mounds created as a result of gradual human settlement activity. Notably, not every location is suitable for the emergence of a center, even of a local nature, and each site had advantages and disadvantages in relation to factors such as security, water supply, transportation (roads), and the availability of soils for agriculture. Consequently, only several locations could, in antiquity, provide livelihood for a large population at any given region. This resulted in a repeating pattern in which the centers of many periods were continuously located one on top of the other, thus creating the famous tells which are so typical of the Middle Eastern landscape. Although in many instances extramural neighborhoods were built on the slopes of the tells (and in some rare instances cities were not built on tells), it is only in the later half of the first millennium BCE that the overall pattern changed. By then most *tells* were abandoned, and cities were built practically everywhere. The gradual process of tell abandonment resulted from many factors, including changes in security conditions, increased population, and improved technology, but this process lies outside the scope of the present discussion.

Notably, the towns (and tells) of ancient Israel were much smaller than their contemporaries in Mesopotamia and Syria. An average city of the Bronze and Iron Age covered some 3–5 ha (and sometimes even less); larger towns, in the scale of 7–12 ha, were also present. Towns of 20 ha, however, were exceptionally large, and megalopolises of 60 ha and more were extremely rare – very few such sites existed in the periods discussed here

(e.g., Hazor in the Middle Bronze Age II and Late Bronze Age and Jerusalem in the Iron Age II).

Defining a city is a complex enterprise. Within the scope of the present entry, suffice it to note that the urban centers were much larger and more crowded than their rural contemporaries. Their inhabitants were of diverse backgrounds and occupations, and not all of them were engaged in agriculture. Social stratification is evident in practically all such sites, along with public buildings and royal construction activities (palaces, walls, storehouses, water systems, etc.). These urban settlements served as political and economic centers for the villages that surrounded them and, probably also, during most periods, as centers of tax collection and as places of refuge in times of need.

History of Urbanization in Ancient Israel Up to the Persian Period

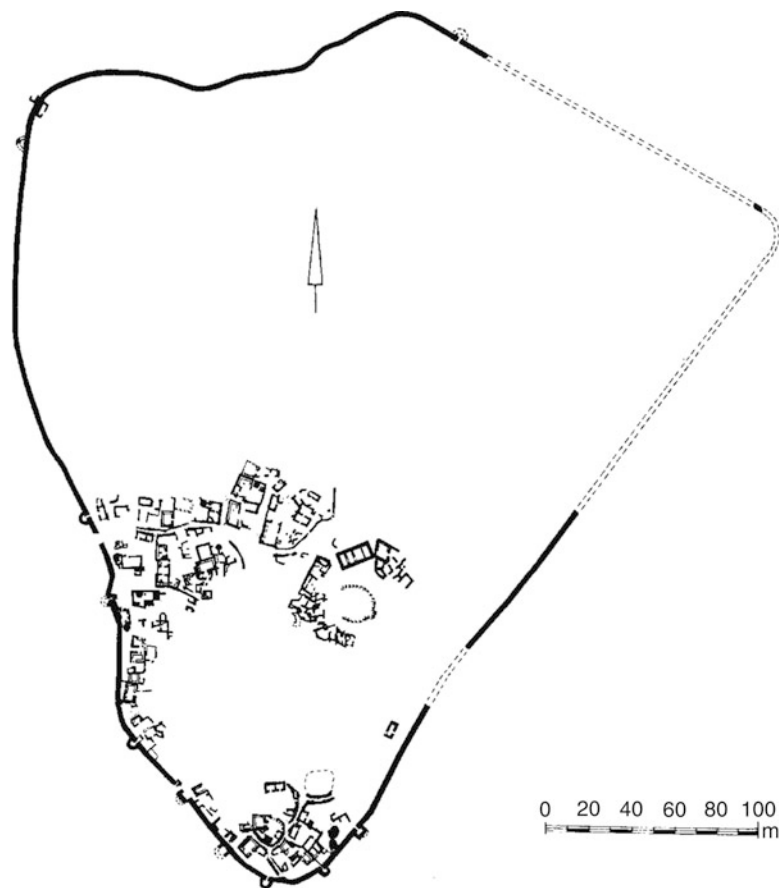
Cities first appeared in ancient Israel around the transition to the third millennium BCE (Early Bronze Age) (see section “[Extra 1](#)”). These first cities usually lie at the bottom of the tells, and in most cases not much is known for certain about their planning. It is mainly in the desert area, where the sites were not resettled in later periods, that we can discuss elements of city planning. ‘Arad, in southern Israel, is the best-known example of such sites (Fig. 1).

The site covers almost 10 ha and seems to have been divided into several public and residential quarters. The former included several small temples and a modest palace. A large, but simple, water system into which rainwater was collected was unearthed in the lowest part of the city. One should remember, however, that it is not certain whether ‘Arad is a representative of the Early Bronze Age urban phenomenon, as, due to its location on the desert fringe, it might have differed from the typical towns of the third millennium BCE.

The Early Bronze cities were gradually destroyed and abandoned toward the end of the millennium, and by the last two centuries

Cities and Towns in Ancient Israel (Bronze and Iron Ages),

Fig. 1 The Early Bronze Age city of 'Arad (Based on Kempinski, 1992a, p. 76; courtesy of the Israel Exploration Society)



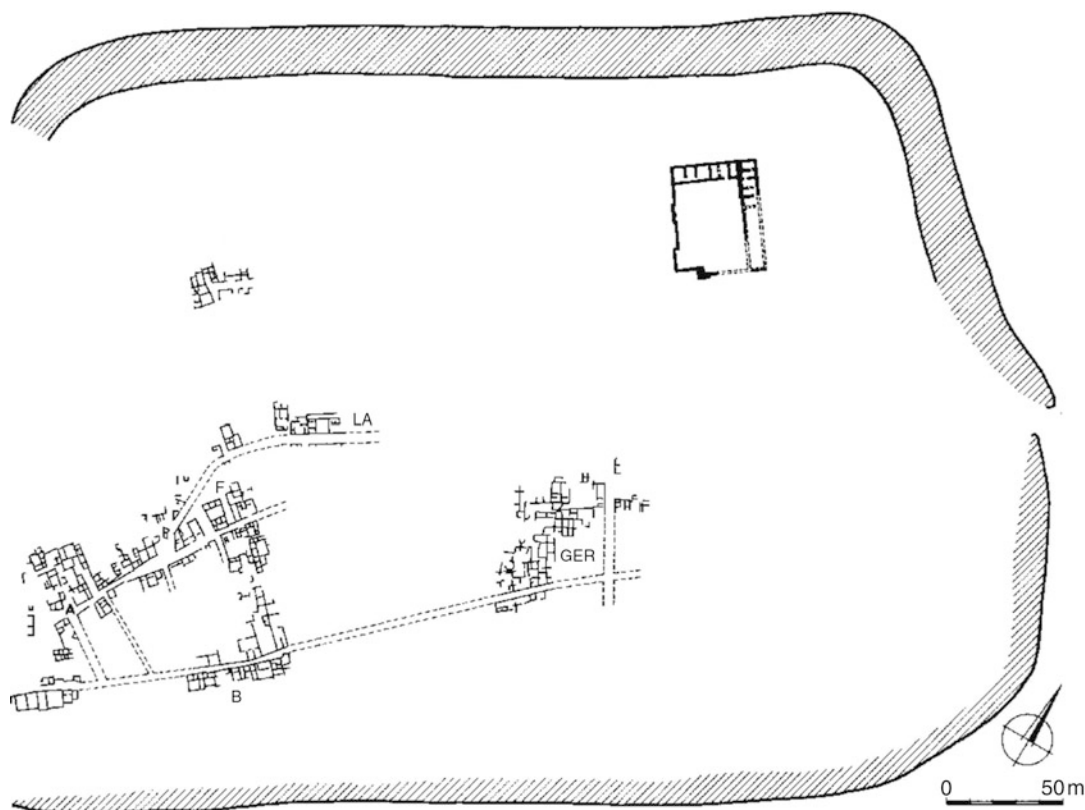
of this millennium (the Intermediate Bronze Age) Cisjordan was devoid of any urban settlement.

Urbanization resumed in the twentieth and nineteenth century BCE (Middle Bronze Age II; 2000–1550 BCE). New cities emerged throughout the country, with an emphasis on the lower regions. Port cities were built for the first time. The largest Middle Bronze Age urban center was Hazor, which was apparently part of the Syrian system of city-states. Many sites were now surrounded with massive earthworks, whose purpose, however, is in doubt, since in many instances no city wall was unearthed on top of them. Some scholars have suggested that their construction, which required much labor but very few experts, served the local leaders as a substitute for the building of large and impressive city walls, as the latter would have required more experts who were not easily available for

most rulers. Some towns show signs of planning, probably following a simple grid (Tell el-‘Ajul) (Fig. 2).

While most characteristics of Middle Bronze Age culture continued during the Late Bronze Age (1550–1200 BCE), the number of towns declined, and they became smaller in size. Furthermore, hardly any settlement was fortified at the time (since the region was an Egyptian colony, the latter can probably be attributed to Egyptian policy).

Further decline occurred during the Iron Age I (1200–1000). The Egyptian domination over Canaan vanished, and many centers were destroyed or abandoned. Other towns, however, continued to exist, especially in the northern valleys, and a new wave of urbanization took place in the southern coastal plain, as a result of the arrival of the Sea Peoples (mainly the Philistines). The latter founded some new cities, for



Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 2 The Middle Bronze Age II center of Tell el 'Ajul (Based on Kempinski, 1992b, p. 124; courtesy of the Israel Exploration Society)

example, in Ekron, covering relatively large areas.

Urbanization in many parts of the country was gradually resumed only in tandem with the formation processes of the Israelite state, in the tenth century BCE, during the transition to the IAI (c. 970–586 BCE) (see section “[Extra 2](#)”). This urbanization probably involved, partially at least, forced settlement of population in urban centers.

The Iron Age II presents a settlement peak in the history of the region. Many urban centers were erected at the time throughout the country. Excavations have uncovered various types of cities and a complex settlement hierarchy. These range from capitals, through administrative and regional centers of different sizes, to small field towns (in addition to rural settlements of course). The largest cities of the period were Samaria and Jerusalem, the capitals of the kingdoms of Israel

and Judah (respectively). At its height, the latter covered some 90–100 ha (including extramural neighborhoods) – larger than any other site in ancient Israel during the Bronze and Iron Ages. Also of significant size were several Philistine centers such as Ekron, Gath, and Ashkelon.

Excavations have revealed clear evidence for socioeconomic stratification. Most of the population lived in small houses, which probably housed small nuclear families. The wealthy and some high officials were better off and lived in large four room houses (see section “[Extra 3](#)”). In some settlements, a form of a middle class is also identified. Palaces, which were identified in several cities, represent the upper part of the socioeconomic continuum, and this is where the royal family and the highest officials lived.

The Assyrian and (mainly) the Babylonian campaigns brought about large-scale destruction and population decline, and the number and size

of towns declined dramatically. Urbanization in the Persian Period was more limited and concentrated mainly in the coastal plain. Real large-scale urbanization reemerged only in the Hellenistic period.

Iron Age Town Planning

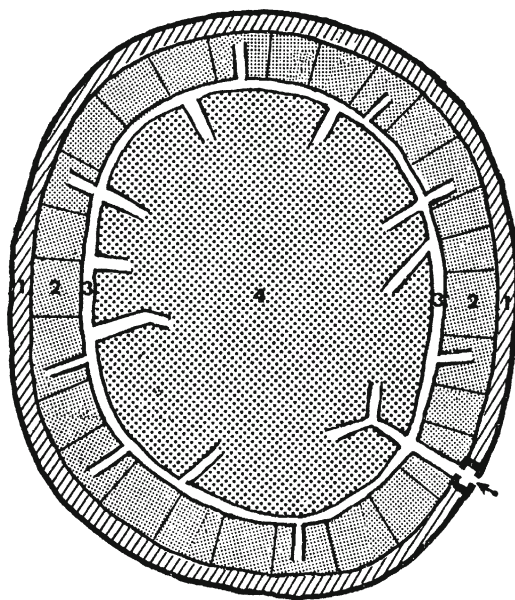
The Israelite towns of the Iron Age II (1000–586 BCE) have received a great deal of scholarly attention. This results from the interest of scholars in this part of the biblical period, from its being a demographic peak in which more sites existed than ever before, and because the Iron Age II usually comprises the upper strata on the tells, therefore permitting large-scale exposure, impossible for other periods.

According to Yigal Shiloh's seminal study, the basic outline of the Israelite "town plan is clear: alongside the line of fortifications there is a belt of buildings bordered on the inner side by a ring road, running parallel to the fortifications, and separating these structures from the 'core' of the city. The 'core' itself was divided into many blocks of residential units of the four-room house type and its subtypes" (Shiloh, 1978, pp. 37–38) (Fig. 3).

Apparently, the outer belt was intersected by small alleys, separating the various houses and leading to the city wall, therefore enabling free access to the wall and to its casemate rooms (when these existed) (Fig. 4).

While some components of this plan can be found throughout the kingdoms of Israel and Judah, it is more typical of the Kingdom of Judah (e.g., Beth Shemesh, Beersheba, Tell Beit Mirsim, and the recently excavated Kh. Qeiyafa). In most cities in the kingdom of Israel (and probably also Philistia), a different planning prevailed. Here the city wall was accompanied by a road, and only inside this street were buildings built, divided into quarters by smaller streets (e.g., Hazor and Megiddo).

Accessibility to the city wall seems to have been a major factor in Iron Age town planning. A besieged city which fell to the enemy suffered a horrible fate, and both types of planning

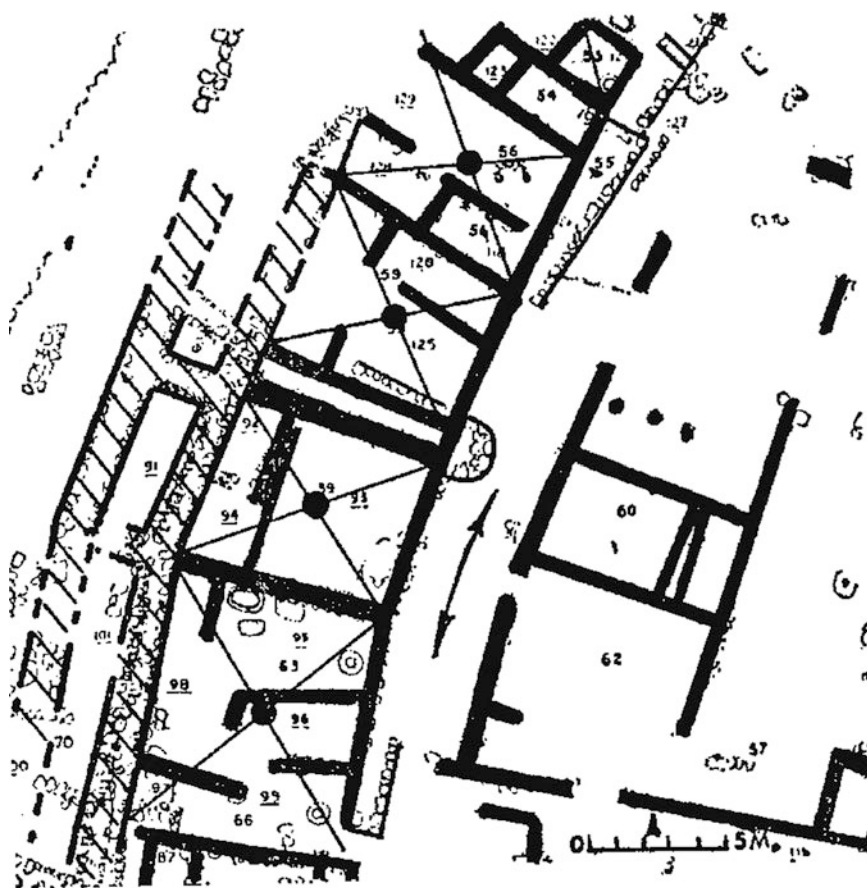


Schematic model of the Israelite city, based on Tell Beit Mirsim, Tell en-Nasbeh, Beth Shemesh and Beer-sheba: 1. fortifications; 2. buildings of the outer belt; 3. ring road; 4. central core.

Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 3 A typical Israelite town (According to Shiloh, 1978, p. 41; courtesy of the Israel Exploration Society)

enabled the defenders easy and quick access to the city walls, through the small alleys in the "Judahite" plan and from practically any place in the "Israelite" plan.

Another difference between Judah and Israel lies in the fact that most towns which were built according to the latter plan were surrounded by a solid wall, while the "Judahite" plan is usually accompanied by a casemate wall. The alleys constructed in Judahite towns enabled the authorities not only access to the top of the wall but also to some casemates, which could have been used for storage. The principle of accessibility to the city wall was adhered to in both plans, and it is likely that the reason for the adoption of different planning was due to space considerations. Larger cities could afford a massive wall and a street that ran along it. Smaller towns, in which space was scarce, tried to save as much area as possible. Casemate walls were therefore built, and the



Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 4 Part of Beth Shemesh city plan (Based on Shiloh, 1978, p. 40; courtesy of the Israel Exploration Society)

ring road was located inside the outer belt of houses (therefore reducing the space it consumed).

Another characteristic of the Iron Age city was a public quarter near the city gate. The impressive gate was usually accompanied by an open square, and near or around it were public structures, palaces, storehouses, barracks, water systems, etc., as can be seen in Beersheba, Tell en-Nasbeh, Beth Shemesh, Jerusalem, Kinrot, and Gezer (see section “[Extra 4](#)”).

Furthermore, cosmological principles had also an influence on Israelite construction on all levels, from dwellings to cities. It seems that as part of their complex cosmology the Israelites regarded the east as the most auspicious direction and the west as the most inauspicious one (like

many other societies). Accordingly, they directed their structures in an easterly orientation whenever this was possible, and when this was not the case, they, at least, attempted to avoid the west. This was manifested also in city gates, and about 75 % of those faced, roughly, the east. Following easterly orientation for dwellings in towns was difficult and was carried out in the following manner: (1) public buildings were adjacent to most of the Iron II city gates; (2) most city gates were oriented to the east.

The result was that no dwellings were built in the eastern part of the outer belt and no dwellings in this belt were expected to face the west, therefore avoiding this inauspicious orientation. The same principle was also followed inside the ring road, as in many cases houses were oriented



Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 5 General plan of Beer-Sheba (Singer-Avitz, 1996, p. 168; courtesy of Prof. Ze'ev Herzog, Tel Aviv University)

toward small alleys (and avoided the main street when it was to their west).

The eastern orientation seems, therefore, to have been a major principle of town planning, influencing not only the orientation of city gates but also of many dwellings and alleys.

The town of Beersheba is a good example of a planned settlement in the Iron Age (Fig. 5).

During the eighth century BCE, Beersheba (stratum II) was a small but well-planned administrative center in the Negev. Its gate was in the southeastern part of the wall, facing this direction. Inside the gate, a small square was located, surrounded by public buildings of various sorts. The city wall was accompanied with a belt of

houses, which used its casemates as their back-rooms, and with a nicely built inner ring road that gave access to these houses. The outer belt of houses was intersected in various points by small corridors that connected the ring road with the casemate walls, enabling easy access to the wall and to some of its casemates. The inner part of the town – its core – was divided by smaller streets which cut through it, dividing it into blocks of houses.

The eastern part of the outer belt of houses was composed of public buildings and did not include any dwellings. The dwellings in this belt, therefore, were oriented to the south, east, and north, but not to the west. Houses in the inner blocks

were oriented toward the inner streets, usually avoiding the west. Adhering to the eastern orientation caused them, in some instances, to orient their backs to the main street and to face small alleys.

Extra 1

Notably, the emergence of towns was a long process, and it is not always easy to identify the exact point in time from which a settlement should be called a city. Some settlements were quite large and complex already in the last phase of the fourth millennium BCE (Early Bronze Age I, traditionally regarded as a “proto-urban” period), and some have suggested that these were the first cities. Other scholars, however, questioned the validity of the term “urban” not only for the centers of the third millennium BCE but even for those of the later phases of the Bronze Age, suggesting that they were just complex villages. Most scholars, however, accept the traditional view and regard these large settlements as cities.

Extra 2

The transition from the Iron Age I to the Iron Age II witnessed the gradual disappearance of rural settlements in most parts of ancient Israel. It is suggested that at least part of this process resulted from a policy of “forced settlement.” The newly established Israelite monarchy transferred some of the population (especially in the newly conquered territories) to other/new settlements, and mainly to cities, in order to facilitate better control of the population, to lower costs, and to minimize the efforts involved in delivering sanctions, be it normative, remunerative, or coercive while maximizing its effectiveness.

Extra 3

The term “four-room house” is a convention used to designate the typical Iron Age dwelling in

ancient Israel whose ideal plan is composed of four main rooms. The typical house includes three parallel longitudinal spaces that are backed by a broad room, with the entrance located at the central longitudinal space. The “rooms” are really spaces/areas and can be subdivided. There are subtypes of the “ideal” form, comprising three or two “spaces” and, in exceptional cases, even five “spaces.” The high popularity of the four-room house was explained as either expressing its close relation with the Israelites (without elaborating the reasons for this relation) or its functional suitability to the needs of the Iron Age peasants, regardless of their ethnicity. Neither of these explanations, however, seem to account for the synchronic and diachronic dominance of the four-room house as a preferable architectural type in all levels of Iron Age settlement (from cities to hamlets; private dwellings and public buildings), all over the country (both in highlands and lowlands), for almost 600 years(!). It is likely that an adequate explanation for the unique phenomenon of the four-room house must relate to the ideological/cognitive realm and to its place within the Israelite social and spiritual worlds.

Extra 4

A typical public building in Iron Age towns is the “tripartite pillared building” (see Fig. 5, to the north of the gate). Such structures were discovered in many cities (especially near the city gate), but their interpretation varies greatly: the most common interpretation is that of a stable or a storehouse. In most instances, however, large quantities of domestic pottery (mainly bowls, jugs, juglets, cooking pots, and also storage jars) were found on the floors of these buildings. Since the finds do not easily fit with the above interpretation, some scholars have raised additional possibilities, including barracks, covered markets, customs house, and a multipurpose public building which had many functions, including a shelter for the poor.

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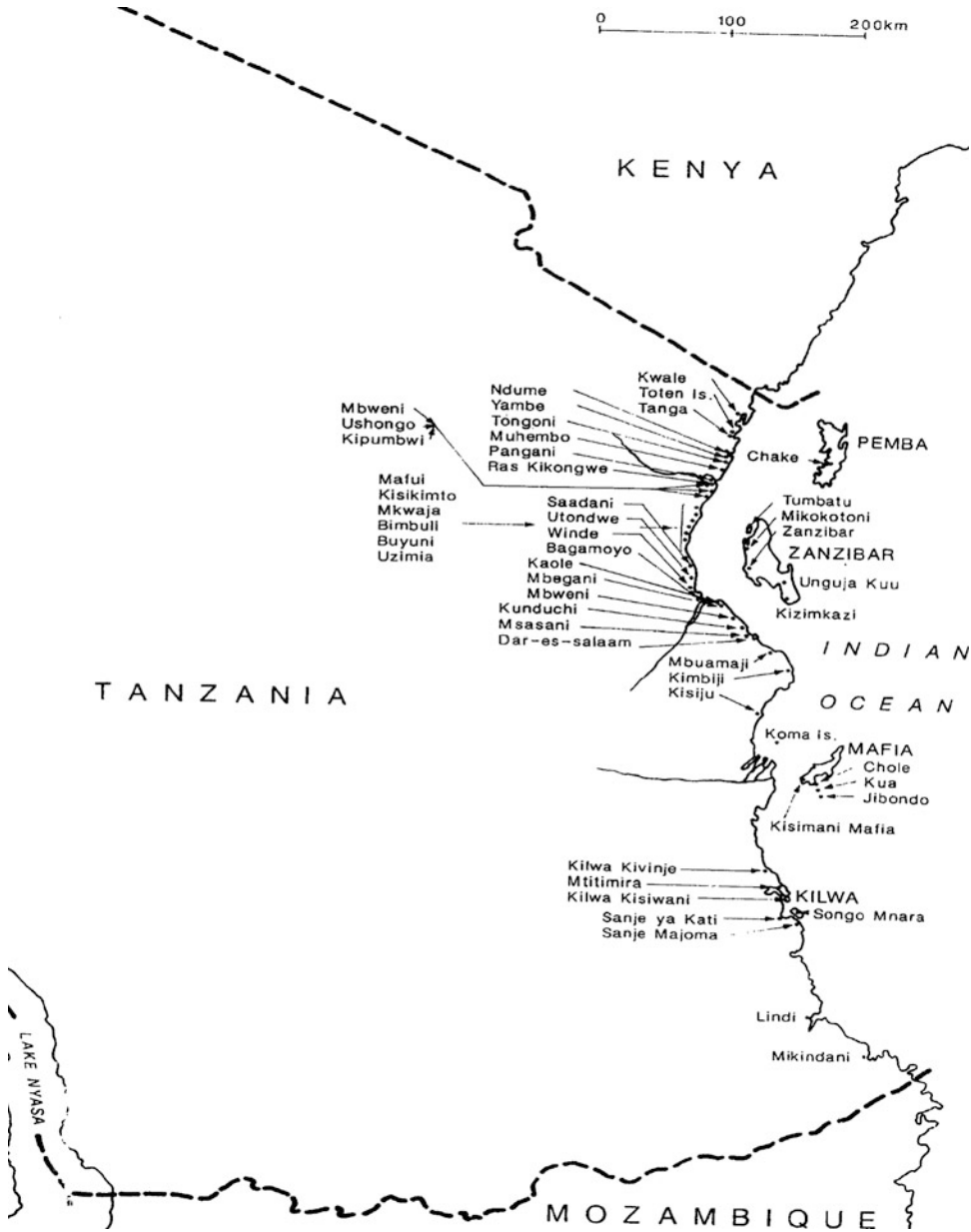
Cities and Towns in East Africa

Felix Chami

The towns of East Africa were built during two periods: pre-colonial and colonial. The former grew up along the coast, facilitating trade and communication between the rim of the Indian Ocean Seaboard and the interior of Africa. The towns, better known in history as Swahili City States, survived from about the beginning of the second millennium AD to about the 1890s. The latter were mostly new administrative centres established with the launch of German and British rule in East Africa from about the 1890s. Only a few settlements of the colonial period had a history pre-dating the colonial era. Such towns include Mombasa, which is a Swahili town, and Mengo in Kampala, which was the seat for the Buganda Kingdom. This article examines the pre-colonial Swahili towns.

The Growth of the Swahili Towns

Swahili settlements spread all along the coast and islands of East Africa (Fig. 1). There were few settlements before the Swahili towns of the thirteenth century, mostly built with mud and



Cities and Towns in East Africa, Fig. 1 The Swahili towns on the Tanzanian coast. For the rest of East African coast (see Horton & Middleton, 2000, pp. 6–7)

wattle. Concentration of these towns seems to have first occurred in the Mafia-Kilwa region on the coast of Southern Tanzania and on the Lamu Archipelago on the northern coast of Kenya. Individual settlements seem also to have flourished elsewhere on the coastal littoral and virtually on every island large enough to settle

from Lamu archipelago to Madagascar. These early settlements are identified by archaeologists by remains there of early Islamic goods including Sassanian Islamic ware, Islamic copies of Chinese pottery and early Sgraffiato [decoration which is scratched through the clay surface coating to reveal the colour of the underlying clay].

Cities and Towns in East Africa, Fig. 2 The water facing side of Husuni Kubwa (Great Palace) in Kilwa Island



Cities and Towns in East Africa, Fig. 3 Port of Kilwa with recent Portuguese to man fort



Probably the largest earliest settlement of this period is that of Kilwa in Southern Tanzania (Figs. 2, 3, and 4). The settlement seems to have become a larger centre by about AD 1000 when the earliest stone structures could have been built (Chittick, 1974). Probably only a few stone structures would have been built then. The spectacular nature of Kilwa centre was the first to attract archaeologists in the 1950s. Mortimer Wheeler led a team of researchers in 1955 to conduct a test excavation. This research paved the way to more intensive archaeological

researches by Neville Chittick, not only in Kilwa but also in other Swahili towns (Chittick, 1974, 1984).

Kilwa was large, the stone town itself estimated to have been about 50 ha in the early period. This settlement must have controlled other larger settlements of the area more economically, as settlements of a similar nature existed on the islands of Mafia, off the Rufiji Delta, and on the nearby island of Songo Mnara. Other settlements of the period related to the development of Kilwa are found in Zanzibar

Cities and Towns in East Africa, Fig. 4 Residential house around the Kilwa Friday mosque



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and Pemba, the central coast of Tanzania, Comore and Northern Madagascar and on the northern coast of Mozambique and Zimbabwe. Archaeological work on sites located in those regions have yielded goods of exchange between these settlements, including coins, pottery and stone vessels, suggesting that Kilwa was a centre with economic influence if not direct control of the peer settlements north and south.

The early towns of Lamu Archipelago were excavated later by Chittick (1984) and Horton (1996). Settlements like Gedi, Malindi, and Mombasa grew to compete with those to the north and even Kilwa at the time when Portuguese had entered the region. What is obvious in the archaeology of the coast of Eastern Africa is that the Swahili towns were related, and this is true whether or not Kilwa controlled affairs in the whole region between AD 1000 and about AD 1400.

In the later phase, from about AD 1300, or slightly earlier, larger Swahili towns were built by coral stones and lime mortar and roofed by mangrove poles, lime mortar and palm leaves. Archaeology also finds a profusion of many smaller settlements, which were built by mud and wattle; the larger settlements may also have had the majority of its population living in such simple houses (Chami, 2002; Horton, 1996; Pradines, 2002). When ► Ibn Baṭṭūṭa visited the

coast of East Africa in the AD 1330s, contrary to what archaeology suggests today, he did not see many stone houses even in larger towns such as Kilwa and Mombasa (Gibb, 1939). Whether this was a personal bias against stone houses if he only saw simpler town places is not yet properly explained (see discussion by Sutton, 1998).

It is also not quite certain whether each large Swahili town had its own trade and cultural link with foreign traders or if trade was only controlled by one or two larger towns which collected trade goods and distributed them to other towns. Ibn Baṭṭūṭa seems to have visited only two towns on the Swahili coast, Kilwa and Mombasa, suggesting that those were the larger ones. However, in the same time period a Chinese trip to East Africa led by ► Zheng He entered a town called 'Malin'. Some scholars think this place was Malindi on the Kenya coast (Chittick, 1975, p. 21; Wheatley, 1975, pp. 90–91); Fuwei (1996, p. 190) suggests that 'Malin' was Kilwa. A support for Fuwei comes from the fact that the wealthy clan at Kilwa at that time was known as Malindi and the most impressive tombs at the water front belong to this clan.

Probably each large town had its own trade abroad or a set of traders visiting particular ports in the Middle East and India. Archaeologists are now finding sites and many Swahili cultural materials in the Middle East, suggesting that the

Swahili people sailed to those distant lands (Sutton, 1998). It is likely that the profusion of foreign trade goods in all Swahili settlements could also suggest that individual towns engaged in long distant trade at least within the western Indian Ocean seaboard. This is testified by the fact that several towns are now known to have made their own coins and that when Vasco da Gama reached Northern Mozambique he had to get a person from Malindi, on the Kenya coast, to guide him to India. Probably the southern towns were not co-operating with the Portuguese.

The Origin of The Swahili Towns

Scholars had, up to the end of the twentieth century, debated the origin of the Swahili people and their stone town culture. Such debates revolved on the question of who the Swahili people were (Allen, 1974, 1983; Chami, 1994, 1998; Horton, 1987; Nurse & Spear, 1985; Pouwels, 1987). The original popular conception was that the Swahili people and their culture originated from the Middle East. These were alleged to have arrived in waves of immigration. Individuals in these waves founded settlements, which later grew into larger Swahili stone towns. Chittick (1974, 1975) used chronicles, particularly that of Kilwa, and archaeology to argue that the earliest immigrants could have arrived on the East African coast not earlier than the ninth century. This view suggested, therefore, that the Swahili people were originally Persians or Arabs who would later have mixed with Africans. Due to their alleged origin in the Muslim world the Swahili people were necessarily Muslims and people of towns.

Archaeologists such as Horton (1987), influenced by Allen (1983), suggested that the Swahili were people of Cushitic origin, from the northeast of Africa, who were originally pastoralists. The pastoralists, who are alleged to have ruled the Bantu speakers in a mythical land called Shunguaya, mixed with Bantu speakers, adopted Islam and spread to the rest of the coast and islands of East Africa. In this theory the Swahili people are seen as Africans who also mixed with

the people of the Middle East in the process of adopting Islam and trade. This position was made more prominent in the 1990s (Abungu, 1994–1995; Horton, 1990; Sutton, 1994–1995) in an attempt to quash the discovery that the Swahili people were Africans of Bantu origin, people of the general region of Eastern and Southern Africa who were agriculturalists and fishermen.

That the Swahili people did speak a Bantu language was a point recognised by linguists from the 1980s (Nurse & Spear, 1985). Archaeologists had also established settlements of Early Iron Working people near the coast; scholars recognised that they were early Bantu speakers (Phillipson, 1977; Soper, 1971). Historians also recognised that the people reported by the Romans in the first centuries AD to have inhabited East Africa, then known as Azania, were agriculturalists and probably Bantu speaking (Casson, 1989). In the early 1990s this author suggested that the cultural tradition found in the earliest Swahili settlements was culturally related to that of the Early Iron Working tradition (Chami, 1994). In some cases settlements of the Early Iron Working people and those of the so-called early Swahili, termed by this author as Triangular Incised Ware tradition, were found in the same location. In some cases the later was found superimposed over the former in the offshore islands and on the coastal littoral of the central coast of Tanzania (Chami, 1998, 1999a).

The evidence of cultural continuity from the time of Christ, through the mid-first millennium AD, to the time of the foundation of the Swahili towns in the early centuries of the second millennium AD, has now been recognised by many scholars (Kusimba, 1999; Sinclair & Hakansson, 2000; Spear, 2000). Those who disagreed with the first set of evidence for this continuity have now revised their ideas (Horton, 1996; Horton & Middleton, 2000; Sutton, 1998). Archaeological findings now prove that the Swahili coast had been settled by an agricultural and trading population from the time of Pharaonic Egypt, 3,000 BCE, through the Greco-Roman period (Chami, 2006). Whereas the former was of Neolithic tradition, the latter was an Early Iron

Working culture. Throughout these periods the Indian Ocean, just like it was during the time of Islam, had brisk trade with communities of Asia, the Middle East and the Red Sea/Mediterranean worlds. Ceramics and beads as evidence of trade of all these pre-Islamic trading periods have now been recovered from the islands of Zanzibar, Mafia, Kilwa and Rufiji River (for conspectus see Chami, 1999b, 2004, 2006).

The most recent thinking that the early Swahili people, or Zanj of the Arab documents, were Indonesians/Austronesians (Dick-Read, 2005) is an attempt to disregard the archaeological, linguistic and historical data already established. For this recent thinking to be regarded as scientific at least a discussion of the previous thinking on the subject matter and its flaws should have been debated.

Some Cultural Aspects of the Swahili Towns

General Culture

The culture of the Swahili towns, as already suggested, is African with an infusion of Islamic traits. It is these infused Islamic traits such as religion, law, language, writing and costume which have made many students of the Swahili culture identify the people as Arabs. The people who had adopted this culture themselves wanted to be identified as Arabs or Persians. However, ► **Ibn Baṭṭūṭa** identified the people as ‘Sawahil’ and the earliest European visitors to the Swahili world, the Portuguese, identified the people as ‘Moors’ or ‘Suaili’ as opposed to Arabs.

De Barros, as Ibn Baṭṭūṭa did, also identified the Sultans of Kilwa as black people (Chittick, 1975, p. 39). Barbosa, writing in about 1518, wrote, “Of the Moors there are some fair and some black, they are finely clad in many rich garments of gold and silk and cotton.” To show that the Swahilis were different from Arabs, the Queen of Kilwa in the mid-eighteenth century wrote a letter calling home her people who had run away from the Arab/Omani domination of Kilwa to Mozambique. This was written in Kiswahili and not in Arabic; a Swahili letter

suggesting that it was only the Europeans/Christians who were in conflict with the Arabs, but not the African/Swahili people (Omar & Frankl, 1994).

Religion

Most Swahili people are of the Sunni sect of Islam, which suggests an early link with Southern Arabia. Large mosques (Fig. 5) had been built with stones from AD 1,300 or slightly earlier in every town of the Swahili coast. Some towns have several mosques, some being smaller for the purpose of a clan or a family. Kiblas/the north of these mosques were elaborately made; probably the one at Songo Mnara in Kilwa (Fig. 3) is the most elaborate of those seen by this author. One very unique religious aspect of the Swahili towns is that of making spectacular burials for the dead. The tombs, which most of them concentrate around the mosques, were built using stones and lime. Walls of some are more than 2 m high with various decorative panels including impressed Chinese porcelain. Some tombs have high standing pillars some reaching up to six meters above the tomb.

These aspects of tombs are non-Islamic as they are found nowhere else in the Muslim world. Muslim burials are supposed to be made humbly and no materials or aspect of wealth are supposed to be involved. That these spectacular tombs are also found attached to houses or are located in compounds where people were living suggests that this is an African culture blended with Islam. I have noted elsewhere (Chami, 2002) that the African tradition of wanting to live with the spirit of the dead in the same house/compound or within the settled landscape is the one portrayed in this context. Like the ancient Egyptian tradition, the spirit should not be abandoned in the wilderness away from human warmth and food. A failure to observe this rule was/is expected to bring bad omen to the family.

Writing and Arithmetic

Whatever type of pre-Islamic writing that could have existed on the coast of East Africa cannot be known for now. Early Islamic characters found on the Swahili settlements are Kuffic, the earliest

Cities and Towns in East Africa, Fig. 5 Kilwa
Friday mosque



known being of the eleventh century tomb of Kizimkazi in Zanzibar (Flury, 1921). Later on Arabic scripts were used to write in the Swahili language. These can be seen in many tombs post dating AD 1300.

In daily counting the Swahili people mixed African and Arabic words. Counting may have followed Arabic languages in schools or official places, but in normal cases African counting was used. Today most counting words in Kiswahili are still African with the exception of a few numbers such as 20, 30, 40 and 50, which are in Arabic. Probably much more Arabic influence came after the rule of the Omanis from AD 1884.

Architecture

Garlake (1966) studied the architecture of the Swahili towns; his interpretation of Swahili architecture has prevailed (Chittick, 1984; Sutton, 1998). As was noted with the tombs, the architecture of the Swahili buildings is of Western Indian Ocean Seaboard origin. It is the tradition that began and evolved within the region. The architecture is very much conditioned by available resources for building lime coral rubble which is made into walls with lime mortar and then plastered with the same mortar. Rarely were bricks and dressed stones (apart from porites) used. The only dressed stone used for door and

window frames, mihrabs [a niche in the wall of a mosque or a room in the mosque that indicates the direction of Mecca] and lamp chambers was porite [coral]. This is a coral cut from underwater while fresh and it is dressed and decorated or inscribed while fresh.

For multi-storey houses floor slabs were made by arranging mangrove or other hard woods across. Lime mortar, sometimes mixed with coral rubble, was spread on top. Some houses, especially mosques, had moulded roofs with decorative arches, domes and vaults. Most houses must have been roofed by wood and palm/grass. Swahili houses had large verandas and corridors for relaxation and cooking. Carved panels decorated the doorframes.

Livelihood

Swahili people engaged in various economic activities. They are traditionally agricultural. They lived in mostly settled communities with vegetable gardens around their compounds and in areas a few hours' walk from towns. Allen (1983) characterized the Swahili as people who commute from town to the countryside for agricultural purposes. This has been the situation from ancient times. Crops cultivated include rice, millet, beans/peas, banana, coconut, sugar cane, spices and fruits such as mango and oranges. In recent history American crops such as maize,

cassava, sweet potato and tobacco have been added to the list.

The Swahili people would have been mixed farmers who would also have domesticated chicken, cattle and ovicaprids (sheep and goats). These are well authenticated from archaeological records dating back to the early Swahili period. They also had dogs and cats and for the northern coast donkeys and camels. Due to environmental variability the northern part of the Swahili coast would have been more pastoral than the south because of the interaction that existed with the nomadic regions of Somalia and Northern Kenya.

Fishing must have dominated the activity of those living near the shore and on the island settlements as it secured the most reliable means of obtaining protein. They fished in the deep and shallower, waters and there is much evidence for times when they consumed a lot of shellfish probably suggesting difficult times (Msemwa, 1994). There was also fresh water fishing. There are several large rivers entering the Swahili coast from the deep interior and also few lakes near the littoral which provided fish. Salting and drying fish facilitated transport to the deep interior.

Sailing, not only for fishing, but also for trade was probably the most prestigious activity of the Swahili man. Swahili towns consisted of people who had travelled far for the purpose of trade or prayers. There was a lot of intermarriage between communities. The Swahili people can therefore be seen as a maritime people. Goods to be exchanged with those arriving from abroad had to be collected from the south or interior of the region and this also involved distribution of those imported goods. So the Swahili towns were trade axes providing for the larger part of Eastern and Southern Africa.

Consequently the Swahili people were also involved in building sailing vessels. The Romans found the people of the Swahili coast already making sewn boats and also importing boats from abroad (Casson, 1989). This technology grew tremendously and by the time of the stone towns the Swahili people must have been building large dhows used to cross the Indian Ocean to Arabia and India. In most of the Swahili

towns today one can find at least one operating dhow/boat building yard, suggesting a continued tradition. Related to this technology was that of metal working, which has passed down since ancient times. This technology was necessary for cultivation and boat making, as wood had to be felled and worked.

Swahili Towns in Ruins

It was noted earlier that the realm of the Swahili culture is in the period between AD 1200 and 1500. After this heyday the Swahili culture entered into a deteriorating moment following the penetration of Europeans into East Africa. They wanted to conquer by destroying the large Swahili towns such as Kilwa and divert trade to the Atlantic Ocean towards Europe. The monopoly of trade was taken from the Swahili traders and put into the hands of European companies and later on, after 1800, into the hands of Oman Arabs and Indians. The Omanis came to East Africa to challenge the Portuguese. It was the Swahili rulers who invited the Omanis to use their Muslim responsibility to assist Muslim brethren, but the Omanis did not leave after they accomplished the task. Only petty trade was left in the hands of the Swahili. In some towns trade was left to the Swahili people, but they had to cater for the masters of the new order.

In the new order, the Swahili towns, which had not given way to invaders before, were suppressed to the extent that they fell into ruins. This was necessary because other prosperous settlements, mostly controlled by the new Portuguese and Omani powers, emerged and it is here the new elite, whether foreign or local, would move (Chami et al., 2004). As Kilwa and other settlements of its type decayed, with only short periods of renewal, previously unknown towns emerged from about 1700. Such towns included Zanzibar, Bagamoyo and Kilwa Kivinje. Mombasa also grew substantially. These are towns founded by the enterprising British and German colonials. From the 1890s the new colonial towns such as Dar-es-Salaam, Nairobi and Kampala challenged these other towns. See (Chami et al.)

for an explanation of the fall and the rise of the Swahili towns.

See Also

- Agriculture in Africa
- Beads
- Ceramics: Mimbres Pottery
- Navigation in Africa

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Cities and Towns in West Africa

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West Africa, like most regions of the continent, is still largely rural. Even after decades of rapid urban growth and the emergence of cities of one million people or more, the majority of the population continues to live in rural areas. However, cities and towns generate higher revenues than the countryside. Urbanisation has brought major changes for both urban and rural dwellers. Large cities, which are often ports, are gateways to the rest of the world. The most traditional practices coexist with the most advanced technology and, in contrast to the negative image conveyed by media about the Developed World, Africans have shown a strong ability to adapt to the global world (see Fig. 1). That said development in West Africa is impeded by a number of problems. This article will address the endogenous and exogenous factors hampering urban development in West Africa. First, we will show that the (long) urban history of West Africa is the result both of indigenous and European influences. Then we will analyse recent urbanisation trends from a demographic point of view before examining the origin and reasons for urban development. Finally we will consider the issue of urban management. For the purposes of this article, “West Africa” is defined as the countries to the west of the line running from Lake Chad to the border between Nigeria and Cameroon.

A Long but Little-Known Urban History

Urbanisation is not only a contemporary phenomenon in West Africa. Urban centres have

developed in this region of the world for over 2,000 years (Coquery, 1990). In the Middle Ages, some were very prosperous and were known by Europeans as great cultural and commercial places (Timbuktu, for instance). Some were even compared by travellers to European cities such as Amsterdam or Lisbon (Benin City in the seventeenth century).

Still, the history of West African towns and cities is still very incomplete, mainly because this is a new field of research. Urban Africa was only ‘discovered’ by historians in the late 1970s and until very recently there has been little interest in pre-colonial urbanism other than through the work of archaeologists (Anderson & Rathbone, 2000). The scarcity of written sources and the fact that few stone monuments survive may explain why African urban history is still very incomplete. For a long time, towns and cities were only presented as colonial creations. Earlier settlements were not recognised as urban because their features were not similar to those of European towns and cities (often considered as a standard to define urban settlements): there were no stones used in architecture, an abundance of agriculture, and very low population density. But recent research has shown that West Africa has nurtured various forms of settlements quite distinct from simple villages long before the Europeans’ arrival.

The first urban settlements in West Africa, as in the rest of the continent, were indigenous creations (Coquery, 1990). The most ancient is Jenne-Jeno (distinct from Djenné), located in Middle-Niger, discovered by archaeologists in 1977 (For more information and to see pictures of the archaeological site, see: www.ruf.rice.edu/~anth/arch/brochure/). It was probably created around 250 BCE, reached its peak between 750 and 1150, declined under Islamic influence and finally disappeared in the fifteenth century. Except for the fact that it had city walls, Jenne-Jeno did not look like a medieval European city. It was quite extended (40 ha around the tenth century), as opposed to very dense European settlements of the same period. There were no monuments in the centre of the city (such as palaces, churches or markets always present in

Cities and Towns in West Africa, Fig. 1

Cotonou, Bénin. Tall, modern buildings are proudly erected next to very crowded places where the informal sector is blooming and *yellow* and *green* taxis are waiting clients to transport goods. Note the mobile phone antenna and the satellite dish on *top* of the *blue* building; all their offices are connected to the Internet. Some investors are less successful, as can be seen from the unfinished building on the *right* (© Franck Houndegla)



European towns and cities). And the buildings were made of adobe. But Jenne-Jeno was an important commercial centre for its region (fishing and agricultural products) and it was also probably one of the first places of the trans-Saharan trade (salt against copper in the fourth century).

Other towns and cities developed in this region of contact between the Sahara and the Savannah (Fig. 2), where international trade was possible. In the Middle Ages, the succession of great centralised states (ancient Ghana (Ancient Ghana's territory is distinct from contemporary Ghana. It broadly covered the oriental Senegal and Mauritania, the occidental Mali and a part of the current Guinea. The creation date of the Ghana Empire is not precisely known, though an Arab writer mentions it in the eighth century. It finally disappeared in the twelfth century), Mali and Songhai empires) contributed to the development of a network of towns and cities, among

which Timbuktu, Djenne and Gao are the most famous. Following the trade Saharan routes, the Islamic and Arabic influences grew in the process of urbanisation. The introduction of Islam gave to the great cities mentioned above their monuments: Sudanese style mosques (Fig. 3). It also gave them a cultural aura (Timbuktu was a famous Islamic intellectual centre). And it played a role in matters of social organization; these cities were cosmopolitan places. Whatever the influence of Islam, their fame in the European Middle Ages is mainly due to the fact that they were the gold providers for the East through the trans-Saharan trade (See a map: www.metmuseum.org/toah/hd/gold/hg_d_gold_d1map.htm). But they also played an important role in the economy and even in the urbanisation process of southern regions of West Africa. Stopover places, first created to facilitate the exportation of gold and other goods from coastal regions, progressively turned into real towns, such as Begho

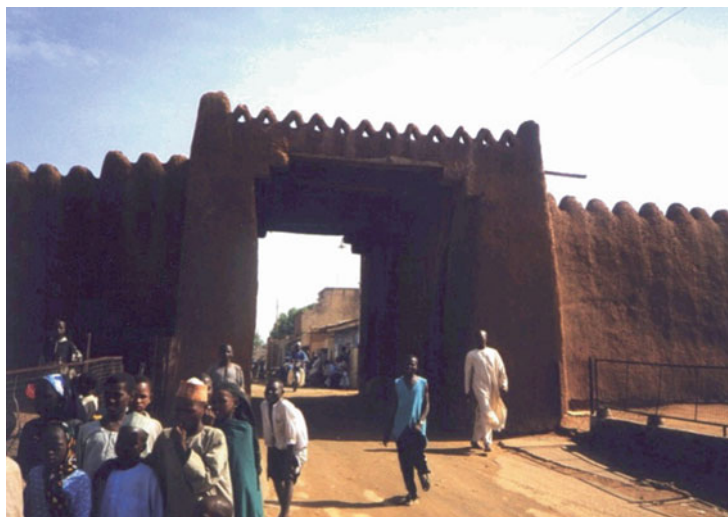


Cities and Towns in West Africa, Fig. 2 The city of Timbuktu: a place of contact between the Sahara and Sub-saharan Africa (Source: www.sum.uio.no/timbuktu/)



Cities and Towns in West Africa, Fig. 3 Djenné, Mali. This town exemplifies early urbanization in West Africa. Situated on the Bani River, Djenné dates back to 250 BCE. In the thirteenth century, Djenné was an important market for trans-Saharan trade, particularly between North and West Africa. The most common items of exchange were

gold, slaves and salt. Djenné also became an important center for Muslim learning during the seventeenth century. The city's mosque (at the rear of the Fig.) is the largest mud-brick building in the world (© IRD – Jacques Champaud)



Cities and Towns in West Africa, Fig. 4 Kano, Nigeria. The old-walled section of Kano is nearly 1,000 years old and is enclosed by a mud wall. Located on the edge of the Sahel, Kano is a Muslim city, one of the oldest in West Africa. Kano was the centre of a prosperous Hausa city-state in the seventeenth century, when the Songhai Empire

declined. Under the Sokoto Empire (nineteenth century), it became a very important place of textile production in West Africa. At the end of the nineteenth century, half of the West Sudanese population was dressed with loincloths from Kano (Source: www.uni.edu/gai/Nigeria/Pictures/kano.html)

(The Dioula merchants were also the actors through which the Sudanese-style mosques spread all over West Africa).

Trade, through trans-Saharan routes, was a major factor of urbanisation in medieval West Africa. However it is worth noting that some great urban regions also developed in West Africa, even if they had weak connections with this trade system. It seems to be the case for the Hausa-speaking city-states, the Yoruba towns or the Ghanaian urban system. These urban regions have some common features. They started their development in the Middle Ages and were especially prosperous between the fifteenth and the eighteenth century (their respective peak periods are however not totally contemporaneous). In contrast with the Middle Niger cities, the towns of each of these regions emerged without a centralised state. They shared a common culture (language, religion, social organisation) but they were in competition, and sometimes at war, each one of them trying to extend its influence on the surrounding countries (Fig. 4). Whereas the Middle Niger cities were mainly turned towards international trade, the towns and cities of the Hausa,

Yoruba and Ghanaian regions were first engaged in regional trade. Agriculture was sufficiently intensive to produce enough surplus to feed an important urban population. In Ghana for instance, around 30 % of the population lived in urban areas and 70 % of the urbanites (merchants, craftsmen, the nobility and their families) bought their food in markets (Coquery-Vidrovitch, 1993). The rural people were under the domination of urban power; they were sometimes forced to leave their villages in order to settle in the towns (Yoruba region) and also paid important taxes. In the Ghanaian region, rural taxes represented between a quarter and a half of peasants' earnings (Coquery-Vidrovitch). Some cities of these three regions remained famous: Kano and Katsina in the Hausa region, Great Accra in Ghana, Benin City, Old Oyo or Ife in the Yoruba area. They have been described by the first Europeans who arrived in West Africa (Iberian sailors) in the fifteenth century. Till the eighteenth century, Ghanaian and Yoruba towns and cities (Hausa city-states were less influenced because they were far from the coast) benefited from the new forms of trade introduced by



Cities and Towns in West Africa, Fig. 5 Gorée, Senegal. This building, built around 1780, may have been the last slaves' house in Goree. The first ones dated back to 1536, built by the Portuguese, first Europeans to set foot on the island in 1444 (Source: www.globalgeografia.com/album/senegal/goree.jpg)

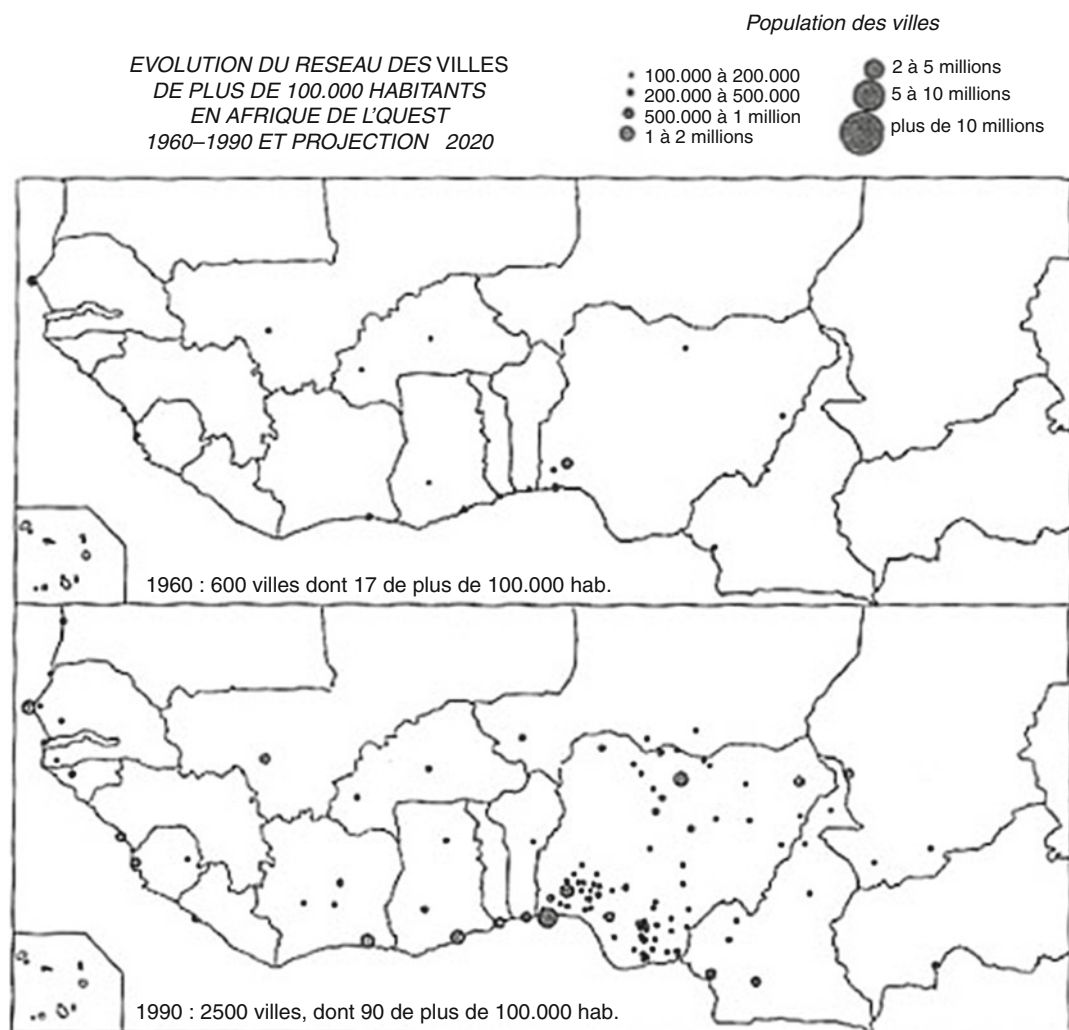
Europeans. But the launching of the slave trade disrupted these urban networks.

The first European settlements in West Africa were not towns: they were only isolated forts on the coast, whose purpose was to resupply the shipping expeditions. They progressively turned into trading posts and finally into small towns when the slave trade was introduced in the eighteenth century (Fig. 5). Gorée, Saint-Louis or Ouidah, for example, were central places at this time. They were inhabited not only by Europeans but also by African people. And a kind of local bourgeoisie, with a Creole culture, appeared. The overseas trade acted as a new vector of indigenous urbanisation on the coast and also in the hinterland. New states, engaged in the slave

trade, emerged and gave birth to new capital cities (kingdoms of Porto Novo and Abomey, Ashanti Empire). For instance, Kumassi, the Ashanti capital city, was a center of the slave economy, but it was also a trade centre for kola nuts, which were exported to the north. It was the heart of a dense road network, quite far from the coast, in order to escape a too strong European influence. There were 77 neighbourhoods (around 13,000 inhabitants in 1870) separated by large and rectilinear avenues. It remains today an important city in Ghana.

The abolition of slavery, declared in 1815 in all European countries, appears as a shock in African urban history. The cities whose prosperity relied on the Atlantic slave trade declined. New settlements were created to welcome freed slaves from the United States (Monrovia) or from the British territories (Freetown). Some existing towns turned the end of the Atlantic trade to their advantage by using for their own development the workforce of the slaves. For instance, Kano became a great centre of textile production in West Africa (Fig. 4). In 1894, there were 100,000 inhabitants, 50 % of whom were slaves. During the nineteenth century, various urban centres emerged as commercial places and/or as capital cities for new West African states (Sikasso, capital city of Kenedougou; Sokoto, capital city of the Fulbe Empire...).

To sum up, it should be clear that the urban history of West Africa started before European colonisation. First contacts with Europeans, from the fifteenth to the nineteenth century, had an impact on the urbanisation process, but they did not totally drive it. When Europeans started to colonise West Africa, they created new cities, mainly ports (e.g., Dakar, Abidjan, Cotonou, Conakry...) and crossroads places (e.g., Bamako) aimed at facilitating natural resources exportation (see Map 1). They also took advantage of the existing urban networks. Indigenous towns and cities happened to be excellent places for the political and economic control of the territories. Colonisation seriously boosted the urbanisation process by creating new urban activities. Labour migration was an important factor in urban development in colonial times when



Cities and Towns in West Africa, Map. 1 Evolution of the West African urban system (1960–1990). 1960: 600 towns and cities, 17 have more than 100,000 inhabitants. 1990: 2,500 towns and cities, 90 have more than 100,000 inhabitants (Source: www.urbanisme.equipement.gouv.fr/cdu/datas/docs/ouvr16/2020_p1.htm).

These maps show the proliferation of towns in West Africa during the second half of the twentieth century. Most of the larger towns and cities were developed under colonial rule and were founded in coastal regions and along rivers

workers were needed for public infrastructure (airstrips, railways and ports), administration (soldiers, clerks) or various private services (maids, etc.). Migration flows to urban centres continued after independence. In sum, colonisation acted as a starter for urban development on a larger scale (Bairoch (1985) estimates that the urbanisation level in Africa as a whole was 5 % in 1900, 12 % in 1950, and 28 % in 1980).

Recent Urban Trends in West Africa: Rapid Demographic Change

In terms of the contemporary urbanisation process, West Africa is at once lagging behind (with the exception of Nigeria, it remains one of the least urbanised regions of the world) and at the forefront of change (the region had one of the highest urban growth rates of the second

half of the twentieth century). Urban growth has not been linear: after a peak in the 1960s (9.3 % per year for West Africa as a whole), it reached a low of 5.6 % in 1990–2000 (Fig. 3), and the region remains predominantly rural (see “[Extra 1 Inconsistent Definitions and Measures Vagaries](#)”). Migration is usually seen as the main contributing factor in the growth of towns and cities. According to a 1988 UN report, almost all governments of developing countries believed that internal rural-to-urban migration was the dominant factor contributing to the growth of cities (United Nations, 1998). But urban growth can be generated by any of three mechanisms: natural growth, reclassification and migration. All these components follow a specific pattern in the context of West Africa.

Natural urban growth (i.e., the surplus of births over deaths) in West Africa remains one of the highest in the world: 2.7 % annually, versus 1.9 % for the developing world as a whole (PRB, 2001). (Natural growth rates are nevertheless lower in urban than in rural areas, since mortality and fertility have declined faster in towns and cities than in the countryside). This is one reason why urban growth remains so high in this region compared to the rest of the world. A United Nations study has shown that the contribution of natural growth to urban growth is much higher in Africa than in other parts of the world. On the African continent, natural growth accounted for 75 % of urban growth in the 1980s, compared with a share of only 50 % in Asia, excluding China (Chen et al., 1998) (Fig. 6).

Another feature of urban growth specific to West Africa is the importance of reclassification. Reclassified settlements are those that cross a population threshold (10,000 inhabitants in the GEOPOLIS database used in this article; see “[Extra 1 Inconsistent Definitions and Measures Vagaries](#)”), beyond which they are considered urban instead of rural. These newly-urban settlements contribute to urban population growth, even though their population may not have moved. In Africa as a whole, between 1950 and 1980, the share of reclassification in urban population growth was 26.4 %. This means that, in 1980, more than one new African urban dweller



Cities and Towns in West Africa, Fig. 6 A street restaurant in Dakar, Senegal. Women prepare and sell traditional dishes (rice on the *left* and vegetables on the *right*) (© IRD – Michel Dukhan)

in four lived in an agglomeration that had been classified as rural in the previous 30 years. This rate was only 13.4 % worldwide, excluding China and Korea for which reliable data are not available (Moriconi-Ebrard, 1994). Thus, urban growth in Africa, much more than in the other continents, is due to the proliferation of new small urban centres that had previously been considered rural (see “[Extra 2 The Urban Future: Mega-Cities or Small Towns?](#)”).

Considering the foregoing arguments, the role of migration in urban growth seems to be less important than is commonly assumed. The process of urbanisation, from a demographic point of view, is more complex than a simple rush of migrants from rural to urban areas. Furthermore, the contribution of migration and reclassification to urban growth appears to be decreasing. Indeed,

according to the GEOPOLIS database, two-thirds of urban growth in West Africa was due to migration and reclassification in the 1960s, versus only one-third in the 1990s (Bocquier & Traoré, 2000). This result is consistent with several other studies (Arnaud, 1998; Chen et al., 1998). To what factor can this change be attributed?

One reason is mathematical. Urban growth due to migration automatically falls as the urban population increases in relation to the rural population, simply because the rural population who could potentially leave their villages becomes smaller. When the majority of people live in villages, net out-migration (i.e., a negative migratory balance) from a rural area means, for the same volume of migrants, a higher net in-migration rate towards urban areas. As the respective proportions of the rural and urban populations balance out, the number of migrants who contribute to urban growth decreases, even though the probability of out-migration from rural areas may remain the same. This is what happens in developed countries; when more than 60 % of the population lives in urban areas, urban growth by immigration from rural areas is necessarily low. But is this mathematical equation sufficient to explain the decline in urban growth in the 1980s and 1990s in Africa, where the level of urbanisation is only around 30 %?

In fact, the decreasing role of migration in urban growth is largely due to new migratory trends. In sub-Saharan Africa as a whole, several recent sources indicate that rural out-migration has not only subsided, but that its counter-stream (i.e. urban out-migration) has increased. West Africa offers interesting examples in this regard. Côte d'Ivoire, for instance, experienced a migratory reversal between the mid-1980s and the late 1990s (Internal migration has probably evolved since then, due to civil war); urban-to-rural migration exceeded the opposite flow, causing the level of urbanisation to decline (Beauchemin, 2002b). Even though the counter-urbanisation process is still marginal in Africa at national level (Zambia is the only other country where this trend has been identified), many countries are experiencing a decrease in rural-to-urban migration to some extent. A West African

network of national migration surveys revealed that secondary towns in seven countries (Burkina Faso, Côte d'Ivoire, Guinea, Mali, Mauritania, Niger and Senegal) recorded a net loss of migrants between 1988 and 1992 (Bocquier & Traoré, 2000). Some larger cities are also affected by a decline in migration; Accra, capital city of Ghana, apparently saw significant net out-migration in the mid 1980s (Simon, 1997); and Abidjan had no migratory growth between 1988 and 1992, excluding international flows (Beauchemin, 2001). Economic decline appears a pervasive explanation for the slowing of urban growth and change in migratory trends. Despite these new migratory patterns, in most West African countries, the urban population continues to grow faster than the rural population. However, due to the slowdown in urban growth, the rural way of life could well remain predominant in West Africa for a long time to come (Bocquier, 2003).

The Economic Roots of Urban Development

Although urbanisation is commonly associated with a gradual reallocation of labour from agriculture to industry, which is what happened in the industrialised world in the nineteenth century (Bairoch, 1985), urban in-migration in West Africa occurred (and continues to occur) without industrial development. In addition, African countries witnessed a massive migration of the rural population to urban areas despite rising levels of urban unemployment and underemployment (Todaro, 1997).

These apparent contradictions in migration and urbanisation were initially attributed to irrational behaviour. A better explanation was found in the concept of economic dualism between the formal and informal urban sectors, first introduced by Lewis (1954) and extended by Todaro (1976). In contrast to the formal sector (geared towards capital-intensive, large-scale modern production), the informal sector is a traditional, unregistered, subsistence sector geared towards labour-intensive, small-scale production.

Cities and Towns in West Africa, Fig. 7

A barbershop in Ouagadougou, Burkina Faso. Female hairdressers usually work at home (© IRD – Marie-Noëlle Favier)



Cities and Towns in West Africa, Fig. 8 Abidjan, Côte d'Ivoire. Informal economic activities range from itinerant micro-commerce to established activities (joinery,

garage mechanic. . .). Here young girls sell plastic bags of fresh water, carried on their head in large baskets (© IRD – Philippe Haeringer)

However, the spectrum of informal activities ranges from the so far predominantly downmarket informal sector to an upmarket informal sector (see Figs. 7 and 8), which is closer to small and medium business type activity, even though it does not comply fully with tax and social security regulations. The existence of the informal sector explains why rural-to-urban migration has persisted-leading to rapid urban growth-despite limited absorption capacity in the urban formal employment sector (see “[Extra 3 Migration, Urbanisation and Development: A Controversial Issue](#)”). Although sometimes discouraged by public authorities because of its illegality and suspected tax evasion, most researchers now recognise that the informal sector has economic advantages; it absorbs surplus labour and provides

a safety net in a context of high unemployment and poverty (Becker, Hamer, & Morrison, 1994; Snrech, 1994). In fact, the sector employs the majority of urban workers and serves the purpose of receiving and integrating migrants and providing them with minimum subsistence. However, this pattern has evolved in the last two decades as a result of the economic crisis.

Since the 1970s, West Africa, still mostly dependent on commodity exports (coffee, cocoa, bananas, petroleum, etc.), has suffered from falling prices on international markets. West African countries first delayed the crisis by maintaining public expenditure. But, as debt became unsustainable, structural adjustment programmes (SAPs) imposed by international organisations and donors focussed on reducing

public expenditure via privatisation and staff redundancies (Duruflé, 1988; Becker et al., 1994). Employment surveys conducted in 2001–2002 showed that public sector employment in seven West African capital cities was 8 % on average, with a higher-than-average rate in Niamey (15 %) and Ouagadougou (13 %), which is still rather low considering that these cities concentrate most of the public sector activities (AFRISTAT, 2005). In the 1990s, urban unemployment reached unprecedented levels, in particular among educated people looking for jobs in the formal sector (Bocquier & Le Grand, 1998; Charmes, 1996; Lachaud, 1994). In 2001–2002, in Cotonou, Bamako and Lome unemployment was relatively low (5–8 %) compared with Dakar (12 %), Niamey (13 %), Abidjan (14 %) and Ouagadougou (15 %) (AFRISTAT, 2005). These figures, computed using the ILO's standard measure of unemployment, would be much higher if they included discouraged unemployed city dwellers (i.e. non-working people who have stopped looking for a job after unsuccessful attempts) and 'underemployed' people. Gugler generally defines 'underemployment' as the underutilisation of labour. This occurs when workers are so numerous that at all times a substantial proportion is employed part-time. It is linked to the economic role of solidarity groups that continue to employ all their members rather than laying them off when there is insufficient work to keep them fully occupied (Gugler, 1982). As most workers turned to the informal sector, the crisis caused the informalisation of the urban economy. In West African capital cities (Cotonou, Bamako, Lome, Dakar, Niamey, Abidjan and Ouagadougou), about 75 % of employment is informal, with little variation (plus or minus 5 %) between countries. However, the informal sector itself suffered from worsening economic conditions. Demand from urban households plummeted as standards of living deteriorated. In 2001–2002, more than 55 % of workers earned less than the official minimum hourly wage, and average monthly household income ranged from \$30 to \$70 (i.e. \$10 a month per urban dweller on average) across the seven capital cities listed above.

Less income in the informal sector is shared by more people as competition was heightened by the arrival of those left out of the formal economy (Arnaud, 1998). Urban poverty has increased dramatically in West African towns and cities. Even though the recession affected both urban and rural areas in West Africa, urbanites seem to have suffered more hardship than their rural counterparts. Jamal and Weeks calculated that, in the 1970s and 1980s, the rural-urban income gap in many African countries either disappeared or shifted in favour of the farmers (Jamal & Weeks, 1993). The fall in real urban incomes has generated a new urban poor population, who are forced to adopt survival strategies. Households diversify their sources of income; previously non-working members, mainly women, enter the petty commodity sector, and wage earners take on supplementary cash-earning activities. They reduce their expenditure by developing subsistence agriculture within and around the urban area (see Fig. 9), and by adjusting their housing arrangements (some move towards less expensive districts, while others rent out a part of their house). Another coping strategy is to strengthen and adapt rural-urban ties, which includes returning to rural homes. This often involves changes in household composition. Adult members are sent to villages to diversify income in order to cope better with economic hazards, some children are sent back to rural areas where schools are cheaper, while foster children are sent back to their original households (Beauchemin & Bocquier, 2004; Potts, 1997). These strategies are not marginal and explain why urban out-migration has increased significantly in West Africa.

Household coping strategies would appear to be effective in adapting to the deteriorating urban economy. In West Africa, no riots broke out in response to the implementation of structural adjustment. However, in this context of rising poverty, social and ethnic tensions have been exacerbated in some countries (On the conflict in Côte d'Ivoire, see Beauchemin, 2005). In other countries, remittances from international migrants might have acted as safety valves. For instance, Senegalese and Malian emigrants are

Cities and Towns in West Africa, Fig. 9

In a context of growing poverty, urban households turn to agriculture within and around urban areas in order to reduce their expenditures. Here, the Figure also shows the progressive building process in West Africa. Construction is usually incremental due to the underdeveloped nature of the housing finance system sector. Therefore, people build as they get money (© IRD – Philippe Haeringer)



known to play an important role in both rural and urban development in their home countries (Bertrand, 1994; Gueye, 2002; Tall, 1994).

Construction of Towns and Cities

The physical appearance of West African cities and towns is mostly the result of a recent and rapid pace of growth, which public authorities, despite their intentions, have been unable to control. Almost everywhere, governments nationalised land after independence, and public authorities were supposed to become the main-if not the only-actor in urban development. They did indeed draw plans and build housing units to supply demand from urban residents. However, the supply of public housing has only ever met a small proportion of needs, and the dwellings or serviced plots made available are not affordable for the lowest income groups. How did the others-in fact the majority-find accommodation? They relied on the informal sector, by buying a plot from a holder of customary tenure rights and building their own houses, or by renting a place in an unauthorised neighbourhood (Durand-Lasserve, 1986; Rakodi, 1997).

As in other sub-Saharan African countries, in West Africa there are overlapping land tenure systems. Although the law imposed public control over land, the customary system has survived informally. Theoretically, in that system, land

cannot be owned as private property. It is vested in a community (usually a lineage whose ancestors settled on the land), and administered by the head of the group. In that system, unused land can be allocated to a non-member of the group, especially if he needs it to survive. In that case, in the traditional system, only a token payment to the land chief is required. This is not a sale since the land remains theoretically inalienable. However, in urban areas, as pressures intensify, traditional payments are moving closer to real land prices. Since the 1960s, in all cities, customary authorities have informally sold (i.e. without transfer of title) land for urban development. Since the occupants have no title, public authorities can always contest the use to which the land is put. Until the late 1970s, informal settlements were demolished. Then policies switched to regularisation and upgrading programmes; titles or occupancy licences were delivered to the previously unauthorised occupants and infrastructure was installed (Amis, 1989). All in all, states now tolerate informal settlements because they meet popular demand. Building a house is for most households the only source and accessible investment while bank savings are unreliable and poorly profitable. The informal land tenure system has thus become more secure. In 2001–2002, between 50 % and 85 % of self-declared landowners in seven West African capital cities possessed a land title (AFRISTAT, 2005). The urban structure



Cities and Towns in West Africa, Fig. 10 Dakar, Senegal. This neighbourhood is next to the airport area (rear of the Fig.). It was officially declared unsuitable for building development by the Senegalese government. However, this land was sold for construction by customary authorities of the *Lebou* (a local ethnic group). The quality

of the houses shows quite well that unauthorized areas do not necessarily become slums. Nowadays, this type of neighbourhood is often regularized after construction (informal owners finally obtain titles from the public authorities) (© IRD – Michel Dukhan)

of unauthorised neighbourhoods is also quite similar to that of regular districts; landowners, intermediaries and buyers are adopting urban and architectural standards likely to facilitate subsequent regularization (see Fig. 10).

In West African cities, the majority of houses in both the formal and informal sectors have been built on an individual rather than mass production basis. The typical West African housing unit is the compound house (see Fig. 11). This type of accommodation houses 85 % of the population in Abidjan (Côte d'Ivoire) and Bamako (Mali) and three-quarters of households in Accra (Ghana). Even in informal areas, urbanites do not build their own houses; artisan builders are commissioned (Coquery, 1990). Construction is usually incremental, mainly due to the lack of title and an underdeveloped housing finance sector (see Fig. 9). According to needs and means, houses

are extended horizontally (by filling empty spaces with new rooms, such as by reducing courtyards to corridors) or vertically (by adding more storeys). Most compound houses are permanent structures, built of cement breezeblocks with corrugated iron roofs. Mostly built for rental, compounds usually accommodate several families and various socio-economic and ethnic groups, enabling a mix of the city's population groups and cultures (see Fig. 12). Compared with other cities in the developing world, including the rest of sub-Saharan Africa, most West African cities do not appear to be very segregated, either socially or ethnically.

The informal nature of land distribution and housing production has led to under-served urban development. There is no legislation governing construction in unplanned housing areas, and consequently there is no tax on the



Cities and Towns in West Africa, Fig. 11 Abidjan, Côte d'Ivoire. Except in the downtown center and in some upper-class districts, the city skyline is very low and horizontal. 85 % of the Abidjan population lives in compounds such as this. Several households surround the courtyard, usually the center of the plot. Each living unit normally comprises one room or two rooms of

approximately 10 m², one which is used as a bedroom and the other a sitting room. Three rooms is the maximum number of rooms for this type of housing and that is very rare. Courtyards are progressively filled with new constructions. At the rear, owners have started to build additional storeys (© IRD – Philippe Haeringer)

capital gain on land sales and no obligation to service land prior to sale. As for housing, publicly provided services and infrastructure have lagged far behind needs. As a result, a large share of the urban population does not have access to basic services. Access to water, vital for health, is a concern for much of the urban population (see Fig. 13); in 2001–2002, only 43 % of all households had access to tap water in the seven capital cities cited above, with the proportion ranging from about one-quarter in Lome, Bamako and Niamey to 41 % in Cotonou, 50 % in Abidjan and 68 % in Dakar (AFRISTAT, 2005).

In response to service shortages, urban dwellers have adopted a range of alternative strategies. In Pikine, the largest suburb of Dakar, by taking advantage of political clientelism, residents in the unauthorised area have obtained as

many facilities (schools, health centres, water points) as their counterparts in the formal area. For urban dwellers, political pressure has become a potentially powerful lever since decentralisation in the mid-1980s. Do-it-yourself is another strategy; illegal hook-ups to electricity may be a way to access power (Marlard et al., 1999). Informal economic activities have also emerged to compensate for the inadequacy of the public service system. Many people rely on private vendors instead of collecting and queuing themselves for water although prices are more expensive than for public supplies (see Fig. 14). Collective taxis and private minibuses (*gbaka* in Abidjan, *cars rapides* in Dakar, etc.) serve the neighbourhoods with terraced roads bypassed by public transport systems and are usually less expensive (see Fig. 15). A large proportion of the residents of



Cities and Towns in West Africa, Fig. 12 Abidjan, Côte d'Ivoire. Courtyards are used for domestic activities and sometimes for economic activities. Here, women sort candies they are going to sell in the street and at the markets. On the right front, notice the collective place

dedicated to the dishes and the washing. Barrels (*red* and *blue*, on the left rear) indicate that there is no tap water in the compound. Women are in charge of getting the water (© IRD – Philippe Haeringer)

unauthorised neighbourhoods thus have access, to some extent, to the highest-priority services. The situation is nevertheless not very satisfactory. Poor sanitation is a major health issue, water that is expensive and remote encourages drinking of non-potable water, and unregulated transport is dangerous. Furthermore, the privatisation of urban services, in line with structural adjustment recommendations, has worsened the situation since the mid-1980s (Stren & White, 1989).

In a nutshell, West African cities and towns face the same problems as other developing regions in terms of access to services and housing. However, due to the informal land tenure and housing systems, squatting (A distinction must be made between squatting (deliberately building on land without permission and against the owner's wishes) and unauthorised settlement (building in areas where the government has not given permission to build, but where customary owners can sell plots for construction)) and slums are much less extensive than in Asia and Latin America (Konadu-Agyemang, 1991; Peil, 1976). A regional study found that 'only' (sic) 15–25 % of urban residents lived in precarious housing (shanty towns), a similar proportion in

planned districts, and the remainder, i.e. the majority, in structured, albeit informal, neighbourhoods. However, the fact remains that in the poorest neighbourhoods, living conditions are so bad that infant and child mortality rates are sometimes higher than in rural areas (United Nations human settlements programme, 2003; National Research Council, 2003).

Urbanisation is known to be historically associated with development. In the past, when the developed world experienced its transition from a predominantly rural-agricultural economy to an urban-industrialized one, urban growth was the highest where economic growth was fast. The urbanisation process in sub-Saharan Africa differs to some extent from the process experienced by contemporary developed nations at a comparable stage in their development (Njoh, 2003). There is nevertheless a consensus nowadays to recognize that the level of urbanisation (percent urban population) is correlated to various development indicators, such as the GDP per capita or the Human Development Index (Davis & Henderson, 2003; Njoh, 2003). Therefore recent slowdown trends of urban growth, especially where migratory reversal occurred, may be worrying in terms of development. Actually, these



Cities and Towns in West Africa, Fig. 13 San Pedro, Côte d'Ivoire. A woman buys water from a neighbour who is equipped with running water. The scene takes place in the Bardo, the largest informal settlement in Côte d'Ivoire; 90,000 people (about to thirds of the town population) lived there in 1998. San Pedro is the perfect example of the urban planning failure in West Africa. It is a new town, created in 1968 to be the exportation (cocoa, wood, etc.) port of the southwest of Côte d'Ivoire. From the beginning, the Bardo, the unplanned part of the city, started to grow faster than the authorized part (© IRD – Philippe Haeringer)

trends reveal a polymorphous crisis, i.e. both a crisis of urban management (unsolved problems of housing, services, infrastructure, etc.) and a crisis of the urban economy (increasing unemployment, insufficient income, high cost of living, etc.). From a global point of view, the peripheral position of the West African countries in the world economy appears to be the main reason for their lagging urbanisation (Simon, 1997). West African countries are still excluded from the more profitable production sectors. Their economies are still highly dependent on

raw materials and from this end they are not able to control the world markets. In this context, West African states remain highly dependant upon international aid. As a consequence, conditions imposed by the financial institutions weigh heavily on national economic and urban policies. Urban management issues are thus more and more delegated to (new) municipalities, which dispose of fewer means. Public services are often privatized, but the poorest do not have necessarily better access to them. Drastic reductions in public expenditure prevent states to invest in infrastructure (electricity, roads, etc.) that are recognized to be necessary for the population's wellbeing and for the enterprises' prosperity. West African states have to reconcile on one hand the conditions that will allow private informal and formal enterprise to expand in towns and cities in order to generate wealth and employment and on the other hand extend basic services in order to guarantee a better health and education for the poor.

Extra 1 Inconsistent Definitions and Measures Vagaries

What is rural? What is urban? There is no global standard to define the line between urban and rural settlements. This issue is not specific to West Africa, but it is particularly relevant there because of frequent discrepancies. For instance, in Côte d'Ivoire, the official definition published in 1975, based on population and activity criteria, has never been used in practice (a list of cities has been established without regard for the official definition) (Dureau, 1987). Furthermore, there are often inconsistencies between national official definitions and definitions published in UN reports (practically the only comprehensive source of international urban data available). In the UN's Statistical Yearbooks, definitions are not stated for some countries, even though this information is available in national reports (e.g., Benin, Burkina Faso and Guinea). Definitions for other countries (e.g., Côte d'Ivoire, Mauritania and Niger) are even in contradiction with national definitions. Obtaining information on the

Cities and Towns in West Africa, Fig. 14 Mopti, Mali. A water street vendor (© IRD – Sophie Martin)



Cities and Towns in West Africa, Fig. 15 Dakar, Senegal. The official public transport system is not sufficient to serve the whole agglomeration and is too expensive for a large part of the population. Private mini-buses, the so-called 'cars rapides' in Dakar (it means fast buses), compensate for this inadequacy. But since the material is old, they are not always secure and contribute a lot to pollution (© IRD – Michel Dukhan)



definition of urban settlements in West Africa is in itself a challenge. In any case, one observation can be made: the definition of 'urban area' varies from one country to another, and can also vary over time, which makes geographical and chronological comparisons problematic. As a result, most publications on urban trends based on UN data are flawed by the inconsistency of definitions (Bocquier, 2003).

In order to draw a more accurate figure of urban trends in the world, Moriconi-Ebrard (1994) has created an urban database based on a standardised definition: in GEOPOLIS, settlements with a population over 10,000 are considered urban, regardless of country and period

(from 1950 to now). This new definition could have a major impact on national figures. However, in the case of West Africa, using a standardized definition does not produce a very different figure of urban trends on the regional scale. The level of urbanisation measured by official definitions appears to have been slightly overestimated, but trends remain similar. The pace of urbanisation in West Africa slowed sharply in the 1980s and 1990s.

Urban studies in West Africa are not only flawed by definition problems. They are seriously hampered by a lack of reliable and up-to-date demographic data. Census data are the principal sources of information on urbanisation. But

censuses tend to be conducted only once a decade and then take several years to be analysed and published. In Africa, deadlines are often delayed due to financial, political or security reasons, so that recent data are rarely available. As a result, figures shown in UN publications are often estimates. Because of the poor quality of available data and an inappropriate projection method (Bocquier, 2005), estimates for West African countries in the 1980s and 1990s have overrated urbanisation levels. To conclude, statistics on urban trends should be used with caution!

Extra 2 The Urban Future: Mega-Cities or Small Towns?

Contrary to popular perception, most urban dwellers in Africa do not live in the slums of mega-cities. In fact, most African cities are small by international standards. Lagos in Nigeria is the only sub-Saharan African urban agglomeration to be included in the UN list of the 30 largest urban agglomerations in the world. Urban systems in Africa, and more specifically in West Africa, are quite different from those in Latin America or Asia. There are no major metropolises (with the exception of Lagos), but many small and medium-sized towns (as a result of the reclassification process). It is precisely because large cities play a less clear-cut role in urban dynamics than in other parts of the developing world that this is such a controversial topic among academics.

Some authors stress and decry the high degree of primacy, where a large proportion of the urban population lives in a single city. This view is widely shared by policymakers who are concerned by the growth of large cities and who claim to have developed policies to reduce migration to cities (United Nations, 1998). Some African cities do clearly predominate in national urban systems (e.g. three-quarters of the urban population of Guinea were living in Conakry in 1994, according to UN data) and have seen spectacular growth, especially in the 1970s (e.g. Abidjan grew by more than 10.3 % per year between 1965 and 1975, a record rate of

urban growth). Furthermore, several studies have shown an increasing concentration of the urban population in the main cities in recent decades; urban systems seem to have evolved from undersized to oversized capital cities as compared to the world average (Bocquier & Traoré, 2000).

Conversely, some authors argue that urban growth in West Africa is largely due to the development of small and intermediate towns. Using other data sources or other calculation methods, they show that primacy is no greater than in other regions of the world and that it has not increased over time (Bocquier, 2003; Cour & Snrech, 1998). Indeed, in most countries, the principal city's share of the total urban population has not changed much since the 1950s. For instance, Dureau (1987) has shown that Abidjan has concentrated about 40 % of the urban population of Côte d'Ivoire since 1936 and that, even when the city saw spectacular growth (1965–1975), 49 % of new urban dwellers settled in secondary towns. In fact, in the mid-1980s, West African small and medium-sized towns became a separate subject of research (Baker, 1990; Dubresson, 1996; Hardoy & Satterthwaite, 1986). Several studies stressed the importance of their development. In West African countries, the number of small towns (settlements with a population of 5,000–20,000) rose from 150 in 1960 to 400 in 1980 (Giraut & Moriconi-Ebrard, 1991) (see Map 1).

What is the urban future? Projections are always hypothetical, especially when they are related to such controversial issues (Bocquier, 2005). Nevertheless, a consensus is emerging. Despite popular perceptions to the contrary, West African people will not all be living in mega-cities in the near future. Primacy may increase in some countries, but it may result from regional integration. Cities like Dakar, Abidjan and Lagos are highly cosmopolitan and their share in the urban population would be more accurately assessed at the regional level (West Africa) than at the national level. In any case, small and medium-sized towns will continue to appear (through reclassification) and grow.

Extra 3 Migration, Urbanisation and Development: A Controversial Issue

Does rural-to-urban migration (and the resulting urbanisation) favour economic development? This question, which is a matter of policy concern in West Africa is also vigorously debated by scholars. Broadly speaking, there are two main contrasting viewpoints.

An anti-migration viewpoint is that rural-to-urban migration is excessive and should be curbed because it leads to a “less than optimal allocation of labour between the rural and the urban sectors” (Gugler, 1982). On the one hand, it exacerbates unemployment and underemployment in African cities. On the other hand, it reduces potential agricultural output, by depriving the rural population of its more innovative and able-bodied members. Furthermore, rural-to-urban migration is criticised as the primary contributor to the uncontrolled expansion of urban areas (Bairoch, 1985). Finally, rural-to-urban migration increases the cost of providing for the country’s population in two ways. Firstly, new infrastructure is required by the migrants, and amenities (housing, transport, garbage and sewage disposal, etc.) are more expensive in cities or towns than in rural areas, where they may not be needed at all (Gugler, 1982). Secondly, urban job creation is generally more costly than rural job creation, because most jobs in the industrial sector require substantial complementary resource inputs. For these reasons, rural-to-urban migration is seen “both as a symptom of and a contributor to African underdevelopment” (Todaro, 1997). This view is largely shared by policymakers (United Nations, 1998).

Taking the opposite point of view, pro-migration authors argue that it is completely inappropriate to regard migration as an undesirable force, which needs to be suppressed (Amis, 1989). On the urban side, authors acknowledge that substantial unemployment and severe underemployment characterise most large African cities today, but they point out that, on average, migrants must be better off in urban places, otherwise rural out-migration flows would slow

(Becker, Hamer, & Morrison, 1994). On the rural side, they argue that there is no labour shortage since emigration has not prevented the rural population from increasing far more rapidly than it has ever increased in the developed countries (except in the United States). On the contrary, rural out-migration is seen as a way of alleviating human pressure on natural resources. In addition, they contend that urbanisation stimulates agricultural activities, since it creates a market for specialised food production with high added value (market gardening and poultry farming). Apart from the impact on rural areas, migration and urbanisation are seen as key components of the development process. Authors argue that, for several reasons, increased urbanisation raises per capita income and other measures of economic welfare. First, when driven by rural-to-urban migration, urbanisation tends to move workers from agriculture to more productive occupations (e.g. urban services, commerce, and manufacturing sectors). Second, urbanisation offers the cost-reducing advantages of economies of agglomeration and economies of scale and proximity as well as numerous economic and social externalities (e.g. skilled workers, cheap transport, amenities, etc.). Finally, urbanisation also contributes to development in more subtle ways. For example, it may lead to lower levels of fertility and mortality, as individuals benefit from improved access to health care. Theory apart, Becker et al. (1994) stress that, from a macro-economic point of view, while less than a third of Africa’s population lives in cities or towns, these centres generate over half of the continent’s gross domestic product (GDP).

To conclude, one is tempted to agree with Portès, who takes the view that “internal migration and urban growth are intrinsically neither good nor bad. Such assessments depend upon the specific social context, and in particular, on the point of view one adopts with respect to the different classes and institutional actors. A case can be made that, in the short run at least, the present trends of rural-urban migration and urban concentration are functional for a wide assortment of groups” (Portès, 1985).

See Also

- [Architecture in Africa, with Special Reference to Indigenous Akan Building Construction](#)
- [Building Construction in Africa: Akan](#)

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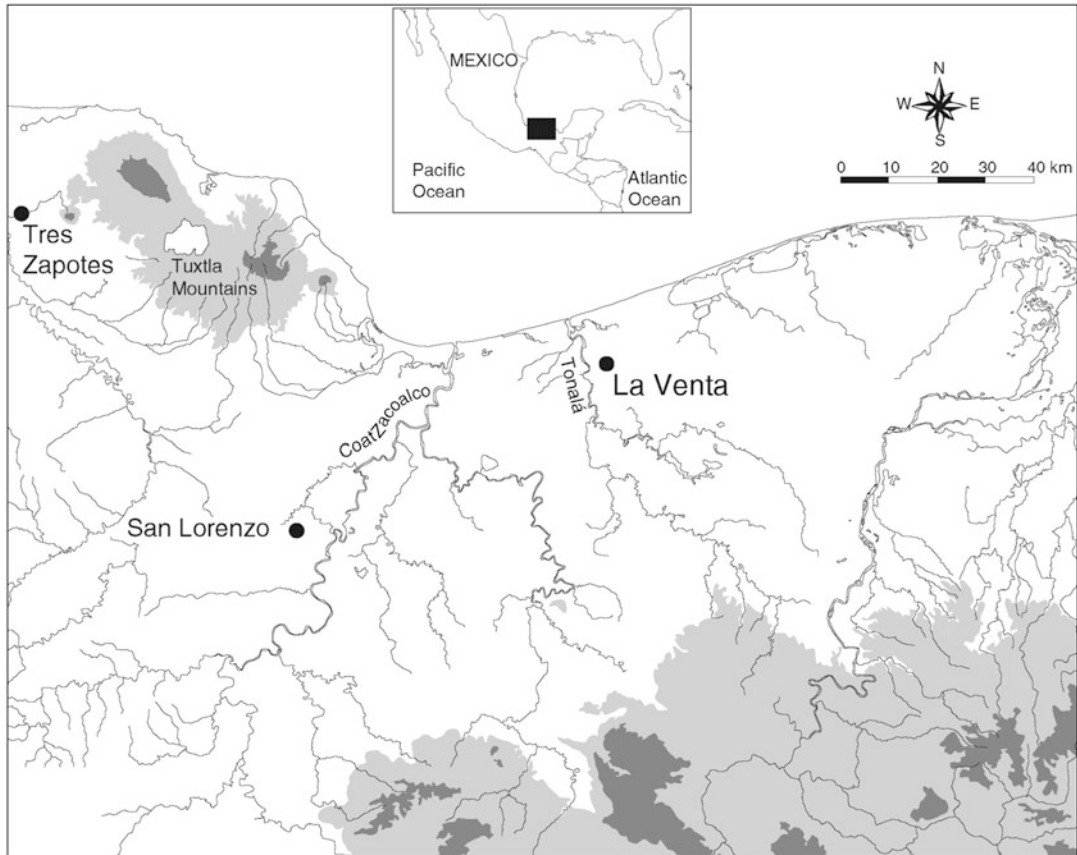
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Cities and Towns of the Olmec

John E. Clark

Mesoamerica's first civilization arose about 3,400 years ago among the Olmecs of the tropical Gulf Coast lowlands of southern Mexico (Fig. 1).



Cities and Towns of the Olmec, Fig. 1 Map of Mesoamerica showing the Olmec region and its principal sites

Olmec civilization lasted a 1,000 years and is recognized by its spectacular and unique art style manifested in colossal stone heads and thrones, figurines, carved pottery, and polished and incised jade objects. Among their many accomplishments, Olmecs created the first cities in North America. Many archeological sites are known for this culture, but only two were large and splendid enough to qualify as cities: San Lorenzo and La Venta. As capitals of dynastic societies and habitats of kings, some bureaucratic functions and services were unique to these cities, as evident in their palaces, thrones, royal tombs, ballcourts, temples, observatories, and state art. Scholars expect cities to accommodate 5,000 or more people. By the standards of function and size, San Lorenzo was Mesoamerica's first city. It enjoyed a meteoric but brief history and was succeeded in the same region by La Venta, the last Olmec city. For its part, La

Venta represented the first mature manifestation of the quintessential Mesoamerican city, and it was a model of a sacred center copied by other peoples. Key issues in Olmec studies are the historic and formal relationships between San Lorenzo and La Venta. These are most easily appreciated by beginning with La Venta and tracing some of its features back to San Lorenzo.

The Last City, La Venta

La Venta was founded and built about 850 BCE on virgin soil in a special place: a long, 20 m high island in the middle of a vast swamp in western Tabasco, Mexico, just 15 km from the coast. La Venta was abandoned about 400 BCE and never reoccupied. This was a fortunate happenstance for investigators because the city has been

preserved as the Olmecs left it 2,400 years ago. The map of the site in Fig. 2 indicates the probable early and final form of this city. At its founding, La Venta was laid out along the eastern edge of the island. This escarpment was cut and terraced to bring it into alignment with the principal axis of the sh-shaped city. Some of the construction fill used to build the city may have come from these land modification operations.

La Venta was built to a rigid plan, in regular 86.6 m blocks, and along a centerline oriented 8° west of north. The original city center was 10 blocks long and 8 wide. Subsequent additions to the city respected the principal axis and measurement interval. Later mounds encroached on the original mounds in the north. The monumental city center eventually extended 1,482 m, or 17 blocks. Late in its history, stone monuments were set up as boundary markers. Three basalt colossal stone heads were placed at the northern end of the city, and they faced north. Three even larger sandstone heads near the southern end faced south. These monuments were placed 1,300 m or 15 blocks apart.

These building intervals, when translated into native Mesoamerican beliefs and practices, show that La Venta was built as a sacred center. The Olmecs measured this city with the 1.67 m fathom used by the later Aztecs and Maya; thus, the 86.6 m block represented 52 fathoms, the year count for the calendar round. Five such macrounits comprise the number of days in the sacred almanac (260), and seven (364) approximate the solar year. These calendar distances separate critical points in the arrangement of buildings at La Venta. For example, the original city was ten blocks long, or 2×260 . Later additions to the site extended it seven blocks, or a solar year count. Other ritual counts are built into the placement of mounds and monuments. They demonstrate that La Venta was carefully planned and built with marvelous precision.

The city was partitioned and arranged according to function. The original layout shows a long, 6 ha plaza (2×4 blocks) with special architecture in each cardinal direction. The plaza was probably for public ceremonies and for viewing rituals performed on the platforms

surrounding it. The plaza could have accommodated well over 100,000 standing spectators. Looking north, a spectator would see a 32 m high stepped pyramid made of nearly 100,000 m³ of dirt and clay. A temple of perishable materials probably graced the top of this artificial mountain. The summit could be accessed from stairs on the south and north faces. The pyramid is the only promontory for over 100 km on this coastal plain and can be seen from over 10 km away. It would have been very impressive close-up in its final form. The pyramid was given a new clay skin several times during the city's history, each time making it slightly bigger and taller. The height of the original pyramid has not been determined.

East of the plaza lies a broad 8 ha platform or acropolis that required nearly twice as much earth and clay to build as the pyramid. This high platform was probably the royal compound: residence of the king, his courtiers, and servants. A ballcourt and an elaborate system of subterranean stone drains have been identified there. In the block south of the plaza lies a long mound flanked on the west by a short pyramid. Together these constituted an astronomical observatory for monitoring the movements of the rising sun through the year, perhaps to coordinate the agricultural cycle and other state rituals. Looking to the west a spectator would see a string of low platforms and their perishable buildings, probably priests' residences or special temples. Axial symmetry is evident in the organization of the original city. Buildings on facing blocks around the plaza were complementary pairs: the pyramid and observatory formed a N-S pair, and the royal compound and priestly residences an E-W pair.

North of the pyramid block a compound was built one fourth the scale of the rest of the original city. The main complex consisted of five low mounds surrounded by a 2 m high and rectangular palisade of upright, basalt pillars. Spectacular jade and serpentine offerings and royal tombs were found in this sector arrayed along the principal axis, and on both sides of it. Some individual offerings had more than 1,000 tons of serpentine. A pair of offerings depict the abstract face of the earth lord, each on top of 28 layers of

carefully placed serpentine rubble. The two images look identical but are color coded to depict an ► east and west image of the same entity. All rock used in these offerings was imported from over 60 km away, so the massive offerings represented a tremendous burial of wealth. Another expense was the importation of tons of basalt for stone monuments and architectural enhancements. These were brought in by canoe or raft from over 100 km of inland waterways. To date, 90 stone monuments and hundreds of 1-ton basalt pillars have been discovered in the city. Sculptures include colossal stone heads, thrones, full-figure images of kings, and low-relief carvings on flat slabs, or stelae. The latter depict gods or narrative scenes. The south side of the great pyramid had a line of six stelae facing the main plaza, three on each side of the stairs.

The mounds added to the southern end of the city later in its history are not as logically arranged as those of the original city. Presumably, they were for privileged personnel and state functionaries. With the exception of the six monuments used as boundary markers, large stone sculptures were confined to the northern part of the city, the domain of La Venta's lords and priests. The oldest buildings in the north were rebuilt or refurbished many times during their centuries of use.

In its final form the city center was about 58 ha in extent, and with its residential neighborhoods the whole city covered at least 200 ha. At its height, the city housed 3,000–5,000 people, with many more on small islands and river levees within 10 km of the city. The extent of the La Venta kingdom has not been determined, but the city was the royal capital for towns and villages located over 100 km distant. La Venta kings were depicted as corn gods, indicating that the city was governed by divine kings, or priest-kings. The institution of kingship became fundamental to Mesoamerica statecraft; its beginnings can be traced to San Lorenzo.

The First City, San Lorenzo

San Lorenzo was occupied off and on from 1750 BCE to AD 1100, but it only functioned as a city from 1300 to 1000 BCE, at which time it reached

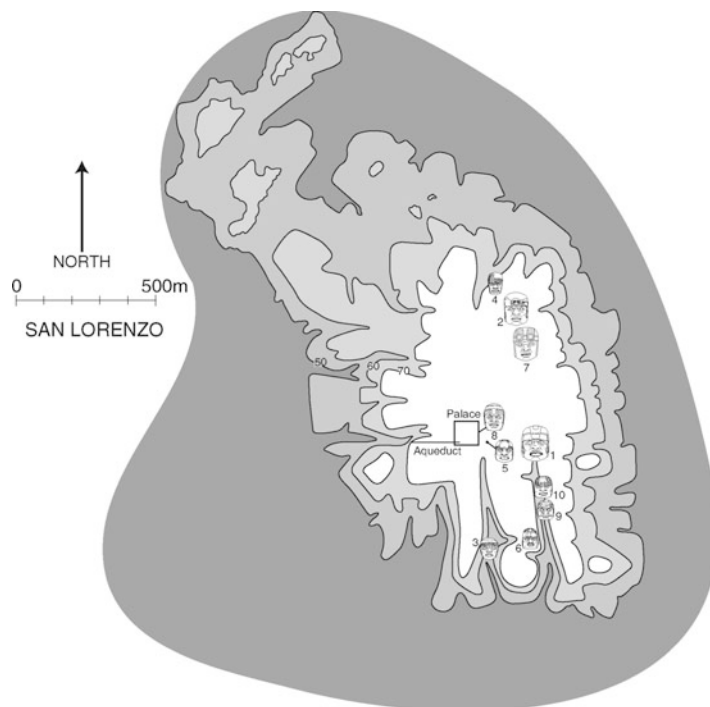
its maximum extent of 500 ha, over twice the size of La Venta in its prime. San Lorenzo collapsed about 1000 BCE, perhaps due to a shift in the course of the Coatzacoalcos River. The city is located 60 km from the coast and currently lies 7 km west of the meandering Coatzacoalcos, the second largest river in Mexico. Just over 3,000 years ago, this river ran on both sides of San Lorenzo, making the site an island and well positioned to control canoe traffic and commerce. The city core lay atop the summit of a 50 m high natural plateau nearly 60 ha in extent. The surface of the plateau was carved and stretched into a ⊥-shape, with the N-S crossbar being nearly twice as long (1,213 m) as the E-W axis (650 m). Elite houses, public buildings, and special stone statuary were confined to the top of the plateau, with residential terraces encircling the heights and spilling down and across the plain below. San Lorenzo was the capital of a region that extended 40 km up and down river. At least 7,000–10,000 people lived in the city in its heyday, with four times as many in subordinate communities and provinces.

Little is known of the layout of San Lorenzo because the city lies a meter or two beneath the current surface, so its format will only be revealed through excavation. The few mounds on the plateau postdate the Olmec occupation. A striking difference with La Venta is that early San Lorenzo lacked pyramids. Recent research discovered a palace with an inner courtyard; a colossal stone head and throne were on display there, demonstrating that stone monuments were associated with royal architecture and that some were buried in place. Plazas and temples have not yet been identified. Ballcourts are known at a junior center and may eventually be found at San Lorenzo.

Judging from the size and shape of the modified plateau top, and the first level of broad terraces below the summit, San Lorenzo was arranged in the same measurement increments as La Venta. The original cruciform of the plateau was 14×9 blocks. Another five blocks are evident in the descending terraces on the western and eastern extensions, making the planned city center a 14 block square, or 2 solar years on a side.

Cities and Towns of the Olmec, Fig. 3

Map of San Lorenzo, Veracruz, Mexico, showing the distribution of colossal heads, the E Group palace, and long stone aqueduct. The heads are shown to scale relative to each other



The shape of the plateau and alignments of stone heads and aqueducts demonstrate that the central part of San Lorenzo was rectangular and aligned to N-S and E-W axes, with the long axis 1° west of true north (Fig. 3). Both cardinal axes at San Lorenzo were important, but the axial symmetry of the city unfolds from the E-W centerline. When Olmecs built La Venta, they rotated the basic San Lorenzo plan 90° counter-clockwise so the most important cardinal direction became north instead of east. San Lorenzo was formally organized and zoned from the center of the plateau outward, and downslope. Residential status decreased as a function of distance from the center. The only palace identified so far was built near the western edge of the city's center (Fig. 3), opposite its placement at La Venta. The San Lorenzo palace was placed near a freshwater spring, and a 171 m long aqueduct ran west from its courtyard to the edge of the plateau. If the colossal stone heads were buried in palace courtyards, their distribution suggests that each king had his own palace and that these shifted during San Lorenzo's history from the west edge of the plateau to the east.

As at La Venta, much engineering and earth moving went into constructing San Lorenzo. The first task in building the city was to level the plateau and extend and straighten some of its edges. The eastern and southern faces appear to have been the most precisely cut, and even after nearly 3,000 years of erosion, their straight, perpendicular edges can be appreciated (Fig. 3). Ramps and causeways were created for hauling the colossal sculptures to the summit. A complex system of stone drains was also installed at their proper gradient.

Many specialized artists, artisans, and bureaucrats resided at San Lorenzo, and they were supported by food brought in from outlying settlements. The clearest evidence of subsidized citizens shows up in the site's 130 stone monuments imported from 60 km away, some of them weighing over 20 tons. The best known are thrones and colossal heads. The latter are thought to be realistic portraits of individual kings. Judging from similarities of facial features, at least three families appear represented in the San Lorenzo king list. These kings were depicted as warriors and heroes rather than gods, as

became the subsequent practice at La Venta. Together, the San Lorenzo heads displayed the city's royal dynasty – the first in Mesoamerica. The artistry and labor evident in these monuments, and the organizational requirements for carving and dragging them through the jungle to the city, reveal the presence of other citizens: artisans, overseers, haulers, and probably slaves.

In summary, similarities between San Lorenzo and La Venta include their orientation, cruciform shapes, concentric zoning, size of city centers, standard block sizes, spacing by calendar distances, axial symmetry and complementarity, palaces, and abundant monuments of gods and kings. Significant differences are the presence of pyramids and special monumental architecture at La Venta and the emphasis on north as the sacred sector of the city, the place of the tallest pyramid. The small hamlet at San Lorenzo at 1750 BCE evolved in place into a glorious city in just four centuries. In contrast, La Venta was planned as a special city before the island was occupied. Many later Mesoamerican cities mimicked the formal layout of La Venta rather than that of San Lorenzo. The latter's contribution was getting kingship and city building started, not giving them their final form.

See Also

► [Pyramids of Mesoamerica](#)

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City and Town Planning of the Maya

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Like cities and towns in many societies, those of the ancient Maya express a spatial logic that mapped the cosmos on the landscape. The Maya cosmos has three vertical layers, ordered by four world directions and a center. Within this structured universe, the Maya – today and in antiquity – have established towns and cities whose properly ordered space makes possible the pursuit of properly ordered lives. The towns and cities of the ancient Maya materialize these ideas, and in the variable forms of their physical expression, modern observers can discern the intertwining of primordial beliefs with historically specific political strategies. Such discernment depends on understanding the structure of the Maya world, the importance of the heavens, the role of political dynamics, and the importance of people's earthly movements and ritual practices in bringing the planned order to life. The whole is examined below in the plans and practices for multiple, well-known ancient Maya cities and towns.

Establishing a Place in an Orderly World

Above and below the world of daily life are supernatural realms, to which physical connections exist as caves and other openings in the earth, as well as in the mountain peaks stretching skyward (Brady, 1997; Stone, 1992). Each Maya community recognizes a sacred mountain, with one or more caves, that ground the village, town, or city in the world and to which community members make regular pilgrimage (Patel, 2009). Along with caves, rivers, seas, and all other bodies of water are conduits to an underworld described as a watery place, as non-Maya observers can witness as well, in the subterranean waters of the limestone karst landscape comprising much of the Yucatan peninsula. Roots of

earthbound trees reach into that underworld as well, while their trunks ascend toward the heavens. The towering *ceiba* tree, in particular, is designated in Maya imagery as the World Tree, the center of the universe, and the *axis mundi* around which the rest of the world is disposed. For this reason, many modern Maya towns in Guatemala have a *ceiba* in the central plaza.

Together with the center, the four corners of the world define a five-pointed quincunx pattern, whose physical manifestation expresses order and completion. Whenever any new place is established – from milpas (cornfields), to domestic altars, houses, towns, and cities – the four corners and the center must be designated and ritually consecrated (Ashmore, 2005; Freidel, Schele, & Parker, 1993; Johnston & Gonlin, 1998; Mathews & Garber, 2004; Tedlock & Tedlock, 1985; Vogt, 1976). As elsewhere in Mesoamerica, each of the five points involved has its own characteristic color, tree, bird, animal, and deity (Bassie-Sweet, 1996). Not surprisingly, east is the position of the red rising sun, while black of the west is linked to the setting sun. North is white, south is yellow, and center is green – the color of corn plants, jade, and all things precious and new. Offerings in dedication of new construction frequently partake of this symbolism to situate the locale properly in the world. These microcosmic offerings might take the form of a cache of appropriately colored pebbles at a farmer's house (Robin, 2013, pp. 76–78), while for a civic building the microcosm might comprise a deposit whose layered shell, jade, and bird bones betokened sea, earth, and sky (Sharer, Fash, Sedat, Traxler, & Williamson, 1999, pp. 237–238), or positioning ritual offerings at the four corners and center of a building meant to mark a city's *axis mundi* (Bell, 2007, p. 341).

Maya space is also ordered by time, and from time immemorial, the calendar ordained perpetual succession of the four cardinal world quadrants, or more specifically their associated deities, in their responsibility for overseeing events of a 365-day period (Coe, 1965). As elsewhere in Mesoamerica, the calendar reckoned time simultaneously according to a 260-day “sacred year”

and a 365-day “vague” solar year. The latter comprised 18 months of 20 days each, plus an unlucky period of 5 days, called *Uayeb*, at the transition to the next year. Mathematically, a year in the 365-day cycle could begin on only one of four named days in the 260-day cycle. In sixteenth-century Yucatan, these 4 days, called “year bearers,” were *Muluc*, *Ix*, *Cauac*, and *Kan*, and each was associated with one of the cardinal directions. Dances, blood sacrifices, and feasts at the end of each year, known as *Uayeb* rites, formally marked transfer of responsibility from 1 year bearer to the next, passing in a counterclockwise direction (*Muluc*, east; *Ix*, north; *Cauac*, west; *Kan*, south). Because images of the deities of those year bearers were housed in the civic center during the year, the places involved and ritual passage between them encompassed the city or town in a quincunx pattern.

These are the basic components and activities from which town and city plans are generated and brought to life, but they are shaped by other considerations, as well, including astronomy, the world's creation, and worldly politics.

Astronomy and Creation

Scholars have long acknowledged the astronomical sophistication of the ancient Maya. Buildings are often demonstrably oriented to the rise or set point of particular celestial bodies, especially Venus and the Pleiades, or arguably to chart wider-scale changes in the sky with the seasons. The Caracol at Chichen Itza, Mexico, is especially well known as an observatory (Aveni, 2001). Ancient builders also choreographed hierophanies – manifestations of the sacred (Eliade, 1959) – by positioning windows, doorways, stairs, or other architectural elements to shape light or shadow at key times. Examples include the serpent shadow that appears at equinox sunset on the north stair of the Castillo, Chichen Itza. At Yaxchilan, the rising sun on the summer solstice shines through the doorway of a building situated deliberately to catch that light, to illuminate a statue of Bird Jaguar III,

a king of the city in the seventh century AD (Tate, 1985). At Palenque, the setting sun at winter solstice appears to dive into the tomb of seventh-century king Pacal the Great, in the Temple of the Inscriptions, while the last rays of light shine on an image of God L, a lord of the underworld into which the sun – and its earthly incarnation, Pacal – has descended (Schele, 1977). A small compound in Belize, aptly dubbed Quincunx for its layout, indicates that rural farmers, too, used architectural assemblages to monitor the sun and the seasons (Zaro & Lohse, 2005).

In the early 1990s, prominent scholars began to write of the sky as a map of Maya creation (Freidel et al., 1993). That is, they linked the acknowledged astronomical sophistication to its citation in ancient times and interpreted many instances of texts and imagery as relating primeval events set forth in the *Popol Vuh*. The latter is an eighteenth-century document committing to paper the oral accounts of creation, according to the Quiche Maya of highland Guatemala (Christenson, 2003; Tedlock, 1985). In it, sequential acts by named creator beings establish the universe as people know it. The objects and actors involved in the narrative enact its key episodes eternally in the night sky. The sun, moon, and Venus are exceptionally potent actors in shaping the Maya universe. But because the observed positions of astral bodies change with the hours and the seasons, the roles of particular stars and planets likewise shift in the course of the celestial narrative. For example, in the early predawn hours of February 5, the Milky Way appears to tilt erect, and according to this interpretation, the apparent movement is read as the raising of the World Tree and, with it, the primordial raising up of the sky. The same action separated the earth from the sky and divided the world into quarters (Freidel et al., 1993). Since that time, each properly established town and city has had its own World Tree, embodying its original counterpart at the center of the four quarters of the world (Coggin, 1982; Freidel et al., 1993). The materialization of an *axis mundi*, often as a tree, is well known in other Native American societies and in other parts of the world (Eliade, 1959; Tuan, 1977).

Political Ideology

If the foregoing had exhausted the factors in Maya city and town planning, all resulting plans would have been very similar, if not exactly the same. The observable variation in plan, however, can be understood as reflecting, as well, the competition, strategies, and assertions of Maya political history. Most fundamentally, the kings who ruled Maya cities sought not only to map the cosmos and situate their city at the center of the universe, but they also aimed to place themselves in cosmically sanctioned positions of authority, in order to personify creator deities – especially the sun – and re-enact the central events of creation.

Most commonly, this political positioning involved placement of palaces, tombs, shrines, and royal arenas in cardinal locations of strength. Perhaps the clearest material expression of such mapping is a series of complexes at Tikal, known as twin-pyramid groups. Flat-topped pyramids flank east and west edges of a spacious open platform that could accommodate gatherings of hundreds of the king's subjects. To the south is a low building with nine doorways into its single room. On the north edge of the platform is an unroofed enclosure containing a single pair of sculptures, the upright one of which displays a portrait of the king who commissioned the construction. Clemency Coggin (1980) describes this as a map of the cosmos, of the vertical path of the sun turned 90° on its side to accommodate the practicalities of construction. The two pyramids mark the sun's rise and set points, and the southern building houses the Nine Lords of the watery underworld. That position is at the nadir of the sun's path, and thus, metaphorically, "down." To complete the solar circuit, the northern building would represent "up" and would thereby place the ruler, through his portrait, in the sky, together with his ancestors and other powerful supernatural beings – especially his avatar, the sun, at its most powerful midday position overhead.

Tikal's twin-pyramid groups offer a key to understanding the significance of the pervasive north-south axis in Classic period civic centers (Ashmore, 1989; Ashmore & Sabloff, 2002).

Preclassic towns and cities, such as Nakbe or El Mirador (ca. 600 BCE–AD 250), tended to emphasize an east–west dimension and thus seem to focus on the rise and set points in the sun’s transit. The shift to a prevailing north–south axis in the Maya lowlands might reflect emulation of the great city of Teotihuacan, in central Mexico, and its Street of the Dead, or even the increasingly well-documented direct intervention of Teotihuacan lords and their emissaries by the late fourth century AD (Cowgill, 2000; Stuart, 2000). The significance of the north–south axis is arguably related to celebration of the Maya king as personification of the raised-up World Tree at the moment of cosmic creation (Ashmore, 2005; Schele & Freidel, 1990).

Then as now, to establish a place properly required dedication rituals. Individual buildings were “ensouled,” given life, and ultimately terminated, all by action of the city’s leader and his people (Gillespie, 2000). Indeed, Marcus, (1983) remind us that in the view of native peoples of Mesoamerica, the affiliation of people with king – or other community leader – was more important than place or territory in social identity. One “belonged to a particular region controlled by a specific native ruler, to whom he owed allegiance and tribute and from whom he received protection and civic-ceremonial leadership” (Marcus, 1983, p. 208). In that vein, planning a city, or reshaping its plan, likely involved public processions, along with sacrificial rites variably open to public view (Fash, 1988; Maca, 2006; Reese-Taylor, 2002), as evident from town city and town founding elsewhere in the world (Rykwert, 1988).

These political considerations shape the earlier statement that Classic-period views on the structure of the Maya cosmos were pervasive, across scale of material expression and social standing of those making the expressions. It therefore should not be surprising that planning is most obvious in the core of towns and settlements (Marcus, 1983). In the sixteenth century, Bishop Diego de Landa, the second Bishop of Yucatan, described Maya towns as concentric rings of settlement, with the leaders and the most important civic spaces at the center and

people and activities of progressively lower civic standing ever more distant from that center (Tozzer, 1941, pp. 62–64). Furthermore, according to Landa, “every town in Yucatan [also] had two heaps of stone ‘facing each other’ at each of four entrances to the town [which were] placed according to the four cardinal directions” (Coe, 1965, p. 100).

Analyzing Observable City and Town Plans

The foregoing principles were expressed in varied specific arrangements and at different scales. Reasons for such variation probably reflected, at least in part, strategies of the person or group in charge of the planning, and in the case of an ancient Maya city, that would have been the king. Changes in dynastic fortune, conquest, and usurpation would have allowed new rulers to rewrite not only textual history but also city plans (Jones, 1991; Sharer et al., 1999; Traxler, 2004). Classic Maya texts indicate that political alliances, warfare, and intrigue among royal houses altered individual polity fortunes repeatedly, although two “superstates,” Tikal and Calakmul, seem to have been enduring foci of lowland alliance networks (Martin & Grube, 2000).

At Tikal, for example, the aforementioned twin-pyramid groups reflect plans of dynastic heads in Late Classic times there, in at least the seventh through ninth centuries AD. Similar invocation and weighting of cardinal directions seems evident in the layout of the Great Plaza area of that city around AD 700, under the same ruling house. In that instance, the pyramids were mortuary shrines, and the bodies of royal ancestors literally lay buried in what mapping teams dubbed the North Acropolis – recognized now as truly a necropolis on the north. But civic constructions of that time had followed major political upheavals and separated the planners from antecedents of the Early Classic (ca. AD 250–600). In that earlier age, emphases on an east–west solar axis are evident in the principal orientation of buildings, where a solstice

observatory complex dominates the civic core (Laporte & Fialko, 1995).

The complex in question manifests a form established elsewhere by the Middle and Late Preclassic (ca. 850 BCE–AD 150), and its early expression is astronomically accurate in such locations as Group E at Uaxactun. Subsequent proliferation of so-called E-Groups across much of the Maya lowlands, however, “served as an architecturally standardized focal assemblage for integrating Late Preclassic and subsequently Early Classic Maya populations, first ritually and then dynastically” (Chase & Chase, 1995, pp. 100–101), and constituted citation and commemoration of the architectural form, more than functioning observatories (Aimers & Rice, 2006; Fialko, 1988). That is, as emphasis on the person of the king expanded, earlier foci of celebration received less attention, in architecture as in other material forms of expression. The picture of ideological transformation that emerges underscores the role of political affiliations, continuities, and disjunctions in shaping construction programs and the city planning of which those were part. The impact for observers today is that the shallower the history of a city is, and the more stable its ruling house, the more likely are we to discern intended civic plans from the cumulative constructions (Ashmore & Sabloff, 2002).

Again at Tikal, preference for north–south orientation was reiterated later in the eighth century as a grand cosmogram, extending a kilometer in each direction from the Great Plaza. That the “eastern” extension is not cardinally true likely reflects the presence of a swamp in that location, and without a modern map, the “inaccuracy” would not necessarily have been perceptible to participants in processions on the great roadways connecting the end points of the cosmogram. Similar cosmograms, at the same scale, are identified from about the same time at La Milpa, in northern Belize (Tourtellot, Wolf, Smith, Gardella, & Hammond, 2002), and at Copan, Honduras (Ashmore, 1991).

Each of these expansive expressions included paved roadways. These presumably served

processions as part of centering and recentering the city, whether allowing all to participate directly or maximizing privileged participants’ visibility to others assembled along the route (Maca, 2006; Reese-Taylor, 2002). The meaning of the city plan, however, would likely have been even more complex than suggested by the foregoing arguments. That is, while the proper disposition of royal precincts may have been paramount in some aspects of planning, there may have been complementary ways of “centering” the city or town. At Copan, for example, Maca (2006) suggests that periodic centering rituals involved progression along a path defining a rhomboid on the modern map of the ruins and neatly enclosing the area of densest Late Classic settlement. This kind of centering is not inconsistent with other aspects of planning, argued earlier as emphasizing a north–south axis of dynastic celebration (Ashmore, 1991).

Elsewhere, the scales of construction differed, as sometimes did the arrangement of positional symbolism. At Xunantunich, Belize, for example, Keller (2010) argues that the city plan is cruciform or a quincunx, cardinally oriented, and repeatedly given life by processions. As at Copan, the paths included paved roads, but the ones in this case were shorter in distance. Contrasts in scale at Xunantunich, Copan, and Tikal likely involved relative abilities to harness labor and material resources, the huge capital at Tikal differing most dramatically from the provincial city of Xunantunich. But Xunantunich differed from Tikal, as well, in the arrangement of plan elements. Both had strong north–south axes. As already noted, Tikal’s Late Classic plan featured varied scales of the “twin-pyramid group” directional symbolism, with rulers metaphorically apotheosized through their portraits in northern positions. In contrast, at Xunantunich, royal portraits and ritual observances seem to have been located more toward the south end of the axis, at the monumental pyramidal building known today as the “Castillo.” In this, and in overall appearance, the plan of Xunantunich is much more similar to those of its long-time overlord, Naranjo, and of Calakmul, the “superstate” far

to the north (Ashmore, 1998). Texts explicitly indicate inclusion of Naranjo in the extensive Calakmul alliance and assert that both were often, if not perpetually, in conflict with Tikal. It thus seems quite possible that the city plans of each place constitute nonverbal expression of political alliance at the point when the plan was commissioned (Ashmore & Sabloff, 2002).

In other places, town and city plans seem to reflect additional alternative models for assembling the elements described at the outset here. These distinct layouts, too, are ascribed to strategic choices and political affiliation. For example, de Montmollin (1995) describes a complex array of spatial arrangements in the settlements along the upper tributaries of the Grijalva River, in Chiapas, Mexico. None of them resembles the layouts described earlier, and de Montmollin attributes the regional variability, at least in part, to contrasting political histories of Maya and people of other cultural and linguistic groups resident in the area.

While Landa's concentric model for town layouts fits some pre-Hispanic settlements, like Classic period Dzibilchaltun (Kurjack, 1974), it has been rejected as a model underlying some other plans. Chase (1986) has written of the fourteenth-century site of Santa Rita, Belize – probably the capital of the historically known province of Chetumal – as organized in quarters but not concentric zones. For Copan, Stomper (2001) sees aspects of concentric settlement rings, quadrants, and the political upheavals of the eighth and ninth centuries as cumulatively shaping the plan of the city and the architecture designated by successive kings as the key symbolic components in the plan. This view differs from but is not incompatible with Ashmore's and Maca's views, described earlier. Once again, such assertions are more likely indications of the complexity of successive planning episodes and building programs in reflecting worldview than they are of any one analysis being either entirely adequate or entirely false.

That Maya cities and towns were planned seems clear (Andrews, 1975). Still to be explored

is the full range of expressions by which planners adapted and residents enacted the fundamental principles governing establishment of orderly town and city space.

See Also

- ▶ [Architecture of the Maya](#)
- ▶ [Architecture of the Maya: Public Architecture](#)
- ▶ [Astronomy in Mesoamerica](#)
- ▶ [Calendars in Mesoamerica](#)
- ▶ [City Planning: Maya City Planning](#)
- ▶ [Cosmology in Mesoamerica](#)
- ▶ [Knowledge Systems of Indigenous America](#)
- ▶ [Mathematics: Maya Mathematics](#)
- ▶ [Pyramids of Mesoamerica](#)
- ▶ [Temples of the Maya](#)
- ▶ [Time in Maya Culture](#)

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City Planning in Ancient India

Paul Gregory

As the birthplace of Indian culture, the towns of the Indus Valley represent an important and rich source of information concerning urban development in the Indian subcontinent. The Indus River is one of the largest and most important rivers in south central Asia. From its source in the Himalayan Mountains to its terminus in the Indian Ocean it traverses a course of over 2,000 miles. For millennia it has been an essential route for travel, trade, and communication and has been the source of much of India’s agricultural production. The valley which surrounds the Indus River has witnessed the birth, growth, and death of many cities.

Excavations of Indus towns have demonstrated the most ancient town planning in the world. The grid pattern (straight streets intersecting other straight streets at right angles) is among the most common and universal types of town planning. The discovery and excavation of the most famous of these sites, Mohenjo-daro, by Sir John Marshall (1931) and Ernst Mackey (1938) supported the contention of Dan Stanislovski (1946) that the development of the grid pattern in western societies – Greece, Rome, and Europe in the Middle Ages – can be linked directly to the development of town planning in the Indus valley.

A recent excavation on the Western plains of the Indus – the Rahman Dheri site – reveals a town plan from the early Indus period. This site comprises an area of roughly 22 ha and could have been home to 10,000–14,000 people. Radio carbon-dating of artifacts places development somewhere in the first half of the fourth millennium BCE. Rahman Dheri is built in the classic grid pattern. It is rectangular in shape surrounded by an immense wall and bisected by a major traffic artery which runs roughly southeast to northwest. Perpendicular to

this road exists a pattern of regularly occurring laneways which appear to create individual dwelling lots.

The successor to the plan of Rahman Dheri is thought to be the Surkotada site in Kutch which dates to ca. 2500–2000 BCE. Though smaller in scale than its predecessor the Surkotada site is built along the same grid pattern as Rahman Dheri. This settlement was enclosed by a stone rubble and brick fortifications. This produced two separate areas each of roughly 60 m².

Similar to Surkotada, only on a larger scale, the Kalibangan site was completely surrounded by an enormous rampart. This site, about 200 km to the southeast of Hirappa on the banks of the (now dry) Ghaggar river, was composed of two mounds. The smaller mound, named the citadel, was to the west and was roughly 240 m by 120 m. The larger mound, named the lower city, was to the east and measured 360 m by 240 m. The lower city demonstrates the grid plan divided into blocks of which the east-west side was roughly 40 m in width. The width of lanes and streets in the lower city ranges from 1.8 to 7.2 m. Interestingly each lane or street is some multiple of 1.8 m. This site is thought to date to the early Indus period, roughly 3000 BCE.

The evolution of Indus town planning reached its zenith at Mohenjo-daro. The town is geographically located on a floodplain of the Indus river; the city occupies about 1 km² – over five times larger than Kalabangan. The basic grid of Mohenjo-daro is about 180 m², subdivided into 16 sections of about 40 m². Mohenjo-daro existed from ca. 2500 to 2000 BCE. During this time it bore the brunt of often severe flooding, and as a result the original grid plan was often modified and transformed. The city itself was originally planned in the same way as Kalabangan: an oblong walled city divided into a citadel and a downtown area divided by an open space. Similar to its predecessor communities, the town plan of Mohenjo-daro indicates the same parallel grid street structure that has come to characterize urban planning in this region at this time.

As this brief history of the evolution of town planning in the Indus river valley demonstrates the grid pattern was commonplace. The importance of the Indus river valley communities to the historical development of culture and civilization in the Indian subcontinent and the East is well known. Stanisloski has suggested that the grid pattern form of town planning has its roots in the Indus valley. Parallel developments in Nepal, Sri Lanka (formerly Ceylon), Burma, Korea, Vietnam, and China also indicate how widespread the influence of the Indus river valleys communities were. It is suggested that this form of town planning was taken up by the Greeks, Romans, and other Western Europeans and eventually became a standard form of urban organization in Europe and the New World.

Excavations at and along the Indus River valley reveal cities strikingly similar in topography to contemporary Western European and North American cities. While some may suggest that the grid pattern evolved in a happenstance fashion without benefit of central planning or administration, substantial evidence exists to support the opposite point of view. First, the grid pattern can be seen in a variety of towns all along the Indus river, which existed and flourished over a several thousand year period. Second, the similarity between these towns and the general division between a lower city area suggests the development of town planning conventions as early as 2500 BCE. Third, there is a remarkable mathematical symmetry in Kalabangan where lanes and streets (which range from 1.8 to 7.2 m in width) all occur in multiples of 1.8 m.

The contribution of this historic period to the development of Western cities should not be underestimated. Much of what we take to be enlightened urban planning was considered over 4,000 years ago by planners in south eastern Asia.

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City Planning in Cambodia

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City planning in Cambodia has gone through four phases: (i) 800–1431 when Angkor was the capital of the Khmer empire, (ii) fifteenth to nineteenth century, (iii) during French colonial rule (1863–1953), and (iv) since independence.

City Planning at Angkor

The key concept that informed early Khmer city planning was the cosmological belief that symbolic correspondences existed between the divine macrocosm of the Hindu gods and the mundane microcosm. The Khmer believed that the flow of power from the former to the latter could be ensured by giving these correspondences material expression in the configuration of centers of power.

In Hindu cosmology, the gods live in a divine city atop Mount Meru, the axis of the world, presided over by Indra, king of the gods (Mabbett, 1983). The mountain is surrounded by annular seas beyond which are the continents of different shapes located in the four directions, the southern one being the triangle of India. The Khmer king was believed to be the representative of Indra on earth, presiding over his court in a city designed to replicate the divine city of Indra.

At the center of each of the sequence of royal cities constructed in the Angkor region, a temple mountain was built to represent Mt Meru. To the northwest stood the palace, while beyond were the fine wooden mansions of high court officials and further away the smaller houses of court retainers and artisans. Square walls surrounded the city, pierced by gateways in the four

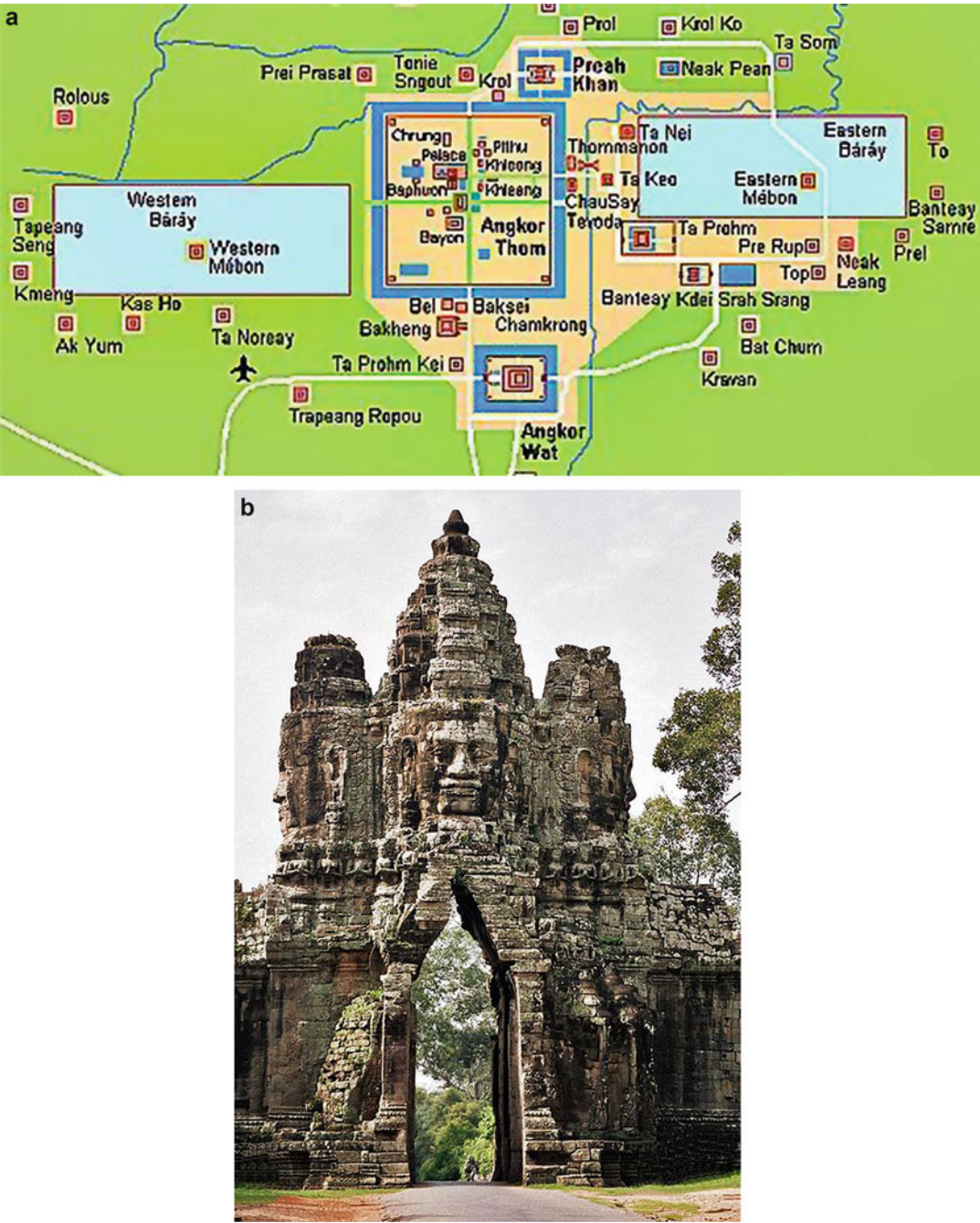
directions large enough for elephants to pass through, plus a fifth gateway reserved for the king. Beyond the walls, vast rectangular reservoirs (called *baray*) represented the seas ringing Mt Meru (Coe, 2003).

The last city, constructed by King Jayavarman VII in the late twelfth century, was Angkor Thom, “the great city”, with walls 3.3 km long on each side (Fig. 1a, b). The central temples of earlier cities had been dedicated to the great Hindu god Śiva, but Jayavarman VII was a Tantric Buddhist. His central temple, called the Bayon, still represented Mt Meru but was dedicated to the bodhisattva whose huge faces stare out in the four directions from each of its many towers and identified either as Lokeśvara, Lord of the Worlds, or Vajrasattva (Sharrock, 2007). The extensive palace complex with its private royal temple was situated as usual to the northwest of the Bayon, while to the east of the palace, high terraces looked out over a large public space where the king reviewed parades (Jacques & Freeman, 1997).

City Planning from the Fifteenth to the Nineteenth Century

Angkor Thom was abandoned following a Thai invasion in 1431. By then, the Khmer people had adopted Theravada Buddhism, the center of population and productivity had shifted southeast toward the Mekong Delta, and seaborne trade was expanding (Chandler, 1993). Although the great days of the Khmer empire had long passed, Khmer kings were still considered semidivine – not because they drew their power from Hindu gods but because according to Theravada belief, they had accumulated great merit in previous existences. Their right to rule was reinforced by the merit they continued to acquire by generously endowing royal monasteries (Tambiah, 1976).

The new capital was situated at the point where the Mekong, Bassac, and Tonle Sap rivers converge, forming “four arms,” in close proximity to a sacred hill known as the “Hill

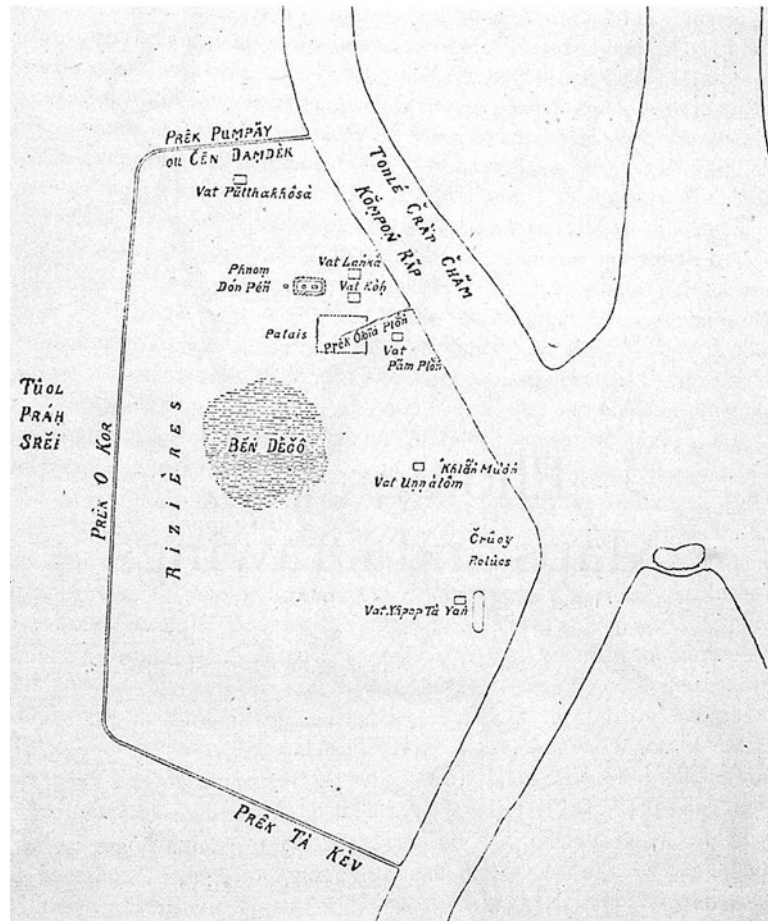


City Planning in Cambodia, Fig. 1 (a) Angkor Thom. (b) Gateway to Angkor Thom

(*phnom*) of (Lady) Penh,” which has given its name to the city of Phnom Penh. The new capital was not constructed as a square facing the four directions like Angkor Thom, but

much Angkorean symbolism survived. In the temple atop the sacred hill, four Buddhas stared out over the four directions, and the long royal title bestowed on the city again

City Planning in Cambodia, Fig. 2 Phnom Penh in the fifteenth century. A sketch by G. Coedes 1913 (BEFEO)



referred to it as the city of Indra (Stuart-Fox & Reeve, 2011). The Phnom was thus clearly conceived as representing Mt Meru, the axis of Buddhist cosmography.

The royal palace was located not northwest of the Phnom, however, but downstream to the southeast and surrounded by a protective wall. Three new royal monasteries were constructed nearby (Cœdès, 1913) to accentuate the king's merit (Fig. 2). Phnom Penh was already a trading port, with the commercial area located downstream from the royal enclave, in accordance with planning principles adopted from Tai custom (see entry on "City Planning of the Lao/Thai"). The city was surrounded by an earth embankment and a moat comprising three straight sections.

The new Khmer capital incorporated the proper symbolic relationships in its planning, but it was not well defended and prone to inundation. Over the next two centuries, Cambodia was ruled from two new capitals constructed upstream, first at Lovek and then at Udong, both of which retained elements of traditional planning. Only after a new external power, France, offered protection in the face of Vietnamese and Thai encroachment, was the capital moved back to Phnom Penh.

City Planning Under the French

In 1865, 2 years after the establishment of the French Protectorate over Cambodia, King

Norodom relocated his capital from Udong to Phnom Penh. With the exception of a small concession granted to the French adjacent to the *phnom*, development of the town proceeded by royal directive (Lamant, 1991). Sacred urban space was organized to reflect the Khmer conception of the divine power of the king, just as it had been at Lovek and Udong. In the process, a riverine market town built of wood and thatch and dominated ethnically by Chinese and Vietnamese traders was transformed into a Khmer royal capital.

French influence on town planning evolved toward the end of the nineteenth century as a consequence of France's increasing political authority. A series of conventions and other legal agreements progressively transferred power from the king and changed local laws. By June 1884, French representatives had assumed almost complete control of the city's administration after forcing a new convention on Norodom under which private land titles were introduced, a municipal commission was created, and the French assumed considerable control over the collection of taxes and the passing of legislation (Muller, 2006). This was critical for investment and for providing a framework within which Phnom Penh could be developed as an expression of French power and economic interests.

In 1889, under the guidance of Résident Supérieur Huyn de Vernéville, work began on creating a French administrative enclave. Buildings for public works, a police station, offices for the Résident, a bank, and a treasury were just some of the impressive constructions to appear in stone, which in function and style helped assert the power of the colonial government. A large canal dug around the French quarter further segregated the area physically and symbolically from the rest of the city.

The rest of Phnom Penh was similarly divided into "quarters" defined largely along ethnic lines, which reinforced the *de facto* geography of the city. Immediately south of the French quarter was the city's economic heartland, dominated by the Chinese, while close-by was the Vietnamese quarter. The colonial government encouraged

economic development through construction of a large covered market designed to move barter-based river trade on land, thus making it easier to both regulate and tax. By the end of the century, Chinese and French property speculators had fuelled a boom in the construction of shop houses that importantly provided confidence for the continued development of the capital.

The Cambodian quarter, centered on the royal palace, remained the cultural and spiritual center of Phnom Penh and indeed the kingdom (Fig. 3a, b). The royal Wats of Ounalom and Botum, the waters where the "four arms" converged and the sacred lake, were the sites of the rituals and festivals that went to the heart of what it meant to be Khmer. In the following decades, a museum, Pali school, a royal library, and the Buddhist Institute would reinforce the cultural orientation of the Cambodian quarter – and in Cambodian eyes, further reinforce the legitimacy of the monarchy.

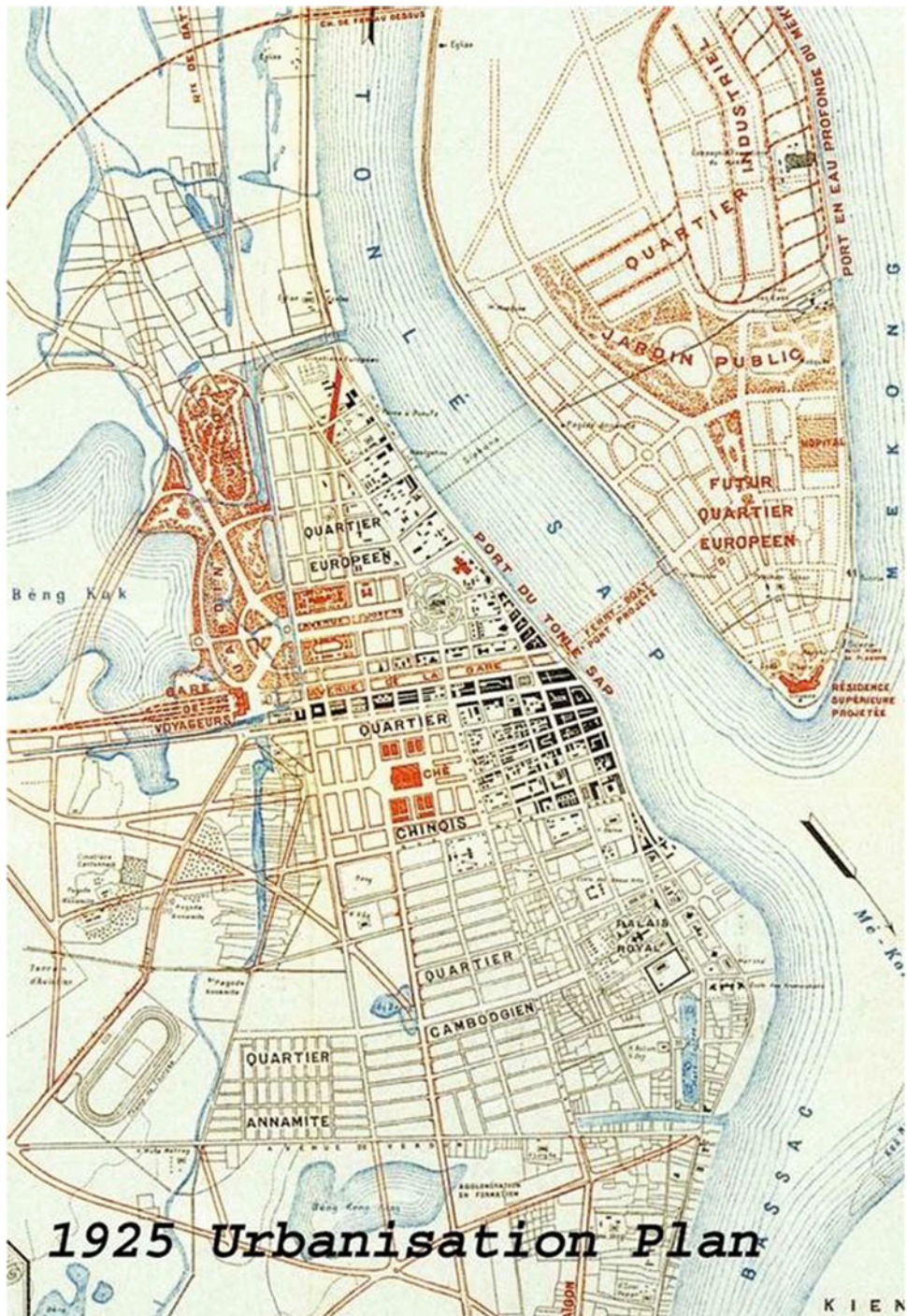
In 1925, Ernest Hébrard, an architect and town planner, formalized the layout of the city in his Phnom Penh Urbanization Plan (Fig. 4). The plan synthesized European concerns over hygiene and class/ethnic segregation with the need for modern infrastructure, economic zoning, and leisure space. Aided by the surveyors and engineers who had created firm footings from a flood plain, Phnom Penh developed rapidly to the north and west. By 1950, the framework, if not the substance of Hébrard's aspirational plan, had become a reality in the form of arterial boulevards, thus providing the foundation for a Controlling Plan that would help shape postindependence Phnom Penh (Igout, 1993).

Modern Cambodian City Planning: Sihanouk and Beyond

In 1953, town planning was not the first priority of newly independent Cambodia, nor its king, Norodom Sihanouk, but it remained a matter of interest and concern. Phnom Penh had been bequeathed an administrative infrastructure orientated toward France and an education system



City Planning in Cambodia, Fig. 3 (a) The royal palace c1934. (b) Phnom Penh c1934 looking north from the royal palace



City Planning in Cambodia, Fig. 4 Ernest Hébrard's Phnom Penh Urbanization Plan 1925

inadequate for the task of supplying the bureaucrats and technicians the country now required. Compounding these problems was a huge influx of rural migrants who had fled civil unrest in the countryside in the lead up to independence.

Initial development reflected these pressures and by the end of the decade, an ambitious program was underway for the construction of schools, universities, and ministries. A lack of space within the existing city forced expansion westward and many of these government buildings were constructed at the beginning of a 10 km boulevard linking the city with the airport. Early testament to the city's modernization was thus showcased to foreign visitors and diplomats. Less visible were the public housing projects in the newly created suburbs of Tuk Laak in the west and Tuol Kork further north.

Great strides were also made in road construction and public works, which essentially followed the Controlling Plan created by the Urban Technical Service in 1950. An uncompromising grid system of streets spread residential areas further west and south while a radial system of roads fanned out from Tuol Kork. Services also expanded to keep up with development. Drainage remained a priority, while water reticulation was extended. Between 1953 and 1965, electricity capacity increased fourfold. In just 17 years, from 1953 to 1970, Phnom Penh doubled its physical footprint (Fig. 5).

The most notable additions to the city were the formidable civic projects of the 1960s: the Bassac Riverfront development consisting of hundreds of apartments, a conference hall, and a national theater built on 24 ha of reclaimed land; the National Sports Complex – a vast sporting facility originally designed to host the 1963 Southeast Asian Games; and a myriad of other prestigious constructions (Fig. 6a, b). Conceived and designed by visionary Khmer architects such as Vann Molyvann and Lu Ban Hap in collaboration with foreign experts like the Russian engineer Vladimir Bodiansky, their work was made possible through the encouragement and generous patronage of Norodom Sihanouk, then head of state (Molyvann, 2003). Much of their work also reflected a style that was uniquely

Cambodian giving us what is termed today “New Khmer Architecture” (Grant-Ross & Collins, 2006).

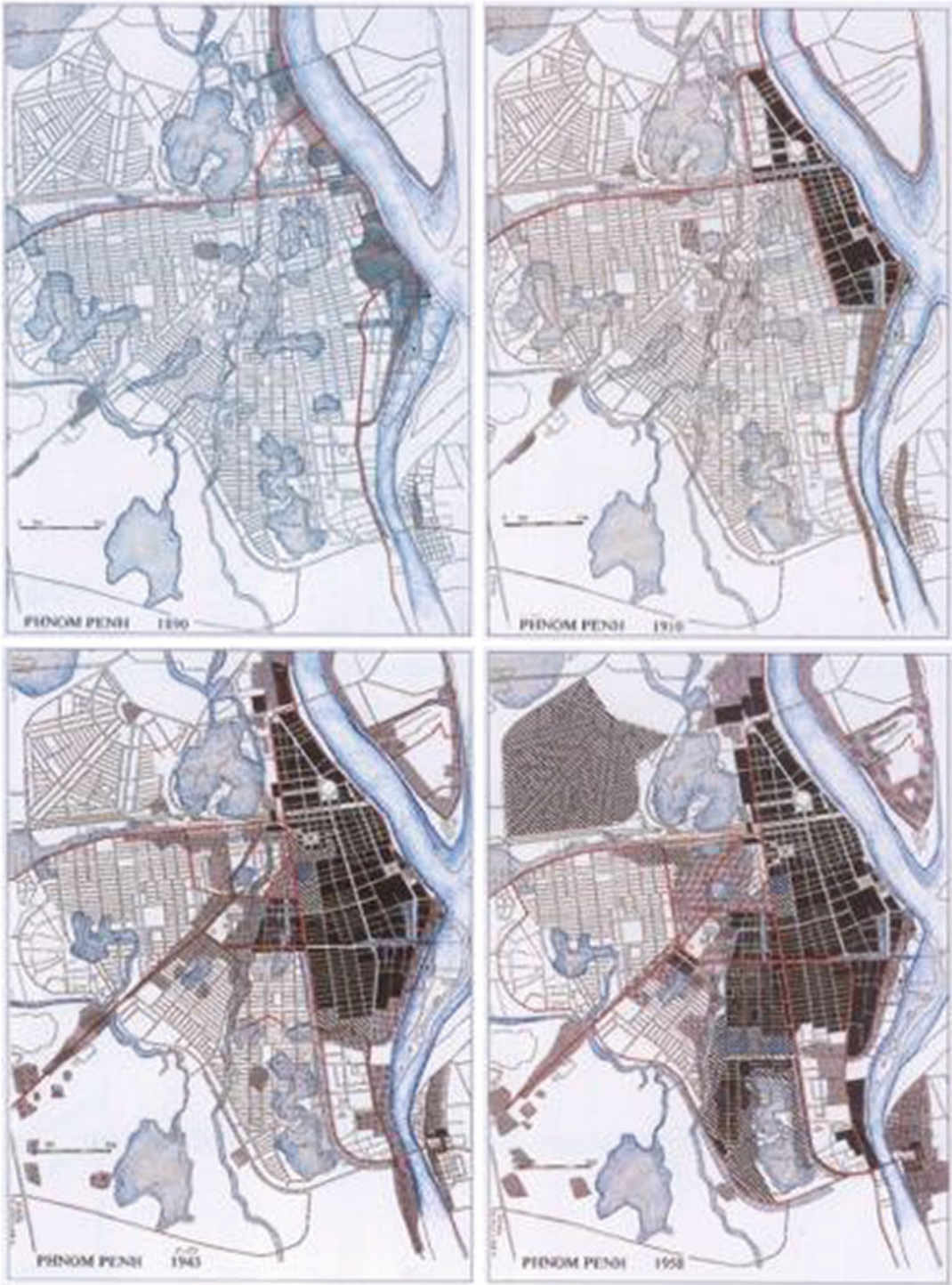
The departure of the French saw the administration move to new ministry buildings located throughout the city. The palace and royal temples, however, remained the locus of traditional culture, now united with the institutions of state power: the National Assembly, the Ministry of Justice, the Ministry of Foreign Affairs, and a new residence for the head of state (*Atelier Parisien d'Urbanisme*, 1997). The biannual National Congresses, which combined popular democracy with political theater, were held adjacent to the royal palace and reinforced popular belief in the relationship between Khmer culture and political power.

Migration into the capital from rural areas and provincial towns turned Phnom Penh into a Khmer city. The Chinese quarter persisted; however, as the center of commercial activity, its density alleviated to some extent by its westward extension and construction of new four- and six-story shop houses. New state-owned enterprises created on the northern and southern peripheries of Phnom Penh further encouraged the city's outward expansion (Goulin, 1966).

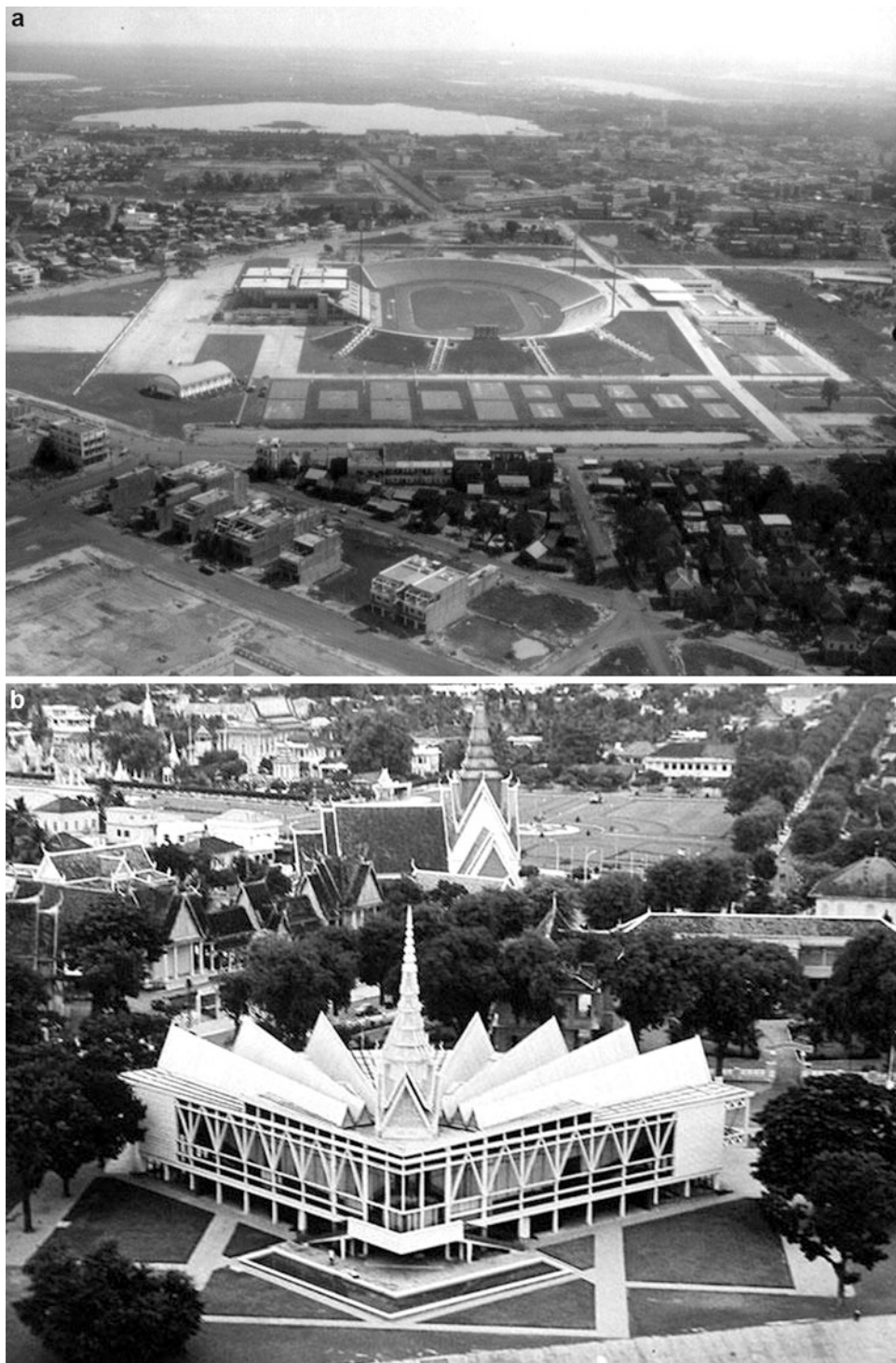
The rapid development and modernization of Phnom Penh owed a considerable debt to the vision and power of one man, Norodom Sihanouk (Osborne, 1994). Unfortunately, much of the development was overly ambitious, ill suited to the social and political aspirations of many of the city's residents and economically reckless.

Social tensions and economic difficulties contributed to the overthrow of Sihanouk's government in 1970, which plunged the country into civil war. Over the next 5 years, the population of Phnom Penh more than doubled as refugees poured in, and city planning was abandoned. Under the Khmer Rouge, the city was evacuated and was only slowly restored to life during the decade after the regime was overthrown.

With the United Nations administered peace agreement and 1993 elections, Phnom Penh entered a period of rapid and uncontrolled growth, which led to the destruction of many old buildings (Igout, 1993). A comprehensive



City Planning in Cambodia, Fig. 5 The progressive development of Phnom Penh, 1890, 1910, 1943, and 1958 superimposed on a 1968 outline of the city



City Planning in Cambodia, Fig. 6 (a) The National Sports Complex 1964. (b) Modern Khmer Architecture: Chaktomuk Conference Hall, inaugurated 1961

plan for the city's future drawn up by French urban planners was submitted to the Cambodian government, but not ratified. In the meantime, land grabbing, forced eviction, corruption, and profiteering continued to penalize the poor, shrink public space, pollute the environment, and destroy the city's architectural heritage.

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City Planning in India

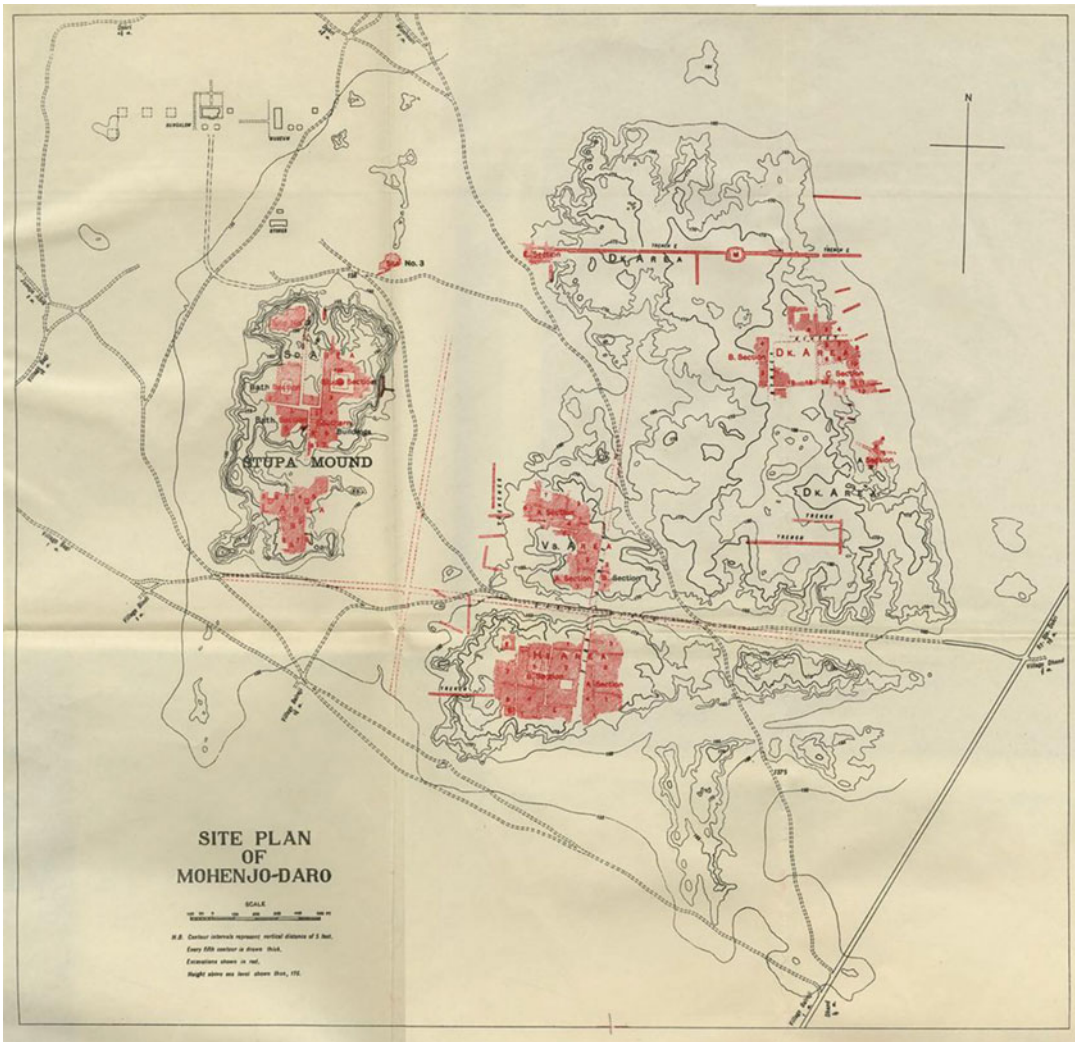
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Ancient Town Planning

Those in search of origins tend to trace the history of urban planning in India back to the cities of the Bronze Age Indus period (2600–1900 BCE). Defined by rectilinear streets and supported by a well-developed infrastructure, cities such as Dholavira, Ganweriwala, Mehrgarh, Harappa, and Mohenjo-daro (but particularly the last two) sit at the center of India's city planning heritage.

Excavations of Indus Valley Civilization archaeology, beginning at Harappa in 1921 and continuing today, have revealed a network of interconnected cities, towns, and villages stretching from the Arabian Sea to Afghanistan. Distributed along the banks of the Indus River and its present-day tributaries, the Sutlej, Jhelum, and Ravi Rivers, Indus Valley cities featured high-density residential areas, large-scale monumental architecture, and efficient water supply and sewage systems (Jansen, 1989). Streets were oriented to the cardinal directions and connected the gates of the fortified perimeter walls to the city center. The best preserved of the cities, Mohenjo-daro, covered some 600 acres and consisted of several spur neighborhoods to the south and east of the main body of the city (see Fig. 1; Marshall, 1931). Because of Mohenjo-daro's location on a floodplain, the buildings and streets were raised on mounds. A variety of materials were used to build Indus Valley architecture, including stone, mud, mud brick, and baked brick. The buildings and walls of Mohenjo-daro were constructed mostly of baked mud brick, supplemented with wood, Indus rushes, burnt brick, and mud. The city's extensive system of roads and lanes was fronted by mud brick walls interrupted only occasionally by doors, seldom by windows (Possehl, 2002, pp. 99–110).



City Planning in India, Fig. 1 Plan of Mohenjo-daro based on archaeological excavations conducted 1922–1927 (Marshall, 1931, endplate)

Mohenjo-daro's archaeological remains are dominated by the Mound of the Great Bath. Walls of baked brick braced this elevated area, which served as a platform for the city's symbolic architecture, including the so-called Great Bath, a large burnt brick tank surrounded by verandas, and the Warehouse, a single-story building constructed of wood with a mud-and-rush roof. Scholars suggest the two structures were located intentionally near each other. The warehouse stored objects for the personal use by the bath

keepers but probably also held goods to distribute as part of their role as patrons. Those responsible for the design of the Mound of the Great Bath understood the symbolic potential of anchoring the city with monumental architecture marked by privilege (Possehl, 2002, pp. 185–192).

At the same time, fieldwork carried out by archaeologists from the Rheinisch-Westfälische Technische Hochschule of Aachen under the leadership of Dr. Michael Jansen contradicts the long-held assumption that the urban form of

Mohenjo-daro and other cities of the Indus Valley Civilization derived from a master plan. It is more likely that the cities grew organically from smaller mud brick houses with accompanying storage areas (Kenoyer, 1998). However, the investment in water management systems, ranging from wells adjacent to housing compounds, to private baths in almost every house, to the monumental Great Bath, suggests that some forethought was given to both the engineering and symbolic potential of infrastructure.

At roughly the same time that the cities of the Indus Valley Civilization were being established in the northwest of the subcontinent, the earliest conventions governing urban planning appeared in south India. The first known reference to building – an invocation of the protector of the house, or *Vāstospati* – is found in the *Rgveda* (c. 1500 BCE), but the rules of building and design, known as the *Vāstu Śilpa Śāstras*, developed from the *Sthapatya Veda*, which was a subset of the *Atharvaveda* (c. 900 BCE) (Rao, 1998). The *Vāstu Śilpa Śāstras*, which can be understood as mental constructs or idealized building codes, covered at least five distinct subjects: engineering, town/urban planning, secular or civil architecture (middle-class residential buildings), palace architecture, and temple architecture (Shukla, 1993). Today, the *Vāstu Śilpa Śāstras* exist only in secondary form; major works such as the *Mānasāra* (450–550 CE) and the *Mayamatam* (1000–1100 CE) have been recompiled from fragmentary texts by scholars in the nineteenth and twentieth century.

Ram Raz was the first to publish a scholarly examination of the *Vāstu Śilpa Śāstras* in 1834, and it is from him that we receive many of our ideas about urban planning in ancient India. His treatise, based on the “shattered remains” of the *Mānasāra*, *Mayamatam*, *Kaśyapa*, and *Vaikhānasa*, described the rules of village and town planning that he had extracted from the remains of ancient texts (Raz, 1834, p. 3). According to his analysis, the 8th village is *cārmuca dandaka* (“that which resembles a staff”), *sarvatobhadra* (“in every respect happy”), *nandyāvarta* (“the abode of

happiness”), *padmaka* (“that which has the form of a lotus flower”), *sivastica* (“that which resembles the mystical figure so named”), *prastāra* (“that which has the shape of a conch”), and *chaturmukha* (“that which has four faces”). Despite the ornamental names, the plans adhered to a standard pattern, with rectangular or oblong site plans, situated such that the north–south line ran diagonally through the city (see Fig. 2). Each village had four gates that opened onto a network of parallel streets. Neighborhoods were zoned according to occupation, with residents separated along class and caste lines (Raz, p. 41).

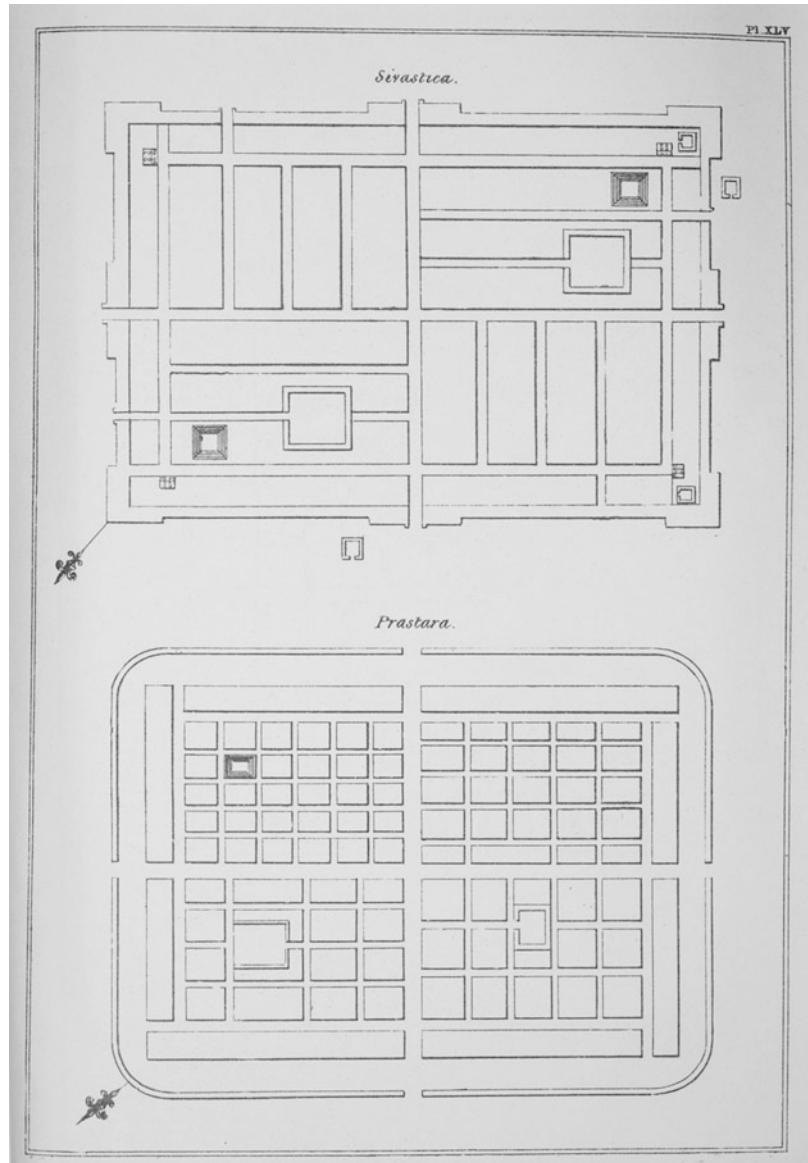
Early Modern Town Planning

Although sometimes formally similar to the idealized plans depicted in the *Vāstu Śilpa Śāstras*, the cities of early modern India (1562–1750 CE) were shaped more by social custom and landscape conventions than by Vedic theory. For example, the Timurid “fourfold” garden (*chārbāgh*) and hierarchy of the military camp both contributed to the organizational strategies of the Mughal imperial capitals of Agra, Shahjahanabad, Lahore, and Fatehpur Sikri. Most of the cities can be read as incursive forms, in that the Mughals established their political centers in established urban centers, reshaping the existing urban fabric to suit their needs.

The Timurid (or Khurasani) *chārbāgh* arrived in India with the conquest of the Lodi Dynasty by the first Mughal emperor, Zahir-ud-din Muhammad Babur (1483–1530). After vanquishing the Lodis from their capital in 1562, Babur laid out a *chārbāgh* on the banks of the Yamuna River opposite the Agra Fort (Thackston, 2002, pp. 363–364). The walled garden was defined by modular parterres separated by elevated walkways (*khiyābān*) and cross-axial canals (*nahr*). Typically anchored by a pavilion or tomb, the garden was experienced as a series of framed scenes and pleasurable sensory experiences. After 1558, when Emperor Akbar (1542–1605) moved the imperial capital from Delhi to Agra, the *chārbāgh* became the defining feature of the

City Planning in India,

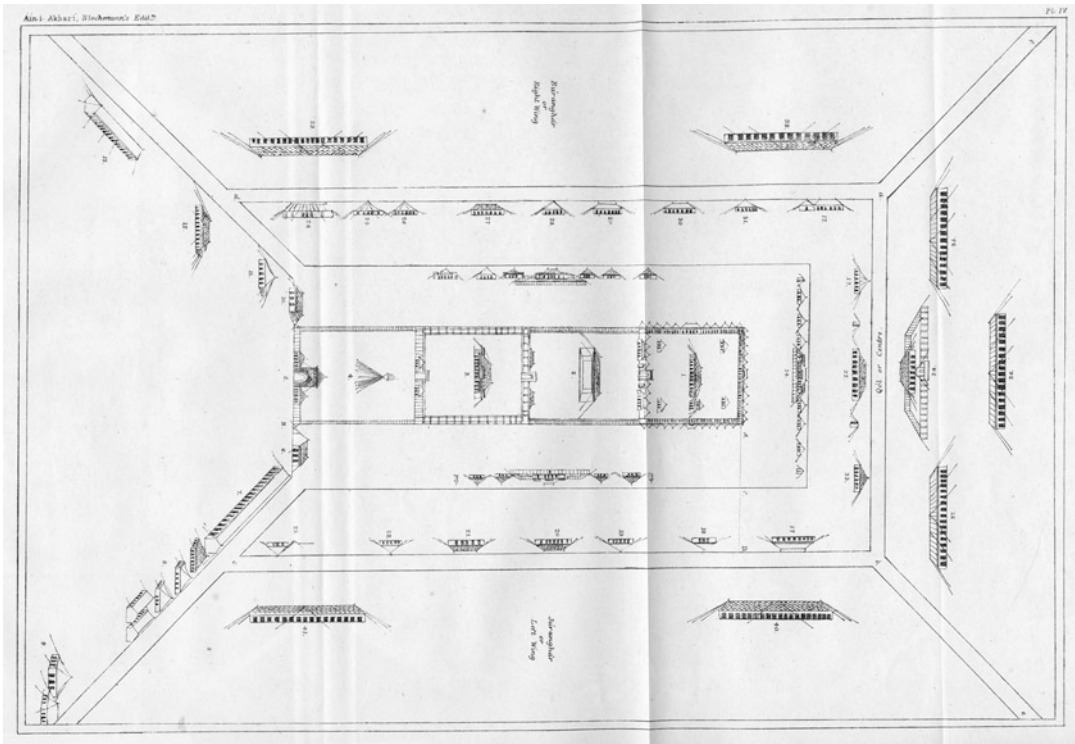
Fig. 2 Ideal plan,
prastāra-type village (Raz,
 1834, Plate 45)



riverbank city (Koch, 1997, 2005). Walled gardens disciplined the floodplains on both sides of the river. By the reign of Jahangir (1569–1627), some thirty-three gardens stretched along the river (Pelasaert, 1925, p. 5). The gardens provided privacy for political intrigue as well as sheltered social space for the women of high-ranking families.

As Ebba Koch points out, eventually the *chārbaḡh* was released from its riverfront

moorings, becoming the main module for planning imperial cities (Koch, 1997, p. 144). The riverfront gardens of Agra influenced the disposition of royal spaces in Delhi and Lahore (Rehman, 2009). Some Mughal cities exhibited a rectilinearity generated not by the adaptation of garden principles but by the influence of military encampments. The imperial camp was laid out in a rectangular scheme, with the most privileged spaces – the imperial harem, Hall of Special



City Planning in India, Fig. 3 The Mughal imperial encampment (‘Allami, 1873, Plate 4)

Audience (*Diwān-i Khās*), and Hall of Ordinary Audience (*Diwān-i Ām*) – occupying the center line. Entrance into these tents was via the Drum Room (*Naqqar Khāna*). Surrounding these tents on four sides, creating an effective barrier between the imperial halls and the encampments of the princes and amirs, were lines of storehouses, guardhouses, and kitchens. The higher the rank of the prince, the closer his tent could be pitched to the imperial center (‘Allami, 1873; Blake, 1991). The distribution of tents, arranged according to imperial rank, was replicated in the built environment of the great Mughal cities (see Fig. 3).

Founded c. 1571, Akbar’s second capital of Fatehbad & Saleem (present-day Fatehpur Sikri) lay west of Agra at a site sanctified by the tomb of the Chishti saint, Shaikh Saleem. Constructed on a ridge, the city was organized around multiple axes running parallel to each other. The inspiration for this arrangement came from the logic of the military encampment and the quadrilateral

form of the Hall of Ordinary Audience (Petrucchioli, 2007; Rezavi, 2013). Central to Fatehpur Sikri’s success was Akbar’s deployment of water management technology. Legend reports that Akbar abandoned the city because of water shortages, but recent scholarship on hydraulics indicates that the city was supplied with potable water by a large lake at Sikri (now dry) as well as a series of wells (*chāhs*) and stepwells (*bāolis*) (Petrucchioli, 2007; Rezavi, 2013). The extensive system of canals and quadrilateral reservoirs provided visual and aural delight to the city’s inhabitants while emphasizing the sharp lines of the architecture.

Perhaps the greatest Mughal imperial city, Shahjahanabad, was constructed by Emperor Shah Jahan (1592–1666) on the banks of the Yamuna River in Delhi. Shah Jahan, who had made limited improvements to the palaces and gardens of Lahore and Agra, decided to build a new capital c. 1638. The plan of Shahjahanabad drew on both garden and encampment

precedents. The city was constructed from east to west, beginning with a palace sector on the western bank of the Yamuna (Krafft & Ehlers, 1995). The city was walled in 1651–1658. Monumental gates in three walls (the fourth wall was fronted by the river) controlled vehicular and pedestrian access to the inner neighborhoods and imperial palace. Although irregularly shaped, Shahjahanabad was centered on the long axis of the main bazaar street, Chandni Chowk, which ran from the Kashmiri Gate in the west to the Lahore Gate of the Red Fort (Lal Qila) in the east. Built in 1650 by Jahanara Begum, Shah Jahan's eldest daughter, Chandni Chowk was 40 yards wide and 1,520 yards long (Blake, 1991, p. 55). A canal, flanked by two rows of streets, ran the length of the bazaar. Despite the number and variety of shops lining Chandni Chowk, the street front maintained an architectural uniformity, with roof lines kept at a uniform height.

Shahjahanabad's social and physical fabric was largely determined by the same hierarchical relationships that governed the military camp. The disbursement of land to princes and amirs for the construction of walled courtyard mansions (*havelis*) came by imperial grant. In return for land revenue, nobles were expected to provide loyalty and military support to the empire. Daily life in the *haveli* was shaped by hierarchical relationships as well, as each amir sat at the apex of a patriarchal pyramid. The body of the pyramid, which comprised laborers, artisans, soldiers, and servants, could encompass thousands of individuals, all living within the walls of the compound (Hosagrahar, 2001).

Ostensibly an imported Mughal form, the *chārbāgh* also affected subimperial urban planning. For instance, the city of Jaipur, founded in November 1727 by the Rajput king Sawai Jai Singh II (r. 1699–1743), owes it rectilinear form to the garden at its center. Established c. 1713, Jai Niwas Bagh, a quadripartite garden that measured some 1,740 ft long (exclusive of its water tank, Talkatora) and 450 ft wide, served as the module for the city's neighborhoods. As the city grew, boulevards and bazaars were laid parallel to Jai Niwas Bagh's walls. The distance between

the roads and size of the blocks took their cues from the garden's scale and proportions (Johnson-Roehr, 2013).

Colonial Town Planning

With European settlement in India came European spatial structures. The earliest colonial towns were military suburbs, built beyond the walls of extant cities such as Lahore, Ahmedabad, and Bangalore. These planned enclaves, known as cantonments (or civil lines when designated for use by senior officers), followed military logic, with spaces defined in terms of rank and race. Streets were ordered and regular, laid out in parallel lines and gridiron formations, and were typically oriented to the cardinal directions. Often the plan centered on a park (*maidan*), which was in turn defined by the structure of a significant cultural institution, such as an Anglican church. Senior officers lived in the center of the cantonment; residences of lesser officers surrounded this core according to military rank. Native troops – infantry and cavalry – were housed in barracks at one end of the cantonment, while British troops occupied the opposite reach.

Cantonments and civil lines were intended to segregate European (read: white, British) military personnel from the perceived threats of Indian life (Cherian, 2004; Glover, 2008; Wald, 2012). The suburbs were functionally zoned, with residential spaces separated from stables, markets, and rifle ranges, but they were also arranged so as to separate “camp followers” (water carriers, cooks, petty officers, etc.) from British soldiers. Laws such as the Cantonment Act of 1864, which governed the sale of alcohol and drugs within cantonment markets, and the Contagious Diseases Acts of 1864, 1866, and 1869 reassured an anxious British ruling class that contagion could be contained through urban planning and legislation.

Recent scholarship demonstrates that the notion of a “white town” was in large part a fiction, maintained by the British as means of coping with the perceived difficulties of their

daily lives (Chattopadhyay, 2000). In some instances, local agents were deeply embedded in the process of shaping the city. This was particularly true in colonial Bombay, where Indian philanthropists contributed to the design and construction of civic and public institutions. The construction of the Gothic Revival buildings at the University of Bombay (Mumbai), Crawford Market, and the School of Practice (now Sir J. J. Hospital), buildings which formed the core of the city's colonial landscape, was made possible only by large donations from noted Parsi philanthropists such as Sir Jamsetjee Jejeebhoy (1783–1859), Sir Cowasji Jehangir Readymoney (1812–1878), and Premchand Roychand (1831–1905) (Chopra, 2011).

The most dramatic example of colonial urban planning came with the George V's proclamation at the imperial durbar of 1911 regarding the imminent transfer of the British capital from Calcutta to Delhi. The announcement was an attempt to undo the political damage done to the Raj by the Bengal Partition in 1905. The partition had aimed to cool nationalist fervor by dividing the region according to religion (Hindu and Muslim). However, it instead gave the independence movement a concrete point of contention. As part of the larger project of creating a new capital at Delhi, the British government reunified Bengal and established Calcutta as a provincial seat, hoping to quell the growing discontent of the Indian National Congress.

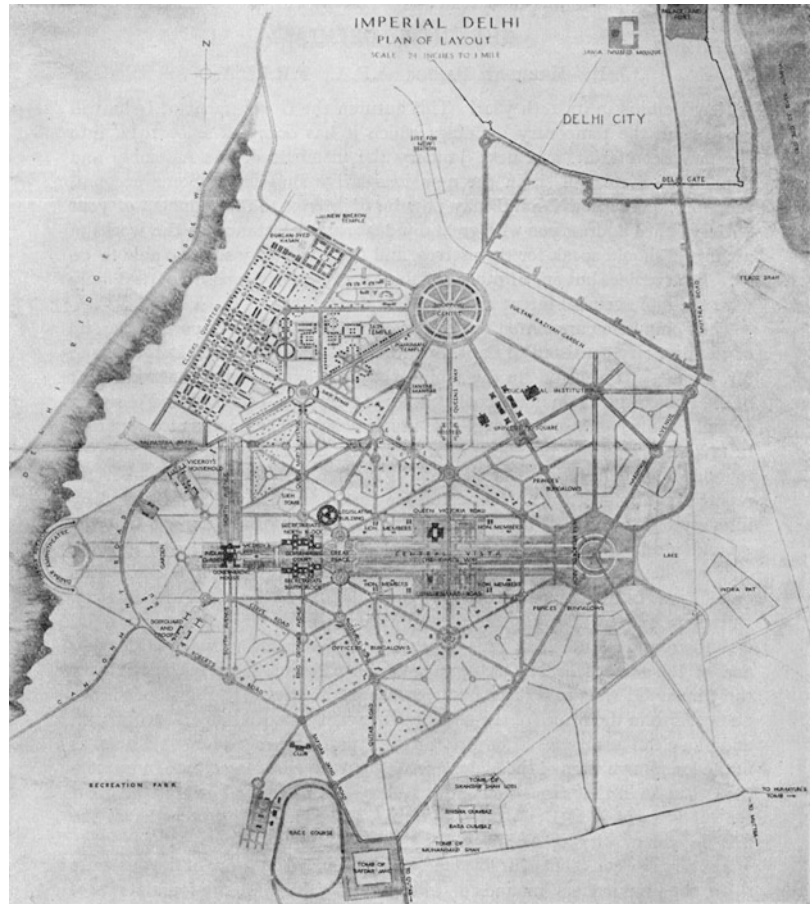
Drafted initially by the trio of British architect Edwin Lutyens, London County Councillor George Swinton, and civil engineer John Brodie, the plan of New Delhi drew equally on the Garden City and City Beautiful movements, both of which responded to the industrialization and urban crowding of the late nineteenth century. Garden City theory evolved largely in the British context. Initiated in 1898 by Ebenezer Howard, the movement valorized the self-contained satellite city (Howard, 1902). Envisioned as a blend of the best elements of town (cultural institutions, good wages, employment) and country (fresh air, beauty, low rents), the Garden City was proximate to a major city but surrounded by a greenbelt and economically self-sufficient.

The aesthetics of the Garden City echoed those promoted by City Beautiful advocates, whose work came to full fruition in the United States. Led by architect Daniel Burnham and landscape architects Frederick Law Olmsted, Sr. (and later Frederick Law Olmsted, Jr.) and embraced by firms such as McKim, Mead and White, the City Beautiful movement prized Beaux-Arts architecture and planning principles (Olmsted, 1911). Put on public display for the first time in the plan and pavilions of the 1893 World's Columbian Exhibition, the movement's neoclassical buildings and cross-axial boulevards soon dominated American urban planning. Between 1902 and 1905, Burnham's office created City Beautiful plans for Washington, D.C., Cleveland, Manila, and San Francisco (Burnham & Bennett, 1909). Regularity, proportion, and a Beaux-Arts formality were combined with transportation management and the restructuring of leisure spaces to create a largely horizontal, largely neoclassical, modern city.

The New Delhi plan combined these two schools of thought, calling for an expansive urban development south of walled city of Shahjahanabad. The desire for political pomp and drama led to a plan featuring broad boulevards pinned by outsize traffic circles (see Fig. 4). Although the scale of construction makes it difficult to discern at ground level, New Delhi was oriented along a west–east ceremonial axis, Rajpath (today's Central Vista). At the west end of Rajpath stood the Viceroy's Residence (today's Rashtrapati Bhavan, or President's Residence). The Secretariat (today's North and South Blocks) flanked Rajpath just east of the Viceroy's Residence. Originally, a commemorative column was to mark the east end of the ceremonial axis. Today, India Gate rises at the center of the hexagonal roundabout that marks the boundary between the colonial development and the ancient city of Delhi as represented by the Purana Qila.

Several village settlements were displaced to build the city, but in an attempt to legitimate the British claim to rule, several Mughal monuments were incorporated into the plan. The southern terminus of the city was marked by Lodi Gardens

City Planning in India,
Fig. 4 Layout of New
 Delhi (Baker 1926, p. 774)



and the mid-eighteenth-century Safdarjung's Tomb. The remnants of the Jantar Mantar, an astronomical observatory constructed by Sawai Jai Singh II, were turned into an archaeological park just south of New Delhi's original commercial circus, Connaught Place. To the east of New Delhi were Purana Qila and Firoz Shah Kotla. The northern boundary of the city was controlled by the walls of Shahjahanabad.

Although New Delhi was the most visible evocation of Garden City theory in India, the movement shaped the work of other colonial era planners as well. For instance, Patrick Geddes, who composed town planning reports for some eighteen Indian cities between 1915 and 1919, promoted many of Howard's "town and country" ideas (Geddes, 1918; Tyrwhitt, 1947). In the typical Geddes planning report, the emphasis was on open space, gardens, and playgrounds, and the

retention (or recreation) of the village scale in the urban environment. Like many modernists, Geddes placed his faith in the diagnostic survey, considering it key for planning "the right places for each sort of people; places where they will really flourish" (Geddes, 1915a, p. 91). A thorough study of "the whole set of existing conditions" would permit British and Indian rulers to conduct what Geddes described as "conservative surgery," or the modification of existing urban fabric through targeted, rather than wholesale, demolitions or implementation of gridiron plans (Geddes, 1915b, p. 17).

Modern Town Planning

In the Independence era, Indian town planning was shaped by two forces: disaster management

(the urgent need to house post-Partition refugees) and urbanization (as a factor of and response to planned industrialization). In this setting, urban planning was intertwined with development discourse and a valorization of “scientific” management of human and material resources.

Exemplary of this approach were the steel towns and political capitals planned with the input of Otto Koenigsberger (1908–1999). Koenigsberger, who worked as the Government Architect for Mysore before accepting an appointment as the director of Housing for the Government of India, consulted on the plans for several new towns, including Jamshedpur, a company town managed by Tata Iron and Steel Company Limited (TISCO), and Bhubaneswar, the new capital of the state of Odisha. Koenigsberger’s interventions at Jamshedpur (1943) and his plan for Bhubaneswar (1949) relied on the fusion of two devices: the *neighborhood unit*, a design module promoted by American planner Clarence Perry but used most recently in the 1943 Plan for Plymouth, England, and the *linear city*, which called for the distribution of neighborhood units on either side of an arterial road. Koenigsberger argued that the neighborhood unit, which could contain houses and services to support up to 18,000 people, would most closely replicate the physical and social conditions of the village. By distributing the neighborhood units along a main artery, he hoped to keep fast-moving traffic out of the residential areas while providing citizens access to undeveloped green space on the outer edge of the neighborhoods (Koenigsberger, 1952).

Koenigsberger’s town plans competed for attention with the urban initiatives conducted in the Punjab, namely, the modernist state capital, Chandigarh. With the partition of India and creation of Pakistan also came the division of the Punjab. Lahore, the historical capital of the region, fell outside India’s new boundaries. In 1948, the Government of Punjab appointed a committee to assess existing towns for their suitability as a new capital. The committee

rejected all the candidate towns and hired the American firm of Mayer and Whittlesey (later Mayer, Whittlesey and Glass) to prepare a master plan for a new city. Chandigarh, a fully planned city at the foothills of the Himalayas, would serve as Punjab’s political capital, but it was also meant to convey India’s modernist aspirations to the world at large.

The first master plan was drawn up by Matthew Nowicki, a faculty member of the North Carolina State College School of Design who was an associate at Mayer and Whittlesey. The fundamental form giver of the city was to be the *superblock*, a walled, self-sufficient neighborhood unit consisting of low-rise single-family dwellings and terraces clustered around a central market-cum-service center. Each superblock contained four neighborhoods, the residences of which were tied to the government pay scale. Three neighborhoods in each block were designated for lower- to middle-class government workers; the fourth was prepared for the wealthier employees. This rationalization of space into a system of superblocks was balanced by Mayer and Nowicki’s incorporation of the site’s topography into the plan. The boundaries of the city were formed by the paths of two rivers, and two drainage valleys within the city proper were to be retained as green space that flowed through the superblocks. The major boulevards would be curvilinear, echoing the riverine topography (Evenson, 1966, pp. 19–24).

The Mayer and Nowicki plan was abandoned by the Government of Punjab after Matthew Nowicki’s death in a plane crash in August 1950 (Mumford, 1954). A new design team, lead by Le Corbusier, Pierre Jeanneret, Jane Drew, and Maxwell Fry, took over the task of creating and implementing a master plan. The European team retained several features of the Mayer and Nowicki plan, such as the superblock (rechristened as a *sector* and re-proportioned according to the golden section), but the sectors were framed by a more rigid, straight-line city structure (Koenigsberger, 1953; Perera, 2004). The

gentle curves proposed by Mayer and Nowicki were replaced by a system of boulevards that adhered to Le Corbusier's theory of "the Seven Vs" (*les sept voies*, the seven ways). The Seven Vs sorted traffic according to speed, limiting high-speed vehicles to arterial roads (V1) and major high-speed boulevards (V2) and shunting slower traffic to pedestrian and bicycle paths (V7 and the newly invented V8) (Le Corbusier, 1961). The final city plan was determined as much by the relationships between automobile and pedestrian, point of origin, and destination, as it was by the city's political purpose.

Many of Chandigarh's major buildings were completed by a cadre of Indian architects, designers, and planners who worked under the guidance of M. N. Sharma. After Pierre Jeanneret returned to Europe, Sharma took control of the project, becoming the first Indian Chief Architect of Chandigarh. Aditya Prakash, A. R. Prabhawalkar, U. E. Chowdhary, J. S. Dethe, B. P. Mathur, and N. S. Lanbha, among others, brought to completion theaters, factories, educational institutions, and hostels.

Although Chandigarh influenced Indian city planning, serving as a model for other post-Partition capitals such as Gandhinagar, it played little role in one of the country's largest urban development initiatives, the planning and construction of Navi Mumbai (New Bombay). Bombay had long suffered from a land shortage. The original seven islands of the city had been brought together as one through various land reclamation projects in the nineteenth and twentieth centuries, but no one project was capable of changing the basic topography of the city. In post-Partition era, when the city experienced an influx of refugees, the solution had been to retain the industrial center in the south of the island while expanding residential districts in the north. This created increasingly lengthy commutes that, which were often made longer by an overburdened infrastructure. Many workers chose to live closer to their place of employment in the south of the island, but unable to

afford property, they resorted to squatting on open land.

By the 1960s, it was clear that northern expansion was reaching its limits. A number of solutions had been proposed at the city and state level, but none had relieved the pressure on the north-south transportation corridor or the densely populated slums in the center of the city. In 1964, architect Charles Correa, together with engineer and planner Shirish Patel and structural engineer Pravina Mehta, submitted a proposal to the Bombay Municipal Corporation. In order to relieve the pressure on the north-south corridor, they suggested the city develop its east-west axis. The city should look east, across Bombay Harbor, to the mainland, where there was space for new construction. While the manufacturing heart of the city could remain on Bombay Island, government offices, the shipping industry, and white-collar workers would move across the water to New Bombay (Patel, 1997).

The proposal made by Correa, Patel, and Mehta reached the public courtesy of *Marg*, a magazine dedicated to both the preservation of traditional arts and the dissemination of modernist theory (Correa, Mehta, & Patel, 1965). A mixture of romantic dreaming and rational planning, the proposal garnered public approval, so much so that by 1971, the City and Industrial Development Corporation (CIDCO) was formed to build New Bombay. Charged with creating residences and infrastructure to support an initial population of four million, Correa, Patel, and Mehta, in concert with Chief Planner, R. K. Jha, drew on Ebenezer Howard's Garden City theories. Enough land was acquired to establish 14 satellites towns (or nodes), connected with a network of new infrastructure (highways, rail lines, bridges). The development of housing (low- and mixed-income cluster developments, luxury high rises) and service sectors (banking, hotels, markets) was divided between private parties, and the Navi Mumbai Municipal Corporation (NMMC) was established in 1991 to support the construction of the city.

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City Planning of the Lao/Thai

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The closely related dominant ethnic groups in modern-day Laos and Thailand both belong to the broader ethnolinguistic group of people speaking Tai languages that extends into north-western Vietnam and southern China. Small bands of Tai began migrating out of southern China into what are now Laos and Thailand from around the eighth century on. As they took possession of fertile river valleys, they established small principalities (called *muang*) dominated by powerful aristocratic families who differentiated themselves from the commoners over whom they ruled (Condominas, 1990). These social distinctions determined how their principal settlements were planned, in relation to the flow of the rivers on which they were constructed.

In northern Laos, the Lao displaced Mon/Khmer-speaking subsistence farmers. But further south in Laos and in northern and central Thailand, Tai expansion encountered advanced civilizations in the form of Mon and Khmer kingdoms, whose capital cities incorporated quite different planning principles. Lao, and more especially Thai, city planning evolved as an amalgam of traditional Tai and borrowed Mon/Khmer organizing principles, which in turn derived from both Hindu and Theravada Buddhist cosmological beliefs.

The Principles of Traditional Tai Planning

The Tai peoples were originally animists. They believed that the natural world was inhabited by a vast array of spirits (known as *phi*), which needed to be propitiated. Particularly dangerous were dragon-like monsters called *ngeuk* that lurked in the rivers in which they fished, tipped

over canoes, and sucked the blood from the drowned. *Ngeuk* that accepted Buddhist teachings, however, became protective *naga*, about which an extensive mythology was developed (Ngaosrivathana & Ngaosrivathana, 2009; Fig. 1).

Rivers were the life blood of the migrating Tai, providing water for wet rice irrigation, a principal source of protein, and means of transportation. The direction of flow of the river was thus more important for them than the cardinal directions. Settlements were built along river banks, with the roof beams of all houses parallel to the direction of flow (Clément-Charpentier & Clément, 1990). Upstream took precedence over downstream.

Tai social structure was patrilineal and hierarchical. Tai society comprised three social groups: an aristocratic ruling family clan, the commoner farmers who provided labor in return for protection, and any non-Tai who attached themselves to the settlement. Settlement patterns reflected these social divisions. The houses of the ruling clan were located upstream; Tai commoners were grouped downstream; and further downstream again non-Tai were permitted to build their houses and conduct trade.

Narrow river valleys provided limited land for rice cultivation. Younger sons of the ruling clan were therefore encouraged to lead a few retainers in search of new land, usually further downstream. On riverine plains, larger settlements developed, which became the centers of small principalities (*muang*). In this way, the Lao filtered down the fast-flowing tributaries of northern Laos until they reached the mighty Mekong River, the mother of waters. At the junction of the Nam Khan River and the Mekong, a larger plain set within an amphitheater of hills provided resources for a more extensive polity. Here the Lao founded their royal capital (Stuart-Fox, 1998).

Luang Prabang, meaning city of the sacred Phra Bang Buddha image, was not originally so named. Not until centuries after the Lao had established their capital on this site did they convert to Theravada Buddhism. The city they built reflected Tai concepts of social order. The royal

City Planning of the Lao/Thai, Fig. 1 A protective *naga* and a river monster or *ngeuk*



City Planning of the Lao/Thai, Fig. 2 Xiang Thong temple, Luang Prabang



compound was located at the tip of the peninsula formed by the confluence of the Nam Khan and the Mekong. Downstream along the Mekong were the houses of minor aristocrats and court officials and beyond them the houses of

commoners, mainly palace servants and artisans. Downstream again, beyond the city wall, were pottery kilns and lodging for the Mon traders who made their way up the Mekong, bringing with them their Buddhist beliefs (Fig. 2).

City Planning in Northern and Central Thailand

By the early thirteenth century, the middle reaches of the Mekong and Cao Phraya river systems had been incorporated into the Khmer empire, ruled from Angkor. Further north was the Mon kingdom of Haripunjaya, with its capital at Lamphun. Both employed Tai as mercenaries, but by the end of the century, the Tai population had increased to the point where their chieftains were able to seize power.

The cities they occupied embodied Khmer and Mon principles of city planning (see “► [City Planning in Cambodia](#)”). Khmer cities incorporated Hindu cosmological symbolism. They were square, with outer walls facing the four directions, each with a gateway in the middle leading to a central temple symbolizing Mount Meru, the *axis mundi*, in which usually the god Siva was worshipped. A separate gateway reserved for the king led directly to the royal palace, located just northwest of the temple mountain. Mon cities placed less emphasis on the four directions and more on the need for the king to demonstrate the great merit that for Buddhists legitimizes his power. The king’s palace replaced Mount Meru at the city center, with royally endowed temples in close proximity.

Through contact with the Mon to the south and Burmese to the west, the Tai *muang* of Laos and northern Thailand adopted Theravada Buddhism while retaining popular belief in *phi*. King Mangrai founded the Kingdom of Lanna (“a million rice fields”) in 1262, with his capital at Chiang Rai, built in accordance with Tai planning principles on the south bank of the Nam Kok River. In 1296, however, Mangrai began construction of a new capital, Chiang Mai, meaning literally the “new city,” on the Nam Ping River further south, which incorporated Mon/Khmer city planning (Wyatt & Wichienkeo, 1995).

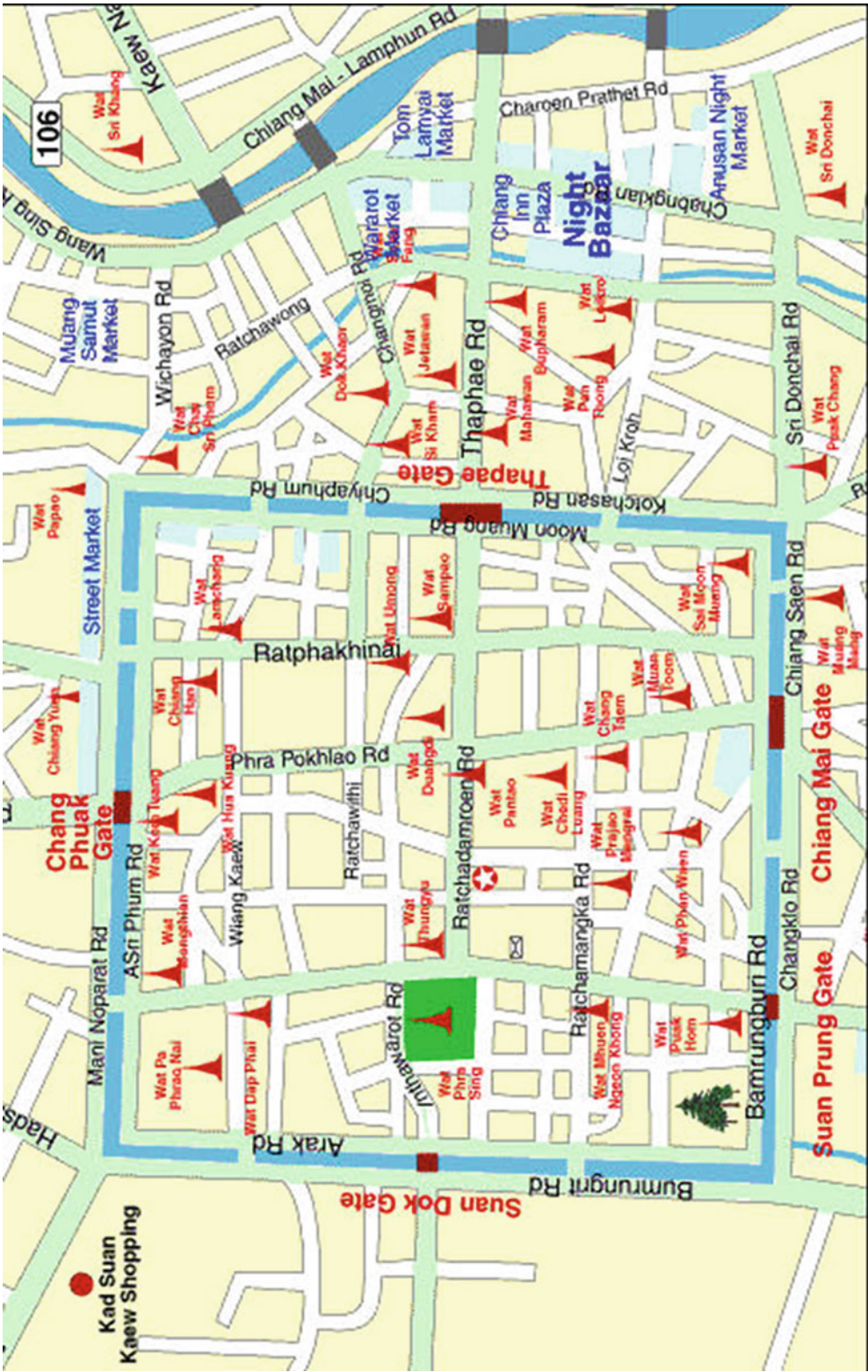
Chiang Mai was not built on the river, like Luang Prabang, but a short distance away from it with an outer wall and moat. The city was square, with sides 1.5 km long aligned with the four directions. The palace compound was

located near the city center, with the principal royal monasteries close by. Walls to the east, north, and west were pierced by central gates that led directly to the palace, but the south wall had two gates, bringing the total to five, the same number as the great Khmer city of Angkor Thom. The fifth gate was not restricted to royalty, however, but rather gave access to the commercial area located, in accordance with Tai principles, outside the wall and downstream (Fig. 3).

Chiang Mai was the first new city built by the northern Thai to combine borrowed Khmer principles of city planning with Mon Theravada Buddhist and traditional Tai concepts. Elsewhere in Thailand, Tai conquerors occupied existing Khmer provincial towns like Lopburi and Sukhothai. In later Thai capitals, the Khmer model still strongly evident in Chiang Mai was abandoned, leaving Theravada Buddhist and traditional Tai principles to dominate.

Ayutthaya was built on an island artificially created by joining up the Lopburi and Pasak rivers at their junction with the Chao Phraya. Though the palace compound has square outer walls, the city itself relied for protection on its river perimeter. The four directions played no part in the city plan. Nor was the royal palace at its center. In accordance with Tai planning principles, the palace was located near the bank of the most upstream part of the Chao Phraya River, surrounded by royal temples. The commercial areas where Chinese and European traders were allowed to take up residence were situated downstream (Garnier, 2004; Fig. 4).

When the Thai capital was moved to Bangkok early in the nineteenth century, the royal palace was again located close to the river and surrounded by royal temples, one of which, Wat Phra Kaeo, was constructed within the palace walls. The outer wall protecting the city was not square or rectangular, but roughly lozenge shaped, following the contours of the river to the west and moat to the east. In accordance with Tai planning principles, Chinese traders previously settled upstream of the palace were relocated downstream (Askew, 2002).



City Planning of the Lao/Thai, Fig. 3 Map of Chiang Mai showing the outline of the old city



City Planning of the Lao/Thai, Fig. 4 Map of Ayutthaya



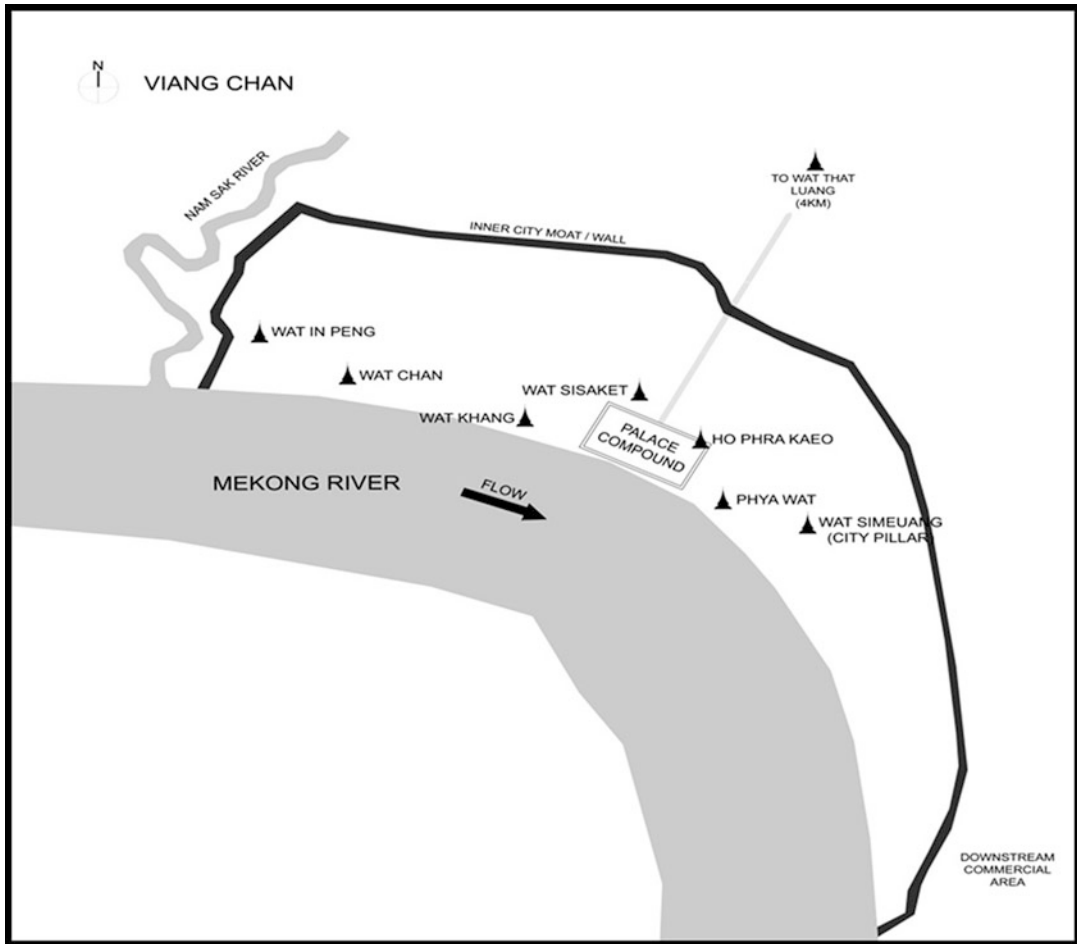
City Planning of the Lao/Thai, Fig. 5 Map of Luang Prabang

The Lao Variant

The original planning of Luang Prabang showed no Buddhist influence. The first Buddhist temples were constructed not near the palace but in the vicinity of Mount Phu Si, the small hill directly behind the old town, which missionary monks identified with Mt. Meru (Népoté, 1997). Subsequently, royal temples were built in the vicinity of the palace to attest to the merit of the king. The symbolic significance of Mt Phu Si was recognized by capping it with a Buddhist stupa, but the

palace remained where it was at the junction of the Nam Khan and the Mekong. All houses continued to be constructed with their ridge poles parallel to the flow of the closest river, whether the Nam Khan or the Mekong (Fig. 5).

When the Lao capital was moved to Viang Chan (Vientiane) in 1560, Buddhist cosmological principles took precedence over traditional Tai upstream–downstream relationships. The new royal palace was positioned not at the upstream extremity of the city but in relation to the revered That Luang stupa so that the line between them



City Planning of the Lao/Thai, Fig. 6 Sixteenth-century Viang Chan (Stuart-Fox & Reeve 2011)

was perpendicular to the flow of the river, which took precedence over the cardinal directions. The palace was bracketed, upstream and downstream, by royal temples, where the king could display his merit (Stuart-Fox & Reeve, 2011; Fig. 6).

The significance accorded to the That Luang in planning Viang Chan was reinforced by reconstruction of the stupa to symbolize Mt. Meru and its rededication as the Phra Chedi Lokachulamani, meaning “sacred reliquary stupa, precious jewel at the summit of the world.” One of the grand gateways piercing the city wall, each large enough for an elephant to pass through, was located on the direct line between the palace and the stupa (Fig. 7).

In the early eighteenth century, the Lao Kingdom of Lan Xang (a million elephants) broke into three separate kingdoms: Luang Prabang in the north, Viang Chan, and Champasak in the south, each named after its capital city. Within 70 years, all three had been forced to accept the suzerainty of Bangkok. Luang Prabang, however, once again became a royal city, but with altered symbolic relationships that followed the model of Viang Chan. The new palace was constructed not where the original royal palace had been but further downstream in close proximity to the sacred hill of Mt Phu Si. Temples and the house compounds of aristocratic families were located upstream of the palace, while the commercial area remained well downstream.

City Planning of the Lao/Thai, Fig. 7 The That Luang stupa, Viang Chan



Modern City Planning in Thailand and Laos

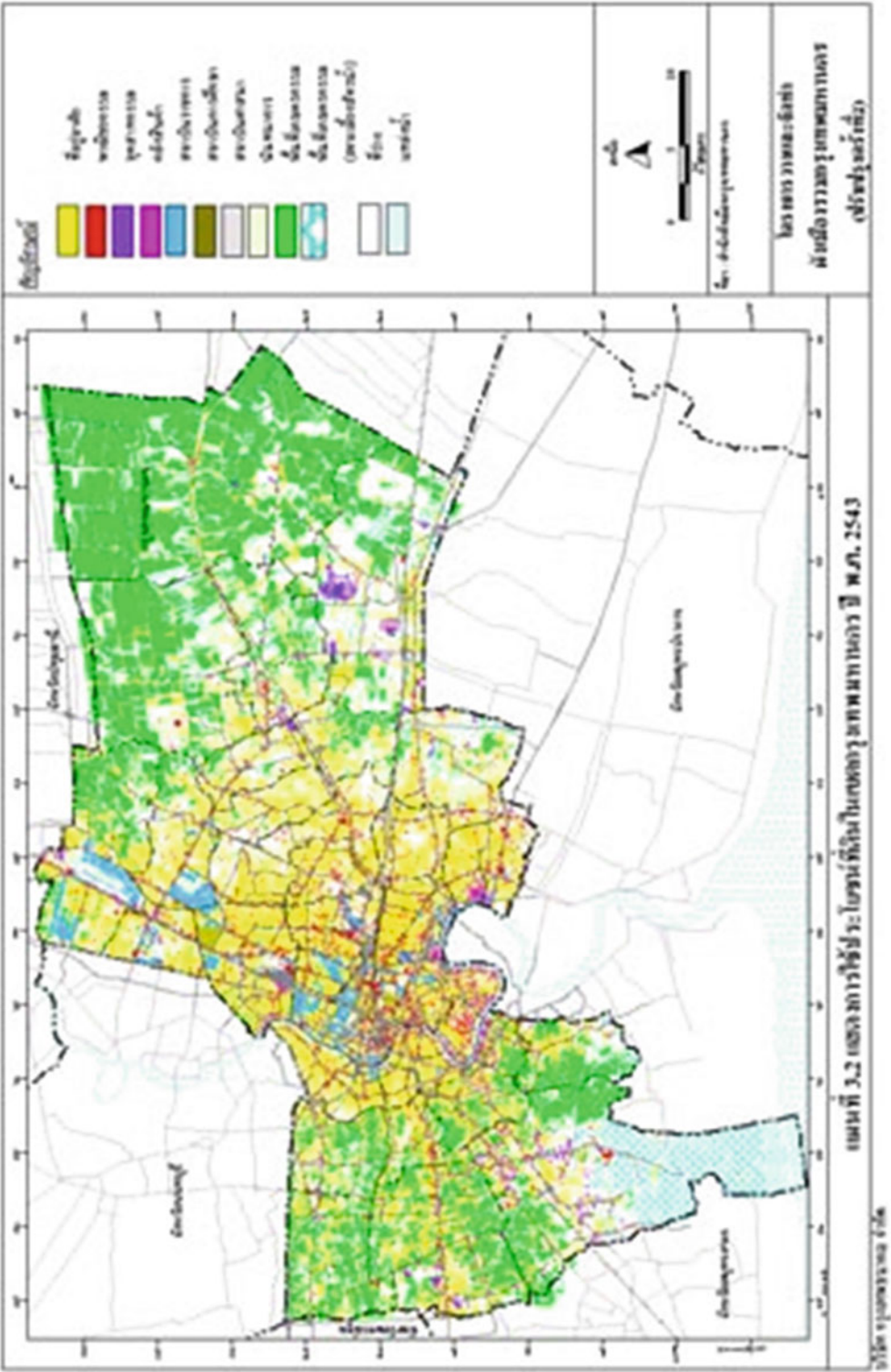
Bangkok changed little during the first half of the nineteenth century, but under kings Rama IV and Rama V, commerce and industry began to develop. New canals were dug for drainage and arterial roads constructed to extend the city. Subsequently, many canals were covered over or filled in to create roads, as vehicles replaced boats for transportation and roads began to be paved. Trams were introduced and a railway terminus built for the new northern line. In 1932, the first bridge was constructed across the Chao Phraya to link Bangkok with Thonburi. As the city expanded upstream and downstream as well as east–west, all that remained of its original symbolic layout was the palace and royal temples.

The expansion of Bangkok was largely unplanned, as nearby villages were incorporated into the urban sprawl. Though the population grew steadily, not until 1960 was the first comprehensive city plan drawn up (known as the Litchfield plan, after the American company entrusted with the task). The Greater Bangkok Plan 2533 (1990) envisaged a 30-year timeframe. It was essentially a land use plan (Sternstein,

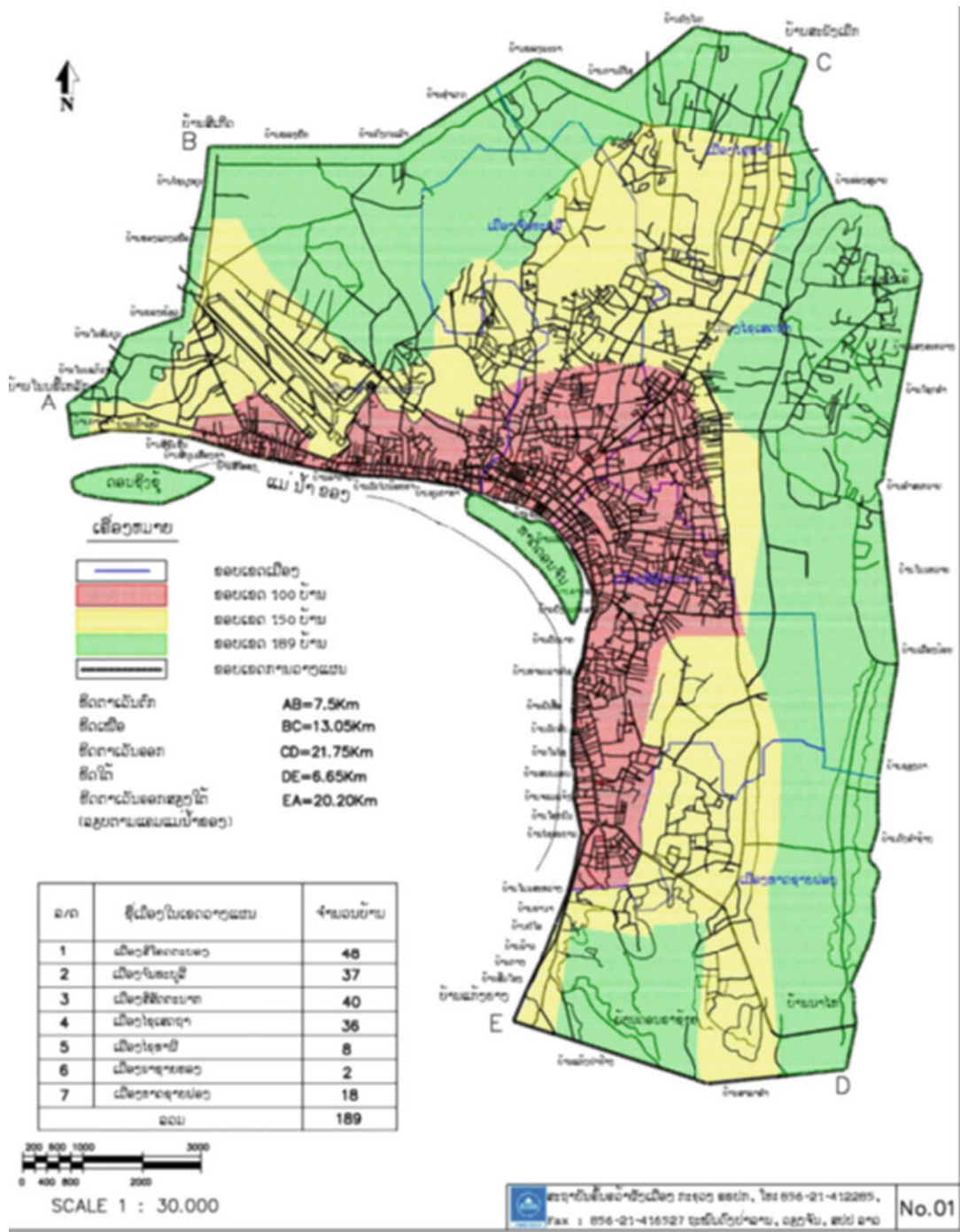
1972), but was overtaken by increasingly rapid rural migration, which placed pressure not just on housing but also on transportation, distribution, and services. In 2006, the city's Planning Department drew up a new Comprehensive Plan for Bangkok-Thonburi, covering land use, transportation, and regulation, though implementation remained patchy (Fig. 8).

As Bangkok blossomed as the trading capital of the Siamese empire, Viang Chan languished. The city was completely destroyed during a Siamese invasion in 1827 to put down a Lao bid for independence, and its territories incorporated into the expanding Siamese empire. In 1893, however, France forced Siam to cede all Lao areas east of the Mekong. Six years later, it was decided to rebuild Viang Chan as the colonial capital of French Laos (Askew, Long, & Long, 2007).

The decision was powerfully symbolic: Laos was resurrected as a French protectorate, independent of Bangkok. The French began by mapping the earlier city within its ruined walls, taking care to preserve the grounds of the former royal temples. But this was no longer a royal city. The only remaining Lao king ruled in Luang Prabang. Viang Chan became the French administrative capital. To reinforce the fact that France was



City Planning of the Lao/Thai, Fig. 8 Comprehensive plan for Bangkok-Thonburi 2006



City Planning of the Lao/Thai, Fig. 9 Map showing planned expansion of Vientiane

now the ruling power, the mansion of the French governor was built precisely on the site of the former royal palace (Stuart-Fox, 2006).

The French planned Vientiane with care. A grid of roads ran perpendicular and parallel to the Quai Pavie along the Mekong, while, as in the old city, a main road ran at right angles to the Mekong from the Résidence compound to the That Luang (Clément-Charpentier, 2008). The city grew slowly by comparison to Bangkok, within the framework of a French Master Plan for the city prepared in 1962. Lao involvement in the Second Indochina War brought an influx of foreigners, but major expansion did not occur until Laos opened up to the outside world in the 1990s. Thereafter increased rural migration necessitated two further revisions of the 1985 Master Plan to envelop a total of 189 villages (Thammanosouth, n.d.). The growth of Vientiane has been less chaotic than in Bangkok; however, one controversial issue has been a large-scale Chinese housing development in the vicinity of the That Luang (Stuart-Fox, 2009; Fig. 9).

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City Planning: Aztec City Planning

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The Aztecs were the most urbanized of the ancient civilizations of Mesoamerica. The last in a long line of urban societies, they selected principles of city planning from an ancient Mesoamerican heritage and adapted these to their needs. Most Aztec urban centers were modest settlements best called towns, but the central capital Tenochtitlan was a huge metropolis of a different order.

Most Aztec towns were founded between AD 1100 and 1350 when the Aztec peoples immigrated into the central Mexican highlands. They established new settlements and dynasties leading to a system of autonomous city-states. The construction of a royal palace marked the official founding of a new city or town, most of them city-state capitals. In 1430, three Aztec peoples – the Mexica, Acolhua, and Tepanecs – formed a tributary empire, known as the Triple Alliance or the Aztec empire. Two of their capitals, Tenochtitlan (Mexico) and Texcoco (Acolhua),

City Planning: Aztec City Planning, Table 1 Historical sources of planning principles employed in Aztec cities

Principles of urban planning	Aztec towns	Tenochtitlan
Ancient Mesoamerican planning principles		
1. Inventory of public architecture	x	x
2. Urban epicenter	x	x
3. Central public plaza	x	
4. Astronomical orientations	x	x
5. Unplanned residential zones	x	
Teotihuacan innovations		
6. Huge size of the city		x
7. Massive scale of main temples		x
8. Orthogonal planning of entire city		x
9. Layout dominated by central avenue		
10. Lack of central public plaza		x
11. Standardized housing		x?
Tula innovations		
12. Formalization of the epicenter	x	x
13. The largest temple on the east side	x	x
14. Circular Quetzalcoatl temples	x	x
Aztec innovations		
15. Twin-temple pyramids	x	x
16. Multiple small altars	x	x
17. Walled ceremonial precinct		x

became the preeminent cities of the Valley of Mexico. By the time Spanish conquerors arrived in 1519, this empire had conquered much of Mesoamerica, and Tenochtitlan had grown into a city of 200,000.

One of the remarkable features of Aztec urban planning is the extent to which basic buildings and planning principles were standardized among cities throughout central Mexico. This standardization long preceded the formation and expansion of the Aztec empire, and its explanation probably lies in the common cultural origins of the Aztec peoples, coupled with processes of interaction that kept the rulers and nobility of the Aztec city-states in constant contact with one another. This uniformity in urban planning contrasts strongly with other Mesoamerican cultures, such as the Classic Maya, the Olmec, or the Zapotec, whose individual cities show far greater variation in architecture and urban layout.

Historical Development of Planning Principles

The Aztecs drew upon several ancient historical traditions to select principles of urban planning for their cities and towns. Not surprisingly, the two major Aztec urban types – city-state capitals and Tenochtitlan – had somewhat different historical legacies. In this section I outline 17 principles of urban planning employed in central Mexico, grouped into four historical categories based upon their historical origins: ancient Mesoamerican principles, Teotihuacan innovations, Tula innovations, and Aztec innovations. Table 1 lists these principles and their use in Aztec towns and in Tenochtitlan.

Ancient Mesoamerican Principles of Urban Planning

The Aztecs drew on ancient Mesoamerican principles of urban planning in the design of their

cities. Five such principles can be identified for the pre-Aztec cities of Mesoamerica, including those of the Classic Maya lowlands, Oaxaca, and other regions (for Mesoamerican architecture and cities, see Hardoy, 1968):

1. *The inventory of public architecture.* A basic set of public buildings were used in most ancient Mesoamerican urban centers: large temple pyramids, smaller temples, royal palaces, ballcourts, and a suite of less common special purpose buildings that included council halls, sweat baths, schools, and other structures.
2. *The urban epicenter.* Public architecture in Mesoamerican cities tended to be concentrated spatially in a central zone, called the urban epicenter. The locations and orientations of individual buildings often suggest coordination and planning, although strict formal patterns, such as orthogonal layouts, were rare.
3. *The central public plaza.* The basic unit of urban planning was the public plaza, an open rectangular space whose sides were taken up with public buildings. Large cities with multiple concentrations of public buildings often had multiple public plazas of different sizes.
4. *Astronomical orientations of buildings.* The ancient Mesoamerican peoples were accomplished astronomers, and key public buildings were often aligned with significant astronomical phenomena, such as the direction of sunrise on the solstice. There is a general tendency for urban epicenters to be aligned roughly to the cardinal directions (most typically several degrees east of north), a pattern that may also have derived from astronomical considerations (Aveni, 2001).
5. *Unplanned residential zones.* Most urban housing was located outside of the urban epicenter. Individual houses typically show little or no evidence that their locations, forms, or orientations were coordinated or planned by central authorities.

Teotihuacan Innovations

With a population of around 150,000 inhabitants, the huge metropolis Teotihuacan was the largest city in Mesoamerica (and one of the largest anywhere in the world) during the Classic period (ca. AD 150–650). Teotihuacan dominated central Mexico politically, and its economic and cultural influence extended to all corners of Mesoamerica. In its form and size, Teotihuacan was utterly unique in Mesoamerica, and only the later Aztec imperial capital Tenochtitlan can be said to resemble Teotihuacan at all (Cowgill, 1997; Millon, 1992). Six innovations in urban planning can be identified at Teotihuacan:

1. *The huge size of the city.* With an extent of over 20 km² and its huge population, Teotihuacan was a city of a different scale from anything seen previously in Mesoamerica (Fig. 1).
2. *Massive scale of the main temples.* Although not the tallest pyramids in ancient Mesoamerica, Teotihuacan's "Pyramid of the Sun" and "Pyramid of the Moon" are among the most massive in volume.
3. *Orthogonal planning of the entire city.* The principle of orthogonal city planning was quite rare in ancient Mesoamerica, found only at Teotihuacan, Tenochtitlan, and perhaps Tula. Teotihuacan is remarkable for the consistency of orientation of its buildings.
4. *Layout dominated by a central avenue.* The so-called Street of the Dead is a central avenue several km in length that forms the central axis for the layout of Teotihuacan (Fig. 1). This use of a dominant central avenue is not found elsewhere in Mesoamerica.
5. *Lack of a central public plaza.* There is a moderately sized open plaza at the north end of the Street of the Dead, but this plaza differs from typical Mesoamerican central public plazas in several key respects: it is small in relation to the size of the city; only a few of the central public buildings are adjacent to the plaza; and it is not centrally located within the city. Instead, the Street of the Dead



City Planning: Aztec City Planning, Fig. 1 The “Street of the Dead” at Teotihuacan (Photograph by Michael E. Smith)

at Teotihuacan can be considered a functional analogue of the Mesoamerican central public plaza in terms of urban layout and planning. The major public buildings were arranged along this feature, which gave form to the entire plan of the city.

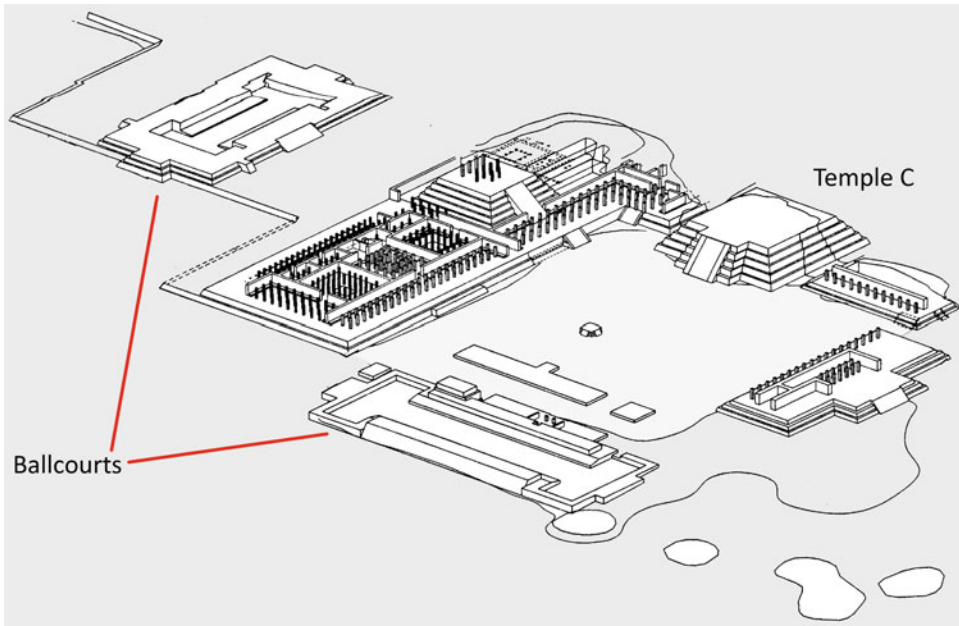
6. *Standardized housing.* One of the most remarkable urban features of Teotihuacan was the highly standardized form of commoner housing, the apartment compound. There were more than 2,000 apartment compounds in the city, all aligned to its orthogonal grid.

Tula Innovations

Tula, the next large political capital in central Mexico after Teotihuacan, drew on the layout of Teotihuacan for inspiration in urban planning. Although the rulers of Tula returned to the older Mesoamerican pattern of urban layout around a large public plaza, they employed several of the Teotihuacan innovations (nos. 6, 7, and perhaps 8). Although not as large as Teotihuacan, Tula was much larger than its central Mexican contemporaries and one of the largest cities in

Mesoamerica during the Epiclassic and Early Postclassic periods, ca. AD 800–1200 (Mastache, Cobean, & Healan, 2002). Three urban planning innovations can be identified for Tula:

1. *Formalization of the epicenter.* The public plaza at Tula established an orientation that was used for all of the buildings in the urban epicenter (Fig. 2). This shows a higher level of coordination and formalization than was typical of other Mesoamerican urban epicenters. The Aztecs later adopted this principle for their urban epicenters.
2. *The largest temple on the east side of the plaza.* At Tula, the largest pyramid, Temple C, is located on the east side of the central public plaza, a pattern also used by the Aztecs.
3. *Circular Quetzalcoatl temples.* The cult of Quetzalcoatl, the feathered serpent, spread throughout Mesoamerica in the Epiclassic and Early Postclassic periods. In Postclassic times, circular temples were dedicated to Quetzalcoatl’s avatar, the wind god Ehecatl



City Planning: Aztec City Planning, Fig. 2 Reconstruction of the epicenter of Tula (Modified after Mastache et al., (2002, p. 90))

(Pollock, 1936). At Tula, a circular temple was built at the El Corral locality, a concentration of public architecture outside of the main urban epicenter.

Aztec Innovations

The rulers of Aztec city-states drew primarily upon general Mesoamerican planning principles and Toltec innovations when they laid out their towns. The rulers of Tenochtitlan, on the other hand, emphasized these principles to a lesser extent, preferring planning principles from Teotihuacan. Three innovations can be identified for Aztec cities:

1. *Twin-temple pyramids.* Several of the earliest Aztec cities (e.g., Tenayuca and Teopanzolco) used a new form of pyramid with two temples on top and two stairways (Fig. 3). By the Late Aztec period, this form had fallen out of fashion except at the central temples of Tenochtitlan and Tlatelolco.
2. *Multiple small altars.* One of the notable attributes of Aztec cities is the prevalence of small platforms or altars throughout the urban

epicenter (Fig. 4). These were often located within the public plazas, and some altars were adjacent to large pyramids.

3. *Walled ceremonial precinct.* The central religious architecture at Tenochtitlan was concentrated within a walled compound called the “sacred precinct.” Although some authors have suggested that this was a regular feature of Aztec cities, Tenochtitlan is in fact the only example with a well-documented walled precinct.

These 17 principles are listed in Table 1.

Urban Architecture

In addition to their use of ancient Mesoamerican traditions of urban planning, the Aztecs also made use of Mesoamerican patterns of monumental architecture. The basic religious structures were temple pyramids, typically rebuilt and expanded by successive kings. When archaeologists excavate into a Mesoamerican pyramid, they typically find the buried remains of one or



City Planning: Aztec City Planning, Fig. 3 Aztec twin-temple pyramid at Teopanzolco (Photograph by Michael E. Smith)



City Planning: Aztec City Planning, Fig. 4 Row of small altars at Teopanzolco (Photograph by Michael E. Smith)

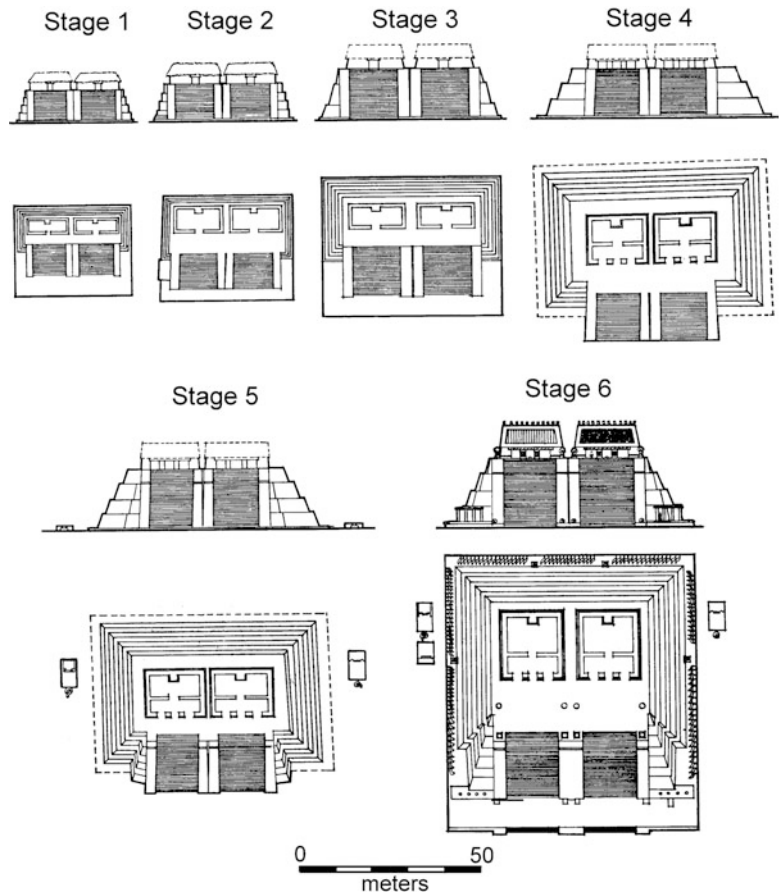
more earlier construction stages (Fig. 5). This continual rebuilding of temples in the same location was related to notions of sacred space and the importance of continuity with the past. In addition to temple pyramids, the Aztecs also used the basic Mesoamerican architectural inventory of palaces, ballcourts, altars, and commoner houses.

Twin-Temple Pyramids

This innovative form of temple pyramid is found at only five Aztec cities. Two of the major political capitals of the Early Aztec period – Tenayuca and Teopanzolco – employed large twin-temple pyramids for their central state temples (Fig. 3). Excavation of the Tenayuca pyramid revealed

City Planning: Aztec City Planning

Fig. 5 Construction stages of the twin-temple pyramid at Tenayuca (From Smith (2003a, Fig. 2.8); based upon (Marquina, 1951, p. 169))



a series of enlargements and expansions (Fig. 5), all employing the double temple design. By the Late Aztec period, this style had fallen out of fashion at most Aztec cities, whose main pyramids had only a single temple. But the Mexica peoples at the twin cities of Tenochtitlan and Tlatelolco revived this form for their central pyramids. At the well-known Templo Mayor of Tenochtitlan, the temples were dedicated to Tlaloc (an ancient central Mexican fertility god) and Huitzilopochtli (patron god of the Mexica with associations of warfare and sacrifice). This structure is known both from excavations (Matos Moctezuma, 1988) and from pictorial sources (Fig. 6).

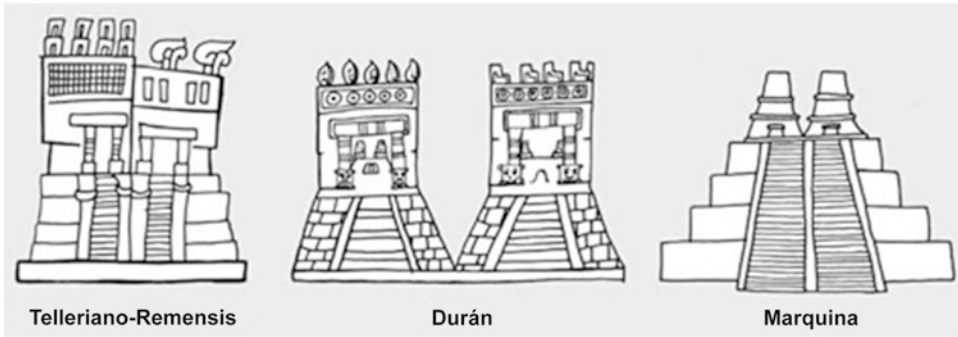
Single-Temple Pyramids

The single-temple pyramid was the standard form of temple throughout most of Mesoamerican

history. The extent of its use during the Early Aztec period is hard to judge, but by Late Aztec times, this form dominated Aztec cities, serving as both their central temples and as subsidiary temples (Fig. 7).

Circular Pyramids

Many Aztec cities and towns had circular pyramids dedicated to the wind god, Ehecatl (Fig. 8). These temples were rarely if ever located in central positions in Aztec cities. In some cases (e.g., Tlatelolco and Tenochtitlan), these temples were located within the urban epicenter but somewhat apart from the central twin-temple pyramid (Guillien Arroyo, 1999). In other cases (e.g., Huexotla, Zultepec, and perhaps Calixtlahuaca), the circular temples were located far from the urban epicenter, as at the earlier city of Tula.



City Planning: Aztec City Planning, Fig. 6 Native drawings of the Templo Mayor of Tenochtitlan (From Smith (2003b))



City Planning: Aztec City Planning, Fig. 7 Small single-temple pyramid at Calixtlahuaca (Photograph by Michael E. Smith)

Ballcourts

Only a few Aztec ballcourts have been located, but given the prominence of ballcourts and the ballgame in Aztec codices (Nicholson & Quiñones Keber, 1991) (Fig. 9), it is likely that these features were integral parts of most city layouts. The restored ballcourt at Coatetelco (Fig. 10) is probably typical of Aztec ballcourts; see also Matos Moctezuma (2001). The Aztecs played a version of the Mesoamerican ballgame, a public performance using a rubber ball that

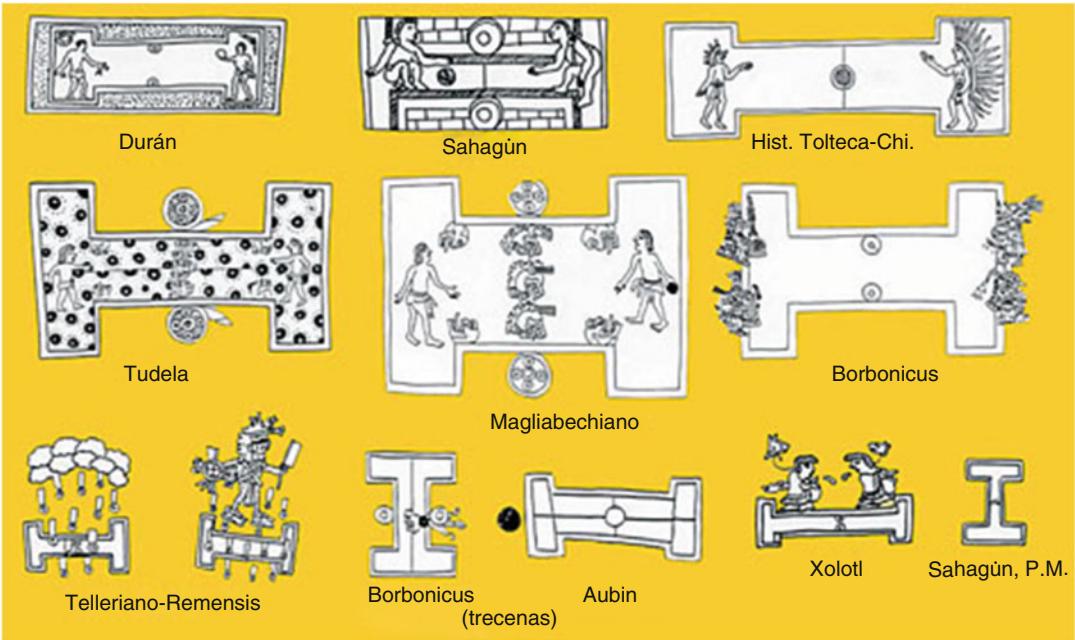
combined sport, ritual, and politics in poorly understood ways.

Palaces

Aztec palaces, unlike those of the Classic Maya, were highly standardized in layout. They contained a central courtyard with a single entrance. The courtyard was enclosed by raised platforms, on top of which were arranged a series of rooms, halls, altars, and other features (Figs. 11 and 12). This standard plan was followed for



City Planning: Aztec City Planning, Fig. 8 Circular temple at Tlatelolco (Photograph by Michael E. Smith)



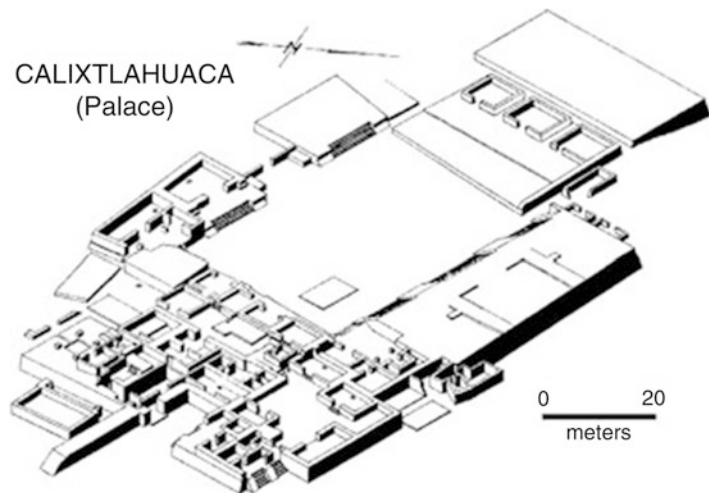
City Planning: Aztec City Planning, Fig. 9 Depictions of ballcourts in the Aztec codices (Modified after Nicholson & Quiñones Keber (1991))



City Planning: Aztec City Planning, Fig. 10 Ballcourt at Coatetelco (Photograph by Michael E. Smith)

City Planning: Aztec City Planning, Fig. 11

Reconstruction of the palace at Calixtlahuaca (Modified after Smith (2003a, Fig. 8.7); based originally upon (García Payón, 1981, Fig. 8))



a whole range of palaces, from the sumptuous royal palaces of Tenochtitlan and Texcoco to the modest residences of provincial nobles (Evans, 1991; Smith, 2003a).

Special Purpose Buildings

A variety of specialized buildings are known from archaeology and documentary sources. Written sources mention two types of schools,

but none have been excavated. Special buildings for elite warriors have been excavated adjacent to the Templo Mayor of Tenochtitlan and in a rock-cut chamber at the hilltop ceremonial precinct of Malinalco (Fig. 13).

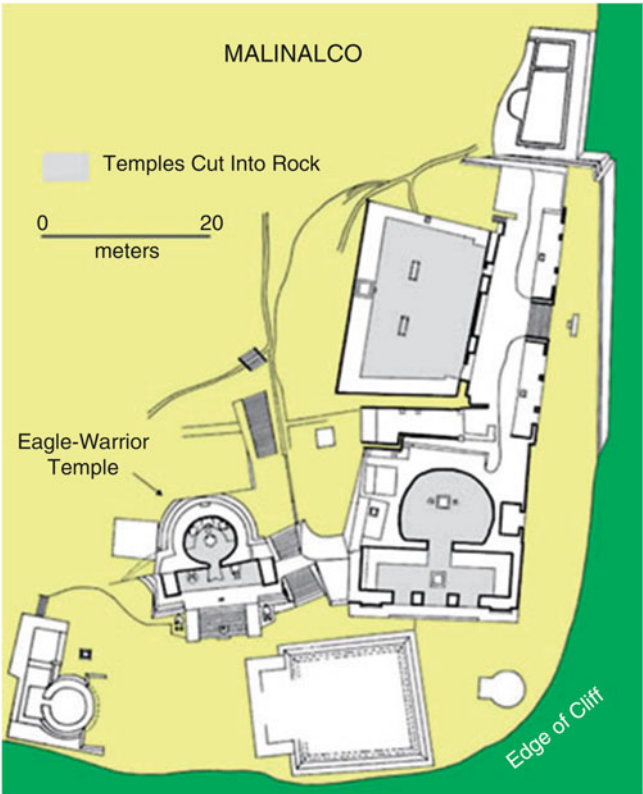
Altars and Small Platforms

Among the more intriguing and poorly understood features of Aztec cities are small altars



City Planning: Aztec City Planning, Fig. 12 Rooms in the royal palace of Yauhtec (Photograph by Michael E. Smith)

City Planning: Aztec City Planning, Fig. 13 Map of the hilltop ceremonial zone of Malinalco (From Smith (2003a, Fig. 7.5); based originally upon Marquina (1951))



City Planning: Aztec City Planning, Fig. 14

Altar decorated with carvings of human skulls at Tenayuca used to worship the *tzitzimime* deities (Photograph by Michael E. Smith)



and platforms that typically occur in multiple groups (Fig. 4). There were evidently numerous categories of such altars, dedicated to diverse deities and with a variety of uses in ritual and performance. Two specific functional types have been identified so far: platforms that supported skull racks (for the display of the skulls of sacrificial victims) and altars dedicated to the curing principles of the *tzitzimime* deities (Fig. 14) (Klein, 2000). The Aztecs even journeyed to Tula to build a small altar in front of Temple C, perhaps symbolically to convert the ancient structure into an Aztec temple.

Commoner Housing

Two patterns of commoner housing have been identified at Aztec cities. At Tenochtitlan and other cities in the Valley of Mexico, house compounds enclosed by low walls was the norm (Calnek, 1974; Evans, 1988). These compounds contained a number of structures and rooms arranged around an open work area (Fig. 15). In the provinces, in contrast, commoners lived in individual adobe houses (Smith, Heath-Smith, Lisa, & Montiel, 1999). Although often arranged into groups around a central patio, these house groups were never enclosed with walls (Fig. 16). Commoner housing exhibited considerably more variation within and between cities than was found in the palaces of the nobility.

Categories of City

City-State Capitals

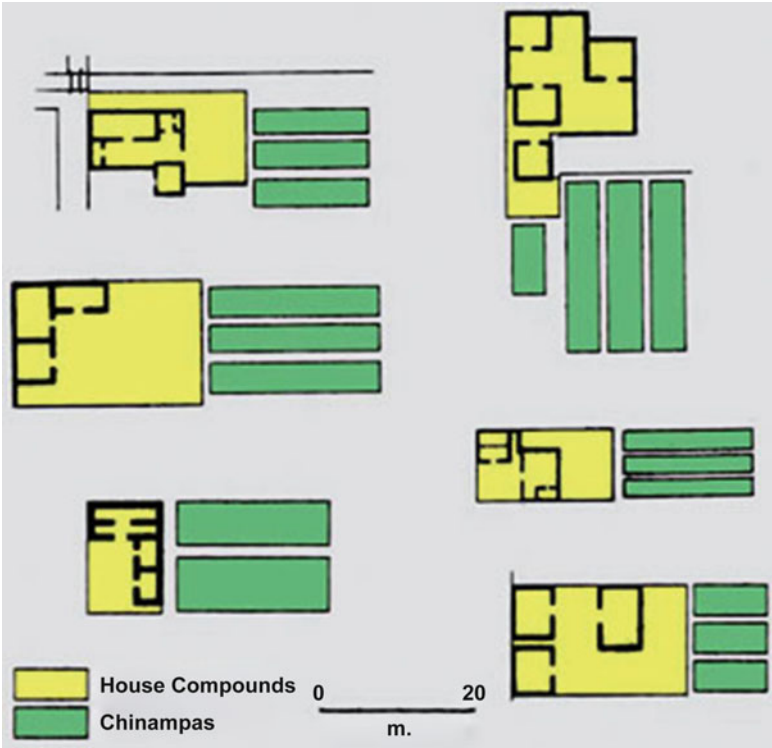
As noted above, the designers of Aztec cities and towns drew upon the principle of the formalized urban epicenter as articulated at the ancient city of Tula (Fig. 17). The city of Coatetelco in Morelos (Arana Alvarez, 1984) illustrates this pattern (Fig. 18). The central pyramid lies on the east side of the plaza (as at Tula), with the ballcourt opposite. Five small altars or platforms, attached to the exterior wall of the ballcourt, extend into the plaza. The buildings on the north and south sides of the plaza were only partially excavated and their functions are not known. The formal, planned central plazas of Aztec towns are clear even in the overgrown mounds at unexcavated urban sites such as Coatlan Viejo (Fig. 19). Although it is possible that the planned layout of the epicenters and their consistent orientations just east of north are related to cosmological principles, there is no concrete evidence to support this interpretation.

Outside of the epicenter, the residential zones of Aztec towns exhibited little evidence for planning or coordination. Although only one Aztec town – Cuexcomate – has been mapped in its entirety (Fig. 17, top), residential excavations in other cities and towns are consistent with this interpretation of unplanned residential areas (Smith et al., 1999).

A related type of settlement was the hilltop ceremonial zone, found in a number of Aztec

City Planning: Aztec City Planning,

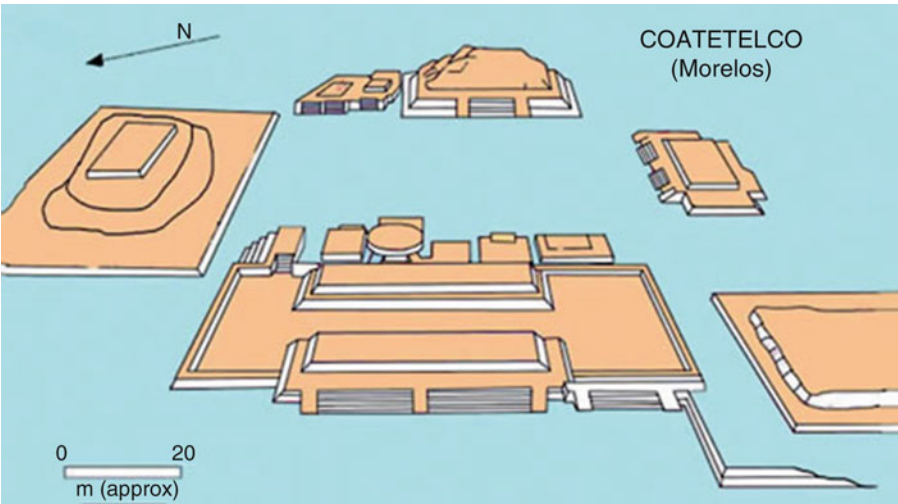
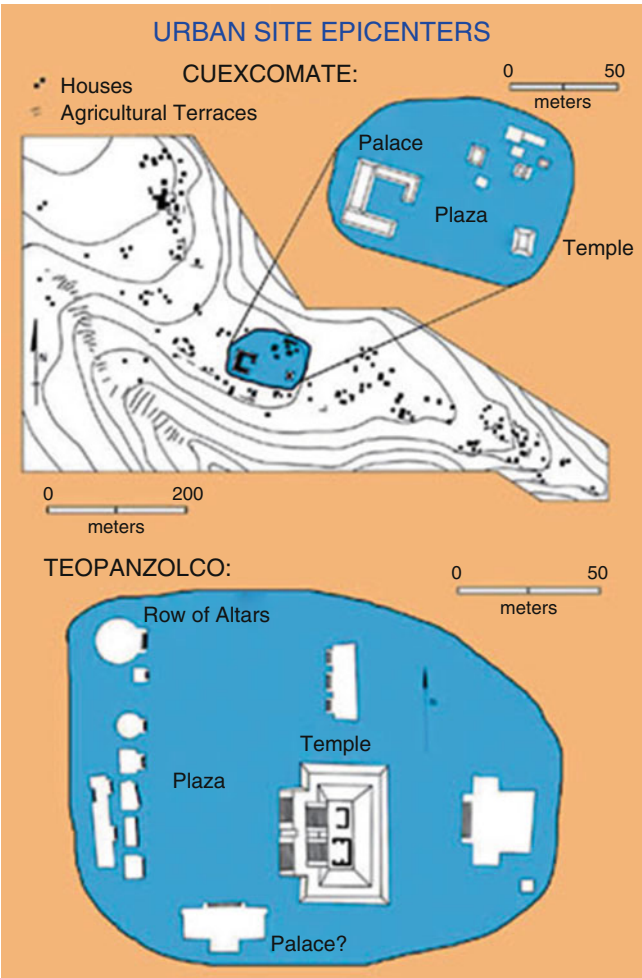
Fig. 15 Commoner houses with chinampa (agricultural) fields (Modified after Calnek (1972, p. 112))



City Planning: Aztec City Planning, Fig. 16 Commoner houses excavated by the author at Yautepec (Photograph by Michael E. Smith)

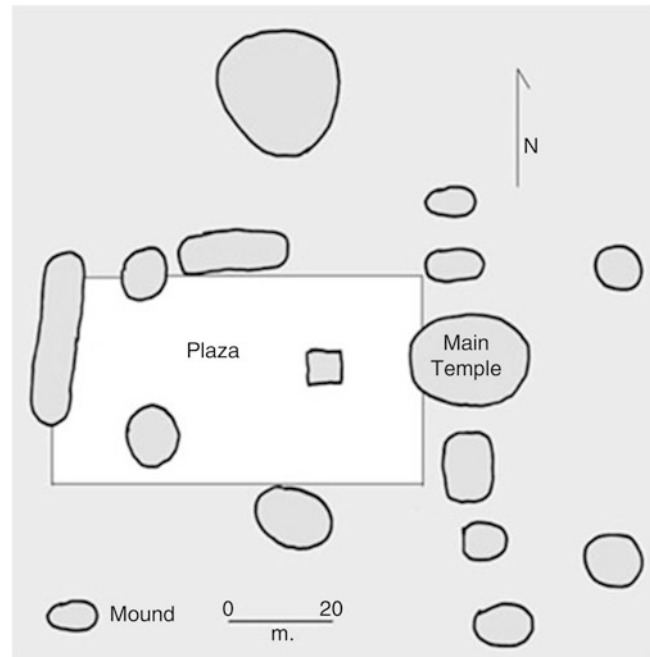
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Fig. 17 Definitions of urban epicenters of Cuexcomate and Teopanzolco (Modified after Smith (2005, Fig. 2))



City Planning: Aztec City Planning, Fig. 18 Reconstruction of the plaza at Coatetelco (Modified after Smith (2003a, Fig. 8.2); based originally upon Konieczna (1992))

City Planning: Aztec City Planning, Fig. 19 Map of the epicenter of Coatlan Viejo, an unexcavated city-state capital in Morelos (Modified after Mason (1980, p. 53))



city-states. The rituals carried out at these locations were typically political ceremonies linked to both agricultural fertility and the religious legitimization of kings and dynasties. The best known examples are Cerro Tlaloc in the Valley of Mexico, Malinalco in the State of Mexico (Fig. 13), and Tepozteco in Morelos.

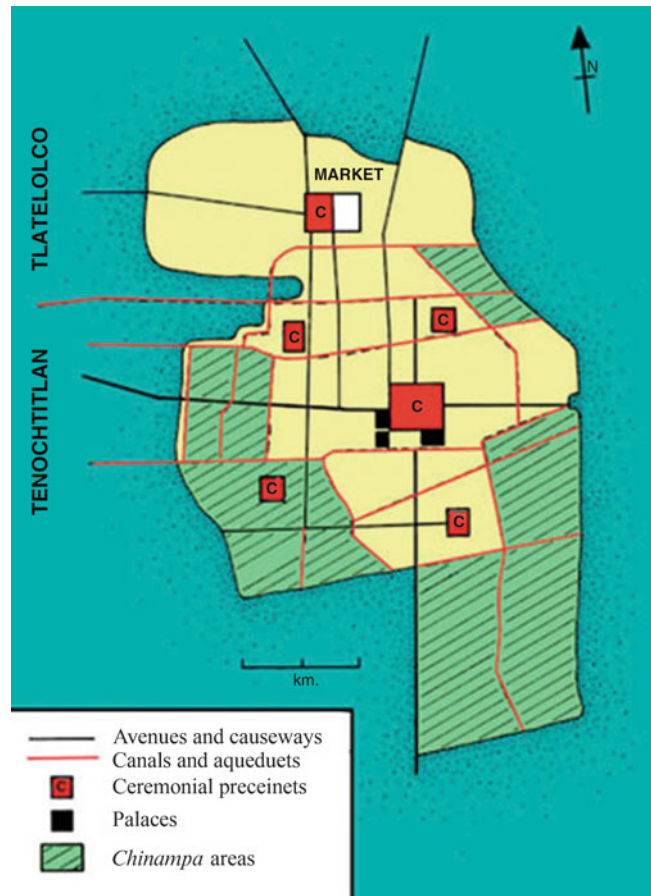
Tenochtitlan

When the Mexica peoples constructed Tenochtitlan on an island in Lake Texcoco in the early fourteenth century (the official date for the founding of the city is AD 1325), they drew more inspiration from Teotihuacan and Tula than from the standard Aztec urban plan already established at many towns in central Mexico (Table 1). The use of orthogonal planning is one of the remarkable features of the imperial capital (Fig. 20). Although few explicit articulations of urban planning concepts have survived, three factors were most likely responsible for creating the form of Tenochtitlan: the city's island location, imperial ideology, and cosmological

principles. Most of Tenochtitlan's 13.5 km² were reclaimed from Lake Texcoco. Spanish observers were struck by the great number of canals in the city, which they likened to Venice. The canals were used as transportation arteries and for agricultural purposes. Raised fields or *chinampas*, an extremely productive method of farming, were built to cultivate reclaimed swampy land in the outer neighborhoods of the city (Calnek, 1972). Families living on their individual small plots worked these fields (Fig. 15). As the city expanded, many of these rectilinear chinampas were converted into dry land, contributing to the orthogonal plan of the city.

Tenochtitlan's orthogonal layout is seen in the major avenues radiating out from a central ceremonial precinct in the cardinal directions (Fig. 20). The avenues divided Tenochtitlan into four quarters, each with its own smaller ceremonial precinct. Outside of the chinampa areas, houses were packed tightly together. The city of Tlatelolco, with its own impressive epicenter (Fig. 8), was originally a separate town but was later incorporated into Tenochtitlan (González

City Planning: Aztec City Planning, Fig. 20 Map of Tenochtitlan (From Smith (2003a, Fig. 8.8); based originally upon (Calnek, 1972, p. 108))



Rul, 1998). By drawing on the orthogonal layout of Teotihuacan (Fig. 1), the Mexican rulers proclaimed Tenochtitlan's continuity with the past and its legitimacy as the imperial capital of central Mexico (Umberger, 1987).

Cosmological principles also contributed to the form and layout of the capital. The largest structure, the Templo Mayor (Fig. 6), was viewed as the symbolic center of the Aztec empire (Carrasco, 1999; López Luján, 1994), and it was the setting for elaborate state ceremonies including human sacrifices. The Templo Mayor was built in alignment with sunrise on a key holy day (Aveni, 2001), and the entire layout of Tenochtitlan can be viewed as an extension of the sacred orientation of the central temple.

In sum, the planners who laid out Tenochtitlan made radical breaks with past

Aztec (and Mesoamerican) norms in two ways. First, they filled the central plaza with buildings. In place of an open plaza is the sacred precinct, a large walled compound packed with temple pyramids, altars, priests' residences, and other sacred buildings (Fig. 21). The palaces of the Mexica kings were arranged around the outer walls of the precinct. The sacred precinct occupies the place of the public plaza in other Aztec (and Mesoamerican) cities. Second, the imposition of a common grid over the entire city was a radical practice that expressed the power of the rulers to shape their city and differentiate it from other Aztec cities. The orthogonal layout also exemplified continuity with Teotihuacan and resonated with ancient Mesoamerican cosmological principles of the importance of the cardinal directions.



City Planning: Aztec City Planning, Fig. 21 The walled “Sacred Precinct” at Tenochtitlan (After Marquina (1951, lámina 55))

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City Planning: Inca City Planning

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Although the Incas were not great city builders, they redesigned their capital, Cuzco, on a grand scale, and founded numerous new settlements.

Ollantaytambo is one such new town. Because it has what “may be the oldest continuously occupied dwellings in South America” (Kubler, 1975), and because many parts of the town are well preserved, it would seem the perfect object for the study of the town planning principles of the Incas.

Ollantaytambo is located about 90 km to the northwest of Cuzco at the confluence of the Urubamba and the Patakancha rivers. It is built on a narrow, gently sloping bench of artificially leveled ground squeezed in between Cerro Pinkuylluna to the east and the Patakancha river to the west. It is carefully sited so as not to occupy prime agricultural land, yet to provide easy access to the terraced fields to the north and the south. The glacier-fed Patakancha provides an ample water supply for both agricultural and domestic uses. Tucked in between the high mountains at the mouth of the Patakancha valley, the town is well protected from the fierce afternoon winds which often sweep through the broader Urubamba valley.

The town was laid out on a regular grid, trapezoidal in shape, of four longitudinal and seven transversal streets. The transverse streets, oriented at 110.5° east of magnetic north, are perfectly parallel to each other, suggesting that the Inca were knowledgeable about geometry, and that they had a method of surveying to lay out the streets.

In the time of the Incas, there was a large plaza in the middle of the town. On its north and south sides it was bordered by great halls, long buildings with many openings toward the plaza. If what Garcilaso de la Vega tells us about Cuzco holds for Ollantaytambo, then the plaza was the theater for ceremonies and festivities, and the great halls were the place where the revelers withdrew to pursue their activities on rainy days (Garcilaso de la Vega lib. VII, cap. X; 1976: II, 108).

The fifth transverse street manifestly divided Ollantaytambo into two parts with distinct architectural features: the street facing walls in the southern half of town were built of cut and fitted stones, whereas in the northern half they were

built of unworked field stones. The blocks in the southern half show a rigorously repetitive block design of two walled-in habitation compounds, called *kancha*, arranged back to back, that is not reflected in the northern half. Cobo stated:

The Incas imposed in all their kingdom the same division in which the city of Cuzco was divided, Hanan Cuzco and Hurin Cuzco; cutting each town and lordship into two parts or factions called hanansaya and hurinsaya, which means "the upper district" and "the lower district," or the part or faction from above and the faction from below;... (Cobo lib. XII, cap. XXIV; 1964: II, 112).

This division, which is a social one and probably has ancient Andean roots, was used by the Incas to control, administer, and inspire their subjects (Cobo lib. XII, cap. XXIV; 1964). The two moieties were essentially equal, and each was governed by its own leader, with the *hanan* leader having first rank. It is possible, but not demonstrated, that the architectural division observed at Ollantaytambo is a referent to this social division.

Because of the rigor and clarity with which the town of Ollantaytambo has been laid out, one might be tempted to interpret it as an exemplar of Inca town planning. A comparison from a formal point of view with other Inca sites, however, does not sustain this proposition. Outside Ollantaytambo regular grids are only found at Chucuito, on Lake Titicaca, and Calca. The Chucuito grid too is trapezoidal in shape, and that of Calca appears to be strictly orthogonal. It is not known with certainty whether the Chucuito grid is of Inca origin. Calca, on the other hand, is known to have been established by Waskhar, the twelfth Inca. Whether or not the blocks in these two sites were occupied by *kancha* is not known. Cuzco, the navel of the Inca empire, shows an ordered street pattern, but the grid and the block sizes are not as regular and uniform as those of Ollantaytambo. At least some blocks in Cuzco were built up with compounds very similar to the *kancha* at Ollantaytambo. Huánuco Pampa, a large administrative center in the central highlands, lacks a regular street pattern, and although there are discernible town blocks, they are quite irregular in size and shape. Many *kancha*-like

compounds are scattered throughout the site, but their design is quite varied and irregular, and the compounds do not define blocks or streets. At Patallaqta, some 20 km downstream from Ollantaytambo, the *kancha* design is prominently in view. There are two arrangements of *kancha*; one consists of two *kancha*, back to back, similar to Ollantaytambo, except that it is not walled in; the other is made of four smaller *kancha*. Even though the *kancha* are not walled in, their groupings nevertheless define town blocks and streets. Tambo Colorado, an administrative center in the coastal valley of Pisco, has neatly rectangular compounds, but the center is not built on a grid pattern of streets, and the compounds only remotely recall the *kancha* design. The only feature common to the sites discussed above appears to be a plaza. At Huánuco Pampa the plaza is huge; it measures about $540 \times 370 \text{ m}^2$, is surrounded by buildings on all sides, and is dominated by what must be the largest remaining *usnu*, a ceremonial platform. Two great halls face the plaza on its east side. The plaza, *Hawkaypata*, in Cuzco was also quite large, about $200 \times 250 \text{ m}^2$. It too had an *usnu*, and was bordered with great halls on its north and east sides. Tambo Colorado's trapezoidal plaza is surrounded by buildings on three sides and has an *usnu* on its fourth side, but no great halls face it. Whether the plaza at Ollantaytambo had an *usnu* is not established. Thus, if the plaza is a recurrent element of Inca settlements, its configuration is by no means standard.

If no specific town planning rules seem to emerge from the comparison of different Inca settlements with Ollantaytambo, it stands to reason that Ollantaytambo is not representative of Inca town planning. It has been said that the Incas laid out their new settlement in the image of their capital, Cuzco. However, a comparison of the various plans analyzed above does not fare much better; there are no more similarities between Cuzco and the other sites than there are between them and Ollantaytambo. Rowe suggested that Cuzco was laid out in the shape of a Puma. Neither of the plans reviewed can be made to fit this shape. Perhaps similarities between Cuzco and other sites should not be

searched for the physical form, but instead, as Gasparini and Margolies (1980) suggested, “in the meaning and the functions of the form.” They argue that, if one makes abstraction of the physical form, one will note that certain elements are “repeated with considerable insistence.” They list the division into *hanan* and *hurin*, a principal and a secondary plaza, the great halls on the plaza, the *usnu*, the *inkawasi* (house of the Inca), the *aqllawasi* (house of the Chosen Women), the temple of the sun, and the storehouses. In light of the difficulties of attributing specific functions to particular ruins, and the uncertainties regarding a physical referent for the division into *hanan* and *hurin* discussed above, the effort to establish similarities among settlement patterns, and to derive planning canons, is considerably weakened.

The Spanish chronicler Bernabe Cobo described an elaborate set of about 40 lines, called *zeq'e*, radiating out in all directions from the Qorikancha, the holiest of all Inca shrines, in Cuzco. Along each line were arranged a number of sacred places and objects. Each line was the responsibility of a specific royal family of Cuzco. The families were in charge of officiating at the shrines in their care and of providing the appropriate sacrifices on the designated days. Although Tom Zuidema (1964) argued that the *zeq'e* influenced the plan of Cuzco, and perhaps of other Inca settlements, it is obvious that the radiality of the *zeq'e* did not affect the city's layout which is orthogonal in its core. As John Hyslop (1990) noted, “it is still uncertain to what degree the Incas are actually portraying zeque systems (even) in radial layouts, or just the principles and spatial relationships found in the system.”

Another reason why it may be difficult to extract generally applicable town planning rules is that the various settlements served different functions and were used in different ways. Ollantaytambo, Machu Picchu, and Patallacta discussed above were royal estates, that is the private property distinct and apart from state property, of the ninth Inca Pachakuti, and Calca was an estate of the Inca Waskhar. Cuzco, on the other hand was the all important capital of the Inca Empire, whereas Huánuco Pampa, like

Tambo Colorado, was a regional administrative center in a newly conquered territory. The different types of settlements may have operated and functioned along different lines, such that any comparison may be spurious. Little is known about life in Inca settlements. Of Cuzco, Pedro Sancho de la Hoz, Francisco Pizarro's personal secretary, wrote that it “was so large and so beautiful that it would be worthy of being seen even in Spain,” and he added that it was “full of palaces of the lords, for in it there lived no poor people.” What Sancho described referred probably only to the core of the city, for it is known that there were people from every corner of the empire also living in Cuzco. Of life in Cusco Protzen and Rowe (1994) wrote:

Street life was probably limited to the movement of people from one place to another, with a stop perhaps for a bit of gossip, or to fetch water from the canals. There was no mercantile activity in the streets and there were no storefronts. Most residential and religious compounds [or *kancha*] were surrounded by walls with only one doorway giving access to the street. Supplies for sustenance of daily life were delivered directly from the state warehouses to the compounds. All production, weaving, wood and metal working, pottery, brewing, baking, and so forth was carried out within the compounds. On official occasions, civil or religious, the street scene may have been animated by parades and processions: the Inca being carried around town in his litter with the requisite entourage of nobles and bodyguards; the arrival of a dignitary from the provinces accompanied by llama trains loaded with gifts of all kinds; the triumphant return of a war party, with soldiers displaying their loot and parading prisoners; or a solemn religious procession, with priests in colorful attire carrying idols and other paraphernalia.

It is not known to what extent what happened in Cuzco can be extrapolated to other Inca towns. There are very few eyewitness accounts of life in other places of the Inca Empire. Little is known about the organization, function, and operation of royal estates. However, as in the case of Ollantaytambo, one can assume that there was a royal residence for the Inca and his immediate entourage, that there were accommodations for the accompanying nobility and administrators, and that there were quarters for the servants. Yet, the layout of the settlement, its size and its

architecture, suggest that it was more than just a rural retreat with its requisite appendices. It has the character of an agglomeration in which a population of perhaps a thousand people was permanently settled.

Discovering general planning principles may be, at least in part, also complicated because the principles, whatever they were, may have been altered to fit the specific features of a site and its topography.

In Cuzco, in spite of colonial modifications, the major features of the Inca plan can still be appreciated. The grid-like street pattern was squeezed and bent into the neck of land between the Watanay and the Tulumayo rivers to conform to the Puma shape. At Patallaqta the street pattern also is grid-like, yet it is shifted and broken to fit the crescent-shaped plateau on which it is built. At Machu Picchu, where the terrain is much more accidented, or broken, than at Patallaqta, the intent of an orthogonal layout can still be detected. Alleyways and staircases generally cross at right angles. The modifications brought to the layout are subtle adaptations to the specific topography. Streets and alleyways, like the terraces, follow the contour lines, and staircases follow the terrain's fall lines. The town occupies two natural ridges, and is completely split into two sectors by a plaza which is molded into the saddle between the ridges. The *kancha* are squeezed, stretched, and distorted to fit the available space on the terraces, as they do at Wiñay Wayna, about an hour from Machu Picchu.

One of the most striking site planning efforts, and some of the most spectacular adaptations of building forms to suit the particular terrain, are seen at Phuyupatamarca. The buildings literally grow out of the bedrock and espouse the terrain to become one with the site; the man-made world again is inseparable from the natural world.

Today's tourists, arriving at Machu Picchu by train and bus, miss one of the most important features of Inca site planning; they are deprived of the dramatic encounter with the site the ancient traveler experienced when coming through the gate of Intipunku. That encounter involves a succession of open spaces that are scaled from the vast horizons of the Andes to the intimate

courtyard in town, strung together by narrow passages over precipitous cliffs, steep staircases, alleyways, and gates. Along this pathway the site is veiled and unveiled in a sequence of vistas that reveal the lay of the land and the setting of the town, and attract attention to details of nature or architecture framed by narrow passages or gates.

The gate of Intipunku affords a distant view of Machu Picchu, still too far away to discern individual architectural features, but close enough to grasp its general layout, and to appreciate its scenic setting and subtle incorporation into the majestic landscape. When one descends the trail from Intipunku, Machu Picchu disappears from view completely only to reappear in a succession of mere glimpses. Only when one rounds the bend in the trail, just below the so-called Watchman's House, does the site reveal itself again in its entire splendor, spread out immediately at one's feet with the sugar loaf peak of Wayna Picchu looming over it. Continuing down the stairway toward the main gate, most of the site vanishes again, and it is not until the very last step before the gate that Wayna Picchu is unveiled again in a dramatic view, perfectly framed by the gate.

Moving on through the site, one's view is alternately constrained by high walls bordering the alleyways and broadened as one emerges onto a staircase, a terrace, or an open space. There is a progression from the open and public spaces through narrow alleyways and gates to the enclosed and private spaces. At many junctures, one's attention is drawn to important features in the landscape. Sometimes this is achieved by narrowing one's field of vision, sometimes by widening it. The windows of the Temple of the Three Windows concentrate the view upon the half dome of Putukusi to the east and to the west the plaza, defined by the temple and the two buildings which flank it, opens wide to a sweeping view of the snow-capped Cordillera Vilcabamba and its many sacred peaks.

Machu Picchu is not unique in this; orientations upon features in the landscape are rather common in Inca architecture and can be observed at many other sites.

The rigid street grid of Ollantaytambo was by no means the norm for Inca settlements. Where regularity in the layout of the streets is found, it is probably a by-product of the rectangular design of the kancha, and not so much a reflection of the intent to parcel out the land in a grid. In accidented terrain the kancha and the building forms were “deformed” and modified to adapt to the topography, rather than made to conform to an abstract principle. While some commonalities and the repetition of certain elements can be observed at various sites, there is simply not enough empirical evidence available to induce a set of formal town planning rules by which, if they existed, the Incas laid out their settlements. It may be that the incorporation of views and the orientation on architectural and landscape features was the all-pervasive site and town planning criterion. To support this hypothesis, if it is at all tenable, many more sites will need to be analyzed dynamically; that is, as one moves through the sites rather than by merely investigating their plans.

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City Planning: Maya City Planning

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Much of ancient Maya civilization flourished in the period from AD 250–900 in the area encompassing the whole of Mexico’s Yucatan Peninsula, the Mexican states of Chiapas and Tabasco, and the countries of Belize, Guatemala, western Honduras, and El Salvador. During the course of nearly twenty centuries of development, the distinctive architectural styles of the Maya heartland evolved and collapsed. As with other aspects of the Native American legacy, ancient Maya architecture was once seen as far too sophisticated to have been the product of aboriginal genius, and was long credited to Old World voyagers ranging from Egyptians to Israelites, and from white men or Danes to “great white Jewish Toltec Vikings” (Silverberg, 1968).

As scholarly knowledge of Maya architecture, settlement patterns, and city planning has grown exponentially over the course of the last 60 years, so too has our respect and admiration for this ancient American tradition (Morley, 1983).

Until quite recently, scholars perpetuated the belief that the Maya had neither a literate tradition or history, nor true cities or political economies. They often typecast Maya architecture as inferior, because it did not employ the “true” arch in the Roman sense. And they were unable to demonstrate that Maya centers were planned and constructed under the direction of professional architects with drafted plans. Given the geomantic principles, astronomical alignments, and geometric sophistication inherent in Maya cities, it would be more difficult to demonstrate that the Maya had no such architects or recorded plans. This review will begin with an overview of the role of astronomy, cosmology, and geomancy in Maya architectonic arrangements, and then move to a broader consideration of the question of site planning in the ancient Maya heartland.

Maya Architecture, Sculptural Programs, and Cosmology

Archaeologist and architectural historian H. E. D. Pollock has defined ten primary architectural and planning styles for the lowland Maya heartland. To these may be added another four highland Maya areas that I believe may be distinguished for the Quichean highlands of southern Guatemala, the Cotzu-malhuapan Pacific coastal tradition, the Middle Classic (AD 400–650) styles of Kaminaljuyu and vicinity, and the hybrid regional developments of the present-day state of El Salvador.

Where the Maya lowlands are concerned, Pollock describes the influence of environment and topography on planning and architectural layout:

The flood plains of Copan and Quirigua; the flat or gently sloping banks of the Pasion River; the steeply rising hills along the Usumacinta River; the mountainous shelf of Palenque and alluvial plain of Comalcalco; the low, wet, but often sharply broken terrain of the Peten; southern Campeche; and southern Quintana Roo; the savannas, valleys, and hills of the Chenes and Puuc regions; and the flat northern Yucatan plain all offered different opportunities and challenges to the ancient builder.

Custom was mediated by local and regional environmental conditions and the adaptive traditions which arose from them. Clearly, civil planning developed well beyond the purely “organic” (Andrews, 1974) organization of monuments oriented to topographic and natural features of the immediate environment. Even in the earliest periods of Maya city planning, cosmological, astronomical, ritual, genealogical, and dynastic variables were integrated into site plans and construction programs. Plans were formulated in terms of multiple variables, not the least of which were the mechanistic dimensions of astronomical and cosmological cycles and dimensions, and the organic or topographic, and natural or practical realities of urban planning.

The period immediately preceding the Classic period was a time of great dynamism. According to archaeologist C. Bruce Hunter, “between 600 BCE and AD 250 great activity in city planning was taking place all over Mesoamerica. Cultural areas were defined, ceremonial complexes in the heart of the cities were constructed, and trade routes and luxury goods fostered trade competition between regions.” Many of the greatest urban centers were built at this time. By the end of the Preclassic era – ca. AD 100 – Tikal and Uaxactun in the Peten lowlands and Cerros and Cuelling in Belize had added to the architectural traditions of the era. The ancient cities of Dzibilchaltun in the northern lowlands, El Mirador in the southern lowlands, and Kaminaljuyu in the Guatemalan highlands defined the ceremonial construction for each of these subregions.

On the basis of recent glyphic transcriptions, we can now say that the iconography and architectural order inherent in the earliest city planning incorporated cosmological, dynastic, ritual, architectonic, and geomantic principles used in the organization of sacred geography and the built environment. My own study of the sculptural program embodied in the architecture and planning of the rock-cut temples of Malinalco, Mexico, and Carolyn Tate’s more recent architectural survey of the ancient Maya center of Yaxchilan provides compelling evidence for

Mesoamerican site plans based on pre-Columbian solar configurations or cosmograms, as well as the use and deployment of solstice-based axial alignments in city planning (Mendoza, 1975; Tate, 1992).

Geomancy and Maya City Planning

Geomancy, referred to as “mystical ecology” and as cosmological ecology or sacred geography, was the ancient Chinese practice of situating burials, monuments, and entire towns on the basis of cosmological principles. Because ancient Chinese scholars documented this practice so extensively, it is largely identified with Chinese civilization, although recent studies make clear the use of geomancy in ancient Mesoamerica (Freedman, 1969).

Much of the divinatory practice embodied in geomancy is particularly relevant to Mesoamerican, and specifically Maya, city plans. According to John Carlson, geomancy is “a divinatory art involving the interpretation of local topographical features for the purpose of properly locating and orienting the constructions of man – be they graves, houses, or entire cities.” However, Carlson has redefined geomancy as a:

profound system of thought, deeply rooted in ancient and fundamental oriental philosophy and involving perception of the dynamic balance of the controlling forces of nature. It is the system in which man divines his own place in relation to the play of these forces, and it is the mechanism by which he can influence them in order to re-establish equilibrium when imbalance is perceived. (Carlson, 1981)

Maya city centers all provide archaeological evidence for the interpretation that plans were based on cosmological and geomantic models; however, few such sites have been examined with such principles in mind. Recent studies, such as those of William Rust (1992), Jeremy Sabloff and Gair Tourtellot (1992), Wendy Ashmore (1992), Robert Sharer (1990, 1992), and Carolyn Tate (1992), make clear the ancient Olmec connection to Maya ceremonial and

settlement planning, the influence of changing economic and demographic patterns on planning, the icons of power, divinity, and divine mandates invoked through creation myths and expressed through architectural vocabularies and sculptural programs, the concentric patterning of civil monuments, and the deployment of solar cosmograms in site planning, respectively. We shall examine one site in detail.

Yaxchilan

The site of Yaxchilan, Chiapas, which overlooks the Usumacinta River separating Mexico from Guatemala, is one site that has been examined from the perspective of world plan as embodied in city plan. The site underwent dramatic transformations in construction during the reigns of Shield Jaguar, his father Bird Jaguar III, and his grandfather. The site was altered to establish “specific axes of solstitial orientation for architecture depending on the function of the building or space or the message of its sculptural program, and was conceived to define ritual areas used by particular rulers” (Tate, 1992). Yaxchilan was constructed on an elongated shelf and used terraces, tiers, and elevated plaza-platforms within the context of a larger acropolis-centered pattern. Yaxchilan also incorporated a series of hills into the larger plan of the site, and was situated in a position providing the only unobstructed vantage point from which to observe solstice alignments between major buildings and prominent mountain peaks – serving as clefts in the horizon and as points of astronomical reference. Other recent observations document that major buildings at Yaxchilan were devoted to rites of passage – particularly those pertaining to dynastic accession, succession, calendrically based Period Endings, and to the capture and sacrifice of living kings. Such monument are oriented with respect to the eastern horizon and the summer solstice, whereas funerary chambers and obituary monuments and stelae are oriented along solstitial axes pertaining to the winter solstice at 118° east of magnetic north. Several of the obituary

monuments and funerary shrines in question are aligned to 115–116°, as opposed to the more exacting 118° east of magnetic north; apparently so as to allow for the use of doorways with half-quatrefoil overhead jambs to provide for architectural-solar hierophanies, or light and shadow patterns serving to record the passage of summer and winter solstice events. Such information provides a direct correspondence with ancient Maya identifications of the summer solstice with royal and/or divine renewal and the planet Venus, and the cosmological association of the southern horizon with caverns as the portals to the underworld, the moon, and the land of the dead. The fact that Yaxchilan's southern precinct skirts the mouths of two prominent caves is cosmologically significant. According to Carolyn Tate, the caves “must have played a role in Bird Jaguar's decisions on how to shape the ritual landscape” (Tate, 1992).

Major buildings, monumental stelae, altars, and ritual markers from Yaxchilan all bear orientations that speak to political and ritual events. Buildings were aligned horizontally, and “situated from high to low vertically” (Tate, 1992). By employing “alignments of stelae that conceptually linked the reigns of successive rulers,” the architects and planners coordinated the organization of the royal house of that era.

Recent studies at the sites of Tikal and Quirigua (Guatemala), Cerros (Belize), and Kohunlich (Mexico) provide dramatic examples of the means by which Maya world view and the realm of the supernatural were incorporated into city planning in a manner reminiscent of Christian, Muslim, Buddhist, and Hindu towns and cities of the Old World. While the sites of Cerros and Kohunlich provide architectural arrangements centered on monumental depictions of solar, lunar, terrestrial, and venusian cosmograms, the sites of Tikal and Quirigua incorporate these same dimensions in addition to those iconographic vocabularies and Twin Pyramid groups and precincts intended to symbolize the Classic Maya conception of the cosmos. Maya city planning has only recently undergone

scrutiny with an eye to the larger mechanistic and organic dimensions and concepts of time and space inherent in Maya planning and design of the built environment. Wendy Ashmore has recently identified what she deems the five principle components of the Maya pattern pertaining to Tikal and related sites, these are (1) north-south axial arrangements, (2) complementary and paired functions of buildings centered along the main axes that serve to demarcate supernatural and celestial from underworld or terrestrial dimensions, (3) subsidiary eastern and western monumental arrangements within precincts providing for a triangulation with monuments located on the northern perimeter of individual precincts – and identified with the celestial vault and the cosmic tree of the north, (4) ball courts as transitional zones between north and south, and (5) the construction of causeways and paved roads linking precincts into a symbolically coherent cosmogram. To this listing I would add specific buildings that embody solar cosmograms and cosmic templates, as well as sculptural programs and iconographic vocabularies deployed across whole sites to imbue them with a sacred geography and cosmological ecology (Mendoza, 1977). We can no longer assume that the Maya built in a random and largely organic fashion – by accretion and accommodation as opposed to design and structure. Primitivist and eurocentric portrayals of the ancient Maya have eroded in recent years under the onslaught of a new world order reinterpreted on the basis of surviving hieroglyphic stairways, monumental texts, commemorative stelae, funerary shrines, frescoed murals, painted ceramics replete with textual information, and pre-Columbian and contact period codical documents and screenfold books. These sources are now providing a revolutionary perspective on the Maya (Schele & Freidel, 1990).

See Also

► [Geomancy in China](#)

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City Planning: Yorùbá City Planning

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The Yorùbá are a finite set of adjacent groups – including the Ègbá, Òndó, Àwóri, and Ìjèbu – who share a mutually intelligible language, myths of origin, religious beliefs, cultural practices, experiences of bondage, and Anglo-Franco colonial heritage. Historians have argued that this ethnic identity coalesced in the nineteenth century, while their historical tendency to settle in large, densely populated cities and towns has pushed them to the forefront of discourse of indigenous urbanism in Africa. In West Africa today, Yorùbá-speaking people can be found split mainly between two countries, with over one million in southern Benin Republic and close to 40 million in southwestern Nigeria. Substantial minor communities are also established in Ghana and Togo.

Established as a confederacy of city-states thriving between the twelfth and the late seventeenth century, historically Yorùbáland maintained its autonomy and power – split between the political capital of Old Òyó (Òyó-Ilé) and Ilé-Ifè, the religious center – by virtue of competitive advantages versus its neighbors. These advantages included sociopolitical organization, military alliances, and monopolization of ritual activity and commerce, especially in the light of its geographic position between the savanna plains of the hinterland and the forests close to the Atlantic coast (Usman, 2000).



City Planning: Yorùbá City Planning, Fig. 1 “Map of the Yorùbá country” drawn by the Yorùbá historian Samuel Johnson (published 1921)

The collapse of Old Òyó in 1835 and various Yorùbá kingdoms in the nineteenth century has been ascribed to both to pressures from the north by the consolidation of the Hausa-Fulani city-states and from the south by the growing involvement of the British missionaries, traders, and administrators in an era of the slave trade and its complexities. This was a time of disappearance and displacement of many classical Yorùbá cities (such as Òyó, which moved southward),

reconfiguration of others (such as Ilorin, overtaken by the Sokoto Caliphate), and general decline. But it was also a time of reinvention and establishment of several prominent other cities such as Abẹ̀òkúta and Ìbàdàn (see Fig. 1). Yorùbá cities offer a paradox to Western scholars. As Africa had been traditionally considered by them as overwhelmingly rural or semi-rural at best, such conceptions were tied with other philosophies as the “noble savage”

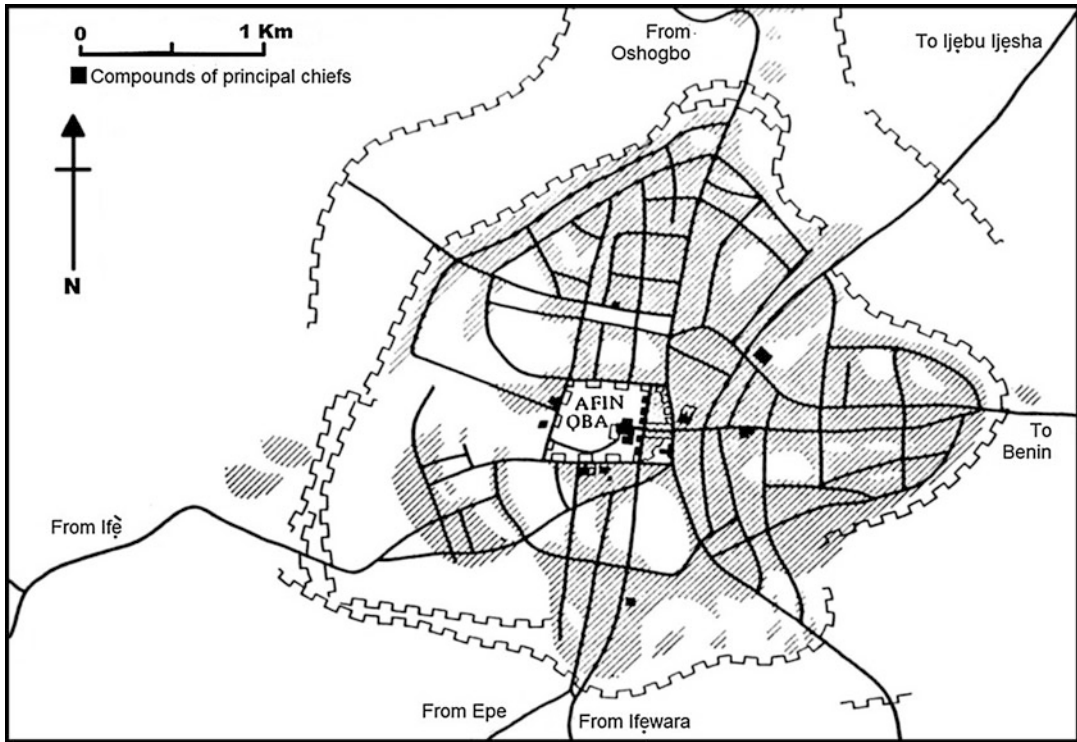
imagery; research on preindustrial cities tended to focus solely on Western cities. In the rare cases where Yorùbá cities were mentioned in urban history works by the 1960s, they were designated as “semi-urban” (Coquery-Vidrovitch, 2005, pp. 12–13). Their markedly different modalities in form and function by comparison to cities in the West were saliently rooted, inter alia, in the use of temporary building materials and the lack of distinct division between urban and agricultural space. As a result, early debates among Western scholars centered on the idea of whether these settlements were cities at all (Sjoberg, 1960). These questions were settled from the 1970s and finally summarized by the basic premise laid by the urbanist Spiro Kostof, arguing that cities are places that are intimately engaged with the countryside and their separation is thoroughly injudicious (1999, p. 38). Since then, new debates about the longevity and morphology of Yorùbá cities have taken center stage.

The origins of Yorùbá cities are obscure, though local traditions, well documented by the Yorùbá-educated elite during the long nineteenth century, trace the origins of all Yorùbá to Ilé-Ifè. While this spiritual and urban focal point is estimated to date as far back as the ninth century, the circumstances of the original foundation of Ifè itself are ambiguous (Law, 1984). The earliest recorded reference to Yorùbá settlements comes however from a Portuguese map in the sixteenth century, with Ìjèbu-Òde clearly indicated. Indeed, Yorùbá oral traditions of origins show some Islamic influence regarding geography and anthroponomy (Johnson, 1921; Law, 1984), an influence that is clearly reflected in the configuration and arrangement of historical urban layout (Moughtin, 1985). Surprisingly, no research exists examining the relationship between the oral and built traditions of the Hausa and Yorùbá.

Though there is little to no evidence for a centralized or top-down process of planning before the nineteenth century, many Yorùbá cities share remarkable morphological similarities. Though little evidence of individual planners or architects survives, what is clear is that these towns map a social and political reality that was fairly stable across different cities. The king

(*Oba*) was the political nucleus of each town, and thus, his palace or *àfin* was invariably the physical center. People and place were inextricably tied and tiered in the plotting of these cities. In this mapping, the classic or traditional Yorùbá city is a permanent, fortified settlement with an interior divided into distinct quarters settled by different distinct lineages, distributed along a spoke-and-wheel pattern arranged around the ruler's palace and main market. This spatial effect also reflects the ruler's centralized authority and the city's overall social organization (see Fig. 2). Anthropologists, namely, William Bascom (1955, 1969) and Peter Cutt Lloyd (1973) championed this Yorùbá urbanism model, and sociologists (Krapf-Askari, 1969; Mann, 2007), geographers (Mabogunje, 1969; Ojo, 1967), and historians (Aderibigbe, 1975; Oguntomisin, 1999) soon followed suit. Most recently, urban historians rendered in-depth visual narratives regarding Yorùbá cities such as Lagos, expanding on cartographic and planning modalities (Adelusi-Adeluyi, 2015 PhD dissertation; Bigon, 2009); critiques of the idealized premise of Yorùbá urban form also exist (Watson, 2003).

The cities (*ìlú*) are almost always oval in shape, with the *Oba*'s palace (*àfin*) normally as the focal point where the main roads and paths converge. Scholars point to Ilésà as the “perfect formal representation” of the ideal spoke-and-wheel pattern of the Yorùbá city (Peel, 2000). *Ọ̀yọ́*, *Ọ̀sogbo*, *Ilé-Ifè*, and *Ọ̀wọ́* are said to have had two or three concentric walls. Walls were punctuated with gates to control access, often serving as tollgates. In 1825, Lander and Clapperton reported that Old *Ọ̀yọ́*'s mud wall was 20 ft high, surrounded by a moat with a circumference of 15 or so miles. The nineteenth-century towns, often the hasty product of roaming, desperate refugees, depart quite dramatically from this ideal, most notably as a consequence of the circumstances of their formation. In *Ìbàdàn*, for instance, this meant an absence of a palace (Mabogunje, 1968), even though the main market (*Oja Iba*) still constitutes the heart of the old part of the city, now a polycentric and polymorphic conurbation.

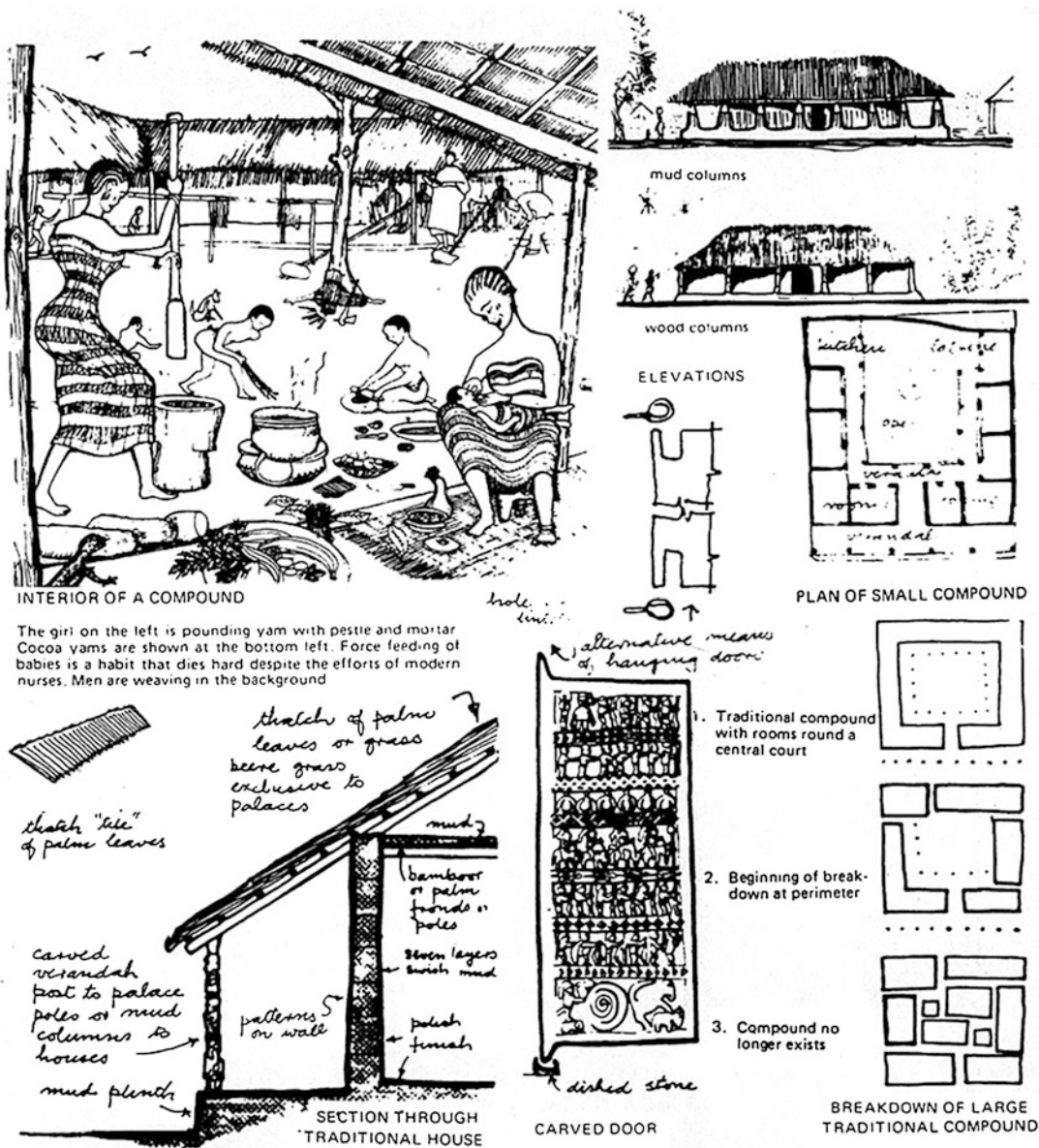


City Planning: Yorùbá City Planning, Fig. 2 Town plan of Iléshà, an ideal plan of a Yorùbá city (Amended by the authors from Ojo, 1967)

The Yorùbá employ a complex urban vocabulary to differentiate between scale, population, and political importance (Ojo, 1966). Historically, a town's rank was based on a system of classification that privileged the existence of a crowned ruler at its nucleus. *Ìlú*, or city, refers not only to the town alone but to its sociopolitical structure. Despite the importance of population and density, the most important factor to these urban inhabitants was its sociopolitical quality. For the Yorùbá, the *ìlú* or town was both town and polis. *Ọyó*, *Abẹ̀òkúta*, and *Ìjẹ̀bu* have crowned kings whose authority is derived from *Ilé-Ifẹ̀*; hence, they are known as *ìlú aláḍé*. Cities lacking these rulers can be *Olu-Ìlú* or capital towns, such as *Ìbàdàn* and *Ọ̀gbómòṣó*. The *ìlú ọlọja* are market towns (e.g., *Èpẹ* and *Ejirin*) and *ìlú-eréko* are dependent, subordinate towns (e.g., central Lagos, which is still known as *éko* in local parlance, as in the mid-seventeenth century, it became a vassal to Benin city and paid tribute). Finally, there are numerous *àgó* (war camps),

ileto (villages), and *abúlé* (hamlets) scattered between the major and minor towns. This generic Yorùbá terminology of settlement forms and accompanied imagery has yet to be thoroughly studied, such as other specific toponyms that can teach us much on the spatial implications of the colonial encounter and the influence of global economy. One example is *Ìbàdàn's* Gbagi District, which designates the formerly white residential quarter, with *gbagi* meaning "to peg" in Yorùbá. This is due to a local fascination with the European preoccupation with title to land by pegging their plots, in marked contrast with communal land ownership and other indigenous conceptions regarding the central role of the land in the circle of life and death.

Among the other historic morphological characteristics, traditional public buildings such as small shrines could be identified in certain localities – to be later exchanged with more imposing mosques or churches. Within the



City Planning: Yorùbá City Planning, Fig. 3 Reconstruction of a precolonial Yorùbá compound made of perishable materials (Akinsemoyin & Vaughan-Richards, 1976, p. 8)

walls, periodic markets were an important economic feature and functioned as gendered spaces as women controlled many aspects of the economy (McIntosh, 2009). Residents of the city lived in differentiated quarters made up of grouped compounds. Houses, compounds, and walls were built of locally sourced materials, such as mud, country thatch, and other vegetation

(see Fig. 3). These materials were later condemned by both Anglo and Franco colonial regimes, using building regulations as a tool for imposing capitalist economy and residential segregation on a racial basis between the expatriate and autochthonous societies, and slum clearance schemes (Bigon, 2008; King, 1995; Marris, 1961; Njoh, 2007).



City Planning: Yorùbá City Planning, Fig. 4 Late-nineteenth-century “Brazilian” house from Lagos, later roofed with corrugated iron; below: street scene from Ìbàdàn, showing *ilé petesy* variations (Photos: L. Bigon)

Yorùbá family compounds were most often built on a square plan, with numerous rooms surrounding an enclosed space in the center. The homes were bounded by a mud wall. These compounds were distinguished by size and rank, with their space increasing from half an acre for modest homes to many acres for chiefs, noblemen, and finally the largest space for the *àfin* (Izomoh, 1994).

During the mid-nineteenth and the twentieth century, a new vernacular domestic housing style evolved. It was initiated by ex-slaves of Yorùbá descent who returned to West Africa from Brazil. Using the masonry skills they acquired there, they developed the two-storey *ilé petesy* or “upstairs house” built with permanent materials and decorated in the baroque style. These Brazilian houses emerged first in Lagos (and simultaneously in other coastal towns like Porto-Novo) but gradually became naturalized all over Yorùbáland (Vlach, 1984) (see Fig. 4).

While cement-plastered rectangular compounds also characterize Yorùbá architecture, and the corrugated-iron roofing became so popular in dictating the reddish eroded cityscape today, a variety of deviations from traditional patterns also exist (Aradeon, 2012). Many of these changes initially took place during the colonial period and include the micro (residential unit) and macro (spatial urban expansion) levels, such as the filling in of the rectangular courtyard with built units and vertical, peripheral, and poly-centric growth.

The first third of the nineteenth century was a time of dramatic upheaval for Yorùbá cities, mostly due to the effect of broken alliances and internecine wars. The emergence of Ìbàdàn and Abẹ̀òkúta in the first third of the nineteenth century showed a radical change in the conception and consolidation of urban Ifẹ̀ for Yorùbá people (Mabogunje, 1968; Smith, 1988). At least three important Yorùbá cities have roots in the wars of the nineteenth century, and these cities emerged from the efforts of refugee populations. These roots account for the ways that their morphologies departed from the ways that cities had been constructed in the past. Ìbàdàn and Abẹ̀òkúta, the most recent of the important cities, were both founded circa 1830. Old Òyó was also relocated around this time. Owu, one of the largest Yorùbá cities, was destroyed by an Ìjẹ̀bu-Ifẹ̀ alliance, and the survivors from this city encamped in a deserted village. It was on this site that a new city, Ìbàdàn (roughly “war camp”), was built. Around the same time, Ègbá refugees fleeing south camped around Olumọ̀ Rock, building Abẹ̀òkúta (meaning “under the rock”). Ìbàdàn was a new sort of Yorùbá town, borne of the circumstances of the fragmented internecine wars that ravaged Yorùbáland. Its population was made up of people from Ifẹ̀, Òyó, and Ìjẹ̀bu. The quarters and compounds were comprised of what John Peel (2000) termed non-kin affiliates, and there, the compounds no longer corresponded simply to grouped lineages.

Yorùbá cities differed in size and scale. Though no official census figures survive for the nineteenth century, visitors to Yorùbáland recorded several towns with over 10,000 inhabitants, with at least 22 towns numbering over 10,000 residents. Estimates for medium-sized towns like Ìjèbù Òde, Lagos, Ògbómòṣṣò, and Ìjàyè ranged from 20,000 to 40,000 in the 1850s. The larger cities – Abẹ̀òkúta, Ìbàdàn, Òsogbo, and Ilorin – each numbered over 60,000. In the 1850s, Ìbàdàn's population was estimated at between 70,000 and 100,000, and estimates of Abẹ̀òkúta's population were most often set at 60,000, though one observer (Richard Burton) guessed that there were possibly 100,000 residents within the town's walls in 1861 (Mabogunje, 1968). Today, Nigeria (Africa's most populous country) accounts for about 18 % of the continent's total population, and thriving Yorùbá cities such as Lagos are estimated as among the fastest-growing cities in the world. Metropolitan Lagos, for instance, which in the 1950 consisted of only about 290,000 inhabitants, is expected to reach, according to UN HABITAT, to close to 20 million residents by 2025 (2014, p. 103).

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Clocks and Watches

Donald R. Hill

There was a long tradition in the Hellenistic world for the construction of large water clocks. Vitruvius, writing in the first century BCE, mentions the water clocks constructed by an Alexandrian engineer called Ctesibius (ca. 300 BCE) which incorporated gearing, automata, and audible time signals. The Alexandrian writer Hero, who flourished around AD 60, is known to have written a book on water clocks. The Byzantine historian Procopius described a monumental water clock constructed at Gaza in the sixth century AD. It is almost certain that the inspiration for the construction of water clocks in the Islamic world came from this Hellenistic tradition.

Islam

Monumental water clocks are described in detail in two Arabic treatises. ► [Al-Jazarī](#) in his machine book *Kitāb fī maʿrifat al-ḥiyal al-handasiyya* (The Book of Knowledge of

Ingenious Mechanical Devices), completed in Diyar Bakr in 1206, describes two such machines. Riḍwān ibn al-Saʿātī, in his treatise *Kitābʿamal al-sāʿāt wa ʿl-ʿamal biha* (Book on the Construction of Clocks and on Their Use) dated 1203, describes the water clock built by his father Muhammad at the Jayrun gate in Damascus. It fell into disrepair after Muhammad’s death and was restored to working condition under his son’s supervision. It was a large construction, having a timber working face about 4.73 m wide by 2.78 high, built into the front of a masonry structure. The clock had several design defects which undoubtedly caused the breakdown that Riḍwān undertook to repair. Moreover, Riḍwān himself was not an engineer and his description, though containing some valuable information, omits to deal with some important constructional details.

Al-Jazarī’s two clocks, on the other hand, were manufactured and constructed in a very workmanlike manner. Although very similar in principle to al-Saʿati’s they did not incorporate any design defects. The first and larger of the two was described in such careful detail that it was possible to construct a full-size working facsimile from al-Jazarī’s instructions and illustrations for the World of Islam Festival, in the London Science Museum in 1976.

The working face of the clock consisted of a screen of bronze or wood about 225 cm high by 135 cm wide set in the front wall of a roofless wooden house which contained the machinery. At the top of the screen was a zodiac circle about 120 cm in diameter, its rim divided into the 12 signs. It rotated at constant speed throughout the day. Below this circle were the time-signaling automata which were activated at each hour. (The clock worked on “unequal” hours: i.e., the hours of daylight or darkness were divided by 12 to give hours that varied in length from day to day.) These included doors that opened, falcons that dropped balls on to cymbals and the figures of five musicians – two drummers, two trumpeters, and a cymbalist. The musicians were operated by the discharge of water from an orifice, whereas all the other automata were operated by a heavy float that descended at constant speed in a reservoir.

A cord tied to a ring at the top of the float led to a system of pulleys that activated various tripping mechanisms.

The speed of descent of the float was controlled by very ingenious water machinery that included a feedback control system and a flow regulator, the latter for varying the rate of discharge daily in order to produce the “unequal” hours. The same system was used by Riḍwān and both writers attribute its invention to Archimedes. There is a treatise that exists only in Arabic and is attributed to Archimedes. The treatise almost certainly contains Hellenistic, Byzantine, and Islamic material but its first two chapters describe water machinery that is essentially the same as that used by Riḍwān and ► [al-Jazarī](#). There is every likelihood that these chapters were indeed the work of Archimedes.

Al-Jazarī's book also contains descriptions of four other water clocks, two of which embody the principle of the closed-loop, and four candle-clocks which, on a small scale, are as impressive from an engineering point of view as the water clocks.

Other Arabic works add to our knowledge of Islamic hydraulic timekeeping. A certain Ibn Jalaf or Ibn Khalaf al-Murādī worked in Andalusia in the eleventh century. Unfortunately, the unique manuscript of his treatise on machines is badly defaced, but it is possible to determine the essential details of the automata and water clocks that are described in it. The most important feature that they incorporate is complex gear-trains which include segmental gears (i.e., gears in which one of the wheels has teeth only on part of its perimeter, a device that makes intermittent action possible).

Al-Khāzini's justly famous book on physics, *Kitāb Mīzān al-Ḥikma* (Book of the Balance of Wisdom) was completed in 1121–1122. In the eighth treatise two steelyard clepsydras are described. On the short arm of the beam was a vessel that discharged water at a constant speed from a narrow orifice. Two sliding weights were suspended to the long arm, which was graduated into scales. At a given moment the weights could be moved to bring the beam into balance and the time could then be read off from the scales.

A number of noteworthy references to water clocks can be found scattered among the works of Arabic writers. For example, we read of one such device in the works of the Anadusian poet ‘Abbās ibn Firnās (d. 887). Two water clocks were constructed by the famous astronomer al-Zarqallu in 1085 on the banks of the river Tagus at Toledo. The remains of two large water clocks still exist in Fez, Morocco. One of these is in the street opposite the Bu'ananiyye Madrasa and was built in 1357. According to the historian of Fez, Al-Jazna'ī in *Zahrat al-Ās*, at each hour pellets fell onto a gong and a pair of door leaves opened. The door openings and the brackets for the gongs still exist. A second clock was constructed in 1361. It had an astrolabic dial and it also released pellets and had doors that opened. It is in the minaret of the Qarawiyyīn mosque. The doors and the dial still survive, but in neither of the Fez clocks does any trace of the water-machinery remain. Another North African water clock, in Tlemcen, was mentioned by Abū Zakariyyā Yaḥyā ► [ibn Khaldūn](#) in *Bughyat al-ruwwād*.

In 1276–1277 a work entitled *Libros del Saber de Astronomia* was produced in Castilian under the sponsorship of ► [Alfonso X](#) of Castile. This consists of various works that are either translations or paraphrases of Arabic originals. It includes five timepieces, one of which is of significance in the history of horology. This consisted of a large drum made of walnut or jujube wood tightly assembled and sealed with wax or resin. The interior of the drum was divided into 12 compartments, with small holes between the compartments through which mercury flowed. Enough mercury was enclosed to fill just half the compartments. The drum was mounted on the same axle as a large wheel powered by a weight-drive wound around the wheel. Also on the axle was a pinion with 6 teeth that meshed with 36 oaken teeth on the rim of an astrolabe dial. The mercury drum and pinion made a complete revolution every 4 h and the astrolabe dial made a complete revolution in 24 h.

This type of timepiece had been known in Islam since the eleventh century.

China

The commonest method of timekeeping in China, for many centuries, was the inflow clepsydra. In its simplest form this consisted of two vessels: a reservoir and a receiver below it. The reservoir had an overflow pipe near its top and an orifice in its underside. The water supply ran into the reservoir and the overflow pipe ensured that the water level remained constant. The rate of flow from the orifice into the receiver was therefore also constant as was the rise of the water in the receiver. A float in the receiver was used to activate various time-recording mechanisms.

The inflow clepsydra was used extensively in China from the Han period (202 BCE–AD 221) onwards. Two main types were developed. The first type involved the introduction of one or more compensating tanks between reservoir and receiver. At each successive stage the retardation of flow due to diminishing pressure head was more and more fully compensated. The introduction of at least one compensating tank can be dated to the second century AD. As many as six tanks are known to have been used. In the second type an overflow or constant head tank was placed in the series, a practice that began in the middle of the sixth century AD. There can be no doubt that this type of water clock was widely used in China throughout the medieval period.

The most notable achievement of Chinese horologists was the clock described by Su Song in *Xin yixiang fa yao* (New Design for an Armillary Clock or Description of a New Astronomical Instrument) begun in 1088 and completed in AD 1094. This was a monumental clock, 30–40 ft (9–12 m) in height, having a rotating armillary sphere and celestial globe, together with numerous jack-work figures with both audible and visible effects. These devices were driven, through a complex system of gearing, by a water-wheel 11 ft (3.35 m) in diameter carrying 36 scoops on its perimeter. Water stored in an upper reservoir was delivered to a constant-level tank by a siphon, whence it was discharged on to the scoops of the wheel, each of which had a capacity of 0.2 ft³ (0.6 cm). The wheel was provided with a very ingenious escapement system,

in essence two steelyards upon each of which the scoops acted in turn. When a scoop was full, its weight overcame the balancing system and it fell freely for a given distance until checked, without recoil, by a locking device. The next scoop then came under the delivery jet and the cycle repeated itself. There is no evidence that the system of escapement used in Su Song's clock was ever transmitted westward.

The mechanical clock was invented in western Europe toward the end of the thirteenth century. Almost certainly its inventor came from the ranks of the makers of water clocks. The verge escapement made the mechanical clock possible, but all its other features – weight-drive, automata, gear-trains, and segmental gears – were present in Islamic water clocks. It is highly probable that these ideas were transmitted from Islam to the European makers of water clocks. An Islamic influence on the genesis of the mechanical clock may therefore be postulated.

Several of Taqī al-Dīn's writings are concerned with timekeeping, and one of these, *Al-kawākib al-darriyya fī al-binkāmāt al-dawriyya* (The Brightest Stars for the Construction of Mechanical Clocks), written about 973/1565, has been edited with Turkish and English translations.

In this he described the construction of a weight-driven clock with verge-and-foliot (an early form of balance) escapement, a striking train of gears, an alarm, and a representation of the moon's phases. He also described the manufacture of a spring-driven clock with a fuzee [a conical pulley or wheel] escapement. He mentions several mechanisms invented by himself, including, for example, a new system for the striking train of a clock. He is known to have constructed an observatory clock and mentions elsewhere in his writings the use of the pocket watch in Turkey. This is a surprisingly early reference to the use of watches in Turkey; the manufacture of watches began in Germany about 1525 and in England about 1580.

Taqī al-Dīn's descriptions are lucid with clear illustrations, showing that he had mastered the art of horology. Clockmaking did not, however, become a viable indigenous industry and Turkey

was soon being supplied with cheap clocks from Europe. ► [Taqī al-Dīn](#) himself commented on the low price of these European clocks, which entered Turkey, he said, from Holland, France, Hungary, and Germany.

See Also

- [Alfonso X](#)
- [Al-Khāzinī](#)
- [Ibn Al-Zarqāllu](#)
- [Ibn Khaldūn](#)
- [Taqī al-Dīn](#)

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Clocks: Astronomical Clocks in China

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Timekeeping was a necessary preoccupation of the Chinese imperial state from its inception in the third century BCE. It was essential to the effective performance of ritual, which required the selection of auspicious hours as well as days, and to the proper interpretation of the astrological portents carefully recorded by the Astronomical Bureau. In addition it underpinned the fine tuning of increasingly elaborate systems of mathematical astronomy. The earliest devices used by astronomers were simple outflow or inflow waterclocks (clepsydras), which depended on the flow of water from a vessel to a small orifice. A graduated float indicated the time elapsed. Several later sources mention the Han dynasty scholar ► [Zhang Heng](#) (AD 78–139) as having succeeded in rotating an armillary sphere by means of “flowing water” so that it kept time with the heavens.

More detailed accounts survive of a similar project under the Tang dynasty in the eighth century AD, when the Buddhist monk Yixing and his colleague Liang Lingzan made a water-powered armillary sphere, which incorporated jack-work to announce the hours and quarters by bells and drums. In neither case we have enough data to begin to reconstruct the mechanism involved. However, in AD 1086 the high official and scholar Su Song was commissioned to construct an astronomical timekeeper which was to be much more complex than any of its predecessors, and a detailed illustrated description of this device has come down to us in his monograph entitled *Xin yixiang fa yao* (Description of a New Astronomical Instrument or New Design for an Armillary Clock).

From this book we learn that the device Su Song constructed was in effect a clock-tower more than 10-m high, surmounted by a great bronze armillary sphere automatically rotated, with a rotating celestial globe in an inner

chamber. On the front of the tower was a complex array of jacks and annunciators to mark the passage of time. The mechanism which turned the shafts was based on a great water-driven scoop wheel, with a weighbridge and trip-lever movement which allowed the wheel to advance one step each time a standard weight of water had run from a constant-head tank. This happened once every hundredth of a day, about 15 min, so that the correspondence with the heavens was somewhat jerkily maintained. While the utility of this device to astronomers can only have been moderate, its possession must have been seen as a considerable enhancement to imperial prestige. Su Song's tower fell out of use when the capital fell to invaders in AD 1126.

See Also

- [Calendars in East Asia](#)
- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [Zhang Heng](#)

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Cloth Making at Chichen Itza

Gabrielle Vail

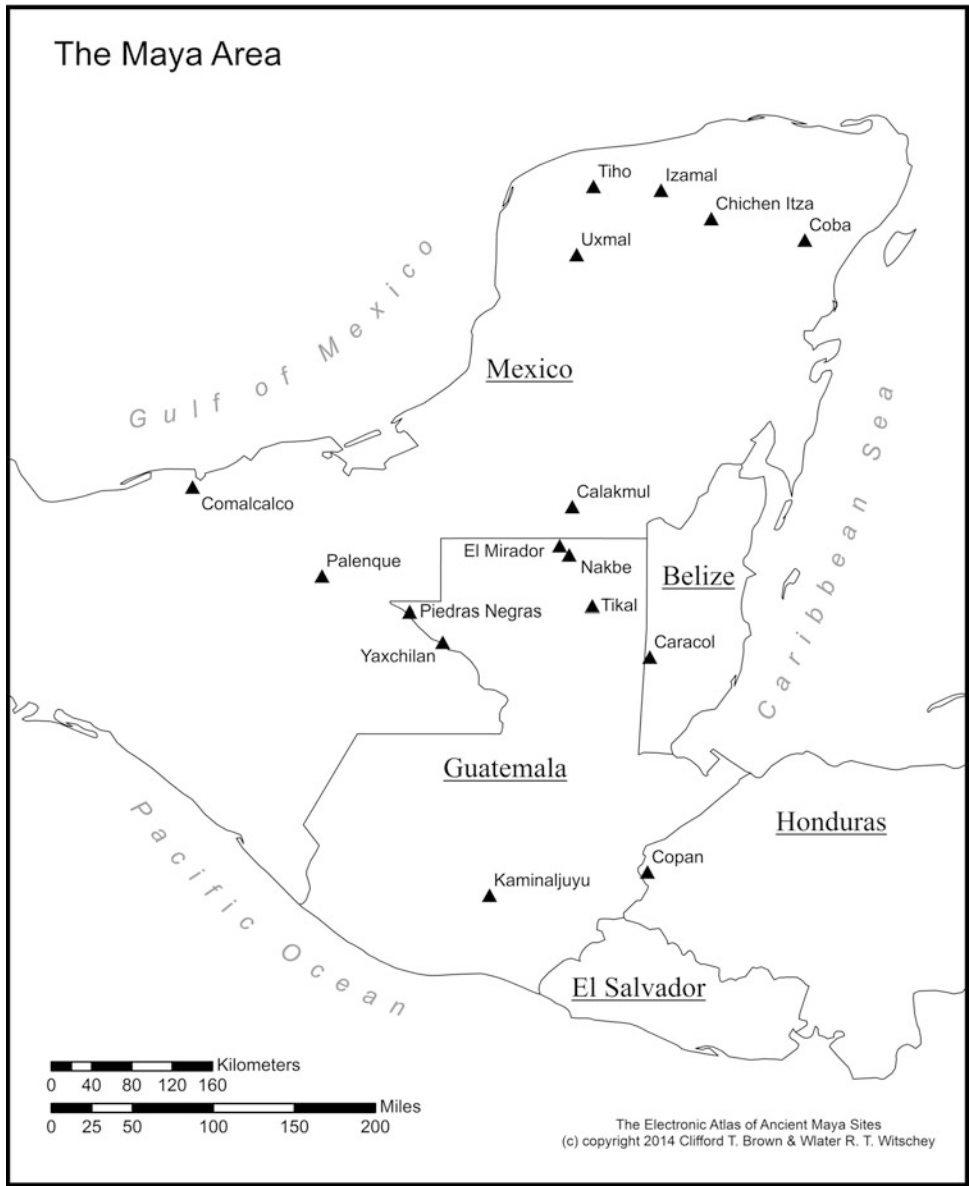
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The manufacture of cloth is a tradition with deep roots throughout the Maya area (Fig. 1), which encompasses the Yucatán Peninsula or northern region, and the area south of this, comprising what are today the Mexican states of Tabasco and Chiapas, Guatemala, Belize, and parts of Honduras. Because of the humid nature of the climate characterizing much of the Maya area,

few textiles survive from the pre-Hispanic time period (i.e., prior to the sixteenth century). The largest collection that does, however, comes from the Sacred Cenote at Chichén Itzá. Over 600 fragments of textiles were found in the early twentieth century dredging operations at the cenote (a natural pit or sinkhole resulting from the collapse of limestone bedrock that exposes groundwater underneath), most of them only a couple of centimeters in size. They exhibit a variety of weaves, although a plain weave is the most common (Lothrop, 1992; Mahler, 1965). The original provenience and dating of the Chichén textiles remains unknown, as pilgrims came from great distances to make petitions and leave offerings as payment to the deities over a period of time that likely spanned a millennium (Lothrop, 1992). Many of these were bundled or wrapped in cloth (Fig. 2).

The question of where textiles were being manufactured can be answered by archaeological evidence, primarily that provided by the recovery of specialized tools. The most common of these are spindle whorls, which consist of a round disk that is attached to the base of a spindle to serve as a weight when fibers are being spun to create thread, and bone implements that may have served as weaving picks. Spindle whorls may be made of various materials, including stone, bone, baked clay, or wood; the latter is rarely found in archaeological contexts, however, because of their perishable nature. Clay spindle whorls recovered in Yucatán appear to have been mold made and have a variety of designs, the most common being four-part compositions (including flowers) and birds (Fig. 3).

Spindle whorls have been recovered from a number of Maya sites, both in the northern region (where Chichén Itzá is located) and further south, at sites such as Caracol, Copán, and Motul de San José (Chase, Chase, Zorn, & Teeter, 2008; Halperin, 2008; Hendon, 1997). The largest concentrations come from the Late and Terminal Classic periods (c. 600–1000 CE). Analyses of these artifacts provide a great deal of information about weaving technology, gender roles, and production techniques over time and across the Maya area.



Cloth Making at Chichen Itza, Fig. 1 Map of the Maya area, showing the major sites mentioned in the text. Balankanché and Xuenkal are located in the vicinity of Chichén Itzá (Brown & Witschey, 2014)

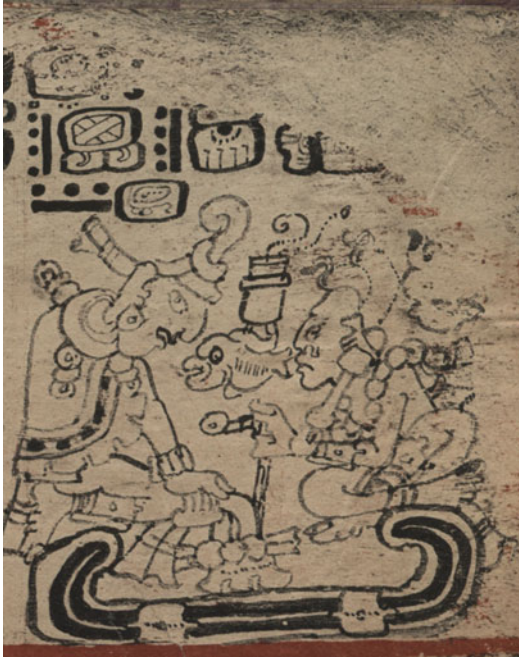
The technology employed by the pre-Hispanic Maya in producing textiles has changed little over the millennia, as suggested by depictions of weavers in three-dimensional media, such as figurines and whistles, as well as painted in screenfold books called codices. The first step would have involved the gathering of fibers (cotton and hemp were two that are known to

have been used pre-Hispanically) and their processing to clean and prepare them for use. The processed fibers were then spun to create thread, using a process similar to that illustrated here (Fig. 4); they were also sometimes dyed, either before or after spinning, using various plants and mineral substances. Prior to being woven, the threads had to be warped in a figure-8 pattern,

using a warping frame, as shown in this image from the Madrid Codex (Fig. 5). They were then soaked in a corn gruel to strengthen them, before being transferred to the loom.

The type of loom used by the pre-Hispanic Maya, referred to as a backstrap loom, differs little from that used by their descendants today. It consists of a collection of sticks and a strap.

Eight sticks are commonly used in contemporary Maya backstrap looms, including the front and back bars, the heddle rod, the shed rod, shuttle, batten, tenter, and lease stick (Fig. 6). Pre-Hispanic looms (Fig. 7) were likely very similar in their design. One end would be attached by a rope to a tree or post and the other to the strap worn by the weaver to increase or decrease the tension when weaving.



Cloth Making at Chichen Itza, Fig. 2 Two deities making offerings to a cenote (represented by the U-shaped glyph) on page 33a of the Dresden Codex. The figure on the left offers a cloth-wrapped bundle (Förstemann, 1880)

Archaeological Evidence of Textile Production

The largest assemblage of spindle whorls recovered from the northern lowlands comes from Chichén Itzá itself (a total of 147), followed by the nearby sites of Xuenkal (25 total) and Balankanché Cave (26 total). The bulk of these collections come from Terminal Classic contexts, suggesting an intensification of textile production during this period, likely as the result of the transition from primarily household production to production for tribute and trade networks (Ardren, Manahan, Wesp, & Alonso, 2010). The largest concentration from Chichén (31) was found in the structure called Las Monjas, suggesting that spinning and weaving took place there on a regular basis. Because it has been identified as a primary residence for some of the more important women of the site, researchers have proposed that spinning was a prerogative associated with elite women at Chichén (Krochock, 2002, p. 160). Data from other sites

Cloth Making at Chichen

Itza, Fig. 3 Spindle whorls from Balankanche'. Both depict birds, which played an important role in narratives relating to the moon goddess (who is frequently shown spinning and weaving in her human form) and her lover the sun, who appears in the guise of a bird (Andrews, 1970)



and archaeological contexts – principally burials – suggest that this correlation was true in other regions as well. It is likely that elite women produced fine cotton thread that was used for weaving ceremonial garments and those for the nobility and that women of other classes spun and wove with coarser materials for household (or community-wide) consumption.

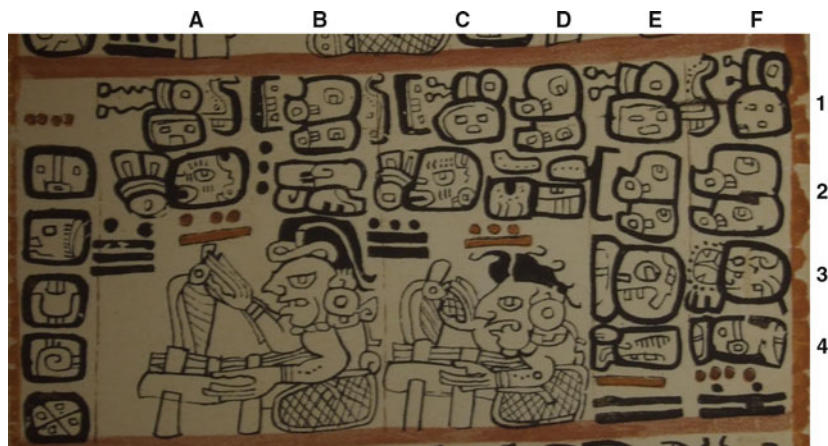


Cloth Making at Chichen Itza, Fig. 4 The spinning of wool to create thread. Wool was introduced by the Spanish; prehispanic Maya women would have spun cotton or other fibers into thread (Photograph by Nicholas Manting-Brewer. With permission)

Xuenkal, located approximately 45 km from Chichén along the most direct route to its port facility, underwent a number of transformations during the Terminal Classic period, at a time when Chichén exerted its influence over a large portion of the surrounding region. Changes in the material inventory, along with new types of structures found at Chichén, suggest that the residents of Xuenkal either voluntarily or forcibly became part of the Chichén sphere of influence (Ardren et al., 2010).

The recovery of 17 ceramic spindle whorls from one of the Terminal Classic platforms at the site suggests that it was a locus for textile production. An analysis of the whorls indicates that they were likely used for the production of fine cotton thread (based on the size of the spindle whorl and the diameter of the hole; larger examples were used for spinning coarser fibers, such as maguey). Ardren et al. (2010, p. 284) interpret these data as indicating the spinning of high-quality cotton thread, likely for the production of textiles to be given in tribute to Chichén. The question of whether weaving, as well as spinning, was done at the site remains unknown.

Xuenkal and Chichén are located in an area where cotton was grown in both pre-Hispanic and colonial times (Gates, 1978). According to colonial period sources, the manufacture of cotton *mantas*, or lengths of cloth, was one of the principal activities of Maya women, and the trading

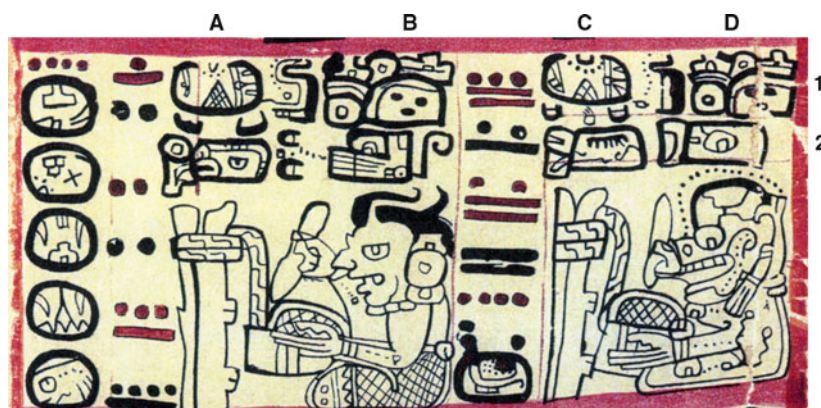


Cloth Making at Chichen Itza, Fig. 5 The use of a warping frame (*chuch*) on page 102c of the Madrid Codex. The word *chuch* is spelled in the hieroglyphic text at B1 (Brasseur de Bourbourg, 1869–1870)

Cloth Making at Chichen**Itza, Fig. 6** Maya weaver

Concepción Poou Tharin
illustrating the use of the
backstrap loom

(Photograph by the author)



Cloth Making at Chichen Itza, Fig. 7 Weaving with a backstrap loom on page 102b of the Madrid Codex. The cloth being produced is referred to at B2 in the text as *y-al*, “her child” (Brasseur de Bourbourg, 1869–1870)

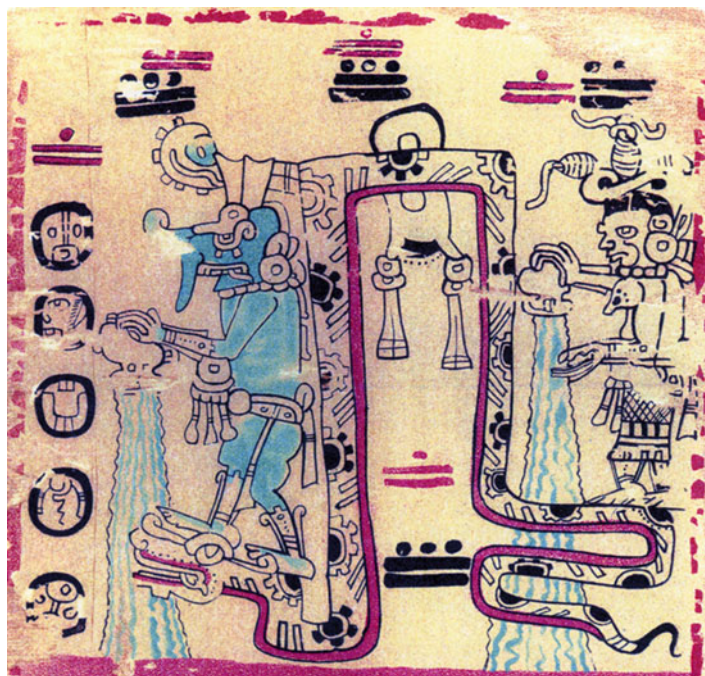
of textiles was second only to that of salt (Landa, in Ardren et al., 2010, p. 275).

In addition to their practical uses, spindle whorls also have ritual and symbolic associations. In Group III at Balankanché, 25 spindle whorls were recovered, in association with a number of vessels for burning incense. As Vail and Hernández (2012) note, they were likely deposited as part of rituals related to the recreation of the world, which emphasized the creation of humans and of the rains to sustain them. The *incensarios*, which have modeled images of the rain god, were probably used to burn incense to

create dense clouds of smoke to imitate the rain-laden clouds that gather during the rainy season, whereas the spindle whorls are indicative of the Maya creator goddess Chak Chel, who wears spindles wound with thread in her hair (Fig. 8). Among contemporary Maya cultures living in the highlands of Guatemala, the creator goddess is said to have woven the world into existence (Prechtel & Carlsen, 1988). Additionally, in highland Chiapas today, the daughters of the earth lord are responsible for fluffing cotton for spinning, which then escapes into the sky to form rain clouds (Morris, 1987).

Cloth Making at Chichen Itza, Fig. 8

Chaak and Chak Chel as rain-makers on page 31a of the Madrid Codex. Note spindles wound with thread worn by Chak Chel (Brasseur de Bourbourg, 1869–1870)



The presence of such a large number of spindle whorls in Group III at Balankanché, paired with the incense burners, suggests that they form a symbolic part of a rainmaking ceremony dedicated to the rain god Chaak and to Chak Chel (Vail & Hernández, 2012). The two are portrayed as bringing the life-giving rains in several almanacs found in the Maya codices (see Fig. 8), which are believed to date to the Late Post-Classic period (c. 1250–1500) and to come from Yucatán.

Use of Pre-Hispanic Textiles

Textiles appear in a variety of contexts during the Classic period (c. 250–800) in the southern Maya lowlands: as clothing worn by elite members of society (as seen on stone monuments, pottery vessels, and murals), as curtains and room dividers in palaces, as tribute given to the ruler of Classic period kingdoms, and as gifts cementing elite relations (Looper, 2000; Reents-Budet, 2002). Additionally, remnants of cloth have been found in Classic period tombs, where

they appear to have served as wrappings for the bodies (Hendon, 1999). Cloth also played a significant role in rituals. Sacred objects and deity effigies were wrapped to contain their power when not in use and unwrapped for particular ceremonies, such as the accession of a ruler to office (Reents-Budet, 2002, p. 115).

Images from Classic Maya art and monuments stress the importance of clothing in defining social roles and gender identity. Special accoutrements were worn ceremonially, including headdresses of various forms (made of cloth and feathers) and jewelry (primarily of jade). In certain regions, women wore a long garment called a *huipil* when performing ceremonial functions (Fig. 9); in others, a type of netted skirt and top were more common. Elite women and men are both depicted wearing capes. Men of all classes wore loincloths, and women wore skirts or wrap-around (sarong-like) garments (Looper, 2000). Evidence from the Aztec region of Mesoamerica indicates that only the upper classes wore garments made of cotton, whereas other fibers (such as maguey, or agave) were used for the clothing



Cloth Making at Chichen Itza, Fig. 9 Elaborately decorated *huipil* worn by Lady K'ab'al Xook, queen of Yaxchilan in the eighth century. She performs an act of auto-sacrifice (a bloodletting ritual) by drawing a rope studded with thorns through her tongue (Photograph by the author)

worn by commoners (Anawalt, 2000, p. 207). It is not known whether this was the case in the Maya region as well, and if so, in what particular areas or time periods.

Textiles recovered archaeologically display a number of decorative techniques, including brocading, embroidery, and painting (Hendon, 1999), but the question of when these techniques came into use remains a matter of debate. Brocading and embroidery had developed by the Late Post-Classic period (c. 1250–1500), but it is unclear if they were used before then. Although some scholars have suggested that elaborately decorated garments depicted in pre-Hispanic stone sculptures may have been made by brocading (see Fig. 9), others argue that the intricate designs were made instead with a cylindrical stamp that was rolled across the cloth to create the very even patterns seen (Looper, 2000, p. 8). Maya women in Chiapas today reproduce these designs in a brocade technique (Fig. 10), and brocading may be represented in the Madrid Codex (Fig. 11).

Discussion

At the time of the Spanish conquest, the manufacture of textiles was one of the most significant economic practices in the northern Maya region.

Cloth Making at Chichen Itza, Fig. 10 Maya weaver from Chiapas brocading a series of prehispanic designs (Photograph by Nicholas Manting-Brewer. With permission)



Cloth Making at Chichen Itza, Fig. 11 Possible example of brocading using a weaving pick from page 79c of the Madrid Codex (Brasseur de Bourbourg, 1869–1870)



Archaeological evidence suggests that weaving fine cotton cloth was a high-status activity in earlier time periods, associated with the upper echelon of Maya society, and that cloth was being produced not only for household consumption but also for tribute and trade (Ardren et al., 2010; Hendon, 1997). Because all known artistic depictions show females performing the tasks associated with cloth production (spinning, warping, and weaving), researchers conclude that Maya women primarily did these activities. In light of this, the depiction of women's garments on Classic period monumental sculpture provides evidence not only of female status but of women's economic power as well (Looper, 2000, p. 17).

Among Maya cultures today, as was likely true in the past, men are responsible for providing the raw materials, which are then transformed by women into those things needed to sustain the family (cooked food, woven textiles, etc.). This can be likened to procreation and childbirth – although both partners contribute, it is the woman who ultimately gives birth to the child. Weaving is seen as analogous to giving birth, and the creator grandmother is said to have given birth to the world by weaving it into existence. Maya women from parts of Guatemala today likewise believe that a textile is born through the process of weaving (Prechtel &

Carlsen, 1988). A similar belief appears to have existed in the pre-Hispanic period as well, as the text associated with the weaving scenes in the almanac on page 102b of the Madrid Codex (see Fig. 7) refers to the weaving as the goddess' *y-al*, meaning "her child."

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Clovis Blade Manufacture

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Introduction

During the last glacial stage (ca. 11,000 BCE), Clovis people introduced from Eurasia into the New World a culture reflective of their Paleolithic homelands. Archaeological evidence indicates that these cold-adapted groups employed “hard” technologies for making lithic and osseous utensils and “soft” technologies for textiles, basketry, and cordage (Bradley, Collins, & Hemmings, 2010). Animal remains and environmental information at some sites, combined with artifacts, suggest that Clovis people were organized into egalitarian nuclear families and bands; that they followed a nomadic lifestyle, which included hunting mammoth and other large game; and that they gathered wild foods seasonally (Boldurian & Cotter, 1999; Neusius & Gross, 2013). While it is likely that generally poor organic preservation at sites exaggerates the importance of lithic tools in Clovis culture, the finely flaked projectiles known as fluted points, grooved and edge-polished along the base, are found across all of North America (Fig. 1). Like fluted points which unmistakably signify Clovis, other stone tools of superior flintworking – prismatic blades – firmly demonstrate the Old World ancestry of Clovis and may be another diagnostic component of this ancient culture (Collins, 1999).

Tools of Choice

Prismatic blades served a variety of functions in antiquity, such as cutting, scraping, scoring, perforating, and shaving. Like utility knives of today, blades were superlative kitchen and household utensils. With long, sweeping edges, blades

were either held by hand or attached to a handle, to perform more efficiently. Though of delicate appearance, blades were surprisingly strong and of high tensile capacity, which enabled them to resist snapping under heavy force (Collins, 1999). Blades were robust and durable and withstood repeated repair. Whether new or well worn,

blades were versatile and served as stock for making brand new tools. These next-generation utensils served in an array of domestic tasks, including scraping hides, planing and shaping wood, shredding plant fiber, scaling fish, and scoring and perforating leather, as well as etching and drilling bone and antler (Boldurian & Hoffman, 2009). The fact that blades were readily recycled into new forms immensely extended their importance in ancient toolkits (Fig. 2).

Making Clovis Blades

Manufacturing Clovis prismatic blades required much knowledge and skill. Yet the highly complicated procedure was unpredictable and, even for the best artisans, sometimes went awry (Bordes & Crabtree, 1969). Thus, the following description implies an ideal, error-free progression that was not always the case. To procure suitable stone, flintworkers searched outcrops for roughly head-sized masses of flint of sub-cubical to spherical shape (Fig. 3). Also, nodules were tested for purity in silica content and absence of internal flaws. Experienced artisans determined these qualities by removing just a few flakes. Next, a suitable nodule was carefully formed into a designated shape, which prepared it for detachment of prismatic blades. This stage entailed making a striking platform and building a guide ridge, after which the mass of stone could be called a “core.” A blademaker’s toolkit, including hammerstones and antler utensils, is depicted in Fig. 4.



Clovis Blade Manufacture, Fig. 1 Clovis fluted projectile points. Scale is in cm

Clovis Blade Manufacture, Fig. 2 Clovis blades fashioned into formal tool types. *Left-to-right:* combination side-end scraper, backed knife, end scraper, combination graver-end scraper, and combination knife-side scraper. Scale is in cm



- **Striking Platform**

Cleaving a large portion from one end of the nodule created a flat surface, which served as a stage to receive force for each blade removal. This broad area could last for the entire blademaking procedure (Fig. 5).

- **Guide Ridge**

On nodules that had a rounded, featureless surface, it was essential to create a ridge. This prominence guided force from the striking platform so that the first blade could be detached and allowed force to propagate farther along the core's main axis, which yielded the longest blade possible. To create this ridge, alternate flaking along one side formed an elongated area raised above the rest of the stone's mass. If the nodule had a natural

ridge, then building a guide ridge was unnecessary.

The first blade to be removed was the crested blade defined by the guide ridge. Its removal left two parallel ridges on the core, each of which was formed by the lateral margins of the crested blade as it detached. These ridges guided detachment of additional blades. Each new blade was removed via force applied to the striking platform at the proper angle, directly behind a ridge. At this advanced stage in manufacture, the prepared core looked like a truncated cone with many flat facets and is termed by archaeologists a polyhedral core. Two techniques for detaching Clovis blades from a polyhedral core have been proposed: direct percussion and indirect percussion.



Clovis Blade Manufacture, Fig. 3 Procurement of unmodified stone. Note its weathered exterior or cortex

- **Direct Percussion**

With one hand holding either a hammerstone or an antler billet [a soft hammer], the artisan applied force directly to the core's striking platform. In the other hand, he held the core, either freely or resting it upon his lap (Fig. 6a, b).

- **Indirect Percussion**

Two flintworking tools were employed, an antler hammer and a punch. At its distal end, the punch had a blunted tip, which was placed at the point on the striking platform and at the precise angle where force was desired. Force

Clovis Blade Manufacture, Fig. 4 A contemporary

blademaker's toolkit. Utensils include hammerstones, antler punches (left), antler hammer (center), and antler billets (right)



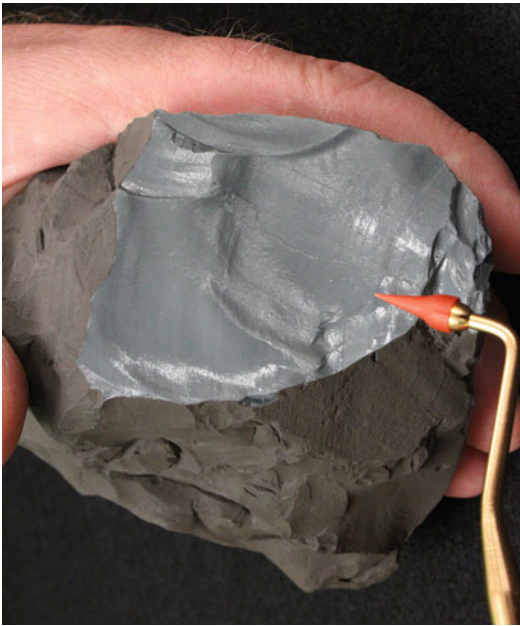
traveled from the hammer to the core via the intermediary punch. To facilitate this manner of delivering force, the core was braced in one of three positions: (1) unsupported at the

bottom and gripped between a seated artisan's knees; (2) with the core at rest on the ground, secured under one knee; or (3) again supported from below, held between both feet (Fig. 7a, b).

In repetitive sequence, blades were then detached from the prepared core (Figs. 7b and 8). Each time, force was directed onto the striking platform directly behind a guide ridge, thereby ensuring an unimpeded flow of force that was needed to remove a blade (Fig. 9).

Blade Morphology and Landmarks

Prismatic blades are long, narrow, and thin. On the dorsal surface, they have at least one ridge as evidence of prior blade removals. Blades with one ridge are triangular in cross section; those with two ridges are trapezoidal. These features of blades – elongate and slim with a three- or four-sided sectional shape – explain why they are commonly called *prismatic* (Bordes & Crabtree, 1969; Crabtree, 1972). At the proximal end, Clovis blades retain only a tiny remnant of

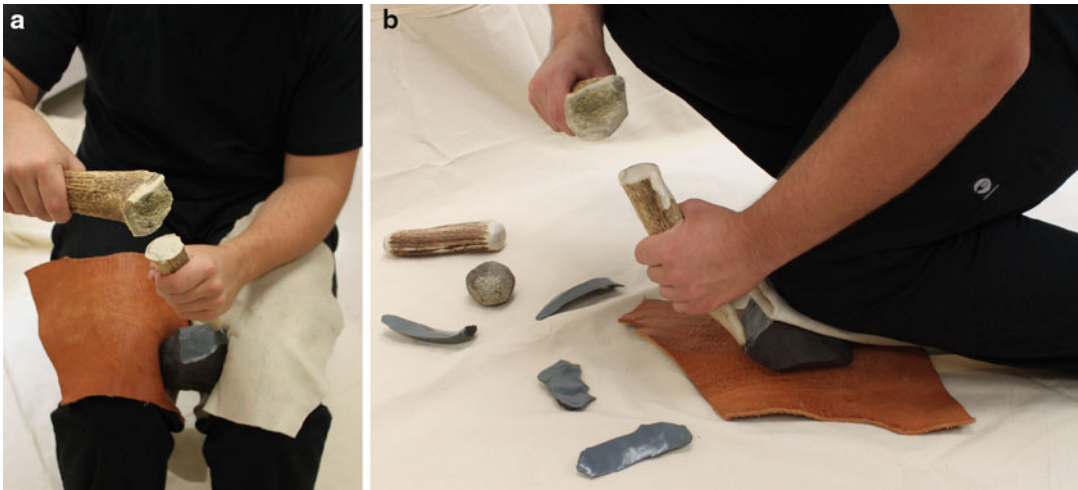


Clovis Blade Manufacture, Fig. 5 Making a striking platform



Clovis Blade Manufacture, Fig. 6 (a) Making prismatic blades via direct percussion using an antler billet. Image depicts moment prior to blade detachment (*top*) and immediately afterwards (*bottom*). In both images, note

how the core is cradled in the flintworker's hand. Blade detaches into the palm. (b) Making prismatic blades via direct percussion, using the lap to rest the core



Clovis Blade Manufacture, Fig. 7 (a) Making prismatic blades via indirect percussion with an antler hammer and punch, using the knees to brace the core. (b)

Making prismatic blades via indirect percussion with an antler hammer and punch, using the knee and a rest to brace the core

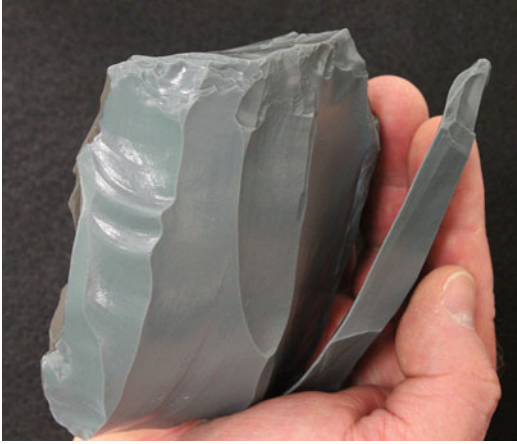
Clovis Blade Manufacture, Fig. 8 Replica Clovis blade core and prismatic blades



the core's striking platform. Blades made by other prehistoric peoples usually have much larger platform remnants (Collins, 1999). The ability to take only a diminutive platform was enabled by preparation to the point of detachment immediately prior to force application. Scars from this preparation appear at the blade's proximal end. These features of Clovis blades reveal great skill in the process of detaching blades while sacrificing only the smallest amount of the striking platform. Interior surfaces of Clovis blades typically are smooth and free of

undulations. Though in shape and design very similar to Old World Upper Paleolithic blades (Fig. 10a), Clovis blades differ in that they usually curve inward near the distal end (Fig. 10b). On the ventral surface near the proximal end of Clovis blades, the bulb of force is typically slight or diffuse, suggesting that force was delivered by a soft hammer such as a billet, instead of a dense, stone hammer. Collectively, these features, depicted in Fig. 11a–e, indicate the Clovis artisan's intimate knowledge of flint and reflect his ability to manage its physical properties (Collins, 1999).

Newly manufactured Clovis blades are usually 10–20 cm (4–8 in.) in length and rarely exceed 5 cm (2 in.) in width (Fig. 12). Lithic analysts measure many linear dimensions of blades and ascertain myriad conditions of blade morphology (Boldurian & Hoffman, 2009; Meltzer & Cooper, 2006).



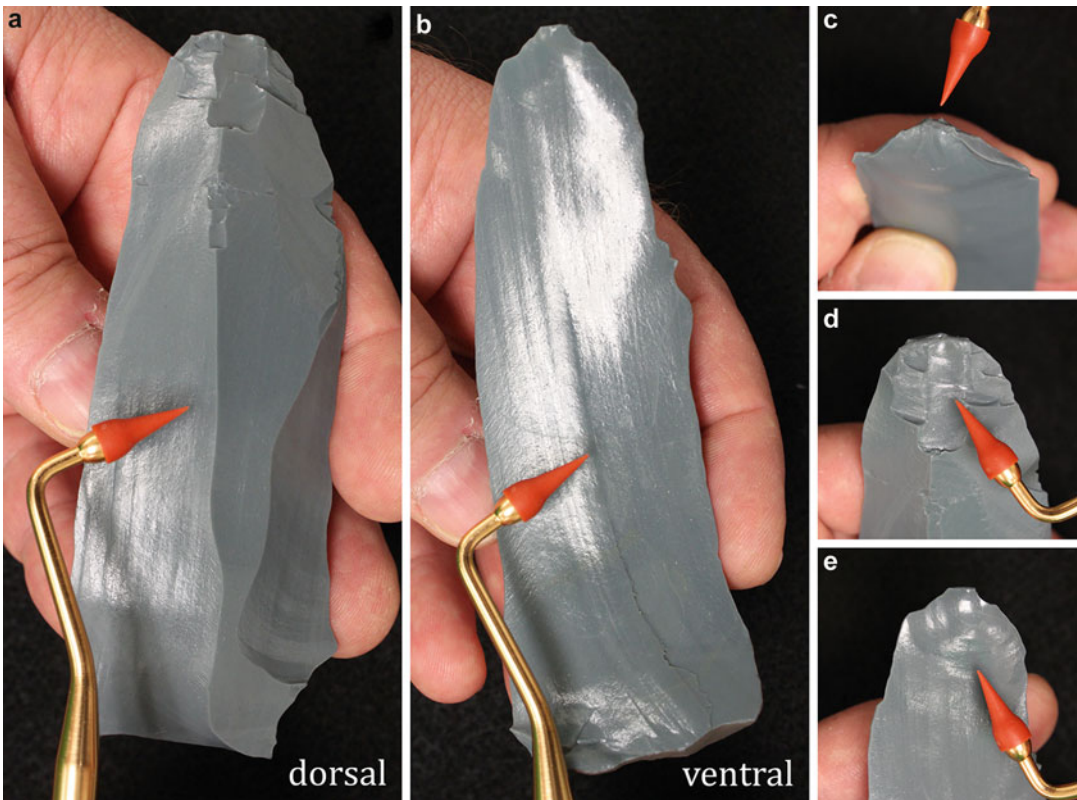
Clovis Blade Manufacture, Fig. 9 Replica Clovis prismatic blade detaching from prepared core

Uncertainties, Issues, and Debates

After 50 years, issues and debates over the entire manufacturing process of Clovis prismatic blades continue (Hammatt, 1970; Montgomery & Dickenson, 1992; Stoltman, 1971; Warnica, 1966). Uncertainties exist regarding whether Clovis artisans routinely employed direct percussion or, alternatively, indirect percussion in the blademaking procedure (Bordes & Crabtree, 1969; Crabtree, 1972; Newcomer, 1975). An intriguing feature of Clovis blade manufacture is the curvature of blades, which regularly does not appear in Eurasian Upper Paleolithic counterparts (Collins, 1999). Finally, there are questions about the distinctive character of Clovis blades. Since Clovis groups were not the only prehistoric peoples of the New World to make blades, to what extent are certain blades in their overall shape and design indicative of “Clovis” (Bradley et al., 2010; Collins, 1999; Haag, Bergman, & Carr, 2014)? Like fluted points, may prismatic blades be considered diagnostic artifacts of Clovis culture? Only the briefest answers to these questions are offered here.



Clovis Blade Manufacture, Fig. 10 (a) European Upper Paleolithic prismatic blade. (b) Lateral view of European Upper Paleolithic blade (*left*) and Clovis blade (*right*). Note differences in curvature



Clovis Blade Manufacture, Fig. 11 Landmarks of Clovis prismatic blades: (a) dorsal surface with ridge separating parallel negative flake scars; (b) ventral surface with

smooth, inward curving interior; (c) tiny platform remnant at proximal end; (d) platform preparation flake scars; (e) slight bulb of force on ventral surface

Prismatic blades bearing virtually all the features of Clovis blades have been manufactured by contemporary flintworkers using both direct percussion and indirect percussion (Boldurian & Hoffman, 2009; Bordes & Crabtree, 1969; Collins, 1999; Newcomer, 1975). Elongate, thin blades with tiny platform remnants, diffuse bulbs of force, smooth interiors, and curvatures like those of Clovis blades have been manufactured in independent studies using both techniques. Pronounced curvature in experimentally produced blades occurs most frequently when the prepared core is either cradled in the hand during direct percussion or stabilized between the knees or feet during indirect percussion. In each of these scenarios, the core rolls slightly due to applied force during blade

detachment. This forward movement may explain why Clovis blades are frequently curved (Boldurian & Hoffman, 2009).

The archaeological value of Clovis blades as diagnostic artifacts is an open question (Bradley et al., 2010; Gramly, 2013; Green, 1963; Haag et al., 2014; Meltzer & Cooper, 2006). Some analysts believe that the ensemble of features which typify Clovis blades is sufficient to render them as truly diagnostic (Collins, 1999). Others caution that, whereas this may be so, blades – unlike fluted points – are often absent from Clovis sites and, therefore, are an unsuitable spot test for Clovis. Still, when prismatic blades occur in Clovis assemblages, they are easily identified from those of other cultures (Collins, Hudler, & Black, 2003; Ellerbusch, 2004;



Clovis Blade Manufacture, Fig. 12 Clovis prismatic blade, dorsal view. Scale is in cm

Tunnell, 1978). Further research on prismatic blade manufacture is sorely needed, all of which will stimulate additional lively discussions among archaeologists as they strive for a deeper understanding of America's Ice Age Clovis culture.

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Coir in India: History of Technology

K. T. Rammohan

Coir, a natural fibre used extensively to make brush, spin yarn, twist rope, and weave carpets, is obtained from coconut. The coconut tree (*Cocos nucifera*) grows in many tropical countries but chiefly in India, Thailand, Sri Lanka and the Philippines. Within India it grows best on the southwest coast of Malabar, especially in the state of Kerala. Europeans and Arabs used to refer to it as the Indian Nut. One of the earliest references to its production in Kerala appears in a temple inscription of tenth century, which refers to the fruit as *tengai* and lists it as a major source of revenue to the temple. *Ten* means the south, probably indicating its arrival from South Sea Islands and/or Sri Lanka by the sea. While there is inscriptional evidence of coconut groves from this period, really large-scale cultivation – turning almost the whole region into a vast coconut grove – begins from the sixteenth century. For the people of Kerala, the coconut tree is what the reindeer is to the Eskimos; it fulfils many needs.

The coconut tree with its long trunk – very rarely branched – stands tall on sandy tracts adjoining the sea and backwaters. It yields fruits – coconuts – about three-quarters the size of a football. These are green on the outside when tender, turning into brown as the coconut ripens. Coconuts are usually plucked by a male worker climbing up the tree using a loop grip-chord at the ankles. Sometimes, to ease labour, a single ► **bamboo** (*Dendrocalamus strictus* or ‘male bamboo’) is leaned against the tree and used to gain the first long ascent from the ground – the

branches extending from the nodes of the bamboo serving as steps – while the rest of the climb is completed using the loop grip-chord. On reaching the top, the climber cuts off bunches of coconuts with a knife and drops these to the ground. The nuts are picked from the ground, collected and carried in bamboo and reed baskets, mostly by women.

Only male workers of specific castes group engage in plucking coconuts. Usually they do not take up other work. The collecting women could be of any caste and are not restricted solely to this activity. Even today the wages of the climber and the collectors are paid partly in coconut. Over the past two decades semi-mechanical devices for tree climbing have been introduced but these have not gained popularity as experienced climbers do the job much faster.

A hard shell with an outer cover of fibrous mass protects the coconut kernel. The coconut is first removed of its husk with an iron spike or a knife. To obtain the kernel the inner shell is cracked, yielding two, fairly hemispherical pieces, brown on the outside and white inside. The coconut kernel is an important component of the everyday diet of the people of Kerala and is their chief source of oil for cooking and anointment. It is the coconut husk obtained while cutting up the coconut for kernel that yields fibre. Coir is thus the product of a by-product obtained in coconut cultivation.

Yet, of the several industries associated with the coconut tree in Kerala, the coir industry is the most important in terms of employment and investment. The use of Malabar coir yarn and rope for maritime purposes internationally has a history that may be traced to the thirteenth century or even earlier. Coir yarn was used to stitch together the planks of a ship and ropes were used to tie the sails to the mast. Coir ropes were also used in fishing. Weaving of coir matting or carpets on the Malabar Coast dates back to the nineteenth century. For the poor in Europe, coir matting substituted for expensive carpets, while for the rich it served as an underlay for expensive carpets. Coir fibre was used in upholstery and in making brush mats. While coir yarn was widely

used locally for agricultural purposes, mat and matting were woven primarily for the world market.

Initially, coir fibre and yarn were exported from Kerala to Great Britain where these were woven into brush mat and matting. As coir fibre is bulky, transport over long distances was uneconomical. Baling presses could not gain wide acceptance because baled fibre was hard to tease. From the mid-nineteenth century, carpet weaving factories were set up in Kerala's port towns, initially under the initiative of British capital and subsequently by local entrepreneurs – although export of fibre and yarn and its processing elsewhere continued. The expansion of the coir matting industry and the consequent rise in demand for raw material yarn prompted changes in the scale and technology of spinning. Unlike weaving, which was conducted in factories spinning was household production. It continues to be so even today.

To produce fibre, the coconut husks are first treated in saline water (retting) and the fibrous mass removed from its semi-hard shell by hand (ripping). That is beaten with a rod to yield tufts of fibre (defibering), and finally cleaned by throwing up in the air. The husks are carried by big, country canoes along canals to the backwater for saline water soaking. To soak the husk, a big, circular net of coir is stretched across the water surface and stacked with husks. A worker standing on the backwater bank throws husks into the net. Workers standing waist-deep in the backwater arrange the husks in layers, one over another, in the net. Usually, 10,000 husks are stacked in a net. The stacked husks are covered with plaited coconut leaves and tied together on the top, crisscrossed with coir strings. The husk mass is then punted to the interior of the backwater and covered with mud and stones dug out from the backwater bed. The plaited coconut leaf cover and mud ensure that the husks do not dry up in the sun. As the husks absorb water, since they are burdened with heavy stones, the husk mass sinks a little. To distinguish between husk mass sunk by different owners, small metal discs bearing the

initials of the owner or a number code are inserted into the husk mass.

The husk mass remains in water for a period ranging from 6 to 8 months or even more. Flushing washes away tannin and facilitates bacterial action that decomposes the fibre-binding pectin. Salinity lends strength to the fibre. The husk mass becomes heavy after retting and has to be brought back to the backwater bank in a canoe. Workers standing waist-deep in the backwater untie the retted husk mass and throw the husks into the canoe. The retted husks are unloaded at the defibering sites that are usually located on the bank. Women workers carry these as head load to the work spot. Male workers, usually drawn from subordinate caste groups, do the entire retting operation.

In certain parts of Kerala retting is carried out by burying the husks under the beach sand. Retting in small ponds in the homestead is also in vogue. Unlike backwater retting, which is a male preserve, women undertake retting in beach sand and ponds. The defibering mills that have been built in the past few years do away with the retting operation and defiber the green husks. The fibre so produced has to be soaked for a few days in saline water later. Even then, its quality is inferior to that produced by retting (Figs. 1 and 2).

Defibering or separating fibre from the retted husk is done entirely by women, mostly of subordinate caste groups. The worker squats on the ground and rips off with her hand the loosened fibrous mass from its semi-hard shell. She then places the fibrous mass on a flat stone or wood and gently beats it with a small iron or metallic rod. A few beatings and the black, retted husk turns into a tuft of golden brown fibre.

A large quantity of fibre dust or pith is produced in defibering. Accumulated pith makes small hills on the backwater side. This is occasionally removed and used as a saline input or as ash in coconut groves and vegetable gardens. More recently pith has been put to new uses. It is baled into pith bricks for use in indoor gardening or into pith logs to block soil erosion. Like other coir products these also enjoy global demand.



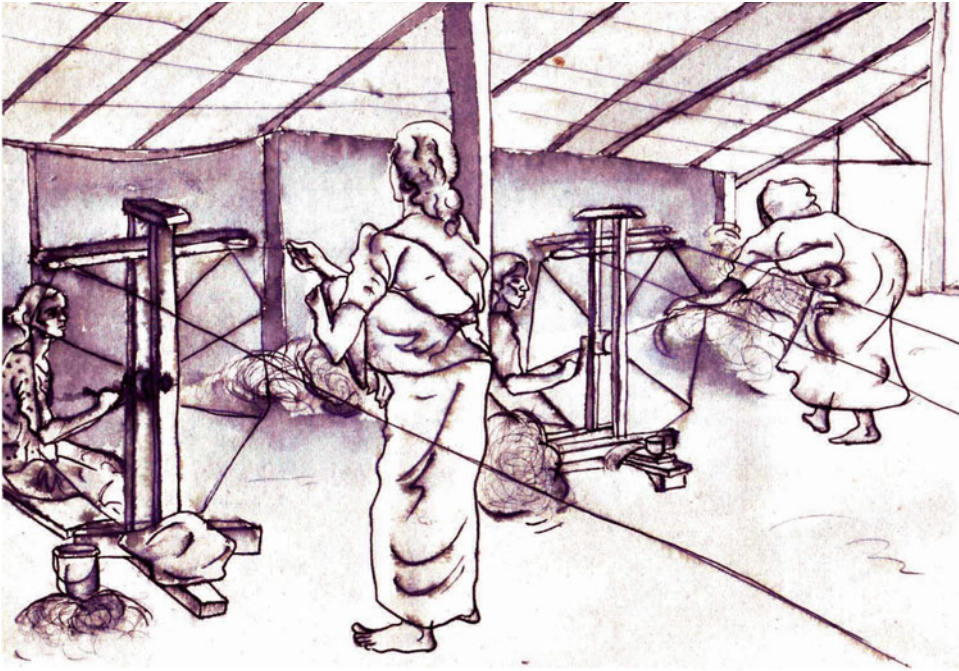
Coir in India: History of Technology, Fig. 1 Retting



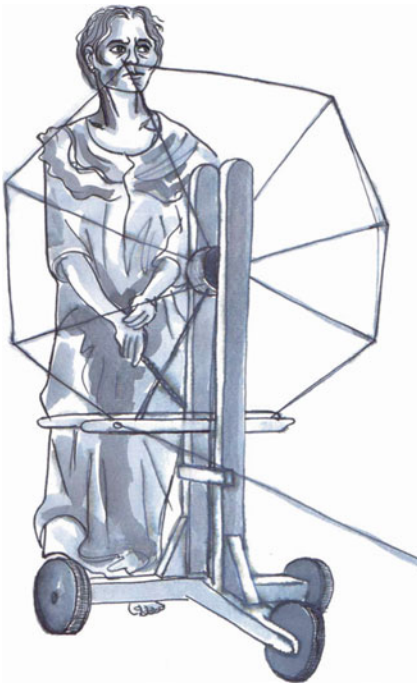
Coir in India: History of Technology, Fig. 2 Defibering

Defibering work is backbreaking. The long working hours, continuous exposure to sun and rain, the uncomfortable squatting posture, contact with fibre particles and dust, and lack of a balanced diet because of the very low wages often cause women's health to deteriorate. There had been attempts to mechanise the defibering operation beginning from the nineteenth century, but these were given up as employing labour was cheaper and capable of producing better quality fibre as compared to the mechanical process. Attempts at mechanisation occurring in the latter half of the twentieth century were defeated by workers who were faced with the threat of unemployment. Over the past decade, however, defibering mills that can process large quantities of raw husks have been established (Figs. 3 and 4).

As with defibering, only women workers and mostly of subordinate castes spin coir yarn. Traditionally the fibre was spun into yarn by rolling between the palms. With the expansion in international demand for coir carpets and therefore for yarn for weaving in the



Coir in India: History of Technology, Fig. 3 Spinning



Coir in India: History of Technology, Fig. 4

mid-nineteenth century, spinning wheels were introduced. A woman worker – most often a child or an old woman – rotates the fixed wheel while two other women workers walk backwards feeding fibre and drawing out a strand of yarn. The workers then walk forward, twisting the two strands into one by pushing a moveable wheel and by running a triangular wedge. The spun yarn is counted and bundled and delivered in the market or sent to the weaving site by country canoes, carts, and trucks.

Spinning is laborious. By the end of the work-day, a spinner, walking forward and backward between the two spinning wheels, would have covered a distance of about 8 km. The spinners often tend to develop body disorders, especially the outward curving of their feet from walking backwards. For centuries, the low wages of spinners has been a disincentive to entrepreneurs in experimenting with mechanised processes. During the past decade, coir workers' cooperatives have sought to increase productivity and reduce labour

by introducing electrically operated spinning wheels. These have not been very successful. The yarn tends to break too often in mechanised spinning and the final output is not of a quality that matches the yarn spun on hand-rotated wheels.

Spinning yarn by rolling it between the palms still continues in parts of Kerala. Rope making is also done by hand. One end of the yarn is tied to a coconut tree and the other end passed through the eye of a coconut shell. A small stick is then tied to the other end and briskly rotated. This draws the yarn and gives it a hard twist. After toughening each yarn, these are plaited to make rope. Depending on the strength required, four or more yarns may be plaited.

Certain kinds of coir yarn are used in agriculture, packing, and house construction. Certain other kinds are raw material for weaving carpets. Traditionally, entirely and even today, mostly, coir yarn is woven into matting on wooden handlooms. In contrast with defibering and spinning done only by women, weaving is exclusively male labour. While a mat is woven on relatively small looms worked by a single worker, matting is made in large looms with six to eight persons working in unison. Power looms have led to a substantial rise in productivity and a widened range of products – sometimes in combination with jute and latex – but some of the designs may be worked only on handlooms.

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Colonialism and Medicine in the Malay Peninsula

Hairudin Bin Harun

The history of British medicine in the Malay Peninsula is synonymous with the history of tropical medicine. It is also a history of colonial medicine, which is a chapter of the history of British colonialism and imperialism in the East.

Three factors were crucial in determining the outcome of the struggles by colonial powers to expand and consolidate their empires in the East: sea-power, colonial settlers, and diseases. The nation that controlled the sea could occupy distant lands with ease. If there were conflict, sea-power enabled a colonial nation to intercept and prevent vital supplies from reaching rival colonies. Colonial settlers were important for political and economic reasons. A claim for the motherland could easily be made over an area well settled with colonial immigrants. Economic exploitation and control could be established by a network of colonial settlements, which also functioned as buffers against economic challenge and security threats from natives or rival powers. Finally, disease was of immense importance in moderating colonial expansion. Diseases could exact a heavy toll on the army, officials, colonial settlers, and their laborers or slaves. Malaria and yellow fever reportedly wiped out some of the British colonies in the tropics and Africa.

British colonial rule over the Malay Peninsula and Borneo Island (now Malaysia) lasted for more than a century. Their use of medicine as a strategic, diplomatic, and political tool to enhance their grip on the indigenous people and resources of the Malay Peninsula is well-documented. Medicine was also an instrument of colonial conscience, one aspect of which was the call to discharge “the white man’s burden,” including the task of “civilizing” the natives. In the Peninsula this entailed, among other things, the aggressive promotion of tropical medicine, and it contributed to Malayan negative

perceptions of colonial medicine. Indeed, colonial medicine came to be perceived as a ruthless campaign to stamp out their traditional medicine.

In spite of that, colonial medicine could still claim success among the colonial laborers and urban dwellers, although among the natives and villagers the campaign seemed to have failed. There are several reasons for this. One was the preexistence of an elaborate traditional medical system. Second, the natives enjoyed better health than the imported colonial laborers, and even the colonial masters, many of whom were afflicted either with beriberi or malaria. Third, local traditional medicine was far more effective in treating some forms of tropical diseases.

The effectiveness of Malay medicine, however, was generally overlooked. It was difficult for colonials to accept that a primitive medical tradition could be equal to or better than colonial medicine. The official attitude further institutionalized such prejudices, as Malay medicine was officially perceived with contempt.

Since the beginning of British colonialism in the Malay Peninsula, combating tropical diseases was a priority. Initially, it was important to the officials and indentured colonial laborers, and it assumed a strategic and political dimension.

If one were to put a date on the genesis of British colonialism in the Malay Peninsula, it is likely to be 1786. This was when the East India Company took possession of Penang from the Sultan of Kedah. By 1830 the Company had added Singapore and Malacca to its inventory list, and by 1895, four of the richest Malay states in the Peninsula were under British influence. Throughout the period, the number of Britons sent to the area increased tremendously. The Peninsula’s climate and geography, however, were harsh, and many of the early colonialists succumbed either to the heat or diseases. The large-scale importation of foreign indentured laborers, known then as *coolies*, was a significant feature of the period. They were crucial for economic and political reasons, but they were also decimated by diseases, especially malaria and beriberi. The result was a loss of productivity and a forced suspension of many economic projects. Thus, disease, or its absence, among

officials, settlers, and coolies acquired an economic imperative; while health or the lack of it among natives acquired a strategic and political dimension.

During the colonial period, the course of events in the Peninsula was inevitably intertwined with that in England. The 1870s saw the emergence of a new political figure in Britain, Joseph Chamberlain (1836–1914). In 1893 he was appointed Secretary of State for the Colonies. He reorganized the Office from an ill-equipped, almost forgotten, department to one of the best around. Indeed, colonial appointments before he took office were seen as more akin to polite exile than glamorous jobs. Chamberlain changed that. He was able to infuse a new attitude, as well as a new policy, so that the colonial jobs gained the same respectability as home appointments.

As far as the history of colonial medicine is concerned, Chamberlain's most significant political act was his appointment of Dr Patrick Manson (1844–1922) as the Medical Advisor to the Colonial Office. Dr Manson was then the most distinguished authority in tropical medicine, which was then a marginal subject within mainstream medicine. The main concern of British medicine was the diseases of Europe, not of the tropics, and health policy was geared to serve home needs and rarely those of the colonies. Under Chamberlain, with Manson as the medical advisor, there was a reorientation of policy and priorities. The medical problems and health policies of the colonies were given serious attention. Soon Chamberlain's name became synonymous not only with the development of British colonialism but also with the development of tropical medicine. Indeed, under his stewardship, Britain's colonial fortune took a positive turn; so too did the health of Britons and the state of medicine in the colonies.

Chamberlain was forthright about the fact that British lives were more important to him than native lives. The participation of his ministry in the development of British tropical medicine was solely to ensure their welfare. The welfare of the natives was looked upon only in terms of Britain colonial interests, if ever. This policy was

reflected in the establishment of the London School of Tropical Medicine in 1899. Its purpose was to foster research and development of the "new" British tropical medicine. The school was backed up by a number of research stations in the colonies, the biggest and most important of which was the Kuala Lumpur Pathological Institute, located in the Federated Malay States (British Malaya). The Institute was formed a year after the London School. Indeed, the rapid development of British tropical medicine in the early part of the century owed much to the linkages of the London School with the Kuala Lumpur Institute.

The Institute's founder was Sir Frank Swettenham (1851–1945), a charismatic colonial official who knew a lot about colonial and local politics but next to nothing about medicine. Swettenham's tenure coincided with the period of intensive colonial economic activities in the Malay States. These were sustained mainly by the extensive importation of coolies from abroad, particularly from China and India. As indicated earlier, this importation was important for both economic and political reasons. It showed the native Malays that the British could easily handle any boycott by local labor; but the importation soon hit a snag. Many of them were decimated by unknown diseases, one of which was later identified as beriberi.

Owing to the epidemic, the local colonial administration was burdened by thousands of sickly and unproductive coolies. A search for a beriberi cure was imperative. Swettenham had come to know about the interest at the Colonial Office regarding tropical diseases, and about the plan to set up a school of tropical medicine in London, but he also knew that the School's priority was research on tropical diseases afflicting European communities in the tropics. In the Peninsula, however, beriberi was a non-European disease. Swettenham was aware that it was extremely difficult, if not impossible, to persuade the Colonial Office to allow it to devote a portion of its research time and money to beriberi. It was at this stage that he toyed with the idea of a local institution modeled after the school, which would facilitate the search for beriberi's cure.

In London, luck seemed to be on his side. Swettenham's plan for a local medical research institute was received positively. It was seen as simply the compliance of a colonial official to London's policy on tropical medicine. Such plans from distant colonies normally received an impersonal go-ahead signed routinely by nameless individuals on behalf of the Secretary. Instead, Swettenham's plan came to the attention of Chamberlain, who personally signed the authorization papers for the Institute. At home, Swettenham did not bother to wait for the official go-ahead; he had made arrangements to set up the Institute even before Chamberlain had signed the order.

Perhaps owing to the excellent staff, the Institute lived up to its expectation. It was able to come up with the cure for several tropical diseases, including beriberi. The riddle to the latter was conclusively resolved exactly 9 years after the founding of the Institute. Thus it succeeded in alleviating the colonial authorities from one of the major causes of the local economic and social problems. The Institute was a bastion of colonial medicine, and far removed from the practices of traditional medicine. Notwithstanding that, some of the major breakthroughs of the Institute were affected directly or indirectly by the latter. For instance, in the search for the cure of beriberi the Institute's scientists looked to traditional cures for clues, and indeed found a lead in Malay medical practices. Colonial pharmacologists examined and benefited greatly from the Malay materia medica, particularly in the search for new drugs and alkaloids. Institute authorities still were extremely reluctant to acknowledge any hint of contribution by native medicine, especially in advancing tropical medicine.

To understand the events that followed, it is necessary to take a brief look at the prevailing colonial health policy, particularly with regard to the natives. There were several discernible phases. The initial phase placed the emphasis on the health of the officials and laborers with no regard to the natives. The second phase involved the missionary zeal to promote colonial medicine among the natives and other non-European inhabitants of the colonies. The *Ordinance to*

Provide for the Registration of Medical Practitioners in the Colony (1905) was passed to control the practice of medicine, by stipulating minimum qualifications for those who wanted to practice medicine in the Malay States. On the face of it, the Ordinance seemed to spell a blow to traditional medical practitioners, particularly the natives and the Chinese, but interestingly, the Ordinance carried with it an exclusion clause:

Nothing contained in this Ordinance shall be construed to prohibit or prevent the practice of *native* systems of therapeutics according to Indian, Chinese or other Asiatic method.

Throughout the British rule the native Malays relied extensively on traditional medical systems for their medical needs. The backbone of the traditional system was the medicine man, *bomor*, or *pawang*. They did almost everything, from preparing herbal medicines, setting dislocated bones, and delivering babies, to variolation and minor surgery like circumcision. Occasionally, Europeans sought treatment from the *bomor* and claimed that they were cured of their ailments by the Malay medicine man.

Evidently, colonial medical officials were intrigued by the ability of the native Malays to live a healthy life in the tropical climate. Many noticed that the native Malay view of nature was totally different from theirs. Nature or the land was treated by the Malays with respect, regarded more as a living or spiritual being than a thing, and more like a member of their family than an artifact of convenience. The Malays maintained a relationship with their land in what one would describe now as balanced ecological relationship. In fact, the need to seek harmony and equilibrium was central to their view of disease and health. Nature was multidimensional and hierarchical, having both a metaphysical and physical dimension – reflecting the spiritual and physical constitution of man. Their doctrine of diseases and health reflected the belief that health was a manifestation of the harmony of human's inner constitution and nature's constitution; disease was the result of a lack of harmony.

The complexities and intricacies of the Malay medical doctrines were left much to themselves.

Occasionally they became objects of anthropological curiosity by colonial scholars. However, this attention was academic; no medical officials or policy makers seemed interested in knowing more about Malay medicine or the Malay medical system. It was not until the later stage, the missionary zeal phase, that they began to take notice of Malay medicine. At this stage, however, Malay medicine was seen more as a rival than a complement.

The effort to introduce colonial medicine to the Malays was apparently a frustrating task to the majority of the colonial officials. Frequently, they expressed their frustrations at what they alleged was the Malays' indifference to "superior medical treatments." For instance, the Colonial Resident Councillor of a Malay State remarked:

If a Malay thinks he is going to be kept in a hospital, he will not apply for medicine as an outdoor patient and will prefer to remain in his own house and be treated by a Malay doctor on simple herbs, together with a judicious supply of still simpler incantations. (Harun, 1989a)

The Colonial authorities also took active steps to restrict the practice of Malay medicine men. This perhaps can be best seen in the checking of the traditional inoculation or variolation practice. Variolation was widely practiced whenever smallpox broke out in a village. It involved the direct inoculation of smallpox virus treated with certain medicinal herbs. Colonial doctors described it as "a barbarous practice," and the practice was targeted for curtailment. In 1905, when smallpox broke out in the eastern Malay state of Kelantan, the Government enforced a law banning variolations. In their place, they introduced large-scale vaccinations. The authorities also recruited some traditional inoculators as "assistant vaccinators," although the actual task of vaccination was undertaken by the colonial medical department.

To the Malays, the inoculation rituals sanctioned by their traditional culture were much preferable to vaccination. Their acceptance of colonial medicine lagged behind official expectation. In fact, the authorities noted a decrease in the number of natives seeking medical treatment

at colonial clinics. They realized that the campaign to promote colonial medicine among the Malays would fail unless their confidence was won over.

The new campaign strategy perhaps can be best seen in the work of Dr Gimlette. He was a colonial medical officer best known for his sympathetic and detailed study of Malay medicine which was originally part of the new campaign. By the time he finished, it had taken an unexpected form. For all practical purposes, it had become a crusade for the preservation of Malay medicine. Gimlette, probably to the displeasure of his superiors, openly urged the colonial authorities to soften their attitudes toward the *bomors*. Indeed he argued that "it would be unfair to damn him [the *bomor*] as an accursed sorcerer who poisons honest folk to gain his private ends." Gimlette even drew parallels between the practice of colonial doctors and that of the medicine man:

It is too much to say that the work of the bomor in clinical medicine is merely fanciful; he endeavors to prepare a *penawar*, that is to say a "neutraliser," for every kind of poisonous principle; this idea of neutralization distinctly anticipates modern science. His knowledge of local materia medica is often profound, and after all, some of his theories as to the etiology of tropical diseases are conceptions now known to modern science in the form of animal parasites (protozoa, spirochaetes, etc.), which are invisible except under high powers of microscope.

Gimlette also claimed that Malays knew mosquitoes were the cause of malaria, evidently earlier than Manson. According to Gimlette, Malays' apparent resistance to malaria was largely owing to their knowledge of mosquitoes. For instance, the Malay traditional ritual of smoking their homes and villages through the burning of *padi* (paddy) straw during harvest season effectively expelled mosquitoes in their homes or in the surrounding area. Malays also bred fish in their *padi* fields during the flooding period. This practice was akin to a form of biological control of pests, since the fish preyed on small organisms and thus destroyed all the mosquito larvae breeding in the *padi* fields. The Malays also practiced selective clearing of

jungles as another form of mosquito control. Gimlette was convinced that the secret of Malays' resistance to malaria or "harmony" with mosquitoes, lay in their practice of such rituals.

It is not known what the actual reaction to Gimlette's views was, particularly within the colonial medical establishment. It is likely that his views would have caused some uneasiness among officialdom. Gimlette assigned a common level of legitimacy to Malay medicine and colonial medicine. It is interesting to note that soon after the publication of his book on *Malay Poison*, Gimlette retired in 1921 from the Colonial medical service. He returned to England and embarked on a project to compile a dictionary of Malay folk medicine. Because of ill health, the project was not completed. However, his friends, Thomson and Skeat, took over the project and completed the manuscript, which was posthumously published in 1934 as the *Dictionary of Malayan Medicine*.

The official version of the development of colonial or tropical medicine was no different from the history of medicine. The motives were Hippocratic idealism and the fanatical dictum that there should be no mention of nonscientific or nonmodern contributions to the development of modern medicine. Understandably, the Malay's contribution to the development of colonial medicine in the Peninsula was largely ignored.

The prevailing colonial view stereotyped native medicine as nothing more than primitive panaceas or "snake-oil cures." However, studies like Dr Gimlette's challenged established prejudices and institutionalized misconceptions. They established that native medicine was a storehouse of perennial wisdom, and collection of empirical observations of scientific significance. Still, Malay medicine was often referred to contemptuously in colonial discourse.

No branch of modern science can be said to have developed almost exclusively under colonial ideological and political impetus than tropical medicine.

See Also

► Colonialism and Science

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Colonialism and Science

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From the very first decades, scientific advances played essential roles in European overseas expansion. Improved astronomical instruments and calculations and an array of new navigational devices and cartographic techniques made the Portuguese voyages into the uncharted South Atlantic possible. Subsequent voyages of exploration and (for the Europeans) discovery led to

further refinements of both instruments and navigational data and stimulated the introduction of ever more sophisticated ways of measuring time, distance, and location. Scientific curiosity was among the main motives of Europeans who planned or led expeditions of discovery and conquest. Astronomers and cartographers often sailed with explorers and merchants for the express purposes of testing new instruments, taking astronomical or meteorological readings from distant latitudes, and charting regions that had hitherto been unknown to the Europeans. The application of the data gathered on these voyages to improving maps, to compiling more accurate navigational charts, and to devising new instruments greatly enhanced European advantages over other peoples in navigation, trade, and warfare by sea.

As European armies and administrators advanced inland, first in the Americas and the outlying island of Africa and Asia and later throughout the globe, botanists and geologists followed, collecting “exotic” specimens to carry home to the gardens and cabinets of their rulers and national scientific societies. European savants examined and classified the bewildering mass of information and objects that flowed in from the rest of the globe, and struggled to fit it into the preexpansion world picture; or, more commonly, used it to build a new vision of both the earth and the cosmos. A host of self-appointed, usually amateur, ethnologists also reported extensively on the diverse peoples and cultures they encountered overseas. Their observations became the basis for elaborate, allegedly scientific, and invariably hierarchical classifications of human types. These classifications in turn provided evidence to support highly contentious theories regarding the relationships among human groups, usually termed races, and between humans and other species, particularly different varieties of apes.

Both in Europe itself and increasingly (but on a much reduced scale) in colonial enclaves overseas, scientific institutions – such as the Hortus Botanicus in Leiden, Kew in London, and the Sibpur botanical gardens in Calcutta – served as clearing houses for flora

and fauna collected from around the globe and focal points for taxonomic inquiries and experimentation in procreation and hybridization. The elected members of Europe’s scientific societies, most notably London’s Royal Institution and the Académie des Sciences in Paris, provided the backing to mount scientific expeditions, certified that what were regarded as scientific procedures had been followed by the explorer or naturalist in question, and made the findings of overseas investigations available to the educated public of their respective nations and the European scientific community as a whole.

From the outset the scientific side of the process of European overseas expansion was all but monopolized by one of a number of approaches to the natural world that had jostled for supremacy in the medieval era and coexisted in the West since ancient times. The predominance of what recent scholars have characterized as the Baconian or mechanistic strain of scientific thinking in European colonial enterprises was of special importance. It meant that other options, such as the organic approach to nature and the cosmos, which might have been more compatible with and accommodating toward non-Western epistemologies, were excluded or relegated to marginal roles in this critical area of interaction between European and non-Western peoples and cultures.

The key attributes of the dominant Baconian or mechanistic strain of Western science rendered European colonial observers and policy-makers particularly unreceptive to non-Western ways of thinking about and interacting with the natural world. The underlying assumptions of the Baconian approach also strengthened the resolve of those among the colonizers who were ironically the most concerned with the well-being of the subjugated peoples to impose Western epistemological presuppositions and standards and procedures of investigation on colonized peoples. Though there were important differences among those scientists who adhered to the Baconian mode, it is possible to distil a number of key attributes that most colonial theorists and administrators would have agreed characterized the proper, or Western, approach to scientific

thinking. Though developed in the West and shown by recent research to have been vitally affected by the social and cultural milieux in which it arose, the science carried overseas by European colonizers was seen to be value neutral, objective in its procedures, privileging abstraction and reason, empirically grounded, and somehow transcending time and space and thus universally valid. These attributes gave the practitioners and advocates of Western science confidence that the spread of this epistemology – and the institutions and procedures associated with it – to the rest of the peoples of the globe was both beneficial and inevitable.

This view is, of course, still held today by many scientists as well as development specialists, social theorists, and assorted intellectuals with an interest in the so-called Third World. Its champions among the colonizers viewed the diffusion of Western science as part of a larger campaign to rationalize the world and conversely to banish what they viewed as superstitious or subjective, intuitively oriented epistemologies. Although only the most reflective and outspoken colonial observers would have acknowledged it, Western science was also aggressively expansive and intolerant of rival non-Western epistemologies – just as it had been of alternatives in Europe itself. By the early nineteenth century, it was also inextricably linked to the great technological advances that drove the Industrial Revolution, and the market-oriented, fossil fuel intensive, interdependent global order that was associated with the resultant transformation of the West. Thus, the Western scientific approach proved to be quite compatible with prevailing Western hegemonic ideologies, such as the *mission civilisatrice*.

Despite attempts to develop general paradigms for the diffusion under the aegis of European colonial domination of Western science, its role in the process of colonization and its impact on non-Western peoples and cultures varied widely by time and place. Important differences can be seen, for example, in the scientific fields and types of investigations that were prominently associated with overseas colonization before and after the Industrial

Revolution. In the early centuries of exploration European scientists overseas were mainly preoccupied with astronomy, zoology, and botany. As Western Europe's need for markets and raw materials grew with the spread of industrialization, fields like meteorology, geology, chemistry, and applied mathematics became increasingly integral to the colonial enterprise. As European colonizers came to administer much of Africa and Asia directly, more sophisticated techniques of surveying, codifying, and statistical gathering became essential for activities as diverse as revenue collection and the formulation of legal codes. Recent scholarship has also shown that the relationships between colony and metropolis in terms of scientific investigation and exchange also shifted dramatically after World War I. These transformations were accelerated in the interwar years and after World War II by the process of decolonization, and a concomitant shift from an emphasis on extraction to a fixation with the rhetoric of development, which became enshrined in modernization theory after 1945.

The process by which Western science was diffused and its impact on overseas societies also differed greatly depending on the timing and nature of European interaction with non-Western cultures, the colonizers' assumptions about the level of sophistication of indigenous epistemologies and material cultures, and the actual attainments of colonized peoples in science and technology. The process of Western scientific diffusion, for example, in settlement colonies such as Australia and Canada, that had relatively small and scattered autochthonous populations, followed a very different course than in densely populated areas, such as South Asia and China, where small communities of European administrators, missionaries, and merchants encountered highly developed scientific and technological traditions with ancient links to their own.

Even within the different types of colonial societies there were critical variations. Thus, for example, the New World colonies in both Latin and North America, which were the first areas of extensive European conquest and large-scale settlement, were the sites of significant scientific

investigations and developed their own scientific societies as early as the eighteenth century. By contrast, Australia and New Zealand were not settled until the following century and were not integrated into the scientific networks of their European metropolis, Great Britain, until the late 1800s. In addition, from as early as the late seventeenth century, the pursuit of science was stunted in much of Latin America, as compared to Canada and the United States, due to Spain's long political and economic decline and its increasing marginalization as a center of scientific learning.

None the less, in all of the settlement colonies, indigenous learning, and epistemologies were pushed to the periphery. Ethnologists studied "aboriginal" beliefs and traditions for their folkloric or antiquarian value, not because they had anything to teach the colonizers about the ecology or topography of the lands they occupied, much less because they might stimulate major modifications in European understandings of the natural world. The research agendas of all of the settlement colonies were also largely dictated by the savants of scientific societies and institutions of higher learning in Europe itself. Though the size and the close links of the elite in the United States to Europe made original work by colonial scientists, such as Benjamin Franklin, more likely than in other settlement areas, until the early twentieth century settler colonists were primarily engaged in applied field research, heavily focused on the collection of local flora and fauna samples. Much of this work was directly linked to efforts to uncover and extract the great natural wealth of settlement areas. The empirical findings of New World botanists, geologists, or ethnologists, who were often merely temporarily transplanted Europeans, were mainly funneled to scientists in European centers for interpretation and theoretical elaboration.

After about 1900, scientific connections between European centers and settlement areas – both those still formally colonized and those, such as the United States, long independent – were radically transformed. Dominions, such as Canada and Australia, were accepted as partners, rather than assistants, in

international scientific inquiry. The settlement areas more generally emerged as important centers of scientific research and theoretical innovation in their own right – as evidenced, for example, in Frederick Banting's discovery of insulin in Canada and Macfarlane Burnet's work on immunology in Australia. This was particularly true of the United States, where the already substantial growth of an internationally recognized scientific community early in the twentieth century was greatly accelerated in the 1930s by the forced migration of leading scientists from Europe, such as Albert Einstein. By the 1940s, this former colony and settlement area had taken the lead in many areas of scientific endeavor, from the most abstract theory to applied research.

In comparison with the tropical dependencies, where small numbers of Europeans ruled large and ancient African or Asian societies, the diffusion of Western science to the settlement areas met with little serious resistance. To begin with, the transfer was overwhelmingly to settler populations of European origins and heritage. This meant, on the one hand, that questions of racial ability with regard to the development of scientific communities and institutions in colonized areas did not arise, even though the arrogance of metropolitan savants was often a source of considerable discomfort for the colonials. On the other hand, because the dominant settlers despised and marginalized or discarded altogether the epistemologies of the indigenous peoples, there were no alternative thought systems or ways of doing to rival or provide foci of resistance to hegemonic Western scientific approaches.

Scientific friction between metropolis and settlement colony arose from personal and institutional rivalries, but scientists in both locales shared epistemologies, methodologies, and presuppositions about the place of humans in the natural order. Local resistance came not from subjugated indigenous peoples defending their own, very different traditions, but from the poorly (or un)educated majority of the settler population. The latter were not so much opposed as indifferent to the endeavors of a rather isolated

scientific elite, whose labors appeared to be wasted unless they could be turned to some immediate practical advantage. Thus, the key challenge for the scientific communities in the settler colonies was expanding popular understanding of and approval for scientific research, and winning government funding for scientific institutions and projects. Evidence of practical application was key to success in these endeavors, and thus a premium was placed on applied research, at least until the middle of the twentieth century.

The linkages between science and colonization in nonsettler areas of Africa, Asia, and Oceania, where small numbers of Europeans dominated large and diverse colonized populations, were markedly different than in Australia or the United States. Here it is important to distinguish between areas that the Europeans conquered outright and ruled directly, such as India and much of sub-Saharan Africa and Southeast Asia, and those they dominated indirectly or “informally” through military threats and periodic interventions, economic influence, and the manipulation of indigenous leaders. The latter areas would include most of the Islamic Middle East, Persia/Iran, China, Siam/Thailand, and Japan – until it became a Western-style scientific and technological power in its own right in the early twentieth century. Even within these two general categories of nonsettlers, critical distinctions need to be taken into account. Colonial policies regarding the diffusion of scientific learning and investigation, for example, were quite different in British India or French Indochina than in most of sub-Saharan Africa or the islands of the Pacific, even though all of these areas were formally colonized. Within the indirectly controlled areas in the informal spheres of influence, the European approach to Islamic societies in scientific matters differed in important respects from their interaction with China, Japan, or Thailand.

In some ways the diffusion of Western science in some formally colonized areas like India shared more with informally controlled areas, particularly China and the Islamic Middle East, than with Africa or the Pacific, which were ruled

directly. In India, China, and the Middle East, the European colonizers recognized not only that the indigenous peoples had produced ancient and sophisticated civilizations – which usually meant that they had certain key attributes, including writing, specialized elites and cities – but that they had long nurtured scientific traditions of their own. Informed European observers even acknowledged that the West owed a large debt to Islamic peoples both for the recovery of much of classical Greek learning that had been “lost” to European civilization after the fall of Rome, and for original scientific advances made by Muslim peoples and transmitted to Europe through Arab and Jewish scholars in Spain and Italy. A handful of European observers also recognized that Islamic civilization had served as a vital conduit of scientific learning and inventions from civilizations further east, particularly India and China.

Recognition of the earlier scientific achievements of selected non-Western peoples informed the attitudes of European colonizers towards the diffusion of science in the societies so designated in important ways. In the early centuries of European overseas expansion, it fed mutual curiosity and ongoing interchange. The first Jesuit missionaries in China, for example, evinced a strong interest in Chinese astronomy, chemistry, and medical techniques. In India, Portuguese and later Dutch merchants and officials routinely consulted Indian physicians well into the eighteenth century. European physicians not only studied the prescriptions and techniques of Indian *vaidas* and *hakims*; they readily conceded the superiority of indigenous specialists in treating tropical diseases.

By the early decades of the eighteenth century, most European observers had concluded that even the most advanced, non-Western scientific traditions were hopelessly outdated and encrusted with superstition and quackery. If it survived at all, recognition of non-Western achievements was focused on the distant past. In the accounts of European authors who concerned themselves with matters scientific or technological, the stagnation of Indian or Chinese learning, in stark contrast to the ever-changing and highly progressive advance of Western knowledge, was

a constant refrain. In areas that escaped direct colonization, particularly China and Japan, scientific knowledge and technological expertise had been and remained the most effective ways for gaining access to Asian rulers and impressing Asian elites with the efficacy of Western ways, which seemed otherwise dubious, if not crude. None the less, the sense that peoples like the Chinese and Japanese had long been civilized and had once excelled in science and technology deeply affected the educational policies pursued by Christian missionaries, when they were permitted to proselytize in these areas, and the trading policies and diplomatic exchanges of the great powers. Japan as a whole closed in on itself after 1600, but Dutch traders at Deshima continued to make the latest European scientific treatises available to an emerging Japanese literati. Christian educators in China frequently pushed advanced training in the sciences (particularly medical) and mathematics. By the late-nineteenth century, regionally based segments of the Chinese scholar-gentry were avidly importing Western technologies in “self-strengthening” campaigns designed to ward off the imperialists’ partition of the Middle Kingdom.

From the mid-nineteenth century similar patterns of diffusion can be found in other non-Western areas, which the Europeans regarded as long civilized but where they increasingly exercised informal sway. French missionaries strove to impress their Lebanese students with the superiority of Western scientific learning, while Siamese rulers strove to educate an elite corps in the engineering skills of the West. Because their own scientific traditions shared much with those of the Europeans – not the least a common, extensive borrowing from the ancient Greeks – the approach of the Muslim peoples of the eastern Mediterranean to these interchanges was somewhat different from that of the Siamese or, most critically, the Chinese. Having given so much to the West in the sciences, Arab and Turkic reformers could claim that it was in no way demeaning for Muslim peoples to borrow back in order to catch up to their European rivals. Though not all accepted this argument, it made the introduction of Western

scientific learning palatable for those who supported advocates of forced “modernization,” such as Muḥammad ‘Alī in Egypt and the Ottoman ruler Mahmūd II. Unable to make a convincing argument for such historical precedents, the Confucian literati of China vehemently resisted the introduction of Western learning or reluctantly conceded its necessity in the name of China’s survival.

Although similar tensions were present in formally colonized areas that had longstanding scientific traditions, such as India, decisions about how much and what sort of Western scientific and technological diffusion should occur were taken out of the hands of the indigenous peoples. Colonization resulted in a growing influx of European scientists, engineers, and medical practitioners, and a great expansion in their activities and influence. The collection of flora and fauna that antedated colonial rule continued and in some respects expanded, but trained scientists and technicians were now employed by colonial administrations for massive and systematic geological and land tenure surveying operations. Statisticians oversaw census counts; botanists tested new plant varieties in state supported gardens; and hydrologists directed the overhaul and expansion of irrigation systems. As these activities suggest and scholars from formerly colonized areas have recently argued, science was a central pillar of the European colonial order.

Colonial science was also field-oriented, overwhelmingly applied, and devoted primarily to enhancing efforts to maximize the extractive potential of conquered areas. Its diffusion to the colonized peoples was consciously channeled and often constricted out of security concerns or fears of future economic competition. Rather than an abstract, objective and dispassionate concomitant of colonial expansion, Western science was the linchpin of rationalizing offensives that sought to reshape the thinking of colonized peoples, reconfigure the spatial relationships in colonized areas, and remake institutional frameworks and social relations in ways that accorded with Western epistemologies and presuppositions about the logical order of things.

Much of the literature on the diffusion of Western science in the colonial empires has concentrated on the biographies and activities of European scientists and on the policies pursued by European colonial administrators. As a consequence the varied and critical roles played by the colonized peoples in the dissemination of Western scientific learning and techniques have been obscured. At a range of levels, their contributions were essential. In the era when naturalists were dominant, the collection and identification of specimens would have been difficult, if not impossible, without Javanese or Indian guides and assistants, and villagers who were vital repositories of local knowledge about animal life or the rain forest. Working in the celebrated miniaturist tradition that peaked under the Mughals, Indian artists sketched flora and fauna in the field and often illustrated the published collections on these subjects that remain standard references to the present day.

As the grip of colonial administrations tightened from the middle of the nineteenth century, subjugated peoples found new ways to become involved in the scientific enterprises that buttressed the new order. Indian surveyors, engineers, and medical practitioners served in colonial administrations both in South Asia and British colonies in Africa and Southeast Asia. Indian chemists, physicists, and biologists worked for British firms, traveled to Europe for advanced study or to take up research positions, and increasingly taught in one of a growing number of universities in India itself. Indian doctors and surveyors set up private practice in colonial towns.

The assumption of many of these roles depended on the spread of higher educational opportunities open to Indians in the sciences and mathematics. The very existence and steady expansion of these opportunities underscores a vital difference between India and most of the other colonized areas. Here again, the colonizers' recognition of precolonial scientific attainments proved critical. The work of Sir William Jones and other "Orientalists" in the late-eighteenth and early nineteenth centuries left little doubt that ancient Indian civilizations had excelled in

many of the sciences and mathematics. Though increasingly disdainful of these achievements and impressed with contemporary Indian backwardness in matters scientific and technological, key colonial officials who strove to reform Indian society premised their educational initiatives on the assumption that Indians could master the most advanced Western scientific learning and mathematical techniques. This assumption and the policy decisions regarding higher education that followed gave Western-educated Indians much greater agency in the process of the diffusion of Western science than was enjoyed by any other colonized people. By the last decades of the nineteenth century, racist objections to these policies were raised by both prominent officials and private individuals. However, the path breaking work done by such Indians scientists as Ray and Bose made a shambles of the racists' aspersions, and bolstered the demands of Indian nationalists for greater opportunities in higher education, particularly in the Western sciences.

With the partial exception of colonies like French Indochina and the Netherlands Indies, opportunities for advanced training in the Western sciences in much of the rest of Asia, sub-Saharan Africa, and the Pacific islands were minimal or nonexistent. In these areas, scientific work was the monopoly of the European colonizers. As in settlement areas, such as Australia and the United States, indigenous epistemologies and local knowledge were dismissed as irrational, ignorant, and superstition-bound. These might be studied in order to understand the "native mind" to control the colonial populace better. However, they had nothing to contribute to Western scientific learning or methodology. Thus, in most nonsettler colonies, which the Europeans deemed devoid of scientific traditions of their own, racist assumptions regarding the mental capacity of the indigenous peoples insured that little or no advanced training in science or mathematics was available. These policies in turn left most colonized peoples ill-prepared for a postcolonial world where Western scientific knowledge and skills have proved vital for successful economic competition, development planning, and many aspects of intellectual discourse.

The colonizers' disdain for indigenous epistemologies and approaches to the natural world has also obscured a number of other important patterns involving the interaction of science and colonialism. However extensive or limited the volume of Western science diffused to different colonies, in all there was a persistence of indigenous scientific thinking and practices. In some cases the colonizers themselves were complicit in this process, as when the British made use of Indian *hakims* and *vaidas* in their campaigns to eradicate epidemic diseases, such as smallpox and cholera in India, or when merchants or officials in Africa resorted to local cures for snakebite or dysentery. In some colonies, most notably India but also in Kenya, Senegal, Indonesia, and other areas, the defense of indigenous epistemologies and procedures was explicitly linked to the nationalist assault on the European colonizers. In the thinking of visionary leaders, such as Mohandas Gandhi, the restoration and reworking of these traditions posed what well may be viable alternatives to the approaches to economic and social development championed by the industrial West.

In virtually all of the formerly colonized societies, non-Western approaches to science in areas as diverse as medical practice, preservation of soil fertility, and care for the emotionally disturbed have persisted. In view of the clear limits in terms of resource exhaustion, environmental degradation, and social inequity of both major Western development alternatives – market-capitalist and socialist command economy – this persistence may ultimately prove critical. It may be that the predominant direction of scientific diffusion will be reversed; that approaches to work, resource use, social organization, and economic well-being pioneered by Gandhi and other non-Western thinkers will have much to offer the beleaguered societies of the postindustrial world.

See Also

- [Ethnobotany](#)
- [Knowledge Systems: Local Knowledge](#)

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Colonialism and Science in Africa

Gloria T. Emeagwali

By 1914, most of the African continent had been subordinated to colonial rule, with 36 % of African territory seized by the French, 30 % by the British, and the remaining 34 % dominated by Belgium, Germany, Italy and Portugal. This of course was not done without bloodshed. Millions of Africans died in the process of resistance against the invasion of the continent, waging guerrilla warfare for as many as 30 years in some cases. Colonialism was essentially a process of administration which denied Africans political and economic autonomy while subordinating them to the dictates of an evolving global capitalist ethic and world market controlled by a Euro-American elite. Indigenous science and technology were adversely affected by

it. Ironically though, institutions such as the British Imperial Institute, through its Scientific and Technical Department, actually aided in the transfer of existing scientific and technical know-how from the colonies to the metropole.

One of the major effects of colonialism was the subordination of science and science education to the logic of colonial production and class structures. Science and technology development in most cases ceased to emanate from the womb of African civilization and indigenous problem-solving and experimentation. A new set of norms, values and relations of production was introduced and superimposed on existing precapitalist structures. In so far as colonialism was an exploitative system geared toward the redeployment of resources in the form of mineral and agricultural wealth, from the periphery to the center, it necessarily led to the destabilization of existing processes of accumulation of knowledge and technique. Colonial capitalism was geared primarily toward the export of surplus from the continent, and colonial education was to focus primarily on the creation of a new collaborative, nonthreatening elite supportive of the colonial agenda and committed to the running of the colonial (and neo-colonial) machine. It was less geared to innovation and creativity than to servile complicity.

References to glass-making and iron fabrication may illustrate the extent to which indigenous capability was undermined. As a consequence of the relatively cheap glass products from Europe dumped on the Nigerian market, indigenous glass producers ceased to produce glass from local raw materials such as silica and potash and proceeded to simply re-smelt and refashion imported European glass objects. In the case of iron there was a deliberate attempt to undermine indigenous initiative by the introduction of the “scrap iron policy” whereby metal designed as “scrap” was imported into the region from Britain. It has been argued that this policy was a deliberate attempt on the part of the British to replace iron products with those from European factories. The policy succeeded in strangulating the local metallurgical industry and arrested the further development of indigenous technology in this field.

The Scientific and Technical Department of the British Imperial Institute, located in London, was aimed at the acquisition of knowledge with respect to various indigenous technologies through experimental research, technical trials, and commercial valuation from within the vast colonial domain, including African colonies. The Institute consisted of a series of well-equipped research laboratories, and a supporting staff of trained scientists and researchers kept active in the analysis of natural and manufactured products from the colonies. Specific attention was placed on medicinal plants and it was explicitly stated that the numerous plants held in high repute as medicinal agents in the colonies should be investigated both as regards their active ingredients and their medicinal value. The above guidelines led to experimentation on *Khaya senegalensis* and a variety of Guinea corn, amongst others, plants held in high repute by indigenous experts. Traditional medicinal knowledge, integrated into the British scientific laboratory, was in fact a contributing factor in pharmaceutical development in the metropolitan center in the first three decades of the twentieth century. Research activity was not confined to medicinal plants, however, and one of the areas of investigative research was textile, specifically silk. Loni or Boko silk from Bauchi, Nigeria was one of those products analyzed. An up-to-date display of the various research findings was kept in the Galleries of the British Imperial Institute, London, and was of particular interest to merchants and industrialists on the look out for new products. Details were provided on application to the Commercial Information Office of the Institute or other authorized officers.

It is clear therefore that colonialism had far reaching implications for both the colony and the metropole. It weakened indigenous African capability with respect to experimentation, problem-solving and the creation of indigenous utilitarian objects and processes. At the same time though it facilitated the transfer of knowledge from Africa and other colonial dependencies while leaving in return an education system more geared to the reproduction of Christian religious norms and values and alienation than the

further development of scientific and technological capability.

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Colonialism and Science in India

Deepak Kumar

Colonization was not merely a political phenomenon; it had far-reaching economic and cultural ramifications. It was an exercise in power, control, and domination. Scientific and technological changes greatly facilitated this progress. Technoscience and colonialism are closely linked and to some extent share a cause and effect relationship. In recent years a good deal of work has been done on the nature, course, and consequence of this relationship in different geographical and culture areas. Some scholars see in it utilitarian and developmental images; many others find it utterly exploitative, while some prefer to opt for a middle path and emphasize both the regenerative and retrogressive aspects of the science and colonization nexus. So the debate continues, and several works have appeared with case studies on Africa, Latin America, and Asia. India, being a prime example of classic colonization, has also received considerable attention.

The fact that India has a very long technoscientific tradition and a rich cultural heritage is fairly well known. It was, however, during the seventeenth to eighteenth centuries, the post-Renaissance epoch (that of Descartes and Newton) that Europe began to outdistance India in scientific and material advancement. The rise of modern science in Europe profoundly disturbed the balance of scientific development among traditional societies. It is also possible that the various sciences and technologies were on a decline in India around 1790. There was definitely no “conscious” spirit of technological innovation and scientific enquiry to match the spirit of Europe. The result was colonization.

The advancing European trading companies became deeply involved in political and military rivalries, culminating in the establishment of the British paramountcy over the Indian sub-continent. A new empire was in the making. The colonizers were out to collect the maximum possible information about India, its people and resources. They reported what was best in India’s technological traditions, what was best in India’s natural resources, and what could be most advantageous for their employers. The English East India Company, for its part, was quick to realize that the whole physical basis of its governance was dependent upon the geographical, geological, and botanical knowledge of the areas being conquered. The colonizers fully recognized the role and importance of science in empire building.

The most interesting feature of this early phase of colonial science lies in its highly individualistic character. State followed the trade, and certain individuals on the spot would largely determine what was advantageous for both. These colonial scientists would try their hands at several fields simultaneously, and were in fact botanist, geologist, zoologist, physicist, chemist, geographer, and educator – all rolled into one. As data gatherers they had no peers, but for analysis and recognition, they had to depend upon the metropolitan scientific culture whose offshoots they were and from which they drew sustenance. The colonial government quickly patronized

geographical, geological, and botanical surveys; after all these were of direct and substantial economic and military advantage. Medical or zoological research did not hold such promises. Research in physics and chemistry was simply out of the question, for there were no laboratories, equipment, or specialized training. The reigning spirit remained that of exploration. Systematization or analysis of its results had to wait for some time, but then, even disjointed and often haphazard studies served some purpose.

Other positive achievements were the establishment of scientific bodies and museums. Pre-British India never had anything like a scientific society, not to say a journal, which could provide some sort of a platform for scientific workers. William Jones was the first to realize this and founded the Asiatic Society in Calcutta in 1784. This society soon became the focal point of all scientific activities in India. It was followed by the Madras Literary and Scientific Society (1805), the Agricultural and Horticultural Society of India (1817), Calcutta Medical and Physical Society (1823), and the Bombay Branch of the Royal Asiatic Society (1829). Trigonometrical and topographical surveys were organized under the Great Trigonometrical Survey of India (1818), and a Geological Survey was established in 1851. Scientific research thus for a long time remained an exclusive governmental exercise, and this largely determined the nature and scope of scientific research in India. Colonial science primarily implied “natural history” and its star (if not sole) attraction was the exploitation of natural resources. It was basically plantation research with emphasis on experimental farms, the introduction of new varieties, and the various problems of cash crops. Next came surveys in geology and meteorology. Another major area of concern was health. The survival of the army, the planters, and other colonizers was at stake. The importance of medical research was always recognized, but the quantum of emphasis varied from time to time. In any case, however, research was not to be a curiosity-oriented affair. Financial considerations were invariably there. The colonial administrators consistently held that

scientists in India should leave pure science to Britain and apply themselves only to the applications of science. They would goad the various organizations to work along only economically beneficial lines. Colonial researchers often found themselves unable to distinguish between basic and applied research. This was particularly true of the geologists and the botanists. Their problem was how to discover “the profitable mean course” in which scientific research, having a general bearing, would at the same time solve the local problems of immediate economic value. The dilemma was fairly acute.

In the field of education, science was unfortunately never given a high priority. In 1835 Thomas Macaulay not only succeeded in making a foreign language, English, the medium of instruction, but his personal distaste for science led to a curriculum which was purely literary. A few medical and engineering colleges were opened, but they were meant largely to supply assistant surgeons, hospital assistants, overseers, etc. What India got was some sort of a hybrid emerging out of a careless fusion between literary and technical education. What is more, adoption of English as the sole medium of instruction in science rather hampered its percolation to the lower classes. Colonial education widened the social gulf and accentuated the age-old divide. Even in government institutions, growth was kept under a self-regulatory check. The Tokyo Engineering College was established in 1873, much later than the Engineering College at Roorkee, and by 1903 it had a staff of 24 professors, 24 assistant professors, and 22 lecturers. The Massachusetts Institute of Technology was established in 1865 and by 1908 it had 306 teachers. And Roorkee, even after 100 years of its existence (i.e., in 1947), had only 3 professors, 6 assistant professors, and 12 lecturers.

Colonialism involved not only exploration and classification but also coding and decoding cultures. Its cultural projects showed deeper penetration and greater resilience than its economic forays. With the help of schools, universities, textbooks, museums, exhibitions, newspapers, etc. local discourse was influenced and colonized.

Modernity was presented as a colonial import and not something intrinsic to humanity’s rational nature. Colonial rule, with its sharp tools, dissected and bared differences and was not inclined to synthesize. Colonialism usually stalls the possibilities of exchange and prefers one-way traffic. One may talk of transfer – transfer of knowledge, systems, or technologies – but it was a transfer restricted or guided to achieve certain determined objectives. As education and awareness grew, several Indians participated in the official scientific associations and institutions, but very often they searched for a distinct identity and established institutions, scholarships, and facilities of their own.

In the first half of the nineteenth century, Bal Gangadhar Shastri and Hari Keshavji Pathare in Bombay, Master Ramchandra in Delhi, Shamhaji Bapu and Onkar Bhatt Joshi in Central Provinces, and Aukhoy Kumar Dutt in Calcutta worked for the popularization of modern science in Indian languages. In 1864 Syed Ahmed founded the Aligarh scientific Society and called for the introduction of technology to industrial and agricultural production. Four years later Syed Imdad Ali founded the Bihar Scientific Society. These societies did not live long. In 1876 Mahendra Lal Sarkar established the Indian Association for Cultivation of Science. This was completely under Indian management and without any government aid or patronage. Sarkar’s scheme was very ambitious. It aimed not only at original investigations but at science popularization as well. It gradually developed into an important center for research in optics, acoustics, scattering of light, magnetism, etc. In Bombay, Jamshedji Tata drew up a similar scheme for higher scientific education and research. This was opposed by the then Governor-General, Lord Curzon. Yet it finally led to the establishment of the Indian Institute of Science at Bangalore in 1909. There was thus greater awareness by the turn of the century.

In the first quarter of the twentieth century, those who put India on the scientific map of the world were J. C. Bose, who studied the molecular phenomenon produced by electricity on living

and nonliving substances, ► [Ramanujan](#), a mathematical genius, and P. C. Ray who analyzed a number of rare Indian minerals to discover in them some of the missing elements in Mendeleef's Periodic Table. C. V. Raman's research on the scattering of light later won him the Nobel Prize in 1930 and gave the name to Raman spectroscopy. Meghnad Saha pioneered the field of astrophysics, while S. N. Bose's collaboration with Einstein led to what is known as the Bose-Einstein equation. These were great sparks, individual and sometimes lonely, yet imbued with both scientific and national spirit. They thought over what role science and technology would play in building modern India, and they dreamt of freedom. The colonial government was aware of its limitations and discomfiture, and gradually permitted greater indigenization of its scientific institutions and cadre. In the wake of the First World War the government realized that India must become more self-reliant scientifically and industrially. It appointed an industrial commission in 1916 to examine steps that might be taken to lessen India's scientific and industrial dependence on Britain. However, few of the Commission's recommendations were actually implemented. Discontent continued to grow. India's national leaders appreciated the importance of science and technology in national reconstruction and worked closely with the scientific talent of the time. A National Planning Committee was formed in 1937 for this purpose, in which several leading Indian scientists and technologists participated. In 1942, the Council for Scientific and Industrial Research was established. The end of colonial science was pretty near. With the A. V. Hill Report in 1944 on Scientific Research in India, the curtain dropped.

The foregoing analysis illustrates that in a colonial situation field sciences may have been developed through imported scientists as an economic necessity, but little fundamental research was possible. A few colonial scientists made important contributions that no doubt enriched science in general, but their activities hardly succeeded in introducing science to the Indian people or in ameliorating their

condition. Colonial science did, on the whole, support and help sustain exploitation and underdevelopment.

See Also

- [Ramanujan](#)
- [Western Dominance](#)

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Colonialism and Science in the Americas

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When the Europeans arrived with Christopher Columbus, they found the set of explanations and dealings with natural realities that constituted the scientific knowledge of the peoples of the newly found lands absolutely novel. They marveled at the constructions, urban organization, clothing, and ornamentation of these peoples, mistakenly called Indians. To explain and understand what they were witnessing, European knowledge was not appropriate. The surprise was total.

Viking traders, and probably some other European, Asian, and African navigators, had previously visited these lands. There is evidence of this in or about the tenth century, but the records of these visits did not reach what we call the official literature.

The Portuguese were the most advanced people in Europe in navigational knowledge. People interested in navigation would study at the court of King Dom João II, in Lisbon, and frequent the entourage of the Infante Henrique, his son in charge of the navigation projects. Astronomers, ship builders, and pilots from all over the world were there. Among them was Martin Behaim, who, upon returning home to Nürnberg in 1490, was asked by his city authorities to produce a report on his studies abroad. He presented this in the form of a model of the Earth: a globe which he called the *Erdapfel*. There, between Europe, Asia, and Africa, shown in a detailed picture, lay a vast mass of water.

Surely views like this convinced Christopher Columbus, also a student in the court of Dom João II, of the possibility of reaching Cipangu and the domains of Grand Kahn. He convinced the King and Queen of Spain, Fernando and Isabel, who financed a fleet of three ships, which left Palos, near Seville, on 3 August 1492.

On 12 October 1492, they landed on an island called Guanahani in the language of its inhabitants. They did not recognize where they had landed; Columbus and the others believed they had reached Asia. The early days of the conquest and first encounters with the natives are related in descriptions of the conquest, by Columbus himself and by other chroniclers.

What the Spaniards encountered, as far as science and technology are concerned, is described in the entry on “► Colonialism and Science in the Americas” in this encyclopedia. The centuries preceding the arrival of Columbus saw a political process very similar to the one which took place in Europe in the Middle Ages, when principalities and other smaller domains were uniting into larger organizations such as kingdoms and nations. The Spanish conquerors were able to destroy the emergent power elites and replace them with the power of the conqueror, based on a well-balanced state-church structure controlling the means of production.

In Central America there was a tax system based on collecting products, while in the Inca Empire, tax was paid in labor. We can identify something that approaches private property and commerce in the Aztec model, while among the Incas the State is all powerful in the economy. Recent research reveals important commercial development in the coastal area of Peru and the beginnings of economic uses of sea resources. Although by and large the economic practices are similar to those in Europe, there is no indication at all of something that resembles capitalism. Maybe these are examples of noncapitalist economies. It is important to note the relatively low use of technology in agriculture. For example, they had no plowing devices and practically no fertilizers. Thus, production relied more on human factors, such as a more attractive division of lands with well-coordinated forms of cooperation and control of distribution, than on the intensive use of technology. At the same time, a considerable intervention of the state in major infrastructures such as irrigation and roads, associated with a rather efficient tributary system, indicates economic models which differ from

those in the Old World (Europe and Asia). This is an important area of scholarship.

This was the situation the conquerors encountered when they met the highland civilizations. Before that two of colonial settlements had been created in the Dominican Republic: Isabela in 1494 and Santo Domingo in 1496. In the beginnings of this process, with agriculture depending on Indian slave labor, local tribes were exhausted. This caused slave-hunting expeditions to the other islands of the Caribbean. To the South, the arrival of the Portuguese Pedro Alvares Cabral in Brazil led to an exploratory mission by Amerigo Vespucci, in 1501, under the Portuguese crown. The establishment of colonial settlements waited until 1532, when Martim Afonso de Sousa founded São Vicente in coastal Brazil. In 1534 the Portuguese king divided Brazil into large areas, the *capitanias*, mostly coinciding with the current coastal states of Brazil and with the right of property to be inherited. This family distribution of the lands of Brazil established much of the style of land possession in the Portuguese colony.

Meanwhile, the search for slaves led the Spaniards to found Puerto Rico in 1508, Jamaica in 1509, and Havana in 1511. From there to Florida was a small step for Juan Ponce de León in 1513. The exploration of the coast of the Gulf of Mexico by Alonso de Pineda was completed in 1519. Also, Vasco Nuñez de Balboa led the remnants of the failed expeditions of Alonso de Ojeda and Diego de Nicuesa to Colombia and Panama to the Pacific Ocean and the founding of Panama in 1519. From there the exploration of the Central America and Mexico and incursions to South America were obvious steps. Founding several cities, the conquerors approached the heart of the Aztec and Inca empires.

The recognition of high civilizations in the region approached by the Spaniards led to political, religious, and philosophical disputes. Under instructions by the King of Spain to establish trading relations, Hernán Cortés contacted the Aztec King Moctezuma. Attracted by the richness of the Aztecs, Cortés joined with peoples conquered by the Aztecs against Moctezuma and ingeniously used Aztec mythology as a war

strategy to defeat him. Cortés completed the conquest of the region and established the Kingdom of New Spain. In 1539, he was recalled to Spain, leaving behind an empire stretching from the northern part of South America to the southern part of the United States, up to the Colorado River.

The successes in Central America led to efforts to conquer South America. In 1530 Francisco Pizarro reached Peru and won over the Inca Atahualpa, who was killed after being baptized. Resistance to the conquerors lasted until 1572, with a prolonged siege of Cuzco, the old Inca capital, ending with the capture and beheading of the last Inca, Topa Amaru. From Peru, the conquest was carried on to the south and north. Founding of the cities of Quito (1534), Lima (1535), Buenos Aires (1536), Asunción (1537), Santa Fé de Bogotá (1538), Santiago de Chile (1541), Potosí (1545), La Paz (1549), and Caracas (1562) completed the period called “the Conquest.” All of Latin America, with the exception of the Amazon Basin, was in the hands of the Spanish and the Portuguese. Attempts by the French and the Dutch to conquer regions in Brazil did not succeed.

In the colonial times that followed, we see the exploitation of the lands and resources and of the peoples of the conquered regions. The colonizers brought with them traditional European agricultural and mining techniques with which they exploited the native production, mainly in metallurgy. The colonizers changed the means of production. This was done to a great extent indirectly. The native religions were simply destroyed. Food habits were also considerably modified. Wheat, rice, coffee, citrus, sugar cane, and bananas were all grown for export. This had severe consequences for the nutrition of the natives. Famine, never known in pre-Columbian times, became a major concern for Latin America. Urbanization, again following the styles of Europe, led to the development of architectural styles unsuitable to the weather and geological conditions of the conquered lands. This can be traced to the current inadequacy of the cities in the face of natural disasters such as earthquakes, floods, and high winds.

In the sciences in general, Latin America was the recipient and not the producer of scientific advances. The peripheral status of the countries was maintained throughout independence. Indeed, the colonial style and submission of the native population, with land distribution determined by the conquerors and colonizers, were kept after independence. Independence was for the *criollos*, never for the native populations, throughout the three Americas. Even after independence, education was modeled on the former imperial system.

Colonial science, considered as contributing to the mainstream of scientific development, is at best very modest. It is very important to recognize isolated cases, but they do not add to universal scientific development. Native contributions are almost exclusively in medicine, particularly in pharmacology.

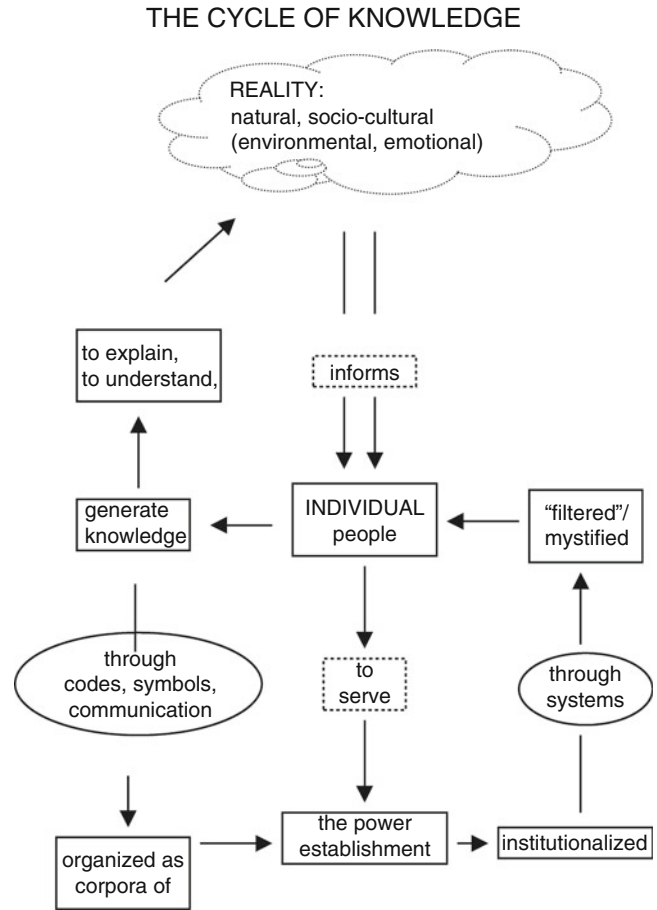
The development of Native American science and philosophy was interrupted with the conquest and colonization. Remnants of pre-Columbian forms of knowledge are limited, and research today only begins to reveal their depths.

An explanatory note: this entry is a critical appraisal of science, technology, and society in the Americas. It deals primarily with the social support for science, technology, and mathematics in colonial Latin America. Other forms of knowledge come naturally in the exposition. They are mutually interdependent and cannot be separated. The frequent references to mathematics reflect the perception that modern science relies, after the success of Newton's *Principia*, on mathematics. Hence, there is sometimes a confusion between science and mathematics, as well as between science and technology. Most of the times we refer only to science, but the reflections imply technology and mathematics. This is the characteristic of the research program, which underlies this entry, called ethnoscience or ethnomathematics.

Every culture generates knowledge as a response to mystical, environmental, and economic demands. The major challenge is to understand the human condition, which aims for survival and transcendence. Survival of the individual and of the species depends on the encounter with nature as a whole, which includes others

Colonialism and Science in the Americas,

Fig. 1 The cycle of knowledge



of the same species capable of cooperation for procreation. The encounter is in the moment, is present. Transcendence results from backing survival by searching the past, trying to understand birth and creation, probing into the future, and questioning death and posthumous influences, and this determines behavior.

Individual knowledge, as well as behavior, is the response to these drives, which implies gregariousness. Individuals are organized in groups, in the broad sense, as families, tribes, communities, and societies in general, and develop communication strategies. These strategies allow for exchanging individual knowledge and generating group knowledge and agreeing on compatible behavior. The culture of a group may be defined as shared knowledge and compatible behavior of the group.

How is knowledge shared and how is behavior made compatible? In other words, how are they generated, intellectually and socially organized, and diffused? These questions are closely related and schematized in Fig. 1.

Science, as well as language, religion, arts, astronomy, mathematics, and techniques, is a corpus of knowledge that have been generated, organized, and diffused in a particular context, with specific motivations. Eventually, the corpora of knowledge become unsatisfactory and subject to criticism and revision. This may be the result of internal cultural factors or, what is very common throughout the history of mankind, as a result of exposure to other cultures. Both the internal and external factors are present in cultural dynamics.

Science in History

The great navigations since the sixteenth century mutually exposed forms of scientific knowledge from different cultural environments. The several ethnosciences involved in the encounters, which obviously include European science, have been subjected to great changes as a result. Ethnoscience, as a research program, focuses on corpora of knowledge established as systems of explanations and ways of doing, which have been accumulated, through generations, in specific cultural environments. This program, typically interdisciplinary, brings together and interrelates results from the cognitive sciences, epistemology, history, sociology, and education. An essential component is the recognition that science and mathematics are intellectual constructs of mankind, in response to the needs of survival and transcendence.

The need for an intellectual framework to organize the corresponding systems of explanations and codes and norms and practices gave rise to many aspects of science and mathematics (D'Ambrosio, 1994). In this research program, particular attention is given to those dimensions of knowledge which bear some relation to what became known as science and mathematics in the European civilization after the fifteenth century.

Today, many of the weather explanations and predictions, agricultural practices, culinary, production systems and commerce, dressing, and institutional codes, such as the legal system, processes of cure, languages, religion, and philosophy, which, as a complex, constitute science, come from the European tradition developed in the Middle Ages and the Renaissance. They were imposed, after the sixteenth century, to much of the world, in the processes of conquest and colonialism. But we see, all over the world, extant practices performed in various levels of intensity and in very distinctive ways. These practices, which have their origins in native communities, have been, and continue to be, significantly modified as a result of mutual exposition of cultural forms. For example, it is common to see indigenous peoples in the Americas using Indo-Arabic numerals, but performing the operations from

bottom to top, explaining that this is the way trees grow. In the more advanced nations, it is not difficult to identify the influence of this mutual exposition in priorities and even styles of scientific action.

Priorities and styles of intellectual action are the substrata upon which new knowledge is built. Thus, new knowledge reflects the individual and cultural history of the agent and reveals the diversity of extant cultures. This is the essence of a multicultural historiography, which is the framework in which we discuss the history of science in Latin America. A new educational posture depends on a new historical attitude which recognizes the contribution of past cultures in building up the modern world and modern thought and which avoids omissions and errors of the past treatment of cultural differences.

We easily identify two categories of scientific knowledge: (1) academic science, sometimes called formal or scholarly science – generated by a restricted professional community; organized as specialties or disciplines, according to a convenient epistemology; and shared with peers through an elaborated language – and diffused through strictly controlled institutions, academic, or governmental, and (2) traditional science, also called cultural science, popular science, practical science, and street science, resulting from everyday practices and common knowledge.

These names are challenged. Many scholars do not agree with using the word “science” with a qualification, reserving the word only for the former and using simply “traditions” for the latter. The main distinction refers to criteria of rigor and truth and to the nature, domain, and breadth of its pursuits. Science is subjected to a concept of truth supported by criteria of rigor and organized in disciplines. The criteria of rigor, hence the concept of scientific truth, are changeable in the light of new evidence. In other words, permanence is not strict in science, which led to scientific evolution or revolutions. This is the main issue behind the Popper-Kuhn controversy. In the traditions the focus of concern and the methods are, necessarily, holistic. Traditions reveal, sometimes explicitly, mystical features, characteristic of revealed truth, giving a sense of

permanence to their fundamental principles. Thus, scientific knowledge tends to be skeptical, while traditional knowledge is more prone to fundamentalism.

Indeed, sciences and traditions are closely related and influence each other. Skepticism and fundamentalism are the consequences of the resistance to recognize the mutual influence. The ethnoscience program is the recognition of this mutual influence. Its main objective is to understand, through a concept of cultural dynamics, this influence.

For example, pre-Columbian cultures had different styles of doing their measurements and computations, and these practices are still prevalent in some native communities (Closs, 1986). Most Amazonian tribes have counting systems that go, "one, two, three, four, and many." And that is all, since with these numbers they can satisfy all their needs (Salvador, 1965, pp. 89–90). We also see important ways of dealing with pottery, tapestry, and everyday knowledge with strong mathematics characteristics in several cultures. The people from these cultures have no problems at all in assimilating the current European number system and deal perfectly well with counting, measurement, and money when trading with individuals of the European culture demands it. Land measurement, as practiced by peasants in Latin America, comes from ancient geometry transmitted to medieval surveyors since land property and measurement (geometry) is strange to pre-Columbian cultures.

The high prestige of science comes mainly from its recognition as the basic intellectual instrument of progress. Modern technology depends on science, and the instruments of validation in social, economic, and political affairs, mainly through storing and handling data, are based on science and mathematics. Particularly important in this respect is statistics, which brings to science an aura of essentiality in modern society. There is a general feeling that there are practically no limits to what can be explained by science. Many of the applications which give science such a prestigious position are part of various forms of cultural conflict (D'Ambrosio, 2000).

Some Remarks on Historiography

History, as a major academic discipline, carries with it an intrinsic bias which makes it difficult to explain the ever-present process of cultural dynamics which permeates the evolution of mankind. This paves the way for paternalism and arrogance and for intolerance and intransigence. This interferes with the understanding, by a cultural group, of the processes of building up cultural realities which respond to the need for survival and transcendence of another cultural group.

This is seen in the encounter of the two worlds, Europe and America, in the processes of conquest and colonialism. The origin of the interference may be related to distinct views of nature. A scientific conceptualization, which resulted from the medieval intertwining of Judaic, Christian, and Greco-Arabic thoughts in Europe, led man to look at nature and at the universe as an inexhaustible source of richness and to exploit these resources with a mandatory drive toward power and possession, ignoring native cultural, economical, spiritual, and social diversities. Man was created, in the biblical tradition, to obey the Creator and to be the master of all the creatures.

In the history of science, these biases have been methodological, as well as ideological. The fact that to pursue historical analyses one talks about the sciences, such as physics, chemistry, or mathematics, as distinct from religion, art, or politics, is an obstacle to understanding the processes of evolution of ideas and methods, of reflection and action, which underlie man's struggle to find explanations and to understand and cope with his environment, as well as to find means of conviviality with nature.

One of the main difficulties in doing the history of science in Latin America concerns the chronological division. In what follows, geographical divisions and historical periods are defined according to the general chronology associated with the conquest and colonization of the Americas.

Geographic divisions are defined following the administrative organization in viceroyalties: (1) New Spain (roughly what is today Mexico,

Guatemala, and upper Central America), (2) New Granada (roughly what is today southern Central America, Costa Rica, Panama, Colombia, Venezuela, Ecuador), (3) Peru (roughly what is today Peru and Bolivia), (4) La Plata (roughly what is today Chile, Paraguay, Argentina, and Uruguay), and the lately created Viceroyalty of (5) Brazil, under the Portuguese crown. Since the independence movements, which began early in the nineteenth century, the cultural map has remained roughly the same.

With respect to periods, it is misleading to adopt, for the New World, the same division as in the history of science in Europe. I propose five major periods:

1. Pre-Columbian era
2. Conquest and early colonial times
3. Established colonies
4. The rise of independent countries
5. The twentieth century (which will not be dealt with in this entry)

These periods reflect the established societies before the conquest, the emerging classes of Creoles, the definition of production and political systems, and international geopolitics, which have, mainly in the twentieth century, major influences in the sciences and technology in Latin America. Of course, there are specificities. While recognizing important attempts of French and Dutch settlements in the Americas, the main colonial role was played by Spain, Portugal, and England. It is important to understand the different styles of these three colonial empires.

Portugal, since its early consolidation as a kingdom, in the thirteenth century, recognized the Atlantic as its essential link to its commercial interests. The limited means of production led Portugal to develop a potent scientific and technological establishment focused on the navigations. The European navigators of the end of the fifteenth and early sixteenth centuries reached all of America, Africa, India, and China. In the case of Africa and in Asia, there had been previous contacts with civilizations which had many encounters among themselves and with the Europeans. Thus, the encounters of the fifteenth and

early sixteenth centuries were amplifications and deepening. Meeting the “new,” the unknown, and the unexpected was experienced by Columbus and the Spaniards, in 1492 and in the subsequent voyages to the New World.

Visions of the World

Earlier contacts with the Americas are known, but the motivations and behavior of earlier navigators were completely different from the Spanish and Portuguese and afterward the English, French, and Dutch. (See the interesting study of Ivan Van Sertima: *They Came Before Columbus*, New York: Random House, 1976 and the reports on the voyages of the Chinese monk Hwei Shen in the fifth century to Mexico. See the communication of Juan Hung Hui: “Tecnologia Naval China y Viaje al Nuevo Mundo del Monje Chino Hwei Shen”, III Congreso Latinoamericano y III Congreso Mexicano de Historia de la Ciencia y la Tecnologia, Ciudad de Mexico, 12–16 Enero 1992.)

The influence of the navigators and chroniclers, particularly Portuguese, in building up the mode of thought which underlies modern European science is noticeable. In the words of Joaquim Barradas de Carvalho, “the authors of the Portuguese literature of the navigation made possible the Galileos and the Descartes” (de Carvalho, 1983, p. 13), essentially through the development of “objective and serene curiosity, rigorous observations and creative experimentation” (Correia, 1940, p. 468).

Particularly important as chronicles are the *Crónica dos feitos de Guiné* of Gomes Eanes de Zurara (1453) and the *Esmeraldo de situ orbis*, by Duarte Pacheco Pereira, written between 1505 and 1508. These, particularly the latter, are probably the earliest major scientific works reporting on what was observed and experimented in the newly “discovered” environments.

The voyages themselves allowed a broader view of the world. For the Portuguese, to venture into the Southern Hemisphere demanded two major enterprises: the construction of the caravel, an extremely versatile ship built by the

Portuguese in the fifteenth century as the result of a remarkable engineering project, and novel navigation techniques, relying on tables constructed from systematic recorded observation carried on by the commanders of those ships. (See Antonio Cardoso, *As Caravelas dos Descobrimentos e os mais Ilustres Caravelistas Portugueses*, Monografia n° 7 do Museu de Marinha, Lisboa, 1984.) As the first European looking at “different skies,” they were responsible for recording what they saw. The contributions of Gil Eanes crossing the Bojador Cape in 1434 and Nuno Tristão reaching in 1443 the coast of Mauritania and the major achievement of Diogo Cão crossing the equator line in 1483 all paved the way for Bartolomeu Dias to cross the Cape of Good Hope in 1488 and for Vasco da Gama to reach Calicut in India, in 1498. Together with Columbus reaching the Western lands in 1492, the vision of the world changed. All lands and peoples were within the reach of the navigators. It was the beginning of a new phase in the history of mankind.

Conquest and Early Colonial Times

America, and to some extent Africa, was more surprising to the Europeans than the lands which had been reached before by land routes, in the so-called Old Continent. Particularly, America showed peoples with new systems of explanation, of rituals, and of societal arrangement. Reflections on natural philosophy or the physical sciences, particularly astronomy, were part of the overall “Cosmo” vision of the pre-Columbian civilizations.

The scientific establishment and native scientists, surely present in the society of the conquered cultures, were not recognized as such by the conquerors. One of the earliest registers of these cultures, Fray Bernardino de Sahagún (1499–1590) writes that “The reader will rightfully be bored in reading this Book Seven, [which treats astrology and natural philosophy which the naturals of this New Spain have reached] ... trying only to know and to write what they understood in the matter of astrology and natural

philosophy, what is very little and very low” (de Sahagún, 1989, p. 478). This important report explains much of the flora and fauna as well as the medicinal properties of herbs of Nueva España. But he does not give any credit to indigenous formal structured knowledge. This is typical of what might be called an epistemological obstacle of the encounter.

In the vision of the conquered, a great impression was caused by the arms, tools, and equipment in general, as seen in pictures, for example, in the *Codice Florentino*. Much research is needed on the science of the encounter. But this needs a new historiography, since names and facts, on which current history of science heavily relies, were not a concern in the registry of these cultures. A history “from below,” which might throw some light on the modes of explanation and of understanding reality in cultures, has not been common in the history of science.

Mexico, in itself, has a very rich colonial history. Developments in Central and South America reveal the important and strategic position of Mexico in the New World.

To acquire fluency in the language of the conquered peoples was a priority. Grammars are a major contribution to this. As early as 1547, Fray Andrés de Olmos (ca. 1485–1571) published the *Arte de la Lengua Mexicana*. Fray Domingo de S. Thomas (ca. 1505–1570) published in 1560 the *Grammatica o Arte de la Lengua General de los Indios de los Reynos de Peru*. The need for this understanding of the culture of the conquered, where much of the mining was taking place, is also seen in numeracy. A description of the number system of the Aztecs was written by Juan Díaz Freyle: *Sumario compendioso de las quantas de plata y oro que en los reinos del Pirú son necessarias a los mercaderes y todo genero de tratantes. Con algunas reglas tocantes al aritmética*. Printed in Mexico in 1556, this is the first arithmetic book printed in the New World. This is a clear indicator that the successful elimination of basic communicative instruments supporting the means of production and the religion of the conquered, such as language and numeracy, had to be mastered by the conqueror. Soon after the consolidation of the conquest, this

book disappeared from circulation, and Aztec arithmetic was replaced by the Spanish system; the Spanish language also became dominant.

Printing of scientific books in Mexico reveals the intellectual atmosphere of Nueva España. Alfonso (Gutierrez) de la Veracruz published, in 1554, *Recognitio Summularum* and *Dialectica Resolutio* and, in 1557, *Phisica Speculatio*. The first book contains an exposition on Aristotle's theory of syllogisms, including modal logic, and the second contains Aristotle's "Categories," with commentary, and includes numerous examples drawn from geometry, such as parallel lines, triangles, and the incommensurability of the diagonal of the square. (I owe this information to Bruce S. Burdick.)

It is interesting to observe that the registration of space location did not have the same importance as language and numeracy. Maps, essential in European actions, were not known in these cultures, while time measurement was done with remarkable precision. This has much to do with the differences in what I call Cosmo vision. (An important study of these differences is that of Fernando Flores Mirador: *Tierra firme antecipada. El descubrimiento de América y las raíces arcaicas de Occidente* (to appear), Lund, 2003.)

Although different production systems and societal organization prevailed in the Atlantic Coast, under Portuguese rule, efforts to master the language were also important. In 1595, José de Anchieta S. J. (1534–1597) published the *Arte de Grammatica da Lingoa Mais Usada na Costa do Brasil*, and in 1640, when Spanish interests grew in the Eastern South America, mainly focused on the Jesuitic Missions in Paraguay, Antonio Ruiz de Montoya S. J. (1585–1652) published the *Arte y Vocabulario de la Lengva Gvarani*.

In early colonial times, the Spanish and the Portuguese tried to establish schools, mostly run by Catholic religious orders. The effort to impose the language of the conqueror was responsible for considerable advances in linguistics. The demand for science and mathematics was essentially for economic purposes related to trade, but there was also an interest in science and mathematics

related to astronomical observations. Reliance on indigenous knowledge was limited, but there was some interest in the nature of native knowledge. The *Historia Natural y Moral de las Indias*, published in Seville in 1590 by Joseph de Acosta S. J. (1540–1600), is representative of the trend to write comprehensive studies of society, history, religion, and science.

Already in the first century after the conquest, there were practical books published in Mexico, such as the *Arte menor de arithmetica*, by Pedro de Paz, in 1623, and *Arte menor de arithmética y modo de formar campos*, by Atanasio Reaton, in 1649. It is also to be noticed the book *Nuevas proposiciones geométricas*, written by Juan de Porres Osorio, in Mexico.

There are some sources for the history of the natural and the health sciences in the general books of the chroniclers. In the conquest, there was a high level of scientific curiosity to observe and understand new diseases and new cures. Indeed, Felipe II (1527–1598), of Spain, sent his personal physician, Francisco Hernandez (ca. 1514–1597), to Mexico, to learn and record new practices and drugs which might be useful in improving health care in the cities. Unfortunately, all of his manuscripts were destroyed in a fire at the Escorial Library.

It is important to remember that social medicine was more developed in Portugal and Spain, as well as in England, than in the rest of Europe. Upon the arrival of ships to and from the New World, it was necessary to provide medical care for the travelers, in many cases subjected to new and unknown diseases. The *Santas Casas* (holy houses), founded in Lisbon in 1498, were built with this purpose. In 1543, Bras Cubas founded a *Santa Casa* in Santos, near São Vicente, one of the earliest urban settlements in the Portuguese colonies, founded by Martim Afonso de Sousa. Soon there was concern about creating formal medical classes in the colonies. In 1653, a Chair of Medicine was established in Nueva Granada, in the Colegio Mayor de Nuestra Señora del Rosario, in Bogota. This lasted until 1865 and was replaced by the Facultad de Medicina de la Universidad Nacional, in 1867. (A detailed history of this chair of medicine is the book by

Emilio Quevedo and Camilo Duque, *História de Cátedra de Medicina, 1653–1865*, Centro Editorial de la Universidad del Rosario, Bogota, 2003.)

Astronomy was a major area of interest in Latin America in the seventeenth century. There are important discussions on the meaning of comets. Many of the interpretations related to the purpose of such strange phenomena: to convey divine messages to mankind. Surely, these were searches for scientific explanations. Several polemical exchanges of letters and papers are known from these times, with important epistemological arguments. The figure of Don Carlos de Sigüenza y Góngora (1645–1700), of Mexico, towers. His works focus on astronomical observations and calculations. His most important book, considered one of the most important works of Latin American science, is *Libra astronómica y filosófica*, written in 1690. In it, Sigüenza y Góngora refutes prevailing astrological arguments about comets.

In Brazil, research on comets was also of major importance. We can see the same tone of the reflections of Sigüenza y Góngora in the work of Valentin Stancel S. J. (1621–1705), a Jesuit mathematician from Prague who lived in Brazil from 1663 until his death. His astronomical measurements are mentioned in Newton's *Principia*. A polemic, which includes another Jesuit, Antonio Vieira S. J. (1608–1697), reveals how important was the discussion about the nature of comets in building up modern scientific ideas.

In the Viceroyalty of Peru, we have the same concerns. The first to be recognized as a mathematician in Peru was Francisco Ruiz Lozano (1607–1677), who wrote *Tratado de los Cometas*, essentially a treatise of medieval mathematics explaining the phenomenon.

The Established Colonies

The death of Carlos II (1661–1700), of Spain, resulted in a turbulent period in Europe, known as the War of the Succession of Spain (1701–1714). An important consequence was the intellectual movement known as the Enlightenment (*Ilustración*), which had important

consequences for the Americas, mainly the intellectual revival, which began in Spain under Carlos III (1716–1788) and in Portugal under José I (1714–1777) and his strong minister, the Marquis of Pombal (1699–1782) (Maxwell, 1995).

Religious orders were not immune to the new ideas coming from Europe, and several descriptive treatises of the world were written. A general geography of the continent, the *Geographia Histórica de la América y de las Islas Adyacentes, y de las Tierras Arcticas y Antárticas, y Islas de los Mares del Norte y del Sur*, authored by Pedro Murillo Velarde S. J. (1693–1753), was published in Madrid, in 1752, as volume IX of a monumental 10-volume *Geographia Histórica del Mundo*. This important and comprehensive presentation of the New World is a remarkable source of the history of the development of the colonies, revealing the political struggles and cultural differences.

As a result of the War of the Succession of Spain, relations with other European nations were intensified, and, as a consequence, a number of foreign scientific expeditions, with mixed scientific and commercial interests, came to the region during the eighteenth century (Weinberg, 2000, pp. 497–515). This contributed to shaping scientific development in Latin America. Great repercussions were caused by the scientific expeditions of Amedée Frézier (1682–1773), published in 1716 as *Relación del viaje por el mar del Sur a las costas del Chile y del Perú realizada durante los años 1712, 1713 y 1714*, and of Charles Marie de la Condamine (1701–1774), whose main results were published as *Relation abrégé d'un voyage fait dans l'intérieur de l'Amérique méridionale*. Alejandro Malaspina (1754–1809) organized one of the most important expeditions. In 5 years, they visited practically all the Spanish possessions and collected precious materials.

A good number of expatriates and Creoles played an important role in creating a scientific atmosphere in the colonies. As a result of the emergence of modern science, following the publication of Newton's *Principia*, mathematics was central in the emerging scientific community. A number of intellectuals, well versed in a variety

of areas of knowledge, were responsible for introducing mathematics to the colonies. These include Juan Alsina and Pedro Cerviño in Buenos Aires, who lectured on infinitesimal calculus, mechanics, and trigonometry. In Peru, Cosme Bueno (1711–1798), Gabriel Moreno (1735–1809), and Joaquín Gregorio Paredes (1778–1839) are best known. In Brazil, José Fernandes Pinto Alpoim (1695–1765) wrote two books, *Exame de Artilheiros* (1744) and *Exame de Bombeiros* (1748); both focused on what we might call military mathematics, and both were written in the form of questions and answers. (Brazil was different from the Spanish colonies; she did not have presses. These two books, although written in Brazil, focusing on Brazilian interests, were printed, in Portuguese, in Spain and Portugal.)

A distinguished figure from the period is José Celestino Mutis (1732–1808), who was responsible for an unpublished translation of Newton but also for the introduction of modern mathematics in Colombia, mainly relying on the books by Christian Wolff. He was the founder of the *Observatorio de Bogotá* in 1803. His most distinguished disciple, Francisco José Caldas (1771–1816), became the director of the Observatory. Caldas was deeply involved in the Independence War and was shot by the Spaniards.

In Chile, the Universidad Real de San Felipe, which was inaugurated in 1747 in Santiago, was provided with a “catedra” of mathematics. Fray Ignacio León de Garavito, a self-instructed Creole mathematician, was responsible for this chair.

Again we have to mention Mexico, where the most important developments of mathematics in Latin America at that time took place. In the first half of the eighteenth century, a number of textbooks on geometry, arithmetic, and astronomy were in use in Mexico, written by local scholars. These were mostly minor scientific works. In the second part of the century, there were publications with more scientific value. Particularly notable are the *Lecciones matemáticas* of José Ignacio Bartolache, published in 1769. In 1772, an unknown person built a “calculating wheel,” capable of performing the four basic operations for numbers up to 10^8 digits. Also in 1772, Benito

Bails published the *Elementos de matemáticas*, which treated infinitesimal calculus and analytic geometry.

A special kind of applied mathematics was developed, stimulated by the complexity of problems related to water and to mining. These two constitute the most important problems in the technological development of the country. “Subterraneous geometry” became a major theme in Mexican science. The needs of mining led to the creation of mining schools, such as the Real Seminario de Minería, founded in Mexico City by the Spanish mineralogist Fausto de Elhuyar in 1792. Particularly important were the efforts for urbanization, which took place in all the colonies (Catalá, 1994). The book *Comentarios a las Ordenanzas de Minas*, by Francisco Javier Gamboa, published in 1761, is most representative of these developments.

Let us move to the South. In Guatemala, which included Costa Rica, the most renowned scholar was José Antonio Liendo y Goicoechea (1735–1814). He taught at the Universidad de San Carlos de Guatemala. This had already become a very important academic center after a new plan of studies published in 1785, written in Latin in the form of 25 theses, under the title *Temas de Filosofía Racional y de Filosofía Mecánica de los sentidos, de acuerdo con los usos de la Física; y de otros tópicos físico-teológicos según el pensamiento de los modernos para ser defendidos en esta Real y Pontificia Academia Guatemalteca de San Carlos*. This was, essentially, a medieval proposition. Goicoechea was responsible for modernizing this plan of studies, incorporating experimental physics into the project, and introducing modern mathematics based on the texts of Christian Wolff.

Independence: The Basin Metaphor

The independence of the Viceroyalties of Nueva España, Nueva Granada, Peru, La Plata, and Brazil was achieved in the first quarter of the nineteenth century. The political division in countries, following independence, was

practically the same as today. The pattern of cultural dynamics since colonial times did not change much, except for the fact that other empires replaced Spain and Portugal as central nations.

There is no way to deny that (Western) science and mathematics are essential in the modern world. Public opinion is ready to support investment in scientific and mathematical research in spite of being absolutely unable to guess what kind of research is being supported. For example, peers and society in general regard those that get good grades in mathematics as potential geniuses, while those that do not do well in mathematics are regarded as potentially stupid. Socially, this has been instrumental in the selection of the elite. The attitude regarding sciences in general is not different. The appropriation, by larger strata of society, of scientific and mathematical terminology, and even results, is reprehended and even derided. Those who do well in the arts or in sports, but fail in mathematics, are considered less intelligent. The references to "hard sciences" subtly reveal contempt for the humanities and social sciences. The best illustration of this is what became known as the "Science Wars," exposed by Alan Sokal's hoax. (See the issue devoted to the theme "Science Wars" in *Social Text*, 46–47, Spring/Summer 1996. The issue has very interesting papers. Regrettably, attention was given only to the hoax of Alan Sokal. As a consequence there was a renewal of attacks on Afrocentrism, warnings against a "new dark age of irrationalism," and other controversial disputes going on in the academic world. All this, which might be interpreted as a form of intellectual fundamentalism, is nothing but a defensive posture against the challenge of the current epistemological order.)

Let me introduce some concepts and reflections that result from what is now called Social Studies of Science or Science Policy. This is basically the study of the politics of scientific development, the backbone of funding agencies. It is very interesting to analyze the substitution of the colonial discourse by the discourse of aid – both multilateral, like UNESCO, and bilateral, like ORSTOM, the British Council, and

others. The nature of the deprived populations in colonial times and after independence, following WWII, did not change. Neither did basic needs. But the strategies to keep them as faithful consumers had to change. (These topics have in the postwar period drawn much attention and generated important studies whose results throw some light on the production of scientific knowledge throughout history. Particularly interesting is the historiography adopted by Harold Dorn in his exciting book, *The Geography of Science*, Baltimore: The Johns Hopkins University Press, 1991.) But let us not deviate from the main objective of this entry, which is the production of scientific and mathematical knowledge.

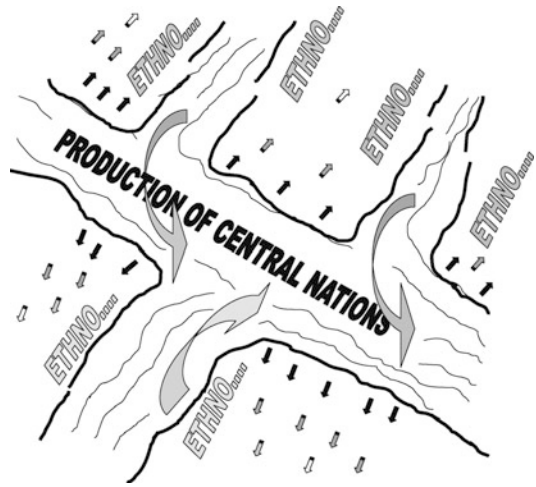
When deciding on investments in science and technology, it is natural to expect social benefits. These investments have been substantial, both through funding agencies, either governmental or through aiding agencies, either bi- or multilateral. The outcomes in the so-called Third World have not been encouraging, as recently mentioned by the Director-General of UNESCO. "The gap between rich and poor countries is a gap of knowledge," said Federico Mayor (1994). Over 80 % of the benefits of scientific and technological research are available only to the populations of the First World. But the gap between central nations and peripheral nations in the production of scientific knowledge is widening. Scientific productivity is related to the cultural atmosphere and self-esteem. Evidence from research shows that both individual and social creativities are enhanced by self-esteem. Self-esteem can hardly prevail among a population deprived of its history.

The most efficient strategy to consolidate colonial control was to deprive the conquered peoples of their systems of explanation and the instruments for survival and transcendence. This was achieved with a subtle deprivation of the history of the conquered and the production of a history "favorable" to the conqueror. This prevailed after independence. Today, Cardinal Richelieu and D'Artagnan are themes of history and literature in former colonies. Hernán Cortez is better known than Moctezuma. Local heroes are ignored or labeled as evil criminals.

For example, in Brazilian history books, Zumbi (1655–1695) was regarded as an outlaw, and although recognized, more recently, as a hero, the space reserved to him in books and classes is negligible. (Zumbi is the leader of the “Quilombo dos Palmares,” a republic created by runaway slaves in the northeast of Brazil, which lasted for about 100 years. It was destroyed in the late seventeenth century. But other such republics lasted and some were contacted only recently. Their economy and production systems, particularly agriculture and mining, are as yet to be studied. See more on the communities of runaway slaves in the Americas in Richard Price’s, org., *Maroon Societies: Rebel Slave Communities in the Americas*, 2 vols. Baltimore: The Johns Hopkins University Press, 1972.)

We may consider, as it is frequent in discussions of policy, especially in the United Nations and other national and international agencies, the production of scientific, technological, and mathematical knowledge as something measurable. Scientometrics relies on several indicators, and the studies of quantitative history allow us to speak of the central nations as those who produce new knowledge and the peripheral nations as those who absorb new knowledge. Production and absorption of knowledge are clearly distinguishable. The sad situation is that the peripheral nations have been slow in absorbing new knowledge. The lack of infrastructure acts as a barrier for this process (D’Ambrosio, 1975, p. 94). The basin metaphor helps us to understand the process. The main producers of knowledge (central nations) are represented by the mainstream. Water always fertilizes their margins. They will produce their effect in the margins of the tributaries (peripheral nations) much later, when the waters have already flown along the stream (thus producing the gap or obsolescence of knowledge). The water (knowledge) does not flow upstream of the tributaries (Fig. 2).

The water of the tributaries fertilizes their margins and also adds and contributes to the volume of water of the mainstream. For example, expropriation of “popular” knowledge – so common in the pharmaceutical industry – and co-optation strategies, particularly the brain



Colonialism and Science in the Americas, Fig. 2 The basin metaphor

drain, encourage this. A strict school system was responsible for this strategy in colonial times. This is manifest in the emigration of academics and, worst, in the subordination of laboratories and research institutions of the peripheral nations to the priorities of their major homologues in the central nations (D’Ambrosio, 1979, pp. 223–229). This strategy plays out, for example, in the valuation of foreign academic degrees over local degrees. Now, it is quite revealing to see the efforts to entice research institutions in the peripheral nations to join major biotechnology research plans.

The co-optation of scientists in the periphery is normally done by sending experts, in many cases scientists with high reputations, to the periphery for short visits and conferences, by offering fellowships, by giving stipends higher than the current national salaries, by sending equipment (in many cases obsolete or already heavily used), and by offering international travel to seminars and congresses. This is true in academics and, in the more developed peripheral nations, also in industry. Particularly in mathematics, we have numerous examples of such practices in the postwar period. The presence of monies of the US Army, Navy, and Air Force research agencies, as well as of the NSF, the CNRS, the British Council, the DAAD, and

other agencies, following the pattern mentioned above, is remarkable.

These cases have not been studied in detail as yet. They have the common feature of producing human resources and results without any analysis of the capability of the peripheral countries to absorb and to make these resources and results useful for their needs. Normally this is the result of a lack of qualitative directives in science policy of the peripheral nations. Practically every scientific development plan in the periphery is a program entirely based on quantitative goals. The World Bank, the UNDP, and other financing agencies rely on, indeed stimulate, plans based on quantitative goals. Clearly, they are easier to check. But the benefits for the poor populations of the peripheral nations are practically nil.

In the basin metaphor, the sources of the rivers, both the mainstream and the tributaries, correspond to ethnomathematical knowledge. Ethnomathematical knowledge, like the waters, flows fertilizing the margins of the tributary and eventually mixes in a major stream, contributing to this flow. Waters of the mainstream do not go upstream through the tributaries.

The notion of progress carried on by the mainstream will benefit the margins of the tributary after a long way through difficult land paths – which correspond to the acquisition of knowledge from other sociocultural and environmental sources. The needs of the margins – peripheral cultures – are met by the water of the tributaries and only later receive the benefits coming from the mainstream. But these can be useful only if the grounds are fertile. To make them fertile requires long, deep, and very complex educational reforms.

In this metaphor, an alternative to mainstream and tributaries would be to have a large lake, where all the sources contribute equally to the main body of water. Each source produces according to its environmental history, and all the waters of the lake fertilize all the margins. The creation of the great lake – the deterioration of the current world order – is identified with a sensible globalization, leading to a new planetary order.

Developments in the Newly Independent Countries

The independence of Guatemala, in 1821, decreased the influence of Mexico in Central and South America. The establishment of new universities and the renewal of old ones, immediately preceding and after independence, generated open attitudes with respect to sources of knowledge on which to build up the newly established countries of Latin America. Formerly restricted to an almost exclusivity of influences coming from Spain and Portugal, the new countries attracted considerable attention from the rest of Europe, and a new wave of scientific expeditions came to South America. They had great influence in creating new intellectual climates throughout the region. This new source is seen very strongly in the building of large and diversified libraries, both public and private, and the acquisition of modern literature.

In Costa Rica, colonial authorities established the Casa de Enseñanza de Santo Tomas in 1814, in which the most influential teacher was Rafael Francisco Osejo, born in 1780. In 1830, he wrote *Lecciones de aritmética*, written in the form of questions and answers, a common feature in that period, as shown above when referring to Alpoim in Brazil. In 1843 the Casa de Enseñanza de Santo Tomas was transformed into the Universidad de Santo Tomas, where courses in engineering were established. But there were no courses in pure sciences and mathematics.

Colombia soon attracted foreign mathematicians. The Frenchman Bergeron introduced descriptive geometry in the country, and the Italian Agustín Codazzi (1793–1859) was influential in creating the Colegio Militar. Lino Pombo (1797–1862), who was particularly influential in founding the Academia de Matematicas de Venezuela, wrote a complete course of mathematics.

In Brazil, the transfer of the royal family of Portugal, who were escaping the Napoleonic invasion, in 1808, was decisive in changing cultural life in the colony. The Portuguese court settled in Rio de Janeiro, where it was necessary to create an infrastructure to run, from a colonial town, the vast Kingdom of Portugal. They

founded a major library and an Escola Militar (Military School), the first institution of higher learning in the colony. Both were influential in the development of mathematics in Brazil. In the school, a doctorate in mathematics was established and a number of theses were submitted and defended (da Silva, 1992). Translation of the textbooks of Lacroix, of Legendre, and of others was quite important in generating what we might call a mathematical style in Brazil.

Particularly interesting is the case of Joaquim Gomes de Souza (1829–1863), known as “Souzinha,” the first Brazilian mathematician to appear in Europe. He presented his results in the Académie des Sciences de Paris and in the Royal Society. Only short notices of the papers were given, and they were posthumously published as *Mélanges du Calcul Intégral*, as an independent printing by Brockhaus of Leipzig in 1889 (*Comptes-Rendus de l'Académie des Sciences de Paris*, tomes XL, p. 1310, and XLI, p. 100, and *Proceedings of the Royal Society*, 1856, pp.146–149). (It is quite interesting to read the referee's reports and the reaction of Gomes de Souza to the fact that Liouville did not give an appraisal of the paper, according to Gomes de Souza, because of “la petite jalousie.” A thorough study of the scientific works of Gomes de Souza has still not been done.) This work, dealing mainly with partial differential equations, is permeated by very interesting historical and philosophical remarks, revealing access to the most important literature then available. This was possible due to the existence of important private collections in Maranhão, his home state in the northeast.

Argentina, independent since 1816, experienced a remarkable intellectual development. In 1822, the ephemeral Sociedad de Ciencias Físicas y Matemáticas was founded in Buenos Aires (Nicolau, 1996). There was an emergence of private libraries. Particularly important is the private library of Bernardino Speluzzi (1835–1898), which listed the main works of Newton, D'Alembert, Euler, Laplace, Carnot, and several other modern classics. Another intellectual, Valentin Balbin (1851–1901), while rector of the National College of Buenos Aires,

proposed a new study plan, in 1896, which included history of mathematics as a distinct discipline. This is probably the first formal interest in the history of mathematics in South America, which eventually led to an important school of history of science in Argentina.

In Peru, there was an interest in statistics, beginning with the book *Ensayo de estadística completa de los ramos económico-políticos de la provincia de Azángaro...* by José Domingos Choquechuanca (1789–1858), published in 1833.

In Chile, the Universidad de Chile was created in 1842, with a Faculty of Physical and Mathematical Sciences. A most distinguished member of the faculty was Ramón Picarte, a lawyer, who had his paper, *La división reducida a una adición*, accepted and published by the Academy of Sciences of Paris in 1859. (I did not have personal access to these papers and to the records of Picarte's presence in Paris.) Much emphasis was given to teacher training. An agreement with the government of Germany provided the pedagogical support to reform education in the country. Fifteen German mathematicians, most with a doctorate, immigrated to Chile in 1889.

The influence of Auguste Comte (1798–1857) toward the end of the century was very important in all of Latin America, particularly in Mexico and in Brazil. Although the main reason was the demand of the emerging political elites to build up the ideological framework of the new countries, Comtian ideas influenced a considerable development of mathematics and the Sciences in general. (See the important doctoral dissertation of Circe Mary Silva da Silva, *Positivismus und Mathematikunterricht: Portugiesische und französische Einflüsse in Brasilien im 19. Jahrhundert*, IDM, Bielefeld, 1991.)

Conquest and colonization had an enormous influence on the course of development of civilization. The chroniclers of the conquest tell of different ways of explaining the cosmos and the creation and of dealing with the surrounding environment. Religious systems, political structures, architecture and urban arrangements, sciences, and values were, in a few decades, suppressed and replaced by those of the conqueror. A few remnants of the original behavior

of these cultures were and still are outlawed or treated as folklore. But they surely integrate the cultural memory of the peoples descending from the conquered. Much of these behaviors are easily recognized in everyday life.

Mathematics, as a human endeavor, is not different. This is one focal point of the research program known as ethnomathematics, which deals with the generation, the intellectual and social organization, and the diffusion of different ways, styles, modes (*tics*) of explanation, understanding, learning, coping with, and probing beyond (*mathema*) the immediate natural and sociocultural environment (*ethno*). This clearly results from the mutual exposition of different cultures, and the dynamics of this process is a major problem we face in doing the history of ideas in every region of this world.

The conquest paved the way to colonization. In the Americas, the early colonizers, the Spanish and the Portuguese, paved the way for the French, the English, and the Dutch colonizer and later on for Africans, Europeans, and Asiatic immigrants. With them came new forms of coping with the environment and of dealing with daily life and new ways of explanations and learning. The result was the emergence of a synthesis of different forms of knowing and explaining which were generated by and available to the different communities, to workers, and to the people. We recognize the emergence of new religions, cuisine, music, arts, and languages, particularly in the Americas – the Creoles. All of these interrelated as a synthesis of the cultural forms of the ancestors.

Science and mathematics, as cultural forms, are not different. The emergence of new cultural behavior is another focal point of the research programs known as ethnohistories and ethnomathematics.

Particularly in the Americas, the variety and peculiarity of the expositions of cultures and the specificity of the population migrations reveal an effort of the colonizer to transfer, with minor adaptations, the forms of social, economical, and political organizations and administration prevailing in the metropolises, including schooling and scholarship (academies, universities,

monasteries). The new institutions in the Americas were based on the styles prevailing in the metropolises, mostly under the influence, and even control, of religious orders.

All this, which took place during most of the sixteenth, seventeenth, and eighteenth centuries, occurred while new philosophical ideas, new sciences, new ways of production, and new political arrangements were flourishing in Europe. The cultural artifacts produced in Europe were assimilated in the Americas under specific, mostly precarious, conditions. There is a clear coexistence of cultural goods, particularly knowledge, produced in the Americas and abroad. The former were consumed mostly by the lower strata of society, the people and workers, and the latter by the domineering classes. These boundaries are not clearly defined, and the mutual influences of the resulting intellectual productions are evident.

This poses the following *basic question*: What are the relations between the producers and consumers of cultural goods?

This guides my proposal for the historiography of science and mathematics and what I have called “the basin metaphor.” Although this is a question affecting the relations between academia and society in general, hence between the ruling elites and the population as a whole, it is particularly important for understanding the role of intellectuality in the colonial era. Thus, ethnohistory and ethnomathematics are fundamental instruments of historical analysis (D’Ambrosio, 1995, 1996).

Curiously enough, the main factor influencing the consumption of what we might call academic science and mathematics produced in an alien cultural environment, sometimes inside the same country, depends basically on what the “outsiders” – that is, the people not learned in science and mathematics – have to say about science and mathematics. This factor has not been given attention in the prevailing historiographies (D’Ambrosio, 1993). This broader look, suggested by new historical scholarship, comes under severe attack, in what became to be known as the Science Wars (D’Ambrosio, 2000). My proposal incorporates to the history of science

and mathematics, in an essential way, the views of aliens, in the sense of strangers to the specific knowledge fields or strange to the cultural environment, about science and mathematics.

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Colonialism and Science in the Malay World

Hairudin Bin Harun

By the sixteenth century, the legends of the Golden Chersonese, about the distant land having more gold and exotic treasures than people, were well established among the sea going nations of Europe. Legend had it that the Golden Chersonese was geographically located midway between India and China. The Golden Chersonese description apparently fit the Malay Peninsula very well. Indeed, it came to be known among the early Europeans by that very name until it was replaced by another, Malacca. By whatever name the Peninsula was known, it was a major focal point of Eastern trade. Indeed, Malacca – actually a tiny coastal city-port situated in the middle of the Malay Peninsula – was not only a commercial Mecca, but also a cultural center and meeting point for the major civilizations of the time.

In 1575, Louis De Roy, writing on the virtues of the new knowledge and inventions spurned by the Renaissance spirit, made a special note about the meeting of Magellan and the King of Malacca. According to De Roy, the meeting was

made possible by the new knowledge of the seas and the use of the magnetic compass for navigation. Malacca, to the Europeans then, as not just a reference to the city-port but rather to the whole Malay Archipelago, including the Peninsula and Islands of Indonesia that were under Malaccan rule. By the time De Roy's article was published, Malacca had actually been under the annexation of Portugal for 65 years, since the Portuguese defeated the Malays in 1511. Some scholars have suggested that the downfall of Malacca also marked the decline of Eastern scientific and technological superiority *vis-à-vis* the European. Others have cautioned against making simplistic conclusions, pointing out that the reasons for the downfall of Malacca were far more complex than those that have been suggested.

The Portuguese ruled Malacca until the mid-seventeenth century. In 1614 the Dutch successfully wrested Malacca from the Portuguese. By the mid-eighteenth century Dutch power in the Malay Archipelago declined, giving way to the British. The British were relatively latecomers to the region, but they were none the less regarded as the best prepared – intellectually, militarily and economically – among the colonizers of the region. They were poised for a long stay.

There were two major factors that were crucial to the expansion and consolidation of the Crown's influence: the colonial economy and the health of officials, colonialists, and *coolies* (colonial laborers). In the early phase of British colonialism, spices, timber, and other agricultural products were the backbone of the colonial economy. Knowledge of economically and medicinally useful plants of the East was indispensable both for the sustenance of the economy and the maintenance of health. This knowledge was to be found in the new discipline of plant science, later known as *economic botany*, and much later as *agricultural science*.

The cultivation of spice trees, and the transfer of economic plants like rubber trees from the Amazon to the Malay Peninsula, was some of the colonial activities made possible by the new plant science and its scientific institutions. Indeed, apart from medicine, no branch of science was regarded as so crucial to the sustenance

of colonialism as economic botany. Before the advent of synthetic drugs, herbs and plants were the main source of medicines. For instance, quinine, an extract from the chichona tree that grew wildly in the Peruvian jungle, was extensively used to cure malarial fever. Hence, knowledge of the indigenous plants was important not only for economic reasons, but for health as well. Health and diseases also assumed an economic and political significance. They were moderating factors in the colonial expansion and exploitation of the East, especially in the tropics. Tropical diseases like malaria were a menace to the health of colonial officials and then laborers. Indeed, malaria reportedly wiped out some of the remote British colonies and military bases and was blamed for slowing down colonial campaigns in the Far East and Africa. In the following discussion we will see how the development and history of British [colonialism and science](#) in the Malay Archipelago became intertwined.

Botany and British Colonialism

As early as the seventeenth century there were attempts to grow exotic and foreign food crops away from their natural habitats. The first attempt to grow pineapples in England was reportedly made during the reign of Charles II (1660–1685). The colonization of the New World and later, Asia, led to the introduction of many new crops to Britain. Maize, a staple crop of the Native Americans, which yields ten times more than wheat, was among the crops that revolutionized European tastebuds. Another imported high yielding crop, that reportedly saved Ireland from starvation, was the potato. However, there were still many food crops that resisted local cultivation and therefore had to be brought over from the colonies. Supply was notoriously irregular and rarely adequate to meet demands. It was not until the nineteenth century that supply became more reliable. This reliability owed much to the active colonization of new fertile lands in the East and the new discipline of economic botany.

In the nineteenth century, the political ideology of the times, the botanic gardens, and the colonial office functioned as an integrated framework, enforcing an economic structure whereby the East became the producer of raw materials for the West's industries. Indeed, this framework was a characteristic description of colonialism which involved, among other things, the establishment of plantations and the large-scale cultivation of economic plants, and the systematic transfer of economic plants from an area less productive or less conducive (either politically, economically, or scientifically) to a more productive and conducive one. Colonialism also entailed the need to coordinate and transfer labor from one colony to another in order to ensure the viability of a plantation or an agro-economic project. Underwriting the success of the colonial plantations and agriculture-based economic projects were the many research oriented botanic gardens established throughout the colonies. The most prominent of these botanic gardens were the Calcutta Garden in India, the Peradeniya Gardens in Ceylon (Sri Lanka), and the Penang, Malacca, and Singapore Gardens in the Malay Peninsula, known then as *British Malaya*.

The Royal Botanic Gardens at Kew in London was the center for scientific research and coordination of the work of the botanic stations in the colonies. Kew's role was very well illustrated in the case of the discovery and cultivation of the cinchona tree – the medicinal tree from which the malarial medicine, quinine, was extracted. The discovery of cinchona involved a large army of field workers and researchers collecting and gathering seemingly irrelevant bits of information and materials, from every remote corner of the British Empire and beyond. The information and materials were sent to Kew for analysis. The discovery and eventual successful extraction of quinine, which turned out to be the most potent antidote for malaria, was a credit to Kew and its network of botanic gardens in the colonies. Indeed, quinine was not just an important scientific discovery; it also had important demographic and political effects. Through the control of malaria it saved the lives of countless colonial officials and their *coolies* (laborers) and

made possible the large-scale colonial exploration and exploitation of Africa and the Far East.

Colonial Botany in the Malay Peninsula

Colonial botany came to the shores of the Malay Peninsula in the year 1822 with the establishment of the botanic garden in Singapore by Sir Stamford Raffles. The staff of the botanic garden was instrumental in overseeing the introduction and improvement of spice cultivation in the Straits Settlements. Indeed, in the Malay Peninsula *botany* was almost indistinguishable from *economy*. Whether the relationship between botany and colonial economy in the colonies had any influence in the formalization of economic botany back in the motherland is a difficult question to answer with certainty; but what is certain is that the colonial economy benefited much from the knowledge and expertise provided by economic botany.

Back in Britain, botany was given a boost following several developments, one of which was the appointment in 1841 of Joseph Hooker (1817–1911), far more widely known as a colonialist than as a botanist, as head of the Royal Botanic Garden at Kew. Kew was responsible for coordinating and supervising all the scientific research on economic plants and agriculture within the British colonial empire. It was under Kew's supervision that in 1858 new botanic gardens were established in Singapore superseding the one established by Raffles. In 1887 botanic gardens were also established in Penang followed soon after by another in Malacca.

Nowhere is the importance of Kew to British colonialism so clear as in the case of the transfer of the wild Brazilian rubber plant from Latin America to the Malay Peninsula. Initially, various species of wild rubber seeds were collected from the Amazon jungle and sent to Kew Gardens for study and analysis. Eventually a species, *Hevea brasiliensis*, was identified as promising and was transferred to the botanic gardens in Singapore. Under the supervision of the Singapore gardens which H. N. Ridley headed, politically backed by the colonial office,

and heavily financed by the Crown companies, experimental plantations were set up in various parts of the Malay Peninsula. The plantations turned out to be experimentally successful and, as anticipated, destined to become commercially successful too. At the turn of the twentieth century, with the advent of motor vehicles industry in Europe and America, rubber became one of the most important raw materials for the new industry. Rubber planting indeed became one of the most profitable colonial commercial ventures. Most importantly, rubber could only be found in abundant quantity and of high quality within the British Empire.

The transfer, identification, and eventual cultivation of economic plants would not have been successful without colonial botany equally recording a success in another related activity: taxonomical works. Indeed, one of the main tasks of the botanic gardens was taxonomical work closely associated with identifying economically and medically useful plants. The varieties of plant life in the tropics became a testing ground for the new system of classification. In the Malay Peninsula, the colonial taxonomical campaigns of identifying and naming tropical plants soon turned out to be an enormous task that almost overwhelmed the colonial scientists and their machinery. The variation of plant life in the tropics rendered it practically impossible for their taxonomists and the new taxonomy to start fresh from scratch. However, starting from scratch was the last thing that they had to do. Long before the arrival of the British, the natives had already classified most of the plants, especially the economically useful ones. More often than not, all the colonial taxonomist had to do was to refer to the local taxonomy and be creative. They eventually discovered that the local folk taxonomy was almost encyclopedic, encompassing the encounter of many generations of indigenous wisdom with the local flora.

Colonial Botany and Malay Ethnobotany

The encounter of the colonialists with Malay ethnobotany probably went as far back as the

arrival of the first Europeans to the area. Tome' Pires, a Portuguese scholar and explorer, who visited Malacca during the Portuguese rule, noted the existence of a botanical tradition among the Malays. The Malay botanical tradition was described as being composed of a complex system of plant taxonomy and knowledge as well as the cultural-educational rituals associated with teaching and imparting the knowledge to successive generations.

The majority of the colonial botanists, with very few exceptions, were genuinely intrigued by the sophistication and mechanics of Malay plant taxonomy. They seemed to agree that the Malay taxonomy was much more than a fanciful accidental uttering of a primitive tribe oblivious to any sense of rationality or systematic thinking. In fact, in many ways it was comparable to the modern colonial system.

In the colonial scientific taxonomy, plants having the same kind of flower and fruit but which differ in details of size, shape, and color of the flowers, fruits, or leaves constituted a *genus*. A specific name came after the generic name either as an adjective qualifying it or as noun in the genitive case if the species was in honor of some person.

Colonial botanists noted that Malay folk taxonomy, on the other hand, was based on either the use or morphological characteristics of the plants, or at times both. Most economically useful plants were classified by their use, whilst medically useful plants and others were often classified by the morphology of their niche, leaves, fruits, or flowers. What was found as a pleasant surprise to many of the colonial botanists was the discovery that in many instances the colonial scientific taxonomy and Malay taxonomy shared common grounds. There were also considerable numbers of Malay taxonomical names that found no equivalents whatsoever with the colonial names. Names like *kedundung*, *Tinjau Belukar*, and *Puding* were morphological names referring to the chief characteristics of the respective plant. They could be either a reference to their growth habit, shape of leaves, flowers, fruits, or combinations of any of those. They did not correspond neatly to the modern colonial taxonomy.

However, in spite of that, Malay ethnotaxonomy was a tremendous aid to the colonial reclassification of plants in the tropical Peninsula to modern taxonomy.

Many of the taxonomical and other scientific findings were published in the *Kew Bulletin*. The Bulletin was not only important academically, but it was also a medium of communication and instruction between Kew and the imperial network of botanic stations. It played the dual role of a scientific medium and a channel for colonial interests, reflecting faithfully the nature of colonial scientific activities.

Colonial scientific activities in the Malay Peninsula, especially the botanical and the taxonomical exercises, were not just scientific per se; they were first and foremost an integral part of the colonial activity to sustain British colonialism. In short, they were by and for colonialism.

See Also

► Ethnobotany

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Combinatorics in Indian Mathematics

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Having prescribed the rule

$$C_n^r = \prod_{k=1}^r \frac{n-k+1}{k}$$

for the number of combinations of r things taken at a time from n things, Bhāskara II (AD 1150) remarked:

This [rule] has been handed down [to us] as a general [method], being employed [for their

own purposes] by the experts [of specific fields of study], namely, for the tabular presentation of possible meters in metrics, for the number of ways of opening ventilating holes, etc., and the diagram called Partial Meru in arts and crafts, and for the varieties of tastes in medicine. [But], for fear of prolixity, they are not explained here. (*Līlāvātī* 113–114)

It is impossible to tell exactly when and by whom this rule was formulated, but from ancient times Indian peoples have had a keen interest in arranging things in order in various aspects of human life and in theorizing in various areas of study.

The *Bhagavatī*, one of the 12 canonical books of the Jainas, counts by enumeration the number of all the possible cases when one person, two persons, three persons, etc., are distributed in the seven nether worlds.

Most books of Sanskrit and Prakrit prosody, such as the *Chandaḥsūtra* of Piṅgala (ca. AD 200?), *Vṛttajāṭisamuccaya* of Virahāṅka (between the sixth and the eighth centuries), *Jayadevacchandaḥ* of Jayadeva (before AD 900), *Chando'nuśāsana* of Jayakīrti (ca. AD 1000), *Vṛttaratnākara* of Kedāra (before AD 1000), *Chando'nuśāsana* of Hemacandra (ca. AD 1150), etc., devote one of their chapters (usually the last one) to “six kinds of ascertainment” (*ṣaṭpratyaya*), namely:

1. Spread (*prastāra*), to spread a list of all the possible variations of a given type of meter consisting of short and long syllables according to a certain method
2. Lost (*naṣṭa*), to find out a lost variation when its serial number in the list is given
3. Mentioned (*uddiṣṭa*), to calculate the serial number in the list when a particular variation is mentioned
4. Short-[and-long]-calculation (*laghu-kriyā/ gala-kriyā*), to calculate the number of the variations in the list that have a given number of short or long syllables (for this purpose, a diagram called the Mount Meru-like spread (*meruprastāra*), equivalent to the so-called Pascal's triangle, is constructed)
5. Number (*saṃkhyā*), to calculate the number of all the variations in the list

6. Way (*adhvan/adhvayoga*), to calculate the space of writing materials required for writing down the list

A chapter on prosody in the *Nāṭyaśāstra* of Bharata (before AD 600), a dramaturgical work, and one in the *Agnipurāṇa* (ca. AD 800), a work on sacred traditions, also contain a section on these topics.

Four out of the six kinds of ascertainment, namely, spread, lost, mentioned, and number, were applied to the melody (combinations of seven notes) and the rhythm (combinations of a half, one, two, and three beats) in Indian music (Śārṅgadeva's *Śaṅgītaratnākara*, ca. AD 1250), for which a diagram called Partial Meru (*khaṇḍameru*) was employed. This was also the case with the combinations of five subcategories taken severally from five categories of “carelessness” (*pramāda*) when they contain different numbers of subcategories, in Jaina philosophy (Nemicandra's *Gommaṭasāra*, ca. AD 980).

Medical treatises such as the *Carakasamhitā* (ca. AD 100) and *Suśrutasamhitā* (ca. AD 200) treated combinations of the six basic tastes (*rasa*) and of the three humors (*doṣa*) of the body. Varāhamihira dealt with the problem of combinations of nine and sixteen basic perfumes in the *Brhatsamhitā* (ca. AD 550). He gave a simple method for obtaining ${}_nC_r$ in tabular form which is essentially the same as Pascal's triangle.

Indian mathematicians prior to Bhāskara, too, are known to have been interested in these problems of combinatorics. Brahmagupta devoted one whole chapter consisting of 19 (or 20) stanzas of his astronomical work, *Brāhmasphuṭa-siddhānta* (AD 628), for combinatorics related to Sanskrit prosody. The problem of tastes was taken up by the mathematician Śrīdhara in his *Pāṭīgaṇita* (ca. AD 750). Mahāvīra treated the six kinds of ascertainment of Sanskrit prosody as well as tastes in his mathematical treatise, *Gaṇitasārasaṃgraha* (ca. AD 850).

In addition to the traditional rule for combination mentioned above, Bhāskara gave six rules for permutations concerning sequences of numerical figures in a chapter called “nets of numbers” (*aṅkapāśa*) of his famous *Līlāvātī*. However, it is

Nārāyaṇa who for the first time treated various problems of permutation and combination, including the system of “spread-lost-mentioned,” of different areas systematically from the viewpoint of mathematics with the help of variously defined sequences of numerals. Chapter 13 entitled “nets of numbers” of his mathematical treatise, *Gaṇitakaumudī* (AD 1356), consists of about 100 stanzas for rules of combinatorics and 45 for examples.

See Also

- ▶ Bhaskara I
- ▶ Brahmagupta
- ▶ Mahāvīra
- ▶ Nārāyaṇa Paṇḍita
- ▶ Śrīdhara
- ▶ Varāhamihira

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Combinatorics in Islam

Ahmed Djebbar

Among the factors which influenced mathematics in Arab-Islamic civilization was a cultural life which fostered, particularly between the ninth and twelfth centuries, rich interaction between the different intellectual activities of the time.

Taken in a general sense as a study of configurations in one-, two-, or three-dimensional spaces, combinatory analysis had its beginnings in early studies in music, chemistry, astrology, and especially in metrics and Arabic linguistics. From the ninth century on combinatory processes asserted themselves in truly mathematical disciplines like algebra, astronomy, and trigonometry.

Combinatory Practices in Nonmathematical Fields

In music, many works contain a study of the combinations of sounds and rhythms, for example, the *Rasā'il* (Epistles) of the Ikhwān al-ṣafā' (Brethren of Purity, tenth century) and the *Kitāb al-mūsīqā al-kabīr* (Great Book on Music) of al-Fārābī (ninth century). In the field of chemistry, as early as the eighth century, ► [Jābir ibn Ḥayyān](#) introduced combinatory arguments in his theory of balance, which was based on the principle that everything is a combination of numbers. Jābir goes so far as to identify the language, i.e., the combination of words, in chemistry which he considers to be a morphology of metals.

In astronomical astrology, the conjunctions of the seven planets known at that time played an important role in predicting events. One needed to know the number of conjunctions which corresponded with the number of combinations of seven elements two times two, three times three...seven times seven. There was a great need to construct configurations by manipulating numbers or letters. Many mathematicians worked on this problem trying to invent processes of construction and new types of magic squares, for example, ► [Thābit ibn Qurra](#) (d. 901), Abū'l-Wafā' (d. 997), Ibn al-Haytham, ► [Ibn Mun'im](#) (d. 1228), and ► [Ibn al-Bannā'](#) (d. 1321).

In the field of Arabic poetry, it was al-Khalīl ibn Aḥmad (d. 791) who originated research on meter. He began by deriving a superficial structure of Arabic verse (which also serves for prose). Then he derived an underlying structure based on ten measures which, in combination, provided the five fundamental meters. In turn, these meters provided other meters to Arabic poetry thanks to a purely combinatory operation, circular permutation.

In the field of Arabic prose, there is even more interesting information about combinatory practices. As early as the eighth century, al-Khalīl undertook an analysis of the structures of the Arabic language and attempted to develop a theory based on the results of his investigations by studying the constitution of the roots of the

language from the 28 letters of the alphabet, and then the composition of words from those roots. To that end, he calculated combinations, without repetitions, of letters two by two, three by three, four by four, and five by five, in order to determine the numbers of roots of two to five letters in the language. The results of his calculations, without any explanation, appear in his book *Kitāb al-ʿayn*. After him, a long tradition was established in this field, but the combinatory aspects have not been systematically studied.

That being said, the examples cited above are really too sparse and isolated to prove any continuity in combinatory practices. In particular, we have not yet found anything which demonstrates the beginning of the mathematization of these combinatory practices in the Muslim East or in Andalusia before the twelfth century.

Combinatory Practices in Mathematics

Combinatory practices in the field of mathematics prior to the twelfth century were relatively modest and concerned only two disciplines, astronomy and algebra.

In astronomy, for example, there is the book of Thābit ibn Qurra, *Al-shakl al-Qaṭṭā'*, in which combinations occur, two by two, in six sizes occurring in the formula fixed for the secant figure. In his book, *Maqālīd 'ilm al-hay'a* (Keys to the Science of Astronomy), ► [al-Bīrūnī](#) also uses small combinatory results for the purpose of determining the unknown elements of a spheric triangle as a function of the known elements.

In algebra, there are two works which contain certain aspects of combinatorics. The first, the *Kitāb al-ṭarā'if fi'l-ḥisāb* (Book of Rare Things in the Art of Calculation) by ► [Abū Kāmil](#) (d. 930), deals with the resolution of certain systems of indeterminate equations, stated in the form of problems of birds, the aim being to enumerate, for each system, all the possible solutions. The second work is the *Kitāb al-Bāhir* by as-Samaw'al (d. 1175) on algebra, its objects and its instruments.

We have, as yet, no way of proving that these combinatory practices from within the

mathematical tradition gave rise to any real research in the field between the ninth and the twelfth centuries, and in instances where research did occur, we do not know the results. In any case, it was not the combinatory elements encountered in mathematical problems which inspired the mathematicians of the Maghreb who became involved in combinatorics. It was the tradition of linguistics and lexicography which was the basis of their research.

Ibn Mun 'im

The oldest mathematical work from the Maghreb which deals with combinatory problems is the *Fiqh al-ḥisāb* of ► Ibn Mun'im, a scholar originally from Andalusia, living in Marrakesh in the Almohad era. To our knowledge, his book was the first in the entire history of mathematics to have devoted a whole chapter to this type of problem and to have stated them and solved them according to a common procedure.

Combinatorics After the Thirteenth Century

In the second half of the thirteenth century or the beginning of the fourteenth, another Maghrebin mathematician, ► Ibn al-Bannā', took up some of the results of Ibn Mun'im in at least two of his works, the *Raf' al-ḥijāb* and the *Tanbīh al-albāb*. In the latter work, he notes only a table of combinations from Ibn Mun'im without giving exact references, but he explicitly lays claim to the demonstration of a result long attributed to Pascal (d. 1662) which gives C_n^p as a function of C_n^{p-1} , thus allowing the calculation of the combinations two times two, three times three, etc., of a certain number of objects, using the arithmetical formula:

$$C_n^p = \frac{n(n-1) \cdots (n-p+1)}{1 \cdot 2 \cdot 3 \cdots p \cdot (p-1)}$$

which today takes the form of

$$C_n^p = \frac{n!}{p!(n-p)!}$$

In the same spirit, he deduced the expression of arrangements without repetition of a certain number of objects, after having calculated the number of their permutations.

It is important to point out that, at the same time, in the East, the mathematician al-Fārisī (d. 1321) identified the values of the different combinations of the elements of the arithmetic triangle of ► al-Karājī and used them to establish a theorem of the theory of numbers such that one can determine the number of divisors belonging to a certain whole. Unfortunately, we do not know if this contribution of al-Fārisī spread throughout the East nor can we affirm that it was known in the Muslim West.

However that may be, we can discern two significant processes from Maghrebian writings after Ibn Mun'im. First, there occurred the extension of the field of application of formulas and of combinatory reasoning. This field was no longer concerned just with the elements of an alphabet, since that became an abstract model operating in different mathematical fields: in astronomy, with the reformulation and enumeration of compound ratios occurring in spheric trigonometry; in geometry, with the classification of figures and the enumeration of all the equations one can deduce; and finally in algebra, with the enumeration of systems of equations (the work of Ibn Haydūr (d. 1413) and of equations of a certain degree greater than three (the work of the Egyptian Ibn alMajdī, d. 1447, in his commentary on the *Talkhīṣ* (Summary) of Ibn al-Bannā').

In the second place, there was a taking account of enumeration in general, in very different fields not always related to mathematics. The most typical case is that of Ibn al-Bannā', who devoted part of his work *Tanbīh al-albāb* to these types of problems: the enumeration of different cases of possible inheritances when the heirs are n boys and p girls, the enumeration of prayers to be said according to the exigencies of Malekite ritual in order to compensate for having forgotten other prayers,

and the enumeration of all the possible readings of the same sentence according to the rules of Arabic grammar.

The presence of the same combinatory vocabulary in the works of different authors and the fact that none of them laid explicit claim to their results reinforces the characters of continuity of combinatory practices, a continuity made possible, probably, by the persistence of this new chapter in the teaching of certain professors of that time.

However, if to our eyes this new material and these new instruments seem objectively to be of a piece, we do not know to what degree those who contributed to their formulation were conscious of them or what importance they held in their eyes.

The reasons for this are to be found in several places at once: the state of the society itself and the nature of its activities and preoccupations which did not allow for the significant development of combinatorics; the absence of local or regional institutions responsible for renewing programs and imposing, and then perpetuating, the teaching of new ideas; and the imprint of certain specialists whose authority influenced at certain moments the content of scientific teaching, fixing it or simplifying (or deleting) certain theoretical developments and certain chapters. At least that is what ► *Ibn al-Bannā'* implies in his *Raf' al-ḥijāb* and what ► *Ibn Khaldūn* confirms in his *Muqaddima* (Prolegomena), writing about the abandonment of theoretical problems and the perpetration of a more utilitarian mathematics.

See Also

- [Algebra in Islamic Mathematics](#)
- [Al-Karajī](#)
- [Ibn al-Bannā'](#)
- [Ibn Khaldūn](#)
- [Ibn Mun'im](#)
- [Ikhwān al-Ṣafā'](#)
- [Magic Squares in China](#)
- [Number Theory in Islamic Mathematics](#)

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Comet and Meteorite Traditions of Aboriginal Australians

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Introduction

This research contributes to the disciplines of cultural astronomy (the academic study of how past and present cultures understand and utilise celestial objects and phenomena) and geom mythology (the study of geological events and the formation of geological features described in oral traditions).

Of the hundreds of distinct Aboriginal cultures of Australia, many have oral traditions rich in descriptions and explanations of comets, meteors, meteorites, airbursts, impact events, and impact craters. These views generally attribute these phenomena to spirits, death, and bad omens. There are also many traditions that describe the formation of meteorite craters as well as impact events that are not known to Western science.

Comets

Bright comets appear in the sky roughly once every 5 years. These celestial visitors were commonly seen as harbingers of death and disease by Aboriginal cultures of Australia. In an ordered and predictable cosmos, rare transient events were typically viewed negatively – a view shared by most cultures of the world (Hamacher & Norris, 2011). In some cases, the appearance of a comet would coincide with a battle, a disease outbreak, or a drought. The comet was then seen as the cause and attributed to the deeds of evil spirits. The Tanganekald people of South Australia (SA) believed comets were omens of sickness and death and were met with great fear. The Gunditjmarra people of western Victoria (VIC) similarly believed the comet to be an omen that many people would die. The coincidence of a comet and a drought led the Euahlayi people of New South Wales (NSW) to believe comets were evil spirits that sucked the water from clouds, causing the drought. The tail of the comet was a large family that consumed the water from the river.

Other Aboriginal groups gave significance to the tail of a comet resembling smoke. Aboriginal communities of the Talbot district (VIC), Cape York (QLD), and Bentinck Island in the Gulf of Carpentaria (QLD) made this association – one shared with the Maori of Aotearoa (New Zealand). Groups in the Central Desert of the Northern Territory (NT) believed comets represented celestial spears thrown by spirits or ancestors in the sky, including the Pitjantjatjara, Kaitish, Luritja, and Arrernte.

Meteors

Views of meteors across Aboriginal cultures are many and diverse, but most relate to death and evil spirits (Hamacher, 2011; Hamacher & Norris, 2010). A frequent interpretation is that meteors were the spirits of the recently deceased. In Wardaman traditions (near Katherine, NT), when a person dies, his spirit ascends into the sky and passes through the star *Garrndarin*

(Spica), becoming a star of its own. It was looked after by the Rock-Cod star *Munin* (Arcturus) before falling back to Earth as a meteor. The star-spirit fell into a stream, where the earthly Rock-Cod looked after it again. The spirit then pursued a potential mother and entered her to be reincarnated as a baby.

Across northern Australia, meteors are seen as the fiery eyes of celestial serpents (sometimes called the Rainbow Serpent). The Tiwi people of Bathurst and Melville islands north of Darwin, NT, see meteors as the *Papinjuwari* – evil spirits with long claws that steal the hearts of babies. In the Yolngu traditions of Arnhem Land (NT), a similar spirit is called *Namorrordo*, and in Lardil traditions of Mornington Island (QLD), it is called *Thuwathu*.

Meteor traditions also involved war. Aboriginal groups in northern QLD followed the trails of meteors, believing the falling stars would lead them to enemy warriors. The Ngarigo people of NSW believed a meteor pointed to the direction of a group preparing for war. The Wathi-Wathi people of the Murray River region in VIC perceived meteors as the path of a *nulla-nulla* (a short spear) in the sky. Similarly, Arrernte revenge rituals in the Central Desert (NT) involved throwing a small spear filled with evil magic in the direction of the intended target. If a meteor appeared, it signified the death of the person.

Impact Events

Oral traditions of Aboriginal groups across Australia describe fiery stars falling from the sky with a roar, striking the land and causing death and destruction. All of these accounts, except for Henbury (described below), do not coincide with impact sites known to Western science (Hamacher & Norris, 2009).

The Weilan people of north central NSW tell of a large star that fell to Earth, lighting up all of the surrounding land. A similar story is recounted from the Aboriginal people of Wilcannia in northwestern NSW who describe a large fiery star that rumbled and smoked as it fell from the

sky, crashing into the ground in the Darling riverbed northeast of Wilcannia at a place called *Purli Ngaangkaliitji*. A deluge followed the impact. It is not certain if these stories are related, but no known impact sites are located in NSW.

Yuin traditions from the Shoalhaven region near Nowra, NSW (south of Sydney), describe an impacting meteor shower and airburst. In the story, the sky heaved and many stars fell to the Earth, flashing in the sky. A large reddish mass burst in the air, causing a deafening roar and scattering debris across the region, leaving burnt holes in the ground. A Gurudara story from east of Darwin, NT, tells how a bright star named *Nyimibili* fell from the sky onto the camp near the Wildman River, burning all of the grass and trees.

Some published research suggests that impact rates are higher than currently predicted by scientists and that large impacts in the ocean have occurred in recent times (<1,000 years), causing huge tsunamis to strike coastal Australia and New Zealand. These claims are circumstantial and have been refuted, but remain a controversial topic in modern studies of cultural astronomy and geomorphology.

Meteorite Craters

Aboriginal people have oral traditions that relate to the Gosses Bluff crater (NT), Liverpool crater (NT), Wolfe Creek crater (WA), and the Henbury crater field (NT) (Hamacher & Goldsmith, 2013). The Liverpool crater, which is 1.6 km wide and formed over 500 million years ago, is called *Yingundji* in the Kunwinjku language of eastern Arnhem Land. It is believed to be the nest of a giant catfish, and rock art depicting catfish was found in caves along the crater wall.

The Wolfe Creek crater, located in the eastern Kimberley region of WA, was formed 300,000 years ago and is 900 m wide. It is called *Kandimalal* in the local Jaru language, and there are several stories about how the crater formed (Goldsmith, 2000). These include a being that was digging for yams, a Rainbow Serpent emerging from the ground, and a star falling to the

Earth. Some traditions seem to have incorporated the views from Western scientists working in the area, as attested by an Elder who claimed the star story was “white man’s story” (Reeves-Sanday, 2007).

Gosses Bluff crater, west of Alice Springs (NT), is 22 km wide and heavily eroded, having formed about 142 Ma ago. What remains is a ring-shaped mountain range, 5 km in diameter and 150 m in height. The Western Arrernte people call it *Tnorala*. In Arrernte traditions, a group of eight women were going to look for the form of stars to have a ceremony in the Milky Way. One of the women set her baby in a wooden basket called a *turna*. As she danced in the ceremony with the other women, the baby rolled off the Milky Way and fell to the Earth. The impact of the baby and the *turna* drove the rocks upward, creating the ring-shaped mountain range. The *turna* can be seen in the sky as the constellation Corona Australis (the Southern Crown). The baby’s parents - the morning star and evening star - continue to search for their baby.

One of the youngest impact sites in Australia is the Henbury crater field, south of Alice Springs. It formed when a meteoroid broke apart in the atmosphere and created 13 craters covering a square kilometer. The impact occurred <4,700 years ago and was probably witnessed by Aboriginal people. Oral traditions collected in the 1930s describe the crater field as a place where a fire devil came from the sun and ran down to the Earth, forming the craters. The spirit burned and ate the people for breaking sacred laws. Aboriginal people would not collect water that pooled in the craters for fear the fire devil would fill them with iron.

Meteorites

Some Aboriginal people used meteorites as axe heads, which were generally viewed with reverence as sacred objects. Aboriginal people were “deadly afraid” of meteorites from the Tenham meteorite fall of 1879 in western QLD. There is evidence of Aboriginal people transporting meteorites long distances, but the reasons for this are

not known (Bevan & Bindon, 1996). In the early twentieth century, interest in meteorites by white Australians prompted Aboriginal people to collect meteorites and tektites for sale to interested parties. Tektites were commonly used as surgical tools and ritual implements (Baker, 1957; Edwards, 1966).

Conclusion and Future Directions

Aboriginal Australians have complex and varying perceptions and traditions regarding comets, meteors, meteorites, and impact events across Australia. New research is identifying additional oral traditions about these phenomena and ways in which these phenomena were represented in ceremony and sacred law, which contributes to the growing body of knowledge about Aboriginal astronomical traditions. These traditions may benefit the field of geom mythology by leading scientists to impact sites and meteorite falls that are currently unknown to Western science. This research is now expanding to the Melanesian islander cultures of the Torres Strait (who are indigenous to Australia) that have many traditions, ceremonial dances, and songs related to comets and meteors.

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Comets and Meteors in the Islamic World

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The Muslim records on the appearance of comets during the premodern period are fairly extensive, but they are scattered throughout the entirety of Arabic and Farsi literature rather than localized. There is no unified term for comets during the premodern period: names such as *najm dhū dhū'aba/dhūa'ib* (a star with locks of hair), *najm dhū dhanab* (a star with a tail), or the same combinations with *kawkab* (planetary body) are interchangeable inside the literature. Eventually in Arabic, *najm* came to mean “a fixed star” while *kawkab* “a planetary body” but there are plenty of exceptions to this rule.

In general, the appearance of comets was a disturbing event, and they were usually considered signs of the end of the world. As such, comets were often ignored in standard astronomical treatises since they did not conform to the Ptolemaic patterns of fixed and moving stars (planets). However, unlike in other cultures, there is no evidence that the appearance of comets in the Muslim world actually caused any sort of apocalyptic movement or triggered any form of social disturbance. Materials concerning the sighting of comets are easily divided into several groups:

1. The earliest period of Islam (630–750): Most of the sightings from this period are recorded in Christian chronographies (frequently associated with the astronomer Theophilus of

- Edessa [d. 785]) or are associated with the deaths of the major Muslim figures from this period and are therefore questionable in their historicity.
2. High Islamic period (750–1250): There are extensive and frequently detailed descriptions of comets from this period. Although one cannot say that the Muslim material is as extensive as that of the Chinese from the same period, when one gathers together all of the comet sightings, most of the major comets are attested.
 3. Late Islamic Period (1250–1811): Comet sightings continue after the Mongol invasions in Persian, Ottoman, and late Arabic histories. However, these sightings are few and far between and usually have nothing of the detail contained in the high Islamic period sightings. The latest comet sightings recorded are from 1811.

Gary Kronk in his *Cometography* (1999) has stressed the importance of the Arabic-language materials for the study of historical comets as these sightings are often unique outside of the Chinese sightings, most especially for the period 750–1000 when attestations in European sources are weak. However, one major difference should be noted between the Chinese and Arabic materials: in the vast majority of cases, the Arabic materials are anonymous and do not give us any sense of who made the sighting, where it was made, and more often than not, when it was made. These problems make correlating the sightings problematic. Kronk notes that when the dates of comet sightings can be checked against the Chinese, the Arabic sightings are usually slightly earlier (Cook, 132, personal communication). We must assume, therefore, that the sightings are not necessarily those of astronomers, but were based upon local and popular sources.

Religious Beliefs About Comets and Meteors

Comets are not mentioned in the Qurʾān, although perhaps they are alluded to in Q 53:1,

81: 1–2, and 82:1–2. Beliefs concerning the importance of comets could be either positive or negative. For example, Jalal al-Din al-Suyūfī (d. 1505) includes the tradition ascribed to the Prophet Muhammad: “When the star (*najm*) rises, then malady will be lifted from every land” (al-Suyūfī 21 [no. 49]). However, al-Baghdādī [d. 1071] 27 notes that this could be the Pleiades. He also includes a longer apocalyptic tradition as a conversation between Ibn ʿAbbās [d. 658], the forefather of the ʿAbbasid Dynasty, and Ibn Abī Malika, in which the former said to the latter: “I did not sleep last night.” The latter said, “Why?” Ibn Abī Malika answered “They have said that the star with a tail (*kawkab dhū dhanab*) has risen, and I feared that the Smoke [of the Judgment, Q 54:1] would come by night” (al-Suyūfī 21 [no. 50]). Comets are usually listed as part of the signs of the end of the world.

Popular beliefs associated shooting stars with the nonhuman jinn (Q 72:8–9) and held that the flameouts of the stars were caused by jinn’s attempts to penetrate the heavens and being repelled by God. Traditionally, the jinn would use the shooting stars and meteors to listen into the events transpiring in heaven. The appearance of comets was often mixed in with these beliefs, being seen as more powerful and enduring than shooting stars. Astrologers and other mystics utilized materials supposedly from either Daniel or Enoch (Idris) and sought to make predictions based upon the zodiac signs in which a comet could appear (al-ʿAskari, n.d., pseudo-Idris, 53–55). However, because of their unpredictability, comets do not often appear in astrological materials.

Astronomical Explanations of Comets

Muslim Arabic-language astronomical explanations of the appearance of comets relied heavily upon classical and late-antiquity Greek interpretations of their function. In general comets were considered to be a phenomenon of the sublunar region and should not be associated with the unchanging celestial region (Ragep, ii, 384, citing al-Ṭūsī; also al-Khwārizmī 195).

Later, the well-known philosopher and Aristotelian Ibn Rushd (Averroes) (d. 1198) detailed the positions of a number of Greek philosophers and astronomers in his *Talkhīṣ*, and after refuting the idea that comets could only appear from the north through his personal observation states:

Comets (*kawakib dhū wat al-dhua'ib*) in their totality are among the planets (*kawakib*) which are part of the heavenly body, nor are their locks just a phase of the moon because of the dampness, as it proceeds that the comets are possessed of a fiery nature—both the comets and their locks together. This is because when this fire is an accident, not close to any of the planets (*al-kawakib al-sayyara*). If the locks were composed of a phase of the moon accidental from the light of the planets close by or from the vapor close by burning, then the light of the planets would connect to the light of this vapor, and it would seem elongated. But the locks which are burning smoke do not reach the planets, even though they seem to because the light of the planets is connected with the light of this vapor, and thus it seems as if it is one elongated light. (Ibn Rushd [47–48, no. 43])

Ibn Rushd's general conclusion, therefore, is that comets are similar to shooting stars, but that they are comprised of the phases of the moon together with burning vapor. Much more detail can be found in Heidarzadeh (2008, pp. 28–31), who summarizes a wide range of Islamic materials and places them within their classical context.

Descriptions of Comets and Meteors

The historical material concerning comets begins in 760 with the (probable) sighting of Halley's Comet during that year (Nu'aym 132). There are several sightings of a questionable nature prior to 760 to mark the deaths of prominent figures (Muḥammad [d. 632]; Abū Bakr, first caliph [632–634]; and others), but from 760 onward until the Mongol invasions (1256–1261) the cumulative Arabic-language historical record has approximately 85 sightings of comets. Most of this material is to be found in the large chronographic histories of Ibn al-Athir (d. 1232) and Ibn

al-Jawzi (d. 1200). An example of these sightings, from 1066, will suffice:

In the first tenth of Jumada I [31 Mar.–9 Apr.] a star appeared with long locks of hair in the direction of the east. Its length was six degrees (*dhira'*), while it was spread across the center of the sky. It stayed until the seventeenth of the month [16 April], and then disappeared and then again at the end of the month, at the setting of the sun, a star appeared whose light revolved around it like that of the moon. People were frightened and were very disturbed. When the night grew dark, it had many locks of hair to the south, and it stayed ten days and then disappeared. (Cook 144, no. 69)

This is most probably the appearance of Halley's Comet in 1066, an appearance corroborated by another sighting in the *History of the Patriarchs of the Egyptian Church* (in Arabic).

Alongside the historical comet sightings, there are approximately 50 records of meteors, either in showers visible in the heavens or as meteorites striking the earth. Usually the latter are described in formulaic terms: “[in 918–919] A huge star fell and its light was very strong, it was great and broke up into three pieces. At that point a sound like that of loud thunder when it fell, but there were no clouds in the sky” (Cook 139 [no. 30]). Mention of shooting stars or meteors after the Mongol invasions are comparatively rare and persist mostly in the Yemeni chronicles.

Records of comets and astronomical phenomena drop dramatically after the Mongol invasions, and although they never completely disappear, they become perfunctory. Persian and Ottoman chroniclers infrequently note the appearance of comets (e.g., the comet of 1618–1619 is recorded by the Ottoman chronicler Naima: “There appeared one evening in the heavens a bright pillar or column which shone like a comet, the appearance of which occasioned among the people a variety of conjectures” (trans. Fraser 464)). Comet descriptions are especially frequent in the more outlying regions of the Muslim world, for example, Yemeni chronicles, such as that of Ibn al-Qasim (750–806), are especially rich in comet sightings for the period of the 1600s and 1700s as are those from Western Africa (such as Timbuktu).

The last significant notes of comets in the Arabic historical literature are from 1811, one from the last of the medieval chronographers, al-Jabarti (d. 1822): "During this month a comet appeared in the north between Ursa Minor and Ursa Major, its head in the west and its long lance-like tail climbing to the east. It was visible every night. The people watched it, talked about it, and questioned the astrologers about it. They speculated about its portent and what bloody battles it foretold. It was visible for about 3 months, diminishing somewhat in size. It went off toward the south near Aquila" (Jabarti in Philipp and Perlmann, iv, 189).

It is analogous to the record of Haydar al-Shihabi (d. 1835?) in Lebanon for the same year: "During this year a star with a tail appeared in the heavens, and the first part of its appearance was on the 4th [no month noted] and it continued to appear every day just before the morning in the area of Ursa Minor, and stayed until the end of the summer, and then disappeared and did not leave any trace which would point to its appearance" (Shihabi, 573).

Additionally, comet sightings are to be found in the apocalyptic literature from the period of Nu'aym b. Hammad al-Marwazi (d. 842), who mentions the passing of Halley's Comet in 760 (Nu'aym 132-3) and alludes to several other datable comets. In general, comets in the apocalyptic literature are seen as a sign of the end of the world, but after these initial prophecies, most of the material is too general to be dated.

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Compass

Julian A. Smith

The origin of the magnetic compass is obscure. Medieval and Renaissance European compasses have been analyzed in detail, but until recently

little work has been done on their history in non-Western cultures. Most modern accounts place the birth of the magnetic compass in ancient China, but its inventors are unknown, its development unclear, and historians are divided over whether its later appearance in the West was independent, or borrowed from China through overland or Arabic maritime intermediaries.

The Chinese compass seems to have been derived from a “south controlling spoon” (*si nan shao*) carved from lodestone (magnetite) and used in the early diviners’ boards the Han Dynasty (202 BCE–AD 220). Just as in ancient Greece, Chinese philosophers were first aware of magnetic attraction; the ability of the lodestone to pick up iron was mentioned in the *Lü Shi Chun Qiu* (Master Lu’s Spring and Autumn Annals, third century BCE), the *Lun Heng* (Discourses Weighed in the Balance, AD 83), and a host of other Chinese annals between the third century BCE and the sixth century AD. The discovery of magnetic directivity (the tendency of magnets to point north and south) made the lodestone particularly important in geomancy and divination. Historian Joseph Needham argued that this was known publicly by the first century AD, and may have been a secret of court magicians as early as the second century BCE.

Between the first and sixth centuries AD, Chinese scholars discovered that magnetic directivity could be induced in small iron needles by stroking them on lodestones. These needles, when floated in bowls of water (sometimes hidden inside carved wooden fish), would then guide Chinese navigators by pointing to the north and south; these early “wet compasses” were the first type. The second variety, a “dry compass” consisting of a needle mounted on a pivot (often concealed inside a wooden turtle), was developed much later (early twelfth century). Chinese encyclopaedias such as the *Taiping Yulan* (Taiping Reign-Period Imperial Encyclopaedia) also mention “dry” compasses made by suspending a magnetic needle on a silk thread.

Chinese physicists may also have been first in discovering magnetic declination. The fact that

the compass does not point exactly to the geographic north, but rather to the magnetic north a few degrees away, was mentioned in philosopher Shen Gua’s *Meng Qi Bi Than* (Dream Pool Essays) in 1088 AD. He says the compass needle “always inclines slightly to the east.” Knowledge of this effect was extremely important for ocean navigation. Chinese knowledge of declination goes back to the late Tang period (eighth–ninth centuries AD).

The development of the magnetic compass in India is highly uncertain. According to some scholars, the compass is mentioned in fourth century AD Tamil nautical books; moreover, its early name of *maccha-yantra* (fish machine) suggests a possible Chinese origin. In its Indian form, the wet compass often consisted of a fish-shaped magnet, floated in a bowl filled with oil.

The earliest references to the magnetic compass in Europe appear in the grammatical and philosophical treatises *De Nominibus Utensilium* and *De Naturis Rerum* of English monk Alexander Neckam (1157–1217), French poet Guyot de Provins’ (fl. 1184–1210) *La Bible*, and the *Historia Orientalis seu Hierosolymitana* of French preacher Jacques de Vitry (ca. 1165–1240). Based on these sources, historians have dated the European appearance of both dry and wet compasses to the middle of the twelfth century.

Among Arabic sources, the earliest descriptions of the magnetic compass occur in the thirteenth century. A Persian collection of stories, the *Jāmi‘ al-Ḥikāyāt* (ca. 1232) of Muḥammad al-‘Awfī says that sailors navigate using a piece of iron rubbed by a magnet, and the 1282 lapidary of Bailak al-Qabajaqi, the *Kanz al-Tijar*, mentions a wet compass seen in 1242. Some of these early treatises discuss the use of fish-shaped compass needles among Islamic navigators in the Indian Ocean, suggesting a possible borrowing from Indian sailors; but it is also possible that Arabs got the compass from Europeans (scholars arguing this hypothesis often point out the Arabic word for compass, *al-kunbas*, appears to come from Italian roots). Much more research needs to be done before this argument can be settled.

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Computation: Chinese Counting Rods

Lam Lay Yong

The basic questions in the study of arithmetic in any civilization are: how did the people add, subtract, multiply, and divide, and what were the notations and media that were used to perform these operations.

The ancient Chinese used ► [bamboo](#) sticks or animal bones to count. The first five numbers were tallies in the following form:

| || ||| |||| |||||

The representations for six, seven, eight, and nine were as follows:

┐ ┌┐ ┌┌┐ ┌┌┌┐

The horizontal rod represented the quantity five.

It is easy to imagine how these rod numerals were handled for the addition or subtraction of small numbers such as two plus five or nine minus two. In the case of the addition of, for example, six and seven, the three vertical rods were grouped together and the two horizontal rods representing two fives were replaced by a single

rod positioned horizontally to the left of the three vertical rods. The sum, 13, was expressed in the following form:

— |||

In this manner, a place value notation was created; the tens' place was to the left of the units' place. The nine numerals that could occupy this place were similar in idea to the nine numerals shown above but had a significant difference: the vertical rods were turned into horizontal ones and the horizontal rods were turned into vertical ones. They were of the following form:

— = ≡ ≡≡ ≡≡≡ ⊥ ⊥⊥ ⊥⊥⊥ ⊥⊥⊥⊥

The notion of place values was then extended to express larger numbers. The first set of nine numerals occupied positions whose place values were units, hundreds, ten thousands, and so forth; the second set of nine numerals occupied positions whose place values were tens, thousands, hundred thousands, and so on. For example, the rod numeral for 36,187 appeared as

||| ⊥ | ⊥⊥⊥ ⊥

and the rod numeral for 30,187 appeared as

||| | ⊥⊥⊥ ⊥

which revealed that the thousands' place was empty.

Any number, however large, thus could be represented by the rod numeral system, which used a place value notation with ten as base. The rod numeral system was essentially a computing mechanism; the results of the calculation were recorded in the written numbers.

The rods were used for reckoning in the fifth century BCE. According to *Qian Han shu* (Standard History of the Western Han Dynasty), they were cylindrical bamboo sticks, 0.1 *cun* (approximately 0.231 cm) in diameter and 6 *cun* long. They were carried in a hexagonal bundle made up of 271 pieces. Computation was

performed on a flat surface such as a table or a mat. By the sixth century AD, the rods were shorter in length and square in cross-section. During the Tang Dynasty (AD 618–907), it was quite common for officials, astronomers, engineers, mathematicians, and others to carry their bundles of rods wherever they went. Besides animal bones and wood, the rods could be carved from horn, ivory, or jade.

► *Sun Zi suanjing* (The Mathematical Classic of Sun Zi) written around AD 400 is the earliest existing work to have a description of the rod numerals. It also gives detailed descriptions of how multiplication and division were performed. The step-by-step procedures are the same as the earliest known methods of multiplication and division using Hindu-Arabic numerals, which were described by Muḥammad ibn Mūsā ► *al-Khwārizmī* in his book on arithmetic and by Abū al-Ḥasan Aḥmad ibn Ibrāhīm ► *al-Uqlīdisī* in *Kitāb al-Fuṣul fī al-Ḥisāb al-Hindī*. This fact together with other evidence supports the thesis that the Hindu-Arabic numeral system has its origins in the Chinese rod numeral system.

Just as the Hindu-Arabic numeral system provided the mainstay and impetus for the growth and development of our arithmetic and algebra, the rod numeral system provided the same support for the development of mathematics in ancient and medieval China.

The process of division with rod numerals resulted in an important notation for the expression of a fraction. For example, the notation for four-fifths is



This is the same as the notation for the common fraction in Hindu-Arabic numerals which also originated from the earliest method of division with numerals. The use of this notation enabled an extensive study on operations with fractions – a subject with which other ancient civilizations had difficulties that were frequently insurmountable.

With the concept of the rod numeral system ingrained in their minds and using the rods as the

medium of expression, the ancient Chinese developed arithmetic and algebra. The problems in *Jiu zhang suan shu* (Nine Chapters on the Mathematical Art) (ca. AD 100) show that they were able to solve problems involving fractions, the Rule of Three, proportion, areas and volumes, square roots and cube roots, the Rule of False Position, sets of simultaneous linear equations, and negative numbers.

For numerous centuries the rod numeral system played a dual role: in calculation and in the development of mathematics. It aided the progress of the Chinese civilization till the Ming Dynasty (1368–1644) when it was gradually replaced by the abacus as an instrument for computation. Mathematics flourished from the firm foundation depicted in *Jiu zhang suan shu* and reached its peak in the thirteenth century. When the rod numerals became outmoded and fell into disuse, mathematics also underwent its period of decline and transition.

See Also

- [Abacus](#)
- [Algebra in China](#)
- [al-Khwārizmī](#)
- [Al-Uqlīdisī](#)
- [Shushu Jiuzhang](#)
- [Sun Zi](#)

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Computing Science in Ancient India

Subhash Kak

India's romance with numbers can be seen in the mention of large numbers up to 10^{19} in the Black Yajurveda. The sources for mathematical computing in India in the early phase are the Vedic books including the Brāhmana texts, the *Śulbasūtras* (texts on altar geometry), *Jyotisha* (astronomy), the *Chandahśāstra* (Pingala's book on prosody), Pānini's grammar, the *Nāṭya Śāstra* (Bharata Muni's text on music, drama, and dance), and nonmathematical texts such as the *Mahābhārata* and diverse *śāstras* (scientific and philosophical texts).

The Indian approach to the world was classificatory and computational. In astronomy, an attempt was made to reconcile the motions of the sun, the moon, and the planets that required periodic corrections. In grammar, the most economical rules for different constructions were sought. Not only the sign for zero, but also the binary number system, infinity and its operations, the ideas of metarules, algebraic transformation, recursion, hashing, mathematical logic, formal grammars, and high level language description arose first in India.

The *Śulbasūtras*

The *Śulbasūtras* belong to the *Vedāngas*, or supplementary texts of the Vedas that deal with construction of geometric altars. Their contents, written in the condensed *sūtra* style, cover geometrical propositions and problems related to rectilinear figures and their combinations and transformations, squaring the circle, as well as arithmetical and algebraic solutions to these problems. The root *śulb* means measurement, and the word *śulba* means a cord, rope, or string.

The extant *Śulbasūtras* belong to the schools of the Yajurveda. The most important *Śulba* texts are the ones by ► [Baudhāyana](#), Āpastamba, Kātyāyana, and Mānava. They have been generally assigned to the period 800–500 BCE of which Baudhāyana's text is the oldest. Baudhāyana begins with units of linear measurement and then presents the geometry of rectilinear figures, triangles, and circles, and their transformations from one type to another using differences and combinations of areas. Approximations to the square root of 2 and to π are given next.

In the methods of constructing squares and rectangles, several examples of Pythagorean triples are provided. It is clear from the constructions that both the algebraic and the geometric aspects of what we call the Pythagorean theorem were known. Several geometric constructions in these texts are based on algebraic solutions of simultaneous equations of linear and quadratic types. It appears that geometric techniques were often used to solve algebraic problems.

Jyotisha

Recent researches have established that the altar geometry of the *Śulbas* was used to represent astronomical facts related to the knowledge of the lunar and the solar years. The solution to these problems involved solution to indeterminate linear equations. Lagadha's *Vedānga Jyotisha* (1300 BCE), a book on the motions of the sun and the moon, presupposes knowledge of such equations.

Pāṇini's Grammar

Pāṇini's *Ashtādhyāyī*, "The Eight Chapters" (fifth century BCE), provides 4,000 rules that describe the Sanskrit of his day completely. The great variety of linguistic ideas used in the text mirrors the complexity of cognitive relationships that is the secret of its power and success. It is remarkable that Pāṇini set out to describe the entire grammar in terms of a finite number of rules. Scholars have shown that the grammar of Pāṇini represents a universal grammatical and computing system.

The *Ashtādhyāyī* ostensibly deals with the Sanskrit language. However, it presents the framework for a universal grammar that can apply to any language. Two important early commentaries on this grammar are by Kātyāyana and Patanjali. Bhartrihari examined its philosophical basis in an important work in the fifth century AD.

Pāṇini's grammar begins with metarules, or rules about rules using a special technical language, or metalanguage. Several sections follow on how to generate words and sentences starting from roots, as well as rules on transformation of structure. The last part of the grammar is a one-directional string of rules, where a given rule in the sequence ignores all rules that follow. Pāṇini also uses recursion by allowing elements of earlier rules to recur in later rules. This anticipates in form and spirit by more than 2,500 years the idea of a computer program.

In Pāṇini's system, a finite set of rules is enough to generate an infinity of sentences. The algebraic structure of Pāṇini's rules was not appreciated in the West until about 50 years ago when Noam Chomsky proposed a similar generative structure. Before this, in the nineteenth century, Pāṇini's analysis of roots and suffixes and his recognition of ablaut led to the founding of the subjects of comparative and historical linguistics.

Pāṇini took the idea of action as defined by the verb and developed a comprehensive theory by providing a context for action in terms of its relations to agents and situations. This theory is called the *kāraka* theory. These *kārakas* are:

1. That which is fixed when departure takes place
2. The recipient of the object

3. The instrument, or the main cause of the effect
4. The basis, or location
5. What the agent seeks to attain, deed, object
6. The agent

These *kārakas* do not always correspond to the nature of action; therefore, the *kāraka* theory is only a *via media* between grammar and reality. It is general enough to subsume a large number of cases, and where not directly applicable, the essence of the action/transaction can still be cast in the *kāraka* mold. To do this, Pāṇini requires that the intent of the speaker be considered. Rather than a structure based on conventions regarding how to string together words, Pāṇini's system is based on meaning.

Chhandahśāstra and Nāṭya Śāstra

The *Chhandahśāstra* of Pingala (400 BCE according to tradition) describes the binary number system. The idea of mathematical zero is also implicit in some of Pāṇini's rules. The *Nāṭya Śāstra* presents important results on permutations and combinations. Further results are to be found in later books on musicology such as the *Bṛhaddeśi* and the *Sangīta-Ratnākara*.

The Siddhāntic Age

► **Āryabhaṭa** (born 476) presented the first general solution to the linear indeterminate equation using the method of *kuttaka*.

► **Brahmagupta** (seventh century) solved the quadratic indeterminate equation $Nx^2 + 1 = y^2$. Brahmagupta's expressions for the diagonals of a cyclid quadrilateral are considered most extraordinary.

Virahāṅka (eighth century) gave an explicit rule for what we call the Fibonacci sequence. Vīrasena (ninth century) knew the logarithm to base 2 and its properties. Jayadeva of the same period developed the *chakravāla* (cyclic) method which, according to Hankel, is the "finest thing achieved in the theory of numbers before Lagrange (eighteenth century)." Bhāskara (born 1114) made further advances to trigonometry and analysis.

Navya Nyāya

Navya Nyāya (New Logic) began in Mithila under the leadership of Gangeśa Upādhyāya (twelfth century). The scholars of this school developed an elaborate technical vocabulary and logical apparatus that came to be used by philosophers and writers on law, poetics, aesthetics, and ritualistic liturgy. In their technique of analyzing knowledge, judgmental knowledge was analyzed into three kinds of epistemological entities in their interrelations: “qualifiers”; “qualificandum,” or that which must be qualified; and “relatedness.” Further abstract entities used were qualierness, qualificandumness, and relatedness. The knowledge expressed by the judgment “This is a blue pot” may then be analyzed into the following form:

The knowledge that has a qualificandumness in what is denoted by ‘this’ is conditioned by a qualierness in blue and also conditioned by another qualierness in potness.

At its zenith during the time of Raghunātha (1475–1550), this school developed a methodology for a precise semantic analysis of language. Its formulations are equivalent to mathematical logic.

Kerala Mathematicians

The Kerala school of mathematics flourished during 1200–1600 in South India. One of its great figures, Mādhava (ca. 1340–1425), also provided methods to estimate the motions of the planets. He gave power series expansions for trigonometric functions, and for π correct to 11 decimal places.

A very prolific scholar who wrote several books on astronomy, Nīlakanṭha (ca. 1444–1545), found the correct formulation for the equation of the center of the planets and his model is nearly a true heliocentric model of the solar system. In it, the planets go in eccentric orbits around the mean Sun, which in turn goes

around the Earth. He also improved upon the power series techniques of Mādhava.

These mathematicians made truly fundamental advances in analysis including infinite series and calculus. Almeida and his collaborators have suggested that Jesuit missionaries brought this work to Europe and it may have provided the spark for the European mathematical revolution.

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Conics

Jan P. Hogendijk

The theory of conic sections was discovered in Greece around 350 BCE. The most comprehensive ancient treatise on the subject was the *Conics* of Apollonius of Perga (fl. ca. 200 BCE). This treatise consisted of eight Books, of which only the first four have come down to us in Greek. Apollonius considered an arbitrary cone with a circular base, whose apex is an arbitrary point not in the plane of the base. He obtained the conic sections as intersections of this cone by a plane not through the apex. Apollonius distinguished three types of conic sections: the ellipse, the parabola, and the hyperbola.

The story of the translation of the *Conics* into Arabic is interesting, because it shows the difficulty of translating a technical mathematical text. The first Arabic geometers with an interest in the *Conics* were the three ► **Banū Mūsā** (“sons of Mūsā,” fl. ca. AD 830). At first they possessed only one poor Greek manuscript, containing the first seven Books, and they were unable to understand the very technical contents. Then one of the brothers, al-Ḥasan, decided to develop the theory of the ellipse as the intersection of a cylinder and a plane. He believed that the cylinder was easier than the cone, and he hoped that the theory might be more accessible this way. Al-Ḥasan wrote a book on his discoveries, entitled *Al-shakl al-mudawwar al-mustaṭīl* (The Rounded Elongated Figure). This work is lost.

After the death of al-Ḥasan, his brother Aḥmad obtained a second manuscript of the first four Books of the *Conics* in Syria, together with the commentary of Eutocius of Ascalon (ca. AD 500). This manuscript was much better than the other one, and with the help of the book of his deceased brother, Aḥmad was able to make sense of the contents of the Greek text. He then inserted

cross-references in the Greek in order to make the text more comprehensible. Now that he understood the first four Books, Aḥmad was able to make sense of Books V–VII on the basis of the other manuscript. He then had the Books translated: Books I–IV by Hilāl al-Ḥimṣī, Books V–VII by ► **Thābit ibn Qurra**. Aḥmad supervised and corrected the translation. Thus Aḥmad ibn Mūsā and Thābit rescued one of the most interesting mathematical works of antiquity, namely Books V–VII of the *Conics*. Book VIII of the *Conics* seems to have been lost altogether. It was reconstructed around 1000 by Ibn al-Haytham, and around 1700 by Edmund Halley.

By the ninth century, geometers in the Arabic tradition had already written treatises on conic sections. Thābit ibn Qurra authored a work on plane sections of a cylinder, which is extant. A popular subject was the determination of the surface areas of segments of conic sections and the volumes of solids obtained by revolving a segment of a conic section about one line (such as the axis or the base). The Arabic geometers knew that Archimedes had solved this problem for the parabola, but they did not know his method of solution. The treatises on this subject by Thābit ibn Qurra, and by the tenth-century mathematicians al-Qūhī and Ibn al-Haytham, are among the highlights of Arabic mathematics.

The Arabic geometers applied conic sections in the solution of a group of problems (trisection of the angle, construction of two mean proportionals, construction of the regular heptagon, etc.) which could not be solved by means of ruler and compass. In the tenth century AD, most geometers in Iraq and Iran considered straight lines, circles, and conic sections the only legitimate means of construction in geometry. The reason was that these objects belonged to fixed (immovable) geometry (*al-handasa al-thābita*), whereas all other curves and instruments were believed to be created by motions and instruments, which did not belong to mathematics but to mechanics.

Conics were also used in the solution of the “Problem of Alhazen” (named after al-Ḥasan ibn

al-Haytham, mentioned above). In this problem, the positions of the eye, the object, and a convex or concave spherical, cylindrical, or conical mirror are given. One asks for the points of the mirror at which the object is reflected to the eye. Ibn al-Haytham constructed these points of reflection, and he showed that the object is reflected at no more than four points on the mirror. His solution is very intelligent but also extremely complicated, and several seventeenth-century European mathematicians complained about its difficulty. Earlier, the solution had been simplified by al-Mu'taman ibn Hūd, the king of Zaragoza (d. 1085), but this simplification was unknown in Christian Europe.

In the tenth century, al-ʿAlā ▶ [ibn Sahl](#) studied reflection in parabolic lenses (which had been studied before) and refraction in hyperbolic lenses (this topic was new). He showed that rays parallel to the axis are refracted to one of the foci of the hyperbola. The reasoning implies knowledge of what we now call Snell's law of refraction, but it is unclear how al-ʿAlā discovered this law.

An important field of application of conic sections was the theory of cubic equations. A cubic equation is an equation of the form $x^3 + ax^2 + bx + c = 0$, for a, b, c given numbers. The Arabic geometers were unable to solve this equation algebraically, i.e., to say, by expressing the root x in terms of a, b , and c . However, they learned to solve it geometrically. The history of the theory is connected with a certain division of a line segment mentioned by Archimedes in Proposition 4 of Book II of *On the Sphere and Cylinder*. Archimedes used the divided line segment but he did not show how it could be divided. In the ninth century, ▶ [al-Māhānī](#) showed that the division of the line segment, which Archimedes uses, depends on a cubic equation of the form $x^3 + c = ax^2$ (a and c are positive). However, he was unable to solve this equation. Abū Jaʿfar al-Khāzin (tenth century) knew the work of al-Māhānī and also a commentary by Eutocius of Ascalon (ca. AD 500), who shows how the line segment can be divided by means of conic sections. Apparently, Abū Jaʿfar realized that one could use Eutocius' construction using conic sections to find the root x of the equation

$x^3 + c = ax^2$ to which al-Māhānī had reduced the problem. Soon other Arabic geometers discovered that conic sections could also be used to solve other "types" of cubic equations. (Because they only worked with positive coefficients, they distinguished different types of equations, e.g., $x^3 + c = ax^2$ is of a type different from $x^3 + ax^2 = c$, etc.) In the eleventh century, ʿUmar al-Khayyām gave in his *Algebra* a geometric solution (by means of conic sections) of all types of cubic equations. His theory was considerably improved by ▶ [Sharaf al-Dīn al-Ṭūsī](#) around 1200.

The Arabic mathematicians developed an instrument, the perfect compass, with which conic sections could be drawn, but this does not seem to have been much used and no examples have survived. Ibn al-Haytham used conic sections for mosaic constructions.

See Also

- ▶ [al-Māhānī](#)
- ▶ [Al-Mu'taman ibn Hūd](#)
- ▶ [Al-Qūhī \(or Al-Kūhī\)](#)
- ▶ [Banū Mūsā](#)
- ▶ [Ibn Al-Haytham \(Alhazen\)](#)
- ▶ [Ibn Sahl](#)
- ▶ [Umar al-Khayyām](#)
- ▶ [Sharaf al-Dīn al-Ṭūsī](#)
- ▶ [Thābit ibn Qurra](#)

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Consciousness in Ancient India

Subhash Kak

The Vedic texts from ancient India (approx. 3000–1000 BCE) claim to be *ātmaavidyā*, “science of self” or “consciousness science.” The most ancient of these is the cryptic *ṛgveda*. But prose commentaries, called the *Brāhmanas* and the *Upanishads* that appeared in the centuries following the *Vedas*, provide a framework to decode its narrative, establishing its central concern with consciousness.

Until recently, the question of consciousness was considered to lie outside of the scope of science and, consequently, the Indian texts on the subject were not properly examined. Scientific attitudes toward consciousness have changed due to the recent advances in neuroscience and because modern physics and computer science must confront the question of the observer.

In the Vedic view, reality is unitary at the deepest level since otherwise there would be chaos. This reality is called Brahman (neuter gender). Brahman engenders and, paradoxically, transcends the mind/matter split. It is identical to consciousness at the cosmic scale and it informs individual minds. Turning focus to the very nature of the mind provides insight about consciousness.

Limitations of Language

Since language is linear, whereas the unfolding of the universe takes place in a multitude of dimensions, language is limited in its ability to describe reality. Because of this limitation, reality can only be experienced and never described fully. All descriptions of the universe lead to logical paradox, and Brahman is the category transcending all oppositions. Vedic ritual is a symbolic retelling of this worldview.

Knowledge is classified in two ways: the higher or unified, and the lower or dual.

The higher knowledge concerns the perceiving subject (consciousness), whereas the lower knowledge concerns objects. The higher knowledge can be arrived at only through intuition and meditation on the paradoxes of the outer world. The lower knowledge is analytical and it represents standard sciences (*śāstra*) with its many branches. In addition, *darśana* represents philosophy where the problem of self is taken together with some aspect of outer reality. There is a complementarity between the higher and the lower, each being necessary to define the other. This complementarity mirrors the one between mind and body.

Recursive Reality and Mind

The Vedic texts present a tripartite and recursive view of the world. The universe, viewed as three regions of earth, space, and sky, is mirrored in the physical body, the breath (*prāna*), and mind. This connection is a consequence of a binding (*bandhu*) between various inner and outer phenomena.

The universe is understood to be a living organism and therefore subject to cycles of life and death. The universe evolves according to cosmic law. Since it cannot arise out of nothing, the universe must be infinitely old. Since it must evolve, there are cycles of chaos and order or creation and destruction.

In the Vedic discourse, the cognitive centers are called the *devas*, deities or gods, or luminous loci. Thus the *Atharvaveda* calls the human body the city of the *devas*. Each *deva* reflects primordial consciousness and one can access the mystery of consciousness through any of these.

Mind in Indian Philosophy (*Darśana*)

The six systems of Indian philosophy are paired together in three complementary groups: logic (*Nyāya*) and physics (*Vaiśeṣika*); cosmology (*Sāṃkhya*) and psychology (*Yoga*); and language (*Mīmāṃsā*) and reality (*Vedānta*). Although these philosophical schools were formalized in

the post-Vedic age, we find the basis of these ideas in the Vedic texts. In each of these, the question of the experiencing self is included.

The objective of the Nyāya is *anvīkshiki*, or critical inquiry. Its beginnings go into the Vedic period, but its first systematic elucidation is given by Gautama in his *Nyāya Sūtra* (third century BCE). The text begins with the nature of doubt and the means of proof, considering the nature of self, body, senses and their objects, cognition, and mind. The Nyāya is also called *pramāna śāstra* or the science of correct knowledge. Knowing is based on four conditions:

1. The subject or the *pramātri*
2. The object or the *prameya* to which the process of cognition is directed
3. The cognition or the *pramiti*
4. The nature of knowledge or the *pramāna*

Gautama mentions that four factors are involved in direct perception: the senses (*indriyas*), their objects (*artha*), the contact of the senses and the objects (*sannikarsha*), and the cognition produced by this contact (*jnāna*). The five sense organs – eye, ear, nose, tongue, and skin – have the five elements – light, ether, earth, water, and air – as their field, with corresponding qualities of color, sound, smell, taste, and touch.

Manas or mind mediates between the self and the senses. When the *manas* is in contact with one sense organ, it cannot be so with another. It is therefore said to be atomic in dimension. It is because of the nature of the mind that our experiences are essentially linear, although the quick succession of impressions may give the appearance of simultaneity.

Objects have qualities which do not have their own existence. The color and class associated with an object are secondary to the substance. According to Gautama, direct perception is inexpressible. Things are not perceived as bearing a name. The conception of an object on hearing a name is not direct perception but verbal cognition.

According to the atomic doctrine of Vaiśeṣika ascribed to Kanāda, there are nine

classes of substances: ether, space, and time that are continuous; four elementary substances (or particles) called earth, air, water, and fire that are atomic; and two kinds of mind, one omnipresent and another which is the individual. The conscious subject is separate from the material reality but he is, nevertheless, able to direct its evolution.

The Sāmkhya and the Yoga systems take the mind as consisting of five components: *manas*, *aḥamkāra*, *chitta*, *buddhi*, and *ātman*. *Manas* is the lower mind which collects sense impressions. *Aḥamkāra* is the sense of I-ness that associates some perceptions to a subjective and personal experience. Once sensory impressions have been related to I-ness by *aḥamkāra*, their evaluation and resulting decisions are arrived at by *buddhi*, the intellect. *Chitta* is the memory bank of the mind. These memories constitute the foundation on which the rest of the mind operates. But *chitta* is not merely a passive instrument. The organization of the new impressions throws up instinctual or primitive urges which create different emotional states. This mental complex surrounds the innermost aspect of consciousness, which is *ātman*, the self.

Yoga psychology of Patanjali is a very sophisticated description of the nature of the human mind and its capacity. It makes a distinction between memory, states of awareness, and the fundamental entity of consciousness. It puts the analytical searchlight on mind processes with clarity and originality.

Mīmāṃsā and Vedānta consider the analysis of language and reality, respectively. Mīmāṃsā ideas became a part of the grammatical tradition and Vedānta became a vehicle to consider consciousness in the most abstract sense.

Parallels with Cognitive Science

There are intriguing parallels between the insights of the early Vedic theory of consciousness and those of quantum mechanics and neuroscience. To express Vedic ideas in modern terms, one might say that individual minds emerge out of the reflection that the brain

provides to the underlying illuminating consciousness. Therefore, senses of awareness, such as vision and hearing, may be separated from the person who obtains this awareness.

The human brain represents the clearest structure to focus the self, which is why humans are able to perform in ways that other animals cannot. Self-awareness is an emergent phenomenon which is grounded on the self and the associations stored in the brain.

From a modern scientific viewpoint, living systems are dynamic structures, defined by their interaction with their environment. Living systems may also be defined recursively in terms of living subsystems. Thus, for ants, one may consider their society, an ant colony, as a living superorganism; in turn, the ant's subsystems are also living. Such a recursive definition appears basic to all life. Machines, on the other hand, are based on networking of elements that create a well-defined computing procedure, but they lack a recursive self-definition.

The Vedic system, which was an earlier attempt to unify knowledge, was confronted by paradoxes similar to that of contemporary science. It is noteworthy that Schrödinger, the co-creator of quantum theory, admitted to having been inspired by the Vedic texts. According to his biographer Walter Moore, there is a clear continuity between Schrödinger's understanding of Vedānta and his research:

The unity and continuity of Vedanta are reflected in the unity and continuity of wave mechanics. In 1925, the world view of physics was a model of a great machine composed of separable interacting material particles. During the next few years, Schrödinger and Heisenberg and their followers created a universe based on superimposed inseparable waves of probability amplitudes. This new view would be entirely consistent with the Vedantic concept of All in One (Moore, 1989, p. 173).

The similarity between the Vedic system and quantum mechanics and the fact that quantum mechanical models of consciousness are being attempted leads us to ask how far the Vedic thinkers took their classificatory models of consciousness. We find both hierarchical and distributed cognitive centers listed in the Vedic texts.

Further Universal Categories

If the categories of the mind arise from pattern recognition of shadow mental images, then how are these categories associated with a single "agent," and how does the mind bootstrap these shadow categories to find the nature of reality?

These questions are examined in the later Vedic tradition both within the frameworks of Vaishnavism and Shaivism. Of the latter tradition, the later Kashmir Shaivism of Vasugupta (AD 800) has in recent years received considerable attention (Shiva is the name for the absolute consciousness).

According to Sāmkhya, reality may be represented in terms of 25 categories. These categories form the substratum of the classification in Kashmir Shaivism. The Sāmkhya categories are:

1. Five elements of materiality, represented by earth, water, fire, air, and ether
2. Five subtle elements, represented by smell, taste, form, touch, and sound
3. Five organs of action, represented by reproduction, excretion, locomotion, grasping, and speech
4. Five organs of cognition, related to smell, taste, vision, touch, and hearing
5. Three internal organs, mind, ego, and intellect
6. Inherent nature (*prakṛiti*) and consciousness (*puruṣa*)

These categories define the structure of the physical world and of agents and their minds.

Kashmir Shaivism enumerates further characteristics of consciousness:

1. Sheaths or limitations of consciousness, being time (*kāla*), space (*niyati*), selectivity (*rāga*), awareness (*vidyā*), creativity (*kalā*), and self-forgetting (*māyā*)
2. Five principles of the universal experience, which are correlation in the universal experience (*sadvidyā*, *śuddhavidyā*), identification of the universal (*īśvara*), the principle of being (*sādākhya*), the principle of negation

and potentialization (*śakti*), and pure awareness by itself (*śiva*)

The first 25 categories relate to an everyday classification of reality. The next 11 categories characterize different aspects of consciousness that are to be understood in a sense different to that of mental capacities (categories 21–23). One of these mental capacities is akin to artificial intelligence, which is geared to finding patterns and deciding between hypotheses. On the other hand, categories 26–36 deal with interrelationships in space and time between these patterns and deeper levels of comprehension and awareness.

Deterministic science cannot explain free will. If consciousness is seen as emerging from the ground of the classical world, then scientific laws again remain incomplete. On the other hand, we do not know why the brain-machine has awareness whereas computers never will. Nor do we understand the mechanisms behind psychoneuroimmunology or the astonishing abilities of savants.

The Indian approaches to consciousness seem to have anticipated many difficulties of contemporary science. The classificatory systems developed in the Indian tradition define categories, such as that of universal experience, that can be seen to explain the “complementary” nature of human experience. These categories clearly assign a central role to selectivity, or context, and change. The Vedic system takes the mind to be emergent on the ground of the brain, but this emergence is contingent on the principle of consciousness.

The ancient Indian texts of consciousness were long limited to philosophical analysis alone, remaining an unexplored frontier in the history of science. Further advances in a scientific understanding of mind will lead to a better appreciation of these texts.

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Copper in Zimbabwe

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Early farming communities in central and southern Africa were aware of mineral resources. Iron and copper have been extracted and used since the beginnings of farming in the region in the first millennium AD. The use of gold in particular and tin to a limited extent developed later as economic resources for social hierarchies that began to emerge at the beginning of the second millennium AD. Dubbed the “red gold of Africa” (Herbert, 1984), copper in the Zimbabwean archaeological record contrasts with gold. Gold was mined on a large scale, primarily for export via the east coast Indian Ocean trade network, with limited local use by elite of the second millennium political hierarchy on the

Zimbabwean plateau and in the Limpopo valley. Copper on the other hand was mined for local use as items of personal adornment and as symbols of wealth and position among the socially elite.

Mining

Precolonial mine workings existed on the Central African Copper Belt (Bisson, 1976) the copper-bearing geology of Zimbabwe (Summers, 1969; Swan, 2002), in eastern Botswana (Huffman et al., 1995), and northern South Africa (Van der Merwe & Scully, 1971). Brightly colored malachite and azurite ores likely drew attention to surface outcrops of the resources. Stopes that narrowly followed reefs were tunneled into resources using iron gads hafted through wooden handles, leaving tool marks on rock surfaces. Gads were struck with hammerstones that became dimpled from repeated impact. Chunks of ore were pounded and split using hammerstones to allow selection of pieces rich in copper for transportation away from the mine site.

Debris accumulated around the mines and disused workings. In addition to waste rock and discarded hammerstones, archaeological excavations of these deposits have recovered potsherds and charcoal can be used to indicate time frames.

Manufacture, Use, and Trade

Evidence for copper smelting in Zimbabwe is limited to small quantities of slag and tuyere fragments, so little is known about the methods and types of furnace used. Cup-shaped ceramic crucibles with external surfaces glazed with slag, housed in museum collections, were presumably used in a final purification process (Friede & Steel, 1975) before pouring the molten copper into a mold.

Refined copper was fashioned into beads or into wire by wrenching it with tongs through successively smaller holes in an iron drawplate.

The wire was wound in a tight spiral around a fiber core to make bangles for wrists and ankles. Copper artifacts of this type are reasonably common in the Zimbabwean archaeological record suggesting availability to all levels of society, especially in the second millennium AD.

Two types of copper X-shaped ingots found in northern Zimbabwe appear to have played several roles (Swan, 2007). The earlier of these are about 18 cm long and weigh between 350 and 1,300 g. These have been compared with ceramic molds on the Central African Copper Belt dating from the ninth to the twelfth century AD (Bisson, 1976) and with ingots deposited in elite burials dating in the thirteenth and fourteenth centuries AD, found near the Lualaba River in the Democratic Republic of the Congo (de Maret, 1995). The distribution of this ingot type extended eastward to Mozambique until the fourteenth century and southward to northern Zimbabwe. Reasonably standardized size, shape and weight suggest use as general-purpose currency (Bisson, 1975). Toward the south of Zimbabwe, molds and an ingot found at elite stone-walled settlements of the Zimbabwe state reflect a wider distribution as items of prestige or royal insignia.

Larger X-shaped ingots, around 30 cm long and weighing 3–4.5 kg, are more common than the smaller type in northwestern Zimbabwe. One mold made of soapstone demonstrates local manufacture from copper mined in the region. Found in caches and occasionally with arms broken off, these ingots could have operated as general-purpose currency and for wealth storage and were probably traded as raw material. The most informative archaeological site is Ingombe Ilede near the Zambezi River (Fagan, Phillipson, & Daniels, 1960), where ingots and other artifacts associated with wealth and metalworking were placed in human graves in the fifteenth century AD. Historical documents record their use as trade items in the sixteenth century (Garlake, 1970; Bisson, 1975).

Musuku-type ingots (Hanisch, 1974) found in southern Zimbabwe indicate connections with communities living to the south of the Limpopo River.

Social Context

The stimulus to mining and the social and economic organization of metal production and exchange of goods are poorly understood, but the use of copper from the mid-first millennium AD and increases in production prior to the introduction of imports from outside Africa support the notion that the seeds of social hierarchy were present in the region, discrediting earlier notions that trade contact was the initial stimulus to political centralization (Bisson, 1976). It has been suggested that the elite rank of society mediated in the distribution of subsistence requirements and trade items (Vogel, 1990; Swan, 2008).

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Copper Production in Mexico

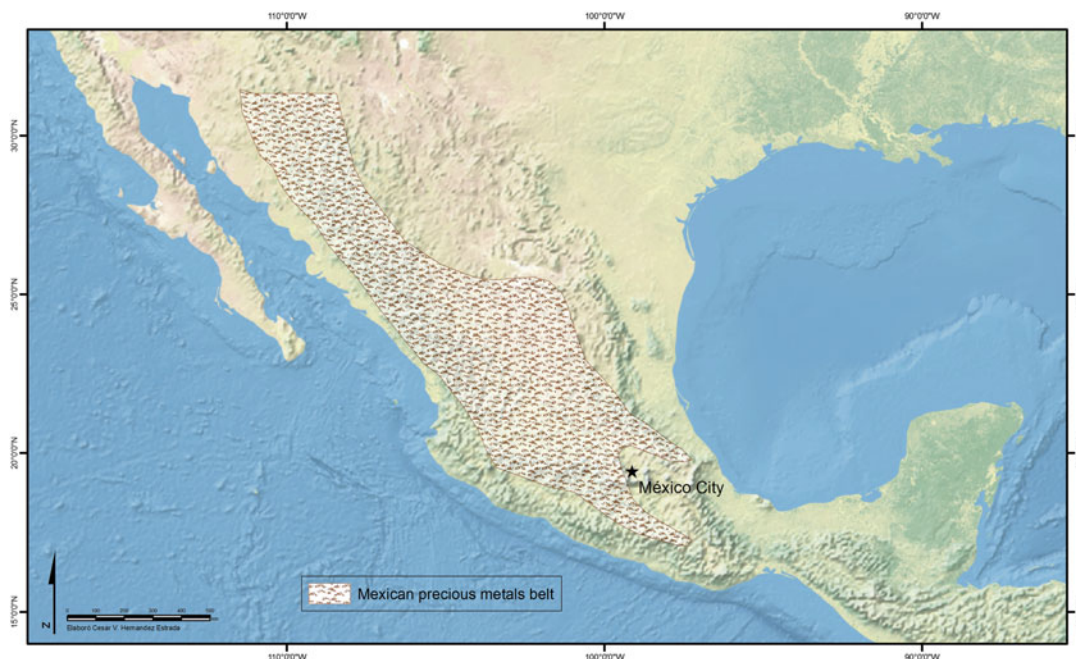
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Copper is a metal more easily smelted than iron and has qualities of malleability, reasonable tensile strength, and corrosion resistance that made it commonly used in preindustrial times (Forbes, 1950) (Video 1). From the standpoint of the Middle American peoples, it was the most important metal and played a prominent role in the prehispanic metallurgy of Ancient Mexico (Hosler, 1994). Today, copper is one of the cornerstones of the Mexican economy.

Most of the Mexican territory lies within a metalliferous zone known as the precious and base metal province of Mexico (Fig. 1). The variety of metals available in this zone is relatively abundant, with copper present largely in the form of ores that have to be extracted from underground deposits. These can be divided into two groups: the easily reducible oxide and carbonate ores, and the more complex ores of the sulfide type. Copper oxides and carbonates are found mainly as cuprite, malachite, and azurite; copper sulfides include chalcopyrite, chalcocite, and bornite. Added to these is native copper,

Copper Production in Mexico, Video 1 Making history: malachite and copper (3:52 min.) <https://www.youtube.com/watch?v=OrBw4L490Y>

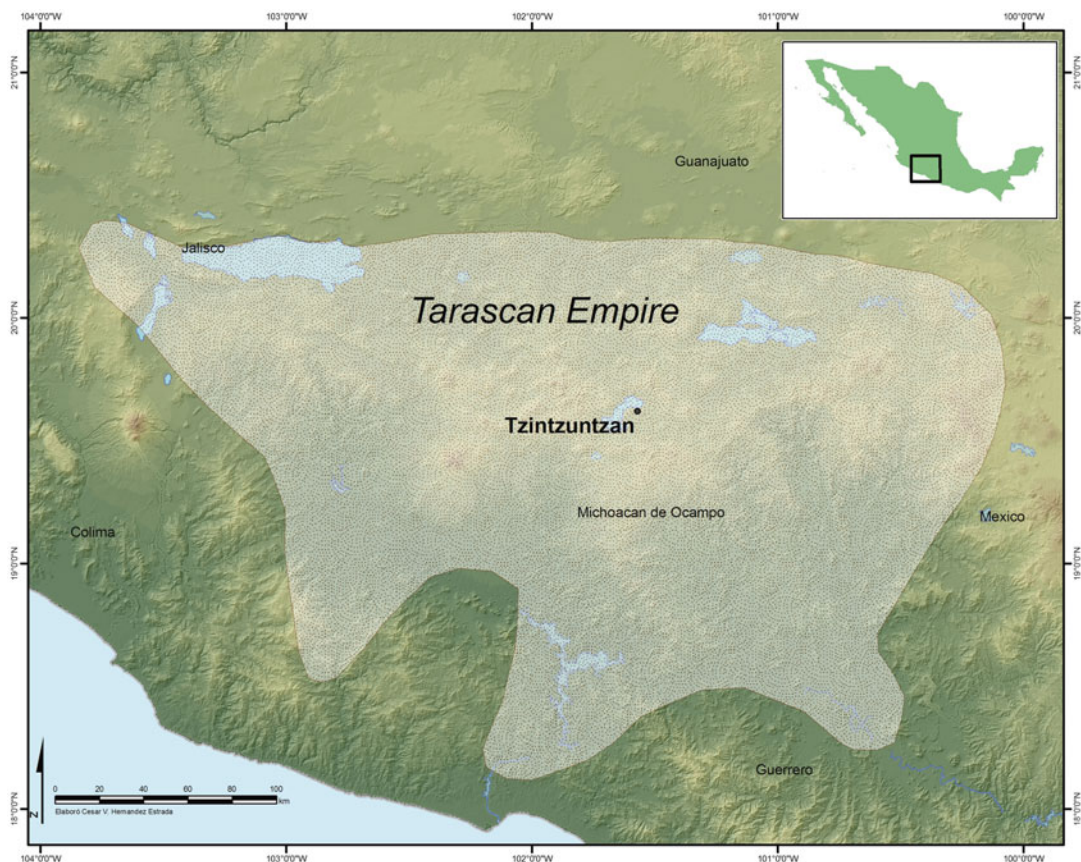


Copper Production in Mexico, Fig. 1 The precious and base metal province of México (Based on data from the Mexican Geological Survey (SGM) [<http://www.sgm.gob.mx>])

which is found in a pure state and was readily available on the surface in some locales (Ostroumov & Corona-Chávez 2000; Ostroumov, Corona-Chávez, Díaz de León, Morales, & Cruz, 2002).

In Ancient Mexico, copper was not only the predominant metal but also the most extensively used base material. Between ca. A.D. 650 and 1200 or 1300, indigenous metalworkers from

Michoacan, Jalisco, Colima, northwest Guerrero, and the southern parts of the state of Mexico, appear to have worked almost exclusively with native copper and easily smelted oxidized copper ores. But from 1300 to the Spanish conquest in 1521, they combined copper with other elements to produce a variety of alloys, including binary alloys such as copper-silver, copper-gold, copper-arsenic, and copper-tin



Copper Production in Mexico, Fig. 2 The maximum extension of the Tarascan Empire in the Late Postclassic period (Based on Pollard 1993:5)

and ternaries like copper-silver-gold, copper-silver-arsenic, copper-arsenic-antimony, and copper-arsenic-tin (Grinberg, 1996; Hosler, 1988b, 1994, 1995).

In the early sixteenth century, the Tarascan kingdom of Michoacán (Fig. 2) was the primary center for metallurgy and metalworking in the region. This technology was largely based on copper and its alloys. Prehispanic copper exploitation reached its height from A.D. 1450 to 1530 in the Tarascan domain. At the time of the Spanish conquest, the Tarascan language used the term *tiyamu charapeti haracuquaro* to refer specifically to copper miners (*tiyamu charapeti* meaning copper or “red metal”).

Presumably, the use of metal goods such as axe-monies, depilatory tweezers, bells, and other ritual objects and adornments (Fig. 3) among the

Tarascons and their neighbors was restricted to the central dynasty and the nobility. Although some utilitarian implements were made, most metal objects were considered to be sacred, to be used for adornment in religious ceremonies, and to enhance the social and political status of the elites (Fig. 4; Hosler, 1988a, 1994; Pollard, 1987, 1993).

Artisans from Santa Clara del Cobre, a modern Tarascan municipality in Michoacán, have maintained the traditional techniques for working copper to this day. Essentially the method employed by these contemporary craftsmen is based on the use of the *cendrada*, a hole in the ground lined with oak ashes which functions as a mold to produce a *tejo*, a disklike copper ingot, which is then hammered into finished shapes (Videos 2a and 2b). Information provided by written sources, along with the factual presence

Copper Production in Mexico,

Fig. 3 Experimental replicas of Tarascan copper artifacts, produced by B. Maldonado (2006)



Copper Production in Mexico, Fig. 4 Tarascan priest wearing a metal tweezer. From Jerónimo de Alcalá, *Relación de Michoacán*, Moisés Franco Mendoza

(estudios y coord. de la edición), Zamora, Gobierno del Estado de Michoacán-El Colegio de Michoacán, 2000, lám. II [primera ed. ca. 1539–1541]

of smelting waste products (i.e., slag) on the surface of archaeological areas near Santa Clara, indicate that the ongoing production of copper has its roots in prehispanic traditions (Horcasitas de Barros, 1981; Maldonado, 2006; Maldonado & Rehren, 2009).

After the Spanish conquest, the principal source of copper in New Spain continued to be the Province on Michoacan, with the main center of copper mining at Real the Inguaran. When Spaniards took over the local copper industry in 1533, natives were employed as both miners and

Copper Production in Mexico, Video 2a Santa Clara del Cobre: Artesano del Cobre – Parte 1 (7:30 min) <https://www.youtube.com/watch?v=G6xZgO8xiCY>



Copper Production in Mexico, Video 2b Santa Clara del Cobre: Artesano del Cobre – Parte 2 (8:39 min.) <https://www.youtube.com/watch?v=9HcZP9Y2FO8>



smelters and for decades continued to use the metallurgical techniques that they knew. According to testimony given in 1533 by Indians who worked in the mines, copper production was much lower than it had been before the conquest (Bargalló, 1955, pp. 213, 295; Barrett, 1987, pp. 14). The low level of production was undoubtedly associated with the continuing decline in indigenous population that followed the Spanish conquest.

The history of commercial mining in Mexico dates back to the Colonial Period. Because of its use in many critical sectors of the economy, copper was a significant resource in New Spain. In a society where iron goods were scarce, copper (unalloyed or mixed with tin or zinc to produce bronze or brass) was indispensable. It was the most widely employed utilitarian metal in Spanish Colonial times. Its importance is manifest in the many ways it was used, from coinage and

armaments to innumerable articles of industrial, domestic, and artistic use. In its nonmetallic form, it was used to process silver ore. In the eyes of the crown, the use of copper for making silver and gold coins and armaments commanded the highest priority followed by its use for making utensils and equipment needed in the manufacture of sugar (Barrett, 1987).

During the next 300 years of Spanish rule, different minerals were extracted from the ground, including copper, coal, lead, and iron. Copper was extracted mainly from the Inguaran mines and the surrounding areas, which remain today among the major mineral deposits in Mexico. Because of its strategic importance, the Spanish crown maintained a monopoly on this mineral resource through the early nineteenth century.

Over the last 100 years, porphyry or high-grade underground mines and large-scale open-pit mines have helped make Mexico one of the larger copper producers in the world, providing approximately 8 % of annual world copper production (Cardenas-Vargas, 1993), mostly from two mines, Cananea and La Caridad. The porphyry copper deposits of Mexico range from the economically insignificant and/or unexplored to the world-class deposits exploited in the Cananea and Nacozari Districts of Sonora (Barton, Staude, Zürcher, & Megaw, 1995). In 2011, 94 % of all copper production took place in the following states: Sonora (80 %), Zacatecas (9 %), and San Luis Potosi (5 %) (Perez, 2011).

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- Production and Distribution of Copper around the World (with maps). <http://www.yourarticlelibrary.com/essay/production-and-distribution-of-copper-around-the-world-with-maps/25468/>
- Mining in Mexico. <http://www.infomine.com/countries/SOIR/mexico/>
- USGS – Copper: Statistics and Information. <http://minerals.usgs.gov/minerals/pubs/commodity/copper/>

Cosmetic Surgery in Ancient India

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Cosmetic operations form a special corner in medicine – much in demand and yet often much maligned for being unnecessary or frivolous. This assumes a clear-cut division between a narcissistic desire for an improved appearance, the correction of a disfigurement or injury that alters appearance in an alarming way without altering physiologic function, and the real disability and danger caused by a disease. Whatever the clarity of the division, the demand persists and also reaches back into antiquity. The undisputed father of the field of cosmetic surgery is Suśruta, a surgeon, educator, and compiler who lived probably around the sixth to eighth century BCE, though his possible dates vary greatly from 1200 AD to well before 1000 BCE. No original texts of his great work, the *Samhitā*, exist today. It has been edited and revised throughout its history, the most significant contributions made by Nāgārjuna, who lived most probably in the second century BCE.

The *Suśrutasamhitā* is a remarkable work in its originality and scope. Though Suśruta is remembered as a surgeon, and division of

medical specialists was practiced at his time (into surgeons, physicians, poison curers, and demon doctors), the *Samhitā* covers a very broad range of medicine as well as surgery, from discussions of the origins of disease, to the treatment of postpartum depression, to the causes of obesity. Remarkable detail is presented on the preoperative preparation of patients and the postoperative care of their wounds. Methods of intraoperative anesthesia and postoperative pain relief are discussed. Over 760 medications are described, 1,120 medical conditions including 76 of the eye alone, more than 125 surgical instruments, and 300 surgical procedures in over 1,000 pages of text and 186 chapters. A broad scope of surgery is also presented, including intestinal repair (with black ants) and Cesarean section. Methods of medical education are discussed including cadaveric and animal dissection for the purpose of learning surgical anatomy; only the bodies of children less than 2 years old could be dissected. Physiology, medical botany, hygiene, and public health are discussed, and Suśruta embraced the Ayurvedic (the science of life) approach to medical care.

Yet it is as a cosmetic surgeon that Suśruta is remembered, at least outside of India. And largely for a single operation and even more specifically for a single aspect of the technique for that operation: that of flap formation for the reconstruction of a severed nose. Here is a selection from the 1907 complete (first) English translation of the *Suśrutasamhitā* by K. K. Bhishagratna:

Rhinoplastic Operations: Now, I shall deal with the process of affixing an artificial nose. First, the leaf of a creeper, long and broad enough to fully cover the whole of the severed or clipped off part, should be gathered; and a patch of living flesh, equal in dimension to the preceding leaf, should be sliced off (from down upward) from the region of the cheek and, after scarifying it with a knife, swiftly adhered (sutured) to the severed (base of the) nose. The cool-headed physician should steadily tie it up with a bandage decent to look at and perfectly suited to the end for which it has been employed (Sadhu Bandha). The physician should make sure that the adhesion of the

severed parts has been fully effected and to insert two small pipes into the nostrils to facilitate respiration and to prevent the adhesions of flesh from hanging down. After that, the adhesions of flesh should be dusted with the powders of Pattanga, Yastimadhuka, and Rasanjana pulverized together, and the nose should be enveloped in Karpasa cotton and several times sprinkled over with the refined oil of pure sesamum. Clarified butter should be given to the patient for drink, and he should be anointed with oil and treated with purgatives after the complete digestion of the meals he has taken, as advised. Adhesion should be deemed complete after the incidental ulcer had been perfectly healed up, while the nose should be again scarified and bandaged in the case of semi- or partial adhesion. The adhesions of nose should be tried to be elongated (or trimmed) where it would fall short of its natural and previous length, or it should be surgically restored to its natural size in the case of the abnormal growth or its newly formed flesh. The mode of bringing about the adhesion of severed lips is identical with what has been described in connection with a severed nose with the exception of the insertion of the pipes. The physician, who is conversant with these matters, can be alone entrusted with the medical treatment of a King.

The innovation that made Suśruta's reputation is the skin flap to make a nose. It involved cutting three sides of a rectangle on the cheek, elevating the skin, while maintaining a blood and nerve supply from the fourth side of the rectangle, thus assuring the viability of the skin flap, which could then be slid over and formed into a new nose. Once healing was complete (and a new blood supply formed through the suture line), the fourth side of the rectangle may have been (Suśruta does not actually say he did it) divided and the donor site freed from the new nose. This is a technique used all over the body to replace skin defects today. Later editors changed the donor site to the forehead, but otherwise the technique remained largely unchanged for the next 2,000 years. Nasal reconstruction was an important part of medical practice in ancient India because nasal injury was common, sometimes

through disease, but more often due to amputation, a form of punishment for many offenses, including adultery.

Yet in one manner of speaking, this is not a frivolous cosmetic operation but a reconstructive one, replacing a severed or damaged part. The Oxford English Dictionary defines "cosmetic" as "of surgery: improving or modifying the appearance. Of prosthetic devices (like grafted noses): recreating or imitating the normal appearance." In that regard the nasal, ear lobe, lip, and eyelid reconstructions described by Suśruta are certainly cosmetic.

The technique of rhinoplasty is quite briefly described with much less detail than a surgical trainee would want today before tackling this operation for the first time. Much is made today about length/width ratios of the flap or flap thickness to assure viability of the mobilized skin. Too narrow or too thin a flap would not have enough blood flow to the mobilized tip to remain viable. The graft would then die and sluff off leaving the unrepaired defect. The width and depth of stitches, the distance from the flap to the recipient site, the degree of rotation, and the time before safe detachment are all left for one to guess in the *Samhitā*. Much more space is devoted to the problem of severed (or bivalved) ear lobes, caused by downward pressure and erosion of earrings worn in pierced ears. Suśruta describes skin flaps again (mobilized from the nearby neck) or debridement and primary closure of the lobe if the amount of tissue was sufficient. Reconstructive procedures are also described for repair of defects, sometimes caused by surgical excision of tumors or ulcers of the eyelid and, as stated above, the lip.

See Also

► [Suśruta](#)

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Cosmologies of India

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From the viewpoint of modern astrophysics, cosmology is the study of the history, structure, and dynamics of the universe. Many of the traditional cosmological concepts of Indian culture have general counterparts in astrophysical cosmology. For example, the parallelism of the macrocosm and microcosm is an important concept for both approaches; our terrestrial physics is mirrored in the stars, galaxies, and distant quasars. Gravity and other long-range forces thread the entire universe. The geometry of Indian temples, cities, and pilgrimage landscapes often replicates the larger cosmos.

Modern physical science relies heavily on quantitative measurement, and according to the architectural traditions of India, the structure of a home, temple, and city is based upon a shared religious symbolism, which involves the bringing of cosmic order out of primordial chaos partly through the act of measurement (Malville, 1992; Zimmer, 1946). Measurement as *cosmogenesis* is asserted in many texts of Indian philosophy and mythology. Purusha, the architect of the universe, “bears the measuring rod, knows division, and thinks himself composed of parts” (Vāyu Purāṇa

4: 30–1; Kramrisch, 1946, p. 131). The universe was created as Purusha was divided into parts, many of which are the measured and ordered features of our current world such as verses, chants, social orders, time, and temples, and cities.

The universe is understood to have spread outward from a primordial center into the four cardinal directions forming a square (Kramrisch, 1946, Malville, 1991; Vatsyayan, 1983). The geometric structure of the universe, as described in the sixth century AD *Bṛhat Samhitā*, was represented by the *vāstu-maṇḍala*, usually consisting of 64 or 81 squares or *padas*, which was also the fundamental plan for houses, palaces, and cities. The *Bṛhat Samhitā* was primarily a treatise on astrology and astronomy, which provided instructions for determining auspicious dates for laying out the foundation *maṇḍala* of a building or city as well as instructions for its precise orientation to the cardinal directions using shadow casting by gnomons. Major features of the *vāstu-maṇḍala* are (1) true cardinality, i.e., parallelism to the fundamental directions in the celestial realm; (2) a center, out of which creation has emerged; (3) mathematical division of interior space into squares or *padas*; (4) the organization of space according to socioreligious rules, assigning specific *padas* to gods, kings, and social classes; and (5) a boundary that represents the barrier between internal order and external chaos.

As organized by the *vāstu-maṇḍala*, the religiously planned city was meant to be a geometrically exact copy of the macrocosm with its pantheon of gods. The symbolism of the city and temple included the point source of creation, the *garbha gr̥ha* (womb chamber) of the temple, and the cosmic tree separating heaven and earth, the *axis mundi*, and the surrounding squares were assigned to 44 Vedic gods, of whom eight were the all-important protector guardians of the cardinal points. The royal palace was to be constructed on one-ninth the total town area to the north of the center. A few of India's ancient cities have achieved the ideal of the *vāstu-maṇḍala* in their design, such as the excavated sites of Sisupalgarh near Bhubaneswar and



Cosmologies of India, Fig. 1 Matanga Hill as viewed from the North in the Tungabhadra River

Vaishali in North Bihar (Chakrabarti, 1997; Joshi, 2000; Krishna, 2000). Often the ideal *vāstu-maṇḍala* was compromised by local topography, as, for instance, the construction of the city on the irregular banks of a river such as Pataliputra (modern Patna) on the Gaṅgā and Ujjain on the Sipra (Krishna, 2000). Furthermore, prominent geographic features often created symbolic forces that drew the orientation of structures toward them and away from cardinality.

In the case of the great city of Vijayanagara, natural features of its dramatic landscape such as hills, caves, and river played major roles in its organization (Fritz, 1985; Fritz & Michell, 1991). With a population which may have reached 500,000 just before its destruction in 1565 AD, Vijayanagara was the greatest imperial city of medieval India, controlling the lower third of the subcontinent (Fritz, 1985). The earliest historical reference to the area is 689–690 CE, when the most important deity was the river goddess, Pampa. Her cult and that of her father, Matanga, reveal the ancient importance and sacredness of the local river and its adjacent hill. Pampa-tirtha developed into the preeminent ritual center of the

region. The prominent hill named after Matanga became a place for protection from enemies. The combination of Matanga Hill, the local cosmic mountain, containing caves deep in its interior, and the Tungabhadra River resulted in a powerful shrine. According to the founding myth of the city, Vijayanagara was placed adjacent to Pampa-tirtha and Matanga Hill to benefit from the “spiritual magnetism” of a major pilgrimage center (Fig. 1).

The dominant north–south axis of the city passes across the summit of Matanga Hill. The axis passes through the Royal Center and precisely divides the domains of king and queen (Fig. 2).

On the western side of the axis lie the palaces of the queen and on the east lie the king’s 100-column audience hall and the great truncated pyramid from which the king would review the parades of subject people coming to express obeisance and pay tribute (Fritz, 1985; Fritz & Malville, 1993; Malville, 2001; Malville & Fritz, 1993a). The significance of this axis and symmetries around it are laid out in the Shilpashastras such as the Manasara and

ideal medieval Hindu kingdom. Matanga Hill lies 0.8 min of arc from true north as seen from the center of the major ceremonial gateway in the Royal Center. The Indian techniques for determining true north using shadow casting by a gnomon had been perfected for centuries, culminating in the work of Sripati in the eleventh century (Yano, 1986). It appears that the architects and astronomers of Vijayanagara, just 50 years before the dawn of telescopic astronomy, were able to obtain accuracies, which were the highest achievable with the unaided human eye. If one stands at night inside the ceremonial gateway facing Matanga Hill, one can observe that the pivot of the heavens lies immediately above it. The visual conjunction of celestial pole and sacred mountain could not be more clearly presented. Beyond Matanga Hill, the north-south axis crosses Chakra-tirtha just at the place where the Tungabhadra River turns northward, in a manner similar to that of the Ganga at Varanasi. Partly for that reason, the Tungabhadra River is known as the “Ganga of the South” (Verghese, 2002). The remains of a substantial dam are found at the southern base of Matanga Hill. The dam would have impounded a lake, which was fed by a ditch from the Tungabhadra River. The lake may have been a representation of the Ocean of Milk, which lies at the foot of Mt. Meru, one of the great symbols of fertility and creation in Hindu cosmogony (Dimmit & Van Buitenen, 1983). It also may be a mimesis of the Lake Manasarovar lying below Mt. Kailash. The most powerful organizing feature of the city was the precise north-south axis that cuts through the center of the Royal Center and passes over the local manifestation of the cosmic mountain, Matanga Hill (Malville, 1994a, 1994b, 2000; Malville & Fritz, 1993a, 1993b).

Cosmology as Illustrated in the Hindu Temple

The Hindu temple can be used as a mnemonic for a wide range of cosmological concepts of India. Manifesting the parallelism between microcosm

and macrocosm, it contains in its center the chaos out of which the universe emerged. Spreading outward along cardinal and intercardinal directions, the stones of the temple are the cosmos into which the universe has transformed itself. The temple is set upon the *vastupurushamandala*, which is the geometric yantra symbolizing the sacrifice and dismemberment of Cosmic Man, Purusha, and the reestablishment of cosmic order. The idea of primordial chaos, which is structured into the center of the temple, is found in many of the cosmological mythologies of the subcontinent and is a well-established feature of the early universe. Creation through disruption of equilibrium, expansion of space-time, and separation of parts are shared concepts of myth and modern cosmology.

The living Indian temple is both a model of cosmos carved in stone and a participatory cosmology. The devotee who enters the temple can travel backward in time by moving from the world of the present, which lies beyond the temple compound, to its center where space and time are collapsed. At the center of the temple, enshrouded by a darkness pierced by only a few lamps, lies the *garbha-gr̥ha*, the womb chamber symbolic of the chaos, potentiality, and undifferentiated wholeness out of which the universe emerged (Kramrisch, 1946). Spiraling inward in space and backward in time, one proceeds from brightly lighted exterior space of the ordinary world to darkness. The large open spaces of the entrance are replaced by the confined small center; the extravagant richness of carving and decoration turns into the simplicity of the unadorned center. Space is focused like a converging beam of light upon the center, becoming ever more constricted and confined as the *garbha-gr̥ha* is approached. It is the center which provides personal renewal and rebirth, paralleling the renewal and rebirth of the universe itself.

The axis of the universe, the axis mundi, passes through these versions of the sacred mountain, and each temple, palace, and city became a connection between the underworld, this world, and the heavens (Eliade, 1963; Bernbaum, 1990). Shamans use that connection as they climb or fly through the worlds. The axis, around which the

Cosmologies of India,
Fig. 3 Mt. Kailash



cosmos revolves, is symbolic of the cycles of the heavens, the changing seasons, and renewal of life. Mt. Kailash in Tibet, the most sacred of all mountains in south Asia, is circumambulated, but it has never been climbed. The symbolism of circulation around an axis is repeated in the spinning prayer wheels, which are often carried by Tibetans as they circle Mt. Kailash (Fig. 3).

The superstructure of the Hindu temple, the *sikhara*, is an explicit metaphor of the cosmic mountain with a cave at its base, establishing the axis and center of the cosmos (Michell, 1988). Often an illusion of height of the *sikharas* is created by decreasing the spacing of higher features of the tower. Built by the Chola King Raja Raja (985–1014 CE), the 66 m-high *sikhara* of the Brihadeshwara Temple of Tanjore is one of the highest in India. The dark sanctum at the base of this surrogate cosmic mountain is understood to be the place out of which life emerged (Fig. 4).



Cosmologies of India, Fig. 4 Brihadeshwara Temple of Tanjore, India

Chaos and Equilibrium

“In the beginning was darkness swathed in darkness; all this was but unmanifest water” *ṛgveda* 10.129.3.

The birth of the universe from primordial chaos is one of the most fundamental creation mythologies of our planet (O’Flaherty, 1975).

In Hindu cosmology, the metaphors for chaos are water, darkness, disorder, lawlessness, and potentiality. Chaos in the center of the temple is protected by massive stones, priests, and doorway guardians. The *garbha-gr̥ha* is the cave in the side of the cosmic mountain, Mount Meru, which

is the axis mundi, connecting heaven and earth. The cave is the womb out of which the world and life have emerged. The small cubical space of the garbha-gr̥ha is symbolic of the primordial seed of creation. Chaos, as a source of creation, is thus contained, protected, preserved, and intensified in this dark space. The energy of the cosmic cycle is contained in the temple and is available each day of the year for the purposes of cleansing, symbolic death and rebirth, and rejuvenation.

Indra and Vṛtra

The conversion of chaos into cosmos is described in two well-known Hindu myths, the battle of Indra and Vṛtra and the churning of the cosmic ocean. Vṛtra, the Restrainer, held the dark waters of creation tight within his coils and had to be destroyed by Indra in order for the waters of time and creation to flow. The battle between the Aryan war god Indra and his archenemy Vṛtra is rich in thermodynamic meaning. The universe was initially imprisoned as dark and unmoving waters held tightly within the coils of Vṛtra. Actualization of potential inherent in the universe was thus prevented; time could not flow and space could not expand. This metaphor addresses one of the great mysteries of existence: what initiated expansion of space-time? As the god of lightning and thunder, Indra slew Vṛtra with his thunderbolt, the *vajra*. The death of Vṛtra symbolizes the victory of change over stasis, time over eternity, light over darkness, as well as summer over winter. One interpretation of the slaying of Vṛtra is that it is a depiction of the transformation of winter ice into summer waters as the light and heat of the sun destroy the darkness and frozen immobility of winter; the mountain streams, which are held fast in winter's coils, are released to flow to the ocean when winter is conquered by the springtime sun.

The initial symmetry, quietude, and perfect balance of the cosmos were broken when the circular coils of Vṛtra were forced open, and, like the escaping contents of a broken pot, the imprisoned waters of time and change were

allowed to flow. The sun and moon, locked as embryos in the dark waters, were born with the death of Vṛtra. The transformation from the state of stasis to that of change involved violent activity, disruption of tranquility, and death of the old.

Churning of the Cosmic Ocean

Thermodynamic elements abound in the story of the churning of the primordial ocean for the purpose of obtaining *amṛta*, the elixir of immortality (O'Flaherty, 1975). Primordial equilibrium, symbolized by the undifferentiated cosmic ocean, was disturbed by the outside agent of the inverted Mt. Mandara, used as a churning stick. In a manner similar to that of the patterns of convection in a heated pot of water, structures hidden in the water were evoked. The cooperation of all aspects of creation was needed for such transformation of chaos: *asuras*, *devas*, Viṣṇu who as the cosmic tortoise provided support for Mt. Mandara, and Śiva who drank the poison which emerged before the *amṛta*, the cosmic mountain, and the cosmic serpent, Vasuki. The transformation of equilibrium required extraordinary actions, and the inversion of the cosmic mountain seems to symbolize that ordinary, traditional action was inadequate for such an endeavor. Ordinary action cannot bring about major transformation when powerful self-maintaining cycles, i.e., negative feedback, suppress perturbations. The old standards and ordinary behavior were inverted: Mt. Mandara was converted into a stirring stick, the *asuras* and *devas* cooperated, and the serpent as the churning rope became the agent for change rather than the traditional agent for eternity and stasis. The consequences of the churning were violent: fire, loud noises, upsetting of nature, and death of many creatures. Polar opposites emerged from the waters such as poison and the elixir of eternal life, *amṛta*. All beings and gods were protected from the poison by Śiva who acquired a blue throat while drinking it. Out of the disrupted equilibrium of the ocean emerged the embryonic sun and moon (Fig. 5).

Cosmologies of India,
Fig. 5 Churning of the
 cosmic ocean (Bangkok
 Airport by Sailko)



Rescue of Earth from the Waters

The story of the rescue of Mother Earth from the waters involves one of the ten incarnations of Viṣṇu as the boar and is a member of the worldwide class of earth diver creation myths (Long, 1963; *Taittirīya Saṃhita*, *Viṣṇu Purāṇa*: O'Flaherty, 1975). In each of these stories, a creature dives to the bottom of the ocean to retrieve mud which, when brought to the surface, grows to become the planet on which we live. In one version of the Hindu story, there is a violent battle between the cosmic boar and the demon of the waters who, like Vṛtra, has held the earth prisoner, preventing thereby the flow of time. The recurrent symbols of creation in these Hindu myths are again present: formless, rich, and fertile primeval material locked in the eternal, changeless dark waters is released only after a violent struggle. Another important aspect of this myth involves Viṣṇu in his role as expander and extender. After bringing Earth to the surface of the waters, he spreads her out into a flat disk so that, like a lotus leaf, Earth can float on the waters and not sink back to the oblivion of the dark waters and the death of equilibrium. In the astronomical universe, it is the continuing expansion of space-time which causes departures from

equilibrium and prevents structures from sinking back into equilibrium.

Primordial Incest

The stories associated with Prajāpati and his daughter, Rohiṇī, form a highly complex collection of symbols involving both sexual and astronomical allusions (Kramrisch, 1981). Back in the timelessness which existed before the creation of our world, the “first created,” Prajāpati, desired a second. Instead of a wife, he acquired a daughter with whom he sexually united. The onlooking gods were so outraged by such an unthinkable violation of a fundamental law of nature that they created Rudra, the archer, to prevent and punish the incest of Prajāpati. The arrow shot by Rudra struck Prajāpati, too late, causing him to withdraw from his daughter and spill his seed on the ground. From such an unlikely sequence of actions, human life sprang from the impregnated soil.

Meant to prevent the act, the flowing of the seed, the shot failed to prevent its consequences. The failure in timing at the dawn of the world was due to time itself, for the latter had not set in as yet; it was just about to begin. The transition from an

integer without dimension of space and time into existence is a danger zone between eternity and the passing moment... Had the timing been perfect, the flying arrow of Rudra would have prevented the coming into existence of man and the flowing down on the earth of the substance of the Uncreate. (Kramrisch, 1981, p. 26)

The sequence of events can be described in thermodynamic terms as follows. Primordial equilibrium contains within itself processes which may become unstable and grow out of control; the result can be a destruction of the old system and the production of something entirely new. As already mated, an equilibrium system has self-maintaining processes built into it designed to prevent such destruction of equilibrium and stability. Incest as a violation of equilibrium was present in the original plenum of creation. In order to prevent change, a negative feedback loop was created in the form of Rudra to suppress the perturbation. Ironically, the consequence of Rudra's action was the opposite of the original intent. The incestuous act was not punished in a manner such that the original equilibrium could continue, but, quite the contrary, the initial instability grew, life on the earth appeared, and the unchanging primordial state was replaced by time and change.

The Prajāpati myth may have astronomical implications concerning a very early discovery of the precession of the equinoxes. Between 4500 BCE and 3500 BCE at the time of vernal equinox, the constellation which we know as Orion rose heliacally just ahead of the sun. Prajāpati was identified with that constellation (Kramrisch, 1981; Tilak, 1972). Prajāpati was also the year (*Śatapatha Brāhmaṇa* 3.2.2.4) which, exhausted from his labors, needs to start afresh at the time of the vernal equinox. The rejuvenation and rebuilding of Prajāpati, the year, was accomplished symbolically by the construction of the Vedic altar, the bricks of which symbolized the days and seasons of the year. The death of Prajāpati, the old year, was necessary for the continuation of the annual cycle of vegetative life. The symbolism of Orion-Prajāpati rising heliacally on the morning of the vernal equinox may have had great ritualistic significance, announcing by its

presence in the equinoctial dawn the time for the rebuilding of the sacrificial altar and the rejuvenation of the exhausted year.

For over a millennium, following 4500 BCE, the constellation of Orion-Prajāpati had provided that announcement. But around 3000 BCE, Prajāpati no longer appeared briefly in the ruddy dawn of vernal equinox, having been replaced due to precession by his daughter, Rohiṇī, the red star Aldebaran, the eye of the modern constellation of Taurus the Bull. The shock of this change in the makeup of the heavens may have been considerable. No longer was the start of the year announced by the heliacal rising of the grouping of stars which had symbolized the year, no longer was there a synchronization of the heavens with terrestrial phenomena and human affairs, and no longer could the heavens be viewed as eternal and unchanging. The astronomical language which is used to describe this event is extraordinary in its allusion to the forbidden act of incest. Prajāpati as the beginning of the year had moved into Rohiṇī due to the process of precession.

A complex variation on the Rudra-Prajāpati-Rohiṇī myth is the story of Dakṣa, the antagonistic and jealous father-in-law of Śiva. The wife of Śiva, Satī, was the first born daughter of Dakṣa. He had 27 other daughters who had been given to the moon in marriage; these are the Nakṣatras, the asterisms through which the moon passes each month in his journey along the sky. Dakṣa performed a great sacrifice but did not invite Śiva nor did he reserve a portion of the sacrifice for Śiva. Dakṣa's jealousy toward Śiva at one level of the myth may symbolize the desire to preserve primordial equilibrium. Satī reproached her father for not having invited her husband. In anger and shame, she committed suicide by throwing herself into the sacrificial fire ignited by her father. Śiva, outraged at the consequence of Dakṣa's insult, came in the form of Vīrabhadra, a fierce manifestation of Śiva. He cut off Dakṣa's head with a sacrificial knife and replaced it with the head of a ram. Vīrabhadra picked up the corpse of his wife and performed a wild and agonized dance with it over the face of the earth. In his dance, his arms flailing to the far

reaches of the universe, the stars were scattered by the sweep of his hair. Fearing that the wild dance, the Tāṇḍava, would destroy the earth, Viṣṇu cut the body of Satī into pieces, and where each piece of flesh dropped to earth, a shrine was built (*Devībhāgavata Purāṇa*: O’Flaherty, 1975). Here again, we encounter the use of horrible and unthinkable mythic deeds to dramatize the consequence of the disruption of cosmic equilibrium and consequent creation in the form of the establishment of shrines and temples across the land.

The Waters and Fires of Chaos

Though structureless themselves, water and fire are infinitely creative (Eliade, 1967). Everything which possesses form has separated itself from water. The gods of chaos must be sacrificed in order for life to appear. When form emerges beyond water, there is a dying of potentiality, and form becomes subject to limitation by the laws of time, change, and decay.

In the temple tank, fed by deep underground springs, lie the dark and murky waters of chaos, reinforcing the meaning contained in the dark sanctum of the temple. Water is a transformational symbol, both life-giving and life-threatening, the source of vitality and creation, as well as the agent for destruction. The waters of the *pralaya*, the cosmic flood at the end of time, provide the source for new creation and new birth. Life is born out of these dark, destroying waters which periodically sweep the earth.

In the city of Vārāṇasī, also known as Kāśī, one finds the intensified symbols of water and fire (Eck, 1983). In the center of Kāśī in the Viśvanātha Temple is the Jyothir liṅga, the great pillar of fire connecting heaven and earth. Near the center is the Maṇikarṇikā *kuṇḍ*, the place of the very first dawn of the world at the beginning of time. In an interesting twist, the *kuṇḍ* associates water in the form of sweat with the act of creation. The *kuṇḍ* was excavated by Viṣṇu using his discus and filled by his sweat before he created the world. Viṣṇu symbolizes the activity, expanding power, and movement of the sun as it

traverses the sky with great strides. The discus, which is carried in one of his hands, is a sun symbol (Begley, 1973). Glowing brilliantly, yet terribly dangerous, it is called *sudarśana*, “beautiful sight.” The chaos of the earth has thus been disturbed by the sun disk. The water so necessary for creation has come from god himself. Maṇikarṇikā is also identified by local tradition with the jeweled earring of Satī, fallen to the ground while Śiva was performing his dance after her death by fire.

A central theme of Hindu cosmology is the homology of universe and human body, i.e., the body is a microcosm, a model both of the universe but also for the universe. The universe is the dismembered body of Prajāpati and Puruṣa, the Cosmic Man. It is a complex cosmological homology as, in this view, the human body is both a description of how the universe behaves and a model for the universe, i.e., how it should behave. The significance of these “of” and “for” models in cultural symbols has been explored extensively by Geertz (1973). The equality between the sun and the *ātman* which lives in everyone’s heart is one such homology. Another homology, suggested by Parry (1981), relates the process of creation and destruction of the universe to the constant stream of sacrificial cremations staged at the Maṇikarṇikā *ghāt*. Parry argues that the human body has been so “cosmicized” in India that the cyclic movement of the entire universe relies upon the unceasing human acts of cremation at Maṇikarṇikā.

The Hindu temple with chaos in its center is surrounded on all sides by the chaos of the profane world; the walls of the temple serve as ramparts against the threatening flood of chaos. Such a flood of chaos can be creative as well as destructive. The devastating flood may be followed by a creative flood as described in the myth of the temple town of Kumbakoṇam:

When the time of the universal deluge drew near, Brahmā came to Śiva and said, ‘Once the world has been destroyed how will I be able to create it anew?’ Śiva instructed him to mix earth with *amṛta*, fashion a golden pot, and put the Vedas and other scriptures into the pot along with the Seed of Creation. Brahmā made the pot and decorated it with leaves, and, when the flood began to

rise, he put the pot in a net bag and sent it off on the waters. Pushed by the wind and waves, the pot floated southwards; the leaves fell off and became holy shrines, and the pot came to rest at a spot proclaimed sacred by a heavenly voice. . . Śiva took the form of a hunter and shot an arrow, which hit the pot and let loose a flood of *amṛta*. When the waters of the deluge receded, Brahmā fashioned a *liṅga* from earth mixed with *amṛta*, and Śiva merged into the lingam in the presence of the gods. (Shulman, 1980)

Creation thus follows the flood of *amṛta*. The creative flood flows because Śiva has broken the restraining pot. Creation thus results from the violent disruption of equilibrium. He repeated the archetypal act of Indra when he slew Vṛtra with his thunderbolt, the *vajra*, and allowed the waters of time and creation to flow. The arrow of Śiva was a shaft of light and time entering the darkness of the watery chaos that existed before creation; the pot was the womb, which releases life.

Other Tamil temple myths echo this theme in which a moving shaft such as a spear plays a crucial role of creation following a flood (Shulman, 1980, p. 73). In over 70 Śaiva temples of Tamil Nadu, the sun penetrates the center of the shrine at sunrise or sunset on a few days of the year near the equinoxes. There are numerous interpretations of the event celebrated as a Sūrya *pūjā*. A popular myth is that Sūrya has become afflicted with leprosy and is requesting that Śiva relieve him of the disease. The reference to leprosy may have been associated with an unusually high level of sun spot activity that we know occurred in the thirteenth century. Another interpretation of the event is that the horizontal shaft of sunlight lighting the Śiva *liṅga* in the otherwise dark *garbha grha* is symbolic of the first shaft of light that destroyed the darkness of chaos (Malville, 1985, 2007; Malville & Swaminathan, 1998, 2006).

The temple doorway, through which pass shafts of light, arrows of time, priests, and devotees, contains symbols of chaos and water: the marvelous water creature, the *makaram*, with wings of a bird, body of a crocodile, and snout of an elephant, yawns widely on either side. Out of the opened mouth of the *makaram* flow the

forms of creation to be reabsorbed at the end of the world age by the opposite *makaram*. Intertwined about the doorway are stalks and leaves of water plants and river goddesses. To pass through the doorway from the profane to the sacred world requires transformation which water provides. The priest when he enters the *garbha-grha* experiences a transmutation “promoted by the (water) divinities on the door jambs” (Kramrisch, 1946, pp. 313–314). Coormaraswamy (1980) has written extensively and creatively on the symbolism of this “water cosmology” of India. Upon murky waters floats the white lotus, unpolluted by the mud, a symbol of separation of creation from the waters of chaos. Out of the waters, it climbs on a stalk which is the *axis mundi*, connecting primeval mud with the light of the sun. The earth, the sun, or Brahma is carried by the lotus, suspended above chaos, protected from sinking back into oblivion by the lotus raft. The lotus is also the characteristic symbol of Sūrya, always carried in his hands, expressive of the separation of creation from chaos provided by the light of the sun.

Expansion, Separation, and Differentiation

Nonequilibrium in the universe is the consequence of the expansion of outer space. Portions of the universe were thrown out of equilibrium following the Big Bang as the initially homogeneous matter clumped and hot stars separated from cold space. Expansion is the fundamental dynamic of our universe, constantly forcing matter and energy out of equilibrium and allowing structures to form and complexity to grow.

Viṣṇu as the expanding dwarf who tricked the demon Bali into giving him all the space he could cover in three steps is an oft-repeated allusion to cosmic expansion (*Viṣṇu Purāṇa* 2.36.74-86) (Fig. 6).

As an expanding fish, Viṣṇu saved Manu from a return to chaos through the flood (*Śatapatha Brāhmaṇa* 1.8.1.1-6). When Viṣṇu as the Boar rescued Earth from the bottom of the waters of chaos, he expanded Earth and spread her out, to



Cosmologies of India, Fig. 6 Vishnu, as the expanding dwarf (Kyle Tortora)

prevent her from sinking back again into chaos. The infinitely expanding *liṅga* of fire which confounded Brahmā and Viṣṇu during the darkness before creation as it rose from the cosmic ocean reproduces these resonating symbols of dark waters and expanding form (Zimmer, 1946).

The central tower of the temple, the *sikhara*, the “mountain peak,” is another *axis mundi*, which pillars apart heaven and earth and lets creation proceed. In Vedic terms, to separate is to create, and to merge and reabsorb is to dissolve and destroy (O’Flaherty, 1975, p. 125). The myth of the triumphant destruction of the triple cities of the demons by Śiva, as Tripurāntaka, again resonates with the insight that to separate is to create and, conversely, that which causes polar opposites to unite and lose their separate identities is to reverse the course of creation and return to chaos (O’Flaherty, 1975). The triple cities symbolize heaven, earth, and sky and their reabsorption returns the universe to formless equilibrium and chaos.

The symbolism of chariots and wheels is found both in the temple architecture itself and in *ratha* festivals. The temple of Konārak has been fashioned into huge chariot of the sun with 24 wheels pulled forward into the east by seven horses (Malville, 1989; Fig. 7).

The wheel is a preeminent symbol of time with stillness at its center, which allows movement and change. It is also a symbol of sustained separation of the earth and the heavens. The wheels of the sun’s chariot are supported and separated by the axle tree, which performs the same function as the *axis mundi*, holding apart the turning wheels of earth and sky. Creation is possible only because of the separation provided by the axle. The wheels are those of Kāla, time, bringing life out of darkness and returning life to darkness and death. The sun god, Surya, is often shown holding lotus flowers in each hand. The lotus, emerging brilliantly white from muddy waters, symbolizes the purity of the sun (Fig. 8).

A frequent icon in many temples is that of Kirttimukha, the “face of glory,” another image expressive of creation emerging from separation. Kirttimukha represents both the awesome destructive power of Shiva and the creative powers of the cosmos. Creation flows from his open mouth only so long as it is open; once his jaws close, creation ceases. Fortunately, since Kirttimukha lacks a lower jaw, the mouth of creation can never be closed (Kramrisch, 1946).

The sacrifice of Purusha, Primal Man, contains the three primary cosmological symbols of chaos, separation, and differentiation (*ṛgveda* 10.90.1-16). Primal man represents chaos and infinite potentiality. He must be sacrificed before in order for creation to occur. Like water and fire, chaos and creation, equilibrium and ordered structures are mutually exclusive; once water becomes structured, it is no longer water, but it becomes plants, fish, and people. The strongest image of the sacrifice of Purusha is that of differentiation of the original parts of primordial chaos. Various parts of the body became the infinite variety of the cosmos: the atmosphere, the heavens, and the earth, the creatures of the earth, and the social classes, waters. Prajāpati, also the primal man, “fell apart,” separated, and

Cosmologies of India,
Fig. 7 Konarak



Cosmologies of India, Fig. 8 Surya

Symbols of Expansion, Separation, and Differentiation

1. Lotus: separation from mud and water; suspended above chaos
2. Śikhara: separation of earth and sky; expansion upward
3. Tree: expansion downward and upward
4. Gopuras: expand outward and upward from the center
5. Wheels: separated by axle tree
6. Vishnu as dwarf: expanded to step across three worlds
7. Viṣṇu as fish: expanded to save Manu
8. Viṣṇu as boar: expanded earth to prevent it from sinking into chaos
9. Kirttimukha: open mouth allows continuing creation
10. Indra: separates earth and sky by expanding
11. Puruṣa: separation and differentiation
12. Tripura: separation of the three worlds (Table 1)

Return to Chaos

dispersed to become our cosmos: his semen became sun and heaven, his breath became wind and atmosphere, his body became food and earth (*Śatapatha Brāhmaṇa* 7.1.2.1-6).

At the end of a thousand world ages, a day of Brahmā, a Kalpa, the world becomes barren of life. Siva scorches the earth with his eye, drying

Cosmologies of India, Table 1 Hindu cosmochronology (Dimmitt & van Buitenen, 1978; O'Flaherty, 1975)

Yuga	Duration (years)
Kṛta	1,728,000
Tretā	1,296,000
Devāpara	864,000
Kali	432,000
1 Mahāyuga: breath of Brahma	4,320,000
1 Kalpa: day of Brahma	4,320,000,000

up the oceans and rivers. The earth catches fire and burns until it is as bare as the back of a turtle. Then the rains come and pour water on the earth for 100 years, converting the earth into a shoreless ocean. At that time, when only the ocean exists, all creation is absorbed and united into Vishnu who sleeps on his bed of coils of Ananta, meaning infinite, in the darkness of cosmic night (*Viṣṇu Puraṇa*: Dimmitt & van Buitenen, 1978). Over and over, this sequence is repeated without end. Life appears and vanishes as passing days and nights. As in the story of the cities of Tripura which were destroyed when they are brought together by the arrow of Siva, union and absorption mean equilibrium and death.

Our astrophysical understanding of the end of the universe involves death by fire in the collapse of space into a cosmic black hole or death by cold of unlimited expansion. In the more likely future of death by expansion, stars will eventually fall into black holes in the centers of galaxies and the universe becomes a dark and cold system of galactic black holes, silently and darkly revolving one around the other. Even black holes are subject to change, and matter and energy will eventually evaporate from them to produce a return to chaos in the form of a vast expanding ocean of thin, cold light. According to our current understanding, the rate of expansion will accelerate as dark energy pushes our universe apart. Lurking somewhere in the immensity of future time, there must be other universes waiting to be born.

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 Viṣṇu as a dwarf takes three strides: *ṛgveda* 1.154.1-6; Vāyu 2.36.74-86; Vāyu 2.36.74-86.
 Viṣṇu becomes a boar to save Earth: Viṣṇu 1.4.3-11, 25-9, 45-9.
 Vishnu becomes a fish to save Manu from the flood: *Śatapatha Brāhmaṇa* 1.8.1-6; *Matsya* 1.11-34; 2.1-19.

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Cosmology in Mesoamerica

Keith Jordan

The Native American peoples who occupied Central and Southern Mexico, the Yucatan Peninsula, Guatemala, Belize, El Salvador, and Western Honduras prior to the Spanish Conquest of the sixteenth century shared many aspects of both material culture and ideology. This cultural unity, underlying varying expressions of the basic pattern across linguistic, ethnic, and political divisions, is the basis for the modern

anthropological construct of Mesoamerica as a distinct culture area. Among the achievements of the pre-Columbian Mesoamerican civilizations of the Aztecs, Maya, Mixtecs, Zapotecs, and others are complex myths and mental maps of the universe as they understood it. These elaborate conceptualizations encompass multiple realms of existence and sequences of creation and destruction across vast epochs of time. While each distinct culture generated its own cosmology, all such models of the nature of the cosmos are united by common features marking them as distinctively Mesoamerican. This entry will employ as representative examples the world views of two Mesoamerican cultures for which much information has come down to us across centuries, the Aztec and the Maya. The reader unfamiliar with the sources and chronology for Mesoamerica should view Extras 1 and 2 before reading further.

Shared Features of Traditional Mesoamerican Cosmologies

Although details vary across time and political/linguistic boundaries, pre-Columbian Mesoamerican cosmologies share a number of general characteristics. The universe is conceived as arranged in multiple levels, broadly divided into an upper world (the sky), a middle world (the earth), and an underworld beneath the earth. The upper world, home of the gods, may have 13 levels, while the underworld, land of the dead, usually has nine. The earth is pictured as a disc, square, or aquatic reptile floating on the sea. Its surface is divided into four quarters corresponding to the cardinal directions. At its center is a vertical axis symbolized by a tree or primordial mountain, bridging the multiple tiers of the cosmos above and below. This center may be identified with a capital city or sacred site, or with the body of a ruler. Deities, rulers, and ritual specialists use the central axis as a conduit to travel between levels of the universe. Other portals to the ancestral realm of the underworld are depicted as the mouths of mythical reptiles, and equated with caves. Mountains are envisioned as hollow

sources of plenty, repositories of water and maize.

Similarities in maps of space are matched by shared, cyclical conceptions of time. The present universe is the last of a series of creations. Each prior cosmos fell victim to catastrophic destruction. A ritual calendar year of 260 days is paired with an approximate solar year of 360 days, a hallmark of Mesoamerican culture (see “► [Calendars in Mesoamerica](#)” in this volume). Unlike contemporary Western thought, in the Mesoamerican vision, cosmology is distinguished neither from religion nor from politics. The social order and its activities – like warfare and human sacrifice – are part of the natural order and crucial to the viability of the entire cosmos. The forces that animate and manifest as the phenomena of nature are supernatural beings.

Mesoamerican thought is characterized by dynamic pairings of binary oppositions: male/female; upper world/underworld; rain/dryness; and death/life. Although sometimes labeled as dualism, these conceptions are not dualistic in the Platonic or Manichaean senses, i.e., separating mind and matter. Rather, the opposite qualities interact dynamically and are themselves manifestations of an underlying unity (Fig. 1).

Origins

The beginnings of Mesoamerican cosmology are lost in the distant past. Mesoamerican world views share features with Asian, Native North American, and South American shamanic traditions – e.g., a multilevel universe bridged by a vertical axis conceived as a world tree. Because of these similarities, some scholars trace the roots of Mesoamerican cosmologies back to the presumed shamanistic beliefs of the first settlers of the New World who crossed the Bering Strait or arrived by boat along the Pacific coast during the last Ice Age. Other parallels suggest connections with Asia: the occurrence in both areas of directional symbolism associated with colors, or the identification of the markings on the surface of the moon as a rabbit. However,

Cosmology in Mesoamerica,

Fig. 1 Ehecatl/Quetzalcoatl (right), a deity associated with life and fertility, and Mictlantecuhltli, god of death and ruler of the underworld, showing duality of opposing forces in the cosmos (Reconstruction of MS painting from *Codex Borgia*, p 56, Mixteca-Puebla style, Puebla/Tlaxcala (Mexico), Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Reproduced by permission of Alan Rodgers)



the archaeological record does not yield clear evidence for cosmological beliefs in Mesoamerica from the arrival of the first hunter-gathers (pre-10,000 BCE) through the transition to a sedentary agricultural lifestyle (ca. 2000 BCE). The relevance of shamanism to understanding Mesoamerican civilizations has been questioned ([Extra 6](#)).

The earliest clear signs of a developed mythic cosmology occur in the monumental art of the Olmec culture of the Mexican Gulf Coast. This civilization, which flourished between 1200 and 400 BCE, has been touted as the “mother culture” of Mesoamerica, although more recent views hold it to be the most developed regional manifestation of a pan-Mesoamerican art style and ceremonial complex. In the absence of readable glyphic inscriptions, reconstruction of Olmec cosmology is a speculative exercise, drawing on inferences from Maya beliefs (see shamanism in Mesoamerica in this volume).

Maya Cosmology

On the basis of artistic, inscriptional and ethnographic data, we know that the Maya of the Classic through Postclassic periods envisioned the earth as a disk or square surrounded by water, or as an aquatic animal, a turtle or a caiman. The earth’s surface could be represented as a quadrilateral, based on the traditional Maya maize field or milpa. In the *Popol Vuh* ([Extra 5](#)), this shape was mapped out by the gods using a cord during the last creation. This surface was divided into eight by the four cardinal and four intercardinal directions, and transfixes vertically in the center by the world tree, the central axis and path between upper, middle, and lower worlds. This cosmic tree was identified with the ceiba tree, whose sanctity may be related to the resemblance of its sap to blood. In Classic reliefs from Palenque, the world tree is depicted as a cross, with the Celestial Bird, Mut-Itzamna, perched at the top,

and the entrance to the underworld, personified as the skeletal jaws of the White-Boned Serpent or Centipede, gaping at its base. In the sky, the world tree seems to have been equated with the Milky Way, called “the White Road” in Classic texts. Its uppermost terminus was located at the north celestial pole. Deceased souls, along with shamans, move up and down this conduit between cosmic tiers, hence the euphemism for royal death, “he entered the road,” in Classic texts. As shamans, Classic kings were supposed to navigate between worlds along the world tree via trance states induced by bloodletting. The king’s body itself is symbolically equated in art with this axis mundi.

Each of the four cardinal directions was equated with a symbolic color. Red, color of the sunrise, represented the East, a positive direction because of its solar associations. By contrast, West was associated with black and had negative connotations because of its connection with sunset, and by analogy, death. North (white) was the direction of the sun’s zenith, followed by dead kings in their apotheosis to the celestial world (Extra 7). It was the domed house of the sky, raised by the Maize God during the last creation of the world. South (yellow) pointed to the depths of the underworld. The earth was supported by four beings referred to as Bakabs or Pauhatuns. According to the *Chilam Balam of Chumayel* (Extra 5), they were survivors of the destruction of the third creation. In other sources, they are the winds. The Maya rain god, Chaak, is also depicted with four manifestations corresponding to the cardinal directions.

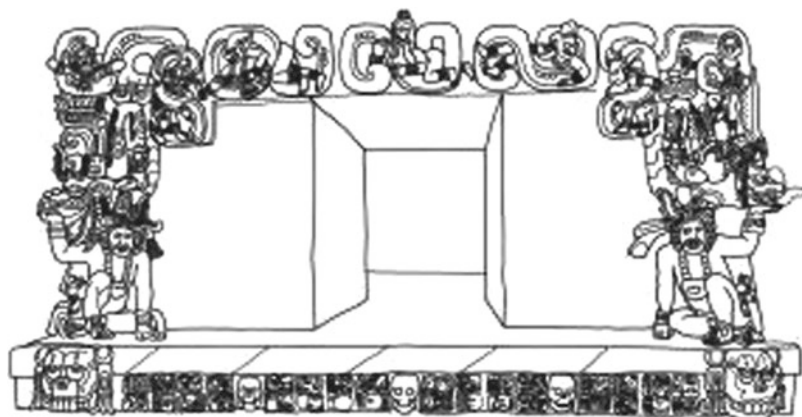
Below the earth lay the nine-tiered underworld, Xibalba, “place of fright.” This underwater realm was pictured as dark, foul, cold, associated with disease, death and rot, home of monsters and malevolent gods like the Lords of Death named in the *Popol Vuh* by such epithets as “Pus Master” and “Stab Master.” Xibalba rotates over the earth at night to become the night sky. Caves, the jaws of the earth, were entrances to Xibalba, paths taken by the setting sun as it entered the underworld. At the same time, caves carried connections with fertility, being the source of rain, clouds, and maize. Another type

of cosmic portal, perhaps a manifestation of the *axis mundi*, is represented in Classic art by supernatural snakes, Vision Serpents. These entities, brought into transient existence by the bloodletting rites of Maya kings, serve as bridges between the rulers and the realm of their ancestors, who are seen emerging from the serpent’s jaws to bestow their blessings (Figs. 2 and 3).

The upper world, with its 13 levels, was represented in art by the Skyband, a two-headed serpent or crocodile symbolizing the ecliptic. The serpent image may be a visual pun: in the Cholan Maya language, *kan* (snake) resembles *can* (sky). Skybands were used as borders demarcating the upper world in art. The ecliptic can also be represented as a cord which guides the celestial bodies across the sky. The daytime sun was represented by the male deity, Ah Kin or Kinich Ahau. At night, the sun passed through Xibalba, where it took the form of the Jaguar God of the underworld (although an alternate interpretation connects him with the moon). The moon could be represented by a goddess, often depicted as a youthful seductress, accompanied by the rabbit that was seen in its features. Lunar eclipses, recorded and predicted with accuracy, may have been the preserve of a separate divinity (Figs. 4, 5, and 6).

The Maya also charted the movements of Venus. As in other parts of Mesoamerica, this planet was associated with warfare. It is possible that military engagements were timed in the Classic period according to the planet’s 584-day cycle, though recent epigraphic work suggests that more pragmatic factors no doubt also influenced such decisions. In the *Popol Vuh*, Venus is depicted as carrying the sun. The Maya kept track of the behavior of other planets visible to the naked eye, but our understanding of their planetary symbolism remains uncertain. For example, Mercury may have been identified with the deity Kawil, whose reclining posture may reflect the planet’s observed position just above the horizon, but another interpretation links the same deity to Jupiter.

The stars were set in motion by the raising of the world tree at the last creation. Maya conceptions of the zodiac and constellations remain poorly understood. It appears that the Pleiades



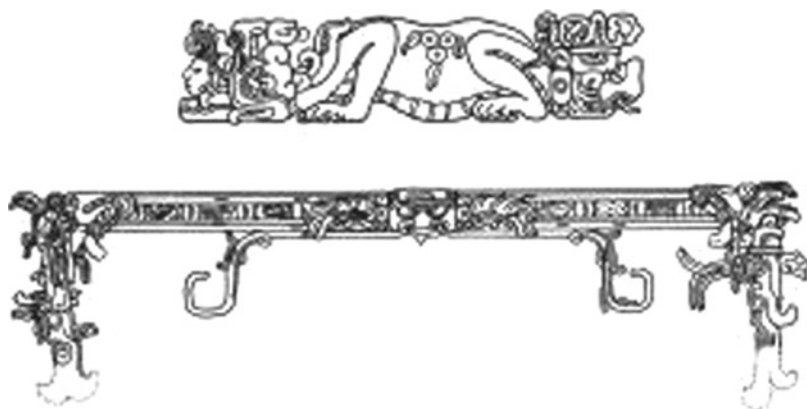
Cosmology in Mesoamerica, Fig. 2 Doorway of Temple 22, Copan, Honduras, Late Classic Period. The decoration of this temple structure symbolizes the Maya cosmos. At the *top*, the serpentine Cosmic Monster represents the sky. The crouching figures on either side of the entrance are bacabs or pauhtuns, the deities who support the world. The skulls at the base represent the underworld.

The doorway itself represents a symbolic cave, entrance into the underworld. When the Copan ruler Waxaklahun Ubah Kawil (18 Rabbit), who commissioned the structure, entered the temple he was symbolically entering a portal to the supernatural world of his ancestors (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))

Cosmology in Mesoamerica,

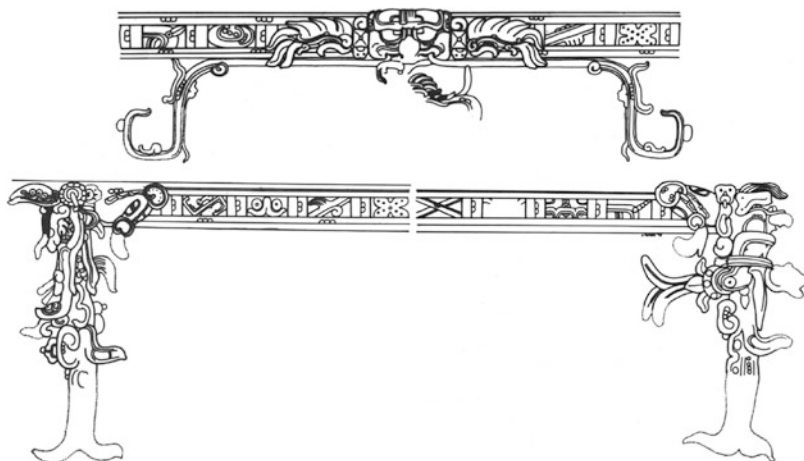
Fig. 3 Vision Serpents, Late Classic. Detail of two vision serpents with ancestors emerging from mouth and two double-headed serpent bars with deities emerging from opened mouths (Drawing/ text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)





Cosmology in Mesoamerica, Fig. 4 Classic Maya Sky Serpents. Two variants of the double-headed serpent representing the ecliptic. *Top*: legged variant, Altar 41, Copan, Honduras. *Bottom*: stucco relief sculpture

from House E of the Palace at Palenque, Mexico (Late Classic, ca. 600–800 CE) (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))



Cosmology in Mesoamerica, Fig. 5 Skybands from Palenque, Late Classic Maya. Reconstruction of stucco relief sculptures from “bicephalic Room,” House E, Palenque. The *top* drawing shows the Celestial Bird and skyband, from the north wall. The *bottom* drawing represents a second two-headed deity, a composite of skyband

segments from the west and east walls. The skyband on the Western wall has a saurian or reptilian head with Venus markings (Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)

were envisioned as a rattlesnake (*Sab*), while the belt of Orion was equated with a turtle (*Ak*), through whose shell the Maize God resurrected at the last creation ([Extra 7](#)). Alternatively, *Ak* may correspond to Gemini, and the Pleiades were also identified with 400 boys killed by the monster Zipacna, an event placed by the *Popol Vuh* shortly before the last structuring of the world. A scorpion constellation may be identical to

Scorpio, or correspond to Gemini. Mut-Itzamna, avian shamanic alter ego of the sky deity Itzamna, seems to have been identified with the Big Dipper.

For the Maya, the present universe is the most recent of cyclic creations destroyed by past catastrophes. The last reordering of the cosmos occurred in 3114 BCE, the mythic starting point of the ► [Long Count](#) dating system ([Extra 6](#)).



Cosmology in Mesoamerica, Fig. 6 Paddler Sun, Early Classic Maya. Drawing of lidded four-legged vessel. Each of four legs represents a downward facing peccary. Atop the lid, the Sun God, wearing a cap marked with k'in ("sun") paddles his canoe through a watery environment containing fish. This vessel has been interpreted as representing the Sun God paddling his canoe across the ecliptic and the constellation of Gemini (Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)

According to an inscription in the Temple of the Cross at Palenque, the creator deities First Mother and First Father (the Maya Maize God) set three hearth stones at the center of the universe, identified with the stars Alnitak, Saiph, and Rigel. As the sky lay flat upon the earth, the Maize God lifted it up to its present position, supported by the world tree. This ordering of the cosmos set in motion time and the movements of the stars.

In the *Popol Vuh* creation myth, the gods of creation reside in watery chaos, silent and dark. They create the first version of the universe, populated by animals, but are unsatisfied because the

beasts are incapable of worshipping their makers. To rectify this deficiency, the gods create the second world and make the first humans out of mud. However, these creatures were incapable of thought, and the gods destroyed them and their world by water. On the advice of an elderly couple skilled in divination, the gods created the humans of the third creation out of wood. These people were able to speak, but had no emotions, and did not recognize the gods as their creators. This failed experiment was brought to an end by a flood and rain of pitch. The few surviving wooden men were transformed into monkeys.

Order was brought out of the chaos left by the flood by the erection of the vault of the sky and separation of the earth from water. The gods created the current race of humans from maize, but they proved to be too smart for their creators' liking. As a countermeasure, the gods limited their understanding. From the interior of the terrestrial cornucopia, First True Mountain, came seeds, maize and water for the sustenance of humanity.

Aztec/Nahua Cosmology

The Mexica, or Aztecs, and related peoples of Postclassic Central Mexico, envisioned the universe as a fluxing reality permeated with spiritual forces in endless transformation. Like the Maya, they seem to have believed in an upper world of 13 levels and an underworld of nine, though this conclusion, based on colonial sources, has been questioned. The earth was pictured as a disk or a floating crocodilian or toad-like monster, Tlaltecuhltli, bounded by a square or circle of water joined to the vault of the sky. For the Aztecs, the central axis connecting the three realms of the universe transfixes the earth at their capital city, Tenochtitlan, on the site of the Templo Mayor (great temple). As in Maya cosmology, the world was divided by the four cardinal directions. East, associated with solar hues of red and yellow, was viewed as positive. North was referred to as the Land of the Dead, as it was believed that the journey of souls to Mictlan, the underworld, began here. It was cold and its color

Cosmology in Mesoamerica,

Fig. 7 Detail of ceremonial mosaic shield interpreted as representing the central axis of Aztec cosmology. A world tree sprouts on the upper level, the sun symbol with the four directions and the center laid out in a quincunx pattern decorates the middle level. A serpent spirals through the four layers of the cosmos (Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)



was black. West, the Region of Women, was associated with the positive colors, blue and green, while South, called the Region of Thorns, was symbolized by white. Each direction had its own version of the rain god, Tlaloc, in a similar fashion to the Maya Chaaks. A slightly different Nahuatl conception of directional symbolism, probably produced in Puebla or Tlaxcala, is illustrated in [Extra 8](#) (Figs. 7 and 8).

On the earth's surface, mountains were hollow repositories of water and clouds, entrances to Tlalocan, the paradise of the rain god. The mythical Mountain of Sustenance was the source of maize, from where it was stolen by the god Quetzalcoatl at the last creation for the benefit of humans. Rivers and caves were the hungry orifices of the Earth Monster, who bore crops for human survival but devoured humans when they returned to the earth at death (Fig. 9).

The upper realms included the paradise of the sun, to where the souls of warriors slain in battle or captured and sacrificed, and of women who died in childbirth, ascended after death. They were privileged to accompany the sun on its daily journey across the sky. Tlalocan was another celestial paradise where the spirits of humans who died by drowning, lightning, or

diseases associated with water went to spend the afterlife in joy. The uppermost heaven belonged to the primordial couple, the creator deities Ometecuhtli and Omecihuatl. The sun was represented by the god Tonatiuh, and also equated with the Aztec tribal patron, the war god Huitzilipochtli. As among the Maya, Venus had a malevolent role among the heavenly bodies. The god of Venus as the Morning Star, Tlahuizcalpantecuhtli, is represented in the Borgia group of manuscripts with a skeletal mask, hurling darts at his victims. This deity was a manifestation of Quetzalcoatl. It is commonly repeated in the literature that another form of Quetzalcoatl, the dog god Xolotl, represented Venus as the Evening Star. Meteorites were equated with caterpillars and worms and were referred to as the excrement of the stars. Some stars were *tzitzimime* – demons who will devour humans at the end of the present creation. The Milky Way was represented as a divine couple, Citlaltonac and Citlalicue (Fig. 10).

At the nadir of the underworld was Mictlan, land of the dead, destination of those souls who did not die in battle or by sacrifice. This was a shadowy half-world much like the Greek Hades, where the dead were not tormented but faded into

Cosmology in

Mesoamerica, Fig. 8 The five directions of the Nahua cosmos: the four cardinal directions and center, with deities. *Clockwise from top right:* sun god, patron of the East; Tlaloc, god of rain, patron of the South; Xipe Totec, Our Lord the Flayed One, god of agricultural fertility and patron of the West; Mixcoatl, god of hunting, patron of the North (Reconstruction of MS painting from the *Codex Borgia*, p 25, Mixteca-Puebla style, Puebla/ Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola: NY: Dover, 1993. Used by permission of Alan Rodgers)



nonexistence. It was reached by the soul after an arduous journey through bitter cold and obstacles like wind-blown knives. A dog was sacrificed and included in burials to help the departed navigate this difficult passage.

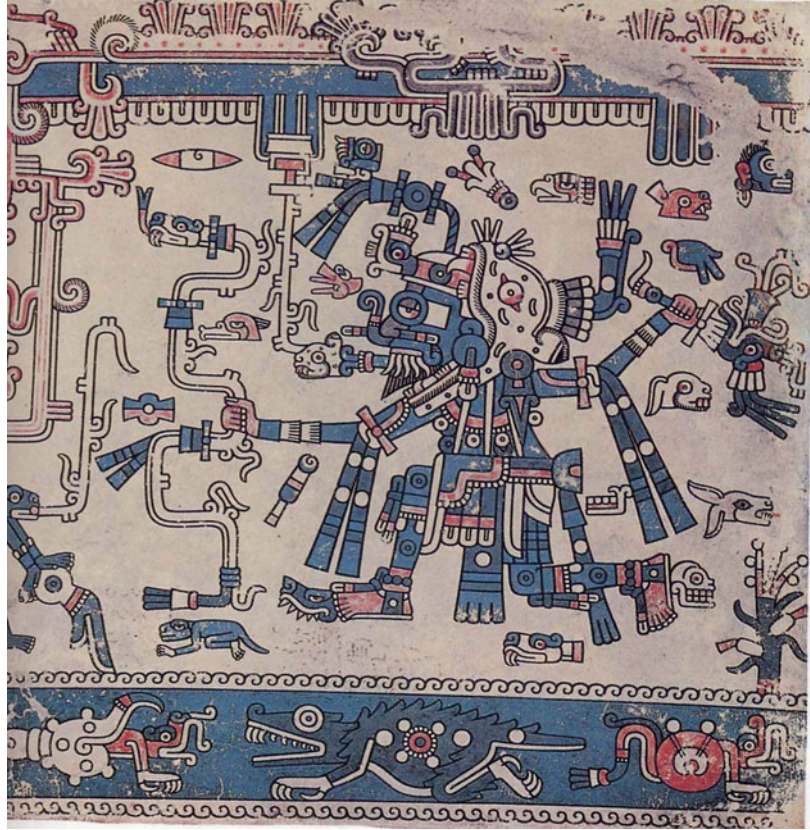
The Aztecs saw the present world as the fifth in a series of successive creations, or Suns, brought to an end by a series of destructions. According to one commonly repeated variant of the creation myth, the first world, Four Jaguar, was created out of primordial chaos, and ruled over by Tezcatlipoca, the protean god of kingship, fate, the night, and sorcery. The first created humans were giants – the Aztecs identified the bones of mastodons as their remains. At the end of this era, jaguars devoured these primal men. This catastrophe coincided with the defeat of Tezcatlipoca by his rival, Quetzalcoatl, god of the wind, fertility, and a culture bearer for later humans. The second creation, Four Wind, was effected and ruled by Quetzalcoatl in his

manifestation as the wind, Ehecatl. In turn, he was defeated by Tezcatlipoca, and his world and its humans wiped out by hurricanes. The few survivors became monkeys. Tlaloc governed the third world, Four Rain. This creation was brought to a violent end by fire and water, and the survivors became dogs, turkeys, and butterflies. Four Water, the fourth world, appropriately had Chalchiutlicue, goddess of ground water, as its patron. Fittingly, Four Water was destroyed by a flood; its human survivors were changed into fish (Fig. 11).

After the destruction of four Water, Quetzalcoatl and Tezcatlipoca collaborated to raise the sky from the earth, supported on the trees of the four directions. The Milky Way marks their path where they walked across the new sky. A crocodilian monster, variously identified as Tlaltecuhli or Cipactli, was vanquished by the two gods and split in half to become the earth. The gods altered her body to yield crops for

Cosmology in Mesoamerica,

Fig. 9 Tlaloc, god of rain, thunder, and lightning (MS painting from *Codex Laud*, p 45, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reproduced from Gordon Brotherston, *The Painted Books of Mexico*. London: British Museum Books, 1995, Fig. 148, p 135. Reproduced by permission of Gordon Brotherston)



humans, but in her pain, she required blood sacrifice in return for her bounty. Quetzalcoatl retrieved by trickery the bones of past humans from Mictlan to create new humans. He animated them by letting his own blood, another reason for offering blood sacrifices to the gods in gratitude. The gods assembled at the ancient city of Teotihuacan, to sacrifice themselves to create the Fifth Sun and start its motion across the sky. A disfigured god, Nanahuatzin, (“the purulent one”), sacrificed himself by immolation and became the sun. The future moon, who had hesitated to volunteer his life, followed Nanahuatzin’s example and emerged from the flames as brilliant as the sun. The other gods, remembering his cowardice, dimmed his brilliance by striking him in the face with a rabbit, leaving the pattern visible still on the moon’s surface.

This present Sun, Four Movement, will be destroyed by earthquake. In the hopes of delaying

this catastrophe, the Aztecs found further justification for human sacrifice on a grand scale to strengthen and nourish the cosmos.

Extra 1: Historical Time and Space in Mesoamerica

The indigenous peoples of Mesoamerica, like all other Native Americans, are the descendants of migratory hunter-gatherers who arrived in the New World from northern Asia by 12000 BCE, and perhaps considerably earlier. By 2000 BCE, the first Mesoamericans had developed a system of agriculture based on the staples of beans, squash, and most important, maize. This shift in economy led to the rise of permanent village communities and increasing levels of social stratification and cultural complexity.

By 1500 BCE, hierarchical societies with sophisticated cosmologies, monumental



Cosmology in Mesoamerica, Fig. 10 Tonatiuh, the Nahua sun god (*left*), and the moon with rabbit (*upper right*) (Reconstruction of MS painting from *The Codex Borgia*, p 71, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz

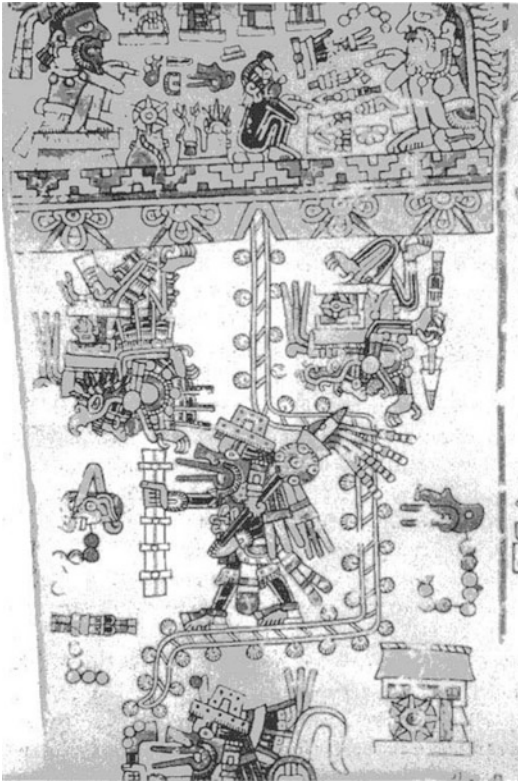
and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Reproduced by permission of Alan Rodgers)

architecture, urban settlements, and specialized artists had emerged along the Mexican Gulf Coast in the modern Mexican states of Veracruz and Tabasco, and in the highlands of Chiapas and southern Guatemala.

Mesoamerican scholars traditionally used the term “Preclassic” or “Formative” to refer to the period from these first manifestations of civilization down to the third century of the Christian era. This terminology is an artifact of the historical development and biases of Mesoamerican studies over the last 200 years. Because Maya art is relatively naturalistic and reminded nineteenth and twentieth century archaeologists of the Classical styles of the ancient Mediterranean, it was given a privileged status relative to the rest of Mesoamerican art. This, and Maya achievements in mathematics, astronomy and the calendar, led early scholars to equate the apogee of

Mesoamerican civilization with the period when the Maya erected cities and monuments dated by hieroglyphic inscriptions using the [Long Count](#) system. This time interval, ca. 250–900 CE, thus became the Classic Period, and rather predictably, the periods before and after it became the Preclassic (1200 BCE–250 CE) and Postclassic (ca. 950 CE–1521). During the Classic, it was alleged, the Maya and other Mesoamerican civilizations were governed by theocracies of astronomer priests and lived in utopian peace, free from conflict. During the Postclassic, the political and social order found among the societies encountered by the sixteenth century Spanish, based on war, human sacrifice, and monarchy, supposedly eclipsed this priestly paradise.

Discoveries in archaeology and epigraphy during the second half of the twentieth century have shattered the illusion of a Classic period



Cosmology in Mesoamerica, Fig. 11 Nine Wind, the Mixtec equivalent of Quetzalcoatl, descending from the heavens (MS painting from the *Tepexic Annals*, *Vienna Codex*, p 5, Late Postclassic. Reproduced from Gordon Brotherston, *The Painted Books of Mexico*. London: British Museum Books, 1995, Fig. 141, p 127, by permission of Gordon Brotherston)

governed by pacifist stargazers. It is now clear that the Classic civilizations, especially the Maya and the city of Teotihuacan in the Basin of Mexico, were engaged in warfare and human sacrifice on a large-scale, and that the Classic Maya were ruled by kings who were as much politicians and warriors as they were priests. It is also apparent that Mesoamerican civilization did not “degenerate” after the Classic period. It merely changed in directions that did not suit the prejudices of early pundits. But the chronological system has remained in use, despite proposed alternatives. The Preclassic, however, is now generally referred to as the Formative, in an attempt to characterize it based on its own characteristics – the formation of the general

Mesoamerican cultural pattern – rather than by comparison with the Classic.

The Formative Period is in turn divided into three stages. During the Early Formative (ca. 1500–900 BCE), Olmec civilization flourished on the Gulf Coast around the site of San Lorenzo, while chiefdoms in Oaxaca, Chiapas, and southern Guatemala participated with the Olmec in a system of trade and shared ideologies among elites. During the Middle Formative (ca. 900–300 BCE), San Lorenzo collapsed, and Olmec civilization became focused on other sites like La Venta. Elite centers as far away as the Mexican states of Guerrero and Morelos shared symbolism and perhaps even artists with the Gulf Coast. In Oaxaca, the Zapotec people founded the great city of Monte Alban, where the first evidence of the distinctive Mesoamerican calendar system appears. In the Maya region, urban centers with monumental architecture appear in both the highlands and lowlands of Guatemala.

By the Late Formative (300 BCE–250 CE), the Olmec culture declined and vanished from the archaeological record. In the central highlands of Mexico, the huge metropolis of Teotihuacan emerged as a major power with influence felt throughout Mesoamerica. In Veracruz and Chiapas, the oldest known inscribed dates in the Long Count come from this period. In the Maya region, huge cities rivaling their “Classic” descendants were raised at sites like El Mirador in Guatemala, and the ideology of Maya kingship began to take shape.

The Classic Period is usually divided into Early and Late phases. During the Early Classic (ca. 250–600 CE), Teotihuacan reached its peak of political, religious, and artistic influence on the rest of Mesoamerica, even apparently interfering in the political affairs of distant Maya city-states like Tikal, Guatemala. In the Maya area, fully developed hieroglyphic inscriptions appear. Centers like Tikal and Copan rose to political prominence and artistic glory. In Oaxaca, the Zapotec capital of Monte Alban reached its florescence. The Late Classic saw the full cultural and political development of Maya cities such as Tikal, Copan, Palenque, Yaxchilan, and Piedras Negras. In Central Mexico, Teotihuacan’s sacred center

was burned and abandoned, ending the city's dominant position, while other centers like Xochicalco and Cacaxtla flourished in its wake. Long-distance trade contacts are revealed by the eclectic art of these sites, showing influences from as far away as the Maya.

By 900 CE, most of the southern Maya cities were abandoned after overpopulation, soil exhaustion, drought and warfare led to the breakdown of the Classic Maya institution of kingship. No more ► [Long Count](#) dates were recorded. In Yucatan, however, Maya centers like Uxmal and Chichen Itza continued to thrive, the latter perhaps for several centuries. In Central Mexico, a multiethnic people, the Toltecs, established their capital at Tula in the modern state of Hidalgo, marking the transition to the Early Postclassic (950–1150 CE). In Oaxaca, the warring Mixtec dynasties described in their screenfold books began their rise to power. An art style or group of related styles, usually called “Mixteca-Puebla” after the two regions believed to be its place of origin, became an international visual language among Mesoamerican elites.

In 1168 CE, Tula was sacked and burned by invaders from the north, an event sometimes used to mark the inception of the Late Postclassic. In Yucatan and Guatemala, the Maya split into small warring polities. In Central Mexico, a certain degree of political unity was brought about by the Mexica or Aztecs. Originally from the north, the Aztecs migrated into the Basin of Mexico and founded their capital city of Tenochtitlan on the site of modern Mexico City, in the early fourteenth century. Within less than two centuries, they had established a system of tribute states, often erroneously labeled an empire, west into Guerrero, south into Oaxaca and Chiapas, and east to the Gulf Coast. The arrival of the conquistadors in 1519 brought Aztec hegemony – and native rule of any kind in central Mexico – to an abrupt end. By 1521, Tenochtitlan had been destroyed and Mexico became the Vice-royalty of New Spain. The Maya, less centralized, and with less gold to attract the attention of the invaders, held out longer. Yucatan was not firmly under Spanish control until the 1540s, and the last autonomous Maya kingdom, Tayasal in

Guatemala, was able to maintain its independence until it finally fell to Spanish forces in 1697.

Extra 2: Sources and Their Problems

Our knowledge of prehispanic Mesoamerican world views derives from several sources via which evidence of cosmological beliefs has survived both the ravages of time and the impact of the Spanish Conquest of the sixteenth century. Yet, each line of evidence is marked by ambiguities and gaps in information, simultaneously preserving and obscuring pre-Columbian conceptions of the universe. From the period of initial Spanish contact with Native Mesoamericans, we have written documents, chronicles, and letters by conquistadores and missionaries. In particular, the writings of Duran and Sahagun on the Aztecs, and Landa on the Yucatec Maya, have preserved much information about Mesoamerican cosmology in the sixteenth century. However, Colonial accounts of indigenous beliefs are frequently incomplete, propagandistic in their efforts to justify conversion of the “idolatrous” natives, and distorted by the conceptual frameworks of their authors. Western assumptions are forced onto very different views of the cosmos, leading to debate and uncertainty for centuries to come ([Extra 3: Did Mesoamericans Have Gods?](#)). In addition, the validity of using these late traditions to interpret the beliefs of earlier Mesoamerican civilizations is limited, since systems of thought rarely remain static for centuries. Many attempts to “read backwards” from colonial sources to interpret earlier belief systems founder on the uncertainty created by such large gaps in time.

At the same time as they were preserving aspects of Mesoamerican cosmology in their writings, the friars of the sixteenth century were busy destroying another type of evidence – indigenous screenfold books. Many of these documents, painted on bark paper or deer skin, were burned by the colonists in their zeal to destroy Native Mesoamerican religions. Few have survived as a result ([Extra 4](#)). These painted

books contain scenes illustrating episodes from cosmogonic myths, symbolic maps of the universe, and astronomical observations. Unfortunately, they are frequently fragmentary or poorly preserved. Without surviving oral tradition, their imagery is often difficult to interpret, and owing to their fragility, only examples from the centuries immediately preceding European contact have endured.

Over the last half century, epigraphers have made tremendous progress in deciphering Maya hieroglyphs. These advances have led to increased understanding of Maya cosmology during the Classic Period (ca. 250–900 CE) on the basis of inscribed texts. However, work in this field is still in an early, rapidly developing stage, with the result that newly published translations are often provisional and sometimes quickly superseded – hallmarks of a discipline in flux.

Art historians have contributed to our comprehension of pre-Columbian conceptions of the cosmos through interpretations of iconography. While their work has led to the recognition of cosmograms, astronomical symbols, and creation myths in Mesoamerican art, it is frequently speculative and controversial. In particular, attempts to interpret the religious art of earlier cultures by using Conquest-era sources are fraught with uncertainty, as noted above. In a similar fashion, archaeology has played its role in the recovery of ancient Mesoamerican world views via careful excavation of monuments and art as well as traces of ritual behavior. But again, interpretation of the data in the absence of written texts or clear-cut continuities with historic observations remains limited by the incomplete nature of the archaeological record. The looting of archaeological sites, leading to the appearance on the art market of artifacts orphaned of their context, has further contributed to the loss of information.

A hybrid discipline, called archaeoastronomy in the US and astroarchaeology in Britain, arose in the 1970s out of collaboration between archaeologists and astronomers. It focuses on ancient knowledge and practice of astronomy as revealed by site orientations, building alignments, and visual images. In Mesoamerica, it has elucidated the understanding and observation of celestial

phenomena in pre-Conquest times, frequently working in close conjunction with epigraphy and archaeology.

Traditional Mesoamerican cosmologies are by no means dead systems confined to the past. Indigenous conceptions of space, time, and creation persist among some of the present-day descendants of the pre-Columbian peoples, notably Maya groups in rural Guatemala and Chiapas, and the Mixtec of Oaxaca. Historic and contemporary ethnographic data have been used to clarify prehispanic beliefs, although again caution is needed when extrapolating meanings from the present to the past across centuries marked by the disruption of colonization and the influence of Christianity ([Extra 5](#)).

Extra 3: Did the Ancient Mesoamericans Believe in Gods?

The sixteenth century missionary friars who recorded accounts of Mesoamerican religions for the ultimate aim of destroying them, imposed preconceived frameworks derived from the classical Mediterranean and Judeo-Christian traditions onto the alien belief systems they sought to understand. Faced with images and stories of a myriad of supernatural forces, the colonial writers classified these mythic entities along the lines of the Greco-Roman pantheon of deities, each a discrete being with clearly distinguished personality, function, and symbols. The limits of this approach led to strange contradictions from the start. For example, the mercurial Aztec deity Tezcatlipoca, associated with both kingship and sorcery, was equated by the Spanish chroniclers with both Jupiter and Lucifer. However, the Eurocentric assumptions behind such taxonomies remained unquestioned until well into the twentieth century ([Fig. 12](#)).

In the 1970s, a number of scholars began to argue from closer reading of colonial sources as well as the results of archaeological, ethnographic and art historical research, that the Aztec, Maya, and Zapotec peoples had no conception of separate and distinct gods. Rather, what the Spaniards erroneously interpreted as a

Cosmology in Mesoamerica,

Fig. 12 Tezcatlipoca, (Reconstruction of MS painting from the *Codex Borgia*, p 17, Mixteca-Puebla Style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Used by permission of Alan Rodgers)



well-defined pantheon was in fact a series of overlapping symbolic complexes, representing natural phenomena conceived as protean and fluxing manifestations of a generalized notion of holiness or sacred force. The words employed for this dynamic concept – *teotl* in Nahuatl, *ku* in Maya, and *pee* in Zapotec – had been translated as “gods” by the Spanish.

Some modern writers – most notably the American anthropologist Joyce Marcus – have argued the extreme conclusion that ancient Mesoamericans had no gods at all, just symbols of natural phenomena and venerated ancestors. This interpretation in its strictest sense certainly applies to some alleged “deities.” The Maya icon designated “God C” by the nineteenth century scholar Schellhas in his attempt to classify the supernatural images in Maya codices is now generally accepted by epigraphers and art historians to denote a general quality of holiness rather than a specific divine personality. On the other hand, it seems clear from recent hieroglyphic decipherments that the Classic Maya did believe in a series of relatively separate gods whose acts are recorded in texts and whose distinctive emblems appear in art. While more fluid and dynamic in their identities than the denizens of Olympus, these entities can be usefully conceptualized as

gods, a view argued by the American anthropologist and iconographer Karl Taube, among others.

Extra 4: Mesoamerican Screenfold Books

At the same time as they were creating one source of evidence for prehispanic Mesoamerican cosmologies via their writings, the Catholic missionaries of the Spanish Conquest were busy destroying another – the screenfold books of the indigenous peoples. These fragile testimonies to Native American thought were burnt as symbols of the “heathenism” or “diabolism” that the friars sought to replace with forced conversion to Christianity. As a result of this holocaust of texts, very few of these manuscripts have survived to receive the attention of modern anthropological, epigraphic, and art historical study.

Mesoamerican folded manuscripts, often referred to in the literature by the Eurocentric term “codices,” consisted of long sheets of beaten bark paper or (in the Mixtec area) deer skin. Narrative scenes, deity images, and glyphs were painted, usually in polychrome, on a thin outer surface of plaster. The paper was folded like an

accordion, dividing it into “pages” or “folios.” The resultant manuscript was “opened” by unfolding it.

No prehispanic Aztec painted books survived the depredations of the colonial clergy. A manuscript illustrating Aztec deities and calendrical practices, the *Codex Borbonicus*, was once thought to represent such a miraculous survival, but art historical data now suggest a date early in the colonial period. From this transitional epoch, we have several manuscripts, in both screenfold and European bound formats, commissioned and annotated by Spanish officials and missionaries but painted by Aztec artists. Frequently, the style is a fusion of pre-Conquest traditions with varying admixtures of the visual language of European Renaissance art. Some of these books preserve Aztec myths and calendric information, albeit incompletely.

A group of screenfold manuscripts of late prehispanic (Late Postclassic) date have been labeled the Borgia Group because of their stylistic affinities with the best-known example, the *Codex Borgia*. These manuscripts appear to have been collected at the time of the Conquest and to have found their ways by often untraceable routes into famous European collections, hence their names. In the opinion of the majority of art historians and anthropologists, this group was painted in the present-day Mexican states of Puebla and Tlaxcala, though a small scholarly contingent still suggests a Mixtec origin. They are frequently labeled as “Aztec” in the popular literature. If the dominant theory is correct, the artists who created these works spoke the same language as the Aztecs (Nahuatl) but were politically and ethnically distinct. The Tlaxcalans, in particular, were the traditional enemies of the Aztecs and assisted Cortes in his destruction of Aztec power. The manuscripts of the Borgia Group seem to have been guides for a divination system based on the 260-day ritual calendar, also containing prescriptive representations of other rituals, astronomical information, and narrative scenes of mythic events in a distinct style characterized by bright, flat colors, bold outlines, and cartoon-like exaggerations of distinguishing features and costume elements. Their symbolic

maps of the universe – like the frontispiece of the *Codex Fejervary-Meyer* reproduced here – constitute excellent graphic evidence for ancient Nahuatl cosmology.

Another group of screenfold manuscripts collected during the Spanish invasion and scattered through European collections was produced by the Mixtec in what is now the Mexican state of Oaxaca. Although the style has similarities to that of the Borgia group, the content consists mostly of historical and genealogical narratives documenting the deeds and land claims of elite families. The most famous of these manuscripts is the *Codex Zouche-Nuttall*, which chronicles in pictorial form the exploits of the eleventh century Mixtec king Eight Deer. All date from the last centuries before the arrival of Europeans. Although their emphasis is not on ritual or calendrics, images of origin myths and deities contribute to our knowledge of Mixtec cosmology.

All of these Central Mexican manuscripts include glyphs of names and dates in the 260-day calendar, rebus writing and symbols for geographic locales, but only the Maya painted books contain phonetic texts. Three examples escaped the friars’ fires in the sixteenth century to appear in Europe: the *Dresden Codex*, the *Madrid Codex*, and the *Paris Codex*, named after their present-day locations. These books appear to have been painted shortly before the Conquest in Yucatan. A fourth book appeared in 1973, with claims that it had been discovered by looters in a dry cave in the Mexican state of Tabasco. Although it was rejected in some circles as a fraud at the time, subsequent radiocarbon tests indicate an age in the twelfth to thirteenth century CE, and the Venus tables it contains reflect Maya concepts that were not rediscovered until several years after the book’s appearance. Contemporary consensus therefore holds it to be genuine. All of these Maya books contain tables of observations for predicting eclipses and the movements of celestial objects like Venus, almanacs for agriculture, and guides to ritual performance. Like the Borgia Group, they were once the property of indigenous priests.

Extra 5: Maya Myths in Historic Manuscripts

In the centuries following the Spanish Conquest, some indigenous myths, including much information on cosmology, were preserved by being recorded in Latin script by Native writers. In Yucatan, several versions survive of the *Book of Chilam Balam*, or Jaguar Priest. These variations of the text are titled after the town that was each one's origin. The most famous example of these was composed in the town of Chumayel. These contain oral historical traditions, astrology, ritual practices, and prophecies tied to the cycles of time in the Maya calendar. Some of this material appears to be of prehispanic origin and is a valuable source for understanding the world view of pre-Columbian Yucatan. However, it is also clear that events from colonial history and the Judeo-Christian tradition also figure in the *Books of Chilam Balam*, suggesting the need for caution in using their contents uncritically as a basis for understanding pre-Christian beliefs.

In the southern highlands of Guatemala, an epic poem of the Quiche Maya, the *Popol Vuh* or “book of the mat” (mats were a symbol of rulership in ancient Mesoamerica), was apparently written down in Latin script by a Spanish-schooled Maya shortly after the Spanish Conquest. No original of this early version has been preserved, but copies were transcribed into the mid-nineteenth century when they came to the attention of European scholars. Like the *Books of Chilam Balam*, the *Popol Vuh* seems to contain a considerable amount of prehispanic material, drawn both from oral tradition and screenfold manuscripts, though here, too, Catholicism and colonialism have made their mark upon the contents. The *Popol Vuh* is a history of the Quiche people incorporating a version of the Maya myth of the previous creations and destructions of the universe. Perhaps the most well-known section is the saga of the Hero Twins, Hunahpu, and Xbalanque, whose adventures intertwine with and set the stage for the last creation of the cosmos and man.

Recent studies in Maya epigraphy and iconography have demonstrated that aspects of the

Popol Vuh – especially the Hero Twins epic – represent survivals of Maya myths dating back to the Classic period and probably earlier. The Hero Twins' legendary battles with the gods of the underworld recur in Classic Maya vase painting, and contribute to the trappings and ideology of Classic Maya kingship. The art historical and hieroglyphic material has in turn begun to permit the reconstruction of sections of the Classic version of the myth that did not survive to be incorporated in the colonial text. The identification of the father of the Hero Twins with the Maya maize god, his role in the creation of the world, and further details of the twins' defeat of the lords of death have emerged from Classic scenes and texts. The case of the *Popol Vuh* is one instance where post-Conquest materials have been fruitfully used to increase our understanding of pre-Columbian beliefs and symbols.

Extra 6: Olmec Cosmology

According to the theories of Joralemon (1996), based on his readings of Olmec iconography, the Olmec lived in a shamanic, multilevel mental universe akin to that of their Maya successors. In his view, the earth was pictured as a crocodilian Earth Dragon floating in a primordial sea. Mountains were its scutes, and vegetation sprouted from its back. Mountains may have been viewed as containing water as in later myths – certainly archaeology shows that the Olmec venerated mountains and springs. The sky was represented by a Bird Monster, and the ocean under the earth by the shark-like Fish Monster. As in Maya belief, this watery underworld was the home of ancestral spirits. According to Joralemon and other scholars like Reilly (1996), carvings of rulers seated in jaguar or serpent mouths are shaman-kings accessing portals to the underworld (Reilly) or the upper world (according to Karl Taube) through trance and ritual. The site of La Venta is now interpreted, along Maya lines, as a cosmogonic center, recreating the creation and structure of the cosmos through its architecture, buried offerings, and associated rituals. A stone mosaic intentionally

buried there has been read as an image of a jaguar, associated with the underworld via later Aztec and Maya myths; or as the saurian earth monster on the surface of the sea. Serpentine (greenstone) pavements from the same center have been interpreted as representations of the blue-green watery underworld itself. A massive pyramid, forerunner of later temple platforms throughout Mesoamerica, is equated with the primeval “Snake Mountain” which emerged from watery chaos at the creation of the world in later cosmogonies. Schele (1996) has interpreted Olmec art as reflecting belief in a world tree, the bridge between levels of the cosmos, equated as among the Maya with the person of the ruler. These interpretations, which seek to demonstrate continuity between Olmec and later cosmologies, are widely accepted, but not without critics who call assumptions of such continuity in beliefs over several millennia into question (Fig. 13).

Extra 7: The Maya Hero Twins

The myth of the Hero Twins Hunahpu and Xbalanque from the *Popol Vuh* is intertwined with the Maya creation myth. Its action is set during the transition between the end of the third creation and the inception of the fourth. Recent discoveries from epigraphy and art history reveal that the Classic version of this myth was even more explicitly tied to the story of the making of the fourth world.

The saga begins with a first set of brothers, Hun Hunahpu and Seven Hunahpu. During the Classic period, Hun Hunahpu was identified as the Maize God, and his death and rebirth in the narrative were associated with the cyclical growth of corn. This first pair were avid players of the traditional Mesoamerican rubber ball game, known in the archaeological record from Olmec times, played by the Aztec and Maya at the time of European contact, and still practiced today in parts of rural Western Mexico. Unfortunately, the noise created by the brothers’ favorite pastime irritated the ruling gods of Xibalba, who summoned them to the underworld and challenged them to a ball game where the stakes



Cosmology in Mesoamerica, Fig. 13 This inscribed greenstone celt from Rio Pesquero, Mexico, depicts an Olmec ruler symbolically equated with the axis mundi. His legs form the head of a serpent, and he holds another in his arms. The four-stylized corn plants represent the four directions. The ruler occupies the center, representing the mediating vertical axis of the universe which, like the king himself in his role as shaman, provides humans access to the supernatural worlds above and below the earth. This interpretation is by Linda Schele and F. Kent Reilly and is based in part on later Maya iconography (Middle Formative, ca. 900–400 BCE) (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))

were life or death. Because of the supernatural powers and trickery of the lords of Xibalba, Hun Hunahpu and his brother were rapidly defeated and executed. Their bodies were buried but Hun Hunahpu’s head was hung up on a tree for display. As befitting a maize god, its presence made the formerly barren tree sprout an abundance of

fruit, identified with the calabash in the *Popol Vuh*, but apparently with cacao (chocolate) in some Classic Maya vase paintings.

One of the daughters of a lord of the underworld, Blood Moon, visited the tree out of curiosity at its sudden fertility. The skull of Hun Hunahpu hanging there spit into her palm, magically impregnating her. When her father learned of her pregnancy, he attempted to have her murdered, but she fled Xibalba to the middle world where she gave birth to Hunahpu and Xbalanque.

As youths, these twin boys distinguished themselves by a number of exploits. They defeated the bird monster Seven Macaw, who falsely proclaimed himself to be the sun. This usurper seems to have been equated in the Classic period with Mut-Itzamna, the Celestial Bird shown perched atop the world tree. The vanquishing of this false sun seems to coincide with the destruction of the last creation. The twins also conquered Seven Macaw's son, the crocodilian Zipacna.

Eventually Hunahpu and Xbalanque discovered the ball game equipment of their father and took up the sport with great energy. Their noise eventually also reached the Lords of Xibalba, who summoned them to a challenge like that which their father and uncle had failed to master. Unlike the first brothers, the Hero Twins rose to the occasion, outwitting the ordeals and tricks of the gods of the underworld with clever strategies and magical powers of their own. In the last and most spectacular of these supernatural feats, the Hero Twins followed the advice of a diviner and submitted to execution. Their bodies were burned and their ashes cast into the waters of Xibalba. The rulers of the underworld believed they had defeated these troublemakers as decidedly as they had beaten their father.

But Hunahpu and Xbalanque were reborn, appearing first as catfish and then disguised as itinerant magicians. They performed a magic trick in which they killed each other and then magically restored the other to life. Hearing of this spectacle, the lords of Xibalba were intrigued and summon the performers to demonstrate this wonder. Having seen this miraculous resurrection, the underworld gods are so enthusiastic

that they demand to be used as volunteers for the trick. Predictably, the twins kill the lords of death as requested, but do not bring them back to life.

In the *Popol Vuh*, the twins attempt to raise their father and uncle from death, but are only partially successful, and cannot bring them back to the land of the living. The iconographic and inscriptional evidence from the Classic period provides an alternative ending. After defeating the lords of death, apparently with the connivance of the moon goddess and her rabbit, they succeed in resurrecting the Maize God, who is shown in several painted scenes as emerging from the body of a turtle representing the earth. The Maize God then acts as the demiurge of the most recent creation, separating earth from sky, raising the world tree, setting up three hearthstones (the traditional number in Maya houses) at the center of the universe, and erecting the vault of the heavens. In the Classic scenes and texts, the chief of the underworld gods is God L, an elderly deity associated with wealth and the profession of merchant. He appears not to have been sacrificed but humiliated and forced to pay tribute to the gods of the sky (Figs. 14 and 15).

The Hero Twins have been equated with the sun and moon, and the first brothers with Venus in its twin guises as Morning Star and Evening Star. In both versions of the myth, the victory of the Hero Twins limits the power of death in the world and points the way toward the hope of rebirth. Like the first brothers, the Maya elite were believed to descend to the underworld after death, but they hoped to be reborn as were both the Hero Twins and the Maize God, and to ascend triumphantly to the celestial world like the latter following his resurrection. Like the Christian myth in Europe, the story of the Hero Twins was the template for tomb art and funeral practices among the kings of the Maya, a model for their anticipated conquest of death.

Extra 8: A Nahua Cosmogram

The Codex Fejevary-Mayer is a painted manuscript belonging to the Borgia Group,

Cosmology in Mesoamerica,

Fig. 14 Resurrection of the Maize God. This scene from a Classic Maya (600–900 CE) painted ceramic vessel shows the resurrection of the Maize God, pictured emerging from a cleft in the carapace of a turtle representing the earth. He is attended by his sons, the Hero Twins. The skull at the base of the cleft represents the head of the Maize God, decapitated following his defeat by the rulers of Xibalba. As corn sprouts from seeds, so human bones were viewed by the Maya as the seeds of eventual rebirth in the afterlife, following the pattern set by the Maize God's story (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))



Cosmology in Mesoamerica, Fig. 15 This scene, painted in black line on a white background on a ceramic vessel of the Late Classic period, illustrates a section of the Classic version of the myth of the Hero Twins not found in the later *Popol Vuh*. Following his resurrection by the Twins, their father, the Maize God, is depicted triumphant over God L, chief of the Lords of the underworld. On the *left*, the Maize God is trampling his former

persecutor, while in the scenes at *center* and *right*, the Lord of Death is stripped of his regalia by the victorious Maize God. The dwarf accompanying the Maize God represents the undeveloped or stunted ears of corn frequently found attached to complete examples (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))

manufactured probably in the Mexican states of Puebla and Tlaxcala in the century preceding the Spanish Conquest of 1521. The first image in this amazing pictorial document is a symbolic map of the cosmos organized around the four cardinal directions, complete with their associated divinities. This diagram, frequently reproduced in surveys of Mesoamerican art and religion, is a remarkable window onto the world view of the Nahuatl-speaking peoples of Central Mexico in the Late Postclassic period.

At the center of the diagram is the black world axis connecting the vertical layers of universe, represented by the fire god Xiuhtecuhtli. This deity spanned the three realms, and was thus equated with the axis mundi, as was his implement, the fire-drill. Streams of blood flow toward him from the four cardinal directions, representing the human sacrifices to sustain the gods. Each direction has its own associated tree, the pillars of the sky. As in most Mesoamerican maps and cosmograms, East is on top, with its patron deities Itzli (a personified sacrificial knife) and Tonatiuh, the sun god, its colors appropriately red and yellow. To the left is the North, ruled by Tepeyollotl, an aspect of the royal god Tezcatlipoca, and Tlaloc, the rain deity. North for the Nahuatl-speaking peoples was the direction where the difficult journey of souls to the afterlife began. Fittingly, its color is black. At the bottom is West, where the earth monster Tlaltecuhltli swallows the sun at sunset. The patron gods shown here are Chalchiutlicue, goddess of ground water, and Tlazelteotl, “eater of filth,” a goddess of sin and confession. Its color is white. To the right is South, associated with blue and green. Here a cocoa tree accompanies the ruling deities of this direction, Mictlantecuhtli, the skeletal god of death and the underworld, and Centeotl, the goddess of mature corn. Between the arms of this cosmic cross are the four intercardinal directions: summer solstice sunrise, upper left; winter solstice sunrise, upper right; summer solstice sunset, lower left; and winter solstice sunset, lower right. The eight-lobed band around the world trees represents the 260-day ritual calendar. Like the other books of the Borgia Group, Fejevary-Meyer contains

information for divining the future of individuals based on their birth date in the 260-day cycle. It probably belonged to a priest or oracle.

See Also

- ▶ [Astronomy in Mesoamerica](#)
- ▶ [Calendars in Mesoamerica](#)
- ▶ [Eclipses in the Americas](#)

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Cosmology of the African San People

Sven Ouzman

Using words to capture and convey our beliefs and experiences may seem precise and comprehensive, but such omniscience is illusory (Mitchell, 1994). It may, however, be possible to fragment the totalising influence of words and concepts like “cosmology” – knowledge of the world – by using historically specific texts, images, sounds and sensoria to promote epistemological diversity. This approach works well

Cosmology of the African San People,

Fig. 1 Bushman group, colonial South Africa, 1884 (From Bleek and Lloyd 1911, p. 99)



within a culture. I can, for example, distinguish between Southern Baptist and Greek Orthodox as two heterodox forms of Christianity. But what about other people, in other places, at other times? The people on whose behalf we interlocate – in this case the San or Bushmen of southern Africa (Extra 1) – have histories marked by imperialism, colonialism, missionisation and Apartheid (Fig. 1). How then do we know when our information about these people draws on their remembrances of original traditions or when it embodies recent histories of violence? Despite ethnography’s ethical problems (Clifford & Marcus, 1986), we can use multiple strands of evidence to produce working knowledge that tacks between absolutism and hyper-relativism (Benhabib & Fraser, 2004).

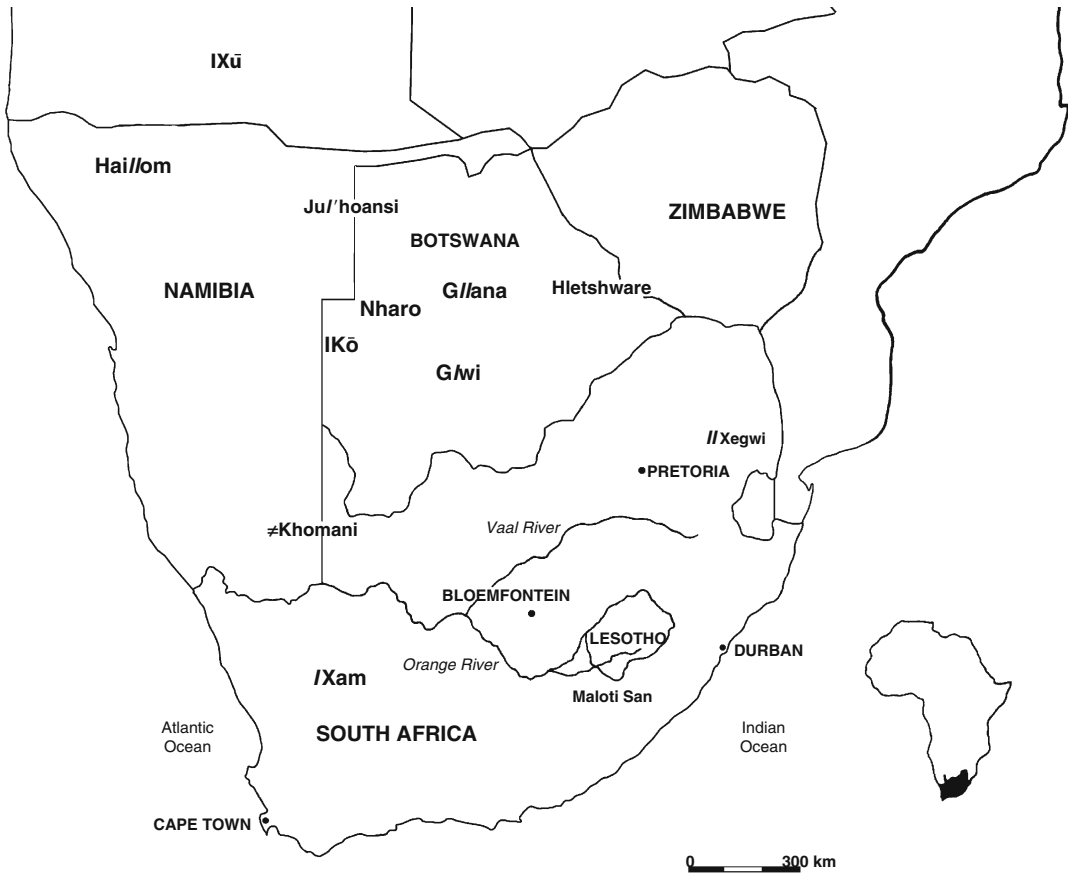
A First People

The San of southern Africa (Fig. 2; [Hyperlink 1](#)) are the most studied people on earth because of their perceived uniqueness as models of original humanity. Such study has not always been accurate. In 1719 the German astronomer Peter Kolb published the statement that Hottentots worshipped the praying mantis (*Mantis religiosa*), generating the Mantis God myth (Marshall, 1999, pp. 242–245). In fact, this insect

worship was San genuflecting to the powerful trickster, Kaggen, in one of his many corporeal forms (Barnard, 1992, pp. 84–85). Even today myths endure. San contextual egalitarianism, shamanic healing and environmental stewardship are often represented as timeless and apolitical, ossifying the dynamic and idiosyncratic flow of San life in which individual action and cosmological constants combine to create a flexible matrix for being in the world (Extra 2). San groups present and past do, however, show remarkable congruence in “territorial organisation, gender relations, kinship, ritual, and cosmology” (Barnard, p. 3). For example, colonial ethnographies suggest a common origin realm inhabited by “People of the Early Race” (Bleek & Lloyd, 1911, pp. 55–57, pp. 175–199), who both created the cosmological order and delight in transgressing its boundaries. This primal time relies less on personnel, location or temporality than on the relationships between these components (Katz, Bieseke, & St Denis, 1997, pp. 47–62). What we comprehend as separate Spirit and Ordinary worlds constantly intersect.

A Connective Cosmos

The Ordinary World has nodal topography studded with campsites, hunting grounds and



Cosmology of the African San People, Fig. 2 Distribution of San language groups

what Ju/'hoansi call *n!oresi* – bundles of relationships and obligations between animals, beings, people, places, plants and things (Katz et al., 1997, pp. 16, 50). Material traces of these relationships date back millennia, appearing as artefacts archaeologists classify on a continuum between functional and symbolic. Thus, artisanal artifacts such as stone tools and bone points grade into non-utilitarian items like ostrich eggshell beads and decorations, which intensify into symbolic crystals and rock art (Figs. 3 and 4). Some say functionality is easier to prove than symbolism. Yet our best evidence of San life is symbolic rock art present at over 30,000 sites (Ouzman, 1998; Extra 3). What we call images were for San actual apocalypse dogs, Beings, cynosuric animals, rain-animals, supernatural potency and part-human therianthropes emergent from an inner Spirit World behind the rock face.

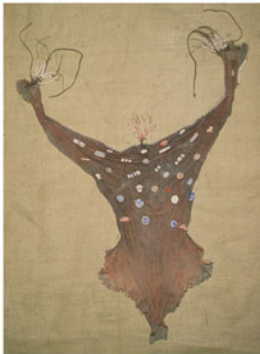
Other connexions to the Spirit World, which exists in multiple locations above and below the Ordinary World, are via water, striking landscape features, and events like death and dancing. These do not permit universal access because the Spirit World is dangerous and inersive. It requires great skill to negotiate its pathways, cul-de-sacs, and denizens like the Spirits of the Dead. Two great but capricious gods – whom the G//wi call *N!eri* (creator) and *//Gauwa* (trickster) – have a fearsome entourage of wives, carnivores and spirits (Guenther, 1999, pp. 61–64). Consequently, the task of traversing worlds is left to shamans – skilled negotiators of boundaries who make sense of the seemingly impossible such as being neither and both male and female (Atkinson, 1992, p. 319). This skill is superhuman and requires what Ju/'hoansi call *n/om* – a supernatural potency vested by



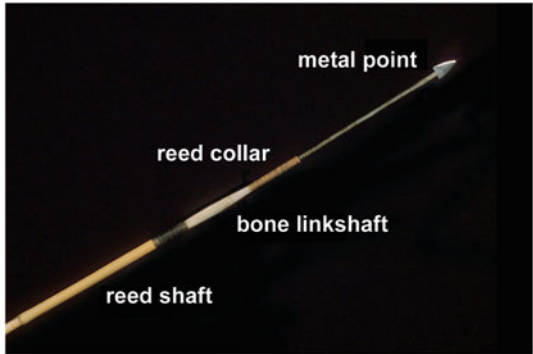
a



b



c



d

Cosmology of the African San People, Fig. 3 San material culture. (a) Bored stone, bone scraper, freshwater mussel shells, grindstone, lithics, pottery. (b) Medicine

container. Hearst Museum, University of California Berkeley, California. (c) Decorated leather woman's apron. (d) Arrow

God in certain interconnected receptacles such as comets, honey, lightning, large animals, plants, rain, shamans or sun (Marshall, 1999, 20, pp. 49–62, p. 218).

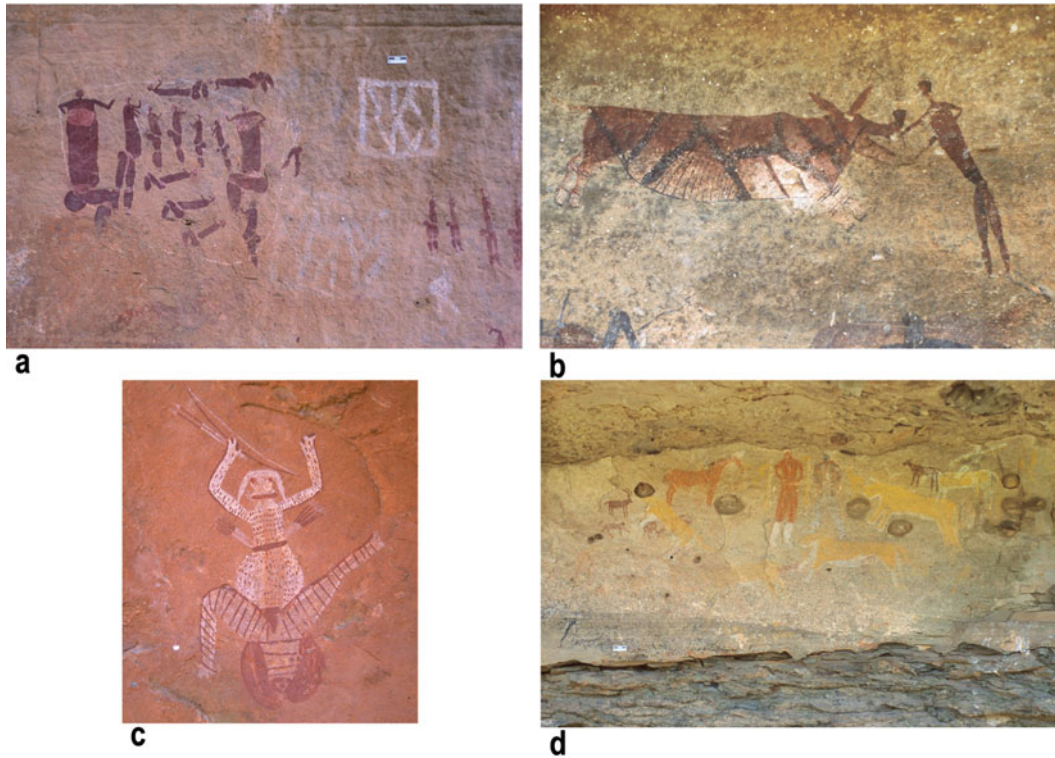
The spirit is in the air. When you dance it comes down to you. When it gets into you, you can see it as a string of light. The light carries you in the dance. It can take you to another person who needs healing or it can carry you to another village in the sky. The light is *num* [n/om]. It doesn't have another name than *num*. Xixae Dxao (Keeney, 2003, p. 41).

But potency, like the gods, is complementary – a foundational feature of San cosmologies. Small amounts of potency aid apotropaism astral travel, healing, and rainmaking, but high concentrations can kill. Controlling potency and passage to the Spirit World requires everyone's labour (Katz, 1982, pp. 34–57). Nowhere is this complementarity better

exemplified than in the Medicine Dance – perhaps humanity's oldest surviving ritual (Hyperlink 2). The atmosphere of the Dance is social and electric. People clap, dance, sing and talk to create a spiritually charged and socially cohesive atmosphere that launches shamans to the Spirit World.

It is endlessly varied by disciplined improvisation, within the bounds of repeated musical phrases. When the awesome sound of the men's rattles is added to the singing and sharply clapped cadences, a music of truly unearthly beauty is produced. This music is one of the basic vehicles of transcendence, enabling curers to achieve the altered state of consciousness called trance (Biesele, 1984, pp. 165–166).

In trance, with the support of the women in the community, who sing and clap, a master of trance works himself into a state where he transcends himself and enters the realm of the supernatural



Cosmology of the African San People, Fig. 4 San rock art. (a) Medicine dance, (b) Rain-animal, (c) Therianthrope and (d) Colonists

where the ghosts of dead ancestors live. Here he struggles with the ghosts. The struggle is intense both emotionally and physically. He is overcome with pain and fear, afraid that he will lose himself in the realm of the supernatural and not return. (Wiessner & Larson, 1979, p. 25)

The physical and spiritual labour of females, males, children, movement, sound, spirits and potency is thus not equal but harmonises. Shamans are pre-eminent but they serve a community. The Medicine Dance is an enduring *genius loci* still performed in Angola, Botswana and Namibia where it attracts non-San like Damara, Herero and Tswana for healing and community. The Dance incorporates elements of ecstatic Christianity and political resistance, whereby shiny European goods are eschewed and shamans act as agents of social change by voicing concerns about alcoholism, marginalisation and so forth (Guenther, 1999, pp. 195–196).

San Science: Past, Present and Future

San cosmology is thus not narrowly spiritual but entails “an all-encompassing world-view, the influences of which extend into every sphere of their existence” (Yates & Manhire, 1991, p. 3). An especially complete synthesis of gender, science, religion and technology is !Kō and //Gana arrow poison (Heinz, 1978, p. 151; Hyperlink 3; Neuwinger, 2004). The paralysing toxin comes from the haemolymph of *Diamphidia simplex* beetle larvae and cocoons, but not the adult beetle (Fig. 5; Hyperlink 4). These larvae live up to 1 m below the ground near a host tree, the sandy corkwood (*Commiphora angolensis*). Six to ten larvae are sufficient for one arrow’s toxin, which is applied by man-the-hunter (Hyperlink 5). San arrows are tripartite constructions designed so that the impetus of the linkshaft breaks the reed collar, causing the shaft which the animal could otherwise dislodge from its body to fall away,



Cosmology of the African San People, Fig. 5 *Diamphidia* beetle cocoons and larvae used for arrow poison (From Neuwinger, 2004)

leaving just the arrow point behind to deliver the toxin (Fig. 3d). But men are ignorant of the toxic larvae's location until women, more attuned to subterranean signs (Hyperlink 6), tell them where to look. This female-male, nature-science relationship is spiritually triangulated through the great God ≠ Gao N!a who "taught them how to find it and how to put it on their arrows so that they would have meat" (Marshall, 1999, p. 32).

Lest San be characterised as waning guardians of an ancient spirituality, it is useful to examine complementarities between San and Western worlds. Sometimes this juxtaposition is conflictual. Pfizer Pharmaceuticals were sued for bio-pirating ≠Khomani intellectual property of the appetite suppressing properties of the *Hoodia gordonia* plant, now marketed as a slimming product (Wynberg, 2004). In more fulsome spirit,

the Cybertracker project pairs renowned San tracking skills with Global Positioning System (GPS) technology to aid game management and counter poaching (Hawthorne, 1999; www.cybertracker.co.za). San trackers, often text-illiterate but masters at reading sign, note spoor by selecting species-specific keypad icons. The GPS registers this input, capturing data like the location, movement, number and health of animals, which is transmitted to a central database. This hybrid approach is more effective than either San or Western science. Indeed, Western science may originate out of the art of tracking:

To interpret tracks and signs trackers must project themselves into the position of the animal in order to create a hypothetical explanation of what the animal was doing. Tracking is not strictly speaking empirical, since it also involves the

tracker's imagination. Generally speaking, one may argue that science is not only a product of objective observation of the world through sense perception. It is also a product of the human imagination. (Liebenberg, 1990, p. v)

More than science, San tracking is a deeply spiritual activity necessary for the renewal of life. "Tracking is like dancing. This is the Great Dance. You are talking to God when you are doing these things" (Hyperlink 7). However, while San cosmological complementarity works well in Habermasian ideal speech situations (Habermas (1929-) sets out five conditions for his ideal speech situation (a) Every subject with the competence to speak and act is allowed to take part in a discourse; (b) Everyone is allowed to question any assertion whatever; (c) Everyone is allowed to introduce any assertion whatever into the discourse; (d) Everyone is allowed to express his attitudes, desires and needs (e) No speaker may be prevented, by internal or external coercion, from exercising his rights as laid down in (a) and (b). (*Diskursethik*: 86). These conditions make possible free discourse and pure communicative action), these examples of accord should not mask the devastation of acculturation, cultural property theft, forced removals and genocide experienced by many San. Celebrating only the positive can veer dangerously close to liberal social contracts and commons that are open to unpunishable abuse (Hardin, 1968). Mindful of this, San have reformulated their egalitarian ethos to uplift themselves and to educate well-intentioned and wilful outsiders (WIMSA, 2003; www.san.org.za). The long and ongoing tradition of San cosmology is not something conservative and ancient, it is a fund of beliefs, places, objects, skills and stories that allow people to innovate and to impact the modern world.

Extra 1: The Name Game: San or Bushman?

Ethnonymy – the process by which people name themselves, are named by others, and the politics that determine which names stick – is critically

important to people's sense of self. Both San – a Nama word meaning "vagabond" – and Bushman – an anglicisation of the Dutch *bosjemans* – are exonyms. Today's approximately 100,000 San who live in Angola, Botswana, South Africa and Zambia have group-specific autonyms like/Gwi, Ju/'hoansi, and !Kǀ, which translate as people, real people or red people, but that do not apply beyond the group – even to other San (Traill, 1995; http://en.wikipedia.org/wiki/Khoisan_languages). The corporate term Khoisan was coined by Leonhard Schultze in 1928 (Barnard, 1992, p. 7) and conflates the overlapping but distinct histories of Khoekhoe herders like the Nama, with San. During Apartheid, Bushman and *Boesman* were deeply offensive, but today these words are being reclaimed as a form of resistance (Gordon, 1992, pp. 6–7). Where possible, group specific names should be used. Elsewise either San or Bushman are acceptable, if used respectfully.

Extra 2: San and New Ageism

Thanks to films like Jamie Uys' *The Gods Must be Crazy*, books like Laurens van der Post's *The Lost World of the Kalahari*, and high profile academic research, San are viewed as a distillate of pure humanity – noble savages. Such stereotyping, while well intentioned and having some basis, leads to social and political marginalisation. Nowhere is this more apparent than in the New Age movement's appropriation of San shamanism and rock art (Sullivan, 1995) and archaeology in general (Morris, 2005). Modern primitives' urge to leave offerings at archaeological sites, to mimic ceremonies and dress, and continued idealistic portrayal of San cosmology causes communities great distress (Katz et al., 1997). New Ageism is a very partial practice that selectively ignores modern circumstances like the syncretic adoption of Christianity and very real social problems such as alcoholism, domestic violence and persecution and how San succeed and fail to deal with these.

Extra 3: The Meaning of San Rock Art

In 1945 the French prehistorian Abbé Henri Breuil sent word to South African Prime Minister Jan Smuts of “a portrait of a charming girl who has been waiting for us on a rock in the Brandberg range for perhaps three thousand years.” Breuil was describing what he thought to be a Phoenician White Lady painted on the rocks of Namibia’s Brandberg (Breuil, 1955; www.namibia-1on1.com/Namibia-Northern/White-Lady-Of-Brandberg.html). Breuil’s inability to acknowledge indigenous authorship of southern African rock art was influenced by the Eurocentric Great Chain of Being (Lovejoy, 1936). Hierarchically ordering the world between God atop and rocks below; white humans were placed nearer God while San, Bantu speakers and Khoekhoen were placed near and even under rocks. Art produced by these lower races was believed either simply to record daily life or to spring from an innate native ability to make art. Appreciation of San rock art’s symbolic and spiritual meanings lay dormant until half-forgotten nineteenth and twentieth century ethnographies (www.lloydbleekcollection.uct.ac.za) revolutionized southern African rock art research (Lewis-Williams & Pearce, 2004; <http://rockart.wits.ac.za>). Today we know that most southern Africans made some form of rock art. Whether shamanistic San statements, group-specific Khoekhoen engravings and paintings, initiation and political resistance arts of Bantu speakers, or Depression-era marks of white work gangs, the landscape bears a multitude of marks – some of which have yet to be understood.

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Cotton in India

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The Indian subcontinent is one of the world’s largest producers of cotton and cotton textiles. From a long time past, cotton and cotton textiles were major articles of trade. Due to the exposure to the world economy, cotton farming and textile production were shaped by a variety of external influences.

A key moment of transition in this history was the establishment of the British East India Company as a political power in the late eighteenth century. The Company was already a major buyer of cotton textiles for export to Europe. Later, as it gained territorial control, it tried to export raw cotton from India to the mills of Manchester. In the course of European interest in these Indian products, a great deal of data on Indian cotton and textile technology was collected. The knowledge revealed that while cotton was cheap in India, the yield of the lands that produced cotton was small. Despite this drawback, the availability of a wide range of natural dyeing materials and highly developed craft skills had made possible the largest and commercially most successful cotton textile industry of the premodern world.

There were many changes in cotton and cotton textiles in the last two centuries, but two features proved persistent. First, while cotton was extensively grown, productivity remained relatively low, and production was exposed to a variety of risks. Improvements in conditions of production have proved either difficult or controversial. Second, cotton textiles have done well in domestic and world markets, despite temporary setbacks in the early nineteenth century and the mid-twentieth. This entry will present a long-range survey of the products with particular reference to these long-term features.

Cotton Cultivation

Cotton is an indigenous crop in India, and it is grown in several regions, of which the most important ones before the nineteenth century were coastal Gujarat, Khandesh, and eastern Rajasthan in western India, Bengal in the east, Narmada Valley and Malwa in central India, and Rayalaseema and Coimbatore in the south. Before the Industrial Revolution and before the railways connected these regions with the major ports (c. 1870), cotton cultivation, cotton spinning, and sometimes cotton weaving on handlooms developed side by side in these zones. For example, in Bengal, cotton cultivation expanded because of the demand for certain varieties in the textile industry (Roy, 2012).

Descriptions of the Arabian Sea trade before 1500 CE recorded a trade in Indian cotton. Little is known as to how large or how systematic the trade was. Very likely, cotton trade did not involve a specialized trading system yet. This was to change in the seventeenth and eighteenth centuries under the impetus of Indo-European trade in cotton textiles. The expansion of textile production for export in Gujarat, Coromandel, and Bengal led to the growth of cotton production and trade in several regions.

While overland trade expanded, a small quantity of Indian cotton reached Britain in the early 1780s via Flanders and Denmark. In 1788, the Company placed an order for 250 tons of Indian cotton and placed its Bombay office in charge of implementing it. Bombay, however, found it difficult to divert the trade toward the Company ports. A large part of Gujarat cotton still went to Bengal overland, and the prices offered by the Europeans did not succeed in diverting this flow toward export trade.

The Napoleonic wars made trade between Britain and the United States uncertain and increased the importance of Asia for British manufacturers. It was becoming clear to the officials engaged in procuring Indian cotton that the demand in Manchester had grown too fast for the government alone to cope. Two Scottish

firms, Forbes and Co. and Bruce, Fawcett, and Co., were hired to procure cotton for the Company. At the same time, Indian merchants began to export cotton to China. The export helped Britain, which consumed a great quantity of Chinese tea, balance its accounts.

Securing a future for the trade demanded attention to two obstacles – quality of ginning and the poor yield of indigenous cotton varieties. There was no one method of ginning and cleaning cotton practiced in India. The best methods were exceedingly labor intensive. For example, in the villages of western India, women rolled the seeded cotton with their feet upon an iron roller until the seeds were separated from the fiber. This process did produce very clean cotton, but at a glacial speed. Trade volume was growing too fast for these manual systems to be adequate. The cotton that came to the ports for loading, therefore, was generally of poor quality. A further difficulty with Indian cotton was the small lots usually traded, in turn, an effect of poor yield. The indigenous plant was a short bush that produced about half or even less than the American varieties on average.

The government's solution to the supply problem was enlistment of the support of amateur botanists. In the early 1840s a government experimental farm was started in Coimbatore under Robert Wight (1796–1872), a surgeon in the Company's service. His project lasted longer (12 years) than other similar ones, but, like these others, was in the end thought to be a failure. The other arm of policy was encouragement to private plantations. Between 1835 and 1850, several attempts to grow American cotton on Indian soil by American and European planters received the Company's approval. These projects did not succeed because the new varieties proved unsuitable to Indian conditions and because contracts between planters and peasants were difficult to enforce. Nevertheless, the knowledge of the seeds diffused among the peasants and was moderately successful with one variety, the New Orleans.

The 1860s presented the peasants and merchants with an unprecedented trading

opportunity. During the American Civil War (1861–1865), Manchester mills were forced to find ways of using more Indian cotton, and the price of cotton in Bombay soared. From this time onward, Indian cotton was established as a major article of trade, supplying raw material first to Manchester, then to the domestic mills set up in Bombay, and in the twentieth century also to cotton mills in Japan. The area under cotton increased from six to ten million acres in 1870 to 25 million in 1936. Cotton export increased from 803 million lbs in 1868 to 1,560 million lbs in 1930. Part of this growth was an effect of general expansion of cropped area, but the share of cotton in cultivated area also increased during these years. By 1940, India was the second largest cotton producer in the world after the United States. Domestic mills used a little less than half of the crop; the bulk of the exports went to Japan and the United Kingdom.

In the fifty years after independence in 1947, growth of acreage more or less stagnated in the South Asian region. In 2010, the combined acreage of India and Pakistan was 29 million, the largest among cotton-growing regions of the world, but not significantly higher than the acreage of 1950. More impressive was an almost fourfold rise in yield per acre between 1868 and 2010. Much of the increase occurred after 1950; in fact the most growth occurred as recently as the 2000s, whereas in the colonial era, yield was more or less stagnant at approximately 100 lbs per acre. The dramatic change in the 2000s was partly a result of irrigation and partly a contribution of the transgenic cotton varieties. The quantum of benefits of these cultivars and to whom these benefit go are controversial issues (Herring and Rao, 2012), but the fact of a rise in yield is incontrovertible.

The revival of cotton production sustained a parallel revival of the textile industry in the region.

Cotton Textiles

Around 1750, India is believed to have supplied a quarter of the world's industrial output. Such

a large quantity reflected India's share in cotton textile production in the world and the increasing usage of cotton in Britain. India was home to an ancient cotton textile industry. The output of the loom came in immense variety and embodied a range of decorative skills. On the Indian Ocean littoral, during the 250 years following the Portuguese mariner Vasco da Gama's discovery of the sea route between Europe and India (1497), cotton textiles procured by the European merchants in Gujarat, Bengal, and the Coromandel Coast had come to shape consumer preference in the West.

Between 1820 and 1870, India's prominence declined, as British machine-made yarn and cloth started trading widely. India's decline together with the rise of a cotton textile industry in Britain produced two unfinished debates. One of these asks how much the British success depended upon capital and knowledge gained from Indian trade (see Riello, 2013). And the other asks how badly the Indian economy was hurt due to the decline of its textile industry. In the early twentieth century, nationalist critics of the British Empire claimed that the fall of trade caused devastation and misery among textile artisans. The fall, in fact, was concentrated in spinning of yarn by hand. Weaving did not suffer as much and even expanded from the late nineteenth century. Indeed, production of cotton cloth in handlooms rose by 30 % between 1900 and 1939.

By 1900, a modern factory industry in cotton textiles had also developed. The development was concentrated in three cities, Bombay, Ahmedabad, and Calcutta, because the capital engaged in these factories came from trading and banking firms based in these cities. Many of them had made money in the cotton export trade of the early nineteenth century and had close links with both the British and the Chinese markets for cotton. That knowledge helped Bombay's mill owners procure machinery and foremen from Manchester and sell cotton yarn to the handloom weavers in China. Their already entrenched position in overland trade gave them a handle on cotton trade that many European capitalists lacked. The Indian textile mill industry, in this way, started soon after the British industry did, using indigenous cotton, cheap

labor, British know-how, and a long-standing mercantile heritage.

Early in the interwar period, India and Japan were among the largest textile-producing countries, thanks to a significant wage advantage they shared over their Atlantic rivals. But between them competition was getting keener. Japan surpassed India in the Chinese market for yarn, and in the 1920s, it started selling cloth in India. Contemporary analysis blamed the colonial exchange policy with its bias for a mildly overvalued rupee. Industry insiders pointed at differences in labor productivity, work ethic, and employment systems. The textile mill owners in Bombay, however, were gaining political strength, thanks to the support they gave to the nationalist movement, and they successfully wrested a measure of tariff protection.

It was a paradox, then, that the developmental state that came into being after independence in 1947 decided to burden the mills with taxes and draconian restrictions. The paradox reflects the diverse origins of economic nationalism. The nationalist leader M.K. Gandhi, for example, favored rural handicrafts as the symbol of village self-sufficiency. The first prime minister, Jawaharlal Nehru, and his economic advisers, on the other hand, were interested in heavy industries like steel and industrial machinery. Squeezed between these two ideals, the cotton textile industry in India failed to take advantage of the postwar revival of world consumption, the benefits of which were reaped first by Europe and later Japan.

Within India, the textile mills were becoming moribund. The range of their production was narrow, and therefore, their market was sluggish. With closed access to international know-how, the mills continued to decline and yielded space to small power-weaving factories called “power looms.” The technological paradigm that came to rule the cotton textile industry in the 1980s was one that used old generic machines, produced unattractive cloth at low prices, and catered to a home market that was losing interest in homegrown cotton cloth. In 1991–1992, the trade regime liberalized. Export of textiles and import of equipment were again encouraged. Deregulation removed barriers to expansion and modernization. It was already too

late for the textile mills. Instead, small-scale textile and clothing firms took advantage of the return to the world market.

In the present times, the textile and clothing industry of India, Pakistan, Bangladesh, and Sri Lanka form the most important manufacturing sector in the domestic economy. They are also very export oriented and almost entirely located in small-scale firms, though there is huge variation in capacity and size among these firms.

Conclusion

The overwhelming importance of cotton in South Asia owed to the region’s natural advantage in cotton cultivation and accumulated knowledge of textile production. These strengths were tested in the nineteenth century when expanding demand for Indian cotton faced a geographical barrier and again in the twentieth century when an autarkic regime slowed learning and skill formation in textile production. These barriers were partially overcome by a combination of technological and political means at the turn of the twenty-first century.

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Cotton in Indonesia

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Since the early 1980s, Indonesia has become one of the world’s biggest exporters of cotton textiles and garments. The expansion of textile

production was based on the processing of imported yarn and raw cotton, rather than domestically grown cotton. This development renewed interest in increasing the local production of raw cotton to reduce import dependence. During the next 25 years, the Ministry of Agriculture pursued various ways to expand the area under cotton and raise productivity, most recently in 2009, as part of a 5-year strategic plan that envisaged lifting domestic cotton production from less than 5,000–63,000 t in 2014, or 12 % of the expected raw cotton needs of Indonesia's textile industry. All signs are that this target will not be reached, as domestic production lingered at an annual average of 3,000 t during 2008–2012.

This outcome may not come as a surprise when looking back in time. Since the nineteenth century, public authorities in Indonesia have unsuccessfully tried to encourage raw cotton production for domestic consumption and export. Due to the country's location around the equator, Indonesian farm households produced raw cotton that sustained a local textile industry. In the course of the eighteenth century, the country imported increasing amounts of cotton cloth. Initially local traders and the Dutch East Indies Company (*Vereenigde Oost-Indische Compagnie*) arranged these imports mainly from India. During the nineteenth century, cloth imports came increasingly also from England and the Netherlands and since the early twentieth century also from Japan. Only the introduction of trade protection in the 1930s bolstered domestic cotton spinning and weaving for domestic consumption. This expanded since the 1950s, but still on the basis of imported yarn and raw cotton, as domestic cotton production remained relatively marginal.

A reason for growing dependence on imported cloth was that Indonesia was and continued to be a marginal producer of raw cotton. Various native cotton varieties were produced throughout Indonesia, particularly in Central and East Java (Demak, Pati, Jepara-Rembang, Madiun, and Madura), South Sumatra (Palembang), and Nusatenggara (Lombok and Flores). A maximum of 25,000–30,000 ha was harvested annually from the 1850s to the 1930s. However,

the preferred varieties produced short-stapled and coarse fibers. These suited the very basic domestic spinning and weaving technologies, but the increasingly mechanized spinning and weaving machinery elsewhere in the world required the long-stapled, fine-fiber cotton varieties that were produced in India, Egypt, China, and the Americas.

The Dutch colonial government in Indonesia tried to encourage raw cotton production since the 1820s, as it was interested in promoting cotton exports, in part to help meet the growing demand for raw cotton by the budding textile industry in the Netherlands. Local and imported varieties were used in a long series of government-orchestrated tests aimed at introducing cotton production and/or improving the quality of the produced raw cotton, particularly in Palembang, but also several other areas such as Banyuwangi (East Java). But the results of all these government efforts were generally discouraging.

Private interests also tried to expand raw cotton production. For example, in 1843 J.L. van Toll used his experience with cotton growing in Surinam to establish a cotton plantation in Cirebon in Java. Although the cotton produced was of good quality, the venture was not commercially viable and ceased in 1847. In the late 1840s, the Netherlands Trading Company (*Nederlandsche Handel-Maatschappij*) supported tests in Palembang to explore possibilities for large-scale cotton production, but abandoned these plans. In 1861 an enthusiastic proponent of cotton production in Indonesia, J.J. van Limburg Brouwer, established the Netherlands Indies Cotton Company Ltd. (*NV Nederlandsch-Indische Katoen-Maatschappij*), which operated a cotton ginning and packing plant in Surabaya and sought to purchase locally grown cotton in nearby Demak and Grobogan. Despite high cotton prices due to the American Civil War, the venture failed to secure the required regular supplies of raw cotton from local growers and the company ceased operations in 1864. In 1905–1907, the Wijnkoopsbaai Exploration Company Ltd. (*NV Wijnkoopsbaai Exploratiemaatschappij*) distributed imported cotton seed free of charge among farmers in the

Pelabuan Ratu region in West Java, but it failed to encourage sufficient local production of raw cotton for purchase and processing. In 1916, the Moluccan Trade Partnership Ltd. (*NV Moluksche Handelsvennootschap*) established a plant in Palembang for the ginning of local raw cotton. It experienced irregular supplies and abandoned the venture in 1930. The Amsterdam-Sunda Company Ltd. (*NV Amsterdam-Soenda Compagnie*) was established in 1917 to produce and process cotton of a promising local variety in Flores. It ceased operations in 1924, when pests reduced yields and international cotton prices fell. In the 1930s, Dutch settlers and the Japanese South Seas Development Company (*Nanyo Kohatsu Kaisha*) tried to grow cotton commercially in New Guinea, but experienced pest problems within a few years. They also found that soil and climate were not always suitable and that yields were too low to make the ventures viable and ceased production in 1939.

Unsuitable local rainfall patterns and soil conditions as well as problems with several pests were key reasons why domestic raw cotton production in Indonesia remained limited. However, the main reasons why Indonesian farm households shunned cotton as a cash crop were the high risk of crop failures, because the plant requires high rainfall in the initial growing stages and then a very dry maturing season. Cotton also yielded low financial returns compared to other crops. Only when world prices were high did Indonesian farmers increase cotton production. In Java, they only did so as a second crop on irrigated fields following the main rice crop, but only in areas where other crops would yield even lower returns than cotton. Given the risk of crop failure (and the low financial yields), cotton-growing farm households did not put a lot of time and effort into weeding and pest control.

Hence, raw cotton was generally produced for local production of yarn and cloth for consumption by local rural households. The varieties that suited the local climate best yielded short, coarse cotton fibers and therefore coarse cloth. Some areas in Indonesia exported much of their raw cotton to China and Japan, where it was blended

with other fibers and used in the textile industry. Very small quantities of ginned, superior raw cotton were exported to Europe. Although the share of ginned cotton increased during the 1900s, most of the exported raw cotton was ginned overseas. Given the uncertainty in the production and trade of Indonesia-grown cotton, much of the raw cotton trade was in the hands of small Chinese traders who purchased relatively small quantities from farmers for export. As most cotton was exported raw, the risk of contamination of the fibers by the oils from the seeds was high, and the quality of the exported cotton was on average low.

Estimates of domestic raw, seeded cotton production are rough, but they suggest that production was less than 5,000 t in the 1930s, rising quickly to 30,000 t in 1945, before declining to less than 1,000 t until the late 1970s. Production increased again since the early 1980s to a maximum of around 5,000 t. However, production fluctuated significantly from year to year, depending on crop failures and the prices of cotton and synthetic fiber substitutes. Throughout, farm households continued to be the main producers of cotton, and in the main cotton-producing regions, traders would purchase surplus cotton for export and/or processing into yarn. Nusatenggara and East Java continued to be among the main cotton-producing regions, but South Sulawesi replaced South Sumatra as the leading cotton-producing region.

The only significant expansion of domestic cotton production occurred during the Japanese occupation of Indonesia during 1942–1945, when the country was cut off from foreign supplies. In 1943, the Japanese authorities announced a plan to make Indonesia self-sufficient in cotton within 5 years. Using a degree of compulsion to persuade farmers, they succeeded in expanding the area under cotton in Java from 5,500 ha in 1940 to 33,000 ha in 1943 and 137,000 ha in 1945. However, crop failures and the unfamiliarity of many farmers with the crop resulted in poor yields. The drastic shortfall of cotton textiles had to be met with imports of yarn and cloth as soon as Indonesia resumed exports of other commodities in 1946.

In the 1950s and 1960s, Indonesia's imports of raw cotton, yarn, and cotton cloth increased steadily, although at times significant shortfalls in export earnings forced its government to impose limits on such imports. In that context, ambitions for the country to become self-sufficient in key commodities such as rice and cotton reemerged. In 1960, Indonesia's Eight-Year Development Plan echoed such intentions. It retained some realism by scheduling reductions of cotton imports on the basis of increasing supplies of rayon (cellulose fibers) produced from Indonesia's abundant forestry reserves, rather than only an expansion of cotton production. The FAO supported research into the feasibility of increasing cotton production in Indonesia around that time. But all plans came to little, as Indonesia's economy deteriorated in the early 1960s. Imports of raw cotton and yarn increased again as soon as Indonesia's economy recovered after 1966 and its oil boom started.

During the 1970s and 1980s, Indonesia's public resources for agricultural research and extension were concentrated on raising the production of staple foods, particularly rice, before they diversified to include non-food agricultural production to a greater degree. In the 1970s the agricultural extension service sought to increase cotton production in some areas that appeared suitable. Extension efforts focused on South Sulawesi, where during 1973–1977 state-owned General Company for Cotton Plantations in Indonesia (*PERUM Perkebunan Kapas Indonesia*) sought to foster cotton production among local farmers and purchase cotton for processing and marketing. It was unsuccessful for various reasons, including inadequate assessment of agroclimatic conditions; limitations on the amount of high-quality seed, fertilizer, and pesticides that the company could make available; and insufficient credit for farmers to purchase such inputs. In addition, the company did not have processing facilities in South Sulawesi to gin cotton. During 1978–1990 the Smallholder Cotton Intensification (*Intensifikasi Kapas Rakyat*) program was implemented in key cotton-growing regions, mainly by the Ministry of Agriculture, which coordinated the involvement of

state-owned enterprises, regional extension officials, and local authorities. Buoyed by relatively high international cotton prices, in the early 1980s, the program succeeded in making South Sulawesi the largest cotton-producing region in Indonesia. But its results were mixed for reasons similar to the 1970s, particularly the variable supplies of superior seed and chemical inputs.

The availability of superior seed improved after 1983, when the Ministry of Agriculture started to support cotton-related research at what is now the Indonesian Sweetener and Fibre Crops Research Institute in Malang. The Institute has since released a range of hybrid Kanesia (*Kapas Nasional Indonesia*) cotton varieties. These new varieties are pest resistant and potentially high yielding and produce a better quality cotton fiber, and due to drought resistance, they may suit local growing conditions better. The institute supplies superior seed to private seed companies for the further multiplication and marketing of seed to farmers through local farmer groups. The institute also conducts demonstration farms and field schools, and its researchers meet with farm groups and local extension workers to monitor results and receive feedback.

This had some results in South Sulawesi, where cotton production increased during the 1990s. This was partly due to the impact of further government programs that improved the availability of seeds and inputs, as well as targeted credit to farmers, but it was also in line with high international cotton prices in 1994–1996. Several firms established processing facilities in the region and elsewhere for the ginning of cotton purchased from farmers, including *PT Nusa Farm* and *PT Kapuas Garuda Putih*. Nevertheless, production decreased again in the region after 2000, when the supply of inputs and credit was largely left to the private sector. As part of the change in policy, *PT Branita Sandhini*, the Indonesian subsidiary of multinational Monsanto, was given permission to distribute imported transgenic pest-resistant Bollgard cotton seeds. This experiment stirred public discussion, but eventually failed to catch on.

Expectations that private sector involvement in the distribution of seeds, inputs, and credit, as

well as the purchase and processing of raw cotton, would increase cotton production did not materialize during the 2000s, despite efforts by the Ministry of Agriculture to give new life to extension programs involving the private sector in 2007 (with a production target of 70,000 t in 2010) and in 2010 (with a target of 63,000 t in 2014). Since the early 2000s, the harvested area with cotton decreased to an average of around 10,000 ha during 2008–2012, despite the fact that international cotton prices skyrocketed in 2010–2011. Cotton yields in Indonesia remained on average around 0.3 t per hectare during 2008–2012, or just one-third of the world average. The main reasons for the reluctance of farmers to grow cotton appear to be the same as before the 1940s. Cotton production is generally still less profitable to farm households than the production of other crops, particularly rice. This is partly due to the low yields of the traditional local cotton varieties, which remain vulnerable to pests and crop diseases and tend to be grown on marginal land with unreliable water supply.

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Couscous

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Couscous is a semi-prepared foodstuff produced since ancient times. Couscous is known by different names in different countries. It is known as kuskus in Turkey, couscous in Morocco, maftoul in Jordan, moghrabieh in Lebanon, seksu in



Couscous, Fig. 1 Rubbing bulgur with egg whites



Couscous, Fig. 3 Pouring on bulgur of the egg milk mixture



Couscous, Fig. 2 Sprinkling on bulgur of flour and rolling bulgur



Couscous, Fig. 4 Sieving couscous

Berber, kuskusi in Libya, keskesu in Tuareg, kouskousaki in Greece, and attiéké in West African (Anonymous, 2013a). In Turkey, wooden bowls (average 60×120 cm in sizes) are used for producing homemade couscous. When using 1 kg of coarse bulgur for couscous, 25 eggs (the amount of egg is variable), 3 kg of boiled and cooled milk, 35 g of salt, and 10 kg of wheat flour are the ideal amounts. First, a homogenous mixture is prepared with the eggs, milk, and salt. Four egg whites are not added to the mixture. Bulgur is rubbed with the four egg whites in the bowl (Fig. 1). Bulgur gets wet and swells. A handful of flour is sprinkled on the bulgur. Then, it is mixed right-left by hand and placed at the bottom of the bowl for 15–20 s (Fig. 2). Afterward, an average of 5 ml of egg-milk mixture is sprinkled

on the bulgur using a dry bunch of corn husk. The amount of egg-milk mixture must be less when semolina and fine bulgur are used. After adding the egg-milk mixture, the bulgur is rolled for 15–20 s again (Fig. 3). Then, a handful of flour is sprinkled on the bulgur and the rolling process is applied again (Fig. 2). The bulgur starts to transform into couscous. When the couscous reaches the ideal size (approximately 3–4 mm), it is sieved in the wooden bowl (Fig. 4). Before it is sieved, it is sprinkled two consecutive times with the egg-milk mixture without flouring to be brighter and then rolled. Sieves, with holes of an ideal size for couscous and made from animal skins, stretching across a hoop, are used to separate couscous into different sizes. Couscous remaining on the sieve is laid on a sheet (Fig. 5)



Couscous, Fig. 5 Laying and drying couscous

at a location with airflow and shade and allowed to dry or dried in the form of baking. The process of flouring and sprinkling egg-milk mixture continues for small couscous passing through the sieve. Making couscous using 1 kg of bulgur takes approximately 3 h. Most people think that the product will not have the original natural scent and flavor after being baked in oven. Couscous is stored in cloth bags.

When the water begins to boil, couscous is added to it. Or couscous can be fried in oil and water is added. Also water can be added to hot oil, with the water boiling at the same time. Then the couscous is added. The cooking process takes about 20 min. Salt (according to taste) is added during cooking. Butter is added after fat-free cooking. After taking the water from the couscous, in other words, after cooking, the pots are covered first with a cloth and then with a pot lid. So the couscous is infused. While the couscous is around 3–4 mm in diameter before cooking, it is around 5–6 mm in diameter after cooking. It can be served plain (Fig. 6) or with sauce or cheese (Coskun, 2013).

In North Africa, couscous can be prepared with semolina of hard wheat (*Triticum durum*), although it can also be prepared with barley, millet, sorghum, or corn. Couscous is processed from fine and coarse grains of semolina (Clifford, 2004). Rolling done to aggregate the semolina is realized in a large wooden dish called *guessâa* (Fig. 7). Four different sieves named *dekkak*, *reffad*, *meâaoudi*, and *sekkat* are utilized in



Couscous, Fig. 6 Serving couscous in Turkey

sieving or sizing operations and correspond, respectively, to 500, 1,000, 1,130, and 1,280 μm mesh opening. The procedure starts with a quantity of 500 g of coarse semolina ($>500 \mu\text{m}$) steam-precooked in a *keskes* (couscoussiere) (Figs. 8 and 9, Anonymous, 2013b) for 8 min at 95 °C. Salted water and fine semolina ($\leq 500 \mu\text{m}$) are progressively added for rolling in the *guessâa*. A sizing operation with *sekkat* sieve (1,280 μm) is practiced before drying under shade and natural air convection (Benatallah et al., 2008). It is always steamed, never boiled (the tiny particles to the left in the photo) (Fig. 10). The two at the right are Levantine pearl couscous (Fig. 10). The small ones (about 0.14 in./3.5 mm), called *maftoul*, were made in Jordan. The larger ones (about 0.22 in./5.5 mm), called *moghrabieh*, were made in Lebanon. These forms are boiled or used in soups and stews like regular pasta rather than steamed (Anonymous, 2013a).

According to a cooking method applied in Morocco, couscous is washed in a large shallow pan with much water. Couscous is spread in a rimmed baking sheet or similar appliance and allowed to swell for 10 min. Stew or broth is added and allowed to boil at the bottom of the pot. The steamer pan is placed on top, sealed as necessary, and the couscous is poured in. The couscous is steamed for 20 min in a *couscoussiere* and is dumped into a shallow pan. One teaspoon of salt and about 3/4 cup of water (for two cups of couscous) is sprinkled evenly over the couscous.

Couscous, Fig. 7 Rolling done to aggregate the semolina in “guessâa”



Couscous, Fig. 8 Couscousier

Then, the couscous is coated with olive oil by hand and must be allowed to rest for at least another 10 min. The couscous is mounded onto a serving plate, and a deep depression is made on top of the mound where some of the stew is put in there (Anonymous, 2013c).

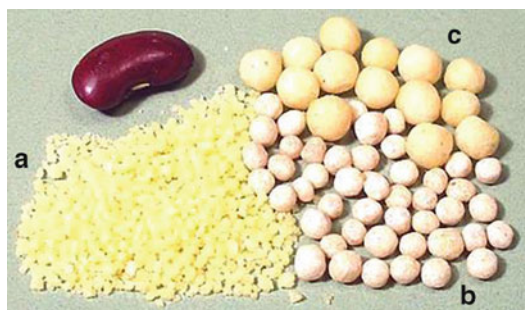
Couscous, more affectionately known as seksu or sikuk, is the national dish of Morocco. While in most Moroccan families this rolled semolina cereal is prepared and eaten on Fridays, a few incorporate couscous into their diet at



Couscous, Fig. 9 Couscousier

least a few times a week. Couscous is also a celebratory dish eaten at weddings, funerals, or the end of festivals or holidays like the 27th of September, an important date in Ramadan (Anonymous, 2012).

In Morocco, Algeria, and Tunisia, couscous is generally served with vegetables (carrots, potatoes, turnips, etc.) cooked in a spicy or mild broth or stew and with some meat (generally chicken, lamb, or mutton) (Fig. 11, Anonymous 2013d). In Morocco and Algeria, it is also served, sometimes at the end of a meal or just by itself, as a delicacy called *seffa* (Anonymous, 2013e). In Libya, it is mostly served with meat. Another way to eat couscous is as a dessert; it is prepared with dates, sesame, and pure honey and is locally referred to as *maghrood*. In Egypt, couscous is



Couscous, Fig. 10 (a) North african couscous (b) Israeli couscous (c) Lebanon couscous



Couscous, Fig. 11 Serving of couscous in Morocco

eaten more as a dessert. It is prepared with butter, sugar, cinnamon, raisins, and nuts and topped with cream (Anonymous).

The instant couscous that is sold in most Western supermarkets is pre-steamed and dried; the package directions usually include adding 1.5 measures of boiling water or stock and butter to each measure of couscous and covering tightly for 5 min (Anonymous, 2013e).

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Crop Domestication in the Amazon

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Domestication of landscapes and plant and animal populations is a behavioral trait of humans and has been since the Pleistocene (Rindos, 1984; Smith and Zeder, 2013; Tudge, 1999) It follows that the humans who first arrived in Amazonia – perhaps 20,000 years ago (Lahaye et al. 2013) – were not mere hunter-gathers, but were at least part-time domesticators and horticulturalists, contrary to standard stereotypes. The first archaeological evidence of plant population domestication in lowland South America appeared by 12,000 years ago in western Ecuador (Piperno & Stothert, 2003) and the domestication process must have started earlier to become visible then, since evolutionary processes, like domestication, have time lags between the

founder event and visibility in the archaeological record (Rindos, 1984).

Landscape domestication is a cultural process whereby human intervention in the landscape and manipulation of landscape components cause changes in landscape ecology and in the demographics of its plant and animal populations, resulting in a landscape more productive and congenial for humans (Clement, 1999a, 2014). Because it is a process, the intensity of intervention and manipulation vary through space and time along a continuum from pristine through promoted, managed, and cultivated to settlements and cities (Clement, 2014). Plant population domestication is a coevolutionary process in which human selection of the phenotypes of individual plants results in changes in the population's phenotypes and genotypes that make them more useful to humans and better adapted to human intervention in promoted, managed, or cultivated landscapes (Clement, 1999a). Because it is a process, the intensity of selection and plant response to selection vary through space and time along a continuum from wild through incipiently domesticated to semidomesticated to domesticated, although not all species used and selected by humans contain examples of all these categories. Species with domesticated populations are expected to contain examples of all of these, but some may currently be extinct and only identifiable in the archaeological record. An Amazonian example is manioc (*Manihot esculenta*, Euphorbiaceae), the most important energy staple domesticated in the region, with thousands of domesticated varieties, but in which no incipiently domesticated populations have been identified. Other species may contain only incipiently domesticated populations, even when the species is very important in subsistence, in which case landscape domestication may be more important than population domestication. Amazonian examples are the two major species of assai (*Euterpe oleracea* and *E. precatoria*, Palmae), the latter perhaps the most abundant palm in Amazonia and the former the most abundant palm in the floodplains of the Amazon River estuary (ter Steege, Pitman, Sabatier et al. 2013).

Their abundance may be partially due to human promotion and management, as both contain incipiently domesticated populations (Clement, 1999a).

A crop is “a cultivated plant that is grown as food, especially a grain, fruit, or vegetable” (<http://www.oxforddictionaries.com>). This definition affirms that the plant is grown in a cultivated landscape, and this implies that it is domesticated, although wild plants can also be cultivated (Harlan, 1992). “Crop” comes from Old English and has a Germanic origin but ignores the importance of landscape domestication in Europe, where the “frutalization” of the Mediterranean landscape occurred (González Bernáldez, 1992). It also ignores the importance of forest domestication in Asia, which is a process of co-domestication of trees, mostly fruit bearing, and forests (Wiersum, 1997). Hence, in a region with even more trees than Europe and Southeast Asia (Michon, 2005), it seems appropriate to expand our definition to include what the ecologists call the “standing crop,” the amount of biomass produced in a given landscape or ecosystem, with the caveat that the biomass is of importance to people, both past and present.

With our terms defined, we can now consider crop domestication in Amazonia and address several questions: When and where did the domestications start? How many were domesticated to some degree? Where were the domesticated crops at the time of European conquest? Which were most important at conquest and which are important today?

When Did the Domestications Start?

This is a question for archaeology. Unfortunately, few Amazonian archaeologists have looked at botanical questions like this in sufficient detail. There is, however, evidence about Amazonian crops along the Pacific coast of Peru, where environmental conditions are excellent for plant preservation. The earliest archaeological remains of Amazonian crops date to between 10,000 and

8,000 years ago and are of manioc, sweet potato (*Ipomoea batatas*, Convolvulaceae), and hot pepper (*Capsicum* spp., Solanaceae) (Pearsall, 1992). None of these are native to the Pacific slopes of the Andes, so we can assume that domestication started much earlier in Amazonia, perhaps as early as the Ecuadorian case, which was with a squash, *Cucurbita ecuadorensis* (Cucurbitaceae), that was later abandoned in favor of other domesticated squashes (Piperno & Stothert, 2003). The earliest Amazonian archaeological site with botanical evidence is Pedra Pintada, in Monte Alegre, Pará, along the lower Amazon River, where the earliest human evidence is dated to 11,200 years ago and botanical remains suggest a broad-spectrum economy (Roosevelt, Lima da Costa, Lopes Machado et al. 1996), including several species with incipiently domesticated populations today, such as Brazil nut (*Bertholletia excelsa*, Lecythidaceae). The earliest site that suggests landscape domestication is Peña Roja, along the Caquetá River, southeastern Colombia, where another broad-spectrum economy that developed by 9,000 years ago used numerous palms, among which milpesos (*Oenocarpus bataua*, Palmae) became continually more important with time (Mora, 2003, 2006). Milpesos also has incipiently domesticated (Clement et al. 1999a) and is hyperdominant in some parts of Amazonia (ter Steege et al. 2013), including along the Caquetá River. From this scanty and widely dispersed evidence, we can hypothesize that both landscape and plant population domestication started quite early in Amazonia, probably as soon as people settled into the landscape since they were part-time domesticators and horticulturalists. Food production, which depends upon cultivation of plant populations in the process of domestication, started by about 11,000 years ago in various parts of the Neotropics (Piperno, 2011), including at Peña Roja between 9,000 and 8,000 years ago (Mora, 2003, 2006), where leren (*Calathea allouia*, Marantaceae) and a *Cucurbita* appear to be the first cultivated plants. As more archaeological sites are studied by archaeobotanists in Amazonia, this first date will probably be considered late.

Where Did the Domestications Start?

This is a question for biogeographers and geneticists, as well as archaeologists. A crop will be brought into the domestication process where four chance events meet: an individual plant or small group of plants with a useful product that catches the eye of a gatherer and is good enough to take back to camp; a place where the useful product's propagule (seed or bud with subtending tissue) can germinate and grow, often in a dump heap (Anderson, 2005); the useful product of this propagule will be as good or better than the original plant's; and the eye of the same or another gatherer who will continue the sequence by selecting and propagating again. As Darwin (1859) pointed out, none of this needs to be intentional.

Since the process of domestication starts with the selection of a single individual or small group of individuals that are then propagated, the origin of domestication can be identified by comparing domesticated populations with a representative sample of wild populations from across the species' distribution. A nice example is the identification of the origin of domestication of manioc in southwestern Amazonia (Olsen & Schaal, 1999, 2001; Olsen, 2004). Wild manioc (*M. esculenta* ssp. *flabellifolia*) occurs in open forests across southern Amazonia; the world core collection of domesticated manioc at the International Center for Tropical Agriculture contains the same alleles in three different genetic markers as are found in southwestern Amazonia, but not in southeastern Amazonia, effectively delimiting the center of domestication. A recent review found that the majority of early crop domesticates originated in the periphery of Amazonia (Clement et al. 2010), especially in open forests along the southern and northern peripheries, as hypothesized by numerous students of Neotropical crop domestications (see Piperno, 2011), but also in more humid forests in the western periphery, which are also open forests because of their dynamics. This is true both for crops that became domesticated in cultivated landscapes, such as manioc, sweet potato, leren, and *Capsicum* peppers, and

for incipient domesticates that are more common in promoted landscapes, such as the assaís, milpesos, and Brazil nut.

How Many Were Domesticated to Some Degree?

This is a question for botanists, plant breeders, and archaeologists. A survey of the Neotropical historical record about natural resources from conquest to eighteenth-century ethnographies (Patiño, 1963, 1964, 1967), as well as other compilations, permitted the identification of at least 138 plant species with populations domesticated to some degree present in Amazonia at and shortly after European conquest, of which 83 are native to greater Amazonia. The others were introduced from Mesoamerica, the mid-elevation Andes and elsewhere in lowland South America (Clement, 1999a). Among the 36 incipient domesticates, 35 are fruit-bearing trees that are more common in promoted landscapes. Among the 28 semi-domesticates, 24 are fruit-bearing trees, some common in promoted landscapes and some in managed and cultivated landscapes. Among the 19 domesticates, nine are fruit-bearing trees or woody perennials with other uses, all dependent on managed and cultivated landscapes. Overall 82 % of the native species with populations domesticated to some degree are perennials, which is not surprising in the world's largest tropical forest biome. There are likely to be many more incipient domesticates and possibly more semi-domesticates, since the identification of most of these depended upon historical records and ethnographies, almost always prepared by non-botanists and never by plant breeders, who create collections of plant genetic resources in preparation for breeding and which allow the careful comparison of morphological and now genetic differences that are essential to identify components of the domestication syndrome of each species (Meyer, DuVal, & Jensen, 2012).

Where Were the Domesticated Crops at the Time of European Conquest?

This is a question for botanists, plant breeders, biogeographers, and archaeologists. The majority of the world's crops have distributions that cover large geographic areas that are often far from the crop's origin of domestication (Harlan, 1992), which is one of the reasons that the search for crop origins is often difficult. The crops native to Amazonia are typical of the trend observed at the world level.

In 1541, when Francisco de Orellana and his expedition descended the Napo and Amazon Rivers for the first time, thus initiating the European conquest of Amazonia, the majority of the largest indigenous societies were located along the major white water rivers of the basin (Heckenberger and Neves, 2009), with several others in the southern periphery, notably in the upper Xingu River basin, in central Brazil, and the Llanos de Mojos, in lowland Bolivia. These large populations produced all, or at least the majority, of their subsistence needs and depended upon an ample assortment of cultivated varieties of native and introduced crops (Clement, 1999a; Piperno, 2011). It is a truism in food production systems that monoculture stimulates the evolution of pests and diseases, which are managed today with pesticides. Before the advent of pesticides, monocultures were much less common, and pests were managed by using polycultural and polyclonal systems and an abundance of cultivated varieties (Clement, 1999a; Denevan, 2001). It is no surprise to find the largest concentrations of crop genetic resources where there were large human societies (Clement, 1999b; Clement et al. 2010). There are exceptions to this trend, of course. One is the Negro River, the major northern tributary of the Amazon River, with nutrient-poor waters and soils, but abundant socio-diversity, which selected and maintained numerous crop varieties (Clement, 1999b). It is important to recognize that these are centers of accumulation of crop genetic diversity and not centers of origins of domestication. In Amazonia, these two types of

centers are clearly different, whereas in other centers of crop genetic diversity identified by the important Russian geneticist and biogeographer of the early twentieth century, Nicolay Vavilov (Dorofeyev, 1992), they are often less clearly differentiated.

Which Were the Most Important Crops at Conquest?

This is another question for archaeologists and historians. Francisco de Orellana's expedition reported an abundance of manioc and maize (*Zea mays*, Poaceae) flour stored in villages along their route, which they sometimes received as presents but most often stole (Carvajal, 1894). Manioc continues to be important today, but maize nearly disappeared during the decimation of Native Amazonians during conquest and colonization (Clement, 1999a). Orellana's expedition also reported that all villages were surrounded by orchards, which certainly started in the home gardens behind the malocas and extended for several kilometers, gradually becoming managed forests and later promoted forests (Levis, Souza, and Schietti et al. 2012). The importance of orchards helps explain the number of domesticated fruit trees, while the managed and promoted forests contained mostly semi- and incipient domesticates. For any plant to contain domesticated populations, those populations must be culturally and economically important enough for people to select, propagate, cultivate, harvest, and process into food and other useful products. The most important crops were the 19 domesticates, with numerous edible fruits (including pineapple, *Ananas comosus*, Bromeliaceae; peach palm, *Bactris gasipaes*), several roots for starch (including manioc and sweet potato), condiments of various types (including hot peppers), an important colorant (annatto – *Bixa orellana*, Bixaceae), an assortment of stimulants (including cocaine, *Erythroxylum coca*, Erythroxylaceae; tobacco, *Nicotiana tabacum*, Solanaceae;

guaraná – *Paullinia cupana*, Sapindaceae), a single seed crop (peanut – *Arachis hypogaea*, Fabaceae), and even the edible starchy stem of a vine (*Cissus gongylodes*, Vitaceae) (Clement, 1999a).

The subsistence economies of the largest, most complex societies depended substantially on food and other products from the domesticates and many semi-domesticates, but they also continued to extract food and other products from forests, all promoted or managed to some degree, as well as fishing and hunting for animal protein (Clement, 1999a; Heckenberger and Neves, 2009). The hyperabundance of the assaís and milpeso palms are the clearest examples of anthropogenic forests that provided important food resources. The Marajoara society of Marajó Island, in the Amazon River estuary, may have depended more on the floodplain assai (*E. oleracea*) than on cultivated domesticates (Schaan, 2011).

Which Are Important Today?

This is a question for modern economists. It is often observed that modern global society depends upon 30 crops (Harlan, 1992). Three of these originated in Amazonia: manioc, sweet potato, and peanut. Among the important tropical fruits, pineapple is the second most important (Chang, 2011), after banana (*Musa* spp., Musaceae), which is included among the 30. However, a large fraction of global society certainly considers that the most important crop from Amazonia is cacao (*Theobroma cacao*, Malvaceae), used to make chocolate, which was invented in Mesoamerica (Foster & Cordell, 1992).

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Crops in Pre-Columbian America

Murdo J. Macleod

Before the European invasion of the Americas, the native peoples harvested a large variety of crops under many types of agricultural and gathering regimes.

Dense concentrations of people had existed for centuries in Mesoamerica and Andean America, and had evolved complex societies of agricultural peasantry and stratified urban elites. These peoples, in fact most Native Americans, had selected and adopted a miracle grass, maize (*Zea mays*), which reached yields of over one hundred to one in regions of good soils, intensive irrigation, and monoculture such as the *chinampas* or “floating gardens” of the central valley of Mexico. These high yields led to maize dominance in many diets, and the societies which evolved around this cereal may have resembled those of paddy rice China, which had highly intensified, quasigardening systems, rather than those of Europe or Africa, which had lower yielding but more diversified systems associated with wheat, barley, millet, and sorghum.

Maize was often associated, especially in Mesoamerica, with various varieties of American beans, especially *frijoles* of the genus *Phaseolus*, which climbed the maize stalks; with squashes (*Cucurbitae*) and their relatives; and with chili peppers (*Capsicum*), often planted between the maize stalks. The insufficiencies of this basic diet led to heavy foraging and to the harvesting of unoccupied areas and forests. In fact, even in settled societies there appears to have been a harvesting continuum from irrigated maize gardens to collecting, often in forests which were themselves results of centuries of human

selection and propagation. Thus, the modern student finds, paradoxically, intensive monoculture, plus slash and burn, plus areas of great biodiversity, all used by the same population.

Tubers of many kinds were widely cultivated but were somewhat more geographically restricted than the maize, beans, squash, and chili complex. Yams (genus *Dioscorea*), cassavas, or maniocs (*Euphorbiaceae*), some of highland origin, were intensely planted, and eaten after conversion to flours and breads, in tropical zones such as the Caribbean and the Amazon Basin. In many such regions, cassava was the staple diet. Musae (bananas and plantains) also appear to have been or become a staple in parts of the tropical lowlands, but scholars dispute their origin, some claiming that they are not native to the Americas.

In the Andes, tubers were also of great importance. Varieties of potatoes (*Solanum*) have been cultivated there for about 8,000 years, selected by humans for the many microenvironments of the mountain tropics. Andean farmers sometimes plant as many as 200 varieties in a single field, although most are being phased out in favor of the modern selected potatoes. Several other tubers were cultivated in highland America, such as *achira* (*Canna edulis*); *arracacha* (*Arracacia xanthorrhiza*); *jicama* (*Pachyrhizus erosus*); *machua* (*Tropaeolum tuberosum*); ova (*Oxalis tuberosa*); and *ulloco* (*Ullucus tuberosus*), still a staple in parts of the Andes. This area also produced tubers and grains which could be grown at great altitudes in poor climatic and soil conditions. Maca (*Lepidium meyenii*), a tuber, can be grown just below the snowline, as can *kaniwa* (*Chenopodium pallidicand*), and the better known quinoa (*Chenopodium quinoa*), both cereal grains rich in proteins and other nutrients.

Several other crops in America were traded widely before the European arrival. Cacao (*Theobroma cacao*), probably of Amazon origin, was known in the regions today called coastal Ecuador and Venezuela, but it was in Mesoamerica that cacao reached its greatest prominence. Planted along the Pacific coast from Colima to El Salvador, and in parts of Honduras, Tabasco, and Veracruz, cacao was important in trade, tribute,

and ritual. In some parts of the region it was used as coinage, and there are also reports that in some states its consumption was limited to the aristocracy. Tobacco (*Nicotiana tabacum*) was somewhat different. Although traded in many regions of America, its use may have been limited to ceremonial occasions.

Mesoamerica also produced vegetable and insect dyes, especially blues from indigo (*Indigofera tinctoria*) and reds from cochineal (*Opuntia cochinellifera*). Both items were traded, paid over as tribute, and used for ceremonial purposes. American cotton and thread from cactus were parts of textile trades and tribute.

European invasion and its consequences had widespread effects on American crops and their diffusion. The catastrophic fall of the native population and the introduction of large- and medium-sized domesticated animals, such as horses, cattle, sheep, goats, and pigs, caused abandonment of fields, destruction of crops, and the disappearance of many forms of ground cover. European need for wood for construction, shipbuilding, and fuel led to the cutting down of forests and the crops harvested in them. Colonial demands for uniformity in taxation caused peasants to give up the growing of marginal cultigens, or ones unfamiliar, distasteful, or useless to the dominant culture. The introduction of animals, and of plants such as wheat, citrus trees, and sugarcane, all cultural preferences of Europe, took up agricultural lands, and drove out native species.

Many scholars have stressed the more positive side of these intrusions and exchanges. Introduced crops such as wheat and animals such as cattle transformed the American diet, and the vast quantities of wheat grown on the prairies of the United States and Canada, and on the Pampas of Argentina, have fed large numbers of people in many parts of the world.

The more positive view also emphasizes the diffusion of American plants throughout the world, while admitting that the impact of some of these exports has been noxious (tobacco) or ambivalent. The potato, for example, the introduction of which to northwestern Europe met some resistance at first, was blamed by some for

the Irish famine. Its high yields and ease of cultivation led to a monoculture, rapid population growth, then famine and mass emigration – ironically to the Americas – when the potato crop failed. The advantages brought, nevertheless, by this productive, nutritious, human selection to the everyday diet of peoples living in the temperate zones are, of course, immense.

Some American crops, while having a generally beneficial impact when exported, had their “booms” modified or cut short by new technologies or crops. The two great American dyes, indigo and cochineal, after enjoying a century or two of flourishing trade, were destroyed by the invention of aniline dyes in the mid-nineteenth century. Sugarcane, not originally an American plant, nevertheless achieved great importance only when exported to the Americas. Plantation sugar, always prized by Europe but historically in short supply because of poor access to tropical areas and labor, boomed when northeast Brazil and the colonial islands of the Caribbean combined tropical climates, African slavery, intensified production, and reasonably close markets, and began to export huge shipments. Sugarcane transformed much of the world’s diet, and was an important fuel for the industrial and commercial revolutions of the nineteenth century. Although it continued to be of importance its monopoly was destroyed by the rise of beet sugar.

There can be little doubt, however, about the continuing beneficial impact of the diffusion beyond the Americas of many of the native crops. Maize, with rice one of the world’s two “miracle” cereals as far as yields are concerned, has spread, now largely as a hybrid, throughout the world, and its productivity has increased since the “Green Revolution.” It has become a staple in parts of the Mediterranean, the Balkans, Africa, and South Asia, and continues to be the largest food item for the masses in many parts of Latin America.

Some American crops required modification or additions before their use expanded. Cacao did not suit European tastes when first encountered; indeed it was repugnant to many, until people

learned to add sugar and vanilla. After Swiss and Dutch houses learned the process of making milk chocolate, cacao became an item of world diet, and West Africa is the main producer today.

Indeed, so pervasive today are some of the high-yielding American crops that their pre-Columbian American origins have been forgotten by the general public. Indian curry and Hungarian paprika, both based on American chili peppers, Italian tomato sauce, Irish potatoes, West Africa *ogi* and *kenkey* (maize doughs), and Swahili *posho* (maize meal), Turkish tobacco, and Swiss chocolate, are now thought of as age-old, integrated parts of regional and national cultures far from the Americas.

See Also

- ▶ [Agriculture in South and Central America](#)
- ▶ [Food Technology in Latin America](#)
- ▶ [Potato: Origins and Conservation of Potato Genetic Diversity](#)
- ▶ [Sugar in Latin America](#)

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Cuneiform

Carol F. Justus

Cuneiform was the script used throughout the Ancient Near East from the fourth to the first millennium BCE. Although a hieroglyphic script came to predominate very early in Egypt, the international second millennium correspondence of the Egyptian Sun King, Ikhnaton, used the cuneiform script. In the last millennium BCE Mesopotamian art depicts a set of scribes, one writing with a stylus on clay tablets, another on parchment. This later overlap between the use of parchment and clay as writing material foreshadowed the demise of cuneiform, the script by means of which literacy as a technological advance spread throughout the ancient world from early Mesopotamian sites such as Uruk in the lower Euphrates River Valley and Susa in what is now Iran.

The Script Form

Cuneiform (from Latin *cuneus* “wedge”; cf. German *Keilschrift* “wedge-script”) is so named because of the wedge-shaped signs which make up the characters of the script. A reed stylus created these signs that resemble the head of a nail. Pressing one corner of the stylus into the damp clay of the tablet made a *Winkelhaken* or corner wedge (◀). This corner wedge could be elaborated by adding a vertical (⌋) or horizontal tail (⌋—), or by tilting the tail at an angle. These basic shapes combine to produce the more than 700 signs of the cuneiform writing system. Cuneiform signs are read left to

right, as are western European alphabetic symbols.

Alphabets used to write modern Western languages reduce those languages to writing on the principle of one sound to one written symbol. The principle underlying the cuneiform system was by no means so simple. A single sign might have phonetic or logographic values. A corner wedge alone could, as a syllabic unit, represent the syllable sound of “u” as in “U-gan-da” or, as a logogram, refer to the word for the numeral “ten”. Two raised corner wedges combined with a vertical wedge (𐎶) form the phonetic syllable “ud” which also had the logographic meaning “day”. While vowel sounds had a one-to-one correspondence with a sign as in “a, i, u”: “a” (𐎶), “i” (𐎶), and “u” (𐎶), there were no signs for consonants such as “p”, “t”, “k”, or “m”. Cuneiform signs had phonetic values as syllables, so there were signs instead for “pa, ta, ka, ma, pi, ti, ki, mi” and so on. But a sign also had a logographic value as in the case of *ud* “day”. This logographic-syllabic principle underlying the cuneiform script, unlike that underlying an alphabet, used signs to refer either to entire words (logograms) or to phonetic (syllabic) units.

The syllable sign “ud” is typical of signs that refer to vowel plus consonant sequences. Cuneiform also had syllabic signs for consonant-vowel sequences, e.g. (𐎶𐎶) “di”, (𐎶𐎶) “gi”, or (𐎶𐎶) “ni”, and, less frequently, for consonant-vowel-consonant sequences: (𐎶𐎶𐎶) “tar” or (𐎶𐎶𐎶) “kur” (Table 1).

This system of writing thus easily recorded a language with consonant-vowel sound patterns and consonant clusters in the middle of a word, but not words which begin or end with consonant clusters like “st”, or “sk” as in English “stop, skate, nest” or “desk”.

While cuneiform syllabic signs often represented speech sounds, the same sign might also have non-phonetic uses as well. In addition to syllabic (phonetic) uses, signs might function as determinatives as well as logograms. As a determinative, a cuneiform sign preceded (or followed) one or more sets of signs without any phonetic value. The non-phonetic determinative merely signaled to the reader that a word in

question was of a particular semantic type. Typically, the determinative for “female” preceded a woman’s name, the determinative for “male” a man’s, or the determinative for “deity” the name of a god or goddess. Used as a logogram, as noted, a cuneiform sign stood for an entire word. Thus, either the single sign (𐎶) or the syllabic sequence *ni-in-da* might stand for Sumerian “bread”. Likewise, “deity” might be written logographically in a Sumerian text using the “an” sign (nr. 13) or syllabically with the sequence *di-in-gi-ir*. Such dual mechanisms illustrate not only the relation between logographic and phonetic representation of words but also something of the syllabic structure of the Sumerian language which had word-medial (-*nd-* and -*ng-* in *ninda* and *dingir*) but not word-initial or word-final consonant clusters.

Scribes often used signs logographically for the lexical content of common words and syllabically for grammatical markings such as the possessive of a noun. Thus, “of god” in Sumerian might be written phonetically as *di-in-gi-ir-ra* (*dingir* plus the possessive suffix *a*) or logographically with the “god” sign plus the syllabic sign, -*ra*. Transliteration conventions using the Roman alphabet distinguish among determinative, logographic, or syllabic uses of cuneiform signs on a tablet by using lower case, upper case, and raised letters. Signs used phonetically are transliterated with lower case letters; signs used logographically but interpretable on the basis of a Sumerian word are transliterated using capital letters for the Sumerian word form. The Sumerian scribe’s writing of the logogram for “god” plus syllabic -*ra* would thus be transliterated DINGIR-*ra* to distinguish it from a scribe’s entirely syllabic rendition, *di-in-gi-ir-ra*.

Determinatives are transliterated as raised sequences, either before or after the “determined” word. Characteristically the plural determinative follows, while others often precede. Thus, “gods”, written with the logogram for “god” (𐎶𐎶) plus a plural determinative whose Sumerian phonetic value was “mesh” (𐎶𐎶), might be transliterated in Roman letters DINGIR^{MESH} and translated “gods”. Similarly, the Sumerian sun god, Utu, would begin with the determinative

for “deity” () and continue with the name, Utu, written syllabically ^{DINGIR}U-tu. However, the sun god’s name was usually written logographically using the logogram for “day”, ^{DINGIR}UD (), transliterated ^{DINGIR}UTU (Sungod). To bring the use of cuneiform signs full circle, one might recall that the “god” sign (), besides its logographic reference to the Sumerian word, *dingir* “god”, also had a syllabic reading, *an*. For a scribe, the same sign thus had multiple values. The sign () had a phonetic (syllabic) value *an*, a logographic value “god” (Sumerian DINGIR), and a non-phonetic use as the determinative for “deity” to which modern scholars assign the phonetic value, *dingir*, for purposes of transcription.

Like determinatives, which had no phonetic counterpart in the speech represented by cuneiform signs, horizontal lines were often drawn across the tablet as a kind of punctuation aid. Because the structure of the languages written in the cuneiform script was very different from English, punctuation principles might also be expected to vary. In fact the scribes’ horizontal lines across the tablet probably marked something corresponding in part to our sentences and partly to our paragraphs. These scribal lines occur from earliest Sumerian tablets down through adaptations of cuneiform to write Semitic and Indo-European languages.

Languages Written in Cuneiform

Questions about the range of sounds that written symbols might need to distinguish, and indeed which units of language should be represented by individual signs, have concerned linguists seeking to reduce languages to writing. Western European languages often solved these problems by borrowing the Roman alphabet. Cultures of the Ancient Near East borrowed the cuneiform script, as the alphabet did not yet exist in the third millennium BCE. Cuneiform scribes thus dealt with issues of defining the linguistic units to be represented by altering a system of cuneiform signs already in use to write Sumerian. Scribes in fact used the cuneiform script to write

languages that differed from Sumerian. They then had to adapt the script to fit the needs of the languages they spoke. The words of some of the languages had long series of suffixes, for example, while others used word-internal vowel changes much as English does in “sing, sang, sung” or “stand, stood”, and Indo-European languages had word-initial and word-final consonant clusters.

A major adaptation of cuneiform was for the East Semitic Akkadian that served as the basis for the spread of cuneiform throughout much of the Near East. Besides Old Akkadian, which had its own conventions for phonetic representations using the cuneiform script, major East Semitic languages include the Old Babylonian in which the southern Mesopotamian Code of Hammurapi was written and Old Assyrian, which records the northern merchant trade between Assur and Anatolian Kanesh (near modern Kayseri, Turkey) even before the time of Hammurapi. Babylonian and Assyrian continue in ever-changing regional forms for nearly 2,000 years as Middle Babylonian, Middle Assyrian, Neo-Babylonian, and Neo-Assyrian. To the east of Mesopotamia the ancient language of Susa, Elamite, also used cuneiform, while Hurrians in Northern Mesopotamia, Syria, and Anatolia adapted cuneiform at different times to write their language. In second millennium Anatolia, the scribes of Hattusa used cuneiform to write Hittite, Luwian, and Palaic, Indo-European languages related to Greek, Latin, and the Germanic language family from which English is descended.

When scribes adapted cuneiform for use in writing other languages, some things changed more than others. While the signs often came to have peculiarly local values in different scribal schools, the most constant aspect of the cuneiform script was its core repertoire of determinatives and logograms. Where cuneiform was used, determinatives such as those for male, female, deity, land, and plural remained the same. Logograms for basic vocabulary, for god, ox, sheep, child, king, mountain, and river, also remained constant. The Akkadian scribe, for example, now had all the options available that the Sumerian scribe had, plus those that involved the phonetic

representation of Akkadian. Akkadian nouns had three different forms depending on whether they were used as subject or object in the sentence, or as a possessive. The Akkadian word for “god” was thus *ilum* (nominative), *ilam* (accusative), or *ilim* (genitive), written as phonetic *i-lu-um*, *i-la-am*, *i-li-im* or logographic DINGIR-*lum*, DINGIR-*lam*, DINGIR-*lim* where syllabic signs differentiate case, or simply DINGIR, if the context was clear without the case ending.

When cuneiform spread via an Akkadian-based scribal school, scribal practices also spread. Thus, sign sequences were now often interpretable, not only on the basis of recognizing Sumerian, but also Akkadian, words. This created a further complication for scholars transliterating the tablets into a Roman alphabet. Instead of signs interpretable as Sumerian logograms (Sumerograms in capital letters), there are now signs interpretable as Akkadian logograms (Akkadograms) which scholars transliterate using italic capitals. Since the Hittites borrowed the script as a form of Akkadian cuneiform, Hittite scribes had still more options for writing “of god”. While the Sumerian scribes wrote “of god” as phonetic *di-in-gi-ir-ra* or logographic DINGIR-*ra* and the Akkadian scribe used phonetic *i-li-im*, logographic DINGIR-*lim* or DINGIR-RA-*lim*, the Hittite scribe could write phonetic *si-u-ni-ya-as* (Hittite “god”: nominative *sius*, genitive *siunias*), Sumerographic DINGIR-(RA), Akkadographic I-LIM, or some combination, DINGIR-(RA-)LIM or DINGIR-(RA-)LIM-as.

The Origin of the Cuneiform Script

The earliest attested use of cuneiform as a developed system of symbols to write a language was its use to write Sumerian ca. 3100. Modern Japanese, which has borrowed Chinese (logographic) kanji characters as a basis for reducing Japanese to writing, likewise uses syllabic symbols to augment logographic symbols. Because the Japanese syllabic symbols (*hiragana*) are an independent Japanese invention to adapt the Chinese script to a language

structure for which the kanji characters were inadequate, scholars have hypothesized that Sumerian, with its logographic-syllabic script, represented an adaptation of an earlier “Proto-Tigridian” script of which we have no record, one used for a pre-Sumerian language of the Tigris river valley. Studies in the origin of writing, however, suggest that writing emerged as a new technology in what became the Sumerian city of Uruk.

The forerunners of the earliest cuneiform tablets were “impressed” tablets, tablets impressed first, not by the stylus which came to be used to write cuneiform, but by small clay artifacts known as tokens. The token-impressed tablets were economic documents recording amounts of various commodities that the society stored or transferred. Discrete symbols for commodities such as sheep, barley, or jugs of wine and oil were impressed on to the tablet. At first repetitions of the sheep symbol, for example, referred to the quantity of sheep in question and repetitions of the “oil jug” impression designated the quantity of oil. As the technology for writing and enumeration matured, forms became stylized to reflect changes in the thinking about the content. Concepts of quantity evolved separately from those for commodity, and both became increasingly abstract. What began as impressions of commodity signs and repetitions of the same sign to indicate quantities evolved as two sign types, “numerical signs” and pictographic signs, that developed independent logographic and syllabic values. “Numerical signs” were so-called before it was clear that their earliest forms did not stand for the abstract numeral values of today but only came to have numerical values as the “systems of numeration” evolved. Originally the 60 shapes of the “numerical signs” stood for values in a measure unit system that was specialized for a particular commodity or class of commodity. Sign values varied depending on the commodity quantified much as traditional measure units such as “foot”, “inch”, “bushel”, “cup”, and “quart” still do. While there are 12 in. in a foot and four cups to a quart, a “foot” does not have the abstract numerical value 12 nor quart the value 4. Quantity values were also relational

Cuneiform, Table 1 Cuneiform signs and their sign list keys (cf. Borger or Labat)

Numerical key	Usual value	Sign shape
411	u	
480	dish	
1	ash	
381	ud	
579	a	
142	i	
457	di	
85	gi	
231	ni	
12	tar	
366	kur	
597	NINDA	
13	an	
533	mesh	

within the system for measuring commodities; they did not yet refer to abstract numerals.

Over time, the early accounting systems of the Sumerian city states that had used older systems of weights and measures with local values became standardized on the sexagesimal basis of factors 6 and 10. With further standardization on the base ten of the decimal system, the way was paved for the abstraction of number and the association of abstract numerical values with

numeral words and signs. Calculation of amounts of commodities in terms of measure units and “numerical signs” replaced the older one-to-one calculation reflected in the early repetitions of impressed commodity symbols, and both are now mostly replaced by systems of abstract numerals. The specialization of script signs as “numerical signs” separate from commodity signs reflected an early stage in this evolution. In this respect, the evolution of cuneiform writing is inseparable from the evolution of early calculation and counting as the evolution of shapes took place as part of the evolution of the new meanings that motivated that evolution.

Commodity unit shapes developed independently of shapes for “numerical signs” when, instead of impressing the token into the clay, the scribe used a stylus to draw the shape of some tokens but continued to impress other shapes, some composite or with added lines. Drawn and impressed shapes that developed logographic and syllabic values became more and more abstract when the corner of a reed stylus came to create wedge-shaped cuneiform signs (<http://www.utexas.edu/cola/centers/lc/numerals/numerals.html>).

Over the millennia in which cuneiform was used, the shapes of the signs evolved from more pictographic forms to highly stylized symbols. Later Ugaritic use of wedge-shaped signs as an alphabet broke with the cuneiform tradition in assigning new values to sign forms.

Early Non-cuneiform Scripts

The existence of other early scripts in the Ancient Near East attests to the rapid spread of literacy and numeracy. While Egyptian hieroglyphs are clearly independent script forms, the basis for reducing the early Egyptian language to writing is probably not independent of the new technology which arose in Mesopotamia as a response to economic and lifestyle changes involving the storage and transfer of surpluses of essential commodities. In the second millennium too a hieroglyphic script, Hieroglyphic Luwian (at first known as Hieroglyphic Hittite) developed independently in Anatolia and North Syria. This

Luwian Hieroglyphic and the cuneiform script coexisted in different functions. The local hieroglyphic script recorded royal inscriptions in the Luwian language on stone monuments but cuneiform was the script of clay tablets. The fact that Hittite cuneiform tablets of Anatolia refer to “old wooden tablets” has led to speculation that hieroglyphic may have been inscribed into a wax coating on wooden tablets. Since none of these waxed wooden tablets has survived, such inferences, of course, remain speculative. The forms of the hieroglyphs are unrelated to the forms of cuneiform signs, but again the two scripts share a common conceptual basis for reducing language to writing. Hieroglyphic Luwian, like cuneiform and Egyptian hieroglyphics, is based on logographic-syllabic principles.

Decipherment

The cuneiform script was deciphered in the nineteenth century as a result of a trilingual inscription found at Behistun in Iran. The languages of the inscription were Elamite, Old Babylonian, and Old Persian, all written in a form of cuneiform. Both Elamite and Old Babylonian were unknown languages at the time, but Old Persian was known from Zoroastrian religious texts. The Old Persian inscription was first deciphered on the basis of hypotheses about the recurring symbols in Old Persian royal names. From there, hypotheses related the signs used to write the Old Persian with signs in the unknown scripts. Little by little, Old Babylonian and Elamite began to be deciphered. With the decipherment of the script came the decipherment and study of the different languages and cultures that used cuneiform to record their history and socio-economic structure. A not insignificant aid in the subsequent decipherment of Sumerian turned out to be the discovery of grammatical texts that Akkadian scribes had developed as pedagogical devices for teaching the learned language of the second millennium BCE, Sumerian, thereby training scribes to support the ever-growing bureaucracy of the ancient world.

Ongoing work on early cuneiform texts and their predecessors is now being catalogued as the Cuneiform Digital Library Initiative (CDLI: <http://cdli.ucla.edu/>).

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D

Dams and Irrigation in Ancient Arabia

Michael James Harrower

Among the many scientific and technological accomplishments of ancient Arabia, dams and irrigation systems stand out as a remarkable testament to advanced skills in hydrological engineering. Arabia's ancient inhabitants developed sophisticated means of capturing and diverting water that not only involved detailed knowledge of water flows, but also required coordination of considerable labor for construction, operation, and maintenance. Although sometimes overshadowed by better-known Egyptian, Mesopotamian, and South Asian irrigation systems that supported some of the world's earliest and most influential civilizations, the remains of advanced water control systems have also been found throughout Arabia. Some of the ancient world's largest dams and most advanced flash-floodwater systems were constructed in Southwest Arabia (Yemen) during the late first millennium BCE. Southwest Arabian floodwater (spate) systems irrigated thousands of hectares and supported ancient states that gained wide recognition for trading aromatic tree resins including frankincense and myrrh to as far away as the Mediterranean. The tenth century AD geographer and historian ► [al-Hamdānī](#) was one of the earliest scholars to report on irrigation works of

Southwest Arabia. In the eighth book of his treatise *al-Iklīl*, al-Hamdānī describes ancient monuments and briefly mentions a number of large dams, including the famous dam near Ma'rib, Yemen (Faris, [1938](#) [945], pp. 34–35, 67–69). Ancient Southwest Arabian irrigation systems subsequently captured the attention of early western explorers, including Arnaud ([1874](#)) and Glaser ([1913](#)), and they remain a topic of considerable scholarly interest today (e.g., Brunner, [1997a, b, 2000](#); Brunner & Haefner, [1986](#); Darles, [2000](#); Francaviglia, [2000, 2002](#); Gentelle, [1991](#); Ghaleb, [1990](#); Hehmeyer, [1989](#); Vogt, [2004](#); Vogt, Buffa, & Brunner, [2002](#)).

The dam near Ma'rib (Yemen), capital of the ancient state of Saba, is one of the largest and most impressive examples of ancient floodwater irrigation (Fig. 1). Small-scale irrigation began in the region as early as the late fourth to early third millennium BCE (e.g., Ghaleb, [1990](#)) and by the first few centuries AD a dam 680 m long and 16 m high diverted water (via two massive sluices at its northern and southern extremities) to irrigate as much as 9,600 ha (Brunner, [2000](#); Brunner & Haefner, [1986](#)). Interestingly, ancient Southwest Arabian state capitals such as Ma'rib developed not in relatively humid highlands where rainfall agriculture was possible, but along the margins of the Ramlat as-Sab'atayn Desert where irrigation farming required far more labor but could also dramatically boost agricultural production. Ancient Southwest Arabian kingdoms of Ma'īn, Awsān, Qatabān, and Hadramawt were part of an intricate

Dams and Irrigation in Ancient Arabia,

Fig. 1 The massive south sluice of the ancient dam near Ma'rib, Yemen (Photo by the author)



network of trade and political relations and utilized analogous flash-floodwater irrigation technologies (Brunner, 1997a, b; Francaviglia, 2002; Gentelle, 1991; Gentelle & Coque-Delhuille, 1998). By the sixth century AD the power and influence of the Saba had dramatically waned. Damaged by powerful floodwaters the inhabitants of Ma'rib were unable to mobilize the labor necessary to repair the dam and agriculture continued at only a fraction of its former grandeur (Vogt, 2004).

Many important questions surrounding the origins of irrigation in Arabia (including the degree to which local technologies developed independently or were inspired by developments elsewhere) remain largely unanswered. Unlike systems of Egypt, Mesopotamia, and South Asia that frequently diverted water from perennial flow rivers such as the Nile, Tigris, Euphrates, and Indus, irrigation systems of the Arabian Peninsula involved diversion of flash-floodwaters that typically occur only a few times a year, quickly appearing and disappearing in a matter of hours. Egypt and Mesopotamia are known to have some of the earliest and most extensive systems, and some scholars have thus speculated that diffusion from one or both of these regions was likely responsible for systems in Arabia

(e.g., Bowen, 1958). But if irrigation systems of Southwest Arabia did indeed diffuse from distant regions, dramatic modifications would have been required before they could operate amidst very different topographic, hydrological, and social circumstances. In Egypt and Mesopotamia, where a tremendous wealth of archaeological research has been conducted, a long history of alluvial deposition and land-use make identifying the earliest irrigation and the precise techniques first involved a significant challenge (e.g., Wilkinson, 2003). Although some of the world's first farmers experimented with water management in the Levant during the Neolithic, possibly as early as the seventh millennium BCE (Bar-Yosef, 1986; Betts & Helms, 1989; Miller, 1980, pp. 331–332) most relied on direct rainfall and/or naturally water-rich areas. By the sixth millennium BCE the prevalence of irrigation had begun to increase substantially. Farming settlements were established in areas of middle and lower Mesopotamia where rainfall was insufficient for cultivation (Maisels, 1999, pp. 125, 147–150), canal fragments are dated to before 5000 BCE at Choga Mami (Oates & Oates, 1976), and linear arrangements of sites in Mesopotamia and Iran suggest they were located

along canals (Adams, 1965, p. 119; Sumner, 1994, p. 57). It was not until substantially later during the fourth millennium BCE that large-scale irrigation became a widely predominant means of plant food production. In both Egypt and Mesopotamia centrally coordinated irrigation was well underway by this time (Butzer, 1976; Postgate & Powell, 1988). While the first appearance of irrigation in Southwest Arabia may have been stimulated by aforementioned developments in the Levant, Mesopotamia, or Egypt, investigations in Yemen have traditionally focused on prominent large-scale systems, rather than their small-scale predecessors from which farmers first accumulated knowledge of water flow patterns and developed organizational means to control them. Recent investigations have made important strides toward identifying Southwest Arabia's earliest systems. Small-scale hillslope runoff systems have now been identified and dated to the late fourth millennium BCE in a number of widely dispersed locales throughout Yemen's rugged highlands (Ghaleb, 1990; Harrower, 2006; McCorriston & Oches, 2001; Wilkinson, 1999).

While peoples of ancient Southwest Arabia developed increasingly sophisticated flash-floodwater irrigation, other regions were simultaneously designing water control systems tailored to their own local circumstances. By the first millennium BCE underground infiltration galleries that captured water from upland aquifers (known in Iran as *qanats*) spread to Southeast Arabia (Oman) where they rapidly became a primary means of agricultural production (Wilkinson, 1977, 1983; Lightfoot, 2000). The inhabitants of Nabataean cities such as Petra (Jordan) and Meda'in Saleh (Saudi Arabia) constructed extensive hydraulic systems of dams, canals, conduits, pipes, and cisterns to provide water for domestic consumption, gardens, and fields (Akasheh, 2002; Orloff, 2005). Increasingly complex perennial flow systems supported long and highly productive agricultural histories in Egypt and Mesopotamia. South Asian cities including Mohenjo-Daro and Harappa operated some of the world's first household

water supply systems for drinking, bathing, and to remove domestic sewage (Scarborough, 2003, pp. 144–145).

In addition to irrigation's importance as an example of ancient technological expertise, water control has held an enduring place in explanations of ancient sociopolitical change. During the 1950s Wittfogel (1957) and Steward (1949, 1955) became key proponents of the hypothesis that the need for bureaucracies to coordinate large-scale irrigation was a primary factor responsible for the rise of centralized political leadership and the emergence of the world's earliest civilizations. Although scholars now recognize that irrigation was certainly not the only factor responsible for the rise of the world's first state societies, Wittfogel and Steward played an important role in emphasizing the near ubiquity of water control among early civilizations. Their assertions prompted a wealth of research on coordination and management of irrigation (e.g., Downing & Gibson, 1974; Hunt & Hunt, 1976; Kelly, 1983; Millon, 1962), and irrigation continues to be a focus of cross-cultural archaeological and anthropological research (Mabry, 1996, 2000; Scarborough, 2003). In some cases large-scale systems developed by accretion as individual farmers or groups of farmers constructed independently devised systems, while in others large-scale systems were designed, constructed, and operated by irrigation administrators with state sanctioned authority (Mabry, 1996, 2000). While the so-called "hydraulic hypothesis" in its most simplistic formulation is clearly flawed and long outdated, water control undoubtedly did play a significant role in shaping the history of many ancient societies including those of Arabia and other arid environments.

See Also

- [al-Hamdānī](#)
- [Irrigation in the Islamic World](#)
- [Qanat](#)
- [Settlements in Egypt: Alluvial Settlements in the Nile Valley \(and Delta\)](#)

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Decimal Notation

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The invention of decimal notation was a landmark in the intellectual history of humankind. Introduced in India during or shortly before the fifth century CE, it reached the Arab world in the following centuries and was transmitted to Europe through the Persian writings of the ninth century mathematician, Abū 'Abdallāh Muḥammad ibn Mūsā al-Khwārizmī'.

The decimal system involves the use of ten notational signs to indicate the numbers 0, 1, 2, 3,

4, 5, 6, 7, 8, and 9. Each of these numbers has an absolute numerical value of its own and a positional value. This positional value, or place value, occurs as units, tens, hundreds, thousands, and so on from the right. Thus, in the number 2,947, for instance, 7 occupies the unit position, 4 has the position of 40, 9 the position of 900, and 2 the position of 2,000. The value multiplies by 10 when a zero is added to the right, so that a zero after 25 makes it 250 and another zero 2,500.

The story of decimal notation is rather protracted. It shows no signs of linear evolution, but only of quantum leaps at different points in time. The Vedic corpus, most of which were composed before the sixth century BCE, used a system of numbers that had 10 as its base or were organized into multiples of 10. This was also known to the Greeks and Romans and, before them, to the Egyptians. But these early systems lacked the zero, and therefore, the digits had no positional values. While other forms of counting, like the sexagesimal (base 60) of the Babylonians, were not unknown, the decimal system appears to have been recognized as the most convenient system of counting. Why this was so is not altogether clear. One plausible reason is that the rudimentary mathematical needs of a pre-agrarian economy, which involved nothing more than counting cattle and other domestic animals, pots, tools and weapons, days and months, and chariots, were easily fulfilled by counting one's fingers, of which were ten. This likelihood is affirmed by the fact that the word "digit" signifies a number as well as a finger and is etymologically related to the Latin word for finger, *digitus*.

This simplicity is seen in the *Ṛgveda*, which mentions all numerals from one to ten, viz., *eka* (one), *dvi* (two), *tri* (three), *catur* (four), *pañca* (five), *ṣaṭ* (six) *sapta* (seven), *aṣṭa* (eight), *nava* (nine) and *dasa* (ten), in addition to several others like *ekādaśa* (eleven), *dvādaśa* (twelve), *caturdaśa* (fourteen), *pañcadaśa* (fifteen), *viṃśa* (twenty), *triṃśa* (thirty), *śata* (hundred), *sahasra* (thousand), etc. The expansion of agriculture, urbanization, the emergence of states, and the rise of trading classes seem to have demanded advanced calculations. In the later Vedic

literature, there are references to fabulous gifts received by Brāhmaṇas, which in one instance is recorded as consisting of 10,000 elephants, 88,000 white horses, and millions of cows, among other things. Buddhist sources tell us that the first Indian ruler of some consequence, Bīmṇisāra, ruled over 80,000 villages in the late sixth century BCE, while a century and a half later, a king of the Nanda family is said to have commanded a wealth of a *mahāpadma* (10^{37} according to one reckoning, 10^{15} according to another, and 10^{12} in yet another), giving him the name Mahāpadma Nanda. While these numbers are certainly exaggerated, they point to a major transformation in the world of numbers.

Calculations using the decimal system had become considerably complex by the first and second centuries CE, when the Buddhist *Lalitavistara* was written. In this work, Arjuna, the teacher, asks the Bodhisattva, the Buddha in the making, to demonstrate the calculation of one *koṭi* (ten million) raised to the power of 100 ($10,000,000^{100}$). In the display that follows, the Bodhisattva states that a *koṭi* multiplied by 100 is an *ayuta*, an *ayuta* multiplied by 100 a *niyuta*, a *niyuta* multiplied by 100 a *kaṇkara*, and so on with *vivara*, *akṣobhya*, *vivāha*, *utsaṅga*, *bahula*, *nāgabala*, *tiṭilaṃbha*, *vyavasthānaprajñapti*, *hetuhila*, *karaphu*, *hetuvindriya*, *samāptalaṃbha*, *gaṇanāgati*, *niravadya*, *mudrābala*, *sarvabala*, *visaṃjñāgati*, *sarvasaṃjñā*, *vibhūtaṃgamā*, and *tallakṣaṇa* (10^{65}). He then gives nine other numbers, but without stating if they followed the same relationship of multiples of 100 s: *dhvajāgravatī*, *dhvajāgraniśāmaṇi*, *vāhanaprajñapti*, *iṅgā*, *kuruṭu*, *kuruṭāvi*, *sarvanikṣepa*, *agrasāra*, and *paramāṇurajahpraveśānugala*. The method that the Bodhisattva follows does not warrant the use of zero.

It is from Āryabhaṭa's work that we learn of the positional value for the first time. Here, he states that the numbers like one, ten, a hundred, a thousand, and so on are multiples of ten (*daśaguṇaṃ syāt*). This does not presuppose the deployment of zero, but the fact that a change in place value is involved in it (*sthānāt sthānam*) is a clear indicator that zero was in use

(*Āryabhaṭīya*, 1.2). A text dated to CE 458, the Prakrit *Lokavibhāga* by the Jaina monk Sarvaṇandi, might have invoked the expression *śūnya* to signify zero, if the surviving Sanskrit version of it by Siṃhasūri (ca. seventh century CE) is faithful to the original.

In spite of these fifth-century developments, the use of the place value system is not found in inscriptions from the Indian subcontinent until the ninth century. Its first known use is from an inscription in Gwalior, recording the grant of land to a Viṣṇu temple. Here, the date of the grant is mentioned as “933” (i.e., CE 876) in numerals and the extent of the land granted as “270” cubits in length and “187” cubits in breadth. There is also reference to “50” garlands in the inscription. Besides, the Gwalior inscription also uses the symbol “0” to represent zero. This is certainly not the first known use of the place value system, although no instance of it antedating the Gwalior inscription is known from South Asia. A Khmer inscription from Sambor in Cambodia of CE 683 used the notation “605” to record the year in the Śaka Era. A year later, a Malay inscription from Palembang in Sumatra wrote “60” and the Śaka Era as “606.” Similarly, “735” figured in an inscription of CE 813 from Ponagar in South Vietnam. The use of decimal notations can be seen in the *Bakhshali Manuscripts*, datable to the third or fourth century CE. But, the surviving manuscript is in the Śāradā script and, therefore, not older than the eighth century CE.

Although the use of zero was systematically discussed as early as ca. CE 630 in Brahmagupta's *Brahmasphuṭasiddhānta*, its absence from inscriptions before the late ninth century and the significance attached to it by al-Khwārizmī earlier in the same century suggest that the place value system gained in popularity only after this period. Who introduced the zero, when, and why, are questions that have baffled researchers for a long time. No clear answer is yet in sight. A tentative suggestion is not impossible, though. The conjunction of the facts that the positional value of numbers is stated for the first time in the *Āryabhaṭīya*, and that it is the same text which gives us some of the earliest postulates of trigonometry, indicates that the need for a base

(or a zero-degree position) from which angular movement can be reckoned for determining the value of various functions like sine and cosine was the impulse behind the introduction of zero. In other words, zero was perhaps trigonometric in origin.

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Decimal System and Measurement in East Asia

Shigeo Iwata

Decimal System

There exists at least one root word that seems to be common to all languages, namely, *tik*, which means a finger, an arm, or the numeral “one.” The word *te* in Japanese language that belongs to Sino-Tibetan languages refers to a “hand” and *iti* means “one” (Table 1).

When modern humans branched out from Africa some 150,000 years ago, they may have been aware of the number “one.” The Caucasoids branched off 100,000 years ago, and Australians 100–70 years ago. The Australians knew numbers as large as three before the eighteenth century. Mongoloids reached East Asia 70,000–50,000 years ago. The Japanese islands constituted an integral part of continental Asia about 12,000 years ago.

Decimal System and Measurement in East Asia, Table 1 Root word and meaning

Family or language	Form	Meaning
Nilo-Saharan	tok-tek-dik	One
Indo-European	dik-deik	To indicate/point
Caucasian (south)	titi, tito	Finger, single
Uralic	ik-odik-itik	One
Austroasiatic	ti	Hand, arm
Sino-Tibetan	tik	One
Indo-Pacific	tong-tang-ten	Finger, hand, arm
Eskimo	tik	Index finger
Amerind	tik	Finger
Na-Dene	tek-tiki-tak	One

Sorai Ogyu (1666–1728) discovered that the cardinal numerals of one type in Japanese include a reduplication system of the vowel-exchanging type. In other words, the replacement of one vowel with another has the effect of doubling the value of the number as can be seen in *hito* (1): *huta* (2), *mi* (3): *mu* (6), *yo* (4): *ya* (8), and *itu* (5): *towo* (10). Apart from Japanese, examples of similar multiplication systems can also be found most typically in Korean (dialect: 1), Taiwanese (8), Micronesian (5), Melanesian (3), and Amerindian (15). The numbers that cannot be obtained in this method are 7 and 9, which can be readily given by combining the approach of one-to-one correspondence.

Peoples using these languages belong to the Mongoloid race. It has been estimated that the cardinal numerals between 1 and 10 emerged no earlier than 50,000 years ago, before these Mongoloids migrated outward from an area of East Asia and made their way to the North, East, and South.

Each of the several bone pieces of 28,000 years ago that were discovered in Shiyu site in China bears a number of lines. Each of these lines denoting a number suggests that the people used to record 20 or more numbers. The 22,430-year-old bone tubes excavated at the Zhoukoudian site in the southwest of Beijing bear symbols that have been deciphered as representing 3, 5, 10, and 13. The shape of the symbol for 10 leads us to believe that its creators employed the decimal system. Presumably, the Mongoloid completed the

Decimal System and Measurement in East Asia, Table 2 Era and unit of length

No.	Site	Region	Year (BCE)	Unit of length (cm)	Standard deviation (cm)
1	Hasamiyama	Japan	26,000	17.3	0.67
2	Nishi-gagara	Japan	22,000	17.2	0.82
3	Shimonjo	Japan	18,000	17.3	1.01
4	Kogure-higashi-arayama	Japan	16,000	17.6	0.94
5	Tana-mukaihara	Japan	15,690	17.4	0.54
6	Taejon	Korea	13,000	18.1	0.60
7	Ushki	East Siberia	12,000	16.8	0.55
8	Kuzuharazawa	Japan	9,000	17.3	1.01
9	Momijiyama	Japan	7,120	17.2	0.68
10	Guhu	China	6,230	17.0	0.37
11	Egou	China	5,950	17.2	0.73
12	Gungsan	Korea	4,750	16.5	0.40
13	Uriba	Japan	4,620	17.4	0.31
14	Banpo	China	4,476	17.5	0.26
15	Giangzhai	China	4,182	17.3	0.18
16	Ichinosaka	Japan	3,875	17.4	0.34
17	Dadiwan	China	3,190	17.4	0.61
18	Ogakuchi	Japan	3,050	17.0	0.33
19	Wangwan	China	2,842	17.6	0.29
20	Ukonjiro	Japan	2,060	17.3	0.74

decimal system 50,000 years ago when they branched into East Asia, both North and South America, and the Pacific islands. The Chinese people recorded numbers as large as 30,000 in the period 3,300 years ago.

Measurement

The greatest numbers of discoveries in East Asia consist of pit dwellings. In most of these cases, the wooden pillars no longer remain; the only evidence left is the postholes. The center of each posthole bottom presumably constitutes the center of gravity. Statistic calculations of the intervals between the centers derive a unit.

Table 2 indicates the age and unit length of typical dwellings. The plan views of some of the dwellings are given in Fig. 1. The mean value of the length of one unit is 17.3 cm. The magnifications of the unit of lengths most frequently used are multiples of 5. In the rare case where irregular numbers only are detected, it is presumed that no ruler was used for the construction.

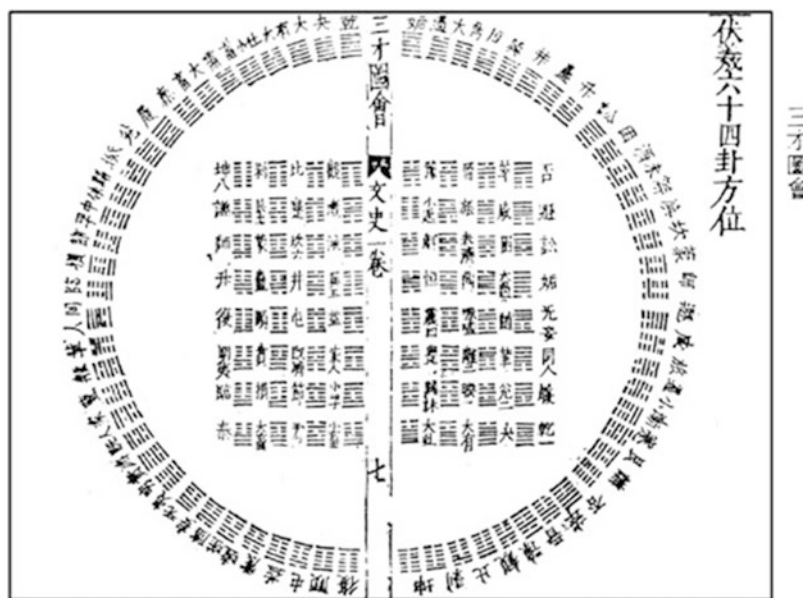
These dwellings were designed according to a triangular standard, with the particular use of isosceles triangles and occasional employment of an equilateral triangle. Later in 8000 BCE or thereabouts, rectangular dwellings emerged.

The era when the practice of measurement began is considered to be the period in the middle of the range with the upper limit of 50,000 years ago when the decimal system was presumably completed and the lower limit of 25,000 years ago, which is the oldest era indicated in Table 1. The region where measurement began in East Asia has yet to be determined.

The origin of the length 17.3 cm is not evident. At present, it is considered to match the hand length of an average female adult of a matriarchal society or the span of thumb and middle finger. Seven rulers that were used in the Chinese Shang dynasty in 1300 BCE or thereabout were found, of which four were made of bone, two of ivory, and one of jade. The shortest length of 1 *chi* is 15.773 cm and the longest 18.672 cm. The mean value and standard deviation of the length of 1 *chi* is 17.1 ± 1.47 cm. A ruler of 1 *chi* bear the graduations of 1/10, namely *cun* and 1/100, *fen*.

Decimal System and Measurement in East Asia, Fig. 1

Plan view. The magnification units of length most frequently used are 5, 10, 15, 20, 25, etc. The mean value of the length of one unit is 17.3 cm. These dwellings were designed according to a triangular standard, with the particular use of isosceles triangles



Then, the length of 1 *chi* significantly increased because of the turbulence of social order. In the period from thirteenth century BCE to third century BCE, it took about 48 years for a measure to propagate from China to the Korean Peninsula, and 150 years or thereabouts to the Japanese Islands that were isolated from the Continent.

The construction ruler (a ruler used for building structures) is the first standard scale of each race and differs from others in the unit of length. The cubit in Egypt measured 52.5 cm, while the cubit in Mesopotamia was 50.0 cm long, the fathom in Indus was 168 cm, and the hand length in East Asia averaged 17.1 cm.

On the Dadiwan site in China, four measures used in the period of $3,190 \pm 170$ BCE were discovered. The mean value of unit volumes was 264 cm^3 , which was close to the volume of a *gowpen* (double handful). Then, 2,800 years later in China, the standard of volume was set to 209 cm^3 with the unit name of *sheng*, which was four times as large as the volume of a single hand-cupped *gowpen*.

In Japan, it is highly probable that some of the potteries excavated from ancient sites of a period ranging from 2,800 to 2,300 BCE were made in accordance with standards of length and volume.

Assuming that such a positional notation as the decimal system was established before 50,000 years ago when modern humans arrived at East Asia and branched into various directions, the first measuring of length was used for building dwellings in a period between the above-mentioned era and 28,000 years ago. In the upper and lower ranges than the subject unit, one or more superior or inferior units were then created. With the gradual implementation of measuring systems of volume and other physical quantities, regional or racial cultures developed, and these different cultures integrated and evolved into the entire Chinese civilization. Thus, "Measurement was the mother of civilization," and "civilization began with measurement."

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which it has lent to all computations, puts our arithmetic in the first rank of useful inventions; and we shall appreciate the grandeur of this achievement the more when we remember that it escaped the genius of Archimedes and Apollonius, two of the greatest men produced by antiquity. (Quoted in (Dantzig, 1930), p. 19)

Due to the simplicity of the decimal notation, children all over the world can now learn basic arithmetic at an early age. This has been a major factor in the proletarianisation of considerable scientific and technical knowledge, earlier restricted only to a gifted few.

For an understanding of the history of this great innovation, we need to make a distinction between the two main familiar forms of the decimal system: the (written) decimal place value notation (decimal notation, in short) and the corresponding (oral) decimal nomenclature.

Forms of Decimal System: Notation and Nomenclature

Our standard decimal notation comprises ten symbols: nine figures called “digits” (or “numerals”) for the first nine numbers (1,2,3,4,5,6,7,8,9) and an additional symbol “0” as a placeholder to denote the absence of any of the nine digits. Sometimes, 0 is also regarded as a numeral or a digit. Every number, no matter how large, can be expressed by means of these ten symbols using the “place value” (or “positional value”) principle by which a digit d in the r th position (place) from the right is imparted the place value $d \times 10^{r-1}$. For instance, in the number denoted by 2107 in decimal notation, the digit 2 acquires the value “two thousand (2×10^3)”, while the digit 1 acquires the value “one hundred”. The Sanskrit word for “digit” is *anika* (literally, “mark”), and the term for “place” is *sthāna*.

In our standard verbal decimal nomenclature, each number is expressed through nine word-numerals (one, two, ..., nine in English) corresponding to the nine digits, and words for the “powers of ten” (like “hundred”, “thousand”, etc.). Here, the number names for the powers 10^n

Decimal System in India

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The decimal notation is an outstanding innovation both in its sheer brilliance of abstract thought and as a practical invention. In the words of the French mathematician Pierre-Simon Laplace (1814 CE):

It is India that gave us the ingenious method of expressing all numbers by means of ten symbols, each symbol receiving a value of position as well as an absolute value; a profound and important idea which appears so simple to us now that we ignore its true merit. But its very simplicity, the great ease

play the role of the place value principle. The concept of zero as placeholder is not required for the verbal expression of a number. For convenience, some additional derived words may be adopted (like “eleven” for “one and ten”, “nineteen” for “nine and ten”, “twenty” for “two ten”, etc.).

Both the above forms originated and developed in India; the decimal notation evolved by the early centuries of the Common Era while the verbal decimal nomenclature was already in vogue when the *Rgveda*, the most ancient extant world literature, was compiled. In addition, there was another system in India of expressing numbers (both orally and in writing) using place value in place of number names for powers of ten but using words in place of symbols for the numerals. The words were usually arranged in ascending powers of ten; like 2107 being expressed as “seven-zero-one-two”. This system suited the tradition of oral transmission.

The word “decimal” (pertaining to ten) is derived from the Latin *decimalis* (adjective for “ten”) and *decem* (ten), resembling the Sanskrit *daśama* (tenth) and *daśan* (ten).

The decimal system is based on the mathematical principle that any natural number can be envisaged as a polynomial-like sum $10^n a_n + \dots + 100a_2 + 10a_1 + a_0$, where $a_0, a_1, \dots, a_n$ are numbers between 0 and 9. Numbers can also be represented in bases other than ten; for instance, in the binary representation used in computers, numbers are perceived in the form $2^n a_n + \dots + 2a_1 + a_0$, where each a_i is either 0 or 1. Such representations involve recursive applications of the well-known “division algorithm” that pervades the later Greek, Indian and modern mathematics. The mathematical sophistication of the decimal system can be glimpsed from the fact that its discovery required a realisation of the above principles.

Antiquity of Decimal Nomenclature

The decimal system in India, at least in its verbal form, is an inheritance from an age of mystic intuition in remote antiquity. Numbers are

invariably described in decimal nomenclature in ancient Sanskrit treatises right from the Vedic *Saṁhitā* and the *Brāhmaṇa*. These esoteric treatises contain the current Sanskrit terms for the nine primary numbers: *eka* (1), *dvi* (2), *tri* (3), *catur* (4), *pañca* (5), *ṣaṭ* (6), *sapta* (7), *aṣṭa* (8) and *nava* (9); the derived decuple terms for the first nine multiples of ten: *daśa* (10), *viṁśati* (20), *triṁśat* (30), *catvāriṁśat* (40), *pañcāśat* (50), *ṣaṣṭi* (60), *saptati* (70), *aṣṭi* (80) and *navati* (90); and terms for powers of ten.

Decimal Enumeration in the Rgveda

The principles of decimal enumeration had already been mastered by the time of the *Rgveda*, the oldest layer of Vedic literature. The Sanskrit terms for the nine numerals occur several times in the *Rgveda*. Among powers of ten, the *Rgveda* frequently uses *daśa* (ten), *śata* (hundred) and *sahasra* (thousand); *ayuta* (ten thousand) too is mentioned in a few hymns. For compound numbers, the names for nine numerals and powers of ten are combined as in our verbal decimal terminology; e.g., “seven hundred and twenty” is expressed as *sapta śatāni viṁśatiḥ* in *Rgveda* (I.164.11). In a detailed study of decimal enumeration in the *Rgveda*, B. Bavare and P. P. Divakaran have shown (2013) that this combination is actually an application of the more general grammatical rules of nominal composition followed in Sanskrit from the Vedic time (at least) and formulated later by Pāṇini. Thus, the verbal decimal terminology – the precursor to, and a certain manifestation of, the abstract place value principle – is an offshoot of the grammatical principles of Vedic Sanskrit.

Mystic Significance and Etymology of Powers of Ten

The choice of base ten and the coining of number names for certain powers of ten might have arisen from the special mystic significance attached to these numbers in an ancient era (Dutta, 2008). In the perception of the Vedic seers, the number hundred represents a general fullness; ten layers of hundred symbolises an entire plenitude, an absolute completeness, and a word for plentiful – *sahasra*, derived from the root *sahas*

(mighty, powerful, plentiful, forceful, etc.), was adopted for it. Ten thousand was considered special as the mystics saw in the illumined mind ten subtle powers each having an entire plenitude (Sri Aurobindo, 1972, pp. 301–302, 416).

Regarding the etymology of *daśa* (ten), the ancient lexicographer Yāska (sixth century BCE or earlier) says: *daśa dastā dṛṣṭārthā vā – daśa* is so called as it closes off a sequence of numbers (the nine numerals) and as its effect can be seen (in forming the next sequence). It may be recalled that similar-sounding Vedic words *das*, *dasma*, *dasra* have the sense of completing, fulfilling, accomplishing; *das* also has the related sense of getting exhausted. Yāska says that *śata* (hundred) derives from *daśadaśa* (ten tens), without further explanation. We mention here that due to their extreme antiquity, the etymology of Vedic words is often obscure; even ancient lexicographers had to use ingenious guesses rather than definitive knowledge.

The mystic civilisation of ancient Egypt also used base ten and had special pictorial symbols, with possible allegorical connotations, for powers of ten up to 10^7 (ten million). However, the Egyptian system of hieroglyphs did not anticipate the idea of “place value” or any analogue: to represent a number like “eight thousand”, the symbol for thousand had to be repeated eight times. The Pythagoreans, inheritors of Egyptian and other mystic traditions, considered ten to be a perfect number (reminiscent of the completeness of *das*). They considered as sacred the *tetractys*, the triangular figure with ten special points arranged symmetrically in four rows containing one, two, three and four points ($1 + 2 + 3 + 4 = 10$) representing, among other things, the dimensions zero (point), one (line defined by two points), two (plane/triangle defined by three points) and three (tetrahedron defined by four points) respectively.

Exposition of Powers-of-Ten Principle in a Sāṃhitā Treatise

A conscious enunciation of the decimal (powers-of-ten) principle can be seen in an incidental reference to it by the seer Medhātithi in the

Vājasaneyī Saṃhitā (XVII.2) of the *Śukla Yajurveda*. This significant verse not only makes a list of terms for successive powers of ten up to 10^{12} , but also each of these terms is perceived, in fact defined, to be ten times the preceding term: *daśa daśa a śata* (hundred); *daśa śata a sahasra* (thousand); *daśa sahasra an ayuta* (ten thousand); *daśa ayuta a niyuta* (hundred thousand); *daśa niyuta a prayuta* (million); *daśa prayuta an arbuda* (ten million); *daśa arbuda a nyarbuda* (hundred million); *daśa nyarbuda a samudra* (thousand million); *daśa samudra a madhya* (ten thousand million); *daśa madhya an anta* (hundred thousand million); *daśa anta a parārdha* (English billion). These terms occur with some variations, and sometimes with further extensions, in other *Saṃhitā* and *Brāhmaṇa* texts. Terms for much higher powers of ten are mentioned in subsequent literature. An anonymous Jaina work *Amalasiddhi* has terms for all powers of 10 up to 10^{96} (*daśa-ananta*).

For expressing very large numbers in words, even the present English terminology (of using auxiliary bases like “thousand” and “million”) is less satisfactory than the Sanskrit system of having a one-word term for each power of ten (up to some large power). This is effectively illustrated by G. Ifrah (2000, pp. 428–429) by comparing the verbal representations of the number 523622198443682439 in English, Sanskrit and other systems.

We mention here that for expressing high powers of ten, Jaina and Buddhist texts too use auxiliary bases like *sahassa* (thousand) and *koṭi* (ten million), resembling our English vocabulary; for instance, *prayuta* (10^6) would be *dasasatasahassa* (ten hundred thousand).

Use of Centesimal Enumeration

When convenient, centesimal (multiples of 100) scales have been used in India for expressing numbers larger than thousand. The *R̥gveda* (I.53.9) describes 60099 as *ṣaṣṭiṃ sahasrā navatiṃ nava* (sixty thousands ninety nine); the *Taittirīya Upaniṣad* (II.8) adopts a centesimal scale to describe different orders of bliss and mentions *Brahmānanda* (the bliss of Brahman) to be 100^{10}

times a unit of human bliss; and in a dialogue in the Buddhist work *Lalitavistara* (c. 300 BCE), Lord Buddha lists numbers in multiples of 100 from *koṭi* (10^7) up to *tallakṣaṇa* (10^{53}). The *Rāmāyaṇa* uses a scale of hundred-thousand (10^5) to mention terms up to 10^{55} (*mahaughā*).

Significance of Zero and Nine Numerals in Place Value Notation

In retrospect, a momentous step was taken by ancient Vedic seers (or their unknown predecessors) when they imparted single-word names to successive powers of ten, thus sowing the seeds of the decimal place value principle. The written decimal place value notation is simply a suppression of the place names (the terms for powers of ten) from the verbal decimal expression of a number, along with the replacement of word numerals by digits and the use of a zero symbol wherever needed. The transition to this notation needed, apart from symbols for the nine numerals, the idea and device of a zero symbol which will not carry any intrinsic positive value (unlike the nine primary numerals) but which will indicate the absence of any of the nine numerals in certain “places”. In the expression “two thousand and eight”, the word numeral “two” acquires the value “two thousand” by virtue of its being the adjective of “thousand”, but in the notation 2008, which no longer carries the verbal support of a word like “thousand”, the digit 2 can represent the value “two thousand” only because of the support of the symbol 0 which, by manning the hundred’s and ten’s places, enables 2 to get stationed in a position of “place value” thousand.

Zero has been denoted in India sometimes by a dot and sometimes by a small circle. The two most common Sanskrit words in Indian mathematics for zero are *śūnya* and *kha*. In *R̥gveda*, the word *kha* refers to the hole in the nave of a wheel through which the axle runs. Its meanings include “cavity”, “hollow”, “aperture”, “vacuity”, “empty space”, “sky” and the “great Void”; the *Br̥hādāraṇyaka Upaniṣad* identifies *kham* with Brahman, the Supreme Spirit. The word *śūnya*

appears to have been derived from *śūna*, which means “hollowness”, “emptiness” as well as “swelled”, “increased”, “grown”; there is another Vedic word *śuna* meaning “growth”, “happiness”, “auspiciousness” and “prosperity”. Apart from the sense of emptiness, *kha* and *śūnya* have a subtle nuance of a potential for growth from a deficient state, a zero state, to a state of fullness. Their synonyms include not only words like *randhra* (small hole) but, more commonly, words like *ambara*, *ākāśa*, *abhra*, *gagana*, *antarikṣa* (all denoting the sky and the vastness of space), *pūrṇa* (whole, full, complete) and *ananta* (infinite). The *śūnya* or *kha* is not a mere void; it has immense possibilities and carries the essence of all that is yet to be formed or created. Using an allusion from Shakespeare, the American mathematician G. B. Halsted beautifully highlighted the analogy between the power of the place value of zero with this philosophical nuance (1912, p. 12):

The importance of the creation of the zero mark can never be exaggerated. This giving to airy nothing, not merely a local habitation and a name, a picture, a symbol, but helpful power, is the characteristic of the Hindu race whence it sprang. It is like coining the Nirvana into dynamos. No single mathematical creation has been more potent for the general on-go of intelligence and power.

Apart from the two key ideas – the place value and the zero – the principle “one symbol for one digit” (reminiscent of the phonetic principle “one sound one symbol” of the Sanskrit alphabet) also contributes to the effectiveness of the decimal notation. A place value system was also used by Babylonians as early as 1700 BCE but with base 60 and with only two basic symbols (for ten and one respectively). It could not attain the economy and compactness of the decimal notation – fourteen symbols (five tens and nine ones) are needed to represent the Babylonian digit for 59.

An interesting feature of the Sanskrit numerals in the Devanāgarī script (now the most commonly used script for Sanskrit) is that each of them can be drawn in just one stroke (without lifting the pen/pencil from the paper), thereby imparting speed to the writing process.

Appearance of Zero and Decimal Place Value Notation

While the structure of the Sanskrit vocabulary contains the key to the decimal system, in the absence of any direct palaeographic record, one does not know how numbers were written in the far-off Vedic times, when the idea of zero (and nine numerals) occurred in the context of number representation, and when the decimal place value notation was invented in India. The sacred Vedic literature was meant to be transmitted orally through a rigorous discipline in memorisation and not to be written down and copied – a step meant to eliminate errors in transmission – and composed accordingly. The purpose was served – we have practically the same versions of the classified Vedas all over India; however, we have to remain satisfied with information about their vocabulary and are in the dark about their script or notation.

It has been suggested on the basis of Indus valley metrology and apparent number symbols that a decimal system was in use in the Indus valley civilisation. In the epic *Mahābhārata* (III.134.16), there is a phrase *nava yogo gaṇanāmeti śaśvat*, “A combination of nine [digits] always [suffices] for any count [or calculation]”. This incidental reference to the decimal place value notation occurs during the narration of a tale (III.132–134) involving ancient names like Uddālaka, Śvetaketu, Aṣṭāvakra, Janaka, et al., whose antiquity goes back to the *Brāhmaṇa* phase of the Vedic era. In fact, the word *śaśvat* (perpetual) has the nuance of “from immemorial time”.

Some Sanskrit scholars see in the term *lopa* (elision, disappearance, absence) of Pāṇini’s grammar treatise *Aṣṭādhyāyī* a concept analogous to zero as a marker for a non-occupied position and have wondered whether *lopa* led to the idea of zero in mathematics. Indeed, in a text *Jainendra Vyākaraṇa* of Pūjyapāda (c. 450 CE), the term “*lopa*” is replaced by *khaṇi*, a standard Sanskrit term for the mathematical zero. Pāṇini says *adarś anaṃ lopah* (non-visibility is *lopa*) and uses it as a tool similar to the null operator in higher mathematics. Unfortunately, mathematical texts of the

time of Pāṇini have not survived. (The date of Pāṇini is uncertain; most estimates vary from 700 BCE to 500 BCE.)

We now give an account of the scattered information we have regarding the (i) verbal mention of the chief ingredients of the decimal notation: zero symbol, places, nine numerals, etc., and (ii) actual occurrence of decimal notation in written documents.

Mention of Zero in Chandaḥ-sūtra of Piṅgalācārya

Two types of syllables *laghu* (short) and *guru* (long) form a Sanskrit metre; thus, any metre can be thought of as a sequence of binary numbers 0 and 1. In his prosody text *Chandaḥ-sūtra*, Piṅgalācārya gives rules to associate with each metre a unique number and to recover from a number the metre which it represents; they are essentially formulae for converting a binary representation of a number into its decimal representation and vice versa. The estimates of Piṅgalācārya’s dates vary between 500 and 200 BCE, 300 BCE being the date used most frequently. Piṅgala’s rules, enunciated two millennia before Leibniz (1596 CE) introduced binary numbers, suggest a deep understanding of the principles underlying place value expansions.

Further, in two consecutive terse aphorisms – *rūpe śūnyam* and *dviḥ śūnye* – Piṅgala gives instructions involving the use of *dvi* (two) and *śūnya* (zero) as distinct labels. The choice of the labels suggests the prevalence of the mathematical zero and possibly a zero symbol. There is then a strong possibility that a decimal place value notation with zero was invented well before the time of Piṅgala; the quoted phrase from *Mahābhārata* supports this hypothesis.

For readers interested in the mathematical details, we mention here that the phrases *rūpe śūnyam* and *dviḥ śūnye* form part of Piṅgalācārya’s algorithm to compute the total number of metres that can be formed using n syllables (i.e., the number 2^n) by a combination of squaring and doubling – the algorithm prescribes when to square and when to double, using the principles $2^m = (2^{\frac{m}{2}})^2$ when m is even and $2^m = 2(2^{m-1})$ when m is odd. The number

n is to be halved continuously, and any stage where halving is done is to be marked with label two (*dvir ardhe*); when an odd number is reached, it is to be reduced by 1, and such a stage is to be labelled by zero (*rūpe śūnyam*). Doubling has to be done corresponding to each stage marked by zero (*dviḥ śūnye*) and squaring (multiplying by itself) at each of the other stages, i.e., where a number was halved (*tāvad ardhe tad guṇitam*). For instance, for $n = 11$, subtract 1 from 11 (put zero mark), then divide 10 by 2 (put two), then subtract 1 from 5 (mark it by zero), divide 4 by 2 (put two) and 2 by 2 (put two) and subtract 1 from 1 (mark it by zero). Reversing, we obtain successively $2, 2^2, (2^2)^2, (2^2)^2 \times 2, [(2^2)^2 \times 2]^2$ and $[(2^2)^2 \times 2]^2 \times 2 (= 2^{11})$. The reversal reminds one of a similar “descent”-like step in the later *kuṭṭaka* principle of Āryabhaṭa for solving linear indeterminate equations in integers (cf. Dutta, 2010).

Mention of Decimal Places and Zero in Jaina Texts

As pointed out by Datta (1929b), the concept of decimal place (*sthāna*) is explicitly mentioned in the Jaina text *Anuyogadvāra-sūtra* (c. 100 BCE). Here, the total number of human beings is described variously as “the product of 2^{64} and 2^{32} ” (i.e., 2^{96}), as a number which “can be divided by two 96 times” and it is also said that this number, “when expressed in terms of denominations like *koṭi-koṭi* (10^{14})”, “occupies 29 places (*sthāna*)”. Indeed, the number $2^{96} (= 79228162514264337593543950336)$ requires precisely 29 digits in the decimal notation. Note that 0 occurs in the thousand’s place in this 29-place decimal expansion. Thus, the reference to 29 places for this number indicates the prevalence, in some form, of the concept of zero as a placeholder.

Zero is explicitly mentioned in sixth-century Jaina texts. Jinabhadra Gaṇi (529–589 CE) abridges the verbal description of a number like 3200400000000 as “thirty-two, two zeros, four, eight zeros”. The Jaina schools adopted the approximation formula $\sqrt{N} = a + \frac{r}{2a}$, where N is a positive integer, a the largest integer for

which $a^2 < N$ and $r = N - a^2$. Jinabhadra Gaṇi describes the (approximate) square root $\sqrt{58545048750}$ (which is $241960 \frac{407150}{483920}$ by the above formula) as “two hundred thousand forty one thousand nine hundred and sixty, removing the zero, the numerator is four-zero-seven-one-five and the denominator four-eight-three-nine-two”. The reference to removal of zero (i.e., to cancel the common factor 10) suggests use of a zero symbol. Similar references occur in the work of Siddhasena Gaṇi.

Occurrence of Written Decimal Notation in a Manuscript

The ancient Brāhmī script (from which evolved the present scripts of various Indian languages) has symbols for the nine numerals, and also separate symbols for multiples of 10 (up to 90) and multiples of 100 (up to 900). There are inscriptions from the third century BCE in the Brāhmī script (including the rock edicts of Emperor Aśoka) where numbers are inscribed in symbols using base 10 but not in place value notation. The modern nine numerals are derived from the Brāhmī numerals.

We directly see numbers written in decimal place value notation in the most ancient Indian mathematics manuscript discovered so far – the *Bakṣālī Manuscript* in the Gāthā dialect (combination of Sanskrit and Prakrit) in Śāradā script. It contains mathematical advancements of the period prior to Āryabhaṭa (fifth century CE) but not the topics (like solutions of linear indeterminate equations) seen first in the treatises of Āryabhaṭa and his successors. The discovered manuscript (dated from around the eighth century CE) is a copy of an earlier document estimated to have been composed between the second century BCE and the seventh century CE (200 BCE – 200 CE by L. Gurjar, 200 CE – 300 CE by B. Datta, 200 CE – 400 CE by R. Hoernle and many others, seventh century CE by T. Hayashi).

The nine numerals we see in the manuscript appear to have evolved from the Brāhmī numerals and closely resemble our present Devanāgarī numerals; zero is denoted by a

small circle. The numbers occurring in this manuscript (in decimal numerals) include the six-digit number 846720, apart from three-digit numbers 330 and 947 (cf. Joseph, 2000, p. 241).

Exposition of Decimal Place Value in a Mathematics Treatise of Āryabhaṭa

The idea of *sthāna* as a denominational place is taught in the *Gaṇita* (mathematics) chapter of the fifth century treatise *Āryabhaṭīya* (499 CE) of Āryabhaṭa. After an invocation in the first verse, the chapter narrates (in Verse two) the first ten notational places: *eka*, *daśa*, *śata* (hundred), *sahasra* (thousand), *ayuta* (ten thousand), *niyuta* (hundred thousand), *prayuta* (million), *koṭi* (ten million), *arbuda* (hundred million) and *vṛnda* (thousand million) and declares them as being *sthānāt sthānaṁ daśaguṇaṁ syāt*, “from place to place, it is ten times [the preceding]”. Subsequent authors list more places (usually 18, sometimes 24). In an earlier millennium, Vedic authors like Medhātithi had already enunciated the “powers-of-ten” principle “each ten times the preceding”. In the above verse of Āryabhaṭa, we see a clear formulation of the next crucial step for decimal place value notation – visualising each power of ten as a *sthāna* (place). The verse is only an exposition and not an announcement of a new concept. In the preceding verse (Verse one of *Gaṇita*), Āryabhaṭa acknowledges that he is recording the “knowledge revered at Kusumapura” (Pāṭaliputra, near modern Patna).

Āryabhaṭa’s methods in *Gaṇita* for extraction of the square root and the cube root of a number, which are slight variants of the modern methods, make intricate uses of the concepts of place value and zero. The fact that these methods are briefly stated without elaboration indicates that the decimal place value notation with zero had already become firmly entrenched in Indian arithmetic. His alphabetical coding of large numbers (Verse two of the *Gītikā* chapter of *Āryabhaṭīya*), using a centesimal system in which the consonants of the Sanskrit alphabet act as digits and the vowels play the role of place value (Dutta, 2006), reiterate how strong was his mastery over all the ideas encapsulated in the decimal notation.

Exposition of Zero as an Integer in a Mathematics Treatise of Brahmagupta

For clarity in our understanding of the development of zero in mathematics, a distinction is made between two of its important features: (i) the notational innovation of the zero symbol as a placeholder in a place value numeral system; and (ii) the abstract conception of the integer zero in a number system amenable to arithmetic operations. Aspect (ii) is central in modern mathematics with its emphasis on algebraic structures. (Note that the two aspects are mathematically equivalent, for the decimal notation $a_n \dots a_1 a_0$ corresponds to the polynomial expression $10^n a_n + \dots + 10a_1 + a_0$ whose coefficients $a_n \dots, a_1, a_0$ are regarded as integers between 0 and 9.)

The profound step (ii) of elevating zero to an algebraic number (*sankhyā*) (and not a mere placeholder) was taken in India. In a section of Chapter XVIII of his treatise *Brāhma Sphuṭa Siddhānta* (628 CE), Brahmagupta defines zero as $a - a$ and gives an elaborate treatment of the four fundamental operations involving numbers – positive, negative and zero – treating all on the same footing. His rules amount to the sophisticated idea of giving integers a ring structure with zero as the additive identity. This comprehensive treatment of zero and negative numbers was an important pillar for the foundations of algebra established by Brahmagupta in the above-mentioned chapter.

The use or mention of zero as a number in arithmetic can be glimpsed earlier in the *Bakṣālī Manuscript*, in the sixth-century treatise *Pañcasiddhāntikā* of Varāhamihira and in the early seventh-century commentary on *Āryabhaṭīya* by Bhāskara I.

That step (ii) needs a conceptual leap from (i) can be seen from the fact that although the decimal notation requires ten symbols, ancient and medieval scholars often refer to it as a system with “nine figures” indicating that the placeholder zero symbol did not always receive the dignity accorded to the other nine numerals. We mention here that a partial use of the placeholder principle (i) had also emerged in some form among late Babylonians during 700–400 BCE;

the Mayan culture (fourth century CE) too used zero as a placeholder and conceived of zero as an ordinal preceding one – the first day of their Haab calendar was day “zero”.

Occurrence of Written Decimal Notation in Inscriptions

A copper plate from Gujarat of 595 CE is so far the oldest discovered inscription depicting a number (346) in decimal place value notation. For numbers with a zero digit, the earliest known examples are certain Sanskrit inscriptions dated 683–687 CE from places in modern Cambodia and Indonesia (then a part of Greater India) which give their Śaka dates 605, 606 and 608 in decimal notation.

Among early inscriptions within present India which represent numbers in decimal notation with a zero digit, the most famous is the Gwalior inscription of King Bhojadeva, dated 870 CE, which depicts the numbers 50 and 270. But older inscriptions with zero in decimal notation have also been reported (cf. Datta and Singh, 1935; Singh, 2007), e.g., the number 30 in Trilingi plates (690 CE) and Ragholi plates (eighth century) and the number 201 in the Khandela inscription (807 CE). It is mentioned in (Mukherjee, 1977) that an inscription dated 672 CE of Āditya Sena at Shahpur (Bihar) depicts the number 60 with zero represented by a small dot. A list of inscriptions from 578 CE which depict the zero symbol, not necessarily as part of decimal notation, is presented in (Singh 2007).

Alphabetical Decimal Notation

A decimal place value notation called *kaṭapayādi* made use of letters of the Sanskrit alphabet in place of numerical figures. The letters were usually written in ascending powers of 10 (the digit in the unit's place written first followed by the digit in the ten's place to its right, and so on). The system was used in Kerala to compose *vākyas* (sentences) recording planetary positions at regular intervals. The earliest known treatise of this type is the *Candra-vākyāni* of Vararuci who is regarded in the astronomy tradition of Kerala as belonging to the fourth century CE. The *kaṭapayādi* system can be seen in several

subsequent treatises of south India, like the *Grahacāranibandha* of Haridatta (c. 600 CE).

The *kaṭapayādi* provided scope for skilled authors to compose brief but pleasant-sounding chronograms, often with connected meanings; sometimes, the Kaṭapayādi value of a name would encode one of its numerical features.

For readers familiar with the Sanskrit alphabet, we describe one of the four versions of the *kaṭapayādi* system. The nine consonants from *k* to *jh*, as also the nine consonants from *ṭ* to *dh*, denoted (in usual order) the digits from 1 to 9; the five consonants from *p* to *m* denoted the digits 1 to 5, while the eight unclassified consonants from *y* to *h* denoted 1 to 8. Thus, 1 could be denoted by any of the letters *ka*, *ṭa*, *pa*, *ya* (hence the name of the scheme). The consonants *ṇ* and *n* and all pure vowels not preceded by a consonant (i.e. occurring at the beginning) denoted 0. A vowel joined to a consonant, or a consonant not joined to a vowel, did not carry numerical value. In a conjoined consonant, only the last one would denote a digit. For instance, the *kaṭapayādi* word *tatvāloke* denotes the number 1346 (*ta* = 6, *tvā* = 4, *lo* = 3, *ke* = 1).

Decimal Place Value through Word Numerals

As most ancient Indian scientific treatises were composed in verses, there was a tradition of expressing numbers verbally by the decimal place value principle including zero using word numerals instead of symbols. The *Bakṣālī Manuscript* has both word numerals and representations in symbols, the word numerals in this treatise being simply the usual number names. Another early instance cited by Ifrah (2000) is a Jaina cosmology text *Lokavibhāga* dated 458 CE.

In a popular system of word numerals, which emerged by the third century CE, the word name for a digit (or even a number) *n* was chosen to be a well-known object or idea which usually occurs with frequency *n* (or has *n* components). Such a word numeral was called *bhūtasaukhyā*, i.e., a number (*saukhyā*) using an object (*bhūta*) illustrating the number. For instance, *candra* (Moon) or *mahī* (Earth) stood for one, *netra* (eyes) for two, *guṇa* (sattva-rajās-tamas) for three, *yuga* (satya-tretā-dvāpara-kali) for four, *indriya* (sense-organs)

for five, *rasa* (taste) for six and so on; synonyms for the sky were used for zero. (Here, *rasa* refers to the six food tastes; in Sanskrit aesthetics, *rasa* refers to various dramatic moods.)

The place values of word numerals in a *bhūtasahkhyā* increased from left to right. For instance, Bhāskarācārya describes his year of birth 1036 Śaka Era (1114 CE) as *rasa-guṇa-pūrṇa-mahī*.

This system can be seen in the *Yavanajātaka* of Sphujidhvaja (270 CE), in the *Sūryasiddhānta* and *Puliśasiddhānta* (original versions composed by the fourth century) and in later astronomy and mathematical treatises, and in the *Agni-Purāṇa* (portions of which were composed within the fourth century). Word numerals are also found in certain Sanskrit inscriptions of the seventh century in the Far East.

B. Datta feels that decimal place value notation had been in common use long before the idea of applying the place value principle to a system of word names was conceived. In the beginning, number names were used as word numerals. *Bhūtasahkhyā* replaced number names as the numerous choices for any digit helped in versification and in infusing a poetic charm to the technical presentations. Bhāskarācārya's phrase *rasa* (taste; delight) – *guṇa* (quality) – *pūrṇa* (full) – *mahī* (Earth) for the number 1036 has a sweet meaning: "The Earth is full of delight".

Place Value and Zero as Metaphors in Philosophy and Literature

By perhaps the first century CE, the place value notation had become so well established among the cultured elite in India that the idea could be used as a metaphor in works on philosophy. A reference to place value occurs in a work of the Buddhist philosopher Vasumitra (probably first century CE):

When [the same] clay counting-piece is in the place of units, it is denoted as one, when in hundreds, one hundred. (Quoted in (Plofker, 2009, p. 46))

Both the *Vyāsa-bhāṣya* (probably fifth century CE) on the *Yoga-sūtra* of Patañjali and *Sārīraka-bhāṣya* of Śaṅkarācārya (c. 750 CE) use the following simile (translation follows the latter):

Just as the same stroke (or figure) conveys different ideas such as a unit, a ten, a hundred, a thousand, etc., according to the place in which it is set down, ... (Original verse with translation quoted in Ganguli (1932, p. 255))

The romantic literary work *Vāsavadattā* of Subandhu (sixth century) uses the simile of a zero-symbol *śūnya-bindu* to describe the stars.

The zero of the decimal system has also been used to explain spiritual principles. Indian philosophy regards the universe as a manifestation of The One Reality, the *Pūrṇa*, but emphasises that without the realisation of (or at least a conscious link with) the One Brahman, the transient universe is an unreal vacant nought, a *śūnya*; just as many zeros form a large number if preceded by 1; but without that 1, a large collection of zeros amounts to nothing. In the utterance of Sri Ramakrishna (1884), translated by Swami Nikhilananda (1944, p. 643):

First realize God, then think of the creation and other things. ... If you put fifty zeros after one, you have a large sum; but erase the one and nothing remains. It is the one that makes the many. First one, then many.

Reverence for the Invention

Indians regarded the invention of the decimal system as something special; it had a status similar to that of an inspired revelation. The Arab historian Abul Hasan Al-Masūdī, who visited India during the tenth century, writes (943 CE), "A congress of sages at the command of the Creator Brahmā invented the nine figures ..." (Datta & Singh, 1935, p. 97). In his popular text *Līlāvatī*, the mathematician-astronomer Bhāskarācārya (1150 CE) makes a special acknowledgement that the decimal system of place values was conceived by the ancients to simplify practical computations.

Impact of Decimal System on Ancient Indian Mathematics

The decimal system is largely responsible for the excellence attained by Indian mathematicians in the fields of arithmetic, algebra and astronomy.

Thanks to the notation, Indians could develop efficient methods for the basic arithmetic operations (which were slight variants of our present methods) at an early stage.

The decimal system (both oral and written) enabled Indians to express large numbers effortlessly, right from the Vedic Age. This traditional facility with large numbers enabled Indians to work with large time frames in astronomy which helped them obtain accurate results. Indian algebraists could venture into problems on equations whose solutions involve large integers. Bhāskarācārya (1150 CE) discussed methods for finding integer solutions of an equation like $61x^2 + 1 = y^2$; the smallest pair of integers x , y satisfying this equation turns out to be $x = 226153980$, $y = 1766319049$. Five centuries later, soon after the decimal system had been standardised in Europe, this equation would again be highlighted by Fermat (1657), heralding the advent of modern number theory.

The decimal system has a dormant algebraic character. The decimal expansion of integers must have influenced the development of the near-analogous algebra of polynomials by Brahmagupta (628 CE) and the power series expansions of trigonometric functions by Mādhava (fourteenth century CE). A millennium after Brahmagupta, Isaac Newton (a pioneer in the study of polynomials and power series in modern Europe) emphasised (1671) that the arithmetic of decimal numbers provides a fruitful model for developing the arithmetic operations on algebraic expressions in variables. Newton had observed (quoted in (Divakaran, 2010, p. 296)):

“Since the operations of computing in numbers and with variables are closely similar – indeed there appears to be no difference between them except in the characters by which quantities are denoted, definitely in the one case, indefinitely so in the latter – I am amazed that it has occurred to no one . . . to fit the doctrine recently established for decimal numbers in similar fashion to variables, especially since the way is then open to more striking consequences. For since this doctrine in species has the same relationship to Algebra that the doctrine in decimal numbers has to Arithmetic, its operations of Addition, Subtraction, Multiplication, Division and Root-extraction may easily be learnt from the latter’s . . .”

The polynomial, power series and p -adic expansions are conscious generalisations of the decimal expansion.

Recursive principles dominate Indian mathematical thought and are prominent features of some of its greatest achievements like the solutions of indeterminate equations and the work of the Kerala school (cf. Dutta, 2010; Divakaran, 2010). The facility with recursive methods is another outcome of the decimal representation of numbers, the first known example of recursive construction.

Note that the Vedic verbal system itself has this polynomial and recursive aspects with their striking mathematical consequences.

Transmission of Decimal Notation

In the absence of records of commercial transactions during the Dark Ages of Europe and the paucity of extant scientific treatises of the period, one cannot ascertain when the Indian notation first reached the West. The Indian numerals have been found in tenth-century manuscripts of the *Geometry of Boethius* (c. 500 CE), the Latin philosopher. It is believed by many historians that sometime in the fifth century CE, the Indian numerals reached Alexandria – possibly through traders and merchants – and spread farther westward. That the fame of the Indian decimal notation had reached the banks of the Euphrates by the early seventh century can be seen in a passing reference by the Syrian astronomer–monk Severus Sebokht (662 CE):

I shall not now speak of the knowledge of the Hindus, . . . of their subtle discoveries in the science of astronomy – discoveries even more ingenious than those of the Greeks and Babylonians – of their rational system of mathematics, or of their methods of calculation which no words can praise strongly enough – I mean the system using nine symbols. (Quoted in (Basham, 1954, p. vi))

A manuscript *Codex Vigilanus* of 976 CE (now kept in a museum of Madrid) by Vigila, a monk in a Spanish monastery, also records a similar appreciation:

The Indians have an extremely subtle intelligence, and when it comes to arithmetic, geometry and

other such advanced disciplines, other ideas must make way for theirs. The best proof of this is the nine figures with which they represent each number no matter how large. (Quoted in (Ifrah, 2000, p. 362; Joseph, 2000, p. 313))

Numerous Arabic texts were written on the decimal notation and Indian arithmetic, beginning with a treatise composed by Al-Khwārizmī around 820 CE. The original text of Al-Khwārizmī is lost, but its Latin translation *Liber Algorismi de numero Indorum* (The Book of Al-Khwārizmī on Indian numerals), composed in the early twelfth century, still survives. The following lines, quoted in (Bag & Sharma, 2003, p. 168), convey some flavour of Al-Khwārizmī's exposition on the place value principle with nine numerals and zero:

When I saw that Indians composed out of IX letters any number due to the position established by them, I desired to discover, God willing, what becomes of those letters to make it easier for the student. . . . Thus they created . . . IX letters, . . . The beginning of the order is to the right side of the writer, and this will be the first of them consisting of unities. If instead of unity they wrote X, it stood in the second digit, and their figure was that of unity, they needed a figure of tens similar to the figure of unity so that it becomes known that this was X. Thus they put before it one digit and wrote in it a small circle "o", so that it would indicate that the place of unity is vacant.

The Latin translation made a significant impact in the West and triggered several adaptations. Al-Khwārizmī's name got so closely associated in Europe with the new arithmetic based on the Indian decimal numerals that the Latin form of his name *algorismus* was given to any treatise on computational mathematics – especially those that made use of the zero. (This is the genesis of the word "algorism" which later became "algorithm".) The numerals were explicitly called *hindisah* (Indian) by Al-Naḍīm (c. 987 CE). The Arabic translation *sifr* (meaning "empty") of the Sanskrit word *śūnya* became *cifra* in Spanish (source of the word *cipher*) and *chiffre* in French, *zephirum* in Medieval Latin, *ziffer* in German and *zero* in English.

A vigorous effort to bring the Indian decimal system into common use in the West was made

by Leonardo Fibonacci of Pisa (1180–1240). Acquainted with various systems of calculations, Fibonacci found all computational systems deficient compared to the Indian system: "*quasi errorem computavi respectu modi indorum*" (Datta & Singh, 1935, p. 95). His influential work *Liber Abaci* (Book of Computations) in 1202 (rewritten in 1228), based entirely on Indian numerals, prepared the ground for the spread and adoption of the Indian decimal system and computation methods. Several subsequent thinkers in Europe too advocated the system. A woodblock engraving *Margarita Philosophica* of Gregor Reisch (1503) contrasts the old and new systems by depicting a gloomy Pythagoras toiling with a counting board, a cheerful and serene Boethius comfortable with his computations (using the decimal system) and Lady Arithmetic giving her smiling approval of Boethius, the Indian numerals adorning her dress (see Fig. 1). In another illustration by the Nuremberg artist Hans Sebald Beham (1550), Winged Arithmetic is shown turning her back on the counting board and pointing emphatically to a tablet with the new Indian numerals.

However, Roman numerals had got so deep rooted in Europe that it took around five centuries for the decimal notation to gain universal acceptance. Initially, the new system "was too advanced for the merchants and too novel for the universities" (Datta & Singh, 1935, p. 95), and there was a determined resistance against it from the abacists. With passage of time, more people began to realise its importance, and the decimal notation eventually came into common use in the seventeenth century.

The introduction of the decimal notation was one of the key factors that triggered the commercial, mathematical and scientific renaissance in Europe. It immensely simplified arithmetic; all modern methods of fundamental arithmetic operations are dependent on the principles of decimal notation. The Australian historian A. L. Basham observed about this priceless gift of India (Basham, 1954, pp. 495–496):

Most of the great discoveries and inventions of which Europe is so proud would have been

Decimal System in India,

Fig. 1 Wood-block engraving from Gregorius Reisch, *Margarita Philosophica* (Freiburg, 1503). Lady Arithmetic (standing in the centre) gives her judgment by smiling on the arithmetician (to our left, her right) working with Arabic numerals and the zero (the numerals also adorn her dress). The quarrel of the abacists and algorists is over, and the latter have won



impossible without a developed system of mathematics, and this in turn would have been impossible if Europe had been shackled by the unwieldy system of Roman numerals. The unknown man who devised the new system was from the world's point of view, after the Buddha, the most important son of India. His achievement, though easily taken for granted, was the work of an analytic mind of the first order, and he deserves much more honour than he has so far received.

Epilogue

The history of the decimal system may be summarised in the words of Swami Vivekananda (from a speech in 1895 titled "India's Gift to the World"):

... the ten numerals, the very cornerstone of all present civilization, were discovered in India, and are, in reality, Sanskrit words. (Swami Vivekananda, 2012, p. 511)

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Defensive Barricades of the Maya

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This overview of Maya defensive barricades is organized into three sections: generalizations, case studies, and controversies/future directions in the study of Maya defensive barricades. Before discussing the Maya defensive barricades,

I provide the who, where, and when of the Maya culture and history. Maya is a term that is used to define a culture that is primarily concentrated in Guatemala; Belize; the Mexican states of Yucatan, Quintana Roo, Tabasco, Campeche, Chiapas, and Veracruz; and the Western portions of the countries of Honduras and El Salvador. Despite popular narratives for the collapse of the Maya society that resulted in vast empty jungle cities, millions of Maya currently live in various parts of the world and many speak one or several of the 28 different languages that are linguistically classified as Mayan. Scholars of the Maya have long-established affinities among extant Maya groups, the indigenous peoples that Spanish colonizers encountered (e.g., Hernan Cortes, Fray Diego de Landa) and the pre-Columbian peoples of contemporary Guatemala, Belize, Mexico, Honduras, and El Salvador (cf. Coe, 2011; Sharer & Traxler, 2006). Based on the closeness of some linguistic, cultural, and material traits, such as the use of a 260-day calendar, evidence for the Maya culture can be found for over 3,000 years and is generally divided into five periods of culture and history: Preclassic (2000 BC–AD 250), Classic (AD 250–900/1000), Postclassic (AD 900/1000–1525), Colonial/Historic (AD 1525–1825), and Modern (AD 1825–present). Although the dates for the start and end of each period can vary by scholar and location (site, region), scholars of the Maya generally use the above periods in the order outlined.

Generalizations

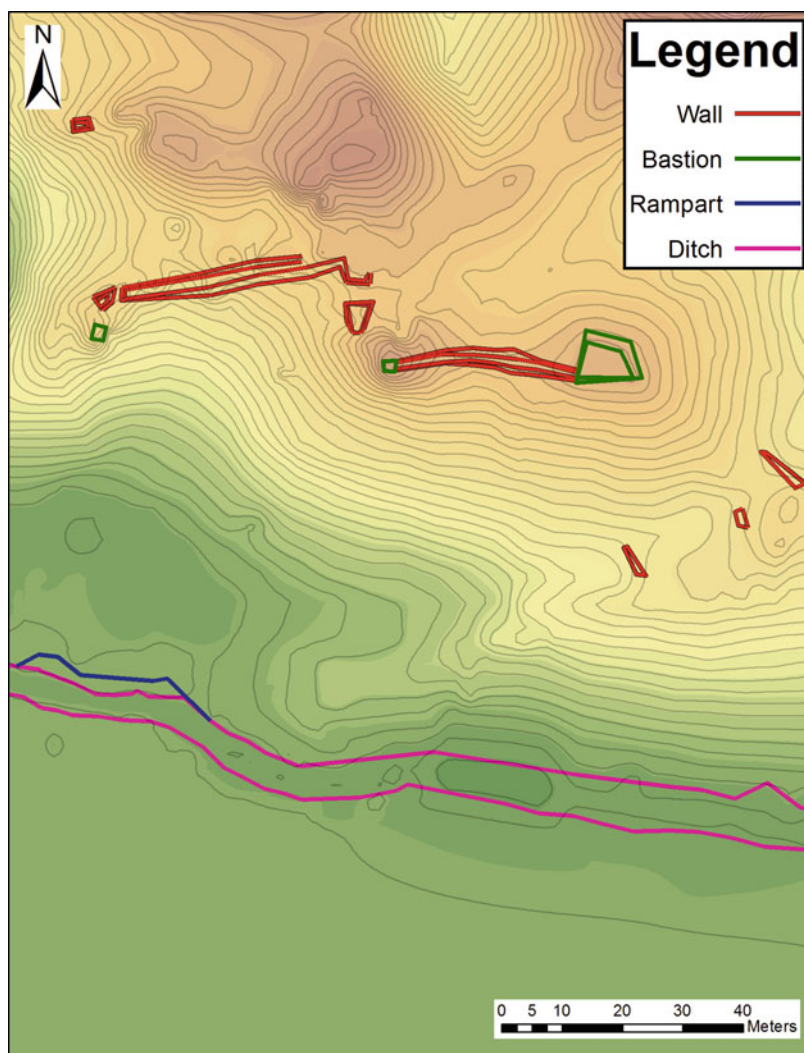
Evidence for Maya defensive barricades can be found in every period of their culture and history. Although a barricade can be defined as a quickly constructed barrier, I define a defensive barricade as any human construction that is designed to obstruct the movement of people during war. Any barrier to human movement, artificial and natural, could become a defensive barricade, but I focus on human constructions that were designed to have defense as one of their major functions.

Maya defensive barricades were designed in roughly linear and concentric forms. For example, at the Classic period site of Dos Pilas in Guatemala, the Maya constructed two concentric walls around the West Plaza Group that served to defend the sites of the remaining inhabitants during the political disintegration and rapid depopulation of the site that is often referred to as the collapse of Dos Pilas (Demarest, 2006). Linear defensive barricades are not built exactly in straight lines but are constructed in a roughly linear form with two unconnected ends, such as at the Postclassic/Colonial period Maya site of Tzunun in Chiapas, Mexico (Fig. 1). Linear and concentric forms are not mutually exclusive, but the form of Maya defensive barricades will generally fall into one or both categories.

Maya defensive barricades can include a combination of ditches, walls, terraces, buildings, and gates. Trenches can be excavated to form dry and wet ditches (Fig. 2). Depending on seasonal rainfall and fluctuations in the local water table, a dry ditch can become a drainage ditch, canal, or moat. The Maya also employed freestanding and retaining walls as defensive barricades (Fig. 3). Retaining walls were generally used to hold back earth and create terraces. Some Maya defensive barricades incorporated the preexisting human constructions in the form of terraces or buildings (artificial constructions with a roof and/or four walls). A terrace is an artificially level surface that in the case of defensive barricades is usually denoted by at least one stone retaining wall at an edge of a level surface. Bastions are types of buildings that protrude from a defensive wall that are designed to house defenders, and the Maya built square-shaped bastions. Maya gates could be simple openings, baffled and screened (cf. Keeley, Fontana, & Quick, 2007). Baffled gates force attackers to expose their sides and rear to enemy fire. The exposure of the attackers' weak points is accomplished by creating a path through the gate that requires people to change direction(s) as they walk through the gate. Screened gates are access points in a defensive feature that have entrances that are obscured to the human eye.

Maya defensive barricades can be constructed of perishable and nonperishable materials.

Defensive Barricades of the Maya, Fig. 1 Linear defensive features at Tzunun, Chiapas, Mexico



Perishable materials can include wood, reeds, sticks, thorny plants, and cloth. Nonperishable materials used by the Maya are earth, stone (mainly limestone), and lime mortar. Most known Maya defensive barricades were constructed of a combination of perishable and nonperishable materials. At Dos Pilas and other nearby Classic period sites, the currently visible freestanding stone walls served as bases to support wooden posts for a palisade. The stone bases were used in areas where the soils were too shallow to adequately support a wooden post (Palka, 2001).

It is difficult to place limits on the height or width of Maya defensive barricades because the

practice of pre-Columbian Maya warfare is poorly understood. By practice, I mean how the Maya fought wars or what is sometimes referred to as the tactics and art of war. I will elaborate on the issues with practice in the final section of this overview. A Maya defensive barricade can have any width and height as long as it can be established that one of the functions of an artificial construction was to obstruct the movement of attackers. Therefore, at this moment, it cannot be determined solely through calculations of height and width whether or not human constructions served as defensive barricades. Instead, scholars must rely on assembling multiple lines of evidence to build arguments for the defensive

Defensive Barricades of the Maya, Fig. 2 Ditch and rampart at Tzunun, Chiapas, Mexico



D

Defensive Barricades of the Maya, Fig. 3 Stone defensive barricade from Tzunun, Chiapas, Mexico



function of structures, except in some cases where populations have experienced conflict and can attest to a human construction as being or having been used as a defensive barricade.

Case Studies

This section provides a more in-depth look at two well-known Maya defensive barricades from the sites of Becan, Mexico, and Aguateca, Guatemala. My goal is to provide concrete examples for the above generalizations and to display the diverse ways that the Maya constructed defensive barricades. Through the case studies, I also want

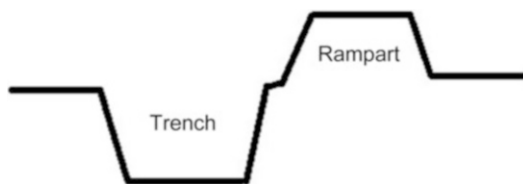
to provide some background for research trends on warfare and defensive barricades in Maya studies. The examples are archaeological, but the Maya did not use defensive barricades solely in their past. Many current Maya have experienced war in Chiapas, Mexico, during the 1990s and in the country of Guatemala during the 1980s, and they built defensive barricades in both cases (e.g., Barmeyer, 2008; Inclan, 2009; Menchú, 1984).

The vast majority of data and studies on Maya defensive barricades focus on the past that no living person has experienced, and I rely on this information to provide arguments on Maya defensive barricades that have become well

known by scholars. Unfortunately, perishable materials do not preserve well in the hot and moist environments where most Maya archaeological sites are located. Consequently, the majority of data available on the pre-Columbian Maya defensive barricades are the remains of nonperishable materials and the occasional recovery of preserved perishable materials.

Becan is a Preclassic Maya archaeological site in Campeche, Mexico, with a dry ditch and rampart that served as a defensive barricade (Webster, 1976). The research conducted by David Webster at Becan is a landmark study on the Maya culture and warfare. Webster was not the first to argue that the Maya prior to the Postclassic period conducted warfare, but his study dealt a major blow to the prominent argument of a peaceful Maya civilization prior to the Postclassic period. Becan is located on a limestone outcrop that elevates the site 10 m above the surrounding terrain. The ditch and rampart surround the site by maneuvering around the outcrop, *bajos* (low-lying areas that seasonally flood), and preexisting structures. The site of Becan contains monumental architecture, and Webster argues that the site was a center for elites. The ditch has an average width of 16 m and height of 2.5 m. The total length of the defensive barricade is 1,890 m. The ditch was excavated to create nearly vertical sides and a flat bottom (Fig. 4). Through excavations, it was revealed that the inner vertical side of the ditch was held in place by a wall composed of limestone. The evidence for the wall was rubble with “nodules the size of golf balls to rocks 30 cm. in diameter or even larger” (Webster, 1976, p. 33). The wall on the inner side of the trench helped to prevent erosion of the ditch.

The material excavated to create the ditch was heaped toward Becan to create the site’s rampart. The rampart ranges in width from 10 to 14 m and 1.0 to 3.6 m in height. Together, the ditch and rampart have an average height of 9.6 m, and when the earthworks were used and maintained, they may have had an average height of 11.6 m. The top of the rampart could have served as a parapet (a structure or extension of a structure that can provide cover for combatants), but this



Defensive Barricades of the Maya, Fig. 4 Profile image of a Becan ditch and rampart (Redrawn from Webster, 1976, p. 64)

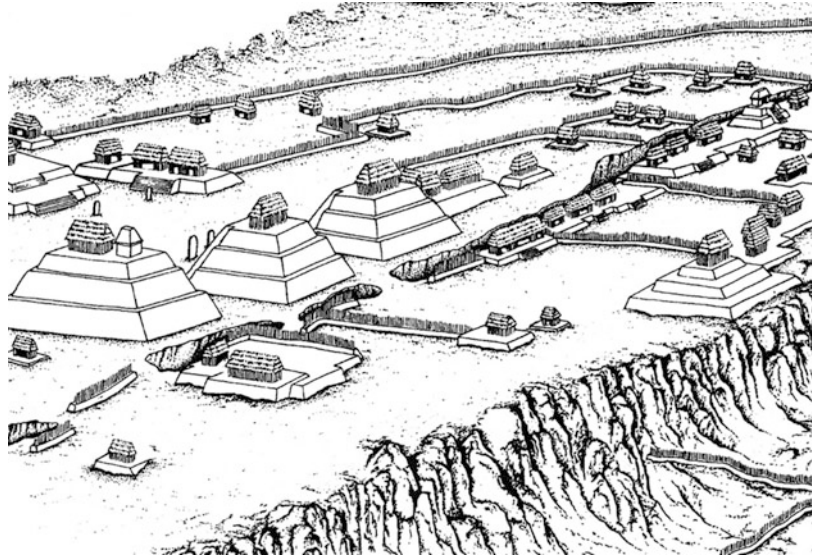
argument is currently a speculation. Nonetheless, the ramparts as a whole functioned as parapets. No evidence for a palisade was recovered from the excavation of Becan’s defenses. The barricade also had multiple causeways that functioned as access points to Becan, and if the access points had gates, they would have been constructed of perishable materials that were not recovered through excavations.

The deciphering of Maya hieroglyphic writing, along with research at Aguateca and other sites in the Petexbatun region of Guatemala, provided the next major jolt in the study of Maya warfare and defensive barricades that resulted in a flurry of research on Maya warfare that continues today. Aguateca is a Classic Maya archaeological site in the Petexbatun region of Guatemala whose past inhabitants used the local terrain together with artificial modifications to create multiple barricades to defend the site (Demarest, 2006; Demarest et al., 1997; Inomata, 2008).

The core of Aguateca contains the site’s monumental architecture and was defended by multiple freestanding stone walls (Fig. 5). During the survey and mapping of Aguateca, the stone defensive barricades of Aguateca were found to range from 0.5 to 1.8 m in height and 1 to 2.5 m in width. The total length of the defensive walls is 4,506 m. The site’s core was inhabited by Aguateca’s elites, and much of the monumental architecture was used for rituals that were tied to the Classic Maya rulership. The core of Aguateca is surrounded by an escarpment to the east, a gorge to the south, and a large sinkhole to the north. These geologic features of the landscape were employed by the Maya as defensive barricades, along with Aguateca’s multiple defensive walls. The walls incorporated

Defensive Barricades of the Maya,

Fig. 5 Aguateca and its defensive barricades (Redrawn from Demarest et al., 1997)



Aguateca's existing structures as part of the defensive walls. The defensive walls also had multiple access points in the form of causeways, but no remains of gates were recovered. Many sections of Aguateca's stone defensive barricades were not completed because Aguateca was attacked and heavily depopulated before the defensive barricades were finished.

The stone defensive barricades of Aguateca served as bases for wooden palisades. The shallow surface soils of Aguateca would have required the Maya to dig into the bedrock to provide adequate foundational support for wooden posts, and the Maya thus created stone bases to support the palisades. The stone walls were likely constructed by a combination of blocks that were naturally formed and blocks roughly shaped by the Maya, but this argument is currently a speculation. There is no evidence for the use of mortar to hold the blocks in place. Excavations of the stone defensive barricades suggest that there are three construction forms for Aguateca's stone defensive barricades (Fig. 6). The most common form consists of large stone blocks that are stacked horizontally with rubble inside to create additional support for a wooden post. The second form is similar to the first except that the bottom course of the outer stones is placed vertically. The third form has two levels of flat surfaces. The tallest level likely supported a palisade that served as a parapet, and

the lower level would serve as a surface for a person to stand and move on. No postholes were recovered from excavations at Aguateca. But in comparative data from other sites in Petexbatun and because excavations revealed that Aguateca's defensive walls were arranged in two vertical lines of stone that would press on an object in the center, Aguateca's stone defensive barricades likely contained a post in the center.

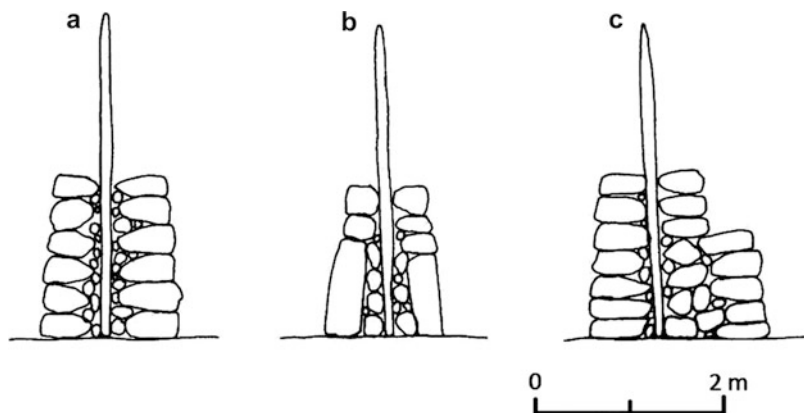
Controversies and Future Directions

Three areas in the study of Maya defensive barricades provide controversy and potential for important future insights on the Maya, technology, and the social behavior of people. First, the practice of Maya warfare is poorly understood, and this void is causing confusion in understanding what human constructions served as defensive barricades. Second, scholars of the Maya need to continue to shift away from studying the monumental cores of large sites such as Tikal, Copan, and Palenque. Third, studying the relationships among warfare, defensive barricades, and Maya culture and society provides the area with the greatest potential for future study.

Without understanding how the Maya practiced war, scholars will have to rely heavily on universalist and Western assumptions on the

Defensive Barricades of the Maya,

Fig. 6 Aguateca wall forms (Redrawn from Inomata, 2008, p. 32)



practice of war to understand what structures served as defensive barricades. By universalist assumptions, I mean assuming that there are common warfare methods and practices for all people past and present, such as the assumption that all warfare requires the destruction of other people and the production of fear. These assumptions, like all assumptions, need to be examined and tested before they can be assumed to be relevant and a part of the past people's experiences. For example, the controversy over whether or not the earthworks of Tikal, Guatemala, served a defensive function highlights how it is necessary to understand the practice of Maya warfare to understand Maya defensive barricades better.

Silverstein and colleagues argue that the Tikal earthworks would not have been effective defensive barricades for the following reasons (2009):

1. There is a 300 m bifurcation on the northwest corner of the earthworks that stood alone, away from the rest of the earthworks and terminated at an *aguada* or small reservoir (Silverstein and colleagues provide no images of the bifurcation).
2. Sections of the earthworks run obliquely on the downward slopes of hills.
3. The height of the earthworks changes at times such that they provide an inadequate barrier for defense.
4. The earthworks are often found in relation to catchment basins (*bajos* or *aguadas*), and, thus, the ditch could have been dug to tap into the water table.

Silverstein and colleagues admit their hypothesis requires more research and excavations of the Tikal earthworks, but a problem they overlook is that they assume a defensive barricade has to be effective in order to be a defensive barricade. Because the practice of Maya warfare is poorly understood, it is difficult to understand the effectiveness of the Tikal earthworks. Consequently, Silverstein and colleagues use the present standards for tactics and effectiveness in their study of the Tikal earthworks that research on the Maya does not support. For example, some sections of the Great Wall of Mayapan, Mexico, do not run along the apexes of slopes, but archaeological and documentary evidence supports that the Great Wall functioned as a defensive barricade (Shook, 2009 [1952]). Therefore, the fact that the Tikal earthworks are not solely on the crests of hills does not negate their defensive function. Furthermore, it is unclear why defensive barricades cannot also have hydraulic and other functions and why a structure's functions cannot change over time.

As a field of study, Maya archaeology has focused on large sites with groups of monumental architecture. However, the study of Maya defensive barricades requires archaeologists to study the peripheries of sites and areas away from monumental architecture. Defensive barricades incorporate the landscape they are a part of in order to obstruct movement. Therefore, the study of Maya defensive barricades requires the survey of large tracts of land that could lead archaeologists very far from large cities. Defensive barricades can be

found among monumental architectural groups, but research at the Classic period site of Tecolote, Guatemala, highlights that some of the largest Maya sites created defensive barricades far from their monumental cores (Scherer & Golden, 2009). Tecolote is a mid-sized Maya site with multiple defensive barricades that served to create a fortified border for the large Classic site of Yaxchilan that is 16 km SE of Tecolote. Consequently, the study of Maya defensive barricades complements movements among Maya scholars to study the peripheries of sites and shifts the Mayanists' focus away from groups of monumental architecture. The shift to studying the peripheries of sites will improve our understanding of the Maya because if we employ the United States as an analogy, how clearly and comprehensively could anyone understand the US culture and society if scholars only investigated the remains of skyscrapers in the largest cities of the United States?

Defensive barricades are technologies in the broadest sense and the adoption of technologies in warfare is a cultural process (Lynn, 2003). Canons and gunpowder did not become dominant technologies in Western European warfare because they were objectively better technologies for war but because in the Western European context, people used castles and gunpowder in ways that people found useful in the practices of Western European warfare and their societies. Therefore, the types of defensive barricades the Maya constructed and may develop in the future provide information on the entanglements of the Maya culture and warfare practices. Two current debates that highlight the important links between the Maya culture and warfare are the development of Maya culture during the Preclassic period and the process that is often referred to as the Maya collapse at the end of the Classic period (cf. Demarest, 2006; Demarest, Rice, & Rice, 2004; Estrada-Belli, 2011; Inomata, 2008; Webster, 1977). In both debates, evidence for warfare in the form of defensive barricades suggests that conflict played a major role in the social processes of both periods. It is clear that defensive barricades can provide many insights into the Maya culture, and with increasing research on Maya warfare, the

future will provide more information on the importance of defensive barricades for understanding the Maya culture.

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Deśāntara

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The *deśāntara* is the distance (*antara*) of a place (*deśa*) toward the east or the west of the prime meridian. It is, in other words, the terrestrial longitude of a place. In Indian astronomy, the meridian passing through the city of Ujjaini (modern Ujjain) in the central Indian state of Madhya Pradesh was identified as the prime meridian. Extending from the North Pole to the South Pole, it cut the equator at a point where the astronomers imagined the existence of a city called Laṅka. The Ujjaini meridian is located at 75° 45' east of the modern prime meridian at Greenwich.

The *deśāntara* was generally expressed as a time measure rather than as the angle subtended at the pole by the meridian of the place and the prime meridian. This was done to enable the local time and the time at the prime meridian to be converted into each other. Time measures used in India to determine the *deśāntara* included the *nāḍī* or the *ghaṭī* (1/60th of a day or 24 min), the *vināḍī* (1/60 *nāḍīs* or 24 s), and the *prāṇa* (1/6 *vināḍīs* or 4 s).

The Sun completes its rotation of 360° in 24 h at the rate of 15° per hour (360/24 = 15). As a result, the time of sunrise varies by 1 h with every 15° on the same latitude. Thus, if x is a given longitude where the sun rises at 6:30 AM, sunrise will take place at 7:30 AM on the longitude $x + 15$ to the west on the same latitude and at 5:30 AM on $x + 15$ to the east. As the longitude is

calculated in relation to the time of sunrise on the Ujjaini meridian, a *deśāntarasaṁskāra* or correction is required to account for the differences in the time of sunrise. Similar corrections are called for in relation to the Moon and other planets. The correction is carried out for the mean Sun, Moon, and planets at the Ujjaini meridian. Expressed in modern notations, this is done through the formula

$$\Delta c = (\Delta n) \times (\alpha/60)$$

where Δc is the *deśāntara* correction required, Δn the longitude in *nāḍīs*, and α the mean daily movement of the Sun, the Moon, or the planet concerned at the Ujjaini meridian. If represented in terms of hours rather than *nāḍīs*, the formula will be

$$\Delta c = (\Delta h) \times (\alpha/24)$$

where Δh is the longitude expressed in hours.

See Also

► [Astronomy in Medieval India](#)

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Devācārya

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Devācārya, son of Gojanma and author of the astronomical manual *Karaṇaratna* (lit. Gem of a Manual), hailed from Kerala in South India. The

K. V. Sarma: deceased

epoch of *Karaṇaratna*, i.e., the date from which planetary computations were instructed to be commenced in that work, is the first day of the year 611 in the Śaka era, which corresponds to February 26 of AD 689. This places Devācārya in the latter half of the seventh century. We know he came from Kerala because he used the *Kaṭapayādi* system of letter numerals and the *Śakābdasaṃskāra*, which is a correction applied to the mean longitudes of the planets from the Śaka year 444 or AD 521, and a unique method of computing the solar eclipse, all of which are peculiar to Kerala, and because his work is popular in that part of the land.

Devācārya uses the elements of the Āryabhaṭa school of astronomy as the basis of his work, as he himself states towards the commencement of *Karaṇaratna*. His work is based both on the *Āryabhaṭīya* and on the second work of Āryabhaṭa, the *Āryabhaṭa-siddhānta*, as abridged in the *Khaṇḍakhādyaka* of Brahmagupta. The influences of the *Sūryasiddhānta* and of Varāhamihira are also apparent. It is also noteworthy that Devācārya himself innovated several hitherto unknown methodologies and techniques.

In eight chapters, the *Karaṇaratna* encompasses almost all the generally accepted aspects of Hindu astronomical manuals. Chapter I of the work is concerned with the computation of the longitudes of the sun and moon, and also the five basic elements of the Hindu calendar (*pañcāṅga*). Computation and graphical representation of the lunar and solar eclipses are the subjects of chapters II and III. Chapter IV deals with problems related to the gnomonic shadow and chapter V with the calculation of the time of the moonrise and allied matters. In chapter VI, heliacal rising of the moon and elevation of the moon's horns are dealt with. The last two chapters are concerned with the derivation of the longitudes of the planets, planetary motion, and planetary conjunctions.

Several peculiarities characterize Devācārya's work. Among these are the computation of the sun, moon, moon's apogee, and moon's ascending node using the "omitted" lunar days, the *Śakābda* correction, and the application of a

third visibility correction for the moon. However, what is most significant in the work is the recognition of the precession of the equinoxes and the rule that he gives for its determination on any date. Devācārya's measure of the rate of precession is 47 s per annum, its modern value being 50 s. Devācārya's importance lies in the fact that his work formed a record of the astronomical practices and methodologies for the quick derivation of astronomical data that prevailed in India during the seventh century AD.

See Also

- [Āryabhaṭa](#)
- [Precession of the Equinoxes](#)
- [Varāhamihira](#)

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Divination: Science, Technology, and the Mantic Arts in Traditional China

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As I have indicated in several recent essays, a great deal of valuable scholarly work has been done on virtually all facets of Chinese divination, past and present, since the last major revision of this entry in 2004. One major reason for this interest in divination as an object of academic study is that over time, and by stages, the "Open Policy" inaugurated by the People's Republic of China in 1978 has vastly expanded the parameters of discourse on traditional Chinese beliefs and practices. During the late 1980s and early

1990s in particular, bursts of “fortune-telling fever” (*suanming re*) and “Yijing fever” (*Yijing re*) not only generated a vast popular literature on divination but also encouraged a significant stream of scholarly studies on the subject, both broadly based and more narrowly focused. Some of these works, like the wildly popular *Zhongguo gudai suanming shu* (The Ancient Divinatory Arts of China, 1990), written by the husband-and-wife-team of Hong Pimo and Jiang Yuzhen, acquired a kind of cult status in the People’s Republic.

Although a number of Mainland authors, including Hong and Jiang, persist in referring ritualistically to the Chinese mantic arts as “superstition” (*mixin*) or “pseudoscience” (*wei kexue*), they, along with scholars from other parts of Asia and the West, have nonetheless investigated the subject of divination thoroughly and enthusiastically, producing a great many valuable articles, monographs, reference works, and collectanea and also making available to the scholarly community a wealth of new research materials – including recently uncovered archaeological artifacts and newly discovered written texts (see below and in the bibliography). Of particular value to Western scholars of the mantic arts are dictionaries that help to clarify technical terms, esoteric expressions, and difficult allusions.

Another factor promoting the study of Chinese divination over the last decade or so has been a growing scholarly interest, both in Asia and elsewhere, in Chinese popular culture. What this work has done, among other things, is to open up a productive space for investigating the complex interaction between elite and commoner beliefs and practices in China at various times and places. Meanwhile, scholars throughout the world have done a great deal of excellent work in areas of Chinese culture closely related in one way or another to divination, including mathematics, science and technology, medicine, and various other therapeutic arts, including *taiji quan* and *qigong*.

How has the recent explosion of books, articles, and other materials on the Chinese mantic arts shaped the contours of our understanding of late imperial China? This work reveals, among

other things, that the roots of almost all Chinese divinatory practices and correlative schemes go back much further than many of us thought. Manuscripts and other artifacts discovered at various archaeological sites over the last two decades or so – recently published and even more recently analyzed – are fundamentally transforming our understanding of the place of the mantic arts in China and their relation to other technical, religious, and philosophical traditions, as well as to games and military affairs.

Efforts have also been made recently to catalogue and study the substantial corpus of materials on divination located at Dunhuang, in far Western China. Unlike other large collections of material discovered at this remote site – including Buddhist, Daoist, and Confucian texts, encyclopedias, and literary compendia – these resources have never been evaluated in a systematic and comprehensive way. Now, however, a team of Chinese and Western scholars, under the general editorial direction of Marc Kalinowski, has done just this, putting together an impressive 2003 volume titled *Divination et société dans la Chine médiévale: Une étude des manuscrits de Dunhuang de la Bibliothèque nationale de France et de la British Library* (Divination and society in Medieval China: a study of the manuscripts from Dunhuang in the Bibliothèque National in France and in the British Library). By their careful attention to the difficult Dunhuang materials, the authors of *Divination et société dans la Chine médiévale* have already been able to show that certain practices thought to have arisen in the Song dynasty (960–1279) actually had their genesis in a much earlier period. Moreover, their explanations of these texts have helped to clarify terms and concepts that have perplexed many students of Chinese divination in the past.

Among the recent Western studies of divination and religious life in post-Tang times, Edward Davis’s *Society and the Supernatural in Song China* (2003) is especially noteworthy for its effort to show that “folk” activities, including spirit possession, shamanism, and exorcism, were not confined to the common people and that they were important coping mechanisms for all strata of society. Comparatively little has been

written recently about divination in the Yuan, Ming, and Qing dynasties, although broad surveys of the magical and mantic arts often give at least some attention to the late imperial era, as do a number of recent works on specific divinatory techniques, including physiognomy (*kanxiang*, *kanren*, *kanzhang*), geomancy or “siting” (*kanyu*, *fengshui*, *xiangdi*), spirit writing (*fuji*, *fuluan*), numerology and time selection (*liuren*, *qimen dunjia*, *taiyi*, *xuanze*), astrology (*zhanxing*, *xingzhan*, *xingming*, *xingbu*), military divination (*bingzhan*), dream divination (*zhanmeng*, *mengzhan*), word analysis (*cezi*, *xiangzi*, *chaizi*), and prophetic texts (*chenyao*, *chenwei*).

One of relatively few Western works that shed substantial light on divinatory beliefs and practices in late imperial times is Benjamin Elman’s *A Cultural History of Civil Examinations in Late Imperial China* (2000). Although most of his past research has been devoted to the rational and scientific traditions associated with evidential research (*kaozheng xue*), Elman devotes most of chapter 6 (Emotional Anxiety, Dreams of Success, and the Examination Life) – more than 70 pages in all – to the way literati of the Ming (1368–1644) and Qing (1644–1912) dynasties “turned to religion and the mantic arts” in an effort to contend with the pressures of examination competition. Elman documents at length how “many Chinese, whether elite or peasant, . . . turned to gods, temples and local religious practices” to negotiate the terms of their “uncertain” daily existence, emphasizing that the interaction between Chinese popular culture, Buddhist and Daoist religious practices, and divination in the lives of Ming-Qing elites “tells us how far off the historical mark our earlier accounts of ‘Confucian agnosticism’ . . . have been.”

Recent research of the sort discussed briefly above suggests that some of the stark dichotomies that have been constructed in the past to make sense out of China’s historical and cultural experience may have to be reconsidered. For example, a close look at Chinese divinatory beliefs and practices over time suggests that the line between what elites thought (and did) and what commoners thought (and did) was not always sharp and clear. Nor was the divide between what was

considered orthodox and what was considered heterodox. Similarly, the distinction between certain schools of Chinese thought – for example, Han Learning versus Song Learning – which often appears so neat in works on Chinese intellectual history, blurs substantially on closer examination. So does the contrast between tradition and modernity. In fact, meaningful lines cannot always be drawn clearly and confidently between what is Chinese and what is foreign.

With this general historiographical overview in mind, let us look more closely at the actual evolution of divinatory practices in China from ancient times to the present.

From the Neolithic era into the twentieth century, divination occupied an extremely prominent place in Chinese culture. By the third millennium, BCE at the latest – and some recent research suggests considerably earlier – specialists in reading stress cracks in the bones of various animals had already emerged as a distinct occupational group in north China. During the Shang dynasty (ca. 1500–ca. 1100 BCE), the interpretation of so-called oracle bones (the dried plastrons of turtles and the scapulae of cattle) reached a high degree of sophistication. Royal diviners sought spiritual advice on behalf of the Shang kings concerning a wide range of important topics, from weather, agriculture, hunting, and travel to civil and military administration, the construction of buildings, the location of cities, religious sacrifices, and personal problems.

The inscriptions on Shang oracle bones do more than indicate the preoccupations of rulers, however; they also reveal patterns of thought and behavior that have lasted for several millennia in China. For instance, they document the early use of sexagenary cyclical characters (stems and branches; *ganzhi*) for marking time – a practice that continued in all subsequent dynasties and can still be seen today in traditional Chinese almanacs. They also suggest a deep interest in dream interpretation that has persisted throughout Chinese history. Furthermore, oracle bone inscriptions testify to an early preoccupation with astronomical observation, astrological prediction, and numerology. Indeed, some Chinese scholars have argued that Shang dynasty

numerological concerns led to the invention of the extraordinarily important divinatory symbols known as hexagrams in English (see below). Significantly, a recent (2012) dissertation by Stephan N. Kory demonstrates that the divinatory cracking of turtle plastrons, conventionally and widely assumed to have more or less died out after the Shang dynasty, persisted as “a potent source of cultural capital . . . [and] an archetypal and common way to access culturally constructed notions of divine or spiritual power” well into the Tang period (618–907 CE).

Paradigmatic Chinese sources such as the *Shijing* (Classic of Poetry), the *Shujing* (Classic of History), the *Yijing* (*I Ching*; Classic of Changes), the *Chunqiu* (Spring and Autumn Annals), the *Zuozhuan* (Commentary of Zuo), the *Liji* (Record of Ritual), and the *Zhouli* (Rituals of Zhou), together with recently excavated inscribed bronzes and writings on both silk and bamboo, attest to the social and geographical spread of divination in the Zhou dynasty (ca. 1100–256 BCE). During the early Zhou, divination remained primarily a royal prerogative, but by the Spring and Autumn era (722–481 BCE), it had become far more diversified and widespread.

A particularly important development during this time was the “invention” of the legendary *Zhouyi* (Zhou Changes) – a divination manual based on sequences of 64 six-line symbols known as hexagrams (*gua*). Each hexagram had a name that referred to a physical object, an activity, a state, a situation, a quality, an emotion, or a relationship – for example, *Ding* (The Cauldron), *Shi* (The Army), *Dun* (Withdrawal), *Meng* (Juvenile Ignorance), *Yu* (Contentment), *Song* (Contention), and *Tongren* (Fellowship). Each hexagram also possessed a short description of several characters called a *tuan* or *guaci* (usually rendered “judgment”) and a brief, one-sentence line statement (*yaoci*) elucidating each line. Over time, the hexagrams and their two constituent trigrams (*alsogua*) came to be used in a wide variety of divinatory systems and also as scientific symbols (Fig. 1).

By the late Zhou period, a great number of mantic systems had developed in China,

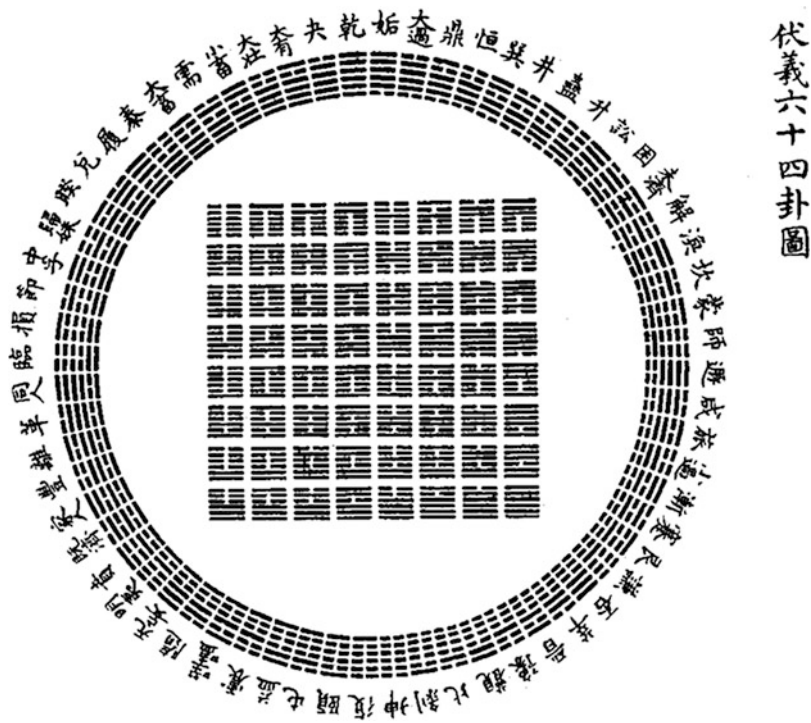
including various schools of astrology (*zhanxing*, *xingming*, etc.), geomancy (*dixing*, *xingfa*, *kanyu*, and later *fengshui*), physiognomy (*xiangren*, *kanxiang*, etc.), and various computational arts (known generically as *shushu*). This growing interest in divination was part of a general burst of remarkable philosophical creativity in the so-called Warring States period (453–221 BCE) – an era marked by social and geographical mobility, the exchange of new ideas, increased professional specialization, and the introduction of new technologies, including advanced methods of astronomical and calendrical calculation. Also, from the late Zhou dynasty into the twenty-first century, almanacs or daybooks (*rishu*, *tongshu*, *huangli*, etc.) – based on elaborate astrological calculations and correlations – specified propitious and unpropitious times for all kinds of activities, from mundane matters such as bathing, traveling, and beginning various kinds of work to extraordinarily important rituals.

During the Han dynasty (206 BCE–220 CE), the correlative cosmology of Dong Zhongshu (ca. 179–ca. 104 BCE) – based on concepts such as *yin* and *yang* and the five agents or activities (*wuxing*; identified with the qualities of wood, fire, earth, metal, and water), as well as the eight trigrams (*bagua*), the ten stems, the 12 branches, and the 64 hexagrams – influenced virtually all forms of Chinese divination, not to mention the related realms of medicine and natural science (Fig. 2). A significant feature of early Chinese divinity, medical, and scientific thought is that *yinyang*, *wuxing*, and other correlations often seem to have been more compelling than empirical observation – even when the correspondences and analogies were internally inconsistent or mutually incompatible.

During the early Han period, in 136 BCE, a series of preexisting commentaries known as the Ten Wings (*Shiyi*), attributed erroneously but convincingly to Confucius, became permanently attached to the *Zhou Changes*, and the work became one of the court’s officially recognized Confucian classics – hence the new name of the document, *Yijing*. These wings, especially the so-called Great Commentary (*Dazhuan*; aka, the

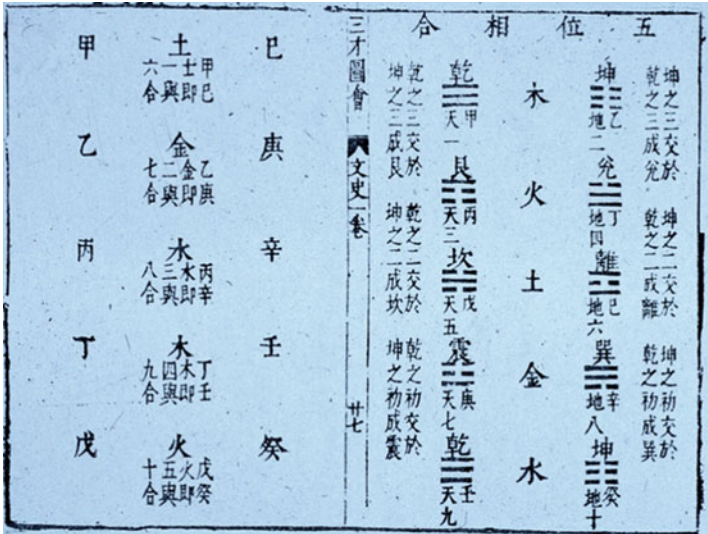
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Fig. 1 The 64 hexagrams, organized in square and circular configurations based on the so-called Former Heaven (Xian Tian) sequence



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Fig. 2 Cosmic correlations involving the eight trigrams, the five phases, and the ten heavenly branches



Appended Phrases or *Xici*), invested the *Changes* with a powerful, colorful, and enticing philosophical flavor. Moreover, they helped to explain the cryptic judgments and line statements of the basic text, attaching to both the hexagrams and tri-grams a great many new meanings and associations. These ranged from family relationships,

social roles, animals, and parts of the body to directions, seasons, times of the day, and colors.

Scholarly approaches to the *Yijing* varied substantially during the Han – in part, perhaps, because different versions of the work existed. It is now generally known, for example, thanks to Edward Shaughnessy's excellent 1998

translation of the Mawangdui silk manuscript version of the *Yijing*, that this work differed in several significant respects from later standard editions of the classic – not only in some of its judgments and line statements, but also in its ordering of the hexagrams (and even some of the names attached to them). Likewise, Shaughnessy's outstanding 2014 book, *Unearthing the Changes*, provides valuable insights into the ways that three recently discovered texts – the Shanghai Museum version of the *Zhouyi*, the Wangjiatai *Guicang*, and the Fuyang *Zhouyi* – influenced the writing and transmission of the *Changes* during the first millennium BCE.

But scholarly differences in the Han were also a function of the many ways in which the received text of the *Changes* could be interpreted. Indeed, for the next 2,000 years, literally hundreds of different approaches to the *Yijing* developed. Although only two main interpretive lineages are usually identified with the learning of the *Changes* – the Images and Numbers (*xiangshu*) School and the Meanings (or Morality) and Principles (*yili*) School – in practice scholars drew freely from both traditions, developing complex schemes that related lines, trigrams, and hexagrams to various calendrical, numerological, and philosophical interests and orientations.

At the same time, the *Yijing* inspired a host of derivative works, from simple prognostication texts (*chanwei* or *tuchan*) to more elaborate apocryphal treatises such as the *Qian zao du* (Opening Up the Regularities of the [Hexagram] Qian; also transliterated *Qian zuo du*). The *Changes* also provoked an extremely interesting divinatory book known as the *Taixuan jing* (Classic of Supreme Mystery) by a brilliant scholar named Yang Xiong (53 BCE–18 CE). This eclectic work reflects standard Han dynasty cosmological assumptions and intellectual fashions, but instead of using 64 hexagrams and 384 lines, it employs 81 tetragrams (*shou*) and a total of 729 lines – each with an appraisal (*can*) loosely patterned on the line texts of the *Yijing*.

The wide circulation of Han divination texts suggests the ever-growing appeal of fortune-telling at all levels of Chinese society. Occult

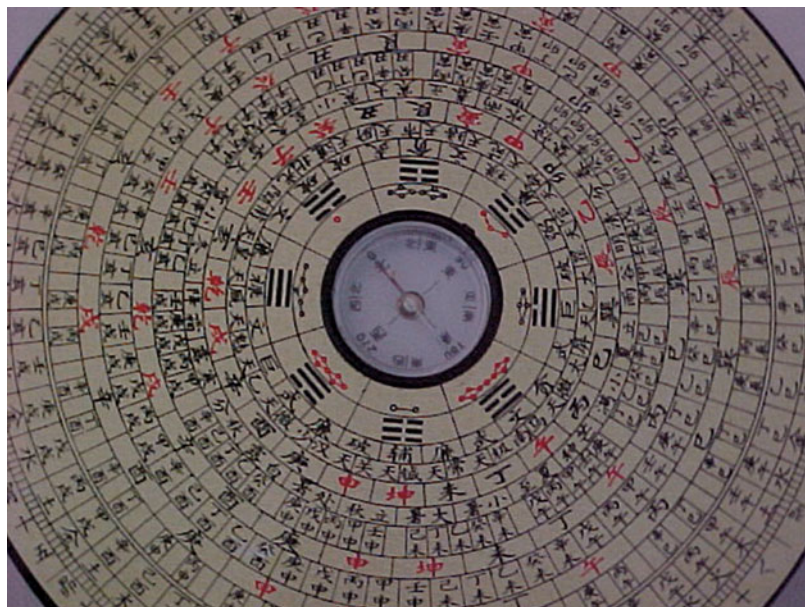
specialists known generically as *fangshi* dominated the mantic landscape in the Han and immediate post-Han periods, and as a result, every subsequent dynastic history, not to mention many local gazetteers and other such sources, contained special sections devoted to biographies of *fangshi*, usually called technicians (*fangji*).

Among the many divination techniques employed by *fangshi* were increasingly varied forms of astrology, fate calculation, and numerology. Specialists also emerged in a myriad of related techniques: consultation of two diagrams closely associated with the *Yijing* and known as the *Hetu* (Yellow [River] Chart) and the *Luoshu* (Luo [River] Writing); the use of divining boards, oracle bones, milfoil stalks, and prognostication texts; the geomantic analysis of landforms; the selection of lucky days; the analysis of heavenly stems and earthly branches; communication with spirits; crack-making with bamboo; the interpretation of winds and vapors, birdcalls, and dreams; physiognomy; and eventually the divinatory evaluation of written characters. Most of these techniques had existed in the late Zhou period or earlier in some form, and virtually all of them continued to be used throughout the Imperial Era (up to 1912). The principal innovations of later years were the incorporation of certain zodiacal elements of Indian astrology into Chinese astrology, the use in front of temples and shrines of spiritual sticks (*lingqian*) and divining blocks (*jiao*), and a particularly dramatic form of oracular spirit possession known as spirit writing (*fuji* or *fuluan*).

From the Six Dynasties period (222–589 CE) onward, Chinese Buddhists and religious Daoists appropriated the symbolism of the *Yijing* and used a variety of other mantic texts in order to know fate – even though one's future was, in a certain sense, ordained by behavior in both systems of belief. In any case, we find a number of monks, priests, and lay adherents from various periods of Chinese history who were experts in one or another divinatory technique. Some clerics even compiled mantic texts (*bujing*), such as the mid-fifth century work titled *Guanding jing* (The Sutra of Consecration). One of the most famous clerics in medieval China was Yixing (d. ca. 740), a Buddhist monk and official court astronomer

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Fig. 3 A geomantic compass, with concentric rings reflecting various cosmic variables, including trigrams



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during the reign of emperor Xuanzong, who excelled in fate calculation, physiognomy, and geomancy, as well as mathematics, calendrical science, and classical studies. He is well known for his studies of Han scholarship on the *Yijing* and as the author or editor of several books on astrology and other forms of divination. He also served as a trusted adviser and interpreter of portents for his imperial patron.

From the Song dynasty (960–1278) onward, diviners increasingly relied upon a new device, the geomantic compass (*luopan*, *luojing*, etc.), to ascertain the relationship between heavenly patterns (*tianwen*) and earthly forms (*dixing*). This invention, derived in part from Han dynasty divining boards (*shi*), delineated celestial and terrestrial relationships by means of a series of concentric circles marked with standard Chinese symbols of time and space. Among the *Yijing*-related symbols regularly employed in these devices were the eight trigrams, the stems and branches of the sexagenary cycle, the 28 lunar lodges (*xiu*), and other such cosmic variables (Fig. 3).

A Song dynasty poem reproduced in a famous Chinese encyclopedia testifies to the importance of the compass to the geomancer's craft. It contains the following lines:

Between the lodges Xu and Wei points clearly the needle's path,

But to the south the lodge Zhang "rides upon all three".

The trigrams Kan and Li stand due north and south, though people cannot recognize [their subtleties],

And if there is the slightest mistake there will be no correct predictions.

Over time, compasses became increasingly sophisticated, with up to 24 concentric rings and a host of symbolic variables that applied to several different divination systems. Similarly, fate calculation based on the time of one's birth grew more complex. Whereas pre-Song techniques involved at most a consideration of the year, month, and day of birth, later diviners took into account the hour as well. These four pillars (*sizhu*) of destiny, each designated by two characters, came to be known as one's eight characters (*bazi*), an extremely common term in Chinese divination up to this very day.

The many hundreds of life stories contained in Yuan Shushan's massive and fascinating *Zhongguo lidai buren zhuan* (Biographies of Diviners in China by Dynastic Periods, 1948) abundantly testify to the central role divination has played in nearly all aspects of Chinese life for thousands of years. Many of the mantic

specialists discussed by Yuan were employed by Chinese officials as formal or informal advisers, and many served in some sort of military capacity. A number made calendrical calculations and/or predicted weather, droughts, and famines. Physiognomers in the employ of bureaucrats often evaluated personnel and sometimes also interrogated witnesses and prisoners. A few even served as negotiators with dissident groups. Diviners also assumed active roles in law enforcement, assisting with difficult legal cases, solving crimes, and helping to apprehend suspects or escaped prisoners. A great many fortune-tellers gave useful advice to officials concerning water management, public works, and the construction or repair of city walls, temples, schools, and yamens (the office or residence of an official).

What made diviners effective enough in these roles to warrant biographies in local gazetteers and other such sources? Putting aside claims to supernatural power, the answer seems to be their technical expertise and social value – the product of both experience within their communities and psychological insight. Although experts in analyzing wind, rain, and clouds (*fengjiao*, *xiangyu*, *zhanqi*, etc.) – like all Chinese fortune-tellers (and most of the rest of the Chinese population as well) – they believed in the influence of supernatural forces, including star spirits. They were also careful observers of natural phenomena. Geomancers used compasses to identify auspicious sites and times for building and making repairs, but they also knew a great deal about landforms and hydraulic systems – information of value in public works as well as military affairs.

Exponents of numerological techniques such as *liuren* (the six yang waters), *dunjia* (evasive techniques), and *Taiyi* (method of the Great Unity [Spirit]), although concerned primarily with calculations to determine proper times and locations, often studied the arts of war as part of their training. And all diviners – fate calculators and physiognomers in particular – were quite naturally careful observers of human behavior. In short, well-cultivated talents of empirical observation and psychological insight gave

fortune-tellers a substantial role to play in Qing administrative affairs.

In local communities, quite apart from their service to Chinese officials, diviners played important roles in helping to resist rebel invaders and bandits. Fortune-tellers provided technical assistance to their local communities in other ways as well. Some undertook famine relief, managed schools, or supervised public works projects. Others used their special talents in *liuren*, *dunjia*, and *Taiyi* predictions to help neighbors find lost or stolen property.

In a number of significant ways, fortune-tellers were like physicians in traditional China – an affinity too seldom acknowledged by historians of medicine. At least 170 of Yuan Shushan's 1,115 biographical entries refer to individuals who knew both medicine and divination (*yibu*). One common denominator between the two diagnostic and prescriptive approaches was a shared cosmology, centered on theories of responsive correspondence (*ying* or *xiangying*). These correspondences involved considerations of time, place, and spirituality (or demonology) as well as notions of physiology and psychology. Discourses in divination and medicine almost invariably revolved around the same basic cosmological concepts, including *yinyang* and *wuxing*, the eight trigrams and 64 hexagrams, the sexegenary stems and branches, positive and negative spirits (*shen* and *gui*, respectively), and so forth.

The four standard categories of Chinese medical examination – visual inspection, listening and smelling, questioning the patient, and touching the body – correspond closely to the approach of many diviners, physiognomers in particular. From the standpoint of treatment, practitioners of traditional Chinese medicine and divination often considered a patient's moral behavior to be a significant factor in that person's well-being. Clients of both doctors and diviners were therefore advised to cultivate good thoughts and to banish selfish desires.

As technicians, physicians and fortune-tellers occupied the same status in Chinese society. Scholars conventionally described both professions as minor employments (*xiaodao*), to be investigated, perhaps, but not to be earnestly

pursued. They also suffered many of the same criticisms. These had to do primarily with inconsistent theories, inaccurate predictions, and fraudulent therapies.

Scholars were particularly critical of fortune-tellers for their exploitation of the ignorant masses and for their obviously mercenary motivations. They could not, of course, assail the idea of divination itself, for the practice had far too long and illustrious a pedigree in China's classical tradition to ignore. But elites made a sharp (albeit rather artificial) distinction between their own enlightened beliefs and the crude customs of the populace at large. In short, the bias against certain popular forms of divination was fundamentally a class prejudice, masked by the rhetoric of Confucian morality. This elitist view of divination is reflected in a well-known adage attributed to the famous Song dynasty scholar Zhang Zai: "The (*Classic of*) *Changes* is for the planning of the superior person, not the planning of the petty person."

Yet Chinese intellectuals made no significant headway in their effort to eradicate popular mantic practices during imperial times. Why? In the first place, most divination systems, like the cosmology on which they were based, had a high degree of complexity. This provided conceptual flexibility and made scientific falsification all but impossible. In the minds of many, wrong predictions simply indicated that someone had misinterpreted the huge number of cosmic variables involved or that either the diviner or his/her client was insufficiently sincere (*cheng*).

In the second place, as indicated above, fortune-tellers played important social roles in premodern China, serving as the equivalents of modern-day scientists, technicians, doctors, psychologists, and social workers. Moreover, divination drew strength from the fact that so many of its features resonated powerfully with other aspects of traditional Chinese culture, including philosophy, religion, art, literature, and social customs. It reflected, for example, the eclectic, synthetic features of Chinese thought, the importance of writing (evident in mantic messages of all kinds, as well as charms, and the analysis of written characters), aesthetics (particularly

evident in the case of geomancy), mythology, medicine, cosmology and popular symbolism (notably the popular *yinyang* illustration known as the Diagram of the Supreme Ultimate (*Taiji tu*)), and the ubiquitous eight trigrams.

Finally, we should remember that the Chinese government reinforced the inherited cosmology and sanctified orthodox practices of divination in every way possible, at all levels. Officials and emperors sought mantic assistance in a wide variety of circumstances, determined to find the right time and the right place for all ritual events, large and small, the conduct of war, the construction of buildings, and so forth. Perhaps the single most significant manifestation of this administrative attitude was production of the state calendar, which dictated auspicious and inauspicious activities for each day of every year, based on the calculations of official diviners at the capital, who were located in the Imperial Bureau of Astronomy (Qintian jian) (Fig. 4).

During the late nineteenth century, Western imperialism brought new challenges to China, as well as new political, social, and cultural options to Chinese intellectuals. Under these unprecedented circumstances, a new kind of cosmological critique arose – a political attack on the cosmological foundations of Chinese kingship itself. It was successful, and when the Qing dynasty finally fell in 1912, state-sponsored cosmology suffered a mortal blow. During the so-called New Culture Movement (ca. 1915–1925), which followed in its wake, modern-minded intellectuals such as Chen Duxiu (1879–1942) railed against Confucian values and ridiculed old-fashioned superstitions (*mixin*). He wrote in 1918, for example, that only by first casting away practices such as geomancy, fortune-telling, spirit writing, and the use of charms, spells, and alchemy could the Chinese people begin to "put their minds right." He was not attacking a straw man, for old-style mantic techniques and cosmological assumptions remained in force, judging from the remarks of a well-informed foreign observer in the midst of the New Culture Movement: "At the present day," he wrote, "soothsayers, diviners and fortune-tellers abound throughout the land, and the people place implicit faith in their vain forecasts."



Divination: Science, Technology, and the Mantic Arts in Traditional China, Fig. 4 A map of Heaven (round) and Earth (square), showing the influence of the

eight trigrams and various heavenly bodies, including the sun, the moon, and the 28 lunar lodges (*xu*)

Periodic efforts were made by the Republic of China (from 1912 to 1949 on the Mainland and from 1949 to present on Taiwan) and the People's Republic of China (1949 – present) to discourage or eradicate superstitious mantic practices, but with only limited success. Virtually all forms of traditional Chinese divination have flourished in both Hong Kong and Taiwan, and even in the People's Republic, despite sometimes fierce antisuperstition campaigns, particularly during the fanatical and destructive Cultural Revolution (1966–1976). Popular divination is alive and well, especially geomancy (*fengshui*).

As indicated above, the so-called Open Policy, inaugurated on the Mainland in 1978, encouraged a dramatic revival of interest in, and publications on, divinatory works, especially since the 1990s. A few of the many noteworthy scholarly publications produced from that time onward are Chen Yongzheng, ed., *Zhongguo fangshu da cidian* (An encyclopedia of the predictive and prescriptive arts in China, 1991); Gao Guofan, *Zhongguo wushu shi* (A History of the Chinese Magical Arts, 1999); Hu Wenhui, *Zhongguo zaoqi fangshu yu wenxian congkao* (Collected investigations into the predictive and prescriptive arts and literature



Divination: Science, Technology, and the Mantic Arts in Traditional China, Fig. 5 Examples of books on divination in Mainland Chinese bookstores and bookstalls

of early China, 2000); Hu Xinsheng, *Zhongguo gudai wushu* (The magical arts of ancient China, 1998); Jin Liangnian, ed., *Zhongguo shenmi wenhua baike zhishi* (An encyclopedia of China's mystical culture, 1994); Li Ling, *Zhongguo fangshu kao* (An examination of the Chinese predictive and prescriptive arts, 2000a) and *Zhongguo fangshu xukao* (continuation of *An Examination of Chinese Predictive and Prescriptive Arts*, 2000b); Zhang Ronghua, *Zhongguo gudai minjian fangshu* (Prescriptive arts of the common people in ancient China, 2000a); Zhang Rongming, *Fangshu yu Zhongguo chuantong wenhua* (The predictive and prescriptive arts and the traditional culture of China, 2000b); Zhang Yongtang, ed., *Zhongguo lidai shushu chubian – zhengshi pian* (Index to the arts of calculation in China by period, first series – orthodox histories, 1992); and Zheng Xiaojiang, *Zhongguo shenmi shu daguan* (An Overview of the Mystical Arts of China, 1993) (Fig. 5).

Naturally enough, the *Yijing* has been an object of particular Chinese interest, both popular and scholarly and on both sides of the Taiwan Straits – especially during the 1900s and 2000s. As I have discussed at length in *Fathoming the Cosmos and Ordering the World* (2008b) and *The I Ching: A Biography* (2012a), encyclopedias, dictionaries, and other comprehensive compilations – as well as compendia produced by literally dozens of scholarly organizations devoted to *Changes* studies – have chronicled at great length the *Yijing*'s wide-ranging cultural contributions. So have the authors of general studies such as Wang

Shusen's *Zhouyi yu Zhonghua wenhua* (The *Zhou Changes* and Chinese culture, 1993), Zhai Tingpu's *Zhouyi yu Huaxia wenming* (The *Zhou Changes* and Chinese civilization, 2000), Ying Dingcheng's *Zhongguo wenhua zhi benyuan* (The origins of Chinese culture, 1990), and Zhang Liwen's *Hejing: Yixue yu Zhongguo wenhua* (Harmonious realm: *Changes* studies and Chinese culture, 2005).

Meanwhile, a number of more narrowly focused works have also appeared in a spate of recent scholarly series – notably the *Yixue wenhua congshu* (Collectanea on the Culture of *Changes* Studies) and the *Yixue zhihui congshu* (Collectanea on the Wisdom of *Changes* Studies). The individual volumes in these two series alone cover topics such as the relationship between the *Yijing* and Confucianism, Daoism, Buddhism, mathematics, medicine, astronomy, the humanities, historiography, aesthetics, geomancy, architecture, business management, the environment, *qigong*, and other forms of traditional physical and mental cultivation (*yangsheng*), and so forth.

In addition, there are a great many individual monographs with titles such as Xu Daoyi's *Zhouyi kexue guan* (The Scientific Outlook of the *Zhou Changes*, 1992) and his *Zhouyi yu dangdai ziran kexue* (The *Zhou Changes* and Contemporary Natural Science, 1995), two of many similarly titled books and articles; He Shiqiang's *Yixue yu shuxue* (*Changes* Studies and Mathematics, 1999); Jiang Chengqing's *Yijing yu Zhongguo yishu jingsheng* (The Classic

of *Changes* and the Spirit of Chinese Art, 1990); Chen Liangyun's *Zhouyi yu Zhongguo wenxue* (The *Classic of Changes* and Chinese Literature, 1999); Wang Zhenfu's *Zhouyi di meixue zhihui* (The Aesthetic Wisdom of the *Zhou Changes*, 1991); Shao Xuexi's *Yixue yu bingfa* (*Changes Studies and the Art of War*, 1996); and Tang Mingbang's *Dangdai Yixue yu shidai jingshen* (Contemporary *Changes* Studies and the Spirit of the Times, 1999).

One of the most powerful and persistent tendencies in recent *Yijing* scholarship has been the tendency to look at the *Changes* as a scientific document. During imperial times, a great many Chinese thinkers tried to approach the *Yijing* by way of mathematics, or at least a highly sophisticated numerology – notably Jing Fang in the Han, Shao Yong in the Song, and Jiao Xun in the Qing. And, as indicated briefly above, the symbolism of the *Changes* also came to be used as an explanation for various phenomena in the natural world. But efforts to link the *Yijing* to math and science in the twentieth century are now predicated on modern Western understandings of these two related realms of knowledge. Thus, impelled in part by national pride, Chinese scholars today – especially those educated in the West – have begun to use data from the *Yijing* to show connections to a number of different realms in modern mathematics and science, from linear algebra and quantum mechanics to molecular biology and computer coding. A readily available example in English is Johnson Yan's *DNA and the I Ching*.

See Also

- Fengshui
- Geomancy in China

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Dwellings and Settlements

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Traditional dwellings and settlements are the built expressions of a heritage that continues to be transmitted from one generation to another. Usually the product of common people without professional intervention they provide the habitat for much of the world's population. In fact, it is argued that professionally designed dwellings account for less than 1 % of the total housing stock in the world. According to one estimate, traditional dwellings and settlements house between eight and nine million households in a variety of urban and rural settings (Oliver, 1987).

In the twentieth century, interest in the social and cultural values, images and perceptions underlying traditional dwellings and settlements has become widespread among scholars in various disciplines. Specific labels, such as "vernacular," "indigenous," "primitive," "tribal," "folkloric," "popular," and "anonymous" have been introduced to describe the subjects of a variety of inquiries. Nevertheless, the inability to come up with a single appropriate label should not prevent a categorization of these dwellings and settlements as one analytical group. One thing common to all the above qualifiers regarding buildings and spaces is that they describe a process that becomes a norm when enough people in a given society adopt it. In this regard, traditional settlements exist in every part of the world and cannot be regarded as being simply primitive or exclusively a product of the developing world.

Since adoption of a practice into a norm is one of the fundamental qualities of tradition in built form, it is legitimate to use "tradition" as an all-encompassing umbrella term. Used this way, the term may also be useful in an age when scholars are beginning to recognize that the study of those dwellings and settlements, whose form originated as part of everyday processes rather than specialized professional aesthetic judgments, is an interdisciplinary arena. Unlike

professional traditions like those of science or medicine, or professional architectural practice, the traditions of dwellings and settlements will remain an open field subject to great changes in position.

One may argue that a thing is traditional if it satisfies two criteria. First it should be the result of a process of transmission from one generation to the next; second it should have cultural origins mainly involving common people. As such, traditional dwellings and settlements are those buildings and spaces which provide for the ordinary activities of common folks and which are produced by both utilitarian logic as well as local aesthetics.

The vast numbers of traditional dwellings and settlements also allow for such built forms to be legitimately classified under the different names and qualifiers mentioned above. Many of these qualifiers originated from particular disciplinary bases and may not be interchangeable. For example, vernacular architecture in many parts of today's world often cannot be regarded as indigenous because it relies on imported materials to achieve local styles. "Indigenous" means of place, and has to do with origin. "Vernacular" means of the masses and hence does not have to be indigenous. It is also a category that has an underlying basis in class and social grouping. "Traditional" as a description is appropriate to use when discussing a system of core values that are transmitted from one generation to another. It is about process; as opposed to vernacular and indigenous, which are descriptions of how things are put to use (AlSayyad & Bourdier, 1989).

The study of traditional dwellings and settlements as a field is not new – it was started in the early nineteenth century by Morgan and Morris. Bernard Rudofsky's famous exhibition at the New York Museum of Modern Art entitled *Architecture without Architects* and an accompanying book further popularized the study of vernacular architecture in the 1960s. The latter part of the decade saw further developments in the field with the publication of such ground breaking books as *House Form and Culture* by Amos Rapoport culminating in the *Encyclopedia of Vernacular Architecture of the World* by Paul

Dwellings and Settlements, Fig. 1 Cave and pit dwellings, China
 and pit dwellings, China
 (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 875. Courtesy of Paul Oliver)



Oliver. Some more recent publications include Paul Oliver's *Dwellings: The House Across the World* and Enrico Guidoni's *Primitive Architecture*.

The study of traditional dwellings and settlements can be defined less by subject than by method. Different means of analyzing traditional dwellings and settlements such as anthropological, architectural, archaeological, behavioral, structural, and so forth use different lenses to understand the ways and means by which people build dwellings and the symbolism and utilitarianism involved in building and conceptualizing these structures. Such varying approaches to studying traditional dwellings and settlements points to the fact that elaborate methods and meanings dictate the form and process by which dwellings are constructed. Factors such as culture, religion, gender relations, privacy matters, climate, security, economic conditions, and so forth intersect to produce dwellings that become part of the popular culture of a place.

Using such varying methods points to the various forms of settlements that are viewed as being "traditional." For example, in China, cave and pit dwellings found in the Hunan region are viewed as traditional forms of settlements (Fig. 1). Many of the people who live in these dwellings are peasant farmers who come from relatively low-income backgrounds. Cave and pit dwellings

therefore allow them to not only save precious farmland, but also to save substantially on the cost of building a house as digging is the cheapest form of labor in the region. The Tunisian troglodyte dwellings, some 10,000 miles away, are primarily habitats of the ethnic Berbers. Largely found in the Matmata plateau area, in the south of the country which is part of the Sahara desert, these dwellings were claimed to have been built for purposes of defense against the invading Romans and later the Arabs (Fig. 2). As the threat increased or decreased, so did the height at which these dwellings were carved or constructed. Thus these dwellings are a product of not only a traditional way of life but also climatic and topographic constraints under conditions of war and peace.

Such climatic and cultural conditions have also been used to explain the forms of Tharu homes in the Terai region of Nepal (Fig. 3). These homes are closely built together not only because the Tharu people live predominantly in forested regions where they are prone to animal attacks, but also because of their traditional beliefs in ghosts and the notion that anyone who sleeps alone is prone to attacks by evil spirits.

Additionally, climate has often been cited as the primary condition for the development of courtyard houses through much of the Middle East. While this type of building is associated

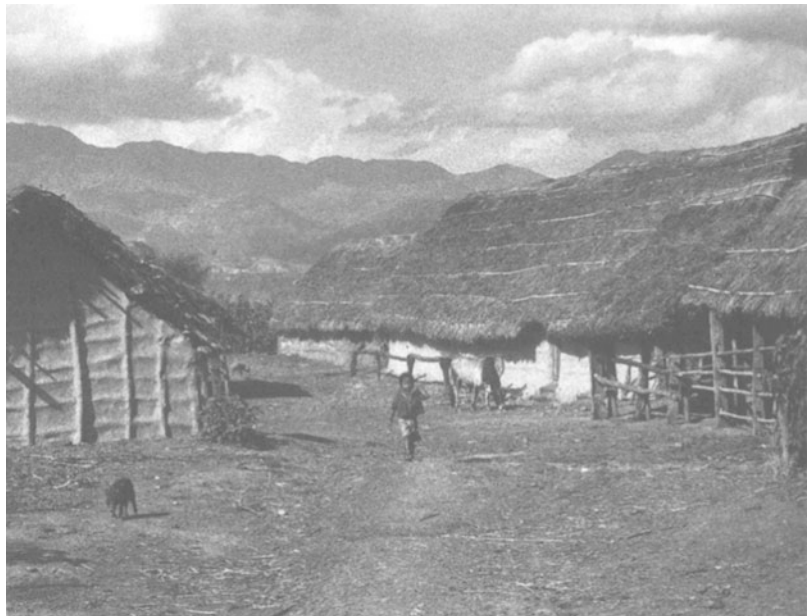


Dwellings and Settlements, Fig. 2 Troglodyte dwellings in the Matmata plateau area, Tunisia (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 135. Courtesy of Paul Oliver)

primarily with Arab culture, its distribution extends from North Africa to South Asia where the *haveli* or atrium house is common to cities such as Jaipur and was developed under Mogul influence. The basic courtyard plan of the Ancient Egyptian peasants which partially survives today includes long single-storeyed rooms on three sides of a yard, the fourth being closed off by a wall as high as the buildings. Constructed of mud, the walls are the thickest where they are exposed to the sun. The courtyard plays a climatically important role regardless of the height of the building. At midday, the sun may reach the courtyard floor but the thickness of the walls and the adjacent buildings prevent excessive solar heating. Cool air in the rooms is drawn into the courtyard and warm air begins to rise, causing convection currents. The deep shadows created by the low angle of the sun offset the circulation of the air currents. When the sun sets, the temperature drops rapidly and the air circulates through the various rooms surrounding the courtyard keeping them cool till the next afternoon (Oliver, 1987, pp. 119–120).

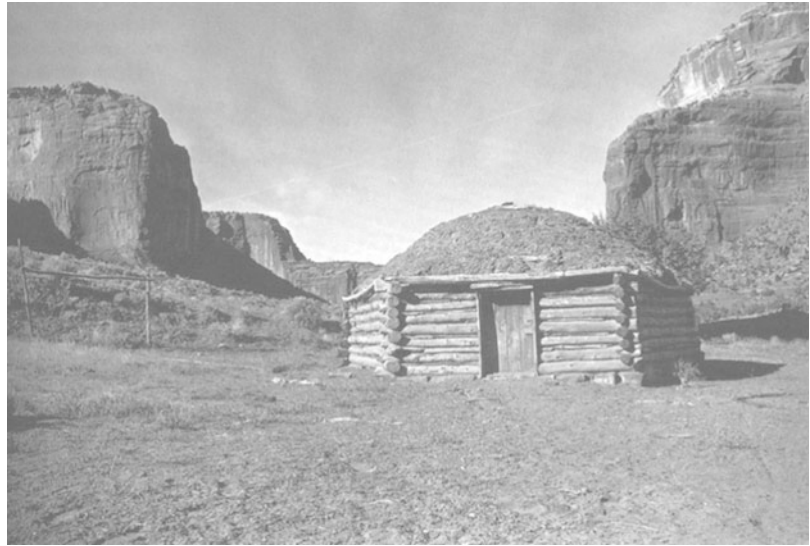
Similar to climatic constraints are constraints presented by the environment as well. This includes the constraint of finding appropriate

Dwellings and Settlements, Fig. 3 Tharu homes in the Terai region, Nepal (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 1041. Courtesy of Paul Oliver)



Dwellings and Settlements,

Fig. 4 Hogan of the Navajo Indians in Chinle, Arizona (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 1935. Courtesy of Paul Oliver)



building materials. In the Altiplano and high Punda regions in Northern Chile, the only source of wooden building material is a cactus commonly known as *cardon* or *pasacana*. The plant once cut and dried produces a wood that is not only very strong, but resistant to rotting. It is cut into boards and bound together to construct doors, ceilings and floors. The bark, which is denser material, is used for window frames, rafters, and furniture-making (Sainsbury, 1997, p. 223).

Questions of privacy are important factors in determining the form of space in traditional dwellings and settlements. How societies regard their relationship to external or public space is often a measure of the importance that they place on privacy. The delineations of public and private spaces vary from one culture to another. In some cultures such as that of the Ashanti, one finds most of the domestic tasks along with economic ones taking place outside the house itself, not inside as it is in most other cultures (Oliver, 1987, p. 142).

As noted earlier, values and symbols play an important role in the development of traditional dwellings and settlements. One example of such practices is that of the Navajo Indians and the symbolic meanings of spaces in their hogans (Fig. 4). Here, the floor slightly dished represents the female (earth) and the roof slightly concave

represents male (sky). Pollen smeared on the house posts supporting the roof symbolizes poles that support the sky. In the middle is the hearth which symbolizes the center of the world. Movement through this space is sun-wise (Oliver, 1987, p. 142).

Aesthetics play an important symbolic role within vernacular architecture practices. In Sumatra, the Toba Batak *huta* (village) comprises of two rows of buildings facing the *halaman* or village plaza which in turn is always oriented east-west (Fig. 5). The massively constructed Toba Batak house has saddle-back pointed roofs and curving eaves which convey an impression of lightness and gable fronts that give shade. Planked panels are fixed over the external gable which comprise of three levels including a stair and balcony. These panels take on decorations which include finely carved spiral and foliated volute patterns and painted in black, red, and white. Female breasts and the *boraspati*, a local lizard, are also carved on to the façade, possibly as fertility signs. Batak houses are meant to be seen and admired from the *halaman*, the hierarchies of the village evident in the size of the dwelling and the quality of workmanship exhibited, which can be restricted by the village heads (Oliver, 1987, pp. 173–174).

Parallel to the Batak traditions of using aesthetics as a marker of social hierarchy is the

Dwellings and Settlements, Fig. 5 Toda Batak house, Sumatra, Indonesia (Source: Paul Oliver, *Dwellings: The House Across the World*, p. 199. Courtesy of Paul Oliver)



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Dwellings and Settlements, Fig. 6 Decoration on the façade of a Hausa merchant's house, Zaria, Nigeria (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 581. Courtesy of Paul Oliver)



Hausa practice of using external decorations to show wealth and prosperity (Fig. 6). The characteristic external house decorations of the Hausa appear to have developed in this century when attitudes to *azziki* or the gaining of prosperity and respect, which had thus far been restrained, were relaxed. Displays of success by homes of merchants and traders appear to have been condoned until 1930s by which time many houses had been elaborately decorated in *zanen gida* fashion and were seen in such cities such as Kano and Zaria.

Over the mud walls, the finishing mud plaster was molded into the desired shapes by hand and coated with water-resistant layer of local cement made from mud, dung, and *laso*-mixed animal hair, and dye-pit residues. The pattern scribed with fingers with the unwanted parts scooped away left figures that stood in relief against the background. This was finished with local cement and whitewashed or painted in earth colors or in commercial paints (Oliver, 1987, pp. 180–181).

Methods of defining vernacular architecture have been categorized by others into four avenues of enquiry namely: object-oriented studies, socially oriented studies, culturally oriented studies and symbolically oriented studies (Upton, 1993). While the first type tries to interpret the intention of a dwelling's creator and the second is concerned with overall social history, the third and fourth suggest a shift toward a typologized study of dwellings within certain socio-cultural and historic contexts, with the purpose of uncovering the enduring values of their builders and the symbols that signify deeper structures of society. A possibly fifth avenue of inquiry is that possibly qualified as "design-oriented studies" which include the work of those people who seek better ways of understanding the past without accepting a simplistic return to earlier traditions. While the above methods have been largely utilized to examine the American vernacular scene, one can easily apply such approaches to the larger field of traditional dwellings and settlements (Upton, 1993).

The various methods of analyzing traditional dwellings and settlements also require a parallel study of the meaning of tradition itself. Some have argued that tradition is something that we value and pass on. The value attached is the element of "traditionality" sanctioned by history or nature itself. Intrinsic to tradition is the constraint of choice. The inability to choose the possibility of waiting is what provides value to an object or a practice. Unique to this concept is the introduction of time and of waiting to the concept of tradition. At some level, traditions emerge simply as a result of the absence of choice. It is the practice evolving out of constraint and that which we are able to reproduce that ultimately becomes tradition and is passed down from generation to generation. In modern societies, consumerism has eliminated many of the constraints folk societies faced and overcame by building on and creating traditions (Tuan, 1989).

It can also be argued that there is no such thing as a "traditional building" but that there are only buildings that embody traditions. The idea that a building embodies tradition rather than it being the means by which the building came to be

allows us to see the continuities between form, content, and process.

The application of the term traditional is vast and all encompassing. For this reason, defining a dwelling as being "traditional" requires an understanding of the attributes that lead to its being qualified in this manner. These attributes may include scale, temporality, continuity, economy, and technology. They may also be expanded to include the process and the product characteristics of built environments ranging from the identity of the designers and their interest on one hand to the degree of cultural specificity and morphological integration on the other hand (Rapoport, 1989). The term traditional has almost always been seen as the opposite to the modern. Hence, in the view of some, it is not uncommon to view the traditional as being precontact and pre-literate. This view, however, does not take into account how traditions emerge.

An important concern that lies at the heart of studying traditional dwellings and settlements is the common mistaken assumption that such built environments mainly exist in the Third World. It is interesting to note that those who study such places almost invariably do so by going elsewhere rather than looking at home. The Eurocentric view that modernity is fundamentally a Western project created an unjustified duality between the developed and the developing worlds when it came to viewing built environments. Begun earlier under British and French colonial rule, the "respect for the native" and the discussion around "traditional" forms was the outcome of the romanticism attached to the exercise of imperialism. Hence, modern was equated with Western, which has led to an ongoing nostalgia particularly in the West for "authenticity" and "tradition" (Abu-Lughod, 1995, pp. 7–10). Similarly, this romantic view of traditional dwellings and settlements has led those who study and admire them to call for their preservation. But in many Third World societies, the rejection of the so-called traditional way of life should be seen as a natural evolutionary or reactionary process as opposed to a destructive one.

It has also been argued that the categorization of buildings and settlements into a "traditional"

category has been a deliberate exercise on behalf of the community of architectural researchers. The idea of the architect as an aesthetic expert depended on distinguishing between professionally designed, aesthetically pleasing architecture, and the mundane structures produced by the masses for purely functional uses. Today, the search for the “traditional” must be seen through the need for differentiated products in a postfordist era. New movements in architectural practice such as New Urbanism attempt to use vernacular and traditional forms as a means of creating a sense of community by creating highly coded and zoned communities that reflect a continuity with the past. Designs borrowed from the traditional homes of the American South, for example, are used to invoke a sense of history. Here, the idea of invented tradition becomes intricately linked to the sense of identity and heritage that a community wants to project to outsiders. Poundbury, an experiment in town planning and architecture undertaken by the Prince of Wales, is a good example of this trend, produced under the belief that the best of architectural progress can be achieved by simply remaking new buildings in a traditional garb. Among the criticisms leveled at Poundbury has been the accusation of it being un-modern and nostalgically harking back to a past. Its praises have included the sentiments of its residents decrying contemporary architecture as being alienating and out of touch with the needs and aesthetics of the common people.

Today, and in many parts of the Third World following independence, many of the former colonies engaged in the exercises of modern nation-building. Their attempt to articulate a unique national identity became an important requirement for maintaining sovereignty. Traditions, whether new or invented, became part of a nation’s identity and of the character of its physical spaces allowing these nations to create markers of uniqueness in an increasingly diversifying and competitive world.

One important cause of debates around using tradition as a means for designing and maintaining buildings and settlements has been the rise of global tourism. Some have argued that modernity depends in its very essence on instability and

inauthenticity. For moderns, authenticity is thought to be elsewhere – in other historical periods and other cultures, in purer, simpler lifestyles. The need for people to overcome the discontinuity of modernity materializes in their desire to see the authentic, the primitive, and the historical. In many instances, this desire materializes in the form of visiting the spaces of the “authentic” or “primitive” people and to view their ways of life (MacCannell, 1976).

The search of tourists for authenticity and traditional lifestyles has become an important means by which countries and localities are able to generate substantial incomes. The preservation of traditional dwellings and settlements hence is not only a means of constructing local and national identity, but has emerged as an important mechanism to survive within the global economy. In this sense, “tradition” fulfills the multiple roles of identity creation, economic stimulus, and in some cases a tool for physical development.

Finally, the discussions about the consumption of tradition and the manufacture of heritage in a global era have led to calls for the end of tradition (AlSayyad, 2001, 2004). Tradition, however, does not end. What may have ended, however, was our conception of it as a reservoir for revered authentic values. Today tradition may be found not only in real places but equally in the simulated and virtual world we inhabit. Tradition in built form will always be what we make and sustain everyday and everywhere through the occasionally contemptuous and ever-changing act of living.

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Dyeing: Indigo Dyeing in Sierra Leone

Cyrus Macfoy

Although many crops have played colorful roles throughout history, indigo appears to be the most colorful. Dyeing with indigo can be traced as far back as 7000 BCE, and is still widespread even today. This form of dyeing using various plant species is practiced in many countries and continents throughout the world, for example, in Mexico, Europe, Egypt, West Africa, Sumatra, Central Asia, Japan, the Americas and China (Adrosko, 1968; Fox & Pierce, 1990; Pettit, 1974). Ancient Britons and other Europeans obtained the dye from *Isatis tinctoria* (woad) but later *Indigofera* from India and other Eastern countries. *Indigofera tinctoria* is native to India and Africa, while *Indigofera anil* of Central and South America, and *I. suffructicosa* is a native tropical American species adopted in Africa (Pettit, 1974). Indigo is a vat dye (Vat Blue1), produced without mordants by a process consisting of a complex series of chemical reactions for the dye to be successful. A lot of care and patience is required. It shows fastness to light and water, it is insoluble and will dye all types of fibers (Adrosko, 1968).

Now synthetic indigo used to dye blue jeans has almost totally replaced the natural one in most societies. This is because it is thought that synthetic indigo is cheaper to produce and more uniform in concentration than natural indigo. Natural indigo tends to be used today primarily by artists and craftsmen producing specialty products and by those dyers involved in textile conservation or historical recreation, or on ceremonial occasions notably weddings and funerals, and in traditional medicine (Abbiw, 1990; Balfour-Paul, 2001). These days some add a few crystals of synthetic indigo to the final dye in order to darken the hue.

Indigo dyeing using the plant species *Lonchocarpus cyanescens* or *Indigofera suffructicosa*, or other *Lonchocarpus* and *Indigofera* species, such as *I. tinctoria* and *I. arrecta* all of which grow wild, were the most common and popular sources of color throughout West Africa (Polakoff, 1982). Both Anglophone and Francophone countries were quite active in this indigenous technology, e.g. Mali, Nigeria, Senegal, Guinea, Gambia, Liberia, and Ivory Coast. Research on excavations from caves in Mali has shown that the indigo dyed cotton garments dated between the eleventh and the sixteenth centuries, indicating that by the eleventh century, weaving and indigo dyeing had already reached a high standard in West Africa. Many of the tie-dye designs found are similar to those still in use today (Balfour-Paul, 2001).

Though the process is quite arduous, it provided a rich color usually missing in synthetically dyed fabric. The basic method of dye production is quite similar throughout the West Coast of Africa with some variation (Polakoff, 1982).

In Sierra Leone, the word *gara* was once reserved only for indigo dyeing, but now it is used more widely for any form of dyeing, natural or synthetic. Since the 1960s, when commercial dyes started to be imported into the country from Germany, U.K. and Nigeria, various colors (violet, green, blue, red, brown, mauve, yellow etc.) became available in the market, apart from the blue “gara” color. The preparation of the commercial dyes and their application are far

less complex and less time-consuming, but they are more expensive. Thus an improvement of the local natural dyes industry, taking due cognizance of the environment, will be invaluable in reducing the price. This latter unfortunately is now rarely used except by a few traditional dyers.

The gara industry, a local craft industry, has expanded over the years, giving an additional sense of economic satisfaction and self worth to these mainly female entrepreneurs who are self-employed. On occasion, men and children are also involved in the industry. Some gara dyers are full-time employees in other establishments but do the gara dyeing on a part-time basis. Some have even been trained at the Crystals Youth Club, a vocational center in Freetown. Other centers in different parts of the country include those sponsored by World Vision programs funded by the Canadian International Development Administration (CIDA) (CIDA Update, 2001); CADS i.e. Center for Alternative Development Strategies for training and production of dyed goods; United Nations Mission in Sierra Leone (UNAMSIL) Trust Fund for training; Commonwealth Human Ecology Council who funded a gara project; and the Christian Reformed Church of North America. These regard the art of gara dyeing as more than a craft; it signifies hope. Displaced women as a result of the civil war, combatant girls and women have all benefited from such income generating tie-dye and batik training *inter alia*. Some non-governmental organizations (NGOs) have initiated microcredit schemes of which gara dyeing is one of the most commonly supported, but availability does not satisfy demand (Walker, 1997). Since 80 % of the dye producers are women and 95 % of their raw materials imported, improvements of this dyeing technology will inevitably help improve the status of women and the environment.

Whatever the source of the dye, the beauty of the finished products obtained gives a great sense of pride and satisfaction to the dyers. This is more so with natural dyes since it gives some kind of connection to nature. Although attempts have been made to develop other colors such as green, brown and pink from local plants, these

have not been followed up, mainly because of time and labor constraints.

Gara dyers also frequently investigate by trial and error. Innovative dyers sometimes investigate different types of fabrics, e.g. cotton, wool, polyester, viscose and rayon, rugs; different combinations of plants, and color fastness. Some even investigate adding the dye at various stages in the production of a garment (to fiber before it is spun, to yarn before it is woven or knitted into a fabric, or to the finished fabric or garment).

Even though there is tremendous usage and potential for development, especially for a country just coming out from a 10-year war, very few research investigations have been conducted in Sierra Leone on dyes, apart from reporting the methods used for indigo dyeing (Cole & Hamilton, 1978; Crystal Youth Club, 1985) and preliminary laboratory work on "gara" leaves (Wright & Cole 1988). In view of this paucity, further work on various plant species has however been conducted by MacFoy, Pratt, McEwen and Johnson at Fourah Bay College, University of Sierra Leone; and by MacFoy in the U.K. and USA.

Some of the results obtained from this work are reported in detail elsewhere (MacFoy, 2003, 2005) on the ethnobotanical survey of the natural dyes used in Sierra Leone and on the history of indigo dyeing. In this West African country there is a wide gap between the rich and the poor and this latter group could benefit immensely from the development of natural dyes as a source of income generation. This research involved interviewing dyers, surveying the literature, cataloguing and collecting the plants used for preparing the dyes, obtaining knowledge of how the dyes are produced and the fabric dyed, and botanical identification of the plants.

Process for Indigo Dye Production and Dyeing of Fabric

This indigo dye is the most common natural dye in Sierra Leone, and several methods (seven identified in this study) are used with varying degrees of similarities for its production and subsequent

use in fabric dyeing. In general, they involve production either from fresh leaves in the dyepot, leaf fermented into leaf balls but dye not extracted, indigo dye extracted into an insoluble lump, or use of the synthetic dye. In some cases up to four other plant species are added to the dye bath, for example, *Morinda germinata* (wanda) roots, and *Cola nitida* fruits (cola), *Mangifera indica*, *Rhizophora recemosa*, *Jatropha curcas* (fignut), *Capsicum frutescens* (pepper); and caustic soda (sodium hydroxide), which creates an alkaline pH environment for the fermentation to proceed from 3 to 7 days; local alum or ash from the 'Kobe' tree (*Sterculia tragacantha*); a black powder called colmet. Rusty nails or metal cups, or *Alchornea cordifolia* (Christmas bush) are also sometimes added to darken the shade. Another method involves mixing the indigo dye with sodium hydroxide (caustic soda) and sodium hydrosulphite in a ratio of 1:1:1 in water.

Dyeing is achieved by first washing the fabric with soap and water and then immersing the cloth (a special white fabric called bryleon of varying quality, or poplin (cotton/polyester) in the dye for different periods of time (sometimes varies from hours to 3–4 days) drying, dipping again, drying and so on, until the desired shade is obtained. After this, the dyed fabric is washed, dried in the sun and ironed by traditionally pounding with a stick on a wooden slab to produce a glossy shine on the cloth or by using other modern forms of ironing.

Pattern Production

Apart from dyeing the whole material uniformly, various patterns can be produced by dyeing only parts of the fabric, leaving the remainder undyed. These methods are known as sewing, tie-dyeing, knotting, folding, and resist dyeing or the use of candle wax/batik.

The full details of these are reported in MacFoy (2005).

It is clear from the above that natural dyes have a tremendous potential in Sierra Leone and other developing countries. There is a high

demand for natural dyes in textile dyeing and in the food, beverage and cosmetics, paper and pulp industries in the US, Europe and Japan. Natural dyes can also serve as useful materials for teaching and experimenting in Adult Education Programs, and in schools and colleges.

Apart from dyeing fabrics, the colors obtained from the natural dyes could also be used as water-colors on paintings by making them thicker as well as experimenting on them for their use as food colorings, biological stains, inks, hair dyes, indicators in titration, in addition to their use in soaps, photography, paper, leather, medicine, eggs, plastics, rubber, automobile finishes, cosmetic industries, rugs, and table mats. Natural dyes can also be used to redye old clothing.

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Dyes

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The human urge to paint the body with symbolic, warlike, or identifying colors may have been among the earliest impulses which led to the discovery of color-yielding clays and plants. The dyeing of human clothing followed. Encounters, both warlike and peaceful, between groups then led to the identification of certain colors with specific regions or groups of producers, and exchanges began. This specialization and trade eliminated many of the poorer dyes of prehistoric times, which may have numbered many hundreds, and by the time recorded history took note of dyes only a relative few still saw widespread use.

Dye exchanges at first were very local. The major ones in ancient times were usually confined to the great areas of early culture and urbanization such as China, northern India, and the eastern Mediterranean. Later, trade in dyestuffs became more long distance, and, with European intrusions into Asia and invasion of the Americas, transoceanic and worldwide. This huge trade in natural dyes was destroyed and again reduced to a local level by the invention of coal tar or aniline dyes and other chemical dyes, in the mid-nineteenth century.

The production and exchange of colorants were always associated with certain other industries. Cloth manufacture and weaving were certainly the main ones. Others arose out of the limitations of some natural dyes. Many were not “fast”; i.e., they tended to fade or discolor when exposed to light, frequent washing, or wear and tear. Accordingly, much effort was historically expended in the search for mordants (dye fixers). Many of these were readily available, such as blood, dung, or urine. Various acids, alkalis, and wetting agents were widely used. Alum, an astringent, was probably the most common, and large cargoes were mined and shipped to dye

factories and market towns. Minerals such as copper, tin, and iron also came to be used for mordanting, and thus added to the importance of mining for these minerals. Tree-borne dyes led to forest cultivation and above all, to extensive and destructive logging industries. The dye-yielding attributes of plants such as ► [indigo](#) stimulated the creation of plantation complexes.

The production of natural dyes and their use in dyeing textiles were often complicated skills requiring apprenticeships and years of training. Certain towns became known as dye centers or markets, such as ancient Tyre or medieval Venice in the Mediterranean, or Oaxaca in colonial Mexico. Guilds of dyers and castes devoted to weaving and dyeing were of considerable importance in European and Indian societies from medieval times.

Before European intrusion reached sub-Saharan Africa, Asia, Australia, and the Americas, there were several dyes which were produced and distributed over large areas. Perhaps the best known of the early root dyes was madder (from the Rubiaceae, of which there are over 30 species). *Rubia tinctorum* roots were used to obtain red dye in India, and were also known to the ancient Persians, Egyptians, Greeks, and Romans. For centuries Baghdad was the center of the madder trade, and it was cultivated extensively – rather than gathered as elsewhere – in Mesopotamia. After its use spread to Western Europe, the Dutch became the most systematic and scientific madder growers, combining it with their leading role in cloth making (wool) and cloth importing (silks and linens). The French began to compete in the eighteenth century, but the French revolution damaged the industry and it never revived.

Before the European expansion, the most widely used dye made from plant leaves was woad (*Isatis tinctoria* of the Cruciferae family). It yielded various blues and grays. Although easy to produce in the temperate areas of Europe and Asia, it was not a very brilliant or fast dye. Woad in medieval and early modern Europe was manufactured and marketed by powerful guilds which – by monopolies, boycotts, and powerful

legislation – managed to prevent large-scale intrusions of other blues, especially indigos, from America and Southeast Asia, until the seventeenth century.

The leading dye made from woad has always come from brazilwood (*Caesalpinia echinata*), although many other trees such as lima, sapan, and peachwood, all soluble redwoods, are often lumped together as brazilwoods. These medium-sized trees have been widely used for dyestuffs in many parts of the world. They are cut into small logs, ground to powder, then soaked and fermented, often with an aluminum or other metal ore mordant. They yield reds and browns, except on silks. Before the sixteenth century, India, Sumatra, and Ceylon (Sri Lanka) were the main producers. Other woods, such as camwood from India, which imparted a rough feeling to cloth because of its resins, were also traded. Cutch or kutch, a brown dye, has been manufactured in India for over 2,000 years and comes from the leaves and twigs of various acacia and mimosa trees.

Humans have elaborated dyes from the bodies of insects and animals for millennia. The most expensive, prestigious dye of ancient times was Tyrian purple. It was manufactured in Crete by 1600 BCE, but is usually associated with the Phoenicians. Tyre became the great market center for this dye until captured by the Arabs in AD 638. Phoenician traders had spread its use all over the Mediterranean. It was so rare and costly that in many areas this fast, blue to purple dye was restricted to the clothing of high ecclesiastics, the aristocracy, or simply the ruling family. This colorant is extracted from a gland found in several shellfish, most notably *Murex trunculus*. A few similar dyes were used in the Americas before and after the European invasions, especially in Nicoya (Costa Rica) and on the Peruvian coast, but the American sources never produced enough dye to be of importance beyond local markets.

Insects have also been significant to the natural dye industry. Kermes is the oldest and most widespread of these dyestuffs. The insects harvested, *Coccus arborum* and *Coccus ilicis*, live on the holm oak (*Quercus ilex*), the shrub oak (*Quercus coccifera*), and a few other trees.

Kermes is Armenian for “little worm” and is a scarlet dye. It is mentioned in the Old Testament and in the writings of ancient Greece, but its origins are probably Asiatic and it was much used in India.

The European invasions of South and Southeast Asia and of the Americas greatly changed dye usage by bringing new and better colorants into the international markets. ► **Indigo**, which produces a range of blues, became for about two centuries the most important of all dyestuffs. It is a vegetable dye of considerable fastness, and has been known in parts of Asia for over 4,000 years. *Indigofera tinctoria*, of which only the leaves bear dye, is of the order *leguminosae*, and belongs to the pea family. It was found in India, Southeast Asia, Africa, and America. It has been discovered in both Egyptian and Inca tombs, and its continent of origin is obscure.

Dutch ships carried indigo throughout the Indian Ocean, and then, in the seventeenth century, to Europe, where, despite a struggle, it eventually displaced woad. Bengal supplied large quantities in the late eighteenth century to the British textile industry. When American indigo, mostly produced in Central America, the Carolinas, and Georgia, began to flood the market in the eighteenth century, the woad industry collapsed in the face of this cheaper and better dyestuff.

Cochineal, a scarcer and more expensive dye, had a similar history. It is made from an American insect, *Coccus cacti*, which feeds on a cactus (*Nopalía* or *Opuntia cochinellifera*), and was used in Mesoamerica, especially in the Oaxaca region, long before the Europeans arrived. While its production is elaborate and costly, the result is a superior scarlet or crimson dye, and it soon replaced kermes in Asian and European markets and dyeworks. After bullion it was the most expensive item carried by the Spanish treasure fleets.

The brazilwood industry grew after the products of the American continents began to enter world commerce. Vast new stands were found in Brazil – hence the name – and to this was added logwood or campeachy wood, a large, tropical American tree (*Haematoxylon campeacheanum*) found especially in Campeche, Tabasco, and

Belize. It yields black or blue dyes, plus edible seeds called *allspice*. By the seventeenth century it was in use in Africa and Europe.

One crop from America moved to Asia. Annatto (*Bixa orellana*) was used by Mesoamerican peoples largely as a food additive and colorant, but when taken to Southeast Asia and India this dye, which is a poor, fugitive yellow to red, was used for cloth, especially monks' robes. It is so culturally accepted in these regions today that many writers describe it as indigenous.

The new dominance achieved by Asian and above all American dyes such as indigo and cochineal, both of which were spread by European expansion, lasted less than two centuries. They, in their turn, were overwhelmed by the new coal tar or aniline dyes invented in the

mid-nineteenth century. Many of the natural dyes, however, remain in use in local and peasant economies.

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Earspools in Mexico

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Earspools (also known as earflares or earplugs) served throughout the pre-Columbian Americas not only as aesthetic devices but also as signifiers of social status. In the Postclassic Era, the act of piercing the earlobes of children was practiced among the Aztec during the quadrennial ceremony of *Izcalli* as part of a ritual program of events marking maturation (Sahagún, 1951a; Joyce, 2000, p. 479). The actual wearing of earpools, however, only began when an Aztec youth reached the status of adulthood in his or her mid-teens. Earpools in earlier contexts in the Basin of Mexico and in other parts of the pre-Columbian Americas may have served similarly to indicate adulthood or other aspects of social identity.

Often finely crafted, earpools could be fashioned from materials ranging from clay, wood, and shell to copper, gold, silver, and such stones as slate, obsidian, serpentine, jade, turquoise, and rock crystal. In Mexico earpools can be divided into four basic types: solid cylinders, rings, flared rings with closed throats, and composite forms. Technologies for producing earpools varied from hand modeling, molding, and assemblage to sawing, chipping, and abrading.

Although nearly all figurines excavated at Basin-of-Mexico formative-period sites depict

men and women wearing earpools, examples of these ornaments themselves have not been recovered in numbers consistent with the populations of these sites. George C. Vaillant (1930, p. 38) speculated that many formative-period earpools may have been fashioned from organic materials that disintegrated over time. Perishable materials were certainly employed to make earpools more than a thousand years later, as the sixteenth-century missionary Bernardino Sahagún (1951a, p. 151) noted Aztec men wearing wooden earpools painted to simulate turquoise.

Vaillant's report on excavations at Ticoman (1931, pp. 295–296) provides a concise typology and chronology of formative-period terracotta earpools in the Basin of Mexico. Early examples, typically measuring between 2 and 3.5 cm in diameter and 1–1.5 cm in width, were modeled by hand as solid cylinders with flattened faces and slightly concave sides (Fig. 1). Ranging in color from buff to black (the former fired in an oxidation and the latter a reduction atmosphere), they were sometimes slipped and burnished. Occasionally they were incised with simple linear or punctuate patterns, and rare examples were indented on one face. Color was added through pigments cold-applied to surfaces, since glazes were unknown in the pre-Columbian Americas.

Ring-shaped terracotta earpools, a second ear-ornament type appearing in formative-period Mexico, were modeled in clay from which all coarse inclusions had been carefully removed. Thin walled, these varied in shape from hollow

Earspools in Mexico,

Fig. 1 (L-R) Ring-type earspool, Nayarit, Mexico, black burnished terracotta 2.1 × 1 cm; solid incised earspool, Cuautitlán, Mexico, terracotta 3.5 × 1.6 cm; ring-type earspool, Cuautitlán, Mexico, terracotta with traces of pigment, 2.6 × 1.5 cm (Photo by Richard E. Brown)



cylinders with a slight concavity at the midsection to straight-sided cylinders with walls at both ends turned outward to form circular flanges. Such earspools resemble pulley wheels (Fig. 1). Occasionally the flanges were modeled, and in some cases, pigments were applied to the surfaces.

A third type of formative-period terracotta earspool found at Basin-of-Mexico sites (Vaillant's "ornate" type) consists of a hollow cylinder with an outward flare at one end. The throat of the flared end was closed to form a throat disk, a circular wall sometimes pierced with geometric openwork designs or carved with relief imagery. Too fragile for burnishing, such earspools were often coated with red slip or painted with red pigment. Associated with Late-Period Ticoman, these more ornate examples apparently did not render earlier types obsolete, though their appearance does correlate with a decline in numbers of solid terracotta earspools.

Stone could be used for earspools, though it was cumbersome to wear unless in thin-walled, hollow form. Methods of working stone among Aztec lapidaries were noted by Sahagún (1951b, pp. 80–82), but specific techniques no doubt varied somewhat by region, culture, and type of stone employed. Among the Maya, jade was favored for its hardness as well as its green color and surfaces that could be polished to a high sheen. In the Postclassic Era, Toltec and Aztec lapidaries fashioned translucent hollow-cylinder-type earspools from obsidian.

Tools of stone, wood, or even string, too soft to affect such materials as jade or rock crystal, could

be employed in a laborious process of working quartz sand or other finely crushed abrasives over surfaces. Sawing consisted of abrading the stone deeply enough so that wedges could be driven into the resulting grooves, forcing two sections to break from one another. The remaining septum, where the stone had not been sawn through, was abraded, possibly with a wooden tool or piece of leather coated in sand. Drilling was accomplished through the use of both solid (for small holes) and hollow bits. Though Sahagún mentions the use of metal drills among the Aztec, most bits were likely of stone, bone, or wood. Drilling with hollow bits was most often accomplished through biconical perforation, cutting equally from both sides of an object until the holes met and a core could be removed. Surfaces were smoothed with successively smaller grits of abrasives. According to Sahagún, Aztec lapidaries achieved a final polish using pieces of cane.

Composite earspools, the most complex variety, have been described at length by Kidder, Jennings, and Shook (1946, pp. 106–111). These generally consisted of four parts: a backing, stem, flare, and throat disk. Backings, thin circular disks of shell, slate, or wood, prevented earspools from slipping forward. Stems, hollow cylinders generally of perishable material, formed the axis embraced by the earlobe. Flares, fashioned either of stones such as jade or of perishable material faced with mosaics, formed the fronts, the parts most visible when earspools were worn. Circular throat disks of various materials could be inserted into the

throats of the flares, either for decorative effect or to secure the flares to the backings by means of a cord or tassel passing through both.

Much of what can be hypothesized about composite earspool construction, and indeed earspool use in general, has been acquired from figural sculptures, which document a variety of combinations of materials and forms. In fact, many artifacts identified as earspools, particularly miniatures or unusually large and heavy examples, may have been produced as appendages to sculptures rather than as ornaments for actual wear.

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Earth Structures of the Olmec

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The use of stone in prehistoric societies for sculptures and structures acknowledges its durability and strength, important qualities for symbolic

sculptures and structures. The value of stone was reinforced by the difficulty of working stone and by the logistics in obtaining the material, often from distant sites and over difficult terrain. Durability overcomes the ravages of weather and other destructive forces over millennia and this profile is in contrast with earth structures because most earth is relatively soft and can lack durability and strength. Nevertheless, the earth does have some advantages and prehistoric societies made good use of the material to hand if we know what to look for. Unlike stone structures, however, earth structures are not always understood for the thinking and knowledge that is being applied to their construction which requires a process of construction to achieve what are inherent properties of stone. As Olmec earth building demonstrates when analysis of the soil profiles and soils used is understood, we can appreciate how the limitations of earth building can be overcome (Fig. 1).

Preclassic Olmec Earth Structures

The known earth structures and stone sculptures show that Olmec (*Olmeca*) society in Preclassic Mesoamerica possessed the knowledge to work both stone and earth. Examples of both are found at San Lorenzo near Tenochtitlan in the modern Mexican state of Veracruz. Notable sculpture objects and statues demonstrate an accomplished understanding of the sculptor's art. Most outstanding among these are large stone heads known as Colossal Heads (*cabezas colosales*), anthropomorphic sculptures modelled on jaguars, and others with a distinctive baby face persona.

Also at San Lorenzo/Tenochtitlan is a prominent largely manmade plateau, some 750 m by 500 m built on an existing rise overlooking floodplains of the Rio Chiquito and Rio Coatzacoalcos. The structure, known as the San Lorenzo Plateau (SL), is complex in form and shape with different explanations being suggested for this. It is the second major and more recent earth structure in the immediate area. Within its perimeters, stone and occupational remains linked to different phases of



Earth Structures of the Olmec, Fig. 1 Showing location of San Lorenzo

florescence have been found. These indicate the site was the center of Olmec dominance between 1500 BC and 600 AD. Although the stone sculptures, in particular those known as the Colossal Heads, are the more recognized, the earth structures found here reveal another aspect of this society as do nearby earth causeways.

The SL plateau on which the heads were found is a natural feature to which earth has been added although survey data to establish its extent has been reviewed recently and this has redefined the perimeters. The manmade volume is estimated to be 67,000 cu.m at least, with the soil used probably transported by basket and perhaps involving 11,000 days, depending on manpower numbers for its construction. The Plateau indicates effective use of suitable soils and their placement by enabling it to still be an imposing feature on the Rio Coatzacoalcos floodplain some 3,000 years later. In addition on the plateau, excavations and a comprehensive coring survey has identified mounds, platforms, and courts.

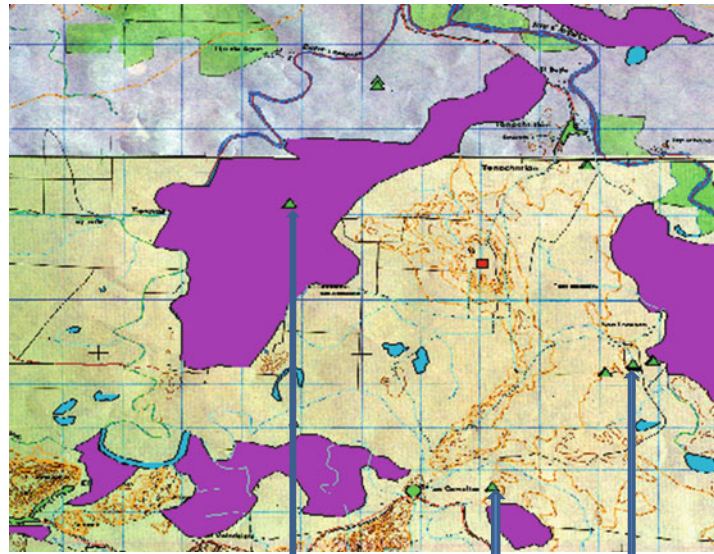
These structures add complexity to its mass and summit making earth use a significant component

of this society. More specifically this is understood more clearly when soil profiles of earth causeways near Loma del Zapote and Potrero Nuevo are used. The purpose of these is not understood, although flood mitigation embankments, docking for canoes, or using similar structures for the land transport of megaliths for the Colossal Heads is suggested by different researchers. Their durability means that essential structural elements of construction existed and are worthy of specific examination. While the causeways near San Lorenzo are described, another later Olmec complex at La Venta near Villahermosa in Tabasco State is also the site of significant examples of earth construction. These include the Fluted Pyramid and other structures described in detail by Drucker from his excavations undertaken in 1955 and his observation that Olmec soil engineering expertise was evident in their structures.

Even though their purpose is unknown to us, causeways are structural entities whose profiles are working examples of Olmec soil engineering. Soil types found in the coring survey of causeway structures by the San Lorenzo Tenochtitlan

Earth Structures of the Olmec, Fig. 2

San Lorenzo area (Hazell, 2008). *Green triangles* indicate coring sites mentioned in the text, *purple* areas are floodplains, and central *red square* pinpoints the San Lorenzo Plateau summit area



Floodplain cores

Natural levee cores

Potrero Nuevo Causeway Cores

Project 08 [SLTP08] (Hazell, 2008) (see Fig. 2) adopted a standard soil classification protocol through laboratory analyses. The protocol tested individual soils, combinations of these as mixtures, or in profile layers. These tests were undertaken to establish compressive resistance rating, compaction capability, and hygroscopic properties and so structural properties. All elements inferred Olmec soil knowledge and the difference between soil as an indicator of archaeological chronology, agricultural material, and an engineered entity which was reinforced by soil physical characteristics under specific environmental conditions.

Soil Use in Theory

Relevant to our understanding of Olmec expertise is the appreciation of soil mechanics or soil engineering as we understand it. These principles consider the physical properties of soils and how they behave which can then be applied to their earth structures.

Physical Properties of Soils

Specific and relevant characteristics and behavior for this research can be broadly summarized as permeability and compaction properties. These elements are a product of composition, in particular, grain size, shape, type, and distribution of these particles. The presence of voids between particles can allow moisture penetration, while the absence of voids will prevent penetration depending on particle shape. Related to this behavior is the action of individual particles to attach to or slip against their neighbors. This is a component of composition and forms the relationship between voids, grain size, shape, distribution, and type which induces the behavior that allows compaction. Compressive resistance or load-bearing capacity and durability are functions of this. Load-bearing properties can often be defined by differences identified between the structures of non-cohesive and cohesive soils. Cohesion, as a component of friction, provides resistance to movement or changes in relative position of particle grains within the whole mass.

This is illustrated with examples of different soil types. Silt deposited by flood water or normal river flows is composed of particles generally with the same size and type that in a natural state of repose have no voids. Its composition therefore allows the passage of moisture due to capillary action and decreases frictional resistance allowing movement of the particles away from an applied load, such as a footstep. Behavior of this nature is reflected in its low compressive resistance rating of 20 kpa. With common sand, moisture can also readily penetrate and seek the lowest point of penetration possible because the particle type, shape, size, and distribution and contribute to the creation of voids which prevent moisture retention. However, should the voids be filled with water, this will allow the grains to grip, but once saturation is reached the soil will flow (Means and Parcher, 1963). This occurs with sand at the beach or with silt on a river bank. In practice this means the water is taking any applied load, not the soil material. The moisture is squeezed under load and so deforms. Thus, the capability of soil to be compacted determines durability and load-bearing capacity achieved by increasing its resistance to moisture penetration.

Another soil type, clay is generally made up of fine, flat, and scale-like particles and in its normal state this allows little moisture penetration or absorption. Yet this small amount of moisture allows slip between the particles creating a higher level of density or by bending of the particles. In comparison gravel or gravelly soils are usually made up of larger or coarse particles with random shape, thus creating many voids, allowing moisture penetration but limiting compaction or compressibility, because of minimal shear resistance. This state allows individual particles or grains to slip easily past each other. Its resistance to doing so determines compressive strength but is dependent on compaction capacity for strength and also durability. If particles vary in shape and size, then a greater degree of compaction is possible or a mixture with different soil types. When these contain smaller particles, their shape and size will assist compaction through shear resistance. The same principle applies if

sand or clay were to be mixed with coarser particles. This combination increases compaction by limiting the degree of moisture penetration, which in turn increases compressive resistance, and being denser with associated increased moisture resistance: this contributes to its durability.

These are broad soil engineering principles associated with major soil categories defined by their mechanical behavior. They underwrite earth or soil as a viable structural medium. Engineering defines structural limitations imposed by singular soils: combining the soils allows those limitations to be overcome. The soils discussed are found in the area of the San Lorenzo Plateau, while variations in texture, grain types, particle shape, and mineral type were found in the PN causeway. Cores taken by the SLT08 survey from the Loma del Zapote causeway were used to analyze the structure and confirmed the presence of artificial soil layers. Such a profile would support megalith transport or make these suitable for the possible uses previously suggested. Core results also defined differences between natural terrain features such as river levees and floodplains found in the area and those of the PN causeway. This contrast highlighted Olmec application of soil properties to suit their earth structures, needed by the limitations of the basic soil types and which were necessary for such basic earth structures and a requirement acknowledged for such structures.

Factors other than engineering elements also determine construction material use and includes "...ease of transport, seasonal availability durability and engineering knowledge..." (Cyphers, 1997). Analysis of soils found, underwrites the first two while justifying soil selection from types available in the area, choices that suit construction constraints.

San Lorenzo Area Soils

An early survey, Rio Chiquito Project San Lorenzo Technochtitlán, (Coe & Diehl 1965–68) of this area of San Lorenzo, identified four soil types. The first, Coatzacoalcos series or *tierra de primera*, is found on river levees. They are important agricultural soils. They are usually

organic silts and soft clays; moisture content is high, with predominately fine grain distribution. The second soil is found above the flooding contour of the plateau and is known locally as *tierra de barreal*: it is a primary agricultural soil, being cultivated year round in modern times. It is sandy or sand mixed with clay. A third classification is known as *tierra de grava* and identified as Tatagapa series soils. They are clay and difficult to cultivate. These were natural categories found in the area, while a fourth classification includes artificial soil(s) found on the San Lorenzo plateau used on mounds and platforms. It is of interest that this survey identified a distinctive structural soil. Cores taken by the SLTP08 survey from the PN causeway held profiles that were different in pattern and soil types to those from natural soil cores such as floodplains or natural levees.

Soil Profiles

Natural Soil Features, Floodplains, and River Levees

Core survey transects taken by SLTP08 included nearby floodplains, lagoons, and swampy areas that flood annually. From these cores (cores 17 and 18), a number of specific characteristics were noted. Typically core 17 had repeated layers of a brown sandy slime (Limo Arenosa Café). Below these layers of colored Arcilla (clay) mixtures, made up of fine grain particles similar in grain size and type were found. The soil type and pattern of this soil layer can be attributed to deposits from seasonal flooding so classifying the feature as natural. It is a profile, typical of the geomorphic process also found elsewhere.

The profile in levee core 18 also held variations of fine clay/sand mixtures (Arcilla Arenosa Café Oscuro, Arcilla Arenosa Gris) throughout the profile as expected with its low position. In this strata though, the profile was overlaid with a mud layer (Barro Amarillo Veteado) that was described as dark in color, fine silt, or grain particles having some organic material present. Adjacent to this bank was a water filled lagoon or *laguna*, distant from the nearest watercourse indicating flooding in the area.

Of the flood plain cores, core 12 typified other profiles found in the SLTP08 survey with some having a gravel base at water level overlaid with fine gray sand and clay. Again geomorphic processes explain the fine sands and silt at upper levels, while at the lower levels being coarse, gray sand particles are heavier, so will be at the deeper levels. As natural layering, these profiles can be compared with those profiles of artificial structures to define the entities and the reason for artificial profiles. Causeways as a functional entity even if their precise purpose is unclear provide useful analytical data.

Soil Profiles in Olmec Causeway Structures

Causeways are defined as being raised and built roadways, distinct from cleared tracks or formed pathways created by repeated use. Importantly in many instances they connect centers and so form trade networks and underscore political control and military functions. The Olmec earth causeways are among the earliest in Mesoamerica, but they are not the only examples in Mesoamerica. Maya causeways or roads known as white roads or *sacbeob* made up of boulders and smaller grades of these with a lime plaster surface layer are a notable example. Preclassic Olmec earth causeways though, in spite of an uncertain purpose, illustrate a deliberate structural profile. The following strata profiles show the engineering element of the Olmec earth structures.

At Tenochtitlan, near the San Lorenzo Plateau, two causeways have been found with a third reported, although not located in recent times. The known Loma del Zapote earth causeways are between 750 and 600 m long and between 60 and 75 m wide. Notably for its durability, the modern village of Potrero Nuevo (PN) has been built on one causeway. The PN causeway extends across the adjacent floodplain for some 600 m and is some 75 m in width. Cores were taken where the causeway connects a prehistoric river course, now a backwater or extended lagoon, to rising and undulating ground. At this point the causeway is only a few meters above the adjoining floodplain and significantly so above the lagoon bed. The source for the soils to build this structure was not determined, but the profile consisted principally of

layers where Arena (sand) was the primary soil type with a clay mixture. In this core a sandy gravelly mixture (Arena Y Gravilla Café Amarillento) not found in other causeway or natural levee cores was also noted at the lowest level. Recalling earlier notes on soil behavior and its structural limitations, these sandy clay mixtures overcome limitations of broad soil types by facilitating compressive resistance through an increased shear resistance. This behavior improves compaction capacity by reducing the profile permeability.

Along the causeway changes from later Olmec occupation are probable as are those resulting from the modern settlement of Potrero Nuevo. Here the causeway is above the adjoining lagoon/watercourse and on the opposite face, extensive floodplains. Of the survey series, core 8 taken on the upper face of the PN formation sampled the deepest part of the cross section and embodied the most construction effort and soil selection needed to build what is visible today. Clearly in evidence were repeated layers of Arcilla Café Grisáceo (grayish brown sand) and also Arcilla Gris (gray clay). This pattern did not occur in natural levee cores and also indicated that a specific soil was preferred on this causeway face. Lower levels held alternating layers of Arcilla Gris (gray clay) and Arena (sand) types.

The repeated layers of Arcilla Café Grisáceo (grayish brown clay) interspersed with Arcilla Arenosa Café Anaranjada (orange brown sandy clay) and a mineral floor provide a cohesive link between different soils types. This allows the soils to act mechanically in combination to produce a specific spectrum of properties. This spectrum includes durability resistance to water penetration and the capacity for compaction leading to improved compressive resistance. The same outcome is achieved with the repeated layers of Arcilla Gris or gray clay over the lowest level of gray sand. The durability achieved is reflected in the causeway being clearly identifiable over most of its length. This is also reinforced by the confidence shown in its stability with modern village dwellings and other structures built along much of its length. Therefore, as an embankment the profile is valid and this could

meet for the load-bearing requirements of megalith transport as established by laboratory tests.

These tests also indicated a clear disparity in compressive resistance values between wet and dry states of the various soils. This characteristic underwrites the importance of either resisting water penetration or creating a profile that allows moisture to disperse from those layers whose intrinsic structure will provide strength, stability, and durability. Compressive values found indicate that the PN causeway would be overengineered as a megalith transport route whose basic requirement would be durability as well as compressive resistance.

The soils would be capable of meeting the needs of megalith hauling when dry depending on the method used. Calculations suggest a sled carrying a load in excess of 25 tonnes would apply a pressure of 314.9 kPa but when wet, this value exceeds the compressive resistance capacity 7 kPa according to the core profile taken and tested. As a further comparison natural river levees composed of Arcilla (clay) under test indicate the levee compressive capability when wet was 663 kPa also capable of carrying megalith loads.

Therefore, why did the Olmec build such a strong (in all senses of the word) structure? A natural levee was capable of carrying a load, but is vulnerable to floodwater erosion as these actions are what create the levee. It could not resist the impact of repetitive trade activities when wet and its position may not have suited a megalith transport route, both reasons why an engineered structure would be needed. Reviewing possible uses for engineered structures and their soil profiles suggests the suitability of the known causeways to resist flooding impact. Such structures are also durable under the seasonal imposts of flooding. As a flood embankment a causeway would need moisture resistance to maintain a stable wall against floods or as a jetty where the same attributes are needed. Soil engineering theory notes the respective properties of Arcilla (clay) and Arena (sand) providing moisture resistance on the one hand or permeation on the other, but in combination they will do both, thus establishing a durable structure. This attribute would be of benefit for

a trade pathway where durability to sustain high traffic levels and moisture resistance to provide a stable base underfoot is needed.

If this was not necessary, why put functional layers into the causeway when plentiful and easily accessible supplies of soils that had compressive resistance values suitable for megalith transport would have performed the same or similarly? Based on volumes involved to establish the plateau and causeways, layer selection suggests use defines purpose and so the structures are engineered accordingly. When this argument is applied to floodplain soils, these are predominantly silts or Barro Veteado (mud) and would not be suitable for flood embankments or as permanent trade route pathways. As a megalith transport roadway, if this material was used, its compressive resistance value is not suitable when wet (8 kPa) although when dry its capability (163 kPa) is comparable to both Arcilla (wet 8 kPa/dry 135 kPa) and Arena (wet 8 kPa/dry 89 kPa). By its nature this soil is unstable due to moisture penetration and so lacks durability. But as a material for temporary causeways for occasional use, this soil would be suitable when dry. This vulnerability underwrites the attributes of the PN causeway.

The presence of the PN causeway after millennia justifies taking note of its construction for this reason. Layering found in core 8 and other causeway cores 15, for example, appear to be in direct response to a specific purpose where the profiles found suit either transportation, jetty, or embankment options. As the PN causeway does not appear to be sited in direction or position between stones sources and final sites, then megalith transport pathways are less valid as an explanation than the embankment or jetty option Cyphers has suggested (Cyphers 1997).

The comparison between natural levees and Loma del Zapote causeway has shown different strata profiles. However, this could be explained by availability, proximity, and quantities needed. An example is Barro Amarillo Veteado (streaked yellow mud). Analyses of soils found during coring from sites both natural and artificial had shown this was the most frequently noted soil type. This soil was found in 15 cores of the

18 cores taken and in some cases in multiple layers and across a range of features besides causeways. Thus, its proximity to earth structures in the quantities needed and a soil type renewed annually due to seasonal flooding could explain its frequency. It is also able to be worked and transported when wet. When dry it holds its form: however, as a singular fine grained material, it is easily dispersed when wet and lacks durability under traffic use, a limitation of those survey soils subjected to compressive resistance tests. Barro Amarillo Veteado when dry has a comparable compressive resistance and when wet only a small fraction of this capability.

Layering that includes Barro Amarillo Veteado as seen in profiles can also be explained by maintenance activity and its availability. Ease of working and transport makes it appropriate for the purpose.

With the selective use of soils present in repeated layers of soils possessing compatible or properties and complimentary behavioral characteristics that overcome functional limitations such as durability and strength, elements of soil engineering are implicit in the construction of the causeway.

Concluding Discussion

This analysis applied a methodology able to examine Olmec earth structures and match soil properties found in their construction to possible uses of the structure. These are important elements of earth engineering, as the structure must perform regardless of its purpose even if only as a barrier. At the very least it must support its own weight besides applied or live loads. This property can be established by laboratory compressive resistance tests. Results have shown differing levels of compressive resistance between wet and dry and between levee and causeway soils. Profiles identified in the PN cores with these characteristics can be used as a model for further research. Use of certain soils for the causeways is defined by soil behavior and is demonstrated in known causeways from samples obtained in SLTP 08 survey cores.

The presence of hitherto undiscovered earth structures is often suspected, but without other archaeological evidence, soil profiles become useful tools for future surveys. At La Venta earth structures associated with the Fluted Pyramid were examined and reported on by Heizer and Drucker in which Drucker acknowledged both the soil usage and engineering knowledge of the Olmec. La Venta though, being occupied between 900 BC and 400 BC, was preceded by San Lorenzo (1150–900 BC). As the earlier site, the engineering knowledge associated with San Lorenzo is potentially more significant for understanding the influence the Olmec had in its so-called heartland and arguably validity in its being known as the Mother Culture in Mesoamerica. Their earth structures, such as the causeways, the San Lorenzo Plateau, and later the Fluted Pyramid at La Venta, are part of this influence.

This article looked at Olmec causeways, but in prehistoric or more recent societies, examples of known earth causeways and other related structures including roads have also been analyzed or examined in detail by researchers as the further reading list shows.

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East and West

Edwin J. Van Kley

As traditionally used in the West, the terms East and West imply that the two are somehow of equal importance. While that might be arguable in the nineteenth and twentieth centuries it was certainly not true during the long reaches of human history prior to the nineteenth century. By 500 BCE the globe supported four major centers of civilization: the Chinese, the Indian, the Near Eastern, and the Western, considering Greek culture antecedent to what eventually became the West. Of the four the West was probably the least impressive in terms of territory, military power, wealth, and perhaps even traditional culture. Certainly this was the case after the fall of the Roman Empire in the fifth century AD. From that time until about AD 1500 the West probably should be regarded as a frontier region compared to the other centers of civilization.

From roughly 500 BCE to AD 1500 a cultural balance was obtained between the four major centers of civilization. During these millennia each center continued to develop its peculiar style of civilized life, and each continued to spread its culture and often its control to peoples and lands on the periphery. While the inhabitants of each center of civilization were aware of the other centers, sometimes traded with them, and occasionally borrowed from them, the contacts were sufficiently thin so that no one center threatened – commercially, militarily, politically, or culturally – the existence of the others. During this long period, that is through much of civilized human history, there was no question of Western superiority or hegemony. No visitor from Mars would likely have predicted that the West would eventually dominate the globe.

Obviously the Greeks and Romans knew quite a bit about the Near-Eastern world, especially about the Persian empire, that of Alexander the Great, and the successor states formed after its

collapse. About India and China they knew much less, and what they knew was much less accurate. Although Herodotus (ca. 484–425 BCE) reported some things about India, most of the information available to the Greeks came from the writers who described Alexander's campaigns in the Indus Valley (326–234 BCE) and from Megasthenes. They described India as fabulously rich, the source of much gold and precious stones. It was hot; the sun stood directly over-head at midday and cast shadows toward the south in summer and toward the north in winter. They described huge rivers, monsoons, tame peacocks and pheasants, polygamy, and the practice of *suttee* (widow burning). However, they also reported fantastic things such as gold-digging ants, cannibals, dog-headed people, and people with feet so large that they served as sun shades when sitting. The Romans knew that India was the source of spices and that China, which they called *Serica* and well as *Sinae*, was the source of silk. There are even possible traces of Asian influence in some Roman silver and ivory work and perhaps even some influence of Buddhism on Neo-Platonism and Manichaeism.

From about the fourth century, even before the fall of the Roman empire, until the return of Marco Polo from China in the late thirteenth century, Europe or the West added little factual information to its understanding of India and China. After the fall of the Roman empire there was no direct trade between Europe and Asia, and thus there were no opportunities to test the stories by observation. The rise of Islam in the seventh and eighth centuries completed Europe's isolation. During these centuries the old stories inherited from the Greeks were retold and embellished with little effort to distinguish fact from myth. To these were added three legends of more recent origin: the stories celebrating the heroic exploits of the mythical Alexander; those rehearsing Saint Thomas the Apostle's missionary journey to India and his subsequent martyrdom; and those describing the rich, powerful, Christian kingdom of Prester John somewhere to the east of the Islamic world with which European rulers dreamed of allying against the Muslims. Even the trickle of precious Asian

products brought to Europe by intermediaries seemed only to confirm the image of Asia as an exotic and mysterious world, exceedingly rich and exceedingly distant.

The rise of the Mongol empire in Asia during the thirteenth century resulted in direct overland travel between Europe or the West, and China. The Mongols' success also revived hopes among European rulers of finding a powerful ally to the east of the Muslims. Even the devastating Mongol incursions into Poland and Hungary in 1240 and 1241 scarcely dampened their enthusiasm. Already in 1245 the pope sent an embassy led by John of Plano Carpini to the Mongol headquarters near Karakorum. He was followed during the ensuing century by a fairly large number of envoys, missionaries, and merchants, several of whom wrote reports of what they saw and did in Eastern Asia. Marco Polo's was the most comprehensive and reliable, and the most widely distributed of the medieval reports. By the time the Polos first arrived at Kublai Khan's court in 1264 it was newly established at Cambaluc (Beijing), from which the khan ruled the newly conquered Cathay (China). Like many other foreigners during the Mongol period (the Yuan Dynasty in China, 1260–1368) the Polos were taken into the khan's service. They were employed in the Mongol administration for 17 years during which time Marco traveled extensively throughout China. On his return to Europe he produced the first detailed description of China in the West based primarily on first-hand observation and experience. No better account of China appeared in Europe before the middle of the sixteenth century. Marco Polo described China as the wealthiest, largest, and most populous land in the thirteenth-century world. While his understanding of Chinese culture was minimal he accurately and admiringly described cities, canals, ships, crafts, industries, and products. He noted the routes, topography, and people encountered in his travels, including his voyage home through Southeast Asia to Sumatra, Ceylon and along the west coast of India.

The decline of the Mongol empire and the establishment of the Ming Dynasty in China in 1368 severed the direct connection between

Europe and China. The fall of Constantinople in 1454 and establishment of the Turkish empire in the Near East disrupted the older connections between Europe and the near East and India. Europe's isolation from the outside world was complete, not to be restored until the opening of the sea route around the tip of Africa in the waning years of the fifteenth century. During this period no European appears to have traveled to China. Some few travel reports refer to India and Southeast Asia. Of them only that written by the humanist Poggio Bracciolini in 1441 and based on Nicolò de Conti's travels added to the West's store of knowledge about India and confirmed some of the more accurate of the ancient Greek reports. In fact amid the Renaissance humanists' enthusiasm for the rediscovery of ancient Greek literature, the Greek reports of India received new respect and attention.

During the long era of cultural balance before AD 1500 many important technological and scientific inventions and innovations appear to have migrated to the West from the other centers of civilization, more often from China than from the others. The migration of technology was usually gradual, involving one or more intermediaries, the inventions usually being established in the West without any clear ideas about their origins. Much of the basic technology that enabled the Europeans to sail directly to Asia in 1500 and later to begin their march towards global domination, was known earlier in the Asian centers and only later adopted or separately invented in Europe.

Among the more important technological borrowings were ► [gunpowder](#), the magnetic compass, printing, and paper, all apparently originating in China. For none of them is the path of migration entirely clear, and thus for none of them can the possibility of independent invention be entirely ruled out. Gunpowder, for example, was known in China by 1040 and did not appear in Europe until the middle of the thirteenth century. The magnetic compass was fully described in an eleventh-century Chinese book, *Meng Qi Bi Tan* (Dream Pool Essays), written by Shen Gua in 1088. It began to be used in Europe during the late twelfth or early

thirteenth century. Most likely Europeans learned about it from the Arabs. The case for moveable-type printing having been borrowed from the Chinese is more hotly debated than that for gunpowder or the compass. Wood-block printing was used in China by the seventh century, and paper was invented much earlier; the first printed books appeared there during the ninth century, six centuries before the invention of printing in the West by Johannes Gutenberg in 1445. Block printing probably became known in Europe through the introduction of printed playing cards and paper money during the Mongol period; medieval travelers frequently mentioned these. Because of the large number of Chinese characters the Chinese continued to prefer printing from page-sized blocks of wood carved as a single unit; European printing almost immediately employed moveable type, thus convincing some scholars that it was a separate invention. However, while they may have preferred block printing the Chinese also developed moveable type as early as the eleventh century. For none of these basic inventions taken separately – gunpowder, the compass, and printing – is the case for its diffusion from China to Europe indisputably demonstrated. Taken together, however, along with a rather large number of other technological and scientific innovations such as paper, the stern-post rudder, the segmented-arch bridge, canal lock-gates, and the wheelbarrow, which all appear to have migrated from China to the West, it becomes apparent that the general flow of technology and science in premodern times was from East to West. This would seem to increase the likelihood that these basic innovations also migrated to Europe from Asia. Those who used the technological innovations probably cared little about their ultimate origin and apparently did not seek it out. Nevertheless European mariners after 1500, confronted first hand with evidence that printing, gunpowder, the mariner's compass, and the like had been in use much longer in Asia than in Europe, frequently suggested that they had been borrowed from the Asians.

Even before gunpowder a group of military innovations found their way to Europe from China and India, again through intermediaries

and apparently without Europeans' being aware of their origins. The Chinese form of the Indic stirrup was the most important of these and may have been as important to military development in the eighth century as ► [gunpowder](#) was later. The Javan fiddle bow and the Indian Buddhist pointed arch and vault were acclimated in Europe before 1100. The traction trebuchet along with the compass and paper appeared in the twelfth century. Still more important for subsequent Western scientific achievements was the adoption of Hindu-Arabic mathematics in the twelfth and thirteenth centuries: the Indian system of arithmetical notation, trigonometry, and the system of calculating with nine Arabic numbers and a zero were all practiced in India as early as AD 270. Some components of Indian mathematics may have come from Babylonia or China. They came to Europe, however, through the translation of Arabic writings, and the European borrowers usually credited India rather than China, Babylonia, or the Arabic intermediaries as the source of the new mathematics. Along with Indian mathematics, Europeans learned some elements of Indian astronomy and also became fascinated with the Indian idea of perpetual motion.

Also before 1500, Europeans sometimes attempted to imitate desirable Asian products, not always successfully. Already in the sixth century the Byzantine emperor Justinian monopolized the silk trade in his realm and expressed his determination to learn the secret of its manufacture. In 553 a monk supposedly smuggled some silkworm eggs into Constantinople carrying them in a hollow stick, perhaps of ► [bamboo](#). Nothing is said in the story about the importation of silk technology, but less than a century later sericulture had obviously taken root in Syria. From there it spread to Greece, Sicily, Spain, Italy, and France. In Italy during the fourteenth century, water power was used in silk spinning, as it had been used in China much earlier. Attempts to imitate Chinese porcelain, however, were unsuccessful. The best attempts to do so were made in northern Italian cities during the fifteenth century. None, however, approached Chinese porcelain in composition, color, or texture. Nor did the Dutch Delftware of

the seventeenth century, another attempt to imitate the Chinese product. Not until the eighteenth century were European craftsmen able to produce a hard-paste porcelain to rival that of China. Also appearing in Europe before 1500 were less important devices or techniques such as the Malay blowgun, playing cards, the Chinese helicopter top, the Chinese water-powered trip-hammer, the ball and chain governor, and maybe Chinese techniques of anatomical dissection.

While impressive, the West's importation of Asian science and technology before 1500 in no way deflected Western culture from its traditional paths. Seldom was the provenance of the new inventions or techniques known, and they could all rather easily be incorporated into the traditional Christian European world-view. They did not provoke any serious questions about the European way of life, its religious basis, its artistic and cultural traditions, or even its traditional scientific views. This is also true for the artistic and cultural borrowings from Asia prior to 1500. They too were often unconscious, and even when they were not they were regarded as embellishments or decoration, rather than in any way a challenge to traditional themes. For example, the incorporation into the Christian calendar of Saints Baarlam and Josephat, derived as they were from stories of the life of Buddha, resulted not in a Buddhist challenge to the Christian faith but simply in the addition of two new saints to the growing Christian pantheon.

Nevertheless, the borrowing and adaptation of Asian science and technology by the West before 1500 was indispensable in making the long overseas voyages to Asia and the protection of the ships and shore installations possible. Without ► [gunpowder](#), cannons, the compass, the stern-post rudder, etc. there would have been no European expansion. While they had lagged well behind the other centers of civilization through most of civilized history, by 1500, European marine and ► [military technology](#) were beginning to equal that of the Near East. India, and China, and were obviously superior to that of the peripheral areas of Africa, Southeast Asia, and the Americas. The Portuguese voyages down

the coast of Africa and Columbus' voyage across the Atlantic attest to Europe's rapidly improving technology.

A small Portuguese fleet under Vasco da Gama reached Calicut on the Malabar Coast of India in 1498, thus establishing direct contact between Europe and Asia by sea and also inaugurating a new era in the relationships between the four major centers of civilization on the globe. Soon after 1500 the Europeans began to dominate the seas of Asia, the Portuguese in the Indian Ocean being the first. The Portuguese, and later the Dutch and the English, moved along sealanes, visited seaports, and fitted into a trading world which had been developed earlier by Muslim traders and which stretched from eastern Africa to the Philippines. As the Europeans at first tried to compete in that world and later tried to dominate and even to monopolize it, they found Muslim merchants and merchant-princes to be their most formidable opposition. That they were able to move so rapidly and effectively into that international trading system was due not so much to their superior technology and fire-power as to the fact that the great Muslim empires of the sixteenth century – the Ottoman Turkish, the Safavid Persian, and the Mughul in northern India – seem to have been too busy consolidating their newly won empires to contest the European intrusion. These Muslim empires, as well as the Southeast and East Asian empires of Siam, Vietnam, China, and Japan had all as a matter of governmental policy turned away from the sea and looked inward to control of their land empires and to land taxes as the source of their wealth and power. Had any or all of these major Asian and Near-Eastern states seriously resisted the western incursion the story might have had a different conclusion. Apart from Muslim traders in the Indian Ocean those who formidably opposed European power in the sixteenth and seventeenth centuries were small Muslim commercial port-city states like Makassar on Celebes and Aceh on Sumatra. The Mughul emperors in northern India usually allowed the Europeans to trade freely in their ports, often exempting them from customs duties. Apart from the illegal but locally tolerated Portuguese settlement in Macao

the Europeans were not permitted to trade in China at all. China briefly contested Dutch maritime power only in 1624 after the Dutch had spent 2 years raiding the coast of Fukien Province, burning villages, seizing junks, enslaving their crews, and constructing a fort on one of the Pescadores Islands; all in an effort to force the Chinese to allow them to trade freely at some port along the Chinese coast. Confronted with a full scale Chinese war fleet the Dutch commander hastily sued for peace and gratefully accepted the Chinese admiral's offer to let the Dutch trade on Formosa, which was not yet considered Chinese territory. From 1500 until about the middle of the eighteenth century the Europeans were able to carve out empires in the Americas, insular Southeast Asia, and the Pacific Islands, but they did not threaten the major centers of civilization in Asia.

During the first three centuries of direct maritime contact between Europe and Asia (1500–1800) the Westerners showed little sense of cultural superiority toward the high cultures of Asia. If anything they tended to exaggerate the wealth, power, and sophistication of the other centers of civilization. Most Europeans were confident that Christianity was indeed the true religion, and they quickly began to send missionaries to convert Asian peoples. By 1600, if not earlier, they were also justifiably confident that European mathematics, science, and technology were superior to that of the Asians. Those areas aside, however, Europeans were endlessly fascinated with what they discovered beyond the line and realized that they still had much to learn from the high cultures of Asia. Between 1500 and 1800 the currents of cultural influence continued to flow mainly from east to west, but during this era the impact of Asia on the West was usually more conscious and deliberate than previously, and it was primarily in areas other than science and technology.

The new seaborne commerce with Asia almost immediately brought greatly increased quantities and varieties of Asian products into Europe. Pepper and fine spices were the first to appear on the docks in European ports, but they were soon followed by such goods as Chinese porcelain and lacquerware, tea, silks, Indian cotton cloth,

and cinnamon. Following these staples of the trade came also more exotic products: Japanese swords, Sumatran or Javanese krisses, jewelry, camphor, rhubarb, and the like, the list is very long. Some of these products, such as tea, provoked striking social changes in Europe. Attempts to imitate others resulted in new industries and in new manufacturing techniques, Delft pottery in imitation of Ming porcelain, for example. Attempts to compete with cheap Indian cotton cloth seem to have touched off a technical revolution in the British textile industry which we customarily regard as the beginning of the industrial revolution.

Along with the Asian products came descriptions of the places and peoples who had produced the products. The earliest sixteenth-century descriptions usually seem designed to inform other Asia-bound fleets about the conditions of trade. After Christian missions were established they were often intended to elicit support for the missionaries. However, before long the travel tales and descriptions became popular in their own right and profitable to publish. During the seventeenth century what had been a sizeable stream of literature about Asia became a veritable torrent. Hundreds of books about the various parts of Asia, written by missionaries, merchants, mariners, physicians, soldiers, and independent travelers were published during the period. For example, during the seventeenth century alone there appeared at least 25 major descriptions of South Asia, another 15 devoted to mainland Southeast Asia, about 20 to the Southeast Asian archipelagoes, and 60 or more to East Asia. Alongside these major independent contributions stood scores of Jesuit letterbooks, derivative accounts, travel accounts with brief descriptions of many Asian places, pamphlets, newsheets, and the like. Many of the accounts were collected into the several large multivolume compilations of travel literature published during the period. In addition to the missionaries accounts, travel tales, and composite encyclopedic descriptions, several important scholarly studies pertaining to Asia were published during the seventeenth century: studies of Asian medicine, botany, religion, and history; and translations of important Chinese and Sanskrit literature.

The published accounts range in size from small pamphlets to lavishly illustrated folio volumes. They were published in Latin and in almost all of the vernaculars, and what was published in one language was soon translated into several others, so that a determined enthusiast could probably have read most of them in his own language. They were frequently reprinted in press runs which ranged from 250 to 1,000 copies. Five to ten editions were not at all uncommon, and some of the more popular accounts would rival modern "best sellers." In short the Early Modern image of Asia was channeled to Europe in a huge corpus of publications which was widely distributed in all European lands and languages. Few literate Europeans could have been completely untouched by it, and it would be surprising if its effects could not have been seen in contemporary European literature, art learning, and culture.

From this literature European readers could have learned a great deal about Asia and its various parts. Perhaps most obviously their geographic horizons would have been continually expanded. Gradually Europeans gained accurate knowledge about the size and shape of India, China, and Southeast Asia. During the seventeenth century, for example, several puzzles which had plagued earlier geographers were solved: for example, the identification of China with Marco Polo's Cathay, the discovery that Korea was a peninsula and Hokkaido an island. By the end of the century Europeans had charted most of the coasts of a real Australia to replace the imagined antipodes as well as those of New Guinea, the Papuas, numerous Pacific islands, and parts of New Zealand. Interior Ceylon and Java, as well as Tibet were visited and accurately described by Europeans before the end of the century. By 1700 only areas of continental Asia north of India and China, the interior of Australia, New Zealand, and New Guinea and parts of their coastlines remained unknown to the Europeans. Most of these lacunae were filled during the eighteenth century. Even more impressive than the greatly expanded geographic knowledge available to European readers in early modern times was the rapidly increasing and increasingly

detailed information about the interiors, societies, cultures, and even histories of Asia's high cultures. Already during the seventeenth century European readers could have read detailed descriptions and even viewed printed cityscapes and street scenes of scores of Asian cities, interior provincial cities as well as capitals and seaports, and they could have learned countless details about Asia's various peoples, their occupations, appearance, social customs, class structures, education, ways of rearing children, religious beliefs, and the like. Details regarding Asia's abundant natural resources, crafts, and arts were described as well as its commercial practices and patterns of trade. Asian governments were described in exceedingly close detail, especially for major powerful states such as China, the Mughul Empire, Siam, and Japan. Jesuit missionaries in China, for example, described the awesome power of the emperor, his elaborate court, the complex imperial bureaucracy and its selection through competitive written examinations, and the Confucian moral philosophy on which it was all based. They also described the frequently less orderly and less savory practice of Chinese government, complete with detailed examples of officials' abuse of power and competing factions within the administration. Similar details were reported for the governments of all the major states as well as for countless smaller states. By the end of the seventeenth century European observers had published many sophisticated accounts of Asian religions and philosophies; not only the frequently deplored Hindu "idolatry" and widow burning, but also the Hindu world view which lay beneath the panoply of deities and temples, the various schools and sects of Hinduism, and the ancient texts of Hindu religion. Similarly sophisticated and detailed accounts of Confucianism and Buddhism were available, as well as descriptions of the beliefs of peoples like the Formosan aborigines, the Ainu of Hokkaido, and the inner Asian and Manchurian tribes. Seventeenth and eighteenth-century readers could also have learned much about Asian history; especially, but not exclusively, that of Asia's high cultures. By the mid-seventeenth century, for example, a very detailed

sketch of China's long dynastic history culled from official Confucian histories by Jesuit missionaries had been published. Martino Martini wrote the *Sinicae historiae decas prima*, which was published in Munich in 1658. During the eighteenth century an important Chinese history, the *Tongjian Gangmu* (Outline and Details of the Comprehensive Mirror [for aid in government]) by Zhu Xi, was translated into French in its entirety by Joseph-Anne-Marie de Mailla and published in Paris (*Histoire générale de la Chine*, 1777). Not only history, however, but also news was reported to Early Modern readers. Their image of Asia was surely not that of a static world far away. Among the more important events reported in almost newspaper-like detail during the seventeenth century alone were the Mughul emperor's successful campaigns in the south of India, the Maratha challenge to Mughul supremacy, the fall of the Indian states of Golconda and Vijayanagar, the Manchu Conquest of China in 1644, the feudal wars and the establishment of the Tokugawa shogunate in Japan (1600), and the internal rivalries and wars in Siam and Vietnam. Natural disasters such as earthquakes, fires, volcanic eruptions, and the appearance of comets were also regularly reported. Readers of this richly detailed, voluminous, and widely distributed literature may well have known relatively more about Asia and its various parts than do most educated westerners today.

The post-1500 literature on Asia also contains a great many descriptions of Asian science, technology, and crafts: such things as weaving, printing, papermaking, binding, measuring devices, porcelain manufacture, pumps, water-mills, hammocks, palanquins, speaking tubes, sailing chariots, timekeepers, astronomical instruments, agriculture techniques and tools, ► [bamboo](#) and other reeds for carrying water, as well as products such as musical instruments, wax, resin, caulking, tung-oil varnish, elephant hooks and bells, folding screens, and parasols. Some, such as Chinese-style ship's caulking, leeboards, and strake layers on hulls, lug sails, mat and batten sails, chain pumps for emptying bilges, paddle-wheel boats, wheelchairs, and sulfur matches

were quickly employed or imitated by Europeans. Some provoked documented experimentation and invention: Della Porta's kite in 1589, and Simon Stevin's sailing chariot in 1600. The effects of the new information on the sciences of cartography and geography are obvious and profound. Simon Stevin, whose sailing chariot was inspired by descriptions of similar Chinese devices, also introduced decimal fractions and a method of calculating an equally tempered musical scale: both of which might also have been inspired by Chinese examples. The sixteenth-century mariners' cross staff may have been inspired by the Arab navigators' *kamals*. The Western science of botany was profoundly influenced by the descriptions of Asian flora and by the specimens taken back to Europe and successfully grown in European experimental gardens; rice, oranges, lemons, limes, ginger, pepper, and rhubarb were among the most useful. More important for botany, however, the Asian plants provoked comparisons with familiar plants, the development of comprehensive classification schemes, and thus the beginnings of modern plant taxonomy. Some Asian cures (herbs and drugs) were borrowed, especially for tropical medicine. Chinese acupuncture, ► [moxibustion](#), and methods of diagnosis by taking the pulse were minutely described and much admired by European scholars, but it is not yet clear to what extent they were actually used in Europe.

The flow of cultural influence was not exclusively from East to West between 1500 and 1800. Many Asians became Christian. Able Jesuit missionaries translated scriptures and wrote theological works in Chinese and other Asian languages; they also translated European mathematical and scientific treatises into Chinese. The Kangxi emperor himself studied Euclidian geometry, Western astronomy, geography, the harpsichord, and painting under Jesuit guidance. Like many Chinese he was fascinated by European clocks. Many Asians, including the Chinese, learned how to use western firearms and cast western-style cannon. However, the cultural consequences of these efforts were disappointingly small and of short duration. Before the end of the eighteenth

century they seem largely to have disappeared along with the Christian mission. The Japanese, however, even during the closed-country period after 1640, were far more curious about Western science. Samurai scholars, for example, studied Dutch medicine and science and in the eighteenth century repeated Benjamin Franklin's kite-flying experiment. Nevertheless through most of the early modern period the Europeans were far more curious about and more open to influence from Asia than were any of the high cultures of Asia to influence from the West.

During the seventeenth and eighteenth centuries the new information about Asia influenced Western culture primarily in areas other than science and technology. The extent of this impact remains to be comprehensively studied, and even of that which is known only a few examples can be mentioned here. Asian events and themes entered European literature in scores of instances from Lope de Vega, Ariosto, Rabelais, and More in the sixteenth century to the several Dutch, German, and English plays and novels depicting the fall of the Ming Dynasty and the triumph of the Manchus in the seventeenth century, to Voltaire's literary and philosophical works in the eighteenth. Even popular literature, seventeenth-century Dutch plays and pious tracts, for examples, shows surprising familiarity with the new information about Asia. Asian influences in European art, architecture, garden architecture, and the decorative arts also began in the sixteenth century and culminated in the chinoiserie of the eighteenth century. Confrontation with China's ancient history challenged the traditional European Four-Monarchies framework of universal history and touched off a controversy among European scholars which by the mid-eighteenth century resulted in an entirely new conception of ancient world history. Some scholars, beginning with Pierre Bayle in the late seventeenth century, have detected a Neo-Confucian influence in the thought of Spinoza and in some aspects of Leibniz's philosophy. Chinese government and especially the examination system were frequently held up for emulation by European states during the seventeenth and eighteenth centuries. It might well be that the institution of written

civil-service exams in Western states, beginning with eighteenth-century Prussia, was inspired by the Chinese example. Of more general importance than any single instance of influence, however, was the challenge presented by long-enduring, sophisticated, and successful Asian cultures to traditional European assumptions about the universality of their own. Perhaps here can be found the beginnings of cultural relativism in the West.

By 1600 European science and technology generally and especially marine and ► [military technology](#) outstripped that of any Asian society, whatever had been borrowed earlier from them. Also, while the fascination with and appreciation of the high cultures of Asia continued through most of the eighteenth century, the West between 1600 and 1800 experienced the radical transmutation of its traditional culture which resulted in the development of a rational, scientific approach to the use of nature, and society – to agriculture, business industry, politics, and above all warfare – which we have traditionally associated with the Scientific Revolution, Enlightenment, and Industrial Revolution. This transmutation has enabled Western nation-states during the past two centuries to establish the worldwide competitive empires which came to dominate all the other centers of civilization and has resulted in the global dominance of Western culture. The triumph of this transmuted Western culture has reversed the centuries-long East-to-West flow of cultural influence and threatens all of the world's traditional cultures. It should be remembered, however, that this rational, scientific, industrialized Western culture was not an obviously natural outgrowth of traditional Western culture, that in its early development it received important basic components from Asia, and that its triumph threatens traditional Christian Western culture almost as seriously as it threatens those of Asia.

See Also

- [Colonialism and Science](#)
- [Compass](#)
- [Gunpowder](#)

- [Mathematics](#)
- [Military Technology](#)
- [Paper and Papermaking](#)
- [Shen Guo](#)
- [Technology](#)
- [Zero](#)

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East and West: Africa in the Transmission of Knowledge from East to West

Marina A. Tolmacheva

Africa's role in the transmission of knowledge from the East to the West has been strongly conditioned and circumscribed by its

geographical location and relative isolation from European and Asian centers of civilization. Africa is to the south of Europe, home of the “West”; it is also positioned to the west and south of Asia, the historical and cultural “East” of Europe, from which it is separated by distance, the Sahara desert, and the Indian Ocean. The contiguity of the Eurasian landmass makes it easy for East-West communications to bypass Africa. Nevertheless, at various periods of premodern history Africa transmitted systems or elements of knowledge and culture to Europe, some generated in Africa, others developed in Asia in the Near, Middle, or Far East. The parts of Africa most actively involved in such exchanges are delimited by the waters of the Mediterranean and Red Seas, the latter guiding to Arabia and the Indian Ocean. The precise role played in these exchanges by Egypt, Ethiopia, and North Africa across time was subject to fluctuations in the environment, growth of early civilizations, long-distance trade, and the development of cities and elites. Nevertheless, Africa had a role to play in alleviating Europe's relative geographical isolation and, especially after the opening of the Cape route from the Atlantic to the Indian ocean, in supporting the global trading system connecting the Old World with the New.

Historically, the intellectual contribution of African societies to world civilization has been overshadowed by the magnitude of African economic and cultural inputs. In addition, numerous direct contacts between Africa and Asia (especially in the northern part of the continent and across the Indian Ocean) bypassed Europe for simple geographical reasons, or failed to have an impact on Western civilization because of circumstances of political, cultural, or religious nature (for example, the rise of Islam). This lack, inconsistency, and sporadic nature of intellectual interaction between Africa and the West are overlooked in some enthusiastic attempts to assert African primacy in world civilization based on incorrect interpretations of evidence. Reconstruction of the African cultures of the past faces serious problems because of the lack of writing systems among the majority of

premodern African societies. In the absence of a written record, the historical existence of knowledge is often inferred from contemporary anthropological evidence or archeological data. To complicate things further, the secret of some African scripts that had existed in the past has been lost, as is the case with Libyan, Meroitic, and Tuareg. Thus the internal written evidence for the ancient period is currently limited to texts recorded in Egyptian hieroglyphics and the Ethiopic script. However, few of the surviving texts deal with scientific knowledge or formal disciplines of learning.

African elements in the culture of Ancient Egypt came primarily from the South (the Nile Valley above Aswan, where ancient Nubia and Kush were located) and the West (Libyan desert, Saharan oases and possibly Lake Chad region, and the rim of the Mediterranean). The prosperity and cultural splendor of Egypt during the Old and Middle Kingdoms (ca. 2600–1780 BCE) were second to none. Both depended on a flourishing agriculture which in turn reflected and supported the high development of astronomy, mathematics, hydrology, and technology. The texts and practices of ancient Egyptians provide evidence of elaborate knowledge of medicine, human anatomy, and chemistry. About the time of the transition from the Middle to New Kingdom (ca. 1500 BCE) Egyptian influence reached the Greek periphery. The early cultures of Crete and Archaic Greece show traces of Egyptian and North African influence. Later, Phoenician colonies in North Africa (most prominently Carthage) became a bridge between Africa and the northern Mediterranean. Although there is no record of formal transmission of knowledge from the Punic roots to Rome, some elements of Punic culture spread through the expanse of the Roman Empire as far north as the British Isles. Beginning with Herodotus (fifth century BCE), early Greek descriptions of Egypt and Africa make clear the Greek admiration for Egypt and vaguely acknowledge a certain cultural continuity with Egyptian learning and philosophy. Greek mythology hints at North African (Libyan) religious influence, and Greek folklore (e.g., Aesop's fables) reflects a cultural-philosophical

connection with sub-Saharan Africa ("Ethiopia" of the Ancients). Egypt was recognized by the Greeks as both an integral part of Africa and a crossroads on the way east. After the conquest by Alexander the Great, Egypt (especially Alexandria) became a major center of cosmopolitan Hellenistic culture and long-distance trade connecting the Mediterranean with Arabia, Ethiopia, India, and East Africa. Late Greek and Greco-Roman astronomy, mathematics, geography, medicine, and philosophy drew upon the knowledge and thinking of Hellenized Egyptians. The geographical and astronomical works of the Librarian of Alexandria, Claudius Ptolemy (second century AD), continued to influence Western and Islamic scholarship until the sixteenth century.

With the rise of Christianity, Egypt, Ethiopia, and North Africa became a major stage for religious rather than scientific developments. Some of them involved religious controversies with Constantinople, Rome, and Near Eastern neighbors, and resulted in cultural and spiritual separation of the Asian and African Christian communities from mainstream Christian societies even where geographical isolation and remoteness (as in Ethiopia) were not a factor. A further transformation of cultural networks occurred after the Arab conquest of Egypt and North Africa in the seventh to early eighth century AD. Arabic became the language of learning and Islam the dominant ideology. A fragile cultural connection between Ethiopia, Egypt, and Byzantium survived for a few more centuries in the religious sphere; it channeled limited influences in theology, art, and hagiographic literature. One unrecognized consequence of this link is the use of Coptic (originally Egyptian hieroglyphic) elements in the Glagolitic (later Cyrillic) script invented in the ninth century for the Slavic vernaculars by the Byzantine monks, Cyril and Methodios.

The early Islamic science was a synthesis of Hellenistic, Middle Eastern, and Indian sciences, to which was added a considerable body of original knowledge, especially in mathematics, optics, geography, and medicine. Egypt and North Africa became a bridge by which these

sciences were then transmitted from the Middle Eastern centers, especially Baghdad, to the rest of the Islamic world and to Europe. Islamicized societies of tropical Africa were most influenced by the legal, theological, and philosophical thought. This Islamic contact stimulated the adoption in the Middle Ages of the Arabic alphabet for writing in some African languages, such as Swahili in East Africa and Hausa in West Africa. Europe, on the other hand, primarily borrowed Islamic knowledge in the fields of natural and applied sciences and philosophy. The Iberian peninsula was involved in this process in a number of ways: first, through the spread of Asian food and technical crops and cultivation techniques as a result of Arabo-Berber occupation in the eighth century; second, in the eleventh to thirteenth centuries under the Almoravid and Almohad empires when Spain was united with northwest Africa as far south as the Senegal River; third, through the Christian translation activities of the late eleventh to sixteenth centuries; and finally as a transit point for transmission to the New World.

From the period of the later Crusades and under the Mamluk dynasties Egypt became the dominant Islamic partner of European traders on the Mediterranean and gained exclusive control of the Red Sea and thus access to the trade of the Indian Ocean. By the thirteenth century the transmission to the Mediterranean of the magnetic compass and the lateen sail (both of them products of the Indian Ocean societies) had been accomplished. After the Mongol conquest of Baghdad in 1258 Cairo became the foremost center of culture and learning for the Near East and Africa. In addition, it was a major transit point on the pilgrimage route to Mecca, visited by many Africans for purposes of both ritual and learning. Cairo kept this role despite the ravages of the Black Death in the mid-fourteenth century and the Ottoman Turkish conquest in 1516, and has retained it to a certain extent to this day. However, even before the fall of Byzantium in 1453 the balance of secular learning in the eastern Mediterranean had shifted, and Muslims became eager students of the early modern West. In the western Mediterranean, the European and

Islamic powers interacted in the hostile atmosphere of the Christian Reconquista and piracy; by the sixteenth century the technological balance of power had tilted in Europe's favor, and the geographical arena of progress moved to the Atlantic.

In modern times, the European discovery of the New World and the expansion of the West to overseas colonial empires led to new patterns of communication which could connect Africa with Asia and the West Indies or the Americas without involving Europe. The new global networks served very different purposes and produced dramatically different results. One such early modern network was the Portuguese seaborne empire spread over three continents; its shipping lanes led from Goa in India east to Macao or west to Mozambique and Angola to Brazil, the vessels often completely bypassing Portugal itself. Another was the Dutch empire that connected the West Indies with the West African coast, South Africa's Cape settlement, the Persian Gulf, India, Malacca, and Indonesia. The new societies developing overseas were molded by the West but no longer European. A special, modern example of crosscultural interaction in the "Old World" is the South African colonial society where European farmers benefited from observing the herding practices and environmental adaptation of the indigenous groups (the Khoi-, San-, and Bantu-speakers). The Dutch-based Afrikaans language of white South Africans contains African loan words illustrative of such informal, unrecorded, and often unrecognized transmission of African knowledge to Western societies.

The Americas experienced heavy influxes of Africans capable of preserving in their midst some of the living African culture even under the conditions of slave plantation economy. These influences originated mostly in the tropical and equatorial areas of western Africa. Another channel of unstructured cultural transmission to early Latin America was the importation, within Iberian culture, of "Moorish" (i.e., Islamic or North African) elements, for example in architecture. Traditional knowledge of the African environment, technology, medicine, philosophy,

and folklore, including occasional Islamic elements, colored the social, economic, cultural, and spiritual life of African immigrants in the New World and fed into the culture of the larger society despite cultural, religious, and social barriers. African food crops as well as methods of plant cultivation and food preparation spread first in the Caribbean and then on the American mainland. The introduction of rice as a North American plantation staple was accompanied by targeted purchases of slaves from African ethnic groups familiar with rice cultivation, including women whose role in African rice cultivation included seed selection, sowing, hoeing, weeding, and transplanting, as well as milling and cooking. Slaves imported from West Africa brought with them skill complexes that helped make the Carolinas and Georgia into rice exporters on a global scale. Africans contributed their experience of rice cultivation in rain-fed areas, river floodplains, and tidal lagoons; plant breeding skills, the use and adaptation of African agricultural tools, and rotational land use combining cattle grazing and agriculture in tropical and equatorial areas.

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East and West: China in the Transmission of Knowledge from East to West

Christoph Koerbs

Despite the distances between them and their totally different cultures, there has been more or less continuous communication between the West and China since classical Greek times. Although the connection was indirect and limited to trade in luxury goods, there were even in ancient times marvelous resemblances between Western and Chinese inventions in technology and engineering. Therefore it is natural to believe that a transmission of ideas and knowledge must have occurred, even if it is impossible to describe the exact exchange of any particular scientific achievement.

In the thirteenth century there was some considerable personal contact between the West and China, of which that of William of Ruisbroek (1210–1270), Marco Polo (1254–1324), and Odoric of Pordenone (1286–1331) are but the most famous examples. By the end of the

sixteenth century in China an era of isolation ended and a new stage of intercultural exchange began. In this period the first Jesuit missionary fathers entered China, bringing with them knowledge of the sciences of Renaissance Europe. The Jesuits' scientific instruction was intended to aid their religious teaching by adding to the prestige of the culture they represented. Although in many respects Chinese technology was more advanced than European technology until the Renaissance, it lost ground in subsequent centuries. Francis Bacon (1561–1626) saw Chinese inventions, namely the magnetic compass, ► [gunpowder](#), and the printing press, as crucial for the transformation of European society. However, after the generation of Leibniz (1646–1716), Wolff (1679–1754), and Voltaire (1694–1778) with the end of the Enlightenment movement, European philosophers and historians began to speak in a disparaging way of Chinese culture. From the late eighteenth century on, the myth of a closed China was born, and Europeans saw the scientific exchange between China and the outside world solely in terms of what the Chinese borrowed from the West. Though Chinese technological advances were old and undeniable, many authors of textbooks on the history of science, technology, and medicine still assured their readers that China never created science as a persisting institution and never consciously developed technology on the sound basis of a theory for applied science.

The British historian of science Joseph Needham (1900–1995) with his work *Science and Civilisation in China* began to restore the reputation of China as a cradle of scientific inventions (Needham, [1954](#)). He showed the patterns of transmission of these inventions and enriched the knowledge of Chinese science and technology. Sivin ([1977](#), [1988](#)), an American historian, introduced a different angle. He presented the argument that it is impossible to equate divisions of modern science and engineering with premodern Chinese divisions. Chinese science was not integrated under the authority of philosophy, as schools and universities merged them in European and Islamic cultures. The Chinese had sciences but not “science,” not a single

conception or word for the sum of all scientific divisions. Traditional Chinese terms for science might exclude empirical methods but include ethical or religious principles discovered through reflection on authoritative texts.

Since there is neither sound evidence for early adoption of Chinese science in the West, nor agreement as to whether Chinese science is distinct from sciences in the West, we have to answer each complex of questions separately. First of all, when immediate contact between China and the West was too limited to be noteworthy, we have to determine whether the Western world owed much to foreign influences which in turn made use of knowledge from China. Second, we must ask whether the conception of Chinese sciences inevitably leads to disparaging treatment by those scholars who are measuring two radically different things by the same standard. To draw a more balanced picture of Chinese scientific thought, we have to look for autochthonous features of ancient Chinese sciences and explain their characteristics.

To solve the first part of the puzzle, we have to consult Chinese historical records which contained much information on foreign relationships. Although there is clear evidence for Arabic, Babylonian, and Indian relations with China, recent archeological finds demonstrate the originality of Chinese culture in many ways. We still do not know enough about the routes and intermediaries by which neighboring states imported cultural artifacts from China. Many transmissions which finally reached the West transformed Chinese, Indian, Iranian, and Greek contributions simultaneously.

Under the Han rule (221 BCE–AD 220), as a result of military campaigns and diplomatic activities, China's immediate contacts with other cultures grew to a degree so far unrivaled in Chinese history. In this period China spread her concepts and skills around all of Asia. As early as 130 BCE, Chinese government officials set out to explore the routes into Central Asia and North China. The success of these missions is very difficult to reexamine, and yet it is probable, because in the official documents of these times we find many references to China's intercultural

exchange. The first record of official visitors arriving at the Han court from Japan is for the year AD 57, and we can furnish proof of a mission from Rome which had reached China by ship in AD 166.

With the downfall of the Han Dynasty in AD 220 China entered a period of decline and disunity with respect to the transmission of ideas. After a period of domestication and growth under the later Han, Buddhism came from India into China. The spread of Indian thought was attended by a dispersion of Chinese thought westward. For the next 300 years the Silk Road which linked China with the West was the most important connection between the different culture groups. On this trade route goods and ideas were carried between the three great civilizations of Rome, India, and China.

Under the Sui reign (589–618), when China was consolidated again, grandiose plans aiming to unify the empire culminated in projects for new canal systems. As a result a great canal linking central and southern China was constructed, and long campaigns in Manchuria and on the Korean frontier were prepared. There was a direct relationship between waterway construction works and active foreign policy. Using the new canals for logistical support, the Sui realm was able to establish sovereignty over old Chinese settlements in the south, and extend its influence to other territories, especially in central Vietnam. In addition to these military operations expeditions were sent to Taiwan, and relations with Japan were opened. Sui colonies were established along the great western trade routes, and rulers of several minor local states of Central Asia became tributaries. This was the time when China was in contact with the eastern Turks, who occupied most of the Chinese northern frontier, and the even more powerful western Turks, whose dominions stretched westward to the north of the Tarim Basin as far as Sassanid Persia and Afghanistan. We can learn from the writings of the Arabian scientist and philosopher ► [Al-Bīrūnī](#) (973–1048) that the Turkish sphere of influence was a fertile soil for intercultural exchange. As a consequence of the history of Turkish engagement in Inner Asia remarkable

transmissions of technological know-how took place and helped to spread, among other things, Chinese defense engineering and mechanical skills.

Various imports and influences into Arabic empires originated essentially from China, or were at least transmitted through the intermediary of the Turks. As we can prove by discoveries of imported pottery and textiles the links between Iran in the Sassanid period (AD 226–651) and China were extremely close. With the decay of Turkish power the new Tang dynasty (618–906) extended its power all over East Asia. Chinese western dominions extended even farther than in the great days of the Han, and trade developed with the West, with Central Asia, and with India. The Chinese capital was thronged with foreign merchants and monks. Every great city contained a variety of non-Chinese communities and had Zoroastrian, Mazdean, and Nestorian temples, along with Buddhist monasteries. This set the stage for even more transfers of knowledge and inventions.

Perhaps it is not exaggerated to call China under the Song rule (960–1279) the most advanced civilization at that time. During the Song dynasty an agricultural revolution produced plentiful supplies for a population of more than 100 million. Acreage under cultivation multiplied in all directions, and a variety of early ripening rice, imported during the eleventh century from regions in modern Vietnam and Cambodia, shortened farming time to below 100 days and made two crops a year the norm and three crops possible in the warm South. Among other new crops the most important was cotton, which provided clothing for rich and poor alike; silk and hemp were also important. Improved tools, new implements, and mechanical devices that raised manpower efficiency were widely used. Although advanced skills were guarded as trade secrets, many technical inventions of these times found their way into printed manuals used at home and abroad. Productivity of such minerals as lead, tin, silver, and gold increased tremendously. In manufacturing the Chinese improved processing in skill-intensive patterns; they began with mass production, and a division of labor as

well, while skills and products entered into diversified specialization. High-quality earthenware progressed to genuine porcelain, which attained international fame.

Despite the fact that until the early eleventh century Chinese maritime trade had been dominated by foreigners, Chinese artisans developed a new type of ship at the end of the century, helping the Song empire to take control over the transport of merchandise and passengers across the waters of East Asia. The Chinese ocean-going junks with large proportions and tonnage were bigger, more solid, but also more comfortable than the Arabian and Indian ships. From the twelfth to the fourteenth centuries the Chinese fleet was at the peak of its power, at least on the routes linking China with the ports of South India. Chinese trade with Southeast Asia increased for the very last time at the end of the fourteenth century when China flooded Sumatra and Borneo with ceramics, and also coins, in exchange for spices, aromatics, medicinal drugs, and precious woods. Chinese ceramics of this period have been found in quite large quantities not only along the silk road, but also on the sites of ancient ports or depots along the navigation routes toward Indonesia, and in the great commercial cities of the Middle East.

In the thirteenth century after the Mongol conquest of China and the founding of the Yuan dynasty (1280–1367) Europeans developed a lively interest in Chinese affairs. The Roman Catholic Church also looked for potential converts among the non-Muslim people of Asia. After Franciscan envoys brought back information on what was known as China in the mid-thirteenth century, Pope Nicholas IV dispatched a mission to the court of the Grand Khan. The Mongol capital Khanbaliq (Beijing) became the seat of an archbishopric, and in 1323 a bishopric was established. From then on missionaries traveled to China and brought back firsthand information to medieval Europe. These reports inaugurated an era of discoveries and created a new vision of the world, with China as a part. Furthermore, shortly after direct contact with China was established, European philosophers and clerics speculated upon Chinese modes

of thinking. Chinese medical treatises were translated into Persian, and Persian pottery techniques show some influences of Chinese handicraft. In addition, Chinese-type administration and chancellery practices were adopted by various Mongol dominions in Central Asia and the Near East. Some scholars suggested that the invention of ► [gunpowder](#) and printing in Europe was due to a sort of stimulus diffusion from China, although there is no sound evidence for a direct influence from China via the Near East.

During the Ming reign (1368–1644) Europe was unable to maintain its contacts with the Far East, partially because the Black Death broke off many overseas trade relations. Toward the end of the fourteenth century China was almost forgotten. Meanwhile Ming dynasty bureaucracy reoriented foreign policy, which made foreign contacts much more difficult. Ming China's influence in Southern Asia reached its climax during the early fifteenth century when official exploratory voyages brought most important South Asian states into the Ming political sphere. Besides protecting China's southern borders, these voyages were undertaken to monopolize the overseas trade by preventing private individuals from taking control of seafaring activities. Foreign states responded to these overtures not only because they feared military reprisals if they refused, but also because they saw great commercial benefits in relations with China. In these years Chinese missions established contacts with most of the important countries from the Philippines to the Indian Ocean, the Persian Gulf, and the east coast of Africa.

The Ming rulers also maintained China's traditional relationships with foreign peoples; they took for granted that the Chinese emperor was everyone's overlord and that other rulers of non-Chinese states were in a strict sense nothing but feudatories. Foreign rulers were expected to acknowledge the supremacy of the Ming emperor and to send periodic missions to the Ming capital to demonstrate their fealty and present tribute of local commodities. Tributary envoys from continental neighbors were received in selected frontier zones while those from overseas states were only accepted at three key ports on the southeast

and south coasts. All envoys received valuable gifts in acknowledgment of the tribute they presented and also were permitted to buy and sell private trade goods at officially supervised markets. Luxury goods flowed out of China and some rarities flowed in. In order to preserve the government's monopolistic control of foreign contacts and trade, and to keep the Chinese people from being tainted by so-called *barbarian customs*, the Ming rulers prohibited private dealings between Chinese and foreigners and forbade any private voyaging abroad.

In the sixteenth century China came into contact with Jesuit missionaries who impressed the Chinese with the superiority of Western astronomy. The most famous of them, Adam Schall von Bell (1591–1666), was trained in Rome in the astronomical system of Galileo. After curing the Empress Dowager of a strange illness, Schall became an important adviser to the first emperor of the Qing dynasty (1644–1911/1912). He was soon given an official post and he also translated Western astronomical books and reformed the old Chinese calendar. Matteo Ricci (1552–1610), another Jesuit, produced the first edition of his remarkable map of the world, the Great Map of 10,000 Countries, which showed China's geographical relation to the rest of the world. Moreover Ricci taught the rudiments of mathematics and translated many mathematical treatises on Western science and engineering into Chinese, notably the first six books of Euclid. At the same time, many books and correspondences of Catholics like Ricci were published in Europe and caused an interest in Chinese culture. This period of intensive cultural exchange came to an end with the imperial decree of 1717 which prohibited the preaching of Christianity and ordered the deportation of all missionaries from the empire with the exception of those working at the court.

From this time on, for more than 100 years China reduced her contact with the West to a minimum. Trade was rigidly limited to a few ports where officials regulated it strictly and taxed all merchandise excessively. Chinese attitudes toward foreign relations clashed with those of the rising Western powers, especially after the newly expanding states of Britain, France, and

Holland all began to develop major overseas empires. In these times, during the last decades of the eighteenth century, China's image changed, and Chinese affairs were viewed in a rather negative way. After the turn of the century China no longer received favorable attention in the West, but metamorphosed into the very archetype of a backward country. By teaching the Chinese the science and technology of the West, Europeans believed they had to stimulate the scientific development of a culture without any noteworthy tradition of its own. For a very long time it was quite inconceivable to Europeans that China had anything to offer in return.

As mentioned above, to draw a more balanced picture of Chinese scientific thought, we have to look for special features of ancient Chinese sciences and explain their singularities. It is easy to understand why traditional Chinese sciences are hard to describe in the modern terms of Western science or engineering. For example, the Chinese science of geomancy (► [fengshui](#), or wind and water) cannot be assigned to any department of modern science. Since the concepts of geomancy differ significantly from premodern European natural philosophy, even recourse to ancient traditions of the West does not help. The geomancer aimed to adapt the dwelling places of the living and the dead in a suitable way to arrange them in harmony with the energy balances existing in a region. In Chinese thought every place has its peculiar topographical characteristics which can alter the local energies of nature. Directions of watercourses, shapes of wooded areas, or forms of hills are treated as important aspects for everything living in this region, and the forms and structure of objects built by humans are believed to be significant factors too. As the art of geomancy was dedicated to exploring the relations between the landscape and the living conditions of its inhabitants, it was an official state science, directed by the Board of Rites in the capital and patronized by the emperor himself.

Western scientists who have written about geomancy agree that this science recognizes certain types of energy which permeate the earth and atmosphere and animate the forms of nature. Further understanding has been obstructed by the

impossibility of equating these energies with phenomena recognized by modern physics. In one aspect they evidently correspond to the emanations from the earth which are detected by water-diviners, or to the earth's magnetic currents. In another aspect they correlate to traditional Chinese medicine and acupuncture. Just as Chinese doctors commanded a great diversity of therapies and techniques, which they generally used in combination, geomancers did the same, and so traditionally both techniques are described as departments of the same science. Acupuncture is based on the same principles as geomancy, being concerned with the flow of subtle energies in the human body which correspond to those perceived by geomancy in the body of the earth. These remarkably abstract and comprehensive systems of acupuncture and geomancy are based on concepts describing the relations of the body, the mind, the immediate physical surroundings of the body, the earth, and the cosmos which are very different concepts from those in the West. What makes geomancy even more complicated are the differences between special schools of this science. One school believed that natural shapes in the landscape tended to affect the characters and destinies of those living within sight of them, while another school paid more attention to astronomical factors, horoscopes, and reading of the geomancer's compass. In Western terms geomancy seems like a mixture of obscure medicine, applied protophysics, esoteric speculations, superstition, or even swindling.

Another example of the interrelationship of different branches of traditional Chinese learning is the alchemical sciences (*fulian*). We can distinguish two major divisions of alchemy, internal (*neidan*) and external (*waidan*). Internal alchemy was concerned with longevity practices and interpreted immortality as the highest kind of health. A special branch also existed for the alchemical process of internal transformations. Adepts of this school considered the interior of the human body as a laboratory in which elixirs could grow by meditation, breath control, or sexual gymnastics.

In theories of external alchemy, the transmutation of metals into gold and the production of

universal remedies for diseases were the focus of interest. Chinese adepts of external alchemy by and large were not interested in exploring chemical reactions, but in simulating cosmic series of transformation and creation. In the laboratories alchemists intended to produce new substances or to convert given materials into new substances by means of allegorical imitations of natural phenomena rather than by controlled chemical experiments.

It is important to outline some Chinese cosmological ideas briefly. This will help us to relate theories of creation and change to patterns of Chinese mathematical astronomy (*lifa*) and astrology (*tianwen*). In traditional Chinese thought, ideas about the origin of the world do not involve any concept of creation by an almighty creator but only by impersonal processes of spontaneous self-creation. The first fully developed cosmological idea is the ► [gaitian](#) (heaven as cover, or umbrella heaven) theory, whose origins are around the first century AD, although its first traces are to be found as early as 239 BCE. According to this theory, heaven and earth are flat and parallel planes. A variation of this theory depicts heaven and earth as bodies having a mild curvature very similar to the curvature of an umbrella. In both theories heaven is thought to rotate once daily about an imaginary axis, normally held to be vertical, and carry with it all the stars and heavenly bodies. Since the observer is some distance from the vertical axis, it is no contradiction that the polestar is not overhead. Rising and setting of the sun, moon, and stars are optical illusions caused by their entering and leaving the observer's pretended narrowed range of vision. Advanced variations of this theory initiated the idea of a spherical or complete heaven ► [\(huntian\)](#) which was thought to surround the earth and rotate daily about an axis inclined to the horizontal. In this theory heaven and earth are compared with the shell and yolk of an egg, e.g., the earth is said to be completely enclosed by heaven, rather than merely covered from above. Chinese astronomers continued to think in flat-earth terms until the seventeenth century, when Jesuit missionaries introduced Western theories.

Traditional Chinese astronomy does not use a zodiac of 12 signs laid out along the sun's annual

path through the constellations. The celestial sphere is sliced into 28 unequal segments, which are said to radiate from the north celestial pole in the same way in which lines of longitude radiate from the poles of a terrestrial globe. These slices are called lunar mansions or lodges (*xiu*). Each mansion bears the name of the constellation found in it. By means of this system, astronomers were able to follow the progress of the stars in the sky, but the mansions also have an astrological function. Each mansion has a corresponding terrestrial territory to which the predictions based on phenomena observed in the sky are applied. The appearance of comets, haloes, or clouds guided the actions of the governors of the states associated with the mansions where those phenomena were observed. Along with the mansion system, 24 guiding stars were chosen by which the position of the other stars in the sky could be determined. In this, Chinese astronomy differs greatly from Greek helical astronomy, which is based on the observation of the rising and setting of stars just before dawn and just after dusk. In China, where the celestial Pole symbolized the Emperor, astronomers studied the circumpolar movements of the constellations around the Pole.

Another science very closely related to mathematical astronomy and in the same way entirely different from its Western correspondent is Chinese astrology. To distinguish mathematical astronomy from astrology we have to remember that from the very beginning astronomy was designed to make celestial phenomena predictable, whereas astrology served as an aid for interpretations of those phenomena which were unpredictable. In the West astrology is in a way the same as horoscopy, but in the Chinese context astrology and horoscopy differ widely. In traditional China the appearance of celestial phenomena guided the actions of the governors of the states. The Chinese astrologer observed and interpreted anomalous celestial or meteorological phenomena to reveal faults and shortcomings in the political order. There was a close correspondence between the cosmic and the political domains. For instance, from the second century BCE there has been the theory of *fenye* (field allocation). The sky was mapped upon political segments, so that strange

phenomena discovered in a particular segment could be related directly to the corresponding political realm existing on earth. Throughout Chinese history the mediator between celestial circumstances and mundane affairs was the Emperor, who was responsible for the undisturbed course of all regularities on heaven and earth. Therefore, astrologers interpreted celestial omens as indications of imperial negligence or correctness. This attitude toward celestial phenomena also influenced calendrical and planetary astronomy. As a result of this attitude toward omens, almost every government aimed to control and sponsor mathematical astronomy and astrology.

Since changes in the heavens predicted important changes on the Earth, Chinese astronomy and astrology were incorporated into the system of government from the dawn of the Chinese state in the second millennium BCE. The result was a system of astronomical observations and records, thanks to which star catalogs and observations of eclipses and novae that go back for millennia survived. Chinese records, therefore, are still of value to every student of the history of astronomy. In our times Western astronomers have identified ancient Chinese observations of the sudden appearance of bright stars with the supernova explosions whose remainders have been detected by radio astronomy. Moreover, observations of sunspots made from the first century BCE onward helped to solve some problems of the variation of solar activity over the centuries.

Astronomy and astrology had no real effect on Chinese mathematics (*suanxue*). On the whole Chinese mathematics was algebraic and numerical in its approach rather than geometric. Since ancient Chinese mathematics was primarily oriented toward practical application, any search for the hypothetical meaning of numbers was rather a system of occultism built around numbers than an exploration into the realm of abstract mathematics. Some historians of mathematics have claimed that only the Greeks produced an abstract, logical mathematics that could function as the language of science. Chinese mathematics, however, consisted of reckoning rules, and, in spite of their great sophistication, these were only intended for practical use.

Perhaps mathematics serves best to demonstrate the whole problem of contingent affection of China by the West. In the first phase this Chinese science was disregarded, because it was inconceivable that a non-European culture was endowed with an efficient mathematical system. In the second phase, a few Western scholars made an attempt to understand such things as an abacus or counting-rods, but still theoretical primary sources were not used. In the next phase mathematical treatises were carefully studied and summarized in a reliable form. Today we can find several first-hand characterizations of the subject by experts in this field, but it is very difficult to obtain a balanced picture. It is clear that ignorance of Chinese sciences was mainly caused by misunderstanding.

See Also

- [Agriculture in China](#)
- [Alchemy in China](#)
- [Astrology in China](#)
- [Astronomy](#)
- [Calendars in East Asia](#)
- [Chemistry in China](#)
- [Compass](#)
- [Eclipses in the Americas](#)
- [Fengshui](#)
- [Gaitian](#)
- [Geomancy in China](#)
- [Gunpowder](#)
- [Huntian](#)
- [Mathematics](#)
- [Metallurgy in China](#)
- [Navigation in China](#)
- [Stars in Chinese Astronomy](#)

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East and West: India in the Transmission of Knowledge from East to West

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The exchange of ideas was more balanced in the time before the European Scientific Revolution, after which the lipid growth of knowledge in the West dwarfed the interregional traffic that had taken place earlier. The Western tradition of the last few centuries has become the only system studied in universities and practiced in centers of science and technology worldwide. Quite often there is no interaction between this new tradition and the earlier knowledge from regions such as South Asia, even though there are many areas of learning that could enrich the Western tradition.

A study of the growth of the European and the South Asian scientific traditions shows

considerable areas of overlap and mutual influence from very early times. When Europeans in the Renaissance looked back to Greek sources for new inspiration, they were in fact looking to Greek sources partly influenced by the South Asians.

Generally speaking, India was outside the world of shared ideas and values of preclassical Greece. After the wars with the Persian empire the myth of a division into ► [East and West](#) was born, as was the concept of Europe. The conditions for a large scale traffic of culture and ideas between Greece and Asia were created when the Persian Empire became a bridge from the Mediterranean to the Indus. One sees South Asian concepts that arose between 700 BCE and 500 BCE in the later Vedic hymns, the *Upaniṣads*, and among the Buddhists and the Jains, being echoed in Greek thought.

There are striking parallels between the two traditions. The *Upaniṣads* seek one reality; this has its echoes in Xenophanes, Parmenides, and Zeno. Pythagoras is thought to have been influenced by the Egyptians, Assyrians, and Indians. He believed in the possibility of recalling previous lives, which is also typical of South Asian philosophy. Pythagoreans abstained from destroying life and eating meat, as do Jains and Buddhists. They expounded many theories in the religious, philosophical, and mathematical sphere that were known in sixth century BCE India.

In Plato's philosophy, the "cycle of necessity," a concept similar to Karma, was central. Humans were reborn as animals or other humans. The Indian elements *pṛthvī* (earth), *ap* (water), *tejas* (fire or heat), *vāyu* (air), and *ākāśa* (ether, or a nonmaterial substance) have their counterpart in Empedocles, who believed that matter had four elements: earth, water, air, and fire.

After Alexander's encounter there was explicit dialogue with India. Several who traveled with Alexander are said to have met with Indian sages. In late antiquity India was seen in some debates as the origin of philosophy and religion. In the second century AD Lucianus stated that before philosophy came to the Greeks, Indians had developed it. It has also been

suggested that Gnostic thought was influenced by Buddhist literature. Gnostic Carpocratians strongly supported the idea of transmigration. At least one Gnostic philosopher, Bardesanes of Edessa (ca. AD 200) had traveled extensively in India. Mani, the Persian Gnostic of the third century AD, incorporated several Buddhist ideas into Manichaeism. By the second century AD India had almost replaced Egypt as the presumed origin of Greek thought and learning.

At a later period, Plotinus, the father of the Neoplatonic school, took part in the military campaign against the King of Persia. Neoplatonism recommended abstention from sacrifice and meat eating. Neoplatonism, vedānta, yoga systems, and Buddhism all have strong similarities. In the second century AD, Clement of Alexandria spoke often about the existence in Alexandria of Buddhists, being the first Greek to refer to the Buddha by name. He was aware of the belief in transmigration and the worshipping of *stupas*.

During the Roman Empire, contacts between the two places continued. There was heavy trade in luxuries with South India and Sri Lanka by the Romans, and ambassadors were sent to Rome. An Indian delegation visited Europe in Emperor Antoninus Pius' reign. In the reverse direction, Apollonius of Tyana traveled to India. These repeated interactions between the two regions probably resulted in the exchange of ideas from South Asia to Greece. The Buddhists had sophisticated discussions prior to Heraclitus around the concept of being in a state of flux. Buddhists and Ājīvakas added joy and sorrow to the five elements, which precedes Empedocles's views that love and hate acted mechanically on the elements. The Buddhists and others taught a doctrine of the mean several centuries earlier than Aristotle (340 BCE). In medicine, the Hippocratic treatise *On Breath* deals in much the same way with the pneumatic system as we find in the Indian concept of *vāyu* or *prāṇa*. In his *Timaeus*, Plato discussed pathology in a similar way to the doctrine of *tridoṣa*.

The above examples should not suggest that there were no transmissions in the opposite direction. The ancient world had much cross flow of intellectual traffic. A well known example from

Greece to South Asia concerns ideas on geometry and astronomy.

When the Classical age collapsed, European and South Asian contacts continued in the Middle Ages through Arab intermediaries. The Arabs performed the functions earlier performed by the Persian, Alexandrian, and Greek empires which brought together the ideas of ► [East and West](#). It is useful to trace the transmission of Indian sciences to Europe as well as trace those that were not transmitted but remained in the region only to be rediscovered much later. This is done to some extent in the article on Indian mathematics in this Encyclopaedia.

The European Renaissance and Scientific Revolution brought about many changes that have been considered unique. However, the evidence indicates that many of the results were known, some albeit in an incipient form, in South Asia.

Alchemy was an important precursor to the development of chemistry. Greek alchemical texts do not show an interest in pharmaceutical chemistry, a marked contrast with China and India. In the *Atharva Veda* (eighth century BCE) there are references to the use of gold for preserving life. The transmutation to gold of base metals is discussed in the Buddhist texts of the second to fifth centuries AD by concoctions using vegetables and minerals.

In the West, iatrochemists, especially Paracelsus, were of the view that the human body consisted of a chemical system of mercury, sulfur, and salt. Sulfur and mercury were already known to the alchemists; salt was introduced by Paracelsus. This theory differed from the four humors theory of the Greeks advocated by Galen (AD 129–200). An Indian alchemist by the name of Ramadevar taught a salt-based alchemy in Saudi Arabia in the twelfth century.

In medicine, the work of ► [Suśruta](#) laid the foundations for the art of surgery. Suśruta emphasized observation and dissection, and described many instruments like those used in modern surgery, listed several kinds of sutures and needles, and classified operations into types. The operations described included those for hydrocele, dropsy, fistula, abscess, tooth extraction, and the

removal of stones and foreign matter. The ancient Indian surgeons practiced laparotomy and lithotomy, plastic surgery, and perineal extraction of stones from the bladder. The region had considerable knowledge in dentistry including artificial teeth making. In AD 1194 the king Jai Chandra when beaten in battle was recognized by his false teeth. Suśruta describes details of operations for the conditions of obstructions in the rectum and for removal of a dead fetus without killing the mother, considered a very difficult procedure. He describes plastic surgery of the nose and cataract operations on the eye.

At the end of the eighteenth century the British studied Indian surgical procedures for skin grafting to correct for deformities of the face, which became the starting point for the modern specialty of plastic surgery. Dharmapal collected several illuminating accounts by Britons on Indian medical practices in the eighteenth century. This included one by Holwell, who gave a detailed report on the practice of inoculation against the smallpox. The smallpox epidemics in the nineteenth and early twentieth centuries have been attributed to the cessation of this practice before the vaccination system could become widespread.

In the West after Democritus, atomic theories were further expanded by Lucretius in the first century BCE but then virtually vanished from intellectual view for 1,600 years. In the seventeenth century Gassendi, Boyle, Newton, and Huygens revived the atomic perspective. Atomic views of several schools such as the Buddhists, the Jains, and the Vaiśeṣika persisted. The Vaiśeṣika's theory of atomism considered atoms as eternal and spherical in form. The disintegration of a body results in its breaking down to constituent atoms. A solid block like ice or butter melts, and this is explained as a loosening of the atoms, giving rise to fluidity.

Evolution is one other element in the modern phalanx of scientific ideas. Evolutionary ideas had existed among pre-Socratic Greek and Indian thinkers. However, evolutionary thinking in Greek tradition was brought to a sudden end by the ideas of Plato and Aristotle. Plato viewed the real world as consisting of unchanging forms or archetypes; Aristotle viewed the physical world

as a hierarchy consisting of kinds of things. For Aristotle the universe was unchanging and eternal. The idea of evolution is found in the *Upaniṣads*, the writings of the Buddhists, and others.

The *Encyclopaedia Britannica* lists three major innovative transformations in British agriculture in the Era of Improvement in the eighteenth century. They were the invention by Jethro Tull in 1731 of the drill plough, “whereby the turnips could be sown in rows and kept free from weeds by hoeing thus much increasing their yields,” the introduction of rotation of crops in 1730–1738 by Lord Townshend, and the selective breeding of cattle introduced by Robert Bakewell (1725–1795). There is evidence that all three were in existence in India, as reported by British scientists working there.

Roxburgh, generally recognized to be the “father of Indian botany” in the contemporary tradition, put this as follows: “the Western World is to be indebted to India for this system of sowing,” meaning the implicit rotation of crops in the Vedic period where rice was sown in summer and pulses in winter in the same field. Other British works have attested to the use of “careful breeding of cattle,” various kinds of drill ploughs, and rotation of crops and mixed cropping.

The Scientific Revolution had a deep impact on the philosophical underpinnings of Europe. There was for example the dethroning of human exclusivity as the special creation of God, as exemplified by the trials of Copernicus or the criticisms of Darwin’s evolutionary theory. The discovery of the unconscious by Freud and others is also in this class. None of these events would have had the same impact on South Asia, whose cosmology allowed for a large number of worlds, for evolution and change, for humans as part of a larger living world, and for a subconscious.

Aside from these historical examples, are there innovations occurring even now which are drawing sustenance from the earlier South Asian tradition?

Helmut von Glasenapp observed that ancient South Asian ideas on fundamental issues had several parallels with those in modern science.

Some of these concepts were (1) an infinite number of worlds exists apart from our own; (2) worlds exist even in an atom; (3) the universe is enormously old; (4) there are infinitely small living beings parallel to bacteria; (5) the subconscious is important in psychology; (6) doctrines of matter in both Sāṃkhya and Buddhism are similar to modern systems; (7) the world that presents itself to the senses is not the most real; and (8) truth manifests itself differently in different minds giving the possibility of a multiplicity of valid truths.

Following are examples of innovations based on the past taken from a few disciplines. The first is medicine. A recent study has documented the use of honey and sugar as treatment for wounds and ulcers in both Āyurvedic and contemporary biomedicine. The tranquilizer Reserpine was based on an ancient āyurvedic medicine. Hoechst, the West German pharmaceutical company, used Āyurvedic literature to help identify useful medicinal plants. By the early 1980s, over 200 Indian medicinal plants were being tested every year in this program.

A recent study has evaluated the effect of *Rasayana* therapy which aims at promoting strength and vitality. The study covered six drugs from classical Āyurvedic literature. The clinical studies indicated that the drugs toned up the cardiovascular and respiratory systems and improved physical stamina. On the biochemical side, a significant drop in lipids was noticed.

References to curative plants in the Indian tradition go back to the ṛgvedic period (3500–1800 BCE). The *Suśrutasamhitā* and *Carakasamhitā*, two compendia which are summaries of earlier works, dealt with about 700 drugs, some of them outside the subcontinental region. Clearly, a vast reservoir of explorable scientific knowledge exists.

One of the areas of study with a very long tradition in South Asia is psychology. There is also a very long tradition of sophisticated discussions on epistemology. There is potential for a fruitful interaction between these and the contemporary study of the mind, including the philosophy of language, methodology, ontology, and metaphysics.

Memory, motivation, and the unconscious are shown to have parallels in the theories of Freud and Jung, as well as in Patañjali. Similar parallels have been noted between the psychoanalytical theorists Heinz Hartmann and Erik Erikson, and the Hindu theory on the stages of life, as well as between Buddhism and early twentieth century analytical thought. Strong parallels between the concept of self-realization used in subcontinental traditions such as Vedantic Hinduism, Theravāda, and Mahāyāna Buddhism and the concept of self-actualization as developed in humanistic psychology by Arthur Maslow and Carl Rogers have been demonstrated.

Francisco Varela, a theoretical biologist and student of cognitive science and artificial intelligence, and coworkers have used Buddhist insights in extending the limitations of both the neo-Darwinian adaptation in biological evolution and of the current paradigm in cognitive sciences. Having noted that in Buddhist discourse, classical Western dichotomies like subject and object, mind and body, organism and environment vanish, Varela applies these discourses to several areas where these dichotomies had traditionally appeared. These include cognitive psychology, evolutionary theory, linguistics, neuroscience, artificial intelligence, and immunology.

Their position is that if cognitive science is to incorporate human experience, then it must have a means of exploring the dimension which is provided by Buddhist practice. Buddhist experiences of observing the mind are in the tradition of scientific observation. They can lead to discoveries about the behavior and nature of the mind, a bridge between human experience and cognitive science.

Another area of interest is that of adaptation in evolutionary biology. In the conventional view it is assumed that the environment exists prior to the organism, into which the latter fits. This is not so. Living beings and the environment are linked together in a process of codetermination or mutual specification. In this light, environmental features are not simply external features that have to be internalized by the organism; they are themselves results of a long history of codetermination. The organism is both the subject and object

of evolution. The processes of coevolution result in the environment's being brought to life through a process of coupling. Taking the world as pre-given and the organism as adapting can be categorized as dualism. Buddhism transcends this duality in its codeterminative perspective.

The standard arithmetic that we use today, based on the decimal place system and the use of zero, was transmitted through the Arabs from South Asia. It entails certain standard procedures, algorithms, to perform various operations. But are these the only such operations that exist and are these the ones that are computationally the most efficient? Could there be algorithms that did not get transmitted from India through the Arabs, or those that were developed after the transmission?

Indeed there are many such, as Ashok Jhunjhunwala, a professor of electrical engineering in the Institute of Technology, Madras, has discovered recently. He has examined everyday practices in arithmetic in areas not yet influenced by European techniques such as those used by artisans and businessmen in the non-Europeanized sector. He came across simple but fast methods of calculation. He described eight of these methods which are faster than conventional methods. These included means of finding area, multiplication, squaring, division, evaluation of powers, square roots of numbers, divisibility of numbers, and factorization. They also included methods to catch errors. Jhunjhunwala has compared the speed of some of these old approaches with contemporary ones and found that some are faster. He is now applying these general methods to speed up calculations in computers.

Jhunjhunwala's collection of mathematics at the local level shows the proliferation of methods possible once the decimal system is understood. Local groups discovered new tricks, a process of grass roots creativity very much like the different responses to changing agroclimatic conditions across the world and the resultant variations in agricultural practices.

Time is yet another area to explore. There are many different philosophical discussions on *Samsāra* concerning what could be termed the nature of long duration processes. According to some Jain views, time was one of the causal

factors in the evolution of nature; and Buddhism alone has a very large tapestry of conceptions of time.

One of these approaches developed an elaborate theory not only of atoms but also of moments, with some schools recognizing four types of moments and others three. Other theories were also proposed by different schools to relate the theory of moments to the fact of continuity of temporal events.

Virtual Reality brings into question the constructor and the constructed. These types of questions are regularly dealt with in Buddhist and other South Asian philosophies. In the virtual realities that use visual representations, parallels also exist with visualization techniques in certain branches of Buddhism. The author of a text on the topic, Howard Rheinhold, says that the Virtual Reality “experience is destined to transform us because it’s an external mirror of something that Buddhists have always said, which is that the world we think we see ‘out there’ is an illusion.”

The ethical and conceptual questions of the future brought about by modern science and technology could have many uses for South Asian perspectives.

There are many stores of valid information still to draw from. One authoritative estimate of manuscripts, roughly covering the areas of mathematics and astronomy, is about 100,000. Yet the recently published book *Source Book of Indian Astronomy* lists only 285. Of these only very few have been studied. They are mines of mathematical ideas and applications that have hardly been touched.

A passage from ► [Suśruta](#) stimulated the growth of modern plastic surgery in the nineteenth century in Europe. However, as Krishnamurty points out, that was only a stray reference in the many procedures described. It had the fortune of catching the imagination of a western expert. There could very well be many other descriptions that could be rediscovered for modern medicine. Under treatment for mental diseases Suśruta gives a very large list of plants. It is possible that screening of these plants could give rise to a much larger set of useful remedies.

Varela stated that the infusion of Eastern ideas into the sciences of the West would have as much an impact as did the Renaissance rediscovery of Greek thought. How far this may be true is for the future to decide. However, this would help make the present Western knowledge system more universal while still maintaining the rigor developed in the last few centuries. It would help both to enlarge the knowledge terrain covered by the present system as well as retrieve what is relevant from other traditions.

See Also

- [Knowledge Systems: Local Knowledge](#)
- [Mathematics in India](#)
- [Time](#)

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East and West: Islam in the Transmission of Knowledge East to West

Richard C. Taylor

Prior to its explosive expansion from the Arabian Peninsula, Islam itself had no substantive body of scientific learning. The Arabic term for knowledge or science, *‘ilm*, had a developing history steeped in religious reflection and writing as a consequence of the extensive use of its Semitic root *‘-l-m* in the Qur’ân. In contrast to the pre-Islamic “Time of Ignorance” (*jâhilîyah*), the advent of Muhammad as Prophet conveying the words of God in the Qur’ân marked the presence of a new, and frequently detailed and legalistic, understanding of how human beings are to submit (*islâm*) to the will of God in all aspects of their lives. Knowledge on the part of humans was viewed as having its source without exception in the Divine, though signs of the presence of Creator were understood to be evident in the created world. For Muslims, as a result, the place of primacy goes to religious sciences directly (the Qur’ân, the Hadîth, etc.) or indirectly (grammatical studies, law, etc.) which deal with what has been divinely revealed, without at the same time excluding natural knowledge. Later forms of knowledge were sometimes divided into the religious and the foreign sciences (al-Khwârizmî, ca. 976), the religious and nonreligious or rational (al-Ghazâlî 1058–1111) or the traditional religious and the philosophical (Ibn Khaldûn 1332–1406), although the philosopher al-Fârâbî (870–950) gave a different account classifying the sciences into those of language, logic, mathematics, natural philosophy, metaphysics, politics, law, and theology. While such distinctions in some cases reflected believers’ deep distrust of foreign learning as superfluous to the guidance and injunctions of the Qur’ân and the natural perception of human beings, the readily apparent value of medicine, mathematics,

astronomy, and even astrology led ultimately both to the full incorporation of Greek scientific and philosophical learning into Muslim intellectual and cultural life and to its enhancement and development at the hands of scientists and scholars in the Islamic milieu.

In the course of its expansion, Islam came to have dominance over populations of Christians, Jews, Zoroastrians, and others in Egypt and the greater Middle East who were already possessed of Greek medicine, technology, and scientific learning and who were active participants in the construction of long traditions of intellectual reflection on God, nature, and human learning. In addition to interest in medicine universal to all peoples, Arabian Muslims and converted native populations had practical religious interests in astronomy and geography because of Islamic precepts calling for prayer by the faithful in the direction of Mecca at five separate times daily and because of the need for exact calculations for holy days and for the proper arrangement and placement of mosques and their interiors. For those in positions of political leadership, there was also the practical need to discern matters related to quality and character of life present and to come as read in the stars by astrologists. Another sort of practical need which contributed to the demand for Greek scientific texts of a logical sort was that posed by theological debate both intramural and extramural to Islam. Christians as well as Jews and their Muslim students marshaled powerful arguments with enviable sophistication thanks to Syrian and Greek intellectual roots in a Hellenistic cultural tradition which had a long theological interest in Aristotelian logic due to controversies among Nestorians, Monophysites and others. In these contexts there arose demand for deeper understanding of the conceptual foundations of Greek knowledge incompletely conveyed in medicine and other vital areas. Thus, there was a need for translations of works which set out the theoretical and philosophical structures for medical, astronomical, astrological, and other studies. The comprehensive multigenerational translation movement arose in part in response to these needs in a way

that would eventually have profound influence on Latin Europe.

Yet it was also driven by the ascendancy of the Abbasid dynasty (758–1258) and its ideology of inclusion of non-Arabian peoples in Islam and in its political, economic, and religious institutions to the benefit of its Persian supporters and to the detriment of traditional Arabian tribes. The unequivocal opening of Islam and its developing culture to all peoples seeking to become Muslim on the part of the Abbasids enhanced the dynasty's power and independence from past sources of political control. That independence was most evident in the founding of the new city of Baghdad with its deliberately designed planning for the location of institutions in the city which was quickly to become the center of a vast empire and the most important locus for the study of science and the development of knowledge in the world in the ninth to twelfth centuries. Recently Dimitri Gutas (1998) has offered the intriguing thesis that operating underneath all these obvious reasons for the translation movement was the continuation of a “Zoroastrian imperial ideology” on the part of Sassanian leaders committed to the recovery of all knowledge conceived of as having been scattered throughout the world following the conquest of the Persians by Alexander. On this account, al-Mansur (r. 754–775), Abbasid founder of Baghdad under whom the translation movement was initiated in earnest, should be regarded as continuing the Sassanian project as part of a Zoroastrian inspired agenda to amass all knowledge in the dominant language of the era, Arabic.

Transmission of Knowledge to Islam

The transmission of works of medicine, astrology, science, philosophy, and other materials was modest before the ninth century. An Arabic rendering from Sanskrit of the ► *Zij al-Arkand* derivative upon the *Khandakhadyaka* of ► *Brahmagupta* which was available around 738 provided important astronomical tables employed by Abû Ja'far M. b. Mûsâ al-Khwârizmî (d. 850) whose work was so

important to the Latin West. He also made use of Ptolemy's *Geographia* and *Megale Syntaxis*, the latter available in Arabic as the *Majisti* by about 796 and known in the Latin West as the *Almagest*. As early as the late seventh century the Jewish physician Mâsarjawayh had rendered the medical *Panducts* of Ahrûn of Alexandria from Syriac into Arabic perhaps for use at Jundîshâpûr, the famous medical center. Organized and sponsored translations from Indian, Iranian, and Greek sources into Syriac and Arabic began to be produced in abundance under the 'Abbasids, particularly during the reigns of al-Mansûr (754–775) and Hârûn al-Rashîd (786–809) at Baghdad, and under the influence of the Barmakid family of physicians and administrators. 'Abdullâh b. al-Muqaffa' rendered from Old Persian or Pahlavi into an exemplary Arabic version an Indian work under the title *Kalîlah wa-Dimnah*, while he or his son Muhammad translated Aristotle's *Categories*, *On Interpretation* and *Posterior Analytics* and the *Isagoge* of Porphyry during the reign of al-Mansûr (754–775). The era of al-Ma'mûn (r. 813–833) who set himself as Islamic caliph over an Islamic empire was a time of religious turmoil (with the mihna or “inquisition”) and also a time of a continuously increasing expansion of translations and scientific studies which continued under his successors to the Caliphate.

In the ninth century two major groups of translators can be discerned by style, vocabulary, and, to some degree, by interest. The name of the philosopher al-Kindî (801–866) is associated with a group with strong metaphysical interests. Ustâth/Eustathios was responsible for the translation of Aristotle's *Metaphysics* while °Abd al-Masih al-Na °îma al-Himsî, a Syrian Christian from Emessa, provided a deeply influential paraphrase and commentary on *Enneads* IV–V of the Neoplatonist Plotinus, part of which was known as “The Theology of Aristotle” in an edition by the Baghdad philosopher al-Kindî. There were also translations from the *Elements of Theology* by Proclus (412–485), head of the Academy at Athens, including modified versions in the treatise, *Kalâm fî mahd al-khair* (*Discourse on the Pure Good*), which was

attributed to Aristotle or Proclus in the Arabic manuscripts and was later famously known in the Latin West as the *Liber de causis* (*Book of Causes*). These works indicate a powerful interest in late Greek Neoplatonic theology and its accounts of the One, the hierarchy of principles constituting the universe, the structure and functioning of the cosmos, and the ability of the human soul or intellect to apprehend principles and cosmological realities and to transcend the body for its own fulfillment and happiness. Also included in this group is Ibn al-Bitriq who translated Aristotle's *On the Soul*, *Meteorology*, *On the Heavens*, *Generation of Animals*, *Parts of Animals*, and perhaps a version of the *Parva Naturalia*, as well as Plato's *Timaeus*. As a group, their translations may contain transliterations, neologisms, and a tendency to simplify or eliminate complicated Neoplatonic hierarchies. Not himself a translator, al-Kindî championed the value of philosophical texts with the argument that foreign philosophical materials lead to the establishment of the sovereignty of God as the True One and as such should be welcomed by faithful Muslims. What is of special interest here is the implicit view that philosophical wisdom is a source at least coequal with Islamic revelation in the ascertaining of the nature of creation and the Creator. The importance of this moment becomes all the more evident in later philosophers for whom philosophy with its demonstrative argumentation is viewed as having primary access to truth, while religion and revelation are understood to be secondary manifestations of truth through image and representation. Of the same era of early translators was Theodore abû Qurrah, bishop of Harrân, who knew Greek, Syriac and Arabic and followed John Damascene in polemic against Islam and translated Damascene into Arabic.

The second group of the ninth century was that associated with the Nestorian Christian Hunayn b. Ishâq al-'Ibâdî (808/9-873) and his assistants whose achievement and influence in the transmission of knowledge was without equal in the entire Middle Ages. The account of Hunayn's role in the transmission of knowledge is a story of personal achievement and high scientific and

scholarly standards. Removed from medical studies by his teacher at Baghdad, the physician, translator, and scholar Yuhannâ b. Mâsawayh, Hunayn disappeared into Byzantium (*bilâd al-Rûm*) to reappear 2 years later with a mastery of Greek and a penchant for quoting Homer in the original. The now trilingual (Syriac, Arabic, and Greek) Hunayn established his expertise with a translation of a Galenic work and attained a funded place among his colleagues. Sometimes translating into Arabic directly from Greek or Syriac, other times translating from Greek into Syriac and then from Syriac into Arabic, Hunayn and his assembled team of translators, 'Îsâ b. Yahyâ, Mûsâ b. Khâlid, Yahyâ b. Hârûn, his son Ishâq, his nephew Hubaysh b. al-Hasan and others, set a high standard of quality for their work: they sought out Greek manuscripts to collate into a single version, worked to standardize Arabic technical vocabulary, and rendered phrases and sentences, not translating word-for-word, in a sophisticated effort to capture the sense of the texts. Hunayn was particularly interested in the work of the physician and epitomizer Galen (129–200?) and translated over 100 of his works and studied the corpus throughout his lifetime. Thanks in great measure to the *Fihrist* or *Catalogue* of the Baghdad bookseller Ibn al-Nadîm (ca. 935–990), our knowledge of works translated and of works available in his day is substantial. Details concerning the translation of Galen by his group are spelled out in a preserved the *Epistle* which Hunayn wrote giving an account of methodology and of which works by Galen had been translated to the extent of his knowledge. Other medical works translated included works of Hippocrates and the *Materia Medica* of Dioscorides which constituted the Arabic pharmacopoeia. This latter was possible only because of extensive Greek pharmacological and botanical vocabulary on the part of the physician Hunayn. They went on during or shortly after his lifetime to translate into Arabic or Syriac, and to comment upon or abridge Plato's *Laws*, *Sophist*, *Timaeus*, and *Politics*, Aristotle's *Categories*, *On Interpretation*, *Prior* and *Posterior Analytics*, *Sophistics*, *Rhetoric*, *On the Soul*, *Magna Moralia*, *Metaphysics*, *Nicomachean Ethics*, *On Generation and*

Corruption and *Physics*. This second phase of the translations also includes the work of the mathematician Thâbit b. Qurrah, a Sabian from Harrân and contemporary and collaborator with Ishâq b. Hunayn. Thâbit worked with a group of astrol-ogers and mathematicians in the Harrânian tradition and translated Nicomachus of Gerasa's *Introduction to Arithmetic*, improved existing translations by Ishâq of Euclid's *Elements* and Ptolemy's *Almagest*, commented on Aristotle's *Physics*, and worked to carry on the Greek Neopythagorean metaphysics of numbers and astrology. Also active in the same era were the Muslim Abû ʿUthmân al-Dimashqî who translated Aristotle's *Topics* and Porphyry's *Isagoge* as well as texts of Alexander and medical and mathematical works and the Christian Qustâ b. Lûqâ who rendered works of Galen and Hippocrates as well as the *Metaphysics* of Theophrastus, the *Mechanica* of Hero, the *Arithmetica* of Diaphantus and the *Placita Philosophorum* (*Opinions of the Philosophers*) wrongly attributed to Plutarch. Among other translations were commentaries and related philosophical materials by Alexander of Aphrodisias, Porphyry, Proclus, Themistius, and Nemesius as well as works by Ptolemy, Archimedes, Euclid and others. Many of the works mentioned here were translated more than once.

The final phase of translation began with the work of the Syrian Greek Christian Abû Bishr Mattâ b. Yûnus (d. 940) who had Muslim, Christian, and Jewish teachers, was an accomplished trilingual writer, and had as his student the renowned philosopher al-Fârâbî (870–950). He translated Aristotle's *Meteorology*, *De sensu*, *Poetics*, and *On the Heavens*. He also rendered into Arabic the *Posterior Analytics* from the Syriac of Hunayn and Ishâq as well as Aristotle's important philosophical account of the divine, book *Lambda* of the *Metaphysics* with the commentary of Alexander of Aphrodisias and other works by Alexander. Al-Fârâbî's student Yahyâ b. ʿÂdî (893/4–974) was a philosopher, theologian and logician as well as a translator and apparently rendered some Syriac translations by Hunayn, Ishâq and others into Arabic. He was involved with the preparation of translations of

Plato's *Laws* and *Timaeus*, Aristotle's *Categories*, *Topics*, *Sophistic Elenchi*, *Physics*, *On the Soul*, *Metaphysics*, and *Poetics*, the *Metaphysics* of Theophrastus, and commentaries on Aristotle's work by Alexander of Aphrodisias, Themistius and Olympiodorus. He also wrote commentaries on most of Aristotle's logical works while writing works of his own on logic, mathematics, natural philosophy, metaphysics, ethics, theology, scripture, and medicine. Of the same era were Ibn Zurrah (942–1008) and Ibn al-Khammâr (942–1017) who were also involved in translations of Aristotelian works, among them *On Generation of Animals*, *History of Animals*, *Meteorology* and works from the *Organon*. Their work brought to a close for the most part the great translation movement which had some beginnings during the reign of the Umayyads but was for the most part a phenomenon of the era of the Abbasids. A massive portion of Greek scientific, philosophical and other literature had been translated and was now in the process of being assimilated. As mentioned earlier, al-Kindî had argued for philosophy as a source coequal with revealed religion for the understanding of creation and the Creator. In the tenth century, the assimilation of philosophical learning in the work of al-Fârâbî takes a further more controversial step in asserting the primacy of scientific and philosophical argumentation over religion which is characterized as opinions set forth by the ruler for the end which that ruler determines. With profound implications for later Arabic philosophy up to the thirteenth century and for its impact on the Latin West, al-Fârâbî boldly asserts the primacy of independent natural reason characterizing religious revelation as at best a diminished, image-filled, and emotive form of the truth obtained properly by philosophers and scientists in the apprehension of primary principles and the attainment of philosophical and scientific demonstration. The universe was conceived by al-Fârâbî not as created *ex nihilo* but as emanated from the One as First Being in a hierarchy of intellects and cosmological spheres descending to the earth where human beings exist in a realm of natural generation. In his classical rationalism in Arabic philosophy al-Fârâbî is followed by Ibn

Sînâ/Avicenna in the eleventh century and Averroes in the twelfth. What is more, in his construction of a framework of the sciences in his *Enumeration of the Sciences* al-Fârâbî set out clearly an Aristotelian inspired division of the sciences which would be central for the conception of knowledge both in Arabic thought and in the Latin West. Further, in his *Aims of the Metaphysics of Aristotle*, he set aside al-Kindî's view of philosophical metaphysics as a pursuit of God or theology as its object and argued instead that the object of metaphysics is being qua being in all its forms, with God studied as cause of being. This reinforced the view that religion and its revelation are regarded as secondary sources for truth and knowledge provided primarily for the guidance of those unable to take full advantage of the intellect's natural powers of reasoning and intellectual understanding. In this and in many other ways al-Fârâbî was influenced by the late Neoplatonic philosophers of Athens and Alexandria.

As indicated in the work of al-Fârâbî in particular, the story of the transmission of knowledge is not merely one of texts moving from one language to another. It is, in an equally important way, a story of the movement of ideas and their reception and development in a new language and cultural framework. This is all the more so in the case of knowledge and its movement from East to West via the Islamic route, for what was transmitted was oftentimes not only texts but methodological thought and intellectual advances and achievements made on the basis of wisdom garnered from foreign sources. Nearly all of the translators mentioned above were also physicians, scientists, or philosophers in their own right. It was primarily out of their desire for knowledge that they studied foreign works. Translation was in part a consequence of a natural thirst for knowledge on the part of the translators, their patrons and Muslim, Christian, and Jewish intellectuals. Thinkers such as al-Kindî and al-Fârâbî worked closely with those who were studying foreign texts and preparing translations. By the time of the Persian Ibn Sînâ/Avicenna (980–1037), the most influential of the philosophers, the cultivation of foreign knowledge

within the context of Islam was yielding more new fruits on native Islamic soil. Ibn Sînâ himself developed a philosophical system with a new conceptual approach to metaphysics and other philosophical matters which had an overwhelming influence in Arabic and a powerful and longlasting impact on the Latin West. Conceiving God as the Necessary Being with arguments which would become standard fare in Arabic and Western Latin philosophical texts, Avicenna argued for a distinction of essence and existence in created entities inspired by issues in the Islamic theological tradition of Kalâm. Drawing on thinking from the Greek Neoplatonic Alexandrian school tradition, Avicenna set forth a view of the human soul as per se rational, immaterial and imperishable, a view much welcomed in translation in the Latin West.

Al-Bîrûnî (973–1043), an encyclopaedic contemporary and correspondent of Ibn Sînâ, wrote extensively on mathematics, astronomy, astrology, the astrolabe, pharmacology, gems, metals, and other matters in addition to his work on Indian thought. Working with translated Greek texts on mathematics and optics as well as more physical accounts of visual perception, Ibn Haytham (d. 1039), a physician as well as astronomer and mathematician, developed a theory of optics (*perspectiva* in Latin) and intromissive visual perception which became dominant in Islam and later in the Latin West where Roger Bacon championed his work. In the area of alchemy, the name of Jâbir b. Hayyân (d. ca. 815) and that of the great physician and scholar, Abû Bakr M. b. Zakariyyâ' al-Râzî (d. ca. 925), stand out in both Islam and the Latin West, although contemporary scholars raise questions about Jâbir's contributions to the corpus of works traditionally attributed to him. The great Islamic theologian, al-Ghazâlî, while severely critical of the philosophers on metaphysical matters, encouraged acceptance of and elaboration upon logic, mathematics, medicine, and the physical sciences. He vigorously combated many insufficiently well founded views of the classical rationalists al-Fârâbî and Avicenna in his *Incoherence of the Philosophers* and argued that the primacy of certainty regarding the human apprehension of

the Divine can only be found in the Sûfî experience of gnostic *dhawq* ("taste"). Ironically, however, his *Intentions of the Philosophers*, apparently written in preparation for refuting the philosophers, was viewed as a work by a loyal follower of Avicenna in the Latin West where its explanatory opening section was lost in early transmission of the translation. In spite of the attack of al-Ghazâlî, classical rationalism continued its development in the East (where it moved closer to religious thought) and in Andalusia which was destined to become the primary locus of the transmission of science, philosophy, and the tradition of philosophical commentary to the Latin West. There the works of al-Fârâbî, including commentaries on Aristotle's writings, were studied by Ibn Bâjjah (d. 1139) who wrote his own commentaries and Averroes (Ibn Rushd d. 1198) whose commentaries of various sorts came to play a central role in the development of philosophy in Hebrew and Latin translations. Both these thinkers continued al-Fârâbî's rationalist approach giving primacy to philosophy and intellect, but Averroes distinguished himself by seeking to make a full return to the philosophical principles and texts of Aristotle and to set aside the accretions from Neoplatonism and from unsuitable religious sources. His *Long Commentaries* – containing complete texts of Aristotle with detailed commentary – had a profound impact on the Latin West and some important influence on Jewish thought. His arguments, *secundum Aristotelem*, for the unoriginated and eternal nature of the world, for the perishable nature of the individual human soul, and for the primacy of the philosophical over the religious, shocked the Latin West when properly understood and contributed in a central way to the Condemnations of 1277 which profoundly affected philosophical studies in Paris and other Latin centers of scientific, philosophical, and theological study. Nevertheless, his *Long Commentaries* on the *De Anima*, *Physics*, *On the Heavens*, and *Metaphysics* were constantly studied guides to the thought of Aristotle and also to the Greek Commentators Theophrastus, Alexander and Themistius whom Averroes cited and engaged in argument. In Hebrew translation the

Middle Commentaries and *Short Commentaries* or *Epitomes* of Averroes came eventually to supplant the works of Aristotle and became the basis of new Commentaries in the Jewish philosophical tradition. In the Arabic tradition, however, the effort of Averroes to return to the pure arguments of Aristotle was not continued, in part due to the banning of philosophy in Andalusia as result of religious and political conflicts, in part due to a lack of interest to return to an Aristotelianism devoid of the mystical at a time when interest in Sufism and forms of illuminationism were on the rise, and in part due to the overwhelming influence of Avicenna throughout the lands of Islam. Another contributing factor was the strife in Andalusia itself as Christian and Muslim kingdoms contested for the Iberian peninsula.

Transmission of Knowledge to the Latin West

In the Latin West science and advanced learning had to be actively sought out from Greek and Arabic sources and then translated into Latin and carried North or West for an economically and politically expanding and intellectually developing Europe. In contrast to Islam, the West did possess some remnants of earlier Greek learning including translations of portions of Aristotle's *Organon* by Boethius (d. 524) and some other works such as Calcidius' incomplete *Timaeus* translation and commentary, as well as an understanding of the importance of philosophy and philosophical argumentation from Greek Fathers and in particular Augustine of Hippo whose influence in the West was pervasive and dominant in theology and philosophy for much of the Middle Ages. Moreover, Greek science and philosophy, while recognized as arising from a pagan culture, were not feared as foreign in the way that they were sometimes in Islam; rather, they were recognized as intellectual treasures to be recovered and put to use in the service of Latin Christianity. Individual scholars began to seek out Greek texts and learning and came to the frontiers of Islam in search of knowledge and more sophisticated intellectual understanding

from a culture which had benefited from and added to the Hellenistic learning which it had received. Spain was by far the most productive geographic area for translations from Arabic, although some important work was done in Sicily with a few other works of significance being rendered into Latin in the Near East. Not unlike the Arabic translation movement, the Latin movement can be distinguished into periods during each of which translations were being made from Arabic as well as Greek sources.

While an important Barcelona manuscript containing Latin translations and other materials from the late tenth century provides valuable evidence of early interest in Arabic scientific knowledge about the astrolabe, the first translations of significance from Arabic began to appear in the eleventh century. Constantine the African (d. ca. 1087), apparently a widely traveled and well-educated North African Muslim, converted to Christianity and became a Benedictine monk at Monte Cassino. According to one source, he brought with him many texts and undertook the task of translating and composing works on medicine when he had learned of the poverty of Latin Medieval medicine. His contribution to the Latin corpus was substantial and included works by Galen (*Ars medica* and a summary of the *Metategni*) and Hippocrates (*Aphorisms* and *Prognostics*, with commentaries by Galen) as well as work by 'Alī b. al-'Abbās al-Majūsī/Haly Abbas (*Pantegni*), Hunayn b. Ishāq/Johannitius (*Isagoge* or *Introduction to Galen's Tegni*) and others. These translations and other work by Constantine played a substantial role in forming the foundations of medicine and its study by Europeans. But it was the Twelfth and Thirteenth centuries which saw floodgates open and a wealth of learning pour forth into Latin Europe.

In the twelfth century, scholars engaged in translation and transmission of Arabic texts were, like their counterparts working in the Islamic milieu centuries earlier, eager and inquisitive scientists and scholars first and translators second. The great majority of them found Spain to provide the needed environment for their work. Some of them were natives to the area but a large number came from afar in search

of scientific learning. An exception to this was Adelard of Bath (d. ca. 1142) who studied in France and then traveled widely in Italy and the Near East before returning to his native England. Among his translations were two of monumental importance to the Latin West: in astronomy al-Khwārizmī's astronomical tables in the usable version of Maslamah b. Ahmad al-Majrīfī of Cordoba and in mathematics Euclid's *Elements*. In 1126 he translated Abū Ma'shar's astrological *Introductorium in astronomiam*.

Toledo was a natural center for translation work after its conquest since its libraries contained books of science, philosophy, and religion and because it remained a place where Arabic was spoken and used by an educated class. It also became a place of refuge for trilingual Jews fleeing persecution in the South by the Almohad regime. There John of Seville (fl. c. 1130–1142) translated Qustā b. Lûqā's *De differentia spiritus et anime* for Raymond, the archbishop of Toledo (1125–1152) and famous patron of the translators, and a large number of astrological texts by Māshā'allāh, Abū Ma'shar and al-Farghānī in addition to the abbreviated version of the pseudo-Aristotelian *Secretum secretorum*. Robert of Chester apparently worked with Herman of Carinthia in that era to produce a translation of the Qur'ān. In mathematics Robert translated al-Khwārizmī's *Algebra*. Herman produced a second translation of Abū Ma'shar's *Introductorium* and perhaps also a second translation of Euclid's *Elements* in addition to Ptolemy's *Planisphere*. Plato of Tivoli was also interested in astrology and translated Ptolemy's *Quadripartitum* and a work by al-Bāttanī, an astronomer and disciple of Thābit b. Qurrah the Harranian astrologer and mathematician.

At Toledo Dominicus Gundisalvi (d. 1190) devoted himself to the study of Arabic and Jewish thought, translating a number of important philosophical works, among them the *Fons vitae* of Ibn Gabirol/Avicemrol or Avicemron, the *Maqāsid al-falāsifah* (*The Intentions of the Philosophers*) of al-Ghazālī/Algazel, and a large number of works from the comprehensive *Shifā'* (*Healing*, rendered into Latin as *Sufficientia*) of the philosopher Ibn Sīnā/Avicenna, among them

the *On the Soul* with Avendauth (Ibn Da'ud) and the *Metaphysics* with an anonymous assistant. Gundissalinus apparently worked frequently with an assistant. The nature of their collaboration is far from clear even though an account of it is given in the dedication of his translation of Avicenna's *On the Soul*. It apparently involved an intermediate step of translation into the local vernacular or a reading of the text out loud. He is also thought to have translated Isaac Israeli's *Book of Definitions* and al-Kindî's *On the intellect* as well as al-Fârâbî's *On the intellect*, *Enumeration of the Sciences*, and *Liber excitativus ad viam felicitatis* (*Indicating the way to happiness*). Regardless of the precise nature of his collaborations, it is clear that his study and translations had substantial influence on the thought of Gundissalinus himself as evidenced in his own philosophical works, such as *On the Procession of the World* and *On the Division of Philosophy*, which in turn together with the translations played an important role in the formation of the thought of the great philosophers of the thirteen century and later such as William of Auvergne, Albertus Magnus, Thomas Aquinas, Duns Scotus, and others who made extensive use of these works as well as the translations of another scholar at Toledo, Gerard of Cremona.

At Toledo at the same time was the great scholar, lecturer and translator par excellence of the age, Gerard of Cremona (ca. 1114–1187), who had come from Italy to Spain in search of Ptolemy's *Almagest* which he then proceeded to translate from Arabic into Latin. He was a canon at the cathedral and, so, like Dominicus, under the patronage of Archbishop Raymond. The list of Gerard's translations is long and detailed and includes works on mathematics by Euclid (*Elements*) Thâbit b. Qurrah, al-Khwârizmî, al-Kindî and others; works on astronomy by Thâbit and al-Farghânî; a medical work by Avicenna, the great *Qânûn fî tibb* (*Canons of Medicine*), which was in use into and beyond the Renaissance; philosophical works of Aristotle: *Meteorology*, *On Generation and Corruption*, *Physics*, *On the Heavens* and the *Posterior Analytics*; works by the philosophers al-Kindî and al-Fârâbî; the influential pseudo-Aristotelian *Liber de*

causis; and a vast array of other works of Islamic philosophical and scientific learning. Like Gundissalinus, Gerard seems to have sometimes worked with an assistant, although this does not seem to have always been the case. As for style, much scholarly work remains to be done in the definitive identification of genuine translations by Gerard before any comprehensive remarks can be made. Still, in his translations Gerard sometimes used a common method following the work of Boethius in translating from Greek into Latin in the early sixth century: *verbum ex verbo*. The attempt was made to give translations which reflected as precisely as possible the original text in the grammatical structure of the original language's sentences and in word-for-word translation. In the case of Indo-European Greek texts, this was a somewhat reasonable way of proceeding. But in the case of Latin translations of Semitic Arabic works, some of which had already gone through translation from Greek into Syriac and then into Arabic, the medieval Latin reader was left with an intellectually challenging exercise with the result that later translations from Greek were oftentimes preferred. Nevertheless, the translations from Arabic by Gerard (and Gundissalinus) frequently conveyed well and clearly the sense and letter of the Arabic.

Translators of the later twelfth and early thirteenth centuries include the Englishman Alfred of Sareshal who translated the pseudo-Aristotelian *De plantis*, on which he wrote a commentary, and Avicenna's *De mineralibus*. Marc, a canon at Toledo, translated medical works, the Qur'ân and some theological tracts of Ibn Tûmart. Most accomplished of Latin translators from Arabic of this era was Michael Scot who was in Toledo in 1215, Bologna in 1220, and Sicily in 1227 as court astrologer to Frederick II where he died in about 1236. Michael completed his translation of al-Bitrûjî's *De spheris* in 1217 at Toledo where he also translated Aristotle's *On Animals* in part. His greatest achievement, however, was responsibility for making works of Averroes available to the Latin West where they continued to be read through the time of the Renaissance. While it is certain that Michael was the translator of *the Long Commentary on Aristotle's On the*

Heavens, on the basis of current scholarship it can only be said that it is likely that Michael was also the translator of Averroes's *Long Commentaries* on Aristotle's, *On the Soul*, *Physics* and *Metaphysics*. All of these *Long Commentaries* contained the complete text of Aristotle with detailed commentary by Averroes drawing on materials from the Greek and Arabic tradition. Michael also seems to have translated the *Middle Commentaries* on *On Generation and Corruption* and part of the *Meteorology*, as well as Averroes's *Short Commentaries* or *Epitomes* of *On the Heavens*, *Parva naturalia* and *On Animals*. Hermannus Alemannus, William of Luna, Petrus Gallegus, and Philp of Tripoli working in the mid-thirteenth century complete the list of well-known translators from Arabic. Herman is responsible for the Latin of Averroes' *Middle Commentaries* on the *Ethics* and *Poetics* as well as for the widely circulated ethical epitome, *Summa Alexandrinorum*. William also translated some of Averroes' texts: epitomes of logical works of Aristotle and middle commentaries on the *Posterior Analytics* and *Categories*. Petrus rendered Averroes' epitome on Aristotle's *On the Parts of Animals*. To Philip is ascribed the complete Latin of the *Secretum secretorum*.

While this enormous wealth of Greek and Islamic learning was being rendered into Latin from Arabic sources in Spain, Sicily, and the Near East, twelfth century Europe was also the recipient of a vast array of translations directly from the Greek by James of Venice, Henricus Aristippus, a certain Ioannes and others. In the thirteenth century there were substantial efforts of translation from Greek by Robert Grosseteste, William of Moerbeke and others. The transmission of knowledge into the Latin West came along two different roads, each of which had its origins in Greek learning. Via the Islamic route, however, the Latin West also received the sophisticated reflections and intellectual advancements of Islamic thinkers whose religiously oriented philosophical and theological reflections on the world and its Creator were oftentimes much closer to the mentality of Christian Europe than were the texts of Ancient pagan authors. The philosophical texts of the Islamic philosophers

Avicenna and Averroes, sophisticated interpretations and complex new intellectual syntheses, early on "explained" Aristotelian works to Medieval Latins and thereby had a profound influence on the methodologies and analyses worked and developed by Christian theological and philosophical thinkers from the twelfth and thirteenth centuries and beyond.

For Jewish communities the thought of ► [Moses Maimonides](#) was dominant and, though he was much influenced by al-Fārābī, it was Averroes who was most important in that tradition. In southern Europe few works of Aristotle were available in Hebrew, though Samuel ► [ibn Tibbon](#) translated the *Meteorology* in the early twelfth century. Instead the *Short Commentaries* (or *Epitomes*) and *Middle Commentaries* of Averroes on Aristotle's *On the Soul*, *Metaphysics*, *On the Heavens* and others proved most important. Some of the translators were Moses ibn Tibbon, son of Samuel, Shem Tov ben Isaac, Zerahyah ben Isaac Hen and Kalonymous ben Kalonymus who undertook translations of Averroes's *Long Commentaries* on the *Posterior Analytics*, *Physics* and *Metaphysics*. In the Jewish tradition the various commentaries of Averroes came themselves to be the subject of commentaries, most notably by Gersonides and his followers who wrote the so-called "super-commentaries" in the fourteenth century. One Kalonymos translated the *Incoherence of the Incoherence* – the commentary of Averroes on the *Incoherence of the Philosophers* by al-Ghazālī – into Latin for the King of Naples, Robert of Anjou, in 1328, though sources are insufficient to determine whether this is the same or a different Kalonymos who translated from Arabic into Hebrew.

In the thirteenth and fourteenth Centuries translations in Andalusia and elsewhere continued to be made from Arabic into Latin and Hebrew and also into the local vernacular. ► [Alfonso X](#) (el Sabio), King of León and Castile (1252–1277), sponsored translations from Arabic into Castilian including codes of law, astrology, magic, and astronomy. In these centuries the translated texts of Arabic science and medicine became central to Western development and texts of philosophy came to play a central role in

Christian theological and philosophical argumentation up to and beyond the Renaissance. In the fifteenth and sixteenth centuries more translations of works of Averroes appeared, this time mostly from Hebrew into Latin. What was most significant in this was their inclusion in Renaissance printings of the works of Aristotle. The Giunta edition printed in Venice in 1550–1552 (and reprinted many times thereafter) in 11 volumes also contained revised texts and new translations by Jacob Mantino (d. 1549) and allowed for the easy use of the translated works of Averroes and the earlier versions of the works of Aristotle to be consulted and studied together.

The centrality of the notion of *‘ilm* or knowledge in Islam encouraged the pursuit of learning in all its various forms and the sharing of knowledge among all the people of society, Muslims, Christians, and Jews. Scientific study and philosophical discourse in the Islamic milieu was much influenced by the late ancient schools of Neoplatonism at Athens and Alexandria. That influence is evident in recognition of the independence of philosophy as an intellectual discipline distinct from religious tradition and its development of theological argumentation. Natural reason and intellectual insight as found in philosophy in the classical rationalist tradition constituted an independent way to the understanding of human beings, the cosmos and the First Cause. The philosophical and scientific works translated into Latin were from the most part from this classical rationalist tradition and conveyed methodologies of investigation bearing an understanding of the attainment of knowledge quite different from that found in the Latin West where the Augustinian notion of faith as the foundation for understanding and knowledge was widely dominant. In the Latin later Middle Ages rationalism of the sort found in the Arabic translations danced a careful and sometimes dangerous dialectic with thinkers committed to that Augustinian notion. Thomas Aquinas developed the notion of theology conceived along the lines of Aristotelian science. Siger of Brabant was attacked in argument and charged by Church authorities for his assertions about independent rationality. And the Condemnations of 1277

caused many thinkers to move away from the more explicit rationalism of Averroes and to find philosophical inspiration in the more compatible conception of God and creation and the rational found in Avicenna's works of metaphysics and psychology. The rationalist movement in the West continued to develop into the Renaissance and Early Modern periods where the Reformation and nationalism undermined Catholic dominance and philosophy and science generally developed into something which viewed itself and its methods as separate from traditional theology, revelation and its issues. The conceptions of knowledge by thinkers of the Islamic milieu founded on translated Greek texts and developed and reconceptualized by scientists and philosophers of the Islamic tradition came to play a central role in that development thanks to the Latin translators of Spain, Sicily, and other border lands. To that extent, the role of Islam, its culture and its people, played a central part in the modern conception of science as a discipline distinct from religion, a distinction at the foundation of today's world.

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Eclipse Observations

F. Richard Stephenson

The theme of this article is eclipse *observations*; for information on calculating and predicting eclipses, see the article on *Eclipse Theories*. Eclipses of the Moon and Sun are by no means rare events. In a typical century, as many as 95 lunar eclipses and 40 solar obscurations are visible at any given location (weather permitting). Observations of both types of event are frequently recorded in the history of several non-Western cultures. In ancient times, reports originate almost entirely from Babylon and China; these mainly commence after about 700 BCE. Although extant Babylonian eclipse records cease around 10 BCE, Chinese accounts continue (almost uninterrupted) down to the modern era. After the middle of the first millennium AD, further observations become available from Korea and Japan and also the Islamic world.

As yet, virtually no eclipse records have been uncovered from other major non-Western civilizations—such as ancient Egypt, India or Central America. Possible explanations for these deficiencies include loss or inaccessibility of original records, or less concern in these cultures with observation rather than prediction.

Surviving reports of eclipses are found in two quite distinct types of text: (1) chronicles and

other literary works; and (2) astronomical treatises. Texts in the first category mainly note eclipses on account of their spectacular nature. Such reports, although often quite descriptive (especially in the case of total eclipses of the Sun) are usually devoid of technical details. However, astronomers often made careful timings of the various stages of an eclipse, as well as estimating the degree of obscuration of the Moon or Sun when the eclipse was at its height.

Most early non-Western cultures adopted a lunar (or luni-solar) calendar. For instance, in Babylon—and later in the Muslim world—each month commenced with the first sighting of the young crescent Moon. However, throughout East Asia months began at the conjunction of the Moon and Sun. On these systems, solar eclipses occurred either at the end or the beginning of a lunar month, while lunar eclipses took place close to the middle of a month.

Modern computations enable the date, time of day or night and other local circumstances of past eclipses to be determined with high precision. Early references to eclipses sometimes prove of value in dating historical events, while the more careful observations enable long-term variations in the rate of rotation of the Earth to be investigated with remarkable accuracy. Eclipses are thus among the most interesting of all celestial phenomena mentioned in history.

Before about 700 BCE, very few records of eclipses are extant and for most of these the dates are in doubt. It has been suggested that astrological tablets from the city of Ur contain allusions to eclipses occurring around 2000 BCE, but this is disputed. Clear references to eclipses, mainly of the Moon, are recorded on Chinese “oracle bones” from the latter part of the Shang Dynasty (ca. 1350 to 1050 BCE). These bone fragments, inscribed with a primitive script, are mainly concerned with divination. Unfortunately, few bone inscriptions are intact. In the case of the eclipse observations, the year is invariably missing, while the lunar month is only rarely preserved. As a result, determination of the exact dates with the aid of astronomical computations presents considerable difficulties.

An example for which the month is extant may be translated as follows:

The divination on day *guiwei* was performed by Zheng: “Will there be no disaster in the next ten days?” On the third day *yiyu* an eclipse of the Moon was reported. (These events occurred) in the eighth month.

In common with numerous other Shang inscriptions, dates are expressed in terms of a 60-day cycle. This cycle has probably continued uninterrupted down to modern times. *Guiwei* and *yiyu* were the 20th and 22nd days of the cycle. The term *shi*, used to identify an eclipse, has remained in use in China down to the present day.

Probably the earliest surviving eclipse report for which a date can be confidently derived is from Assyria. This is recorded in the *Assyrian Chronicle* and may be translated as follows: “(Eponym of) Bur-Saggile of Guzana. Revolt in the citadel; in (the month) Siwan, the Sun had an eclipse (*šamaš attalu*).”

The *Assyrian Chronicle* is mainly a list of annual *limmu*-senior officials after whom the year was named. A complete list of *limmu* is preserved from 910 to 646 BCE, as well as the names of several Assyrian kings. Hence the year of the eclipse can be deduced as approximately 763 BCE. Computation shows that during the entire eighth century BCE only a single solar eclipse was large in Assyria: BCE 763 June 15. This date conveniently fits the lunar month Siwan, which was equivalent to May–June.

A few scattered reports of other eclipses (of both Sun and Moon) are preserved in Assyrian sources. However, much more extensive accounts of these phenomena are to be found in the records of ancient Babylon. Probably commencing about 750 BCE, Babylonian astronomers maintained a systematic watch for eclipses (as well as many other celestial phenomena) for around eight centuries. As well as noting the exact date of such events, estimates were given of the time of occurrence and magnitude (the maximum degree of obscuration of the Sun or Moon). The aim was to use these observations to enable better prediction of future eclipses to be made, although the ultimate goal was astrological.

Both genuine observations and failed predictions are recorded on the Late Babylonian astronomical texts which were recovered from the site of Babylon in the late nineteenth century. Most of these clay tablets-many of which are badly damaged-are now in the British Museum. The operational rules of the Babylonian calendar are well understood. Although earlier years were counted from the accession of each king, they began to be continuously numbered from the Seleucid Era (311 BCE) onwards.

Among Babylonian records of eclipses, the best known is the total solar obscuration of 136 BCE. This is reported on two separate British Museum tablets, which give overlapping details. A composite translation-based on the work of Prof. H. Hunger of the University of Vienna-is as follows:

Year 175 (Seleucid), intercalary twelfth month, day 29. At 24° after sunrise, solar eclipse (*šamāš AN-KU*). When it began on the south-west side, in 18° of daytime in the morning it became entirely total. Venus, Mercury and the Normal Stars were visible, Jupiter and Mars, which were in their period of invisibility, were visible in its eclipse [...] It threw off the shadow from south-west to north-east. [Time interval of] 35° for onset, maximal phase and clearing. In its eclipse, north wind. . .

When reduced to the Julian calendar, the Babylonian date is identical to that of a computed solar eclipse visible in Babylon: BCE 136 April 15. Computation shows that at that time, both Jupiter and Mars were too close to the Sun to be seen under normal circumstances, whereas Venus and Mercury were better placed for regular visibility. The unit of time here translated as “degree” (i.e. *uš*) was precisely equivalent to 4 min. Measurements were presumably made with the aid of a water clock, although reference to the device used is lacking. The “Normal Stars” were certain reference stars in the zodiac belt. Many similarly detailed descriptions of both solar and lunar eclipses are preserved on the Late Babylonian astronomical texts. Extant observations range in date from 713 to 10 BCE.

On many Late Babylonian astronomical texts, the date is damaged. However, unambiguous restoration is often possible. In the following

account of a lunar eclipse, the name of the king is missing, but this omission presents few problems.

[...] year 42, twelfth lunar month, day 15. At 1,30 (=90) ° after sunset [lunar eclipse...] 25° duration of maximal phase. In 18° it became bright. West (wind) went. It was eclipsed 2 cubits below γ Vir.

The small tablet on which the above observation is preserved also mentions another lunar eclipse-in the sixth month of the same year. Among Late Babylonian kings, only Nebuchadnezzar II (42nd year = 563/2 BCE) and Artaxerxes II (42nd year = 363/2 BCE) are known to have reigned for such a long time. However, computation reveals that whereas during the appropriate year of Nebuchadnezzar there were indeed lunar eclipses in the sixth and twelfth lunar months, in the 42nd year of Artaxerxes II eclipses only took place in the third and ninth months. The date of the eclipse in the above text can thus be reduced to BCE 562 March 3. Furthermore, on this night the Moon would be about 3° to the south of γ Vir, in close accord with the record.

Occasional indirect allusions to eclipses are found in the Old Testament, notably in the books of the Prophets Amos (VIII, 9) and Joel (II, 31). However, the most direct reference to an eclipse in the history of ancient Israel is recorded by Flavius Josephus, a Jewish historian of the first century AD. In his *Bellum Judaicum*, Josephus described this event as occurring only a few days before the death of Herod the Great, and it is thus of importance in dating the birth of Jesus Christ. Josephus gives the following account:

As for the other Matthias who had stirred up the sedition, he (Herod) had him burnt alive along with some of his companions. And on the same night there was an eclipse of the Moon. But Herod's illness became more and more severe.

Josephus uses the standard Greek term *ekleipsis* for an eclipse. The events described occurred around the time of Passover, a spring full-Moon festival. Computation shows that between 17 BCE and AD 3, the only springtime lunar eclipses visible in Judea occurred on March 25 in 5 BCE (a total obscuration) and March 13 in the following year (a partial obscuration).

The latter date fits better the chronology of the period, although the two dates are conveniently close together.

For several centuries after the birth of Christ, scarcely any eclipses (whether of Sun or Moon) are recorded in the non-Western world outside East Asia. However, during the ninth century AD, both Muslim astronomers and chroniclers began independently to note the occurrence of these events. Between about AD 830 and 1020, astronomers-largely based at Baghdad or Cairo-frequently made careful observations of eclipses, measuring the times of the various phases and estimating the magnitudes. The main motive for these activities was to test the reliability of contemporary eclipse tables, but lunar eclipses were sometimes effectively used to determine the difference in longitude between two selected cities. Astronomers would first make a prediction of when an eclipse would occur and then assemble one or more groups to observe it.

Our principal source of such observations is the ► *Zīj* (handbook) compiled by the Cairo observer Ibn Yūnus, who died in AD 1009. This work, dedicated to Caliph al-ḥākim, is entitled *ḥākimī Z'īj*.

Medieval Muslim astronomers were in the habit of determining eclipse times indirectly by measuring the altitude of the Sun, Moon or a bright star (probably with a sextant or astrolabe) and then converting the measurement to local time with the aid of an astrolabe or tables.

Among the many preserved lunar and solar eclipse reports, the following provide useful illustrations: a lunar eclipse observed at Baghdad on a date equivalent to AD 856 June 22 and a solar eclipse seen in Cairo on AD 993 August 20. The usual Arabic term for an eclipse was *kusūf*, meaning a 'cut' in the solar or lunar limb.

1. There was a an eclipse of the Moon on the night of the second day of the week (Monday), the middle of the month of ṣafar in the year 242 of *al-Hijrah*. . . It was found by observation that the beginning of the eclipse occurred when the altitude of *al-dabarān* (Aldebaran: α Tau) was 9;30° in the east. The amount of revolution of the (celestial) sphere from

midnight to this time, as we determined (from this measurement) with the astrolabe, was 50° . We did not determine its times except for the beginning. It was found (by observation) that the uneclipsed fraction of its body was more than one-quarter and less than one-third.

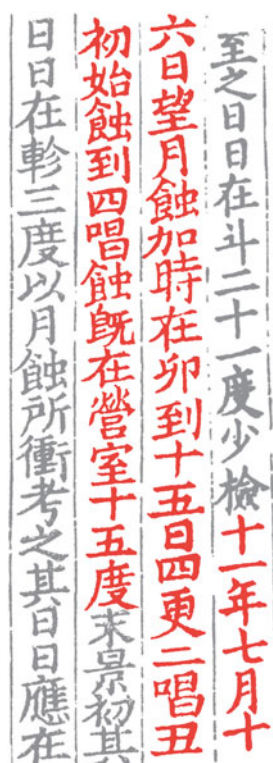
2. This solar eclipse occurred in the forenoon of the first day of the week (Sunday), the 29th day of (the month) of Jumāda al-Ukhra in the year 383 of *al-Hijrah*. . . The eclipse began when the altitude of the Sun was 27° in the east and was complete (i.e. reached its maximum) when the altitude was 45° in the east. The Sun cleared when its altitude was 60° in the east. About two-thirds of it was eclipsed.

In both of the above examples, the equivalent Julian date corresponds precisely to that of a computed eclipse.

It would appear that virtually no eclipse observations made by Muslim astronomers have survived for several centuries after AD 1020. However, many later reports of eclipses by chroniclers are preserved; these writers often emphasised the spectacular nature of these phenomena. A careful description of a total eclipse of the Sun occurring on a date equivalent to AD 1061 June 20 is recorded by the Baghdad chronicler Ibn al-Jawzī. Although he wrote a century after the event, his account is clearly based on an eyewitness description.

(453 A.H.) On the fourth day of the week, when two nights remained to the completion of (the month of) Jumāda al-Aula, 2 h after day-break, the Sun was eclipsed totally. There was darkness and the birds fell whilst flying. The astrologers claimed that one-sixth of the Sun should have remained but nothing of it did so. The Sun reappeared after 4 h and a fraction. The eclipse was not in the whole of the Sun in places other than Baghdad and its provinces.

Reference has already been made to eclipses recorded on ancient Chinese oracle bones. However, the earliest accurately datable reports of eclipses from China are found in a chronicle, the *Chunqiu* (Spring and Autumn Annals), covering the period from 722 to 481 BCE. Although no lunar eclipses are recorded in the *Chunqiu*, this

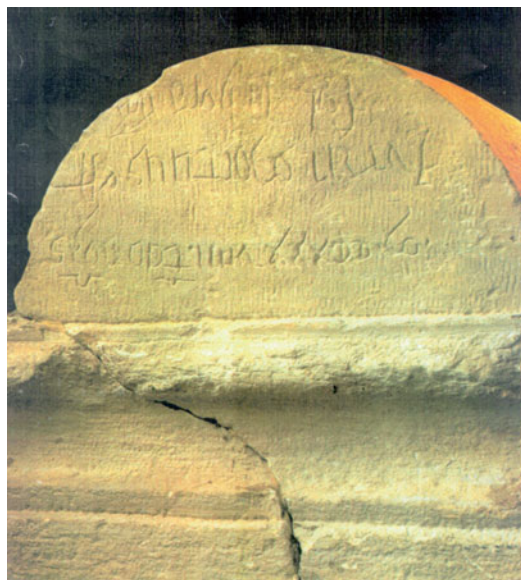


Eclipse Observations, Fig. 1 Chinese text in the calendar treatise of the *Songchu* containing timings of the lunar eclipse of AD 434

work cites as many as 36 reports of solar eclipses. By this period solar obscurations were regarded as major portents, whereas lunar eclipses were considered to be of little astrological significance. Lunar eclipses only began to be recorded regularly in China from the fifth century AD.

For each of the solar eclipses which it records, the *Chunqiu* gives the full date-year of the ruler, lunar month, day of the month and day of the 60-day cycle. Use of the sexagenary cycle (as in later Chinese history) greatly expedites the accurate conversion of dates to the Julian calendar. In almost every case the reduced date corresponds exactly to that of a computed eclipse visible in China (Fig. 1).

Three total eclipses-occurring on dates equivalent to BCE 709 July 17, 601 September 20 and 549 June 19-are noted in the *Chunqiu*, but there are no allusions to such effects as darkness or the appearance of stars by day. Three further



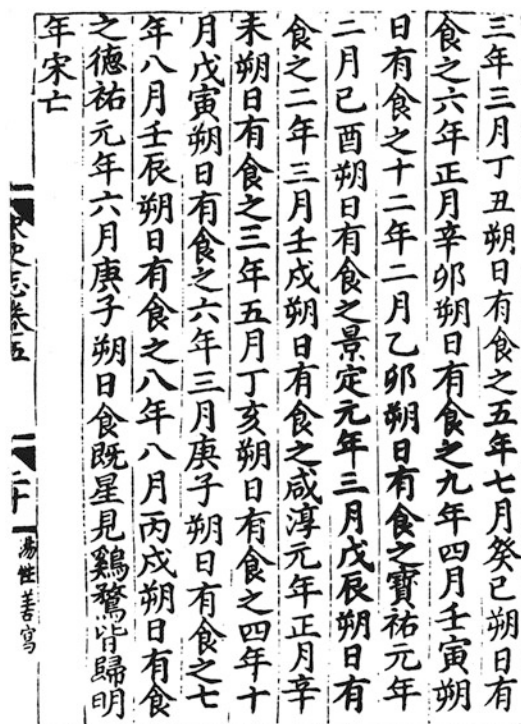
Eclipse Observations, Fig. 2 Latin inscription recording the “death of the Sun” as a result of the total solar eclipse of AD 1239. This is carved on a pillar at Marola, Italy (Photograph used with the kind permission of Dr G.R. Levi-Donati, Perugia, Italy)

accounts (from 669, 664, and 612 BCE) describe eclipse ceremonies in which drums were beaten and oxen were sacrificed.

Records of the Han dynasty (202 BCE to AD 220) contain several reports of large partial eclipses of the Sun. For instance, the account of the eclipse of BCE 89 September 29 may be rendered as follows (Fig. 2):

Zhenghe reign period, fourth year, eighth month, day *xinyu*, the last day of the month. The Sun was eclipsed; it was not complete but like a hook. . . At the hour of *fu* (=3–5 p.m.) the eclipse began from the north-west. Towards the time of sunset it recovered.

The above record only notes the time to the nearest double hour. However, commencing in the fifth century AD eclipses of both Moon and Sun were often carefully timed using water clocks. The main purpose was to verify the accuracy of astronomical tables. Solar eclipses were usually timed to the nearest *ke* (‘mark’)-1/100 of a day and night-roughly equal to 15 min. For lunar eclipses, times were often expressed to the nearest fifth of a night watch instead-



Eclipse Observations, Fig. 3 Chinese text in the astronomical treatise of the *Songshi* describing several thirteenth century solar eclipses, including the total solar eclipse of AD 1275

especially in earlier centuries. The period from dawn to dusk was divided into five equal *geng* (night watches), each of which was in turn divided into five equal intervals. Hence the watches and their subdivisions varied in length with the seasons.

The following account from the *Songshi* (History of the Song dynasty: AD 960–1279) uses both types of time units; the date is equivalent to AD 1186 March 25 (Fig. 3):

Jiandao reign period, fourth year, second month, fourteenth day, *dingwei*, full Moon. The Moon was eclipsed. . . (various predictions). . . On this evening when the Moon rose there was light cloud. Until the fall of darkness it could not be seen that the Moon was totally eclipsed. When the third mark of the initial half of the (double) hour *xu* was reached, as expected it was (partially) shining and so it could be known that the eclipse had been total on rising. It was restored to fullness at the third mark in the central half of the hour *xu*. This was the second division of the second watch.

The very earliest Korean records of eclipses appear to be copied from Chinese history and probably do not become independent until around AD 700. However, the many accounts of both lunar and solar eclipses which are preserved in later Korean history tend to be very brief, seldom giving more than the date of occurrence and noting if the eclipse was total. Eclipse records are mainly found in two major works. These are the *Koryo-sa* (the official history of Korea from AD 936 to 1392) and the *Choson Wangjo Sillok* (an extensive chronicle extending from AD 1392 to modern times). The Chinese luni-solar calendar was closely followed in Korea, although years were numbered from the accession of Korean monarchs. Around AD 1200, there are occasional references to lunar eclipse ceremonies in which the king, arrayed in white robes and accompanied by his closest ministers, attempted to rescue the Moon. However, these may have been no more than empty rites.

Commencing around AD 600, Japanese observations of eclipses are also numerous. Japanese historical sources are much more diverse than those of China and Korea, and it is fortunate that in the 1930s Kanda Shigeru made a detailed search of Japanese history down to AD 1600 for references to eclipses and other celestial phenomena. The earliest Japanese account of a total solar eclipse dates from AD 628 April 10, but this is extremely brief. Several detailed reports of later similar events are preserved, notably in AD 975 and 1460. The following account of the eclipse of AD 975 August 9 is taken from the *Nihon Kiryaku*, a privately compiled history:

Ten-en reign period, third year, seventh month, first day. The Sun was eclipsed. . . Some people say that it was entirely total. During the (double) hours *bo* and *shin* (between 5 and 9 a.m.) it was all gone. It was the color of ink and without light. All the birds flew about in confusion and the various stars were all visible. There was a general amnesty (on account of the eclipse).

In this brief article it has only been possible to cite a minute proportion of the available eclipse records from the non-Western world. However, it should be clear from the selection offered here that many detailed and important

descriptions are preserved. Early eclipse observations often reveal a remarkable level of sophistication, particularly in the measurement of times.

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Eclipses in the Americas

Hugh Thurston

We have no information about eclipses observed in America before the arrival of the Spaniards. There are two descriptions by Bernard Sahagún in his *General History of Things of New Spain* (Book 7: 8–10). Here is a précis.

When the moon was eclipsed darkness spread. Pregnant women were afraid that their unborn children might be turned into mice. To protect themselves they put obsidian in their mouths and on their breasts.

When the sun was eclipsed it turned red, became troubled, and turned yellow. There was tumult and everyone was frightened. People of light complexion were sacrificed and captives were killed. Suitable chants were sung in the temples. People said that if the eclipse is total it will be dark forever.

This applies to the Aztecs. The Incas in South America, according to Garsilaso de la Vega (1609), thought that when the moon eclipsed it

was ill. When an eclipse began they became afraid and sounded everything that would make a noise, even beating their dogs to make them yelp, so that the noise would awaken the moon from the sleep caused by the sickness.

Eclipses of the sun in 1496 and 1531 were pictured in the Aztec Codex *Tellerianus Remensis*.

Perhaps the most interesting eclipse observed in Mesoamerica is an eclipse of the moon on February 29th, 1506. Columbus was stranded in Jamaica, whose natives refused him provisions. He knew that there would be an eclipse of the moon that evening and threatened to destroy the moon if the natives did not agree to provide provisions. When the eclipse started, they agreed.

We have no records of eclipses observed by the Mayas. But we do have calculations concerned with eclipses. There are displayed on pages 51–58 of the Dresden Codex.

Each half-page of each page is a unit. The upper halves come first, so the lower half of page 51 follows the upper half of page 58. The first half-pages are an introduction; the table itself starts on page 53. It has 69 columns, which I have numbered, separated by broad columns ending in pictures which are not part of the table. In each column the top two glyphs are not astronomical; for example, in column 14 they are “death” and “owl” (Davoust, 1997). Then comes a number, presumably a count of days, then three successive days in the sacred round, then another number.

In Table 1 I have translated the Mayan numerals into decimals and replaced the Mayan glyphs for each day in the sacred round by its position in the round (e.g. 1 Imix by 1, 13 Ahaw by 260 and so on). The diagram shows just the middle one of the 3 days. The top row is a cumulative total of the numbers in the bottom row.

There are a few mistakes in the Mayan table. For example, a dot is missing from the first number, which reads 157 instead of 177. But so many totals are right that it is easy to correct the few wrong ones. The interval between the days of the sacred round agrees with the intervals in the cumulative total. There are six places where 178, not 177, is added to the cumulative total (and to the sacred round).

To the nearest whole day, 177 is the number of days in 6 months and 148 is the number of days in 5 months. This suggests that the table is concerned with eclipses; an interval between eclipses of the moon is nearly always the sum of a number of 6-month intervals with or without one 5-month interval. (Because an eclipse of the moon occurs only at full moon, a whole number of months – lunar months, not calendar months – must elapse between eclipses). The intervals between successive eclipses of the moon visible in northern Yucatán between AD 400 and AD 500 are 6, 11, 12, 17, 18, 23, 29, 35, 41, 53, 59, and 65 months. Each of these is made up as described: for example 17 is $6 + 6 + 5$. This could easily give rise to the idea that a table for eclipses should use 6-month intervals and a few 5-month intervals.

Very few eclipses of the sun were visible in the Maya region and only a very nearly total eclipse would be seen. If the sun is even as much as 90 % eclipsed the light will not be noticeably dimmed and looking at the sun would be painful.

How would the table be used? There are far too many columns for each to mark an eclipse, and far too few pictures for the entry before each to mark an eclipse, even though the gap between pictures consists of 6-month intervals plus one 5-month interval. Probably the Mayas had discovered how to pick out dates on which eclipses could not occur and the 69 columns represent 69 full moons that could not be ruled out (out of the 405 covered by the table), so the table eliminates 336 false alarms. (The Babylonians had a table which did this).

Most early cultures had a relation of the form so many months equal so many days. The Mayas seem to have had 405 months equal to 11,958 days. (i.e. 135 months equal 3,986 days).

If we have a starting date for the table we can add the cumulative totals to it to find a date for each column. The introduction contains four dates in the Mayan ► [long count](#) (a) 9.16.4.10.8; (b) 9.16.4.11.3; (c) 9.16.4.11.18; (d) 9.19.8.7.8. Date (a) is 755 AD November 12th Gregorian, and is close to the date of a new moon. Date (b), 15 days later, is close to a full moon, and date (c) is close to the next new moon. Date (d), some

Eclipses in the Americas, Table 1 Transcription of the numbers from pages 51 to 58 of the Dresden codex

177	354	502	679	856	1033	1211	1388	1565	1742	1919	2096	2244	2422	2599	2776	2953	3130	3278	3455	3632	3809	3986
85	2	150	67	244	161	79	256	173	90	7	184	72	250	167	84	1	178	66	243	160	77	255
177	177	148	177	177	177	177	177	177	177	177	177	148	177	177	177	177	177	148	177	177	177	177
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
4163	4340	4488	4665	5020	5197	5397	5374	5551	5728	5905	6082	6230	6408	6585	6762	6939	7116	7264	7441	7618	7795	7972
172	89	237	154	71	249	166	83	260	177	94	11	159	77	254	171	88	5	153	70	247	164	81
177	177	148	177	177	177	177	177	177	177	177	177	148	177	177	177	177	177	148	177	177	177	177
24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
8149	8326	8474	8651	8828	9006	9183	9360	9537	9714	9891	10039	10216	10394	10571	10748	10925	11102	11250	11427	11604	11781	11958
258	175	63	240	157	75	252	169	86	3	180	68	245	163	80	257	174	91	239	156	73	250	167
177	177	148	177	177	177	177	177	177	177	177	148	177	177	177	177	177	177	148	177	177	177	177
47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69

60 years later, is neither. With (b) as starting date we find from Liu and Fiala's *Canon of Lunar Eclipses from 1500 BCE to AD 3000*, that there were 49 eclipses of the moon in the period covered by the table, and every one is within 2 days of the date of a column. The ones near the beginning are mostly correct; several later ones are 2 days early. This may be because the table covers 11,958 days, whereas 405 months average 11,960 days.

Extra: Eclipses in the Americas

Authorities are not agreed on whether the Mayan table refers to eclipses of the sun or eclipses of the moon (or perhaps both). In favor of eclipses of the moon is the fact that there are enough of them for the Mayas to be able to deduce something about their distribution. In favor of eclipses of the sun is the fact that two of the dates in the introduction are dates of the new moon.

Although many writers of programs on television and authors of popular books believe that the Mayas could predict eclipses, few astronomers and Mayanists do. Exceptions are Victoria and Harvey Bricker, in *Current Anthropology* (1983) 24: 1–18.

See Also

► [Calendars in Mesoamerica](#)

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- Many reports of attempts to predict the occurrence of eclipses of the sun and moon are preserved in the histories of non-Western cultures. The majority of these records come from ancient Mesopotamia, ancient and medieval China, and medieval Japan, with a few scattered examples from demotic and Greco-Roman Egypt, India, and the Islamic world (Steele, 2000a). In addition, descriptions of the methods by which the circumstances of eclipses can be calculated are known from China, India, the Islamic World, and Mesoamerica (for the latter, see the entry “► [Eclipses in the Americas](#)”).
- The earliest reports of attempts to predict eclipses are recorded in the correspondence between the Neo-Assyrian kings of Mesopotamia and their scholars during the seventh century BCE (Brown, 2000, pp. 200–206; Hunger, 1992; Parpola, 1993; Steele, 2000b). For example, a letter sent by one Mar-Issar to the king reads (Parpola, 1993, p. 347):
- To the king, my lord: your servant Mar-Issar. Good health to the king, my lord! May Nabû and Marduk bless the king, my lord! May the great gods bestow long days, well being and joy upon the king, my lord! Concerning the lunar eclipse about which the king, my lord, wrote to me, it was observed in the cities of Akkad, Borsippa, and Nippur. What we saw in Akkad corresponded to the other

(observation)s. A bronze ket[tledrum] was set up; the darkness [...] (break) [...] I have extracted the [relevant] interpretation written on the tablet and s[ent] it, together with this letter, to the king, my lord. Moreover, I shall keep watch for the solar eclipse, as the king, my lord, wrote to me. Whether it occurs or not, I shall write to the king, my lord, whatever it may be. This lunar eclipse which took place, afflicted all countries, but all its evil is heaped upon the Westland. “Westland” means the Hittite country (Syria) or, according to another interpretation, Chaldea. With the king, my lord, all is well. However, the guard should not be neglected, and the relevant apotropaic ritual should be performed for the king, my lord.

This letter reveals much about the practice of astronomical observation during the Neo-Assyrian period. The author not only reports his sighting of a lunar eclipse in Akkad but also notes that the eclipse was seen in two other cities, Borsippa and Nippur, and that all three observations were in agreement. The letter also illustrates the serious nature of eclipses in Mesopotamian divination: even though the evil associated with this particular eclipse is directed toward the “Westland,” the king is nevertheless advised to have apotropaic rituals (involving the playing of a kettledrum) performed. Mar-Issar also says that he will keep watching for an upcoming solar eclipse. This reflects an awareness by the Neo-Assyrian scholars that eclipses of the sun and moon often take place half a month from one another: a lunar eclipse in the middle of a month may be preceded by a solar eclipse at the end of the previous month or followed by one at the end of the current month (lunar months beginning with the first visibility of the lunar crescent were used in the Mesopotamian calendar).

Several other letters attest to this awareness of a half-month interval between eclipses of the sun and moon. For example, the report Hunger (1992, p. 502) states:

An eclipse of the moon and sun in Sivan (Month III) will take place. These signs are bad fortune for the kings of Westland and Akkad; and now, in this month of Kislev (Month IX), an eclipse will take place.

The author of this report appears to be saying that during the current month, the ninth of a year,

an eclipse will take place, and this will be followed 6 months later, in the third month of the following year, by both an eclipse of sun and moon. The scholar is referring to the observable fact that the shortest period between visible eclipses of the same kind is 6 months. This circumstance is due to the inclination of the moon’s orbit to the ecliptic; for an eclipse to occur, the moon must not only be in opposition (for a lunar eclipse) or conjunction (for a solar eclipse) with the sun, which recurs after 1 synodic month of about 29.5 days, but also be sufficiently close to the points where its orbit crosses the ecliptic (the ascending and descending nodes), which recurs after half a draconitic month (or a whole draconitic month to return to the same node). Because the draconitic month is a little over 2 days shorter than a synodic month, eclipses do not take place every syzygy. After 6 synodic months, however, the accumulated discrepancy between the synodic and draconitic months will be roughly half a draconitic month, and so at this sixth opposition or conjunction, the moon will now be close to the opposite node, and an eclipse may occur. In fact, however, the average interval for the moon’s elongation at opposition or conjunction to increase by 180° is about 5.86 synodic months. This means that occasionally eclipse possibilities are separated by only 5 months. The existence of eclipse possibilities at 5-month intervals is alluded to in the letter Parpola (1993, p. 45) sent:

Concerning the watch of the sun about which the king, my lord, wrote to me, it is (indeed) the month for a watch of the sun. We will keep the watch twice, on the 28th of Marchesvan (Month VIII) and the 28th of Kislev (Month IX). Thus we will keep the watch of the sun for 2 months.

Understanding the nature of eclipse possibilities marks a crucial step in the development of eclipse theory. Combined with an awareness of long-term eclipse cycles, it provides a means of identifying all eclipse possibilities (months in which an eclipse might occur as opposed to those where an eclipse will definitely not). The most well-known, and indeed most practical, eclipse cycle is the so-called Saros of 223 synodic months (which is very close to 242 draconitic

months), after which eclipses recur with almost the same magnitude and roughly 8 h later in the day. The Saros may very well have been identified and used by the Neo-Assyrian scholars (e.g., Brown, 2000, p. 205; Parpola, 1983, p. 51) although we lack the evidence to be certain (Steele, 2000b). However, we have ample evidence that Late Babylonian astronomers knew and understood the Saros by at least 600 BCE (Steele, 2002).

The knowledge that eclipse possibilities generally occur at 6-month intervals, with occasional 5-month intervals, allows the immediate determination of the number of eclipse possibilities within one Saros period of 223 months as follows: If there are a eclipses at 6-month intervals and b at 5-month intervals with Saros, then the relationship $6a + 5b = 223$ must hold, and so a must equal 33 and b equal 5. It is then a simple step to distribute these 5-month intervals as evenly as possible within the 223 months of the Saros to result in five groups of eclipses each beginning with a 5-month interval and subsequently containing eclipses at 6-month intervals, comprising eight, seven, eight, seven, and eight eclipses. This whole distribution repeats after one Saros, resulting in a large matrix of eclipse possibilities which can then be aligned with observed eclipses to produce a scheme for predicting all future eclipse possibilities (Beaulieu & Britton, 1994; Britton, 1989; Steele, 2000b). Several Babylonian texts are set out in just such a matrix. These include a group of theoretical texts known as “Saros Canon” tablets which contain the months of eclipse possibilities (Aaboe, Britton, Henderson, Neugebauer, & Sachs, 1991) and a remarkable group of tablets that contain a compilation of more than 400 years worth of lunar eclipse observations and predictions put into a Saros matrix (Hunger, 2001, pp. 2–4; see also Huber & De Meis, 2004; Steele, 2001; Walker, 1997). This collection is all the more impressive because over the 400-year period it covers, no eclipses were visible in Babylon that had not been predicted in advance by this matrix scheme.

The Late Babylonian Astronomical Diaries and related texts (Sachs & Hunger, 1988, 1989, 1996) provide evidence that the Saros scheme

described above was used until the end of the cuneiform record, with only occasionally minor realignments to account for the very rare unpredicted eclipses. However, beginning in at least the fifth century BCE, and therefore contemporary with many of the records in the Astronomical Diaries, the Babylonians developed theoretical mathematical methods to calculate eclipses. These developments culminated into two distinct lunar theories, known today as System A and System B (Neugebauer, 1955). Both Systems A and B have as their goal the calculation of the moment of successive lunar syzygies, whether an eclipse will occur at that syzygy, and the date of the first visibility of the lunar crescent which determines the beginning of the month by highly ingenious mathematical schemes which involve separating out the effects of lunar and solar anomaly. However, the two theories differ in how they calculate the various phenomena. For example, in System A, the increase in the moon’s longitude from one syzygy to the next syzygy of the same kind is functionally dependent upon the moon’s position in the zodiac at the previous syzygy (a so-called step function), whereas in System B it is dependent upon the previous increase (a “zigzag function”). In both systems, an eclipse is predicted whenever the moon at syzygy is closest to the node. The node itself is assumed to regress at a uniform rate through the ecliptic (Aaboe & Henderson, 1975), and the moon’s nodal elongation can then be used to gauge the magnitude of an eclipse (Britton, 1989). It remains an open question why these mathematical methods, which admittedly result in predictions that are not significantly better than the Saros methods described above, were apparently not used to make the predictions found in the Astronomical Diaries.

Many aspects of Mesopotamian astronomy were transmitted to India, either through Persia or Greek intermediaries. However, most Indian eclipse theories are founded upon the basic principles of Greek geometrical astronomy (Montelle, 2011). For example, in the *Pañcasiddhāntikā* of Varāhamihira (Neugebauer & Pingree, 1970), a description of five astronomical theories written in the sixth century AD,

we find several methods of calculating eclipses, all of which rely on determining the longitude of the moon and the lunar node at syzygy. If the distance of the moon from the node falls below a certain amount (known as the “eclipse limit”), then an eclipse will take place. The circumstances of the eclipse are then calculated taking into account the effects of parallax.

Remarkably, eclipse theories of the kind reported in the *Pañcasiddhāntikā* were still being used during the eighteenth century in parts of Asia. A report written by Lt. Col. John Warren in 1825 describes his meeting with a Tamil villager who computed a forthcoming lunar eclipse using shells on the ground as counters. He had memorized the tables resulting from Indian eclipse theories in oral fashion, and he was able to predict the eclipse with a remarkable level of accuracy (North, 1994, pp. 165–166).

Many hundreds of predictions of solar and lunar eclipses are reported in the dynastic histories of China (Steele, 2000a). These records, generally found in the *Tianwen* treatises, are often indistinguishable from reports of observed eclipses, simply giving the date of an eclipse. However, study of these dates has revealed that many do not correspond to eclipses that could have been observed in China and so they must have been calculated. Eclipse prediction was one of the most important tasks of the officially promulgated astronomical systems known as *Li* (customarily translated as “calendar”). The *Li* were reformed frequently throughout Chinese history, more often than not for political, rather than astronomical, purposes (Cullen, 1993). Descriptions of these *Li* are found in the calendar treatises of many of the dynastic histories.

The oldest calendars to contain rules for calculating eclipses, the *Santong li*, the *Sifen li*, and the *Qian Xiang li*, date to the Han period (ca. second century BCE to second century CE). All three make use of an eclipse cycle of 135 months. As in Mesopotamia, the eclipse cycle was used to identify all eclipse possibilities, not just eclipses which come 135 months after an observed eclipse. Assuming that the 23 eclipse possibilities within the 135-month cycle are evenly spaced, the mean interval between eclipse

possibilities is $5 \frac{20}{23}$ months. Adding on $5 \frac{20}{23}$ months from the epoch date of the calendar (when it was assumed an eclipse had occurred), keeping the fractions in the running total, but rounding down to find the month of an eclipse allowed the dates of all future eclipses to be calculated (Sivin, 1969).

The first mathematical treatment of eclipses in China is found in the *Qingchu li* of the third century CE (Yabuuti, 1963). Beginning with this calendar, eclipses were calculated by determining whether the moon at syzygy was sufficiently close to a node to produce an eclipse. However, unlike in India, the eclipse limits which were used to determine whether or not an eclipse would occur were not expressed in degrees of longitude but used instead the number of days it would take the moon to reach the node, given by the ratio distance from node/daily lunar motion = x days. For example, in the *Dayan li* a lunar eclipse would occur if x was less than $3523.9/3040$, and if x was less than $779/3050$, the eclipse would be total (Yabuuti). A simple arithmetical formula could then be used to determine the magnitude and duration of the eclipse from the quantity x .

A detailed theory of parallax was never developed in traditional Chinese astronomy; instead a number of semiempirical corrections were added into their calculations to try to account for its effect (Nakayama, 1969, pp. 144–145). However, these corrections were not generally sufficient. For example, in the *Dayan li* corrections were applied to take into account the moon’s declination, but not its hour angle at the time of the eclipse. Similarly, the effect of geographical location was not fully taken into account in Chinese eclipse theory. In the *Dayan li* crude adjustments to the eclipse calculations were introduced to take into account the observer’s latitude, but no corrections were applied for his geographical longitude.

Other countries in East Asia, most notably in Korea and Japan, adopted Chinese eclipse theory, along with many other parts of Chinese astronomy. Often, however, this adoption would lag significantly behind the reforms of the calendar which took place in China. For example, the

Xuanming li was replaced in China in CE 892 but was still being used in Japan until CE 1685. Several hundred reports of predicted eclipses are preserved from Japan. Interestingly, these often include the calculated time and magnitude of the eclipse. Because the calendar did not take into account the difference in geographical longitude between China and Japan, the times are systematically off by about an hour, and the magnitudes of solar eclipses are frequently very inaccurate (Steele, 1998). A rare report which contains both the calculated and observed circumstances of an eclipse illustrates these discrepancies (Steele, 2000a, p. 221):

2nd month, new moon, *dinghai* day [21 February 1319 AD]. The previous night heavy rain fell and a great wind blew. At dawn the wind and rain stopped and the sky cleared. That day the sun was fourteen fifteenths eclipsed. The loss [should have] begun at 4 marks and 17 *fen* in the hour of *mao*, as the calculated time [of the middle of the eclipse] was at 4 marks and 22 *fen* in the hour of *chen*, and [the sun should have] returned to fullness at 4 marks and 27 *fen* in the hour of *si* . . . Investigating at that time (it was seen that) the loss began during the hour of *chen* and it returned to fullness during the hour of *wu*. The calendar gave the eclipse as fourteen fifteenths, but it was only seven fifteenths eclipsed.

Despite these large discrepancies, we have no evidence of any attempts to correct or improve the *Xuanming li* eclipse theory in Japan.

See Also

- [Astronomy in China](#)
- [Astronomy in Medieval India](#)

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Elements: Reception of Euclid's *Elements* in the Islamic World

Sonja Brentjes

Euclid (ca. third century BCE) was a Greek mathematician. His name and his major work, the *Elements*, are famous not only among mathematicians, but also to students of other disciplines.

The *Elements* were sent by the Byzantine emperor from Constantinople to the Abbasid caliph al-Manṣūr (r. 754–775) in Baghdad. We do not know if any of the scholars of his time prepared a translation or at least a summary for him or the scholarly community.

The earliest translation, according to medieval historical sources, was carried out by al-ḥajjāj Ibn Yūsuf Ibn Maṭar (fl. between 786 and 833) for the famous Barmekide Yaḥyā Ibn Khālīd (d. 805), wazir of caliph al-Hārūn al-Rashīd (r. 786–809) or, perhaps, the caliph himself. This translation seems to be lost in Arabic.

Some 20 years later, al-ḥajjāj composed a second Arabic version of the *Elements*, which he dedicated to caliph ► [al-Ma'mūn](#) (r. 813–833). One of those sources reports he did this to gain the caliph's support, because al-Ma'mūn's love for knowledge and his generous attitude toward scholars were well known (Codex Leidensis 399, 1, 1897). To achieve this goal al-ḥajjāj is said to have rewritten the *Elements* extensively with respect to their language, methods, and didactical features for people with

knowledge in and love for this discipline, without changing the contents itself.

Some fragments of his version 2 seem to have been preserved in different forms:

1. As part of a collection of mathematical texts put together in about the sixteenth or seventeenth century in Persia
2. As additions to Arabic translation manuscripts in those parts which transmit by and large the edition of Ishāq Ibn ḥunayn's (d. 910/911) translation by Thābit Ibn Qurra
3. In parts of Book III and the complete Book IV of the preserved Arabic translation manuscripts
4. Perhaps as a variant of books XI–XIII in two of the translation manuscripts; and in a barely recognizable form
5. As parts of a commentary written by ► [al-Nayrīzī](#) probably at the beginning of the tenth century
6. As a paraphrase composed around a hundred years later by Ibn Sīnā (d. 1036)

Those fragments, although they differ in some essential aspects, are characterized by a technical language using expressions from algebra, arithmetic, early logical or theological writings, as well as some words borrowed from Syriac, characteristic of the early translations into Arabic.

Furthermore, two of the Latin translations of the twelfth century, one by Adelard of Bath (so-called version 1), the other ascribed by the editor to Hermann of Carinthia (Busard, 1968, 1977), contain at least extracts, possibly also more, of one of the ḥajjāj versions. It is still an unsettled question as to how close these translations are to an original ḥajjāj text and to which ḥajjāj version they are related. A third possible, but also still disputed, source for the ḥajjāj tradition is the only surviving Syriac fragment of Book I. Finally, some of the Hebrew translations of the *Elements* contain notes which are related to some of the additions ascribed to al-ḥajjāj in the above-mentioned Arabic manuscripts.

Al-ḥajjāj's work, evidently, was crowned by success. In 828/829 he was ordered to translate

the *Almagest*. The scholarly community eagerly accepted his translation and edition. They organized meetings discussing the *Elements*, the *Almagest*, and, probably other subjects. They composed editions and commentaries. Among the earliest works of this type are the editions made by ► [al-Jawharī](#) and ► [al-Kindī](#) (d. ca. 873). Except for short fragments, their texts are lost.

A fresh start was made in the second half of the ninth century. Perhaps because of the shortcomings ascribed to the earlier translation or for some other reasons unknown to us so far, Ishāq Ibn ḥunayn prepared a completely new translation of the *Elements*, probably before 872. Together with his translations of other important mathematical and astronomical texts, it was revised by Thābit Ibn Qurra at about the same time. Yet, we neither know the reasons for nor the extent of those revisions.

The version contained in nearly all preserved Arabic translation manuscripts seems to be this edition – at least in the Books I, II, V, and VII–IX. Other books, however, seem to be based on al-ḥajjāj's work (see above). Most of the Hebrew translation manuscripts as well as the Latin translation by Gerard of Cremona are also derived to a great extent from Thābit's edition. This so-called Ishāq/Thābit tradition exercised the greatest influence upon mathematical research and teaching in the medieval Muslim world until the late thirteenth century. It is characterized by a very literal translation of a text connected with the Greek edition made by Theon of Alexandria (fourth century). It differs in several aspects from the Greek critical edition made by Heiberg (1883). In some cases, Thābit is ascribed variant readings or even whole proofs taken from newly available Greek sources or other Arabic manuscripts, probably derived from the ḥajjāj tradition. In other cases, the differences in text, diagrams, and proofs might well have been already present in the Greek manuscript translated by Ishāq Ibn ḥunayn. This leads to two questions that we are unable to answer at the moment:

1. Did Ishāq follow the methodological rules devised by his father ḥunayn Ibn Ishāq and

collate manuscripts to establish a reliable Greek text or not?

2. Which criteria motivated him in his choice between different variants of the same theorem?

Until the end of the thirteenth century several new Arabic editions based on the two ninth-century traditions were produced. The most successful in terms of later influence were the two ascribed to Naṣīr al-Dīn al-ṭūsī. Only one, however, consisting of 15 books, was composed by him. The other one, which contains only the genuine 13 books of Euclid, was finished in 1298, after al-ṭūsī's death. Both versions replaced the earlier traditions, judging by the number of preserved copies, marginal notes in manuscripts, and references to the *Elements* in mathematical and nonmathematical works.

While the two ninth-century traditions follow the Greek text relatively closely, the two so-called al-ṭūsī revisions are a free rewriting of the *Elements* with respect to language, didactics, proofs, and variations. Proofs are generally abbreviated and condensed, further definitions or lemmata have been added, and for some difficult points new proofs have been provided. Such a free attitude toward a received text by an accepted authority deviated from values characteristic of or defended by the scholarly communities in medieval Islamic societies. It can be observed, nevertheless, since the beginning of the ninth century in nearly all Arabic editions and commentaries on the *Elements*. This is one of the reasons that contemporary research about textual history is so difficult and the study of the mathematical results of the transmission so fruitful.

Although all 15 books of the *Elements* attracted the attention of Muslim scholars, the central points of interest were the parallel postulate (Book I), the definitions of ratio and proportion (Book V), and the geometrical theory of quadratic irrationalities (Book X).

Efforts to prove the parallel postulate started with Greek mathematicians and philosophers, since the form given by Euclid did not fit into their ideas about what an axiom or a postulate

should be. Parts of this discussion were translated into Arabic as Simplikios' (sixth century) commentary on the definitions of Book I and, perhaps, Heron's (second century?) commentary on the *Elements*. Both commentaries are lost in Greek and Arabic. Extracts from both are preserved in a revised form in al-Nayrīzī's commentary on the *Elements*. Extracts from Heron's commentary can also be found in Ibn al-Haytham's great commentary. The Arabic analysis of the parallel postulate started at the beginning of the ninth century with ► [al-Jawharī](#) and other scholars.

The geometers working on this postulate followed two different approaches. One approach, represented by 'Umar al-Khayyām (d. 1131), sought to establish a theory of parallels independent of the Euclidean postulate which would allow them to prove theorem I, 29, the first which Euclid proves on the basis of the parallel postulate, without using this postulate. In modern terms one could call this an effort to establish an absolute geometry. The second approach, represented by al-Jawharī, Ibn al-Haytham, Naṣīr al-Dīn al-ṭūsī, and other scholars, was concentrated solely on proving the parallel postulate.

With respect to Book V the main result of the debate was, however, cautious and reluctantly formulated, the introduction of a new number concept, which enlarged – speaking in modern notions – the Greek concept of numbers as natural numbers (without one) to the positive real numbers (without zero) by 'Umar al-Khayyām and Naṣīr al-Dīn al-ṭūsī. It was developed discussing compound ratios, i.e., the multiplication of ratios, already dealt with by Greek mathematicians. One of the reasons stimulating this research was its use in astronomy. Closely connected was the debate about the proportion theory for geometrical magnitudes. Although Arabic commentators did not reject this theory as wrong, they were dissatisfied with the fundamental definitions V,5 and V,7 about identity of ratios and inequality of ratios. They argued that the equimultiple concept used in those definitions, for instance definition, did not express the essence of a ratio clearly, which in their opinion was the measuring of one quantity by another one. They replaced it by a

definition built upon the so-called Euclidean algorithm or, speaking in modern terms, on the comparison of the expansion of each ratio into a continued fraction. Among the medieval scholars who wrote treatises on it were al-Jawharī, ► [al-Māhānī](#) (ninth century), Thābit Ibn Qurra, and 'Umar al-Khayyām. The latter thought he had proven the equivalence between both theories of proportion, which allowed the use of all Euclidean theorems in Books V and VI in the second theory. Since proportions were of primordial importance for deriving and proving new results in geometry and astronomy, this was an essential project. His proof was based on a theorem that to three proportional magnitudes a fourth proportional always exists. The fundament of his proof for that theorem was a principle attributed to Aristotle about the infinite divisibility of (geometrical) magnitudes. Lacking the notion, not to mention a strict definition, of continuity, this principle, however, was insufficient for his purpose.

The main issue discussed with respect to Book X – which was perceived as the most difficult book of the *Elements* – was the question of how the geometrical magnitudes treated in it were related to the roots of non-quadratic numbers used by algebraists and arithmeticians. To answer this question in a meaningful way meant developing a new conceptual understanding of the objects involved and creating a technical language which made it possible to speak about geometrical and algebraic-arithmetical irrationals on the same mathematical level. After several incomplete trials during the ninth and tenth centuries, the equivalence of the different kinds of geometrical irrationals of Book X and simple as well as compound algebraic-arithmetical irrationals was established in the sense that one type could be translated into the other one. This debate not only brought the heirs of theoretical Greek mathematics together with practitioners trained in Eastern traditions, but it also attracted laymen from other fields, who ordered – at least until the fourteenth century – copies of such commentaries on Book X, asked for explanations of their contents, and were proud to possess them.

See Also

- ▶ [al-Jawharī](#)
- ▶ [al-Kindī](#)
- ▶ [Almagest: Its Reception and Transmission in the Islamic World](#)
- ▶ [al-Māhānī](#)
- ▶ [al-Nayrīzī](#)
- ▶ [Ḥunayn Ibn Ishāq](#)
- ▶ [Ibn Al-Haytham \(Alhazen\)](#)
- ▶ [Ibn Sīnā \(Avicenna\)](#)
- ▶ [Naṣīr al-Dīn al-ṭūsī](#)
- ▶ [Thābit Ibn Qurra](#)
- ▶ [Umar al-Khayyām](#)

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Embalming in Egypt

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Embalming is the artificial preservation of the body. In Egypt, the first examples date to Late Predynastic times (late fourth millennium BCE), when the tight wrapping of the corpse is first found at the site of Hierakonpolis. Prior to this, bodies were simply laid in graves in the desert, where in some cases the hot and dry conditions promoted the natural desiccation of the body, producing a wholly natural "mummy" (Fig. 1).

It has been generally assumed that it was the observation of such corpses that led to the Egyptians developing artificial methods once the introduction of proper tombs divorced the body from the natural preservative environment. It has been further surmised that the motivation so to do was derived from a belief that physical preservation of the body was required for the successful

Embalming in Egypt,

Fig. 1 Naturally preserved mummy, now in the Egyptian Museum, Turin (Photo by author)



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existence of the spirit in the next world. However, there are no explicit statements of this in the ancient texts.

During the Early Dynastic Period and Old Kingdom (ca. 3000–2200 BCE), the emphasis was on the exterior appearance of the completed mummy. Each limb was separately wrapped, and a layer of plaster applied to the outer layer, enabling the modeling of the facial features, genitalia, and other elements. On occasion, the finished body was dressed in real clothing. The body was invariably placed on its left side, initially with the legs drawn up tightly against the body, later in a more relaxed, mildly flexed, pose (Figs. 2 and 3).

At the same time, the first moves toward the preservation of the actual corpse itself were made. The internal organs, a key source of putrefaction, were sometimes removed and placed in four “canopic” jars and/or a chest (Figs. 4 and 5). The viscera were ultimately under the protection of four particular deities: Imseti (liver), Hapy (lungs), Duamutef (stomach), and Qebehsenuef (intestines). The heart was always left in the body: according to Egyptian belief, it was the seat of intelligence and thus needed to remain in place.

The organs were desiccated using natron – a mixture of sodium bicarbonate, sodium carbonate, sodium sulfate, and sodium chloride. It is found naturally in Egypt, most commonly in the Wadi Natrun some 64 km northwest of Cairo. This material came to be fundamental to the embalming process, and by the end of the Old Kingdom, the key activity in the mummification



Embalming in Egypt, Fig. 2 An early Fourth Dynasty crouched mummy, from Medium and now in Bristol City Museum and Art Gallery (Photo by author)

process was the placement of the body on a stone slab, upon which it was covered with powdered natron for approximately 40 days to facilitate desiccation, with probably at least one change of natron during that time, as a batch became saturated with bodily fluids. By tradition, the entire mummification process was supposed to take 70 days, although there are known examples of its taking longer. While it is clear that powdered natron was the normal means of

Embalming in Egypt, Fig. 3 Plaster layer from a Fifth Dynasty mummy from Giza, now in the Museum of Fine Arts, Boston, Massachusetts (Photo by author)



Embalming in Egypt, Fig. 4 Twelfth Dynasty canopic chest from Dahshur, now in the Cairo Museum (Photo by author)

desiccation, recent work has suggested that a bath of a natron solution may have been used during the late Eighteenth Dynasty for some royal mummies.

By the beginning of the Middle Kingdom (ca. 2100–1700 BCE), there had been major changes in the external presentation of mummies. Rather than having their limbs separately wrapped and left visible, the plaster was omitted and extra layers of padding and wrappings added to make the mummy essentially cylindrical, with a mask placed over its head and shoulders. These changes coincided with the rise to the prominence of Osiris as god of the dead and made the corpse into a simulacrum of the god (Fig. 6) which now lays fully stretched out, albeit still lying on its left side, facing east (Fig. 7).

As far as the physical body was concerned, a fair degree of experimentation is seen during the Middle Kingdom. Many were eviscerated in what was to become the traditional fashion, via an incision made in the left flank. There were, however, several mummies that seem to have been treated with an enema of tree oil, most probably juniper or turpentine. This partially dissolved the viscera, the remains of which seem to have been extracted anally. The skin, desiccated with natron, was sometimes coated with resin. Brains were generally left in place, but in some cases were removed via the nose. To do so, the ethmoid bone at the back of the nose was broken through and a probe used to break up the decaying brain tissue, which was then allowed to drain out of the nostrils. The cavity would often be filled with linen and/or resin.

It was during the New Kingdom (ca. 1550–1070 BCE) that mummification reached its “standard” form. Brain removal and organ extraction through the flank became usual in high-status interments, although some bodies retained their brains. Natron treatment often produced excellent results, particularly demonstrated by the considerable number of royal mummies that have survived. Resin was lavishly employed and, as well as being poured, via the nose, into the emptied cranium, was frequently applied to the face and body and molded into little balls and used to plug the ears and, occasionally, the anus. It should be noted, however, that simple wrapping with linen was still practiced in the middle and lower ranks of society, as had always been the case and always would do.

Various ritually protective items were increasingly placed on the body during the New

Embalming in Egypt,
Fig. 5 Canopic jars of
King Taharqa (Twenty-
Fifth Dynasty) from Nuri,
and now in the Museum of
Fine Arts, Boston,
Massachusetts (Photo by
author)



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Embalming in Egypt,
Fig. 6 Osiris, god of the
dead, with the genii Imseti,
Hapy, Duamutef, and
Qebehsenuef in front of
him, and his sisters Isis and
Nephthys behind him. This
vignette comes from the
Book of Dead papyrus of
Hunefer in the British
Museum (Photo by author)



Embalming in Egypt,
Fig. 7 Wrapped mummy
 of Ukhhotep (Twelfth
 Dynasty) from Meir, and
 now in the Metropolitan
 Museum of Art, New York
 (Photo by author)



Embalming in Egypt,
Fig. 8 Protective plate
 from the embalming wound
 of Queen Henttawi
 (Twenty-First Dynasty),
 now in the Cairo Museum
 (Photo by author)



Kingdom and later. For example, a stone beetle (the “heart scarab”) was placed above the heart, and an ornamented plate over the embalming cut in the flank. Various other amulets might also be placed within the wrappings, to surround the body with ritual protection (Fig. 8).

By the Twentieth Dynasty (ca. 1190–1070 BCE), a number of innovations began to appear. Lichen and sawdust began to be used to pack out the abdomen, while small onions were sometimes placed in the eye sockets, all to impart a more lifelike appearance to the emaciated corpse (Fig. 9). This was taken further during the next dynasty, when elaborate packing began to be placed under the skin (Fig. 10).

Typically, the body cavity was filled via the evisceration cut, through which the back was also dealt with. Often, through this same cut, the neck area was filled with semiliquid mud or sawdust. The thighs were also accessible from this incision

with the aid of sticks to push the filling down, although sometimes they were filled from a cut made in the back of the knees, an incision that was generally used to fill the calf. Some mummies show vertical incisions for stuffing in each buttock, with incisions at the ankles used to stuff the feet. Arms were packed through horizontal incisions made in the ventral and dorsal sides of the shoulders and sometimes in the elbows. To complete the effect, makeup was applied to the face, false eyes fitted, and hair enhanced with hair extensions.

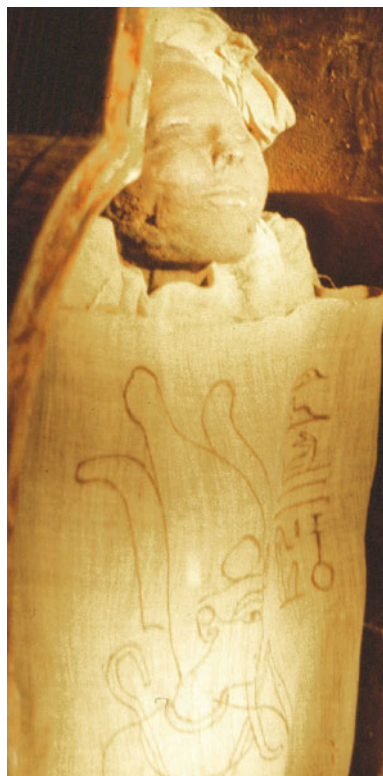
A further change, which started to appear during the Twentieth Dynasty, was the return of the viscera to the body after their separate desiccation, often accompanied by wax images of the four protective genii (Fig. 11). Interestingly, although now without a physical function, canopic jars were often retained as purely ritual objects, ultimately becoming solid.



Embalming in Egypt, Fig. 9 Face of the Twentieth Dynasty mummy of King Ramesses IV (Cairo Museum), which has small onions acting as false eyes (Photo by Martin Davies)

The stuffing of the body was fairly short lived and had largely disappeared by the end of the Twenty-Second Dynasty, although the body cavity was still generally filled with earth and sawdust. There was a revival in the placement of the viscera in canopic jars during the Twenty-Fifth Dynasty (ca. 720–663 BCE), but during the Saite and Late Periods (663–332 BCE), the visceral packages were placed between the thighs or lower down, between the legs.

During the Graeco-Roman Period (from 332 BCE), there was a gradual decline in the quality of embalming. A typical feature of mummies of the first century BCE and first century AD is the heavy use of liquid resin both inside the body cavity and on the surface of the body. The third and fourth centuries AD show that the bodies were neither eviscerated nor de-brained, but thickly covered with resin. One innovation of the Early Roman Period, however, was the gilding of the mummy. Fingers, toes, eyelids, lips, hands, feet, genitals, and on occasion the



Embalming in Egypt, Fig. 10 The mummy of the High Priest of Amun, Masaharta, showing the packing typical of the Twenty-First Dynasty. It is now in the Museum of Mummification, Luxor (Photo by author)

entire body were covered with a fine layer of gold. Another interesting feature of the Roman Period is the arm position found on many mummies. For the vast majority of Egyptian history, arms had been placed at the sides. However, the crossed pose is found on occasion during the Middle Kingdom and, in particular, on the mummies of the kings of the New Kingdom. The pose – associated in particular with the god Osiris – was then revived in Roman times and is found in a large number of burials.

Mummification effectively came to an end with paganism, although there are a few examples of mummies that clearly belong to Christians. The creeds of Christianity and Islam took a very different view of the role of the corpse, bringing to an end three and a half millennia of development.

Embalming in Egypt,
Fig. 11 Wax images of the four protective genii, as placed inside the body cavities of Twenty-First Dynasty mummies alongside the viscera, now in the British Museum (Photo by author)



Embalming in Egypt,
Fig. 12 Mummy of a ram, sacred to the god Khnum and buried in his temple at Aswan, now in the Louvre Museum, Paris (Photo by author)



Mummification was not restricted to human beings. At all periods of Egyptian history, many gods had an animal form, and a representative of that creature would be kept in a temple as an incarnation of the god. These were often embalmed after death using similar methods to those employed for humans (Fig. 12); pets of high-status individuals were also mummified. In Late and Graeco-Roman times, the production of animal mummies was greatly expanded to provide

votive offerings for sale to pilgrims. In these cases the external appearance of the mummy was most important, and the actual embalming could be poor. Indeed, some such “mummies” could contain minimal animal remains, or be wholly fake.

See Also

► [Animal Mummies](#)

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Embroidered Textiles in China

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Embroidery can be traced far back in time in China and has developed different categories in

different areas, and many excellent embroiderers have emerged during a long period.

The History of Embroidered Textiles in China

Generally, embroidered textiles in China went through five important stages.

The Pre-Qin Period (Before 221BC)

Folktales say that embroidery was created by Shun at a very early time. According to a historical record, the singing and dancing girls at the court of King Xia Jie were dressed in embroidered clothes, and the nobility wore white clothes with red embroideries, while the king had embroideries on his skirts in the Shang and Zhou dynasties (1600–221 BC) (Peichu Zhu, 1987). Traces of embroidery executed in chain stitch have been found in a tomb dated to Western Zhou (1046–771 BC) found in Baoji, Shaanxi province. In the Warring States Period (475–221 BC), the technique of embroidery greatly developed, which can be proved by the examples from No.1 tomb found in Mashan, Jiangling, Hubei province (Fig. 1).

During the Qin and Han Period (221 BC–220 AD)

The nobility in this period used a lot of embroidery. In addition to embroidered clothes, there were bed curtains embroidered with gold threads, and when the minister Huo Guang died, the emperor gave him a hundred embroidered quilts. Embroidery was also given to the minorities in the northwest of China as gifts. As the waste in embroidery increased, some emperors enacted ordinances banning the use of embroidery. From No.1 tomb found in Mawangdui, Changsha, Hunan province, a lot of exquisite embroideries dated to Western Han have been unearthed, most of which were executed in chain stitch, consisting of three major categories: *Changshou* embroidery (Fig. 2), *Xinqi* embroidery (Fig. 3), and *Chenyun* embroidery (Fig. 4) (Min Wu, 1992). In addition, embroideries dated to the end of Western Han to Eastern Han (25–220 AD) have

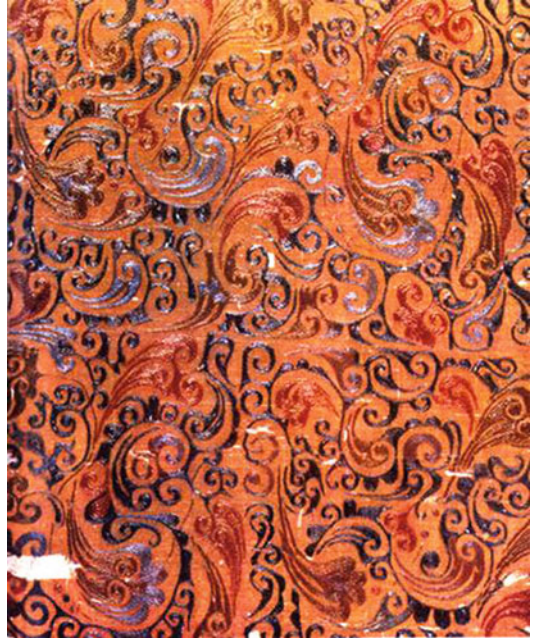


Embroidered Textiles in China, Fig. 1 Embroidery with phoenixes, dragons, and tigers from No.1 tomb found in Mashan, can get more details by visiting <http://big5.huaxia.com/jztb/jzsh/wwjh/2009/05/1438923.html>

been found in Xinjiang and Gansu province (Yanghua Kuang, 2013).

During the Sui and Tang Period (581–907 AD)

Up to 30,000 singing or dancing girls in the pleasure ground in the capital of Sui (581–618 AD) were dressed in embroidered clothes as it was recorded. In the Tang dynasty (618–907 AD), embroidery executed with colored silk threads and gold threads in satin and couching stitches was favored, showing a luxuriant effect. The pattern was mostly flowers in a naturalistic style. Besides being dressed by nobilities, officials, and showgirls, emperors gave embroidered clothes to meritorious ministers as awards. Embroidery used for Buddhism had greatly developed, most of which were used as ornaments in temples for Buddhist images and



Embroidered Textiles in China, Fig. 2 Changshou embroidery from No.1 tomb found in Mawangdui, can get more details by visiting <http://amuseum.cdstm.cn/AMuseum/silk/ys010302.html>

banners. Embroideries of Tang were mainly found in the Mogao Grottoes in Dunhuang, Gansu province (Feng Zhao, 2007, 2010) (Fig. 5), and the underground repository of Famen Temple in Fufeng, Shaanxi province (Fig. 6) (Feng Zhao, 1999).

During the Song and Yuan Period (960–1368 AD)

At the court of Song (960–1279 AD), embroideries were widely used for ceremonial items such as robes, sedan chairs, canopies, and banners. In the capital of Song, in addition to professional embroiderers, nuns were also engaged in embroidery. The painting art of Song boomed under the encouragement of emperors, and the flower-and-bird painting had a great influence on embroidery. In the Yuan dynasty (1206–1368 AD), embroidery executed with gold and silver threads was favored. On a jacket unearthed from the ancient ruins in Jining, Inner Mongolia, there

Embroidered Textiles in China, Fig. 3

Xinqi embroidery from No.1 tomb found in Mawangdui, can get more details by visiting <http://amuseum.cdstm.cn/AMuseum/silk/ys010301.html>



Embroidered Textiles in China, Fig. 4 *Chenyun* embroidery from No.1 tomb found in Mawangdui, can get more details by visiting <http://amuseum.cdstm.cn/AMuseum/silk/ys010303.html>

are more than 90 patterns embroidered with gold threads in couching stitch, including a crane, phoenix, rabbit, and fish (Fig. 7). In addition, pearls were also usually used for embroidery in this period.

During the Ming and Qing Period (1368–1911 AD)

The pattern embroidered on ceremonial robes was standardized in this period, for example, the dragon and phoenix were used for emperors and empresses, and bright birds and brave beasts were used for officials. Collecting fine embroidery became a fashion among upper-class people during the Ming dynasty (1368–1644 AD). Therefore, many women in officials' families were excellent in embroidery, especially the women of Gu Mingshi's family (the embroidery made



Embroidered Textiles in China, Fig. 5 Embroidery with Sakyamuni preaching on the Vulture Peak from cave 17 in the Mogao Grottoes (now in the British Museum collection), can get more details by visiting <http://www.baohuasi.org/gnews/2013714/2013714287314.html>

by women of Gu's family is also known as Gu embroidery). In the Qing dynasty (1644–1911 AD), embroidery developed rapidly in Suzhou, Changzhou, and Yangzhou in Jiangsu province, Changsha and Ningxiang in Hunan province, and Guangzhou and Chaozhou in Guangdong



Embroidered Textiles in China, Fig. 6 Embroidery with clouds executed in couching stitch with gold threads unearthed from the underground repository of Famen Temple, can get more details by visiting <http://hi.baidu.com/zxx59/item/d0ae16898d0427c299255f22>



Embroidered Textiles in China, Fig. 8 Su embroidery, can get more details by visiting <http://gb.cri.cn/3601/2004/06/24/342@208338.htm>



Embroidered Textiles in China, Fig. 7 A jacket embroidered with more than 90 patterns from Jining, Inner Mongolia, can get more details by visiting http://www.china.com.cn/aboutchina/zhuant/zgsc/2008-02/25/content_10680824.htm

province, most of which were exported into Japan, Southeast Asia, Europe, and America.

Four Great Chinese Embroideries

Especially in the Qing dynasty, embroidery in different areas has greatly developed and formed different categories, and the most famous four are Su embroidery, Xiang embroidery, Yue embroidery, and Shu embroidery.

Su Embroidery: Delicate and Elegant

Su embroidery ranks first of these four embroideries. It is a name for the embroidery produced

in Suzhou and the neighboring areas in Jiangsu province. Generally, Su embroidery consists of satin stitch embroidery and double-sided embroidery produced in Suzhou; random-stitch embroidery produced in Changzhou, Danyang, and Baoying; embroidery produced in Nantong; ancient-style embroidery produced in Yangzhou; and embroidery executed with hair in Dongtai. The traditional motifs of Su embroidery are cats (Fig. 8) and goldfishes, mostly being executed in long and short stitch with silk threads in different shades of a color to create a vivid effect (Peilan Sun, 1982).

Xiang Embroidery: Modest and Graceful

Xiang embroidery is a general name for the embroidery produced in Changsha and neighboring areas in Hunan province. It developed from the folk embroidery of Hunan and was greatly influenced by Su embroidery and Yue embroidery. Xiang embroidery pays a lot of attention to sketch; therefore many painters are also involved in the embroidery, and their sketch inherits the naturalistic attributes of the painting of the Song dynasty. The traditional motifs include lions (Fig. 9), tigers, and squirrels, among which the tiger is the most common, being executed in a special stitch – *pengmao* stitch – in a naturalistic style and showing an influence from traditional Chinese painting (Minne Zhou & Feiyue Zhou, 2004).



Embroidered Textiles in China, Fig. 9 Xiang embroidery, can get more details by visiting <http://www.worlduc.com/blog2012.aspx?bid=12560615>

Yue Embroidery: Colorful and Gorgeous

Yue embroidery is a general name for the embroidery produced in Guangdong province, consisting of Guang embroidery produced in Guangzhou and Chao embroidery produced in Chaozhou. Since the Portuguese took it back home and got a reward from the court in the Ming dynasty, Yue embroidery became an important export commodity. Embroiderers engaged in Yue embroidery are mostly male. The silk threads used for Yue embroidery are strong in color, and peacock feathers and horsehair are also used as threads to create a colorful and gorgeous effect (Liming Shao, 2002). The traditional motifs of Yue embroidery include dragons and phoenixes (Fig. 10).

Shu Embroidery: Lively and Vivid

Shu embroidery refers to embroidery produced in Sichuan province, which is famous for quilts of



Embroidered Textiles in China, Fig. 10 Yue embroidery, can get more details by visiting <http://baike.sogou.com/v8904.htm?ch=ch.bk.innerlink>

satin damask with embroidered dragons and phoenixes. Shu embroidery is rich in stitches and totally there are 122 stitches in 12 categories. Traditional motifs include roosters, carp (Fig. 11), and hibiscus (Min Zhao, 2011).

Excellent Embroiderers

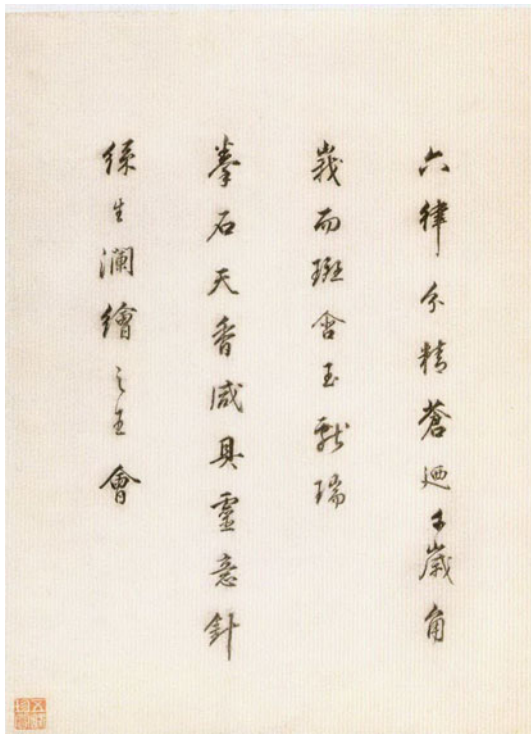
Most of the great embroiderers are female, using needles as brushes, threads as pigments, and textiles as papers to create beautiful “paintings.” Two highly important ones are introduced here.

Han Ximeng

Han Ximeng is a representative artist of Gu embroidery. She is Gushiming’s granddaughter-in-law and especially good at recreating famous paintings by embroidery. She recreated eight famous paintings of the Song and Yuan dynasties (Fig. 12), which were highly appreciated by Dong Qichang (a most important painter in the Ming dynasty). Twenty works or so have survived and are collected in the Palace Museum and Shanghai Museum (Shanghai Museum, 2007).

Embroidered Textiles in China, Fig. 11

Shu embroidery, can get more details by visiting <http://photo.chengdu.cn/bbs/thread-173543-1-1.html>



Embroidered Textiles in China, Fig. 12 A famous painting recreated in embroidery by Han Ximeng, can get more details by visiting <http://www.youshuhua.com/index.php?a = show&m = Works&id = 5282>

Shen Shou

Shen Shou is a representative of Su embroidery. Her works are characterized by using light and shadow, which was learned from Japanese embroidery and painting in the West (Fig. 13). Shen Shou is also a well-known educator in embroidery. In 1914, she established an

embroidery school in Nantong and nurtured about 160 students, including famous embroiderers such as Song Jinling and Wu Yu. She is also a theorist in embroidery, and in her old age, she dictated her lifetime experience to Zhang Jian and finally formed the masterpiece of embroidery, *Xuehuan xiupu*.



Embroidered Textiles in China, Fig. 13 An embroidered image of Jesus made by Shen Shou, can get more details by visiting http://www.airchinanews.com/imerl/article/20080703/11778_2.shtml

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Engineering

Arnold Pacey

Engineering has become the paradigm or model for almost all technology in the West, hence terms such as “genetic engineering”, or “systems engineering”. Applied to the non-Western world, this use of language can be grossly distorting, preventing recognition of other paradigms. Thus the word “engineering” is best limited to construction works and related mechanical devices. Moreover, the smallest of such works, as carried out by individual house builders or farmers practicing irrigation, may often be better considered in other contexts, such as “building” or “agriculture”.

Three kinds of construction works need to be considered, namely those related to fortifications, monuments, and water management. Methods of construction were nearly always labor-intensive, so various ways of organizing a labor force are important for understanding what was involved. In Southeast Asia, for example, irrigation systems for rice culture were often built by groups of farmers working cooperatively. Thus on the island of Bali, there was a social unit known as a *subak* comprising all the farmers whose fields were watered from the same source, who had to come to a mutual arrangement about regulation of water flow, repairs and new construction.

By contrast, very large construction works were usually carried out by order of a king or emperor, supervised by state officials, and using conscript or *corvée* labor. An example is the New Bian Canal in China, completed in AD 635, on which five million people were said to have worked at different times.

The organization of labor, supervision of construction, and payment for materials might take other forms if the work was being done for a rich villager or other notable, or if it had been initiated by a religious community based at a temple. The latter were often very important, and in China, Buddhists helped pioneer the use of iron in bridge building as well as in the architecture of temples

between AD 500 and 1200. Buildings for religious or funerary purposes were also built at the instigation of rulers, often on a very ambitious scale. One thinks of the pyramids of Egypt, Maya temples in Central America, and numerous temples in India and Southeast Asia.

Such buildings could be linked to apparently utilitarian engineering works. The temples of Angkor in Cambodia, founded about AD 880, were built on mounds created by the excavation of large reservoirs or tanks that were part of a system for supplying water for rice culture, and were also linked to a system of transport canals. Stone for building the temples was brought to the site along these canals. The irrigation works reached their fullest extent by about 1150, after which environmental damage – the formation of a ferrous hard pan – seems to have contributed to their decline.

Other remarkable works of hydraulic engineering include large reservoirs with elaborate systems of feeder canals in Sri Lanka, where some canals pass through tunnels from one catchment to another. These systems evolved slowly from about 200 BCE to AD 1300, and like the works at Angkor, may have had monumental as well as utilitarian significance. There were also early canal irrigation systems in India, and in Iran there was a specialized technique for tapping groundwater known as the ► [qanat](#).

In the Americas, there were the impressive Chicoma canals in Peru and the dikes in the former Lake Texcoco built by the Aztecs to separate artificial cultivated islands (*chinampas*) from the salty water of the main body of the lake. The Aztec capital of Tenochtitlan adjoined this system of islands and dikes.

Reviewing early engineering along these lines leaves one with a strong impression of its connections with agriculture, especially where irrigation or other water control was necessary, and indicates the frequent role of state or government authorities with their interest in using engineering also for religious or monumental constructions. The latter were important in demonstrating and legitimizing the authority of the state and its ruler.

This view of engineering can be interpreted in terms of the theory of “hydraulic civilization”

associated particularly with the work of Karl Wittfogel. According to him, the food requirements of growing populations made it essential to develop centralized states capable of organizing large-scale irrigation works. Thus hydraulic engineering is seen as primary, with many other forms of large-scale engineering developing from it. The importance of irrigation in much of Asia, in Egypt, and in parts of Central America seems obvious, and it is at least plausible to think that the necessity for such irrigation works was a driving force for innovation in engineering techniques and for growth of government organizations capable of managing them.

An alternative interpretation of world history arises from the argument that military power emerged for the first time as a distinct force in human affairs – as opposed to an occasional and ad hoc assembly of fighting men – toward the end of the Neolithic, not long before 3000 BCE. Proponents of this view point out that it was in states that expanded as a result of the growth of organized military power that engineering developed most rapidly. The earliest examples were in Mesopotamia and Egypt, but there were parallel developments in many other parts of Asia, notably with the rise of the first Chinese dynasties. Later on, the emergence of empires in Central America and Peru can be seen as having a roughly similar technological outcome. By contrast, kingdoms that remained small, tribal societies, and isolated communities of cultivators and pastoralists had different kinds of technology that hardly involved engineering at all. What may have made the difference was that the experience of creating and commanding armies provided a model for recruiting, organizing, and disciplining the labor force needed to construct fortifications and other large-scale works. In this view, then, military engineering was primary, and monument building and hydraulic engineering were extensions of the same basic techniques into other areas that interested rulers and their officials.

► [Military technology](#), of greater or lesser significance depending on which of these interpretations is adopted, is the subject of a separate article in this volume. Looking in more detail at the civil branches of engineering, we may note

that state officials often played a part in surveying and supervising works, and typically had a good knowledge of the mathematics needed for laying out sites or estimating quantities. The first pyramids in Egypt were accurately square and were built on carefully leveled foundations. Centuries later, Chinese bureaucrats studied books on arithmetic that told them how to calculate quantities and estimate volumes of earth-moving needed on construction sites – but books on machines were rare.

Much early engineering involved the excavation of canals or the building of earthworks in the form of fortifications, dikes, irrigation terraces, or dams, with few striking innovations beyond increases in scale, surveying methods, or the use of gabions (wickerwork containers of stones) in China. Where irrigation canals needed gauging weirs or distribution boxes to divide the flow equally between several farmers, some intriguing designs were developed in Iran, many of them made of stone.

The earliest engineers used stone in construction long before iron tools were available, so that quarrying and dressing the material presented considerable problems. In Egypt, the pyramid builders used wedges and dolerite hammers to work limestone, and the architect and minister of state Imhotep, who was active around 2660–2650 BCE, was credited with the invention of building in stone. Transport was by barge where possible and then on sledges hauled along lubricated wooden tracks. In the absence of pulleys or any other lifting gear, stones were raised by hauling up ramps.

In the Americas, the most remarkable engineering in stone was the terracing and building accomplished by the Incas in Peru. As in Egypt, there were no iron tools, but stones of quite hard rock, including granite, were shaped by grinding until they fitted together very precisely. In the Americas, as in ancient Egypt and many other parts of the world, sun-dried mud brick provided a further option for the construction of buildings and fortifications. A notable example is the fortress of adobe brick at Paramonga, in the lowlands of Peru. In West Africa, mud or clay was sometimes used rather as modern architects use

concrete, to form domes and shell-vaults (for example, at Zaria in northern Nigeria). City walls of mud brick (adobe) date back to the twelfth century AD at Kano (also Nigeria). They were extended twice in later centuries to encircle a 17-km perimeter, and in 1903 successfully withstood cannon fire from the British army.

While much hydraulic engineering depended on earthworks, spillways needed to be faced in stone to prevent erosion, and a dam designed so that overflow water could pass over its crest would usually need to be stone-faced throughout. A fine example was the long, low Cauvery River dam, built to serve an irrigation system in the Chola Kingdom of South India. It was built of masonry laid in clay around AD 200. At about the same date, Persian engineers were using iron dowels set in lead to fix together the massive stones they used in facing some of their dams, and also poured molten lead into the space between stones.

Looking back to an earlier age to consider mechanical aids for construction, one should note that the movement of large blocks of stone along the ground on rollers was not a simple procedure, and was rarely practiced in Egypt. However, the consensus remains that the invention of the wheel derived from experience with rollers, perhaps in Mesopotamia. There, at any rate, wheeled vehicles were in use by 2500 BCE. Moreover, in conformity with the view that [military technology](#) was the leading sector in engineering, the first known examples were on chariots and army supply vehicles.

The development of mechanical engineering from that time on is hard to document in detail. Some commentators stress the emergence of mechanisms involving wheels or rotary motion, such as the pulley (by 800 BCE) or the first toothed gears, probably made in the eastern Mediterranean regions soon after 500 BCE. Another approach is to notice the importance of three main kinds of mechanical development – firstly, a slow evolution of levers, pulleys, and hoists for lifting stone on construction sites; secondly, the development of siege engines, catapults, and other military hardware; and thirdly, the evolution of water-raising devices, sometimes for

drawing water from wells, but sometimes also to supplement irrigation from canals or rivers.

One kind of mechanical water-raising device was the chain-of-pots. The simplest form of this may have originated before 100 BCE as a “necklace” of pots hanging over a roller or pulley which was hauled around manually. The bottom of the necklace dipped in water, and as it was pulled round, pots filled at the bottom, and then were tipped over the roller at the top to empty into a trough. An animal-power version, driven through wooden gears, and with a large wheel replacing the roller or pulley, developed five or six centuries later. Known as the *saqiya* or “Persian wheel”, it came to be widely used in North Africa, the Islamic countries, India, and China. For example, as recently as 1904 some 4,000 were recorded in the Dongola province of Sudan, each irrigating about 15 acres (6 ha).

Other mechanical water-raising devices include the pedal-driven “dragon spine” pump used in Chinese rice culture, and the *noria*, a water wheel with containers attached to its rim, powered by the flow of a river. The latter was known in western Asia by 100 BCE and also has a long history in India and China extending into the twentieth century. Other water-raising mechanisms used in modern peasant cultures have included a form of Archimedean screw in Vietnamese rice paddies and lever-based devices in Indonesia.

The first water-powered mills for grinding corn were adapted to mountainous areas with streams rushing down steep gullies, and their design was perhaps suggested as much by experience of the potter’s wheel as also undoubtedly by the *saqiya* and *noria*. Thus we might expect the first water mills to have been made in a mountainous district where there were people with experience of all these devices and also where there were quarries producing millstones for rotary hand-mills. These considerations support evidence indicating that Iran or Iraq is the place of origin of the water mill some time prior to 350 BCE. There were quarries known for their millstones both in Iran, and on the upper Tigris, in a region now in Turkey.

The mills invented at this date had horizontal, propeller-like water wheels that drove the

millstones directly, and it appears that they were so effective that they were soon adopted in southern Europe and also China. Later, this type of corn mill was used in northern European countries (where it became known as the “Norse mill”), and most notably in the foothills of the Himalayas, especially in Nepal.

The alternative type of water mill which has a vertical water wheel driving the millstones through the wooden gears developed later, and had a more restricted distribution. However, it is noteworthy that it used the same kind of gears as the more widespread animal-powered *saqiya* or Persian wheel, namely “peg and lantern” gears, i.e., a wooden crown wheel with projecting peg teeth on the same horizontal axle as the water wheel meshed with a lantern pinion on the vertical axle.

Almost the only non-Western countries in which this type of gearing was developed beyond the basic corn mill or Persian wheel format were Iran, Iraq, and Syria in western Asia and China in the East. It is striking how little mechanical devices of this kind were used elsewhere. However, in western Asia and China, a considerable variety of water-powered (and animal-powered) machinery was developed, including machinery associated with papermaking and sugar refining, and windmills were also used, all before AD 950. In preparing pulp for papermaking, for example, water wheels turned cam shafts which operated trip hammers. On a smaller scale, experiments were also made with geared astrolabes and clock mechanisms, and in China, an astronomical clock powered by a slow-running water wheel was made by Su Song in the 1080s. At about the same time in Chinese industry, water-powered bellows provided the draught for a few of the many iron furnaces, and water-powered spinning mills were evolving in districts that produced the coarser kinds of textiles.

One distinctive feature of Chinese machinery (as compared with practice in the Islamic world) in the period up to AD 1300 was a preference for using an endless rope running over pulleys for transmission of power from water wheels, instead of gears and shafts. A comparable contrast in style and practice in the West occurred in the

nineteenth century when American designers of New England textile mills favored rope drives from water wheels or turbines to different parts of a mill, whereas European millwrights still preferred gears and shafting.

In conclusion, it is worth observing that although a steady development of engineering can be discerned in several parts of Asia up to about AD 1200, it is hard to identify major innovations dating from after that time. Engineering was never the most important branch of technology over much of that continent, but even where it had developed strongly there was little further progress. One factor was undoubtedly the devastating Mongol conquests of Iran, Iraq, and China, completed by 1260, and then the European conquests that were beginning in 1500. The Mongols destroyed irrigation systems in parts of northern Iran, and allowed others to decay, thus undermining the basis of much engineering in that region. However, it is difficult to believe that conquest and political disruption are the whole story, and one must also look to institutional and economic factors that are beyond the scope of this article.

Another general point is that by concentrating on the civilian uses of technology and leaving the military aspects for separate treatment, this article inevitably demonstrates the great importance of hydraulic engineering. This may seem to justify the idea that many non-Western societies were “hydraulic civilizations.” However, we probably need to be more aware of the many mechanical and structural ideas originating from the experience of building siege engines, chariots, city defenses, moats, and forts. Maybe, too, we ought to appreciate that military engineers traveled more than their purely civilian counterparts and probably contributed more to the spread of ideas. In the third century AD Persian rulers employed a captured Roman army on a dam-building project, presumably learning a little of Roman engineering in the process. In AD 751 a battle between Chinese and Islamic forces in Central Asia led to the employment of Chinese experts on papermaking in Samarkand, and resulted in the transfer of papermaking technology into the Islamic world.

However, the most important point we tend to neglect is that the organization and discipline of armies seem likely to have been a model, at many points in Western, as well as non-Western history, for the organization and management of civilian technology, especially large-scale construction projects.

See Also

- [Building Construction](#)
- [Clocks and Watches](#)
- [Military Technology](#)
- [Qanat](#)
- [Technology in the Islamic World](#)

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Environment and Nature in Africa

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Africa's location astride the equator subjects the continent's environment to tropical and

subtropical conditions. Mean temperatures range above 15 °C in the winter and above 25 °C in the summer. During the northern summer the weather is hot and wet over Central Africa and the Guinea coast, arid conditions prevail over northern and most of southern Africa, and the east coast is affected by the southwest monsoon. During the northern winter the Sahara and the Mediterranean are affected by the westward flows of warm dry air, and the northeast monsoon regulates the weather over the east coast; warm rainy conditions prevail elsewhere except along the southwest coast. The surrounding waters have mean sea-surface temperatures above 20 °C but regional peculiarities distinguish the coastal zones: the Guinea coast with its abnormal subhumid conditions; the hyperarid southwest coast with the cool and foggy Namib desert; the temperate Cape zone; the east coast affected by the monsoon winds and rains, the tropical easterlies, and the semidiurnal tides up to 6 m; and the Red Sea region with its extremely hot and arid climate and the highest seawater salinity in the world.

Only 9 % of Africa's total land surface is well suited to agriculture. Most of the continent's ecological systems occupy latitudinal belts with the climate varying from subhumid to semiarid. The dense tropical forest extends several hundred miles on either side of the equator and along the Guinea coast where precipitation may reach 3,000 mm a year. To the north and south it thins out to woodland savanna and drier forest or bush. The southern edge of the Sahara, called "Sahel" (Arabic for "coast, edge"), forms a transitional zone between savanna and desert. The Horn of Africa is persistently dry, but the Kalahari desert is mostly grassland and scrub, with waterholes and even some marshes. The Ethiopian highlands form the largest single area on the continent where fertile soils, numerous rivers, and abundant rainfall allow for productive agriculture. The width of the coastal zone varies from less than 1 km to over 300 km (200 mile). Most African countries have mixed farming, and most land by area serves as pasture. The rainfall has had a profound influence on the distribution of population. Three rainfall thresholds mark the

risk margin in traditional economies (1) where average annual precipitation is below 500 mm, agriculture cannot be sustained and total dependence on cattle is necessary; (2) where rainfall varies between 500 and 750 mm per year, it is impossible to subsist on agriculture alone, and supplementary stock-rearing is the customary solution; and (3) rainfall in excess of 750 mm per year is generally more predictable and more evenly distributed. Even then, the actual potential for agriculture and livestock raising depends on soil fertility, water evaporation, and ground water retention. African soils are generally poor, and agriculture requires large labor investment for subsistence maintenance. Only where soil fertility is combined with adequate water resources is surplus production possible.

Precarious existence in marginal environments makes for particularly strong connections between ecology and society. The harsh lands where water is scarce and grazing restricted historically produced fierce competition within a society and between neighboring societies. Cultivators and herdsman displaced hunters and gatherers; possession of iron for weapons and implements played a key role in this process. For insurance against famine, in addition to stock-keeping, farmers cultivate different plots, if possible in more than one ecological zone to take advantage of variations in the seasonal rainfall patterns and temperatures either using the same crop (e.g., maize or bananas) or different crops. Usually, two harvests are possible. Cultivation became linked with the idea of civilization, and the conceptual opposition between culture and nature found expression in the dichotomies of farm/bush, coast/hinterland, and civilization/barbarism noted in various settled societies. This polarity was also reflected by the classification of animals into wild or carnivorous, therefore "evil" and unfit for human consumption, and domesticated or herbivorous, suitable for food.

Subsistence patterns affect residential mobility, division of labor, dominant forms of property and ownership patterns, land tenure, social networks, typical marriage age, and marriage transactions. The transhuman cycle depends on the particular botanical and hydrological

environment and may vary from regular moves between wet-season villages and dry-season camps to a continual migration of over 1,000 km throughout the year. In mixed-economy societies, women often provide the bulk of the wet-season horticultural labor and men the bulk of the pastoral activities. Traditional forms of wealth associated with production and sustenance, such as iron hoes or cattle, are still included in bridewealth payments. In sub-Saharan Africa, land was traditionally held in tenure by the producers rather than owned. Towns grew in ecological oases or on trade routes. Markets developed between two ecological zones whose growing and harvest seasons differed, to trade for seed, food (in case of famine), and local specialties. There were seasonal markets, like those on the east coast regulated by the monsoon calendar, and "weekly" markets (e.g., held every fifth day as in the Shambaa country).

There is no formalized or universal world view in African systems of thought. Man is the center of the universe but he is not master of it. If harmony between man and nature is lost, the ensuing chaos harms man the most. In most cosmologies, the earth exists for man's sake but he must show it respect. Nature is seen as animated by spirits, and people depend on it for survival. Nature rituals, especially agricultural rites, punctuate the annual religious cycle: planting, first-fruits, and harvest ceremonies, etc. Special rituals relate to stock-keeping. Rain-making rituals are the most important. They are performed by specialists-priests, witch-doctors, or royalty (such as the Lovedu rain-queen in southern Africa fictionalized by Ryder Haggard as "She Who Must be Obeyed"). Shaka, the founder of the Zulu warrior state, declared himself the greatest of all rain-makers. Such specialists are not "mere" witch-doctors but well trained in weather lore: people are aware that there is order in the laws of nature which normally do not change. They do not ask for rain in the middle of the dry season; the rituals are performed before the rains to ensure their proper and timely coming, if the rains fail to arrive, or to stop the rain when too much water may damage the crops and fields. In Zambia, when the rains start, people

wait for a few days before working in the fields. An Ashanti farmer addresses his ancestors and the earth at the beginning of cultivation, saying:

The yearly cycle has come round and I am going to cultivate. When I work, let a fruitful year come upon me, do not let a knife cut me, do not let a tree break and fall upon me, do not let a snake bite me.

At planting, the Venda of South Africa distribute grain symbolically cooked in the field over a grass fire. At first-fruits ceremonies, grains of the new crop may be sprinkled in the field for the spirits or the remains of last-year's crop cooked and eaten. Among the Basuto the first gourds are taboo until the chief tastes them and offers a cooked dish of the new food to the ancestors.

Traditional African views of nature are thoroughly socialized and transmitted through folklore and rituals. West African cultivators hold that while gold is rare and expensive, iron was given to man by God for universal use as tools. The Zulu believe that the sun, moon, and stars were given by God so men could see, and that cattle were created by God to be man's food. The Masai think that cattle were given by God exclusively to them, and so consider raiding the herds of their neighbors legitimate. A chief's fields must be cultivated first because their fertility, as his virility, guarantees the whole community's well-being. At the Yoruba harvest festivals, gifts of yam tubers due the chief from each household serve as a tool of unwritten population census. When women pound meal, their long-stemmed pestles are thought to knock against the sky. The stars of the Pleiades are thought to follow one another "like cattle returning home from pasture." Water is sacred, and boiling it "kills" the water spirit. Many plants and seeds are used for medicinal purposes. Sacrifices at religious festivals, rain-making ceremonies, and seances of divination and spirit-possession involve agricultural produce (e.g., yam, various cereals) and cooked foods, and domestic animals and fowl (especially chickens; sheep among Muslims, and on very special occasions cattle).

The universe is unending in space and time. The past and present matter greatly, the future matters only within the next growing cycle.

The major rhythms of time are the seasons of rain and dry weather, migrations of birds and animals, flowering of certain plants, lunar months, and day-and-night sequences. The minor rhythms are in the lives of humans, animals, and plants as they move from birth to growth, then procreation and death. The calendars of African peoples are punctuated by references to natural phenomena and production activities. Since there is little temperature variation, the difference is not between the hot and cold seasons, but wet and dry. Usually, the two major seasons are the Greater Rains and the Lesser Rains. The Bantu word for "year," *mwaka*, literally means the rains at the beginning of the Greater Rains. On the East African coast they come in March; the Lesser Rains beginning in July or August are not a good planting season, but about October come the Latter Rains, the second cultivating season. Despite long-term Islamic influence and many Arabic loan-words, the Swahili language has preserved Bantu names for the cardinal points, dominant winds, days of the week, and times of day which reflect the sailing, agricultural, and stock-rearing aspects of Swahili culture. Some coastal cities created an office of "Master of the Sea" or "Master of the Beach." The word "Swahili" itself is derived from the Arabic for "coasts, coastal settlements." The name "Benadir" for the coast of southern Somalia means "harbors."

The pre-Islamic Bantu calendar calculated the annual cycle in 12 months of three 10-day "weeks" (decades, as in ancient Egypt) but within the year it distinguished lunar months in two phases. Different African peoples have "weeks" of 4, 5, 7, 8, 9, and 10 days. Traditional African time-reckoning is not mathematical but event-based. For example, the historical chronology of the Shambaa people of Tanzania is based on the memory of famines. The daytime computation of the Ankole of Uganda begins with the morning milking (about 6 a.m.) and follows the sun with references to times of rest, drawing water for people, driving cattle to drink, returning them to grazing, etc. The lunar months may be called "hot month," "month of rains," "weeding month," "bean harvest month," "hunting month," and so on.

The dwelling and settlement patterns too are affected by reference to the universe and nature, as well as gender. The Dogon of West Africa orientate their village north to south and visualize its plan as a human body prostrated on the ground. The smithy is the head, the family houses are in the center, and separate women's and men's houses, like hands, are on the [east and west](#). Millstones and a foundation altar are lower down like sexual organs, and other altars are at the feet. The shape and orientation of the house mimics the Dogon vision of the earth and the sky as a couple in union. The rooms, the roofs, and the supporting posts indicate the male and female parts; the placement of the hearth, door, and stones supporting cooking pots, even the sleeping arrangements are regulated by traditional spatial orientation. Gender relations in Africa may control the division of both labor and space, and even the use of space for burial. Women play an important role in cultivation, especially of garden crops, and food processing, including disposition of vegetable refuse. Often in charge of food crop seed selection, they also specialize in the knowledge and use of medicinal plants. Men dominate tasks and space involved in herding and animal care, from breeding to the disposition of animal dung, important as organic fertilizer. Among the Bemba of Zambia, who practiced slashing and burning trees for ashbed millet cultivation, the axe became the symbol of masculinity.

Environmental factors have conditioned some major processes in African history, such as population movements and settlement, agricultural production, state formation, and long-distance trade. For example, the arid expanses of the Sahara desert both protected and isolated West Africa from more extensive contacts with North Africa, the Mediterranean, and the Nile Valley, and the remoteness and paucity of resources of the equatorial forest led to historically low population density and lack of contacts with the outside world; the highlands of Ethiopia kept the country independent and self-sufficient but also isolated for much of its history. By contrast, the Swahili culture of the East African coast was totally predicated on coastal location with easy and regular contacts with the Indian Ocean world,

its prosperity fed by fishing, agriculture, and trade. In the West Sudan, the rise of medieval empires of Ghana, Mali, and Songhay was supported by efficient agriculture, access to gold and control of the rivers. However, most African rivers, including the Nile, are not navigable throughout their complete course or through the year; they are thus unable to serve as major communication arterials. Material culture of different localities still demonstrates its dependence on availability and qualities of timber, fiber, clay, and pigments. Traditional architectural forms developed in West Africa reflect the needs of mud construction in the rainy climate, while in East Africa stone architecture was limited to the coast because of reliance on coral rock.

The numerous migration legends of African peoples are misleading in that they highlight the movement of small segments of population while masking a general cultural stability reflective of ecological zones rather than specific ethnic groups. In areas suited to agriculture, shifting cultivation was a usual response to soil exhaustion or population growth until the twentieth century. Although access to water and pasture normally was a key to stability of settlement, some societies developed a tradition of moving large cities to prevent exhaustion of natural resources. Archeologists have suggested that the decline of Great Zimbabwe in the fifteenth century followed overexploitation of subsistence agriculture, in addition to droughts and other factors. Inland East African irrigation and terracing systems were able to support dense populations of people and cattle, but were abandoned before the nineteenth century. On the Atlantic coast, intricate knowledge of food crops and local conditions allowed for wetland rice cultivation in the alluvial and tidal lands; salt-water-tolerant varieties of rice were later exported to the Americas along with enslaved skilled practitioners of cultivation and food processing. In drier areas with sparse vegetation and meager topsoil, ecological changes could lead to long-distance migration, especially by herding populations. The West African *jihads* of the eighteenth and nineteenth centuries were spearheaded by mobile, pastoralist communities

such as the Fulani, and affected mostly the Sahel and savanna zones of the Sudanic belt where both cattle and horses (for cavalry) could live. In the sixteenth century, agricultural Ethiopia suffered major invasions first by the nomadic Somalis and then by the cattle-herding Galla (Oromo). In a later expansion of the Amhara Ethiopian empire, the Amhara armies invading Oromo territories could not feed themselves because the Oromo pastoralists did not grow crops and could evacuate their herds from the path of an advancing army. Once some Oromo settled and became cultivators, they avoided stock-rearing for fear of cattle-raiding Somalis or Masai. In the nineteenth century, southern Africa became the theater of two major late migrations based on cattle-herding and a search for pasture: the southbound Mfecane led by the Zulu and the northbound Great Trek of the Dutch Boer farmer immigrants.

The wagons used by the Boers were the first wheeled transport in sub-Saharan Africa, where trade was moved by head portage in consequence of the tsetse fly infestation and lack of salt in animal diet, which caused the absence of draft and pack animals. Growing contacts with the Western world led to the development of new trade patterns and regional economies: new trade routes connected the forest societies with the Atlantic coast, and some mobile groups (e.g., with access to rivers in the west or sea in the east) became the major agents of change. In the interior, populations seeking safety from slave-raiding moved their villages into inaccessible hills while those seeking trade moved their towns from mountain slopes into plains. By mid-nineteenth century a transcontinental system of routes was in place.

To this day, Africa's food production and raw material bases are still traditional, small-scale and rural; food productivity is the lowest in the world. Sixty-five percent of the continent's population derives its livelihood from agriculture. However, the picture of a static self-subsistence economy is false. African societies have shown both adaptability to change and readiness to experiment. The early spread of three Asian crops – yam, taro, and banana – revolutionized the economy of the humid regions. American

food crops (especially cassava, sweet potato, maize, and groundnuts), introduced early by the Portuguese, spread quickly across the continent and still continue to displace indigenous crops; they were followed by tomatoes, various beans, chili, potato, tobacco, cocoa, agave, and avocado. Innovation improved food supply stability and contributed to agricultural intensification and population growth. Former hunters and fishermen, like the Bakuba of the Congo (Zaire) basin, once they were able to produce agricultural surplus, underwent an economic revolution which allowed them to develop the handicrafts and create a kingdom in the seventeenth century. The risk and responsibility for trying the new crops dwelled with the chiefs or kings, who were deemed responsible for environmental management. In the first half of the nineteenth century the sultan of Zanzibar became a major innovator and plantation owner when he transformed the island into a clove-producing garden; coconut plantations were developed, some numbering hundreds of thousands of trees. While for almost 2,000 years the main articles of African trade with the outside world had been gold, slaves, and ivory, agricultural diversification in the nineteenth and twentieth centuries has led to increasingly varied international trade.

European settlement succeeded only in temperate zones free of tropical fevers. The emphasis on cash crops and the spread of perennial crops (oil palm, cocoa, coconuts, coffee, cotton, etc.) have reduced shifting cultivation and sometimes undermined indigenous strategies for coping with the threat of famine. Application of Western methods of agriculture has been successful in cultivating sisal, tea, and pyrethrum but has shown no advantage in the production rubber, groundnuts (peanuts), oil palms, cocoa, coffee, or sugarcane. Indigenous cattle, although considered poor by Western standards, have shown greater resistance to epidemics of rinderpest, lung sickness, etc., several of which devastated regions of eastern Africa in the nineteenth century, facilitating European colonization. Although, in general, adoption of new crops gave people additional means to shape their environment, many rural anticolonial movements

were linked to environmental issues. Sometimes European settlers tried to limit indigenous hunting to protect game for colonial elite or misinterpreted African agricultural methods as destructive, thus justifying land expropriation. Numerous attempts to introduce western agricultural machinery, both pre- and postindependence, have failed because of their unsuitability to weak soils, traditional multicrop multistory cultivation, and the socially determined patterns of labor and land tenure. Today, the hoe remains the major farm implement and women still grow 80 % of the food consumed by their families and 50 % of the cash crops. The lack of protein, especially in the children's diet, persists as a major obstacle to the development of a productive and healthy African society.

Africa is a continent rich in resources which faces enormous environmental challenges, including deforestation, desertification, loss of biodiversity, and degradation of water resources. In 1960 Africa was a net food exporter but since the 1970s it has developed a dependence on food imports and aid. The droughts and famines of the 1970s, 1980s, and 1990s have been exacerbated by civil wars and government policies, in addition to poor communications and transportation. Deforestation, inefficient cultivation, and destruction of the wildlife are tolerated to feed people quickly. Draining marshes helps reduce the incidence of malaria, typhoid, river blindness, and cholera, but creation of new reservoirs increases bilharzia (schistosomiasis). Hydroelectric power dams built in recent decades have eased Africa's energy dependence, but during droughts the water supply is sometimes insufficient for electricity. Despite government steps for natural preservation and sustained development, some colonial practices such as big game hunting have been replaced by poaching; in Angola and Mozambique, warring factions engaged in predatory elephant hunting for ivory – during the conflicts of the 1970s–1990s. Nevertheless, Africa suffered from colonial intrusion relatively less than other, formerly more isolated, continents, and Africa's potential for preserving and successfully exploiting the environment is higher than in any other developing areas of the world.

Under the prevailing low-technology conditions, indigenous ecological knowledge is an important developmental resource. Planning, changes in mentalities of both rural and urban populations, and wide dissemination of appropriate information are keys to the solution of the many current problems.

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Environment and Nature in Buddhism

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Buddhism is an enormous, diverse, and complex subject. There are many variations on Buddhism's basic themes manifested in the three major traditions (Theravada, Mahayana, and Vajrayana or Tantric) and also in variants of these in the form of at least 18 schools and their numerous sects. Much of the diversity in the expression of Buddhism results from the diversity of its numerous geographical, ecological, demographic, historical, cultural, linguistic, religious, national, and political contexts. Although estimates vary, there are around 488 million Buddhists living in 86 countries of the world. Another complication is that many Buddhists adhere to more than one religion or follow a mixture of elements from different religions, such as Animism and Hinduism in Thailand, Confucianism and Daoism in China, and Shintoism in Japan. An additional variable is that, as in any religion, in Buddhism too there are differences between ideals and practice, text and context, clergy and laity, scholar and laity, urban and rural, young and old, and so on. This tremendous diversity within Buddhism renders most generalizations difficult and tenuous, and they should always be recognized as potentially problematic, especially without adequate explanation and qualification that is usually not feasible in a limited space.

Underlying the enormity, diversity, and complexity of Buddhism, nevertheless, are some common denominators. The three-refuge chant usually begins Buddhist ceremonies:

Buddham saranam gacchami.
Dhammam saranam gacchami.

Sangham saranam gacchami.
In the Buddha I take refuge.
In his teaching I take refuge.
In the monastic community I take refuge.

This chant reflects the three ultimate components of Buddhism: the Buddha, his teachings (Dhamma), and the community of followers, especially the monks and nuns (Sangha). One formally becomes a Buddhist simply by publicly vowing to pursue these three refuges. The individual's pursuit of enlightenment commences with accepting the Dhamma, starting with the Four Noble Truths, and then following the Noble Eightfold Path as discussed below.

This entry surveys nature and environment in Buddhism within the framework of the Buddha, Dhamma, Sangha, and laity and in relation to the Four Noble Truths and the Noble Eightfold Path. Furthermore, Buddhist ecology and environmentalism will be considered from the past to the present and into the future, from East to West, and in terms of contemporary criticisms, problems, issues, and controversies. In this entry, all Buddhist terms are in Pali, unless another language is used in quotes or in personal or place names. Pali is the ancient literary language for Theravada Buddhism and remains its ecclesiastical language.

Buddha

The relevance of the Buddha's life and teachings to nature and the environment is clear in at least three respects. First, major events in his life were associated with trees, groves, forests, and other natural phenomena. Second, he often drew on parables about animals and other aspects of nature to illustrate moral and other principles. Third, during his lifetime, it appears that population and economic pressures were leading to deforestation and resource depletion in some areas where he lived and traveled. Thus, if nature was so relevant to the Buddha, then surely nature is relevant to Buddhism and vice versa.

In the early accounts of the Buddha's life, it is not easy to distinguish between fact, legend,

and myth. Nevertheless, these basic facts are clear: his birth as a human being, his renunciation, studies with Hindu spiritual teachers (gurus), long period of asceticism and intense meditation, enlightenment, 45 years of teaching followers, establishing the Sangha, and his discourses or sermons (suttas). In addition, the core principles of the Buddha's teachings, such as the Four Noble Truths and the Noble Eightfold Path, can be taken as factual.

Buddha is an honorific title meaning an enlightened or awakened being. The historic Buddha's original name was Siddhattha Gotama. His conventional dates are 566–486 BCE. He was born under a sal tree (*Shorea robusta*) in a grove called Lumbini Park near Kapilavastu (now Madeira), about 130 miles north of Benares in the border zone between present-day India and Nepal.

During his youth, Siddhattha's father, King Suddhodana, sheltered his son from sights of the suffering beyond the royal palace. However, eventually Siddhattha witnessed sickness, old age, and a corpse. These impressed him with the suffering and impermanence of human existence. Then, when he observed a holy man, he was inspired to search himself for a spiritual solution to the problems of the human condition. Thus, at 29 years of age, Siddhattha made the Great Renunciation. This was a radical decision to leave his family, wealth, and future as a king to become a wanderer in a religious vision quest.

Nature was the context and source of Siddhattha's search for and eventual achievement of enlightenment. For 6 years, he pursued spiritual awakening with various gurus and through rigorous asceticism in the forest. In the process, among many other things, Siddhattha realized that moderation (the Middle Way) was the best path, instead of the extremes of either asceticism or hedonism. Eventually, he pursued contemplation and meditation on his own for 7 days at the base of a bodhi fig tree (*Ficus religiosa*) near the town of Bodhgaya. There, at the age of 35 years, he finally attained enlightenment (Buddhahood).

After his enlightenment under the bodhi, the Buddha subsequently spent a week meditating under each of several other trees: Nigrodha or

Indian fig (*Ficus indica*), Mucalinda (*Barringtonia acutangula*), and Rajayatana or kingstead (*Buchanania latifolia*). Then, he went to the royal Deer Park of Isipatana in Sarnath (now Dhamek), just north of Benares along the Ganges River. He knew that the five monks (bhikkhu) he had previously associated with would be there. In his first discourse, the Buddha introduced to these monks the Four Noble Truths and the Noble Eightfold Path.

For the next 45 years of his life, the Buddha wandered over much of northern and eastern India as a religious teacher. He died at the age of 80 while reclining between two sal trees in a grove outside the small town of Kusinara and in the company of many of his followers. When death was near, the Buddha declined to appoint a successor; instead, he said the Dhamma and monastic rules (vinaya) should guide his followers. In addition, in his sermons he repeatedly advised that every individual should think on his own and test his teachings against their own reason and experience. Accordingly, Buddhism lacks any single centralized authority, although different schools and sects may have recognized leaders, the most well-known being His Holiness the 14th Dalai Lama of Tibet.

Teachings

Bodhi (1987, p. vii) aptly summarizes the relevance of the teachings of the Buddha's (Dhamma) to nature:

With its philosophical insight into the interconnectedness and thoroughgoing interdependence of all conditioned things, with its thesis that happiness is to be found through the restraint of desire in a life of contentment rather than through the proliferation of desire, with its goal of enlightenment through renunciation and contemplation and its ethic of non-injury and boundless loving-kindness for all beings, Buddhism provides all the essential elements for a relationship to the natural world characterized by respect, care, and compassion.

For Buddhists, the pursuit of knowledge, understanding, and wisdom begins with the Four Noble Truths: all existence is suffering (dukkha); ignorance and desire are the primary

causes of suffering; yet suffering can end; and the way to end it is to understand and pursue the Noble Eightfold Path. Suffering covers a wide diversity of conditions, including dissatisfaction, discontent, disharmony, discomfort, irritation, friction, pain, illness, dying, and death. The ultimate aim of the Buddhist is to reach enlightenment in order to end suffering: first, in one's present life and, second, in one's successive lives in the endless cycle of rebirths. As Ryan (1998, p. 2) asserts: "The fundamental postulate of Buddhism is that all beings are united in distress, in *dukkha*." From this perspective, then, the moral universe of Buddhism transcends humanity to encompass all beings, and in this way among others, Buddhism becomes relevant to nature and environment (to explore some Buddhist texts, see <http://www.accesstoinsight.org>). The Mahayana tradition goes even further. In Mahayana, Buddha-nature refers to the potential of all beings and things to become enlightened. In Chinese and Japanese Buddhism, for example, trees and even rocks may be considered to have Buddha-nature; thus, it is assumed that they strive for and are eventually destined to achieve enlightenment. Consequently, a Bodhisattva is a person who forgoes seeking the end of his or her own suffering (reaching enlightenment or *nibbana*) in order to strive to reduce the suffering of all other beings and things.

Most lay Buddhists do not study the formal texts (sermons, monastic code, and scholastic treatises) but learn about the more important principles in them through the Sangha and popular media. The most outstanding example of the latter is the Jatakas, a collection of 547 parables about the Buddha's previous lives. In these, he is often represented as an animal that sacrifices its own life to save others. These stories illustrate how the Buddha cultivated the core virtues of wisdom, nonviolence, compassion, loving-kindness, generosity, and so on. They also exemplify the interconnectedness and interdependencies among beings. Furthermore, they imply that animals have a moral sense; i.e., they are capable of making ethical choices and behaving accordingly. The great popularity of these stories probably influenced many Buddhists to have positive

attitudes toward animals through affording them intrinsic value. The Jatakas, as readily accessible moral allegories, provide, in effect, many of the essentials of an ecocentric environmental ethic for Buddhists.

The Noble Eightfold Path through thought and action progressively encompasses wisdom (right understanding and resolve), virtue (right speech, action, and livelihood), and concentration (right effort, mindfulness, and meditation). Arguably, each of these eight components is relevant to nature to the degree that it is correlated with the pivotal principle of extending nonviolence (*ahimsa*), compassion (*karuna*), and loving-kindness (*metta*) to all beings and things. Right livelihood, for example, would include occupations and lifeways that do not harm any beings and things. Of course, it is impossible to live without causing some harm; even vegetarians sacrifice plants for food. However, a Buddhist can strive to minimize harm as much as possible. Buddhism makes the elemental and pivotal distinction between need and greed. In pursuing the Middle Way, an individual would attempt to satisfy as modestly as feasible the four basic needs that the Buddha recognized (food, medicine, clothing, and shelter). As a consequence, in effect the individual minimizes his or her harm to other beings and reduces pressure on the environment, including the inevitable waste and pollution that accompany resource consumption. Ideally, Buddhists should be concerned with the contemplation of nature instead of its consumption. This is what is now termed voluntary simplicity, one indispensable ingredient for developing a sustainable, green, just, and peaceful society. As Timmerman (1992, p. 74) asks: "How can we survive on a planet of ten billion points of infinite greed?"

The key to Buddhist ethics and practice is the primacy of the individual's mind. Ultimately, this has profound importance with numerous ramifications in terms of recognizing the causes and solutions of environmental problems. From a Buddhist perspective, although certainly important, the usual sources – science, technology, education, government, law, politics, business, and industry – are neither the cause nor the solution of the ongoing and worsening global environment crisis.

Instead, the cause and the solution are found in the collective, cumulative, and synergetic consequences of the behavior of the individuals who compose humanity, albeit some individuals and groups may be more responsible (or irresponsible) than others. Environmental health is then not so much a matter of the scientific, technological, and bureaucratic management of resources, waste, and pollution, as it is the spiritual management of ourselves. People must be motivated as well as informed to limit their own reproduction, consumption, waste, and pollution in order to minimize harm to other beings and things. Today, environmentalists would refer to this as one's ecological footprint.

If it is understood that the first negative precept (nonviolence) and the first positive precept (compassion and loving-kindness) apply to all beings and things, not just to humanity or some sector thereof, then the environmental implications are immediately obvious and undeniable. Indeed, there is an ecology here; it is possible to detect elements reminiscent of ecology in Buddhism and, conversely, elements reminiscent of Buddhism in ecology, even if these are only a coincidence. Both Buddhism and ecology (1) pursue a monistic rather than dualistic world view, instead of dichotomizing either organism and environment or human and nature; (2) consider all life, including that of humans, to be subject to natural laws; (3) adopt holistic and systems approaches regarding the unity, interrelatedness, and interdependence of the components of nature; and (4) teach respect and even reverence for nature, including the intrinsic as well as extrinsic values of other beings. Although most of these similar elements may be merely parallels rather than identities, surely they are complementary and can even be mutually reinforcing in both theory and practice for contemporary Buddhists.

Clergy

Ideally, the Sangha, the monastic community of monks or nuns, exhibits attributes that are similar, and in some instances even identical, to many of

the characteristics of a sustainable, green, just, and peaceful society. Among these are a small-scale and relatively egalitarian community based on nonviolence, moderation, cooperation, and reciprocity in satisfying basic needs. Monks and nuns have extraordinary sociocultural status and power to transform nations like Thailand that are overwhelmingly Buddhist into a more ecologically sound society because of their unique social and moral roles. By contrast, monks and nuns hold a mirror to society, as, for example, in their vow of poverty. Spiritual development is their goal, rather than Western style economic development through materialism and consumerism. By drawing on the ecological wisdom embedded in the Buddha's life and teachings, monks and nuns have significant potential to contribute to far sounder environmental world views, attitudes, values, and practices of lay Buddhists.

Many of the more than 200 rules for monks (vinaya) are relevant to nature. Several aim to prevent monks from knowingly harming any living being. They can only eat fruit without seeds or if someone else has already damaged them. Bhutagama, the Pali term for a living plant, means the home of a being. For a monk to intentionally cut, burn, or kill a living plant is an offense. It might endanger some animal's habitat, among other things. Harming even small animals like ants should also be avoided, although harming large animals is much more serious. Injuring or killing an organism like a worm by digging in the ground is forbidden and could lead even to expulsion from the Sangha. Also a monk cannot deliberately have someone else kill an animal for him. The rains' retreat (pansa) is the period during the wet season each year when monks refrain from traveling in order to avoid trampling on young crops and small animals that are more abundant then. Monks should check water, or strain it, before using it for drinking or other purposes to avoid knowingly harming any visible organisms in it, even mosquito larvae. They are prohibited from polluting water in any way as well. A monk is prohibited even from acting in self-defense if that would injure another being. In these ways and in many others, monks are supposed to protect and respect all life.

In several places in the sacred texts of Buddhism when the issue of vegetarianism arose, the Buddha explicitly refused to prohibit monks from eating meat, mainly because they subsist on alms food volunteered by local laity. Vegetarianism was only an option. Today, although widely admired, it is not common in Theravada countries and Japan. However, most monasteries in China and Korea as well as Zen monks in Japan are strictly vegetarian. Vegetarianism is one way that an individual can reduce harm and offer compassion and loving-kindness to other beings as well as provide a model or raise awareness for other people (on vegetarianism, see <http://online.sfsu.edu/~rone/Buddhism>). Collectively and cumulatively over time, Buddhist temples and monasteries may help promote the conservation of biodiversity. Many temple complexes can be viewed as sacred ecosystems with groves of bodhi, banyan, and other trees and associated animals. People are prohibited from disturbing plants, animals, fish, and other natural phenomena in and near a temple complex.

Instead of living in a temple or monastery, since the time of the Buddha many monks and nuns have spent much of their time wandering in forests or on mountains or living and meditating in caves. Such secluded and peaceful places are more conducive to meditation and enlightenment. However, in recent times, many forest monks have become environmental activists as well. They view deforestation as sacrilegious, a threat to the forest monk tradition since the forest is their sacred habitat. Also they understand the suffering that deforestation causes to local humans and other beings. Out of compassion for the suffering which diverse beings experience as a result of deforestation, numerous monks have initiated environmental education programs, sustainable economic development projects, and rituals to protect the remaining forests in Buddhist countries such as Cambodia, Laos, and Thailand (for examples of the above, see <http://www.earthsangha.org>, http://www.keap-net.org/project_environment.htm, <http://www.mro.org>, and <http://www.suanmokkh.org>). [Editor's note: see also Susan Darlington's article on Thailand's activist monks.]

Laity

For Buddhists the ultimate pilgrimage is the spiritual journey through meditation to discover the Buddha-nature within oneself. This is a vision quest that reveals the oneness of the individual and nature and thereby the emptiness of self through interconnectedness and interdependence. However, since ancient times, Buddhists have also undertaken pilgrimages to sacred sites associated with the Buddha and other Buddhist personages, as well as to temples, shrines, and other sacred places, many on mountains and/or in forests. In Tibet, Mount Kailas is sacred to Buddhists as well as to the Hindu and the Tibetan Bon religions. At its foot, Lake Manasarovar is also considered sacred and a component of pilgrimages. Because many of the sacred places associated with Buddhism require certain prescriptions and proscriptions, such as not killing any beings, the result, even if inadvertent, is that these sites often function in effect as sanctuaries of nature as well as religion.

To the extent that the laity follows the Buddha's example and teachings as well as those of the clergy, they are also relevant to nature. The laity and the clergy are interdependent. The laity provides for the material needs of the clergy, while the clergy provides for the spiritual needs of the laity. However, whereas the clergy cannot harm other beings, the laity must do so in order to obtain food and income from farming, fishing, and so on. Still, the laity is supposed to minimize harm to other beings as much as is practical.

To this day, lay individuals may gain merit by planting trees, especially in and around temple yards. In Thailand, sometimes tree seedlings are given to people attending a funeral so that they may plant them to gain merit for the deceased and themselves. Planting trees reminds people of the Buddha's life and teachings, including the interdependent relationships between humans and nature.

Socially engaged Buddhism belies the stereotype or myth that Buddhism is necessarily a detached, escapist, or egocentric religion. A phrase coined by the Vietnamese monk, Thich Nhat Hanh, socially engaged Buddhism is

simply the active application of Buddhism for the benefit of others; i.e., putting compassion, loving-kindness, and other principles into practice. It is a matter of emulating the Buddha's life and following his teachings. Among the various concerns of engaged Buddhists are nonviolence, peace, human rights, participatory democracy, social work and community development to alleviate poverty and other problems, appropriate technology such as organic farming and recycling, sustainable and just economic development, and environmentalism (for examples of socially engaged Buddhism, see: <http://www.bpf.org> and <http://www.sulak-svaraksa.org>).

The West

Buddhism originated in northern India more than 2,500 years ago and in subsequent centuries spread far beyond into other parts of Asia. By at least the mid-nineteenth century, if not much earlier, Buddhism started to have some influence in the West. Today, there are large Buddhist populations beyond Asia, including four million in the USA and more than a million in Europe.

The East and West, however, are not completely separate. For centuries they have influenced each other in numerous and sometimes profound ways. For instance, Henry David Thoreau (1817–1862), a student of Asian philosophy as well an icon for environmentalists, first translated into English from French a portion of the Lotus Sutra for the transcendentalist journal *The Dial*. Also, his period of relative seclusion and voluntary simplicity in nature at Walden Pond near Concord, Massachusetts, was somewhat reminiscent of a forest monk.

Beyond Thoreau, Buddhism was among the influences on many other seminal Western pioneers and leaders in ecology and/or environmentalism including Fritjof Capra (physics), Bill Devall (deep ecologist), John Daido Looi (Zen environmentalist), Ernst Haeckel (coined word ecology), Philip Kapleau (vegetarianism), Stephanie Kaza (environmental ethics), Petra Kelly (German Green Party), Rick Clugston (Director of the Center for Respect of Life and

Environment), Joanna Macy (Nuclear Guardianship Project), Peter Matthiessen (novelist), Thomas Merton (Trappist monk and writer), William S. Merwin (ecopoet), Arne Naess (founder of deep ecology), Helena Norberg-Hodge (Ladakh Project), Steven C. Rockefeller (leader in Earth Charter), E. F. Schumacher (Buddhist economics), Albert Schweitzer (reverence for life), John Seed (Council of All Beings), Gary Snyder (Zen poet and deep ecologist), Michael Soule (conservation biologist), David Suzuki (biologist), and Alan Watts (counterculture mystic).

Today, there are more than 2,000 Buddhist centers in the USA alone, often with a mailing list of hundreds or even thousands of individuals. Many practice conserving resources, recycling, and reducing waste and pollution. Voluntary simplicity may be considered to be an environmental as well as Buddhist virtue. Vegetarianism is often followed using organically grown foods. Such practices can be observed, for example, at the Green Gulch Farm in Sausalito, California; Zen Mountain Center near Mountain Center, California; and Zen Mountain Monastery at Mt. Tremper, New York.

Contemporary Buddhism and environmentalism resonate with one another in numerous and diverse ways. In particular, for Westerners, Buddhists, and some others, Buddhism provides new perspectives, rationales, insights, values, and methods for dealing with environmental questions, problems, issues, and controversies. For instance, Buddhist monks have symbolically ordained trees to protect them in Thailand, and this has inspired similar ceremonies by activists in California (see Buddhist contributions on the UN Earth Charter: <http://www.brc21.org>).

Five trends have been growing significantly among Buddhists in recent years: pursuit of vegetarianism, critique of materialism and consumerism, sustainability initiatives, activities to deal with the challenges of global climate change, and concern over Tibet. Vegetarianism and voluntary simplicity are among the means that many Buddhist individuals and centers are pursuing to reduce their ecological footprint while also pursuing the Noble Eightfold Path and

enlightenment. There is increasing concern and action in the face of the gravity and urgency of the challenges of global climate change such as a website called EcoBuddhism with a wealth of information and resources as well as a Buddhist Declaration on Climate Change. In addition, Earth Sangha developed a Buddhist Statement on Climate Change signed so far by 465 Dharma teachers and 1,130 Sangha members that is available in French, German, Italian, Spanish, and Thai as well as English. The indigenous population of the formerly independent country of Tibet continues to suffer from human rights violations and even genocide, ethnocide, religiocide, linguicide, and ecocide because of the Chinese invasion, occupation, exploitation, and oppression. The International Campaign for Tibet is one of the several prominent nongovernmental organizations publicizing and trying to help resolve this ongoing holocaust in Asia.

Problems

Ultimately, the problems and limitations regarding the relevance of Buddhism to nature and the environment appear to revolve around two types of related but separate discrepancies – ideal versus actual behavior and academic versus practical interpretations. The ideals of Buddhism seem to be environmentally friendly, whereas the actual behavior of many Buddhists is far too often not so. This paradox is evidenced in the widespread natural resource depletion and environmental degradation in most countries that are predominantly Buddhist, although it appears that Bhutan and Ladakh are lingering exceptions to this pattern for the most part. Nevertheless, this discrepancy does not invalidate the idea that in principle Buddhism can be environmentally friendly. One must be careful to avoid confusing Buddhism and Buddhists. There are internal contradictions and discrepancies in every religion as well as in other social institutions like government, science, and education. The deficiency is not in Buddhism, but in Buddhists, who, after all, are merely human. An important part of the solution is to educate people about the negative consequences of their

actions so that they are more willing to alter their behavior to eliminate or at least minimize such consequences. Also Buddhists need to adhere more closely to the Noble Eightfold Path as it applies to ecology and environmentalism.

The second discrepancy is the difference between the purely academic understanding of Buddhism, especially the interpretation of the texts, and the actual understanding and daily practice of Buddhism by Buddhists, i.e., context. Ideally context should faithfully reflect text, but critics deny that this is the case in reality. Much of the criticism boils down to the accusation that Westerners are imposing their modern concerns for ecology and environmentalism on Buddhism, whereas a supposedly authentic scholarly interpretation of the texts by the critic indicates that Buddhism is irrelevant to such matters. However, there is considerable room for differences of opinion in the interpretations of the same texts among Buddhologists (scholars of Buddhism). Also, such criticisms fail to recognize the sincere and important environmental concerns and actions of many Asian Buddhists such as Sulak Sivaraksa (for an example of a critic, see articles by Ian Harris in the free online *Journal of Buddhist Ethics*: <http://www.jbe.gold.ac.uk>).

Such puritanical, literalist, or fundamentalist criticisms of the application of Buddhism to contemporary concerns like the environmental crisis do not afford sufficient attention to the actual practice of Buddhism by Buddhists who do not always think that rigid adherence to text is so important. Indeed, the Buddha himself repeatedly emphasized that individuals should test his teaching against their own reason and experience, instead of blindly accepting authority, tradition, or dogma. Furthermore, the scholarly study of Buddhist texts alone may not have much relevance for the actual realities of the daily practice of Buddhism by its adherents. At the same time, there are individuals who have been both Buddhist scholars and monks for decades. The most notable personages in this regard, Buddhadasa Bhikkhu from Thailand, Thich Nhat Hanh from Vietnam, and His Holiness the 14th Dalai Lama of Tibet, think that Buddhism has significant ecological and environmental relevance. Note that

each of these scholar monks represents one of the three main traditions of Buddhism (e.g., see <http://www.suanmokkh.org>, <http://www.plumvillage.org>, and <http://www.tibet.com>).

Another criticism is that Buddhism is basically escapist; it is concerned only with individual enlightenment through meditation and therefore oblivious to any practical problems of ordinary human existence. This last point ignores the example of the Buddha himself, who, among other things, opposed animal sacrifice and the caste system in India. It also ignores socially engaged Buddhism that is no modern invention, even if the particular term is so. Beyond skeptics, critics, and antagonists who question that Buddhism has any relevance to nature, environment, ecology, and environmentalism, there are other problems. For instance, Kenneth Kraft (1997) identifies these dilemmas facing Buddhist environmental activists:

Gaps between the Buddha's teaching and contemporary sociopolitical realities.

Buddhism emphasizes individual morality and action yet many environmental problems demand collective responsibility and action.

Competition between meditation and engagement. Whether to be identified as Buddhist or just blend in with other activists.

The environmental soundness of spiritual practice and rituals. However, in the opinion of the present authors, as long as Buddhists are faithful to the core principles of the Dhamma, then compassionate actions of loving-kindness on behalf of all beings and things are still Buddhist, this no matter how new the particular situation or how innovative the specific actions (for examples of Buddhism in contemporary society, see: <http://www.globalbuddhism.org> and <http://www.urbandharma.org>).

Future

It is unlikely that people millennia or even centuries ago ever conceived of possibilities like anthropogenic mass species extinction or global climate change which have increasingly preoccupied many in recent decades. However, inevitably new problems and issues arise that require creative interpretations and approaches by Buddhists, and this must have happened throughout the 2,500 years of the history of Buddhism,

considering the diversity of contexts and situations in which it has flourished. That Buddhism has endured for so long is a clear demonstration of its continuing relevance and adaptability for its adherents. Now, the most important challenge for Buddhists is to cultivate social, political, and environmental actions that more closely approximate the ideals of Buddhism, especially the Noble Eightfold Path.

If more Buddhists and other people were aware of the negative environmental consequences that are the collective and cumulative results of their individual behavior, then many might change for the better and thereby help to reduce environmental problems. When reason and morality follow adequate knowledge and understanding of the continuing and even worsening environmental crisis, then this may lead to wisdom and action in improving how humans interact with nature. The difference Buddhism makes is that, instead of grounding environmentalism and nature conservation in self-interest of the individual (egocentrism), society (sociocentrism), or the human species (anthropocentrism) as most Western schemes advocate, it is based on respect for other beings and things as having intrinsic value (ecocentrism).

It is noteworthy that in Bhutan, Japan, Ladakh, Thailand, and elsewhere, clear symptoms are surfacing of a growing disillusionment with the uncritical and wholesale pursuit of "modernization" and associated phenomena like materialism and consumerism. Revitalization movements arise in many societies in response to the problems, stresses, and dissatisfactions with rapid and profound sociocultural change. Buddhist-motivated community development and environmental conservation initiatives are becoming significant forces in this revitalization within Buddhist societies.

Undoubtedly, the primary concern of the Buddha was suffering, its causes and alleviation. The Buddha repeatedly stated that ultimately he taught only two things, about the cause and the end of suffering. Certainly the world is bound to suffer even more than ever before during the twenty-first century as a result of accelerating human population and economic growth as well as global climate change. With the inevitability of the

increased suffering of humans and other beings in coming decades, Buddhism may well prove even more relevant than ever before. Buddhists must apply critical and radical thought in examining contemporary problems and issues, something needed in our time as much as in that of the Buddha and probably far more so. Now this must include genuine interfaith dialog so that everyone may learn from each other's religions by comparison and contrast in order to cultivate a more sustainable, green, just, and peaceful world.

For the future, the main task for Buddhists, as well as for those non-Buddhists who simply have an intellectual interest in Buddhism, is to explore wider as well as deeper into the relevance of this religion for ecology, environment, and nature, especially for each of the different schools and sects, and in both text and context. Furthermore, those who are practicing Buddhists also need to strive to apply the Dhamma as faithfully as possible in their interactions with their local environment and nature in general. Buddhists owe no less to the Buddha, the Sangha, and other beings as well as to themselves. It is a matter of survival for Buddhism as well as for nature and humanity.

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Environment and Nature in Buddhist Thailand: Spirit(s) of Conservation

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Two contradictory images strike the traveler in northern Thailand: first is the lush, forested mountains rising beyond expanses of rice paddy

land and small farming villages. Second is the spotty appearance of the mountains, denuded of primary growth in large areas and filled instead with economic crops such as cabbages or corn. Both images are set against the backdrop of congested cities, particularly Bangkok and Chiang Mai, through which all travelers pass before seeing rural areas. The contrasts inherent in these scenes point to a major tension in Thailand between the push to develop economically and efforts to conserve and protect the nation's natural resources.

The struggle to find a balance between development and conservation occurs in many arenas, including culture and religion. Various actors for both pro-development schemes and conservation projects use cultural and religious beliefs, practices, and attitudes toward nature to promote their positions. Religious beliefs themselves are not intrinsically either ecologically or developmentally oriented, but they can be interpreted in ways to support either conservation or development. The Thai government, for example, has used Buddhism to promote rapid national economic development; on the other hand, a handful of Buddhist monks and nongovernment activists incorporate both indigenous spirit beliefs and Buddhist practices to foster an environmental ethic on a local level. Both approaches claim to be based on intrinsically "Thai" understandings of the world as well as basic Buddhist teachings. Yet, as will be shown below, both are reinterpretations of religious beliefs and practices and, particularly in the case of activist monks, examples of cultural creativity designed to promote specific political agendas.

In the search for "Thai" approaches to environmental conservation, a key cultural source is Buddhism. The Thai population is approximately 95 % Buddhist. It is important to note, however, that for Thais, Buddhism incorporates spirit and Brahmanic beliefs and practices (Kirsch, 1977; Tambiah, 1970). Yet scholars and activists often downplay spirit and Brahmanic beliefs in their environmentalist efforts, opting primarily to look at the ecological knowledge of rural peoples and at how Buddhism can be used to promote an environmental ethic (see Chatsumarn, 1990, 1998; Darlington, 1997a, 1997b, 1998;

Davies, 1987; Kaza & Kraft, 2000; Pipop, 1993; Sponsel & Natadecha, 1988; Sponsel & Natadecha-Sponsel, 1995, 1997; Swearer, 1997, 2001, 2003; Tucker & Williams, 1997).

Buddhism alone, however, does not encompass the full range of concepts and attitudes of rural Thais toward nature and the forest. A complementary set of cultural beliefs that influence attitudes of and behavior toward the natural environment in Thailand is spirit beliefs. In particular, the interplay between Buddhism and spirit beliefs affects rural people's concepts of the forest and the ways in which they approach or value it. Similar beliefs are found throughout the Thai cultural region (which includes northern Thailand, Laos, southern Yunnan Province, China, and parts of Burma and northern Vietnam; see Pei, 1985).

This syncretic religious system can be clearly seen in northern Thailand where, as across the nation, it contributes to an elaborate cosmology that includes the natural, human, and spiritual environments (see Kirsch, 1977). This sacred geography provides the framework for efforts to use cultural and religious concepts for both developmental and environmental – both inherently political – ends.

Spiritual Geography

There is no traditional word in the various Thai language dialects for “nature” (Davis, 1984, p. 85). The word used today, *thammachaat*, is a combination word borrowed from Sanskrit. Its root words are *thamma*, or “dhamma,” meaning truth (or the teachings of the Buddha, in a more specific context), and *chaat*, meaning life or rebirth (from the concept of reincarnation). Davis (1984, p. 85) argues that Thais adopted the concept of “nature” underlying this term because of European influence. This concept did not correspond with any indigenous ideas. It is, according to Stott (1991, p. 144), “too refined and wide in its meaning, embracing as it does all natural phenomena, such as rain, wind and sun, and even natural human behaviour.” Applying the concept of *thammachaat* to the forest

sanitizes the barbaric qualities of the wild, bringing it closer within the control of people (Stott, 1991, p. 150). The effects of this process, as we will see, can be either pro-conservation or pro-development. It can enable people to take advantage of the forest resources without fear or concern over maintaining a balance between the civilized and wild worlds, by emphasizing domination and control of the former over the latter. It also has the potential to influence people's attitudes in the direction of responsibility toward rather than domination over the natural environment.

Before the introduction of the concept of *thammachaat*, there was a distinction between the human-built civilized world (*muang*) and the wild, uncivilized forest (*paa thu'an*) (Stott, 1991). The civilized world centered on human settlements, particularly the walled cities of northern Thailand in which the kings and princes lived. In a careful linking of religion and geography, civilization radiated outward through the ruler's religious merit from the *muang* (here meaning the city) to nearby towns and outlying farming villages (Stott, 1991, p. 145). The forest, on the edge of the social and religious domain of the *muang* and the ruler's influence, was the world of wild, dangerous, and unpredictable beings, including tigers, bears, gods, spirits, and non-Thai hill peoples.

Even today, lowland Thais (in the north called *khon muang* or “people of the *muang*”) often consider the hill peoples backward or uncivilized because their ways of life are different from those of Thai peoples. The hill peoples follow their own cultures, speak their own languages, eat different foods, and, especially, are not Buddhist. They are predominantly animist, each group having its own elaborate set of beliefs and practices that the lowland, Buddhist Thais tend to see as primitive. Buddhism for Thais is an element of their cultural identity and a key component of the sacred geography that has defined their civilization for centuries.

At the same time, most Thai Buddhists also believe the universe is inhabited by spirits and gods. Buddhism as a religion has never denied their existence. The classic treatise on Thai

cosmology, *The Three Worlds According to King Ruang* (from the thirteenth century, translated by Reynolds & Reynolds, 1982), describes the interplay between the heavens (the realms of *theewadaa* or celestial beings), earth (where the humans live), and the hells (the place of *phii* [spirits] or lower-level beings living out the consequences of negative behavior). All sentient beings, according to this Buddhist cosmology, can be reborn at any level of these three worlds depending on the merit of their actions in each life. Even the gods, who lead lives of pleasure and comfort, will eventually pass away and be reborn. Only humans can achieve enlightenment, release from the cycle of rebirth and suffering.

While Thais view the three worlds as distinct, they are not isolated from each other. Usually the *theewadaa* and *phii* of the upper and lower realms are benign and do not harm humans. If provoked, however, the *phii* in particular may harass or even possess some humans. Thais believe some *phii* are malevolent and go out of their way to avoid or appease all spirits. Other *phii* may simply appear to people as their paths cross. Guardian spirits (considered both *theewadaa* and *phii*, illustrating the vague nature of these concepts) monitor and protect particular places. Some are considered "lords of the land," associated with the *muang* or principalities of the past (see Shalardchai, 1984). People fear the spirits, *theewadaa* and *phii* alike, because of their supernatural qualities and powers.

Many different kinds of spirits inhabit the northern Thai cosmos. There are ghosts, or *preta*. This ambiguous term covers the spirits that all people become at death before they are reborn into another form of existence. It also denotes the hungry ghosts, *phii* that are constantly hungry and thirsty because their tiny mouths cannot open fully. People believe these *phii* were greedy in a former life and are now paying the consequences of their actions through insatiable hunger.

Other kinds of *phii* include tutelary spirits that help people who ritually respect them and follow the ethics that they enforce. Some of these are guardian spirits of particular places, such as a village or a household. Spirits live in forested

areas, occupying trees, fields, and streams. People make offerings to these spirits before they cut down a tree or clear a field for their crops. Every year villagers hold a series of agricultural rites, including offerings to the spirits of the fields, continually thanking them for allowing the forest to be cleared and the crops to grow. Spirits also look after the cremation grounds and sacred groves that surround some villages as well. In some areas these are the only patches of forest that have not been cut down. They have been left standing due to people's fear of and respect for the spirits believed to live there.

A number of deities or celestial beings share the northern Thai world as well. These *theewadaa* also receive ritual offerings and propitiations for their powers to influence the human world. There are Four Lords who rule over the four cardinal directions, overseen by Indra (Indra is a god borrowed from Indian cosmology and was probably introduced into the region before Buddhism's arrival). Two female spirits affect people's interactions with the natural world. These are Mae Phosop, the rice goddess, and Mae Thoranee, or Mother Earth. These *theewadaa* can either help farmers with their rice and other crops or punish those who offend them.

The annual rituals performed in honor of the various *theewadaa* are examples of how northern Thais interact with supernatural beings. Humans do not have control over these beings but exist in a balanced and dynamic relationship with them. People can influence the *phii* and *theewadaa* for temporary periods but must continually renew their relationship through rituals.

An example of these rituals is an annual rite performed in April during the Thai New Year in honor of Lord Indra, the Four Lords, and Mae Thoranee. A layman trained in Brahmanic practices, often a former monk, usually conducts the rite. Even though technically there are no Buddhist elements to the ritual, I have seen the rite done by a monk. Northern Thais do not make such distinctions within their religious system, and none of the villagers, including the monk himself, saw any contradictions in his performing the rite.

The ritual involves propitiating the six deities with offerings of food, rice, betel nut, cigarettes, and clay models of buffalo, elephants, and other useful and powerful animals. After the formal ritual, conducted in the center of the village, trays made of banana tree trunk and bamboo, loaded with the offerings, are carried to the four cardinal points of the village boundary for the Four Lords. Two trays are left in the center of the village: one on a pole for Lord Indra and the other sitting on the ground at the pole's base for Mae Thoranee. In addition to honoring the deities, the ritual exorcizes the village of evil or harmful forces. These negative forces are carried to the edge of the village with the trays for the Four Lords and are exiled to the wild space beyond the settlement. The Four Lords help guard the village boundaries, as well as looking after the region of each direction. Besides the annual performance for the entire village, ritual specialists will perform this rite when serious illnesses or calamities occur within the village or individual households.

Probably the most feared of the spirit world are the *phii* that inhabit the forests. As the *paa thu'an* represents the antithesis of the civilized world, people see the spirits that live there as especially dangerous. The divide between *muang* and *paa thu'an*, and between Buddhism and animism, however, is not absolute. Even the forest can be used by people if they take the proper precautions, including conducting rituals to propitiate and appease the gods and spirits that dwell there. The rites need to be done on a regular basis or every time someone wants to use forest resources such as trees for building houses or animals for food.

Buddhism and Spirit Beliefs

Buddhism does not teach that spirits do not exist. Instead, its teachings emphasize developing one's ability to control fear, such as the fear of spirits, through recognizing the impermanence of all things, including one's self. This is a learned skill, however, often developed through years of practice and confronting fear (see Kamala, 1997).

When I first began to study Thai Buddhism, I did not expect to find many monks who believed in spirits. Living in northern Thailand and studying with monks, however, I soon realized the extent of the interplay between Buddhism and animism. One monk's story in particular highlights the dynamic relationship between the two.

As a novice in his teens, living in a small, rice-farming village in northern Thailand, this monk walked several kilometers daily to attend classes on Buddhism. His journey took him along a long stretch of road that ran through the rice fields and forest between his village and the next. Often he traveled this road at night when his lessons ran late. He walked with trepidation as the villagers told tales of a hungry ghost that haunted the fields and forest at night.

One dark, moonless night, he related to me years later, as he walked the road, he saw a light across the field. No houses sat in that area, and it was not the season for villagers to be hunting frogs at night. The novice froze in his steps as the light glided across the field toward him. "The hungry ghost," he thought, hardly able to breathe.

As the light came closer, the novice tried to still his panic. All the warnings people had given him about walking this stretch of road at night flooded his mind and he regretted not heeding them. Then he remembered why he walked this way – to study Buddhist scripture in the temple in the district town. "I'm a monk," he thought, "I'm not supposed to fear ghosts. This ghost can't harm me."

With that thought, the light stood still a few meters into the field. The novice smiled at his own silliness and continued on his way home. He never told anyone of his experience until years later, after the forest had been mostly cut down and the road was more traveled, even at night. No point in fostering these fears, he told me, as his story would have only confirmed people's belief in the hungry ghost.

The tale of the hungry ghost involves only one kind of the many *phii* and *theewadaa* in northern Thai cosmology. Nevertheless, it shows how belief in a spirit causes fear and can potentially keep people out of certain places. It also illustrates the belief in the superiority of Buddhism over

spirits in the cosmological hierarchy, a belief that has been used to change the spiritual geography, civilize untamed areas, and develop the forest.

Buddhism and Forest Development

Buddhism has contributed to civilizing the forest in the modern era through subduing the wild forest and its spirits, enabling human settlements to expand beyond city boundaries. In the late nineteenth and early twentieth centuries, forest-dwelling monks bridged the space between *muang* and *paa thu'an* (Stott, 1991, p. 149; see also Kamala, 1997; Tambiah, 1984; Taylor, 1993a). These Buddhist monks chose to follow 13 ancient ascetic practices, including forest dwelling, called *thudong*, that aided meditation and purification. Their spirituality enabled them to face the fears of the wild that most lay people held and enter and even live within the forest for extended periods (Kamala, 1997). Forest monks brought elements of the civilized world to the forest, blurring the distinctions between the two. Their presence helped quell villagers' fears of the forest spirits, leading them to move into the forest, settling previously wild, dangerous, and unlivable areas. If the monks could live there, people believed, then, under the protection of their spiritual powers, so could devout lay people.

Kamala (1997) points to the presence of forest monks as one of the factors that enabled the Thai government to "invade" and then "close" the forest in the twentieth century. She refers to two relevant eras. First was the Forest-Invasion Period (1957–1988), in which the military-backed government manipulated the Buddhist Sangha (or monkhood) in order to promote economic development that led to significant deforestation across Thailand (Kamala, 1997, pp. 229–243). The second was the Forest-Closure Period (1980–present), in which the government, in an effort to retain control of dwindling forest resources, banned monks – and most lay people – from living in the forests (Kamala, 1997, pp. 243–249).

The governmental efforts to develop and control forest resources, and the use of the Sangha in

this process, was epitomized by Field Marshal Sarit Thanarat, the autocratic ruler who, after coming to power through a coup in 1958, pushed Thailand into an intensive development policy. Aiming to bring Thailand into the global economy, Sarit promoted agricultural intensification and expansion based on export and industry. He emphasized a shift toward cash cropping and bringing more forest land under cultivation, continuing the concept of "civilizing" the wild forest and making it useful for humans. He also drew on traditional cultural values to promote his development agenda. Ishii comments:

Sarit thought that national integration must be strengthened to realize national development. To attain this goal he planned to start with fostering the people's sentiment for national integration through the enhancement of traditional values as represented by the monarchy and Buddhism. (Ishii, 1968, p. 869)

Sarit incorporated Buddhism into his development campaign through community development and missionary programs involving monks (Keyes, 1971; Tambiah, 1976, pp. 434–471). These programs included *thammathud*, which sent monks as missionaries to politically sensitive and economically poor border provinces; *thammacarik*, through which monks worked among minority hill peoples to convert them from animism and bring them into the national economy; and community development programs sponsored by the two national Buddhist universities.

The involvement of monks in development programs provided legitimacy and encouraged Buddhist lay people to participate. At the same time as they contributed to national economic growth, however, these monks inadvertently were a factor in the accompanying environmental degradation. The balance of the spiritual geography shifted. The elements of fear of and respect for spirits that limited encroachment into forested land in the past were negated by monks' engagement in and support of national economic development (see Somboon, 1977, 1988).

The contribution of individual Buddhist monks to the destruction of the forest can be seen on the local level as well, through the act

of subduing forest spirits. The following quote from an ethnography done in a northeastern Thai village in the 1960s illustrates villagers' beliefs in forest spirits and the potential role Buddhism plays in overcoming them so that people can use forest resources. It concerns a particular kind of tree, the *takien* tree, in which spirits live.

Takien trees are most well-known for female malevolent spirits. Nevertheless, the villagers have to overlook their harm whenever they wish to cut them down. A certain person with an especially strong *mantra* will have to conduct a ritual to subjugate the spirits. After a rite is performed, the tree may be cut down.

If a person is uncertain as to whether or not it would be right to cut down the tree, he would cut the trunk with an axe and leave the axe stuck in the tree overnight. If the axe is found fallen from the tree in the morning, the man would be able to cut the tree unharmed. Sometimes if the government wants a particular tree, the cutter would put an official emblem on it. This would supposedly bring no danger to the cutter.

When the *takien* tree is cut, one would usually hear the cry or groan of a woman. Sanguan Srisuwarn [a villager] recounts that once he went to carry a *takien* tree which had already been cut. He could not even get close to the tree. Big flies were swarming the tree so thickly that it was impossible to do anything with the tree. This is supposed to have been the doing of the *phi*. So they had to ask a monk from Wat Nong Yang to chase the *phi* away. The monk made holy water and sprinkled it all around with a *takien* branch. After a while the flies were gone (Kingkeo Attagara, 1976, pp. 44–45; quoted in Stott, 1978, p. 16).

A professor at Chiang Mai University told me of stories of villagers asking monks to exorcize spirits from forested areas so that they could cut down the trees and establish farms in the northeast. I never directly met anyone who had witnessed such actions, but the logic of such actions makes sense. The accounts of the government using forest monks – directly and indirectly – to facilitate economic development of forested areas (Kamala, 1997, pp. 229–249) and involving other monks in community development and Buddhist missionizing activities since the 1950s (Keyes, 1971; Tambiah, 1976, pp. 434–471), together with descriptions such as the quote above, suggest that the use of Buddhism to civilize the *paa thu'an* was a common event.

Spirituality and Conservation

In more recent times, however, a small number of monks are working to use Buddhism to protect the forest and the natural environment. These self-proclaimed “environmentalist monks” (Thai: *phra nak anuraksa*) promote environmental conservation based on Buddhist principles such as compassion and the interdependence of all beings. They are concerned about the suffering resulting from unmonitored economic development and environmental damage. They cite the Buddha's close connection with the forest, including stories that his birth, enlightenment, and *parinibbana* (physical passing) all occurred in the forest, to support their calls for people to protect forested areas. Monks have undertaken projects to create protected community forests, clean up polluted rivers, and challenge illegal logging in national parks.

While environmentalist monks emphasize Buddhist principles in their work, they are aware of the importance of the cultural contexts in which they work. Some incorporate local beliefs in their environmental work. For example, Phrakhrū Pitak Nanthakhun of Nan Province in northern Thailand recognizes the potential of spirit beliefs to support conservation projects and gain villagers' commitment to them. In 1990, he sponsored a ritual that symbolically ordained a tree in his home village in order to establish and sanctify a protected community forest (Darlington, 1998). Before the tree ordination, the villagers held a ceremony asking the village guardian spirit, one of the region's “lords of the land,” for permission to create the community forest and his help in protecting it. They established a shrine at the base of the tree to be ordained and made offerings to the guardian spirit. Phrakhrū Pitak did not attend the ceremony, but neither did he oppose it. He commented later on the combined effect of the two rituals:

Holding a tree ordination, establishing a shrine for the guardian spirit and placing a Buddha image as the “president” of the forest to forbid cutting trees are all really clever schemes. It's not true Buddhism to conduct such rituals. But in the villagers' beliefs, they respect the Buddha and fear some of

his power. Thus we can see that there is nothing so sacred or that the villagers respect as much as a Buddha image. Therefore we brought a Buddha image and installed it under the tree which we believe is the king of the forest and ordained the tree. In general, villagers also still believe in spirits. Therefore we set up a shrine for the guardian spirit together with the Buddha image. This led to the saying that “the good Buddha and the fierce spirits help each other take care of the forest.” This means that the Buddha earns the villagers’ respect. But they fear the spirits. If you have both, respect and fear, the villagers won’t dare cut the trees. (Quoted in Arawan, 1993, p. 11; my translation)

Most villagers would agree with the assessment that since the tree ordination, there has been greater cooperation in protecting the community forest and less encroachment within it.

While many of the villagers developed an understanding of the principles of ecological conservation through the education sessions held by Phrakhru Pitak prior to the ceremony, the impact of both the Buddhist principles applied to forest conservation and the power of the spirit’s charge to guard the forest cannot be denied. The local people’s indigenous knowledge of forest ecology, which is fostered and encoded in their spirit beliefs, their awe for the sacred aspects of the project, their respect for Phrakhru Pitak, and the newly introduced concepts of conservation all work together to heighten the villagers’ cooperation and responsibility to preserve the remaining forest.

Nevertheless, the element of fear may have had more of an impact than Phrakhru Pitak intended. Over the 2 years following the ordination ceremony, four deaths and several illnesses occurred in the forest that villagers attributed to retribution from the spirits for violation of the terms protecting the community forest. The people who died or became ill were all believed to be cutting wood or hunting within the protected areas. Their misfortunes were determined by spirit ritual specialists to have been caused by forest spirits who were offended by these people’s actions.

Although some other monks have criticized Phrakhru Pitak for using the fear of spirit beliefs to achieve the ends of environmental conservation (due to the use of fear and because many

monks deny spirit beliefs as being counter to the teachings of Buddhism), he sees it differently. The villagers believe in and respect the spirits of the forest. Their relationship with these spirits defines and reaffirms their understanding of how the world works – in its natural, supernatural, and human aspects. The monk also recognizes that northern Thai belief systems are not static. They have evolved over time, adapting to incorporate various elements of Indian culture, including Buddhism, that have entered the region over several centuries. He recognizes and uses the traditional sacred geography rather than trying to alter it to achieve his aims.

Just as Buddhism was used throughout the twentieth century by the government to encourage a shift in villagers’ attitudes toward the forest in the service of development, Phrakhru Pitak sees the potential for using religious and cultural beliefs to change people’s attitudes again – only this time in the service of conservation. Recognizing the continual evolution of people’s beliefs and practices, Phrakhru Pitak integrates traditional beliefs with Buddhist practices to promote an ecological ethic. While the government and pro-development forces emphasize what they see as “pure” Buddhism (thereby invalidating non-Buddhist beliefs), the monk seeks to incorporate all attitudes toward the natural world. Rather than civilizing the forest through imposing Buddhist concepts in order to conquer and use it, he hopes to instill values that recognize the importance of the forest as an integral component of the environment, which includes humans (Buddhist and non-Buddhist alike), animals, and spirits. Through the Buddhist concept of interdependence (Pali, *paticca-samuppada*, or dependent origination), he teaches that humans need the forest for a well-balanced life.

Accompanying such rituals as tree ordinations, Phrakhru Pitak offers villagers concrete methods for achieving this balance. He acknowledges that he cannot merely forbid people from using forest resources as these provide their livelihood. He works with farmers to develop appropriate, sustainable, and organic agricultural techniques, including integrated agriculture. This method is based on using complementary

plants and animals that sustain and support each other, rather than growing a single cash crop that requires chemical fertilizers or pesticides. Phrakhru Pitak encourages villagers to farm for their own subsistence first, only selling any surpluses that may remain. In this way, he hopes they can avoid getting into debt through the high costs and risks of growing a single cash crop.

Phrakhru Pitak does not only work with Buddhists. He involves the non-Buddhist hill peoples in Nan Province in his environmental education programs, recognizing their relationship with the forest and the potential demise of their traditional lifestyles through rapid economic development and deforestation. As with the lowland Buddhist villagers, Phrakhru Pitak emphasizes the importance of integrated agriculture and sustainability among hill peoples and respects and uses their spirit beliefs in engendering their understanding of their relationship with the natural environment and their cooperation in conservation efforts.

Phrakhru Pitak's tree ordination program is only one example of the kind of work he and other environmentalist monks undertake. In conjunction with the tree ordinations, for example, he also incorporates modified *thaut phaa paa* ceremonies, which are traditionally performed by villagers to offer "forest robes" (*phaa paa*) to monks in merit-making rituals. Phrakhru Pitak expanded the rite to include people's giving tree seedlings along with the robes. The seedlings, after being accepted and sanctified by the monks, are then given back again to the villagers to plant in deforested areas. The trees selected are kinds such as fruit trees that are productive without having to be cut down (Darlington, 1998).

In 1993, Phrakhru Pitak expanded his work to increase awareness of the importance of water for all life through a project designed to show the polluted state of the Nan River and garner support for cleaning up and maintaining the quality of its water and wildlife. Again incorporating local beliefs, Phrakhru Pitak performed a traditional "long-life" ceremony for the river in a 2-day event in Nan City attended by villagers, government officials, military personnel, nongovernment organizations, and over 200 monks from across northern Thailand. At the same time, he

established a fish sanctuary, marking the boundaries of a section of the river within which fishing was not permitted and where the fish would be fed. Here he followed the model of a village upriver from the city; in this village, within a year of creating a fish sanctuary, villagers claimed the numbers of fish increased rapidly, and they were better able to balance between protecting the fish and providing food for their families.

The "long-life" ceremony itself, called *syyp chaa taa* in the Northern Thai dialect, is an exorcism ritual usually performed to rid a person of negative forces and promote a long and healthy life. While Phrakhru Pitak performs several such rites a month for his followers, he says he does not actually believe in the physical effectiveness of the ritual. Rather, he views it as an opportunity to teach people about ways to live their lives following the teachings of the Buddha, thereby decreasing the problems and suffering they face in their lives and ultimately living in greater harmony with the natural world. Adapting the ceremony to the river afforded a similar opportunity to teach the importance of caring for the river and its resources, both water and fish.

Phrakhru Pitak skillfully included elements of Thai society that often oppose the work of the environmentalist monks – government officials, military leaders, and businessmen. All of these groups often have stakes in promoting economic development along the lines laid out through government policy, as discussed in the previous section. Phrakhru Pitak believes, however, that these people are not inherently bad nor do they aim purposely to degrade the natural environment and the quality of life of the people who depend upon it. They have merely been led astray through the traditional Buddhist evils of greed, ignorance, and anger, on which most environmentalist monks blame the problems of rapid economic development. Through involving the government, military, and businessmen in their projects, activist monks such as Phrakhru Pitak hope to teach them as well as the villagers the value of living an ecologically balanced life.

Activists in southern Thailand used a similar approach in organizing several Dhamma Walks (*Dhammayatra*) around Songkhla Lake

(Santikaro, 2000). The purpose of these walks was to bring attention to the environmental degradation of Thailand's largest lake, a unique and complex ecosystem, to local people and local and regional government officials. Participants aimed to strengthen the voice of local, usually poor and marginalized, people. The issues identified by local people included a lack of fish to eat, bad water and reduced water levels, theft of water taken before it drains into the lake, loss of land through nearby urban population increases, and the breakdown of community and loss of traditional livelihoods (Santikaro, 2000, pp. 208–209). Buddhist monks, members of a national, small but growing network of activist monks called Phra Sekhiyadhamma, led the walks and included local people, village leaders, nongovernmental organization workers, foreign environmental activists, and some local government officials. The participants drew on local culture, both Buddhist and Muslim, in order to foster sympathy and commitment to protecting the lake's ecosystem (including the people whose lives are integrally entwined with it). Unfortunately, few Muslims actually participated in the walks, pointing to perhaps too great an emphasis on Buddhism rather than truly integrating local cultures in the project. Nevertheless, the group succeeded in building confidence among the lake's people, involving local monks who previously did not engage in environmental conservation and gaining awareness nationwide for the problems unique ecosystems such as Songkhla Lake face due to unmonitored development. Anthropologist Ted Meyer, who chronicled the walks, observed the potentials of the activities for creating change:

I believe the lake walks have created a unique kind of public space in which a very broad range of issues can be explored by participants and observers. These issues include not only the current state of human relationships with nature at the local and global level, but also the meaning and significance of Buddhist practice, the possibilities and problems of cultivating relations of trust between people of very diverse backgrounds, and the challenges of designing effective strategies for social change. The breadth and openness of this space makes it possible, I believe, for a unique kind of spiritual and social creativity to take place. That

same breadth and openness, however, also increases the range of difficulties that may be encountered. (Quoted in Santikaro, 2000, pp. 213–214)

Demonstrating further cultural creativity and the willingness to face the potential difficulties, environmentalist monks undertake numerous other activities across the country. These programs include a monk who teaches environmentalism to young people through a bird-watching club in northeastern Thailand. Another leads children on Dhamma Walks in the forest surrounding their village in northern Thailand while taking the opportunity to talk with them about both the Buddha's teachings and the ecology of the forest. This same monk (the hero of the hungry ghost story) also runs a model-integrated agriculture farm designed to teach villagers sustainable methods and encourage a shift away from cash cropping.

Even monks identified as "forest monks" (a category that indicates ascetic monks' retreat from the social world to meditate in the wilderness rather than any inherent activist stance toward the forest) protect and maintain the forest within their temple compounds even while everything surrounding them is being cut down (see Taylor, 1993a, pp. 246–252). As Taylor noted in 1993:

Presently the only remaining primeval forests in the northeast with a semblance to that described by elderly informants and pre- and post-war biographical texts are small pockets dotted here and there throughout the relatively less accessible parts of the countryside. The forest monastery, the ancestor/spirit forest (*paadorn puutaa*) and cremation grounds (*paa chaa*) are normally the only forested areas in close proximity to villages. (Taylor, 1993a, p. 250)

The presence of monks, ancestors, and spirits, whether those believed to inhabit the forest naturally or ghosts of the recently deceased, all contribute to protecting forested land. Thai villagers respect and even fear both monks and spirits; thus they avoid destroying forested areas connected with both. This level of protection is not enough, however. These areas tend to be small, often surrounded by denuded land. The quality of the environment within these patches of forest often

deteriorates as well due to the loss of the larger ecosystem that used to enclose them. And ironically, as noted earlier, even the presence of forest monks can often empower people to overcome their fears and cut the forest.

The two approaches described here reflect a (self-)conscious shift in the application of religious beliefs and practices toward influencing people's attitudes toward the natural world. The case of Thailand illustrates the various ways religion, tradition, and culture have been used to influence people's relationship with nature, in favor of both economic development and nature conservation. While neither is intrinsically superior to the other – arguments are made on each side of the need for either development or conservation for the good of the country – the potential for affecting the future is clear. Given the severity of environmental degradation and deforestation in Thailand, largely attributed to rapid economic development (see Hirsch, 1993, 1996a, 1996b; Hirsch & Warren, 1998; Lohmann, 1991, 1993, 1995; Pinkaew & Rajesh, 1991; Rigg, 1995a, 1995b; Rigg & Stott, 1998), I find it encouraging that some monks and activists, such as Phrakhrū Pitak, are engaging in the creative use of all Thai traditions and beliefs – Buddhism and spirit beliefs – for the long-term benefit of both people and nature. The spiritual geography of Thailand has been altered for political ends, but hopefully not to the point of irreversible damage to either the natural environment or the people who live within it.

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Environment and Nature in Hebrew Thought

Jeanne Kay Guelke

It is perhaps inappropriate to include a section on Hebrew thought in an encyclopedia on non-Western cultures. When the Hebrew Bible was adopted in translation as the Christian Old Testament, it became one of the intellectual cornerstones of western civilization. The two principal divisions of Jewish culture and ethnicity, central and eastern European (*Ashkenazi*) and Mediterranean and Near Eastern (*Sephardi*), have extensive European roots. Nevertheless Christianity and Judaism diverged in critical ways over the interpretation of their shared scriptures.

The Hebrew Bible and Jewish Law

The essential core of Jewish belief is the first five books of the Bible, notably the set of 613 commandments (*mitzvot*) handed down to Moses on Mount Sinai. The rabbinical interpretations of Mosaic law (*halakhah*) and explanations of biblical narratives codified principally in Babylon and Palestine during the first centuries of the Common Era as the Talmud (together with some subsequent commentaries on the Talmud) form the essence of traditional Jews' understanding of the cosmos and permissible activities within it. “Hebrew thought” as a body of literature in the Hebrew (or Aramaic) language is not identical with “Jewish thought” (which

includes Yiddish prose and other writings from the Diaspora) but there is a strong correspondence based upon Jewish origins in the ancient Near East.

In the Hebrew Bible, one God created the heavens, the earth, and their creatures, and pronounced them “good.” God placed the first humans in the beautiful Garden of Eden “to dress it and keep it.” Humans were given control over soil and biota: “the fish of the sea, the fowl of the air,” but the Bible explicitly reserves control over physical forces of the environment, notably climate, to God. The Bible links humans’ ability to shape nature to their liking to their obedience to God’s will. In the biblical narratives, few humans are righteous enough to accomplish dominion over nature.

God commanded the patriarch Abraham and his descendants, the Israelites, to worship God exclusively and to obey His commandments. The books of Numbers and Deuteronomy explain environmental change in the form of divine blessings and curses for human good deeds and misdeeds. The Israelites are to receive a homeland, abundant rainfall, and crop yields if they obey the *mitzvot*, but drought, insect plagues, and the “scorched earth” resulting from warfare if they disobey. The environment is a principal means through which God expresses Himself and registers His authority.

The Hebrew Bible and Talmud have little explicitly to say about environmental conservation in the modern sense. There are proscriptions in Jewish law against cruelty to animals, destruction of fruit trees during warfare, tilling the soil during the sabbatical year, and working (and hence altering nature) on the Sabbath day. There is little evidence in the Bible that Middle Eastern, Iron Age farmers and pastoralists even understood that humans were capable of causing extensive environmental degradation (with the possible exception of overgrazing), and considerable evidence that they attributed environmental deterioration to God’s wrath. These cast considerable doubt on some scholars’ assertions that the Judeo-Christian tradition is the root of the West’s callous treatment of nature, simply on the basis of a few verses in Genesis mandating

human use and domestication of plants and animals. Needless to say, both Christian and Israeli settlers in recent centuries have subsequently cited the Genesis injunction for human dominion over nature and Isaiah’s prophecy that the desert shall “bloom like the rose” as a license for resource exploitation.

The ancient Jewish dietary laws (*kashruth*) identify certain animals and slaughtering practices as “clean” or “unclean” as food for the Jewish people. Although the scriptural statement that some species are “abominations” on the Jewish table does not imply reverence for all of nature, the forbidden animals, by the same token, would not have been hunted or raised inhumanely. A modern environmentalist interpretation of *kashruth* is that God expressly limits Jews’ exploitation of the Creation.

Today when many environmentalists seek to undo the dualism between humanity and nature, it is worth noting that the Hebrew Bible indeed has no words for “environment” or “nature” that distinguish these concepts from culture: only the universal and integrative concepts of “everything” (*olam*) or Creation. In the Bible’s original Hebrew (though not in most English translations) animals have souls (*nefesh*, *ruach*) just as people do. Trees and stars praise God and shout for joy.

The Bible is full of evocative nature poetry, notably in the prophets, Job and the Psalms. Eagles, lions, the cedar forests of the mountains of Lebanon, the desert after a rain shower, and lush pastures seemed especially inspirational to the ancient Hebrew mind. The Israelites’ formative early experiences with the desert (as in the book of Exodus) and Mediterranean crop zone appear throughout their religious texts.

The Jewish scriptures also describe an annual cycle of holy days that were based on a lunar calendar and changing seasons as they would have affected ancient farmers and herders. The festival of *Shavuot* (Weeks), for example, celebrates the gathering of first fruits of the land. *Sukkot* (Tabernacles) in autumn culminates a series of days set aside for repentance and atonement with prayers for the winter rains so essential for agriculture in the Near East. While such

environmental connotations were weakened among urban Jews of the Diaspora (who nevertheless continued to observe the holy days), they are quite obvious to visitors of rural Israel today.

Middle Ages and Early Modern Times

With the postbiblical Diaspora or exile from Palestine following Roman destruction of Judaism's institutions and sacred sites, Jews literally scattered to the four corners of the earth. Often forbidden by host governments from attaining the most basic of human rights, owning land, living outside of urban ghettos, or working at most occupations, many Jews were prevented by anti-Semitism from forming a close relationship with environments where they settled. Preserving their faith and studying Torah and Talmud were largely indoor activities.

Although development of Jewish environmental thought was thus limited, medieval Jewish philosophers and mystics who developed the Kabbalah teachings believed that all of nature was imbued with divine emanations, or even with divine substance. Some leaders of the eighteenth-century pietist Chassidic movement of Eastern Europe were noted for retreating alone to the fields and forests for prayer and mystical insight. The agrarian Zionist movement of the late nineteenth and early twentieth centuries advocated a return of Jews to Israel, in the belief that working the soil of their ancient homeland would redeem and ennoble oppressed European Jewry.

Recent Past and Present

The recent history of Hebrew thought on the environment and nature is best exemplified by the modern state of Israel. Since its inception in 1947, it has experienced many of the same environmental problems as other industrialized countries, with particular concerns about water scarcity and reforestation. Israel's push for

development of new settlements and industries despite a hostile international political scene, and its land use needs for military security often overrule environmental preservation priorities. Hostilities between Arabs and Jews clearly have had an environmental impact, notably in the recent expansion of Israel's "security" landscape and in tensions between Arab range lands and Jewish reforestation projects.

Nevertheless Israel is one of the few nations in the Near East with a variety of environmental organizations, such as the Society for the Protection of Nature in Israel (founded in 1953), a Ministry of the Environment, and a system of nature preserves and national parks. Two noteworthy parks, Chai-Bar and Neot Kedumim, are maintained to preserve specimens of vanishing desert fauna and flora, respectively, mentioned in the Bible.

The Israeli response to nature has not lost its ancient religious roots. Some Orthodox Jews in Israel use traditional prayers for rain as a response to drought, and accept halakhic rulings about agricultural fields together with scientific agronomy practice.

Many Jewish environmentalists throughout North America today seek to integrate their faith and environmental concern. Some are reexamining the rabbinical concept of *Tikkun Olam* (healing everything) as the performance of *mitzvot* necessary to restore planetary health. Vegetarianism for some fits in well both with Jewish dietary laws and environmentalist beliefs about the sanctity of life. Clearly the synthesis of ancient traditional texts, religious practice, and recent environmental awareness will lead to a rapid evolution of environment and nature in Jewish thought in the near future.

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Environment and Nature in the Amazon

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The Amazon is bordered by the Andes Mountains, Guiana Highlands, Brazilian Highlands, and the Atlantic Ocean. This region is about the size of the continental United States of America. Portions of the Amazon are included within the territories of nine South American countries: French Guiana, Suriname, Guyana, Venezuela, Colombia, Ecuador, Peru, Bolivia, and Brazil. However, about 80 % of the Amazon is in Brazil.

The Amazon remains a mystery to most outsiders, but their impressions are often more fiction than fact. Demystifying the Amazon requires an understanding of its diversity and human residents. Here biological, indigenous, and colonial ecologies are briefly considered.

Biological Ecology

About half of the world's tropical rain forest is in the Amazon region, the largest reservoir of biological diversity in the world. Typically within just a few square miles of forest live more than a thousand species of plants and hundreds of species each of birds, mammals, amphibians, and reptiles. Most of the Amazon is a variant of tropical rain forest. Among the variants are moriche palm, cloud, mangrove, and anthropogenic forests. However, there are also pockets of various kinds of savanna or grasslands within many forest areas.

The climate in the tropical rain forest is characterized by high temperature, rainfall, and humidity rendering it the norm for plant growth on this planet. Every other kind of plant community is some deviation in response to stresses such as lower rainfall and/or temperatures.

The Amazon is frost free. There is usually no synchronous dormant period in plant growth, unlike in drier and colder regions. The average yearly temperature is around 75 °F (24 °C) and the average yearly rainfall is 2,000 mm or more. The greatest temperature fluctuations are diurnal instead of seasonal.

The dynamics of the ecosystems of the Amazon are mostly related to variations in the amount and distribution of water through time and space. Variations in rainfall more than temperature usually mark the seasons. In the wet season it rains almost daily while in the dry season it rains at least a few days each week although not necessarily for the entire day. Changes in the distribution of water trigger changes in the local distribution and abundance of fish and other wildlife.

Throughout the Amazon water is common in one form or another such as rivers, streams, lakes, ponds, pools, and swamps. The Amazon River is the longest in the world (6,700 km), has more than 1,000 tributaries, drains about 40 % of the continent of South America, and carries 20 % of all of the river water in the world. The flood plain (fluvial zone) and the interior (interfluvial zone or terra firme) are two general types of environments in the Amazon. During the wet season the level of the water in various aquatic ecosystems may rise as much as 20 m. However, actual flood plains compose less than 10 % of the region. Thus, most of the Amazon is interior forest that is not regularly flooded.

There are at least three major types of water in the Amazon (clear, white, and black) with very different physical and biological characteristics. For example, black waters, such as the Rio Negro, are associated with white sands; they are tea colored, high in acidity, and low in nutrients, productivity, and diversity.

It has been estimated that there are at least 30,000 species of vascular plants in the Amazon, although the number may be much higher. The plant community of the tropical rain forest is characterized by its height, luxuriance, and diversity. Giant trees with few, if any, branches in their lower levels stand like tall columns. Often there are several layers in the structure of the forest

which reflect a vertical zonation in the microclimate and associated plants and animals.

Animals are relatively scarce in most ecosystems of the Amazon. While species diversity is high, their population density is low and individuals within a population are patchy in spatial distribution. Moreover, most species are arboreal, small in body size, solitary, camouflaged, and nocturnal. Also animals only comprise a fraction of the mass of the forest, and most of those are invertebrates. Accordingly, animals are not readily available for the hunter, zoologist, or tourist. The major exception to these generalizations about animals is the peccary (wild pig) which is terrestrial, large in body size, large in group size, diurnal, noisy, and leaves obvious trails. Wild pigs are usually the most important prey by weight for most indigenous hunters. However, in riverine areas fish are the primary protein source for millions of people. The Amazon as a whole has the richest freshwater fish fauna in the world with some 3,000 species.

Until a couple of decades ago it was thought that these forests were primeval, pristine, and static. But more recent research reveals that forest distribution has alternately contracted and expanded with oscillations in rainfall abundance and distribution over the last million years correlated with Pleistocene glaciations. The Amazon is also influenced by the climatic oscillations called El Niño and La Niña. Furthermore, there is evidence of the increasing impact of global climate change in some parts of the Amazon with extraordinary drought, flooding, and wildfires.

Indigenous Ecology

The extent of human antiquity, farming, population settlement, and density in the Amazon implies significant human influence on the environment over time. Estimates of human antiquity in the Amazon range to more than 11,000 years ago. Pottery dated from as early as 7,500 years ago has been recovered at various sites. Pottery is associated with relatively permanent settlements and farming. By about 1,000 years ago chiefdoms

were flourishing along the larger flood plains with some population centers estimated up to 100,000 people.

It might appear that the environmental impact of traditional indigenous societies is negligible because of their usually low population and lack of Western technology such as chainsaws. However, collectively through space and cumulatively over time, their environmental impact can be substantial. Yet most of this impact is within the levels and processes of natural disturbances. This is the case for traditional swidden or shifting horticulture. Annually during the dry season, members of a household or community cut small plots of forest. After the sun has dried out the debris, it is burned, and then crops are planted just before the rains of the wet season begin. The garden is harvested for a few years after which it is gradually phased out over a decade or more as the forest encroaches. Through time the swiddens in various phases in an area collectively create a mosaic of plant and associated animal communities at different stages of ecological succession (development), thereby enhancing local biodiversity. Estimates are that 10–40 % of the terra firme forest is anthropogenic. Nevertheless, the forest remained in most areas at the time of Western contact, unlike what has transpired thereafter with deforestation through cattle ranching, logging, mining, hydroelectric dams, and other Western activities which are qualitatively different and unsustainable.

The descendants of the original colonizers of the Amazon created societies that were usually to some degree ecologically and socially sustainable. In the interior forests away from major rivers, these societies were most often characterized by a population with low density and high mobility combined with a rotational system of land and resource use and management for foraging (hunting, fishing, and gathering) as well as for farming. Most traditional indigenous populations enjoyed relatively good nutrition, health, and quality of life prior to major disruptions from Western contact, such as the Yanomami in the mountainous border area between Brazil and Venezuela. The viability of precontact cultures was usually facilitated by a spiritual

ecology encompassing a worldview integrating attitudes, values, customs, and rituals emphasizing harmony between humans and nature, such as in the case of the Desana of Colombia.

Through intimate daily experience and observation in interacting with their habitat, local people have acquired extensive, detailed, and reliable knowledge about the animals, plants, soils, waters, and other aspects of the ecosystems in their territory. This is reflected in native languages with extensive vocabularies of words for plants, animals, environments, and other natural phenomena of the ecosystems in their local and regional habitats. As an example, the Ka'apor of Brazil recognize at least 768 species of plants, 112 of which have medicinal uses. In Peru, the Matsigenka distinguish 69 different environments based on vegetation, 7 based on fauna, and an additional 29 based on various abiotic factors. They recognize ten different types of soils as well. Also in Peru, the Matsigenka identify as many as 178 different environments.

All of this ecology is further complicated by the reality that many cultures do not segregate the natural and supernatural. For instance, many Amazonians believe that shape-shifters exist as animals that might assume human form and vice versa. Usually shape-shifters are species that are mysterious and powerful from a human perspective, such as jaguars, anacondas, otters, and dolphins. Thus, the biophysical, human, and spiritual realms of the forest are not always distinct.

The indigenous cultures of the Amazon have contributed much to the rest of the world. For example, the root crop manioc or cassava was probably domesticated in the Amazon sometime between 7,000 and 9,000 years ago. It grows well even in the poorest of tropical soils and it is resistant to pests and drought. The starchy roots are naturally stored in the ground until needed for food. The distinct advantages of manioc account for its spread throughout the tropics of the world since European contact. Today it ranks as the fourth most important source of food energy in the world. The cashew nut, guava, papaya, peanut, and pineapple are among the foods now consumed in many parts of the world that were originally domesticated by ancient Amazonians.

Among the numerous technological innovations discovered and developed from nature by Amazonians are the drug curare which is used to tip arrows and blowpipe darts for hunting monkeys, the poison rotenone from vines and other plants used to stun fish in quieter sections of waterways, and the rubber latex used for waterproofing containers and footwear. Now the world uses curare for anesthesia, rotenone as an insecticide, and rubber for tires and a multitude of other purposes.

Colonial Ecology

Today some 800,000 people live in 379 distinct indigenous cultures in the Amazon. In addition, millions of other people have migrated into the region in the last few centuries since its "discovery" by Europeans. Now the total human population of the Amazon is more than 25 million. Most of these people are peasants living in rural areas with a mixture of subsistence and market economies. Also they are in various ways and degrees a biological, cultural, religious, linguistic, and ecological mixture of Europeans, Africans, and Amerindians. There are also ethnic enclaves of immigrants such as Japanese settlements.

Many peasants, like indigenes, believe that areas of the forests and waters are enchanted. These places may be associated with drowning, ghosts, mysterious lights, and other extraordinary phenomena. They are thought to be frequented by potentially dangerous spirits. These beliefs influence the way resources and places are used, and this probably helps to preserve the biotic productivity of species of game, fish, and plants.

In the last few decades, Western experiments in economic development have repeatedly failed with grave economic, social, and ecological consequences. The accumulated historical record of the many blatant failures clearly demonstrates that to this day Westerners do not yet really know how to develop the Amazon without degrading and even destroying it. A different combination of causal factors is responsible for environmental destruction in different places and

times in the Amazon, but among the principal ones are cattle ranching, logging, monocrop plantations, mineral and oil extraction, hydroelectric dams, and transmigration (government colonization programs). The use of mercury to procure small grains of gold through amalgamation is contaminating soils, waters, air, and organisms including humans in some areas with long-term detrimental consequences.

There has been considerable investigation and documentation on Amazonian systems of natural resource use, management, and conservation. Yet most Westerners have yet to recognize that, prior to European "discovery," the Amazon had already been discovered, colonized, and even developed by indigenes for millennia. If outsiders would recognize and appreciate the intelligence, creativity, philosophy, science, technology, medicine, cultures, and religions of indigenous and peasant societies in the Amazon, then they might learn sustainable uses of the forest and aquatic ecosystems. Fortunately, in recent decades Amazonians themselves are becoming increasingly organized, vocal, and assertive in defense of their land, resource, and other rights. An example is Davi Kopenawa, foremost political leader among the Yanomami of Brazil who has tirelessly campaigned on behalf of his people and their territory and forest habitat.

The keys for outsiders to unlock the mysteries of the Amazon include attention to diversity in all its manifestations; to the worlds, perspectives, and concerns of the residents; and to the scrutiny of history and colonization.

Considering the accelerating gravity and urgency of the environmental and social degradation and destruction in Amazonia, it is questionable whether this basic science approach is sufficient and ethical. A new approach is required that seeks to integrate basic and applied research with advocacy and action. It would be concerned primarily with promoting the self-determination and other basic human rights of the residents of the Amazon through collaborative research that empowers them with strategic information. Furthermore, the spiritual as well as material aspects of the ecology need to be researched and documented.

The Amazon environment is no longer an undiscovered frontier awaiting Western colonization under the pretense of progress through civilization and economic development. Coming decades will reveal whether or not outsiders have the knowledge, understanding, and wisdom to treat the Amazon and its people in a more reasonable and just manner than previously. If there is any hope for the future of the Amazon, it lies primarily with the people who actually live there.

See Also

► [Swidden](#)

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Environment and Nature in the Andes

David L. Browman

The Central Andes were the home of the Incas, an ancient civilization who created an enormous empire, larger in area than the Roman empire. Only indigenous peoples of the Himalayas have adapted as well as the native Andeans to high mountain environments. The ancestors of the Incas arrived in the Central Andes as nomadic hunters and gatherers perhaps 15,000 years ago. They began agropastoral lifeways (camelid herding and plant cultivation) around 8,000 years ago. Many of the contemporary human-nature relationships can first be identified as developing during that period.

An essentially treeless grassland – the Ecuadorian *paramo*, the Peruvian *puna*, the Bolivian *altiplano*, and the Argentine salt *puna* – which is the home of the native herders and sierra farmers – occurs along the upper slopes, plateaus, and tablelands of the Andean mountain chain. Because similar elevations support trees elsewhere in the world, the question is raised: why is the zone essentially treeless today? Is it because of the elevation and low temperature regimes currently extant? Is it because of a past climate shift? Is it because of human agency?

A popular theory is that somehow the native people destroyed the trees through mismanagement. However, pollen samples prove that these areas were significant grasslands long before any substantial human settlements existed. They supported large herds of wild camelids – guanaco and vicuña – whose subsequent domestic relatives – llama and alpaca – were the basis of support the first Andean civilizations and continue to be economically important today.

On the other hand, one cannot deny significant and extensive impact on the landscape by the humans and their domestic animals. Overgrazing has resulted in decrease in palatable species; an increase in thorny and woody bushes, cacti, and less palatable grass species like *ichu* (*Stipa Ichu*); and an increase in plants toxic to grazing animals. Annual or semiannual burning of pastures to provide new growth for herds has also resulted in changes in plant assemblages, as it removes trees and other woody plants. Cutting trees and woody plants for fuel has further increased deforestation of the small refuge zones where trees persisted. In the presence of grazing pressure from domestic camelids, the tree species usually cannot regenerate. Grazing pressure and human agropastoral activities have significantly depressed the tree line on the eastern slopes of the Andes.

Human activities thus have markedly impacted the local environment since the first major presence of human groups in the high Andes, but the presence of extensive treeless areas predates the colonization of this area by humans. Thus, while human activities are clearly very important in the present configuration, the contributions from the wild herds of deer guanaco

and vicuña which preceded the humans must also be an important factor in the occurrence of these grasslands, as well as that of elevation and meteorological conditions.

The domestic llama and alpaca herds were critical for survival of several highland groups. They provided meat, fat, blood for food; wool for clothing, bags, and rope; leather for footgear and equipment; bones for tools and religious items; dung for fertilizer and fuel; and labor power as caravan animals carrying trade goods. They also served as “banks on the hoof,” resources which could be mobilized for emergencies during the irregularly occurring but not infrequent environmental catastrophes such as sustained droughts, unseasonal frosts, and the like.

Risk and uncertainty also contributed to reliance on extrasomatic sources of help as well. The gods responsible for protecting the flocks and for insuring their increase were believed to dwell among the surrounding peaks. Annual ceremonies, called *pagos*, from the Spanish verb “to pay,” were held to “pay” the gods for current success and to petition for the future increase of flocks. A male and female animal were selected from the herds, fed *chicha*, the local corn beer (*making chicha*), and “married” to begin the next season’s offspring. These llamas and alpacas were treated and thought of as kinfolk of the herders. Today these ancient fertility ceremonies have been conflated with Catholic rituals, and are held during Carnival. Often small *illa* or animal figures of the desired type of animal are blessed and buried with offerings. In Inca times these were sometimes gold and silver, while today they are ceramic, stone, or tin (*Hammered gold objects*).

Plant agriculture was an exceedingly risky undertaking at this elevation; folklore suggests that crop failure occurred as often as 25–35 % of the years. Andean people thus sought to reduce agricultural risk through a variety of strategies. Because rains could fall on one field but not on another a kilometer away, or because early frosts or late freezes could hit a valley bottom one time, but a high slope another time, the farmer might own 2 dozen or more small plots, scattered over several elevations, in several microenvironmental areas. Every farmer maintained a dozen or so

varieties each of potatoes and other seed plants, because in 1 year a tuber which thrived in dry soils would be the only one to produce, in another year a variant which thrived in moist soils excelled, and in a third year a variety which did well in saltier soils yielded best.

In addition to the procedures to manage risk in maintaining biodiversity among their crops, the local residents developed other strategies as well to cope with risk. Elaborate freeze-drying techniques were employed to produce dehydrated potatoes, *chuño* (potato's poisonous roots) and other tubers. These technological procedures served two purposes: enhancing palatability and providing storable surplus. Most of the high elevation plants grown for consumption had significant quantities of phytotoxins, making them poor choices for foodstuffs until various dehydration processes removed the phytochemicals. As a serendipitous by-product, the resulting detoxified tubers could be stored up to 20 years, providing a critical component of sustainability.

Herders often provided a necessary component of this detoxification process, as in following their herds, they located "salt" or mineral licks with various comestible earths. They collected these geophagous clays and traded them with agriculturalists. These clays were fabricated into sauces to consume with meals. Residual phytotoxins in the tubers which had not been removed by dehydration processes, freeze-drying, or by cooking became bound with the clays. In addition, bio-available minerals were exchanged, thus doubly enhancing the quality of the food.

Propitiation of the resident gods for plants was as important as it was for the herd animals. The deity known as *Pachamama* (earth mother) was responsible for providing plant foods for the humans. Proper behavior involved offering a few coca leaves or other items before planting the field, much more substantial rituals at the harvest, and practices in daily life such as always decanting a few drops "for Pachamama" each time one took a drink, thus attempting ritually to insure adequate moisture for the crops.

Andean farmers developed a series of strategies to modify the landscape to control nature, particularly moisture and temperature

parameters. Andean peoples did not simply adapt to the ambient conditions – they were active agents who shaped and created Andean environments, and who transformed and built the landscape in which they lived.

The Lake Titicaca basin is an excellent example of the variety and range of practices employed. The local farmers, who practice small-scale intensive agriculture, make capital improvements to their lands, which are inherited by their descendants. The current elaborate landscape patterns are thus the result of multiple small increments accumulated for millennia. The flat plains usually were poorly drained; they suffered from too much water in the rainy season and too little in the dry season.

The local agropastoralists constructed raised fields systems or *waru-waru* (*Waru waru*) and sunken smaller garden patches or *qochas* (*Qochas*) to address these problems. Construction of raised, ridged fields, with swales or canals between the ridges, resulted in ridge top areas above the waterlogged soils in the rainy season, eliminating rot among the tubers. Both the *qocha* system and the intervening canals among the raised fields trapped rainwater, which was curated through the dry season to provide a continuing water supply.

In addition to managing moisture, these systems also ameliorated temperature extremes. Thus the raised field patterns, and furrows in the *qochas*, were constructed either parallel to, or perpendicular to, the path of the sun, an orientation which permitted maximum solar energy capture by the water. This water kept the fields slightly warmer at night, and often radiated enough heat to prevent frost damage while the surrounding unmodified grasslands suffered heavy freezes.

While this technology was employed through the Inca period, European invaders brought the oxen and plow (and in this century, the tractor). Raised fields could not be plowed efficiently by European technology, and hence they were leveled. Although Western technology permits much less labor per unit area, and thus is more efficient in that sense, the productivity per unit area has fallen off.

Anthropologists have recently reconstructed experimental raised fields in the Titicaca basin. These fields provide both increased yields and decreased environmental risk: local seed growing without any high-tech inputs have produced two to four times more per unit than crops growing on the European-style fields. On more than one occasion, unusually severe, out-of-season frosts have destroyed all the crops in the plowed flat fields, but have at worse only inflicted a little freeze damage on plant tops in the raised fields. While more labor intensive, the original indigenous technology has proved superior to Western technology in these environmental circumstances.

In addition to the raised fields and *qochas*, other landscape modifications were constructed to provide the same kinds of soil improvement and nutrient capture, erosion control, microclimate control, and moisture control or water management. Most noted among these are the stone-faced terraces or *andenes* (*Andenes*) and irrigated pastures or *bofedales* (*Bofedales*). For example, among the local hills, as well as the mountain valleys elsewhere in the Central Andes, often only the valley bottoms or hill bases had adequate moisture for crops, but because cold air is heavier and settles to the lowest areas, these same locations had the greatest risk from frosts. Elaborate terrace systems were constructed, with water provided by extensive canal networks. Thus hillslopes initially too steep to be plowed were remade into a myriad of small, level, irrigated plots. Because they were along the lower and middle valley/hill-slope flanks, they were too low for high elevation freezes but above the pools of supercooled air that collected on the valley bottoms. Thus agricultural terraces were often frost-free during most of the growing season.

Irrigated pastures (*bofedales*) were another means of managing water and temperature for the alpaca and llama herds. While llamas are more like camels in their ability to secure nutrition from high cellulose and other less palatable forage, alpacas thrive on moister, softer vegetation varieties. The neonates of both species are vulnerable to low temperatures in the first few days after birth. Herders thus developed elaborate canals and check dam systems, to bring water into

suitable low-lying areas, where artificial rather swampy irrigated pastures (*bofedales*) were created. The lush environment created optimal fodder for the alpacas, and the ponds provided heat-sinks to ameliorate nearby temperatures on cold nights.

The modification of the environment is exhibited in multiple other ways as well. Rivers and streams have been channelized, artificial canals have been constructed, springs have been enlarged and improved, and various holding ponds and reservoirs have been constructed. Various causeways, roads, and paths lead to constructed villages, defensive retreats (*pucarás*), cemeteries, shrines, and monuments. Fields are marked off by stone walls; large rock piles are scattered among the landscape, some for agricultural reasons and others for religious purposes. Stone corrals are found at various elevations. The Andean peoples of the Titicaca basin thus extensively transformed the local environment; such transformation is typical throughout the Central Andes.

Various strategies were employed in agropastoral production zones to provide the structure and rules for the allotment of irrigation water, distribution of communal and individual land, regulation of land use, scheduling of agricultural activities, definition of crop types, and cycle of rotational fallow. Included in these was the development and maintenance of high biodiversity among crops suited for a wide range of environments.

The Andean peoples often anthropomorphized their environment. The indigenous concept known (in Aymara) as *taypi* structures part of the human relationship with nature. *Taypi* physically is the center between two opposing concepts, the point of necessary convergence where the cosmological centrifugal forces that permit differentiation exists simultaneously with the centripetal force that ensures their mediation. It is thus both an integrating and separating center. The human body is divided into three components, with the *taypi* integrating center the heart and stomach. The cosmos is divided into an upper world, this world, and a lower world, with the earth as the mediating point between the upper and lower world. Hence humans, as residents of

this earth, arbitrate not only between forces of good and evil, but also serve to mediate between the natural environment and the gods. Just as the human body is animated and integrated as a whole by an exchange of fluid elements (blood circulating, water drunk and expelled, air inhaled and exhaled), so too is nature. Analogies are made between the circulation of fluids to animate humans and the circulation of fluids to animate nature.

The human imagery overlay upon nature is even extended to the organization of some of the Andean groups. One of the mechanisms employed to deal with the environmental risks is to spread humans over the landscape, in a pattern similar to the spreading of fields discussed above. Thus a village might send family members up to a new hamlet in the herding zones, or down to lower elevation corn growing areas, spreading production risk so that in case there was complete failure in one zone, the community would have direct access to resources in other environmental zones because they had residents living there. In the case of one group from the Qollawayas, the settlements in the lower, middle, and upper ecological zones were conceptualized and referred to by terms of the human body, with the middle elevation home village thus seen as the heart and vitalizing component of the group, and the landscape itself as replicating the human body. Andeans hence perceive their lifeways as essentially harmonious and replicating nature.

The environment thus is a dynamic, historically contingent component of the Central Andes. The Andean peoples did not simply adapt themselves passively to ambient ecological conditions. Rather they were active agents in the creation, shaping, and transformation of a highly patterned, artificial landscape.

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Environment and Nature: Australian Aboriginal People

Dorothy Tunbridge

Australian Aboriginal people's traditional relationship to their land from a philosophical, economic, and spiritual viewpoint was quite

different from that of the Europeans who arrived toward the end of the eighteenth century. Aboriginal environmental philosophy was related to their being observers, knowers, and users, rather than managers and interferers. This approach was the essence of their genius, enabling them to survive successfully for 40,000 years – perhaps much longer. Their philosophy could be described as nonmaterialistic ecocentrism, expressed through totemism, Dreaming, and the law, contrasting markedly with European materialistic anthropocentrism.

During the millennia before European occupation the continent had undergone big climatic changes followed by enormous environmental ones. Aboriginal people experienced the gradual extinction of the megafauna, commencing from the earlier part of their occupation, and, between 15,000 and 6,000 years ago, the decrease in the size of the continent as the sea level rose, mostly imperceptibly.

One of the significant technological innovations affecting Aboriginal use of the environment was the grinding stone or “grindstone”. Dating from around 18,000 years ago, it gave impetus to settlement in the arid center where there was heavy dependence on seed foods. A lack of suitable stones in some areas, e.g., southwest Queensland’s Channel Country, brought about trade in the course of which grindstones were carried very long distances. Aboriginal mythology underlines the importance of the grindstone right up to the time of European occupation.

As the sea level rose, mainland Australia became separated from Tasmania as well as from New Guinea. As the new conditions became stabilized, an extremely rich and diverse flora and fauna developed. Then, in the period from 1500 BCE to the beginning of the Christian era, colder and drier conditions emerged – perhaps the reason that around this time Aboriginal people made major changes in their methods of exploiting resources. Technological innovation included the emergence of the small tool tradition, and in Victoria, the introduction of water control systems. The building of brush and stone fence traps and pitfalls may also have been developed during this period to allow bigger catches of wallabies

and kangaroos. There is some evidence of the reorganization of society at this time, perhaps to enable better exchange and sharing of resources in the face of new conditions.

Economic Use of the Environment

Although the archaeological record gives a general picture of Aboriginal life, the most detailed knowledge comes from the ethnographic record made since European occupation. Aboriginal cultures and lifestyles varied considerably throughout the continent, according to specific needs, beliefs, knowledge, and availability of resources.

Aboriginal people were hunter-gatherers who mostly operated freely within a limited range – their own “country” – in small groups or bands who moved according to the season and the availability of resources. They were not acquisitive, often leaving behind all but the most needed tools as they moved around. With few (arid zone) exceptions, they did not store food. Included in the diet was a wide variety of flora and fauna – fish, land and sea mammals, some insects, birds, lizards, and snakes, depending on where people lived – providing a healthy, mostly nutritious diet, low in fat and sugar. Generally people did not take out more plants or animals than were needed for day to day survival.

Housing, implements, weapons, clothing, and other utilitarian, ritual, and decorative items were fashioned from materials taken from the environment, e.g., stone, plant material (wood, fibers, thorns, leaves, twigs, branches, gum), animal products (bone, hair, skin, feathers), and soil (mud, ochre).

Examples of crafted wooden instruments and weapons include the spear, waddy or club, and boomerang (each used in fighting and hunting), the scoop-shaped dish (a carrying bowl, ash cooking bowl, or shovel), digging stick, shield, playstick, message stick, and spear-thrower. Wood was also the basic construction material for boats. Shelter in most areas was constructed of wood and branches, and of bark; they were quickly made and easily abandoned. Wood could be selected for its shape, requiring little or no

working for some implements such as building poles, witchetty grub hooks, skewers, brooms, walking sticks, axehandles, spindles, firesticks, fire-making sticks, laddersticks, and implements of secret rituals such as droughtsticks for causing drought. Other plant materials were used in making the tools of daily life, e.g., plant fibers for making string to be woven into bags, nets, headbands, etc., and for making baskets, thorns for tattooing, leaves for bedding, branches for brush fences, and gum for glueing.

Animal skins were used against cold winters for clothing, and animal hair was woven for string from which such items as headbands, phallocks, belts, net traps, and bags were made. Bone items included awls and the bones used in “boning” rituals.

Stone items included hafted hatchets and adzes, unhafted cutting tools chipped from hard stone or quartz, clubs (handheld and thrown), and grindstones. These items were often traded by those communities who had the best supply of raw material. In places where stone abounded, e.g., the Flinders Ranges, stones were also utilized as meat-chopping blocks, throwing weapons for killing, gravestones and other sorts of site markers and stone arrangements.

Modification of the Environment?

Debate continues regarding the extent to which Aboriginal people modified the environment in times past. Many scholars believe that although they utilized materials from the environment, they did not *substantially* alter the environment itself. Others differ. Two issues often debated are the extinction of the megafauna and the use of fire.

It has only recently been confirmed that in antiquity Aboriginal people killed megafauna species at all. As to fire, the fact that they used it extensively is not disputed; what is debated is whether or not they used it deliberately to manipulate and alter the environment substantially. There is still no conclusive evidence that they did this to a degree that made the Australian environment vastly different from the way it

would have been had they never inhabited the continent. From everything known about Aboriginal environmental philosophy and practice, large-scale intervention in the environment to change the way things were would seem unlikely. Aboriginal people’s skill lay in their observation and utilization of nature as it was, including the natural potential fire regime.

The concept of Aboriginal “firestick farming” arose in the 1950s as a reaction to the somewhat idealistic view of Aboriginal people’s “[having lived in] harmony with the environment”. This notion is part of a general view that in recent millennia Aboriginal people modified their environment to the point of being the most significant agents of change within it. More likely, however, is the view presented here, that as change occurred – mostly imperceptible at any given time – Aboriginal people gradually adapted to the new conditions.

The “firestick farming” model has become popular because of its idealistic portrayal of “traditional” Aboriginal people in European terms, firstly as more like (superior) European farmers, and more recently as “resource managers”. This is also often the case with new views of Native Americans and other indigenous people.

Traditional Ways of Looking After the Land

Aboriginal people, like all hunter-gatherers, were above all observers of their environment. Their traditional concept of “looking after the land” was diametrically opposed to a European view. First and foremost it was a question of knowing, and to some extent, of not doing rather than of doing. Every individual had both the need and the right to know his own country to which they were attached through totemic affiliation and the ties of kinship, and to be informed on its terrestrial and celestial natural phenomena.

Dreaming history (mythology) was largely the encyclopedia of knowledge. Here were “stored” maps, vital environmental information, and laws concerning people’s relationship to the land. Knowing the land meant above all maintaining

the Dreaming. The Dreaming had an ecological rationale, the actions and habitat of the totemic ancestral species mostly coinciding with those species' typical behavior and habitats. Place names reflected the Dreaming; they remain today as windows on Australia's environmental past, many incorporating names of species of flora and fauna once prevalent but now extinct.

Knowing the rituals and accompanying songs was also considered crucial in looking after the country. Recently Aboriginal people have even blamed their own failure to maintain the songs and rituals for the dramatic loss of species following European occupation: "We can't look after the country now; no one knows the songs any more."

Totemism, whereby an individual or a clan was in a special relationship with a species or phenomenon in the natural world, was a powerful link between the people and the environment. Maintaining a proper ritual attitude toward one's totemic species was an essential part of looking after the country. In some places this meant maintaining a taboo on killing one of one's own or a near neighbor's totem species – an act akin to fratricide. In some regions, individuals had only one personal totem; elsewhere, through clan membership individuals had a number of totems.

In parts of Australia the lands belonging to a totem clan were located in that totem species' quintessential habitat. This meant that in those places species were protected from human predation in their best refuges. Taboos on hunting and food gathering also applied around certain sacred sites, sometimes ensuring that the best waterholes were completely protected. There are examples also of taboos on killing female kangaroos, which would help to ensure the continuity of the species, and on interfering with certain plants because these were a specific animal's food. These examples, however, do not represent large-scale strategic planning in conservation, even though their evolution would, to some extent, have had that effect.

Over all, then, Aboriginal people's "looking after the land" (rather than "land management" – a very European concept) was based on using

knowledge skillfully and performing the associated rituals. Indeed, it was the very fact of *not* having management schemes that interfered unduly with the ecosystem, which was the secret of Aboriginal survival. The "strategy" for success was knowing.

Environmental Dispossession

According to the philosophy which European colonizers took with them to Australia from 1788 onward, it was the duty of individuals to give value to the land – otherwise seen as valueless – by going beyond the laws of nature through work. As the Australian environment was not "worked" in their understanding, they regarded it as completely empty – *terra nullius* – when they arrived. They would give it value by working it and extracting profit from it. Aboriginal nonmaterialistic ecocentrism, valuing both the human and nonhuman world in a holistic way, had nothing in common with European anthropocentrism and materialism. The philosophy of the dominant group soon prevailed, and Aboriginal people were dispossessed of their land and their traditional lifestyle, if not of their lives. The change to the environment as Aboriginal people knew it was irrevocable. Indeed, the speed and scale of faunal loss may have been unprecedented in the history of the world. For many communities today, the only records of the species which sustained their forefathers are subfossil material, old songs, and Dreamings.

Aboriginal People and the Environment Today

Dispossession has not occurred to the same degree for all. In the process of adapting to their changed environment as Aboriginal people have always done, some desert communities have in recent times introduced new ways of looking after the land, while not abandoning old ways of maintaining the Dreaming and the rituals which reinforce knowledge. Also, there is increasing interest in traditional Aboriginal environmental

knowledge, and here and there attempts are being made to apply it with Aboriginal help, to “bring back” the country.

Traditional ways of caring for the country, however, operated within a supporting philosophical, religious, and economic framework – on a very different landscape, generally for different goals, and above all, on a continent wide basis. It is therefore unlikely that the traditional package of environmental nurture will be reintroduced on a large scale.

Perhaps more significantly, Aboriginal people are seeking – and getting – more involvement in environmental management. Some see it as one way of getting back the country. While dispossession may have left many with limited traditional knowledge to apply, it has not removed their sense of belonging to the land. Moreover, 1993 native title legislation (*Mabo*) is motivating a new appreciation of Aboriginal people’s long relationship to the unique Australian environment.

See Also

► [String and Stories](#)

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Environment and Nature: China

Kenneth J. E. Berger

China represents one of the four ancient civilizations of the world, the others being Egypt, Mesopotamia, and India. The one unifying feature of these civilizations is that they all developed along the floodplains of major rivers. The Chinese civilization started along the valleys of the Yellow and Wei Rivers and gradually expanded to the middle and lower parts of the Yellow River and eventually across the North China Plain. It was not by accident that this occurred. Flood plains are well suited to agriculture and China’s greatest natural resource is her agricultural land. The river waters also served other purposes such as domestic (drinking, cooking, washing), aesthetic, recreational, irrigation, and fishing.

The early Chinese knew that their livelihood was dependent on nature and in turn believed that their fate and nature were intertwined. This belief caused them to hold the soil in reverential regard and, in some areas, even to consider the rain to be the life-giving seed of the Supreme Ruler in heaven. Humans were considered equals to all forms of life. Prosperity and happiness depended on an ability to adjust successfully to the various

forces of nature. To go against nature or to tamper with it might disrupt its equilibrium and ultimately prove to be harmful.

This cooperation with nature, however, did not mean that the early Chinese submitted passively to life. Instead they felt that humanity was the means through which nature's full potential could be realized. In fact, according to some historians, the Chinese have had more of an effect on their environment than any other people (Keswick, 1986). Nature, in turn, has endowed the Chinese with some of the world's most productive agricultural areas. The Chinese regarded the alteration of their environment as a type of adornment and not as a form of mastery and control. Through their diligence and devotion, they were able to develop a natural system to explain nature and the environment. Their understanding was further modified according to ancient traditions and customs, which preserved in the Chinese a spirit of sacred reverence for the divine powers of nature and a sense of community with it. They looked upon nature and the environment not as a dead or inanimate thing but rather as a living breathing organism, in a fashion somewhat similar to the present-day Gaia Hypothesis. The Chinese saw a chain of spiritual life running through every form of existence which bound together, as in one living body, all things existing in heaven above and earth below. They had an aesthetic, poetic, emotional, and reverential way of looking at natural objects.

The fourth and third centuries BCE marked a transition period during which ancient Chinese natural philosophy developed into a more sophisticated and systematized theory. Out of their observation, identification, and dependency on nature came Daoism, a philosophy based on nature. The Daoists championed the independence of each individual, and maintained that the only concern should be to fit into the great order of nature, i.e. the *Dao*. They believed that if left to itself, the universe proceeds smoothly according to its own harmonies. They emphasized the unity and spontaneity of nature. Mankind's efforts to change or improve nature only destroy these harmonies and produce chaos. Humanity's place in nature was to be in harmony with it since both humans and nature obey the

same laws. Thus, they are in a constant dynamic relationship with one another, each able to affect the other's flow. As Laozi (ca. 561–467 BCE) stated in the *Dao De Jing*, "Man follows the way of earth, earth follows the way of heaven, heaven follows the rules. The rules are the *Dao*".

At the same time that Daoism was flourishing, another school of philosophic thought was also flourishing, known as the Naturalist School. This attempted to explain nature's workings on the basis of certain cosmic principles, one of which was the basic dualism of nature, the Yin yang Principle. *Yang* represents masculinity, light, hotness, dryness, hardness, roundness, activity, heaven, the sun, etc. *Yin* represents femininity, dark, coldness, wetness, softness, squareness, passivity, earth, the moon, etc. Rather than being in perpetual conflict, yin and yang are mutually complementary and balancing. The greater *yang* grows, the sooner it will yield to *yin*; likewise the greater *yin* grows, the sooner it will yield to *yang*. In addition, *yang* always contains some *yin* and *yin* always contains some *yang*. *Yin* and *yang* continually interact, creating cyclical change. For example, *Yin* and *yang* helped explain the seasons and the proper actions which should occur, in spring: plow, in summer: weed, in autumn: harvest, in winter: store. The interdependence of the two principles was well symbolized by an interlocking figure, which today is used as the central design element in the flag of South Korea. This ► [yinyang](#) concept was eventually incorporated into Daoism, with *Dao* being the natural process that unites the two.

When perfect balance and harmony exist between the *yin* and *yang* elements and qualities, growth of all living things flourishes and *qi*, the cosmic breath, enhances the environment. *Qi* is believed to exist in all living and nonliving things. This concept of *qi* is pervasive throughout Chinese customs and traditions, from acupuncture to kung fu. It is through *qi* that all things in the universe are related and attached to each other and integrated in the united whole.

The early understanding of the forces of nature which was accumulated over the years, together with the concepts of *yin yang*, *qi*, and later concepts, eventually developed into a complex

science known as *feng shui*. Simply put, *feng shui* is an early form of ecology, conservation, and environmental science. It unites heaven, earth, and humans in such a way that a respect for nature is developed along with the ideas of renewability and sustainability of resources.

The most famous of the Chinese philosophers was Confucius (551–479 BCE). He was primarily concerned with society and interpersonal relationships. As such, the Confucian view of nature is only relevant with respect to how it affects human relationships and interactions. However, he did recognize the importance of the human-nature relationship. This can be seen in the Classics, a set of books associated with Confucianism.

In the *Yijing* (Book of Changes), it is stated that, “The great man is the one who unites his morals with heaven and earth.” *Li Ji* (Book of Rites) in turn states, “Man is the heart of the heaven and the earth..., so a holy man must treat heaven and earth as the root of behavior.” It also says that “to chop down a tree or kill an animal at the improper time is unfilial.” The *Doctrine of the Mean* states, “Let the states of equilibrium and harmony exist in perfection, and a happy order will prevail throughout heaven and earth and all things will be nourished and flourish.” Therefore, in order to unify with nature, we should obey the regularity of nature and take care of it. According to the *Yijing*, also known as the I Ching, the Chinese concepts are revere nature, unify with nature, adapt to nature, spare nature, learn from nature, and play in nature. The Confucian thus asks people to act in a proper manner and to take care of nature; so by leading a moral life, people can assist heaven and earth to maintain a harmonious balance.

Mencius (371–289 BCE), a disciple of Confucius, said, “If you do not interfere with the seasons of husbandry, the grain will be more than can be eaten. If you do not use a net in a fish pond, the fish and turtles will be more than can be consumed. When cutting wood only go into the forest and hills when it is the proper time, and the wood will be more than can be used. Not allowing the exhaustive consumption of fish and turtles, nor the exhaustive use of the woods, enables the

people to live and die generation after generation without interruption.” In other words, resources are for the perpetual use of mankind.

The last major influence on the Chinese concept of nature and the environment is that of Buddhism, which came to China from India in the first century AD. Buddhism gave to the Chinese a respect for the lives of all living things, because it is believed that all things have the potential to achieve Buddhahood and that animals are but a form in which something has returned in its new incarnation. Everything in the world has a relationship with everything else, be it animate or inanimate. The only difference is in the closeness of the relationship.

The concepts of nature and the environment in ancient China are basically a group of general principles, such as the cyclic nature of the natural world, the equality of the natural laws, the creativity of nature as expressed in its biodiversity and abundance, and the belief that everything contains both a positive and negative part. Through Confucianism, these concepts became part of morality; through Daoism, they became part of philosophy; through Naturalism, they became part of cosmology; through *feng shui*, they became a part of science; through Buddhism, they became part of religion. The concepts were easily understood and incorporated into an understanding as to how humans should live their lives, i.e., in harmony with nature.

See Also

- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [Fengshui](#)
- [Geomancy in China](#)
- [Qi](#)
- [Yinyang](#)

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Environment and Nature: India

D. P. Chattopadhyaya

The philosophical and scientific ideas developed in India over the centuries are, on analysis, found to be deeply related to ecological issues, both generally and specifically. Like the ancient ideas of China and of the Hellenic world, the ancient Indian ideas of the comparable period are cosmological and comprehensive in character. The *Vedas* and *Upaniṣads*, Laozi's *Dao* or in Parmenides' *Nature of Being* were all engaged in search of the first principle, One. They were all obliged to relate it to Many-Many individual objects of knowledge. The One-Many relationship is pregnant with both cosmological and ecological implications.

Broadly speaking, the objects we know around us are biotic (living) or abiotic. However, to many thinkers, especially to the pluralists and evolutionists, this twofold classification is simplistic and inadequate. They try to draw our attention to different grades of being or reality – physical, chemical, paleontological, botanical, biological, psychological, and spiritual. The scientific philosophers of the Vedic insights, of the *Samkhya* persuasion, and also of later times could discern different subgrades within each of these grades. These graded characteristics of different living and nonliving beings have to be recognized if we are to understand the complex and the interactive character of our environment.

This insightful approach to ecology as an integral part of cosmology is evident in the tradition of Indian thought. It is very clearly available, for example in *Caraka-Saṃhitā*.

In ancient India the good of human life was thought of in the context of life's environment. The right relation between the individual and his environment received serious attention even at the levels of primary and secondary education. The aim was to impart basic knowledge of personal hygiene and medicine. This education was meant for all. In a way medical education was universal. It is interesting to note the five compulsory subjects for all high school students: Grammar (*Śabdavidyā*), Art (*Śilpasthānavidyā*), Medicine (*Cikitsāvidyā*), Logic (*Hetuvidyā*), and Science of Spiritual philosophy (*Adhyātmavidyā*).

Both abstract and concrete areas of knowledge, understood in their interconnection, are all relevant to the exercise of adjusting to our environment. Linguistic communication, artistic articulation, logical ratiocination, and medication are in different ways intended to awaken the best in us and to strike a balance with the large world around us. From the strength of body to the span of life, from good health to peace of mind, all are a unified function of food, personal hygiene, right actions, and character.

Life has a rhythm of its own, which is not necessarily manifest. The *Dharmaśāstra* are full of injunctions on how to attain that rhythm in terms of purity, diet, regulation, ablutions, behavior, and physical and mental disciplines. These have to be followed as part of daily (*dinacaryā*) as well as seasonal routines (*ṛtucaryā*). Food and drink habits and fulfillment of natural urges, avoidance and indulgence in sexual acts, and eating some ordinary things like curds, butter-milk, and honey are all necessary to define our correct relation with the environment. However, this normative rhythm can hardly be generalized, for it is integrally related to the individual constitution (*prakṛti* and *svāsthya-vṛtti*).

The traditional Indian medical system (*Āyurveda*) takes a comprehensive view of a person. It neither encourages asceticism and mortification of the flesh nor promotes unregulated

sensualism. It highlights the importance of a “sound mind in a sound body”. It points out that *svāsthya-vṛtta* or philosophy of hygiene is to be supplemented by *sadvṛtta* or the right life. Rightly understood, the philosophy of hygiene is a way of life containing in it the principles of eugenics, ethics, and healing.

In ancient Indian thought the basic principles of ecology are ontologically oriented and cosmological in implication. The three main concepts of the Vedas which are evident in *Āyurveda* are *satya* (truth, right, reality, or being), *svadhā* (self-position, self-power, or spontaneity) and *ṛta* (proper, suitable, and settled order). The basic point which is being emphasized here is that the true nature of reality cannot be changed by human will which is not informed of that reality. No technological skill, no arbitrary will of this or that person, can go indefinitely against the true nature of reality without causing harm to those who try to follow this wrong path. Even the most sophisticated biotechnology cannot tamper with the essential nature of reality, the true Nature or *Prakṛti*. This role of the concept of truth has both ontological and axiological implications. Humans are required both to know reality in its true nature and to live and shape their lives accordingly.

Humans are also aided by the principle of becoming or the dynamic nature of reality in shaping their best possible life. This possibility is contained in the concept of *svadhā*. Reality has within itself the impetus or power for self-unfolding or gradual disclosure. It is not static, fixed, or self-enclosed. The world as reality and as a whole is perpetually expanding. This macro-cosmic truth of *svadhā* is at work also in human nature. Consequently, human freedom knows no bounds. Nature and its laws are not antagonistic to the human will to be free. When we can discover the laws governing the true nature of the relation between individuals and the world, our knowledge of the world helps us to live in harmony with it. That harmony creates a favorable environment which not only nourishes our bodies but also enables us to be free from social conflict and tension. When we are free from ill health, we are better placed in our relation to nature.

When we fail to strike the balance with nature, we are not only likely to be poorer in health but also less capable of getting the best out of our environment.

Finally, besides the true nature of reality (*satya*) and the power of self-disclosure (*svadhā*) what helps us to have a right environment is suggested by the concept of *ṛta*. It is orderliness or the law-governed character of reality or nature. From the change of seasons to the changing periods of life, *ṛta* is clearly perceptible. Even human cultures are found to exhibit certain rhythms. Cultures are characterized simultaneously by fragile and stable features. The rhythm of nature is not antagonistic to the spirit of human freedom. Our lives, both individual and collective, are marked by a sort of dynamic equilibrium.

The above three concepts embodying certain abstract principles may appear irrelevant to our actual lives. However, to the thinkers of *Āyurveda* the principles of philosophy and ethics, or those of good living, are inseparable from the basic characteristics of reality.

The same principle is illustrated in defining the ideal principles of town planning and village planning. Aśoka, the Buddhist emperor of ancient India, said that trees, plants, and shrubs of medicinal value had to be planted around every village and along the roadsides. The people were allowed to use the leaves, fruits, and bark of the trees. This practice survives today. Like geography, history, science, and arithmetic, the general principles of hygiene and physiology and simple methods of curing cuts, wounds, and everyday ailments were prescribed for everyone's general education. The underlying belief was that individuals had to be able to take care of their elementary medical needs.

The Indians believed that every village should be so constructed that its population must have the professional service of a medical practitioner (*vaidya*). People were advised to reside in a place with plenty of water, herbs, sacrificial sticks, flowers, grass, and firewood, and which yielded abundant food. They were also advised to live where there was safety of property and person, where the outskirts were

beautiful and pleasing, and where there was a strong presence of learned people.

Ancient Indian thinkers paid attention to the development and preservation of the right type of environment for human life. The state was assigned a very important role for the purpose. It was expected to lay down rules and regulations for rubbish disposal and drainage systems. The state also determined where and how the quality of food and drink should be preserved. Those who violated these rules and thereby polluted the environment were punished. Equally conscious were the decision-makers in charge of public health. The state had a very important role to perform for preservation and promotion of a healthy environment. Various types of punishment were prescribed for cutting for the tender sprouts of trees.

Kautilya mentioned elaborate laws for the promotion of agricultural activities. For example, he prohibited high agricultural taxes and bonded agricultural labor and attached much importance to animal husbandry and soil preservation.

See Also

► [Medicine in India: Āyurveda](#)

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Environment and Nature: Islam

Parvez Manzoor and Ziauddin Sardar

The sacred text of Islam, the *Qurʾān*, contains a theology of ecology, for nature and ethics are at the very core of its moral worldview. Indeed, so central is the theme of the affinity of nature and ethics that even outside observers, such as Marshall G. Hodgson, have epitomized the dictates of the Islamic commitment as “the demand for personal responsibility for the moral ordering of the natural world.”

The creation of humanity is one of the grandest themes of the *Qurʾān*. It is alluded to either philosophically in a symbolic language or biologically, employing the medium of natural science. Philosophically, the first assertion is that of the purposefulness and meaningfulness of human life. The Quranic teleology is preeminently moral: humans are to execute the will of God, but it is an undertaking which they have imposed upon themselves. It is a pledge made by man and woman to God. Hence, God, for His part, has endowed them with all the faculties essential to undertaking this august moral mission. Nature is the testing ground of this moral responsibility. Men and women are thus enjoined to read its “signs.” For this purpose, nature has been created both orderly and predictable. The creation of human beings and the creation of nature are thus two chapters of the single theme of moral responsibility and trust that is the *sine qua non* of Islamic commitment.

Nature, therefore, is a trust or *amāna* and a theatre for a Muslim's moral struggle.

According to the *Qurʾān*, heavens, earth, and mountains refused to assume this responsibility which humans took upon themselves voluntarily. By doing this, no doubt, humans showed ignorance and hubris – but also their willingness to serve God’s purpose. As trust is a mutual commitment, it may also be surmised that God, by entrusting people with this responsibility, expressed confidence in their ability. No wonder that in the Quranic worldview and Islamic tradition the individual is known as the trustee, or *khalīfa*, of God.

The Islamic rationale for an ecological ethics rests on the Quranic notions of *khalīfa* and *amāna*. Nature, being the gift of God to man, is accepted in Islam as an estate over which we have temporary control but no sovereign authority. Our relationship with nature thus can never be ethically neutral. Islam views nature essentially in a teleological perspective and therefore the claims of man’s dominion over her have no resonance in Islam.

While Islam is a monotheistic faith belonging to the Arabrahamic tradition, its teachings on environment and nature contrast sharply with its sister religion of Christianity. To give an example, the Hebrew story of creation is transformed in Christianity into the doctrine of the fall. Creation thus appears to the Christian mind as “fallen,” and nature is viewed as opposed to grace. St. Augustine, to take one example, believed that nature was “unredeemed,” just as many Christian theologians maintain that nature cannot teach man anything about God and is therefore of no theological and spiritual interest. Salvation is the humbling of nature by the miraculous, the intrusion of the supernatural into history. The nearest thing in the physical universe that reflects the miraculous is man. Holiness exists only in a man-made environment. Thus, nature, so devoid of God’s presence and grace, may be “tortured”; it may be justifiably subjected to scientific experimentation. The Islamic view is very different. Creation (nature) in the Quranic view always bears the “signs of God” and is necessary for man’s salvation. It is in accordance with this that Islam holds that there is no such thing as a profane world. All the immensity of

matter constitutes a scope for the self-realization of the spirit. All is holy ground, or as the Prophet Muḥammad said, “the whole of this earth is a mosque.” Earth, creation and nature thus have a sacramental efficacy in Islam which can be ill-accommodated with the perverse applications of the “dominion ethics.” The claim for nature’s “salvational worth,” however, may never be construed as a token of its autonomy. In fact, Muslim theologians have always claimed that nature has no meaning without reference to God; without Divine purpose it simply does not exist. (Hence, nature is simply known as the created order).

The ethical link between faith in God and love for His creation is fully demonstrated in the life of the Prophet Muḥammad himself who declared that whoever is kind to the creatures of God is kind to himself. One authentic tradition narrates that a man once came to the Prophet with a bundle and said, “I passed through a wood and heard the voice of the young of birds, and I took them and put them in my carpet and their mother came fluttering around my head.” And the Prophet said, “Put them down.” And when he had put them down, the mother joined the young. And the Prophet said, “Do you wonder at the affection of the mother towards her young? I swear by Him who has sent me, verily, God is more loving to His servants than the mother of these birds. Return them to the place from where you took them, and let their mother be with them.”

Such environmental teachings were actually translated into environmental policies and legislation in the classical Muslim civilization. For example, the Muslims developed the notion of *ḥaram* – inviolate zones – outsides towns, near water-courses, and other areas where development was forbidden. A second type of inviolate zone was *ḥima* which applied to forests, woods, and wild habitation and was designed to conserve wildlife. Ibn ‘abd as-Salam (fl. thirteenth century) formulated the first statements of animal rights. Muslims were also concerned about the protection of the urban environment; Islamic town planning and architecture provide ample demonstrations of this. Many classic cities, like Fez, were built with the full understanding of carrying capacity and were designed so that the

city's population would not increase beyond a critical limit. The debate about conservation, protection of animals and their habitats, and the Islamic teachings on environment can be clearly seen in such classics as *Disputes Between Animals and Man*, which is a part of the *Rasāʾ-il Ikhwān al-ṣafāʾ* (The Epistles of the Brethren of Purity) written in the tenth century. The deep respect for nature and environment is also evident in Sufism, the mystical strand of Islam, both in its thought and practice. The titles of some of the classic Sufi works reflect their concern with nature. *Gulistān* (The Rose Garden) and *Bustān* (The Fruit Garden) by Saʿdī of Shīrāz, and Farīd al-Dīn ʿAttār's *Manṭiq al-ṭayr* (The Conference of the Birds) provide good illustrations.

Contemporary Muslim societies have lost much of their traditional consciousness and concerns. Both colonialism and the mad rush for modernization have played their part in this oversight, but today we can detect a minor resurgence in Islamic environmental consciousness. This is evident both in the intellectual and academic efforts to shape a contemporary Islamic environment theory – for example in the works of Gulzar Haider, Seyyed Hossein Nasr, and Othman Llewellyn – and the frequent use of traditional Islamic concepts and technologies (such as ► [qanat](#), the ingenious system of wells drained through a network of tunnels) in developing environmentally sound practices in the Middle East and Iran, Pakistan, and Malaysia.

Equipped with the ethical insights of *khalīfa* and *amāna*, and impelled by the Quranic dictates to assume personal moral responsibility in the world of nature, Muslims have a responsibility to meet the challenge of ecology to religious consciousness and provide mankind with a healing vision of the harmony of man and nature under God. Like everything else of value in Islam, its ecological insight can be summed up under the seminal concept of *tawḥīd* (unity). *Tawḥīd*, Islam's eternal quest for the unity of life and purpose, spirit and matter, human beings and nature, law and ethics, faith and morality, implies that man does not dominate the earth or commit violence in any form.

See Also

- [Religion and Science in Islam II: What Scientists Said About Religion and What Islam Said About Science](#)

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Environment and Nature: Japan

John A. Tucker

In traditional Japan, the word *shizen*, also pronounced *jinen*, meant naturalness, or the mode of being which is natural. Its literal meaning is “from itself (*shiji*) thus it is (*zen/nen*).” In modern Japanese *shizen* by extension came to refer to nature, or the environment encompassing all between heaven and earth, especially the earth, oceans, mountains, rivers, flora, and fauna.

Premodern Japanese had no single word signifying nature as a unified entity. Nevertheless passages about nature abound in their ancient literature, philosophy, and religion. Words like *ten*, literally meaning heaven, and *tenka*, meaning heaven and earth, meant something like nature. An understanding of traditional conceptions of nature can be garnered by examining Japanese thoughts about aspects of nature such as heaven, earth, mountains, rivers, trees, flowers, and fields.

Ancient Japanese evinced an unabashed intimacy with the natural world in their earliest poetry as compiled in the eighth-century anthology, the *Man'yōshū* (Collection of Myriad Leaves). Its poems spoke of the world of mountains, rivers, flora, and fauna in anthropomorphic, animistic terms, investing each entity with a living personality infused with *kami*, or mysterious spiritual energy. Mountains were deemed most divine. Indeed, in their verses the ancient poets immortalized Mt. Fuji as a peerless deity. Rivers were considered living forces, manifesting immense spirituality in their rushing flows of clean, life-giving water. The sea was viewed as a more awe-inspiring, fearful spiritual force, one supplying sustenance but also destruction. References to birds and beasts fill the poems, evoking a sense of the four seasons and the human feelings linked to them. The poems themselves were likened to the natural world: the *Man'yōshū* included myriad *yō*, or “leaves” of poetry.

The earliest histories of Japan, the *Kojiki* (Records of Antiquity, 712) and the *Nihon shoki*

(Chronicles of Ancient Japan, 720), open with myths relating the Shintō cosmogony. They give the *Man'yōshū* vision of nature a strongly religious, spiritual grounding, leaving no doubt that the world of nature was the world of creative religious spirit. After heaven and earth congealed out of an undifferentiated, egg-like mass, successive generations of personified *kami* begot one another. Finally the *kami* pair, Izanagi and Izanami, created the first island, Onogorojima, by letting the brine drip off a spear they had plunged into the ocean's depths. On Onogorojima, Izanami gave birth to the elements of nature including the rivers, mountains, birds, beasts, and flowers and trees, and the forces of nature such as fire. Because of the divinity of the progenitors, Japanese traditionally considered their archipelago and all of nature within it as sacred.

According to one account, Izanagi and Izanami also gave birth to Amaterasu the Sun Goddess and her brother Susanoō the impetuous god of storms. Because both Amaterasu, a benevolent *kami*, and Susanoō, a mischievous if not malevolent one, are deemed divine beings, Japanese have not dismissed destructive forces of nature as evil. Nor have they branded acts against nature as necessarily wrong. Indeed, Shintō myths relate that Susanoō wreaked havoc in his sister's rice fields, implying that similar actions contrary to the general good of the world of nature might still have some divine sanction via Susanoō's example. Perhaps this partly explains why many Japanese, despite their close religious, poetic, and mythic ties to nature, have at times tolerated abuses of it.

Pollution, however, was considered anathema, and was dealt with via Shintō purification rites. Pollution did not necessarily mean physical dirtiness or noxious environmental conditions; however, those forms were recognized among the more spiritual nuances associated with the Shintō notion of pollution. Traditional abhorrence of physical and spiritual pollution perhaps explains the energetic opposition of many Japanese, though certainly not all, to environmental pollution.

Amaterasu and Susanoō parented the imperial line and the ancestral stock of all its human

subjects. Belief in the divinity of their islands, their imperial family, and everything within their natural environment thus results from the supposed ancestry of Japanese in Izanagi and Izanami. This became a basic tenet of Shintō, one regularly repeated throughout Japanese history. In the *Engi shiki* (Religious Regulations of the Engi Period, 927) ritual prayers record a similar vision of nature as fully infused with divine spirituality. Kitabatake Chikafusa's (1293–1354) political tract, the *Jinnō shōtōki* (The Legitimate Succession of Divine Emperors, ca. 1340), opened with the declaration, "Japan is a sacred land (*shinkoku*).” Japanese Buddhists and Confucians almost unanimously have accepted the same, essentially Shintō doctrine.

Belief in the divinity of the archipelago encouraged some Japanese to xenophobia: foreigners, typically viewed as barbarians, were feared as potential agents of pollution. Japanese soil, they felt, would be violated if the barbarians were allowed on it. Since 1945, the Japanese have become more accustomed to the presence of foreigners in their country. Still their concern for nature often seems Japan-specific: some southeast Asian forests have been depleted to accommodate the Japanese preference for disposable, wooden chopsticks, even though forest conservation practices are followed within Japan.

Introduced to Japan in the mid-sixth century, Buddhism advanced various attitudes toward nature. The Four Noble Truths, the original teachings of the historical Buddha, Siddhārtha Gautama (563–483 BCE), characterize existence as suffering, implying that *samsara*, or the environment of reincarnation, was similar. Their religious solution, *nirvana*, which literally means “putting out the flame” (of existence in this world), seems to offer an escapist otherworldliness which might have permitted a relative disengagement from nature.

The Mahāyāna Buddhist ideas of the Indian thinker Nāgārjuna (ca. AD 150–250), which were accepted by most Japanese Buddhists, affirmed the natural order. Nāgārjuna equated *samsara* with *nirvana*, disallowing otherworldliness. Nāgārjuna's view was based on the doctrine that everything is empty (*sunya*). Empty here means

empty of self-sustaining substance, i.e., a substance existing in and of itself. Nāgārjuna insisted that everything that exists does so through spatial, temporal, and causal relations with the remainder of the universe. Nothing exists independently of everything else. His ideas could be construed as anticipating the ecologist's belief that all life is interrelated, and that destruction of small niches endanger the entire ecosystem. Nāgārjuna's ideas surely facilitated a more positive appraisal of nature by Japanese Buddhists.

Traditional Buddhist cosmology, however, claims that the world is subject to creation and disintegration just as humans experience cycles of death and rebirth. Arguably this view could allow a cavalier attitude toward the natural environment since regardless of one's efforts the world will inevitably disintegrate and then begin anew. The Buddhist belief that attachment to things leads to suffering also might vitiate wholehearted involvement in an environmental ethic geared toward conservation of nature. The Buddhist two-level theory of truth, assigning ultimate status to *sunya*, and relegating common sense to secondary validity, allows for concern for nature but not in a primary way.

Otherworldly tendencies appeared in the popular Jōdo, or “Pure Land”, School. Based on the Indian writing *Sukhāvatīvyūha-sūtra* (Discourse on Paradise), Jōdo posits both a heaven called the Pure Land presided over by Amida Buddha, and a multileveled hell where sinners suffer eternally. Yet some theorists claim that the Pure Land and hell are merely “expedients” meant to motivate non-believers to meditate on Amida Buddha as the way to salvation. If so, then the Pure Land becomes a symbol of *nirvana*, or existential extinction, while hell becomes a hyperbole of the Buddha's claim that life in this world, the world of nature, entails suffering.

Yet the ideas of many Japanese Buddhists evinced a religiously based concern for nature. The Kegon, or Flower Garland, school asserted that every particle of existence was infused with Buddha-nature, making the natural universe a spiritual one as well, one to be saved from suffering. The *Konkō kyō* (Sutra of the Golden Light), an important text in early Japanese

Buddhism, claimed that rulers who promoted the Buddha's teachings would be protected, as would be their domains, by the Four Deva Kings, tutelary divinities who protected Buddhism throughout the universe. Compassion for all sentient beings, the core ethic inculcated by Māhāyana Buddhists, instilled in some a concern for the natural world.

Buddhist poets like Saigyō (1118–1190) even extolled the world of nature as the primary arena of Buddhist values. Others debated whether plants and trees, though nonsentient beings, could actually attain Buddhahood. Many Japanese Buddhists argued that they could. Some also claimed that nature possessed a healing and even soteriological capability. Probably influenced by Shintō beliefs, the Shugendō (Order of Mountain Ascetics) school had its practitioners make pilgrimages to sacred mountains to glimpse scenery foreshadowing the Pure Land. Buddhist temples aesthetically enhanced the environment. With their rock gardens, moss gardens, and vegetable gardens, temples were practically involved in local environmental improvement as a way of meditation. Zen Buddhists see enlightenment as an experience to be had in this world and in this body. Disregard of nature, therefore, cannot be allowed. Yet Buddhists are not known for authoring agricultural or environmental tracts. It was the Confucian and Neo-Confucian scholars who, in addition to admiring nature's beauty and revering it religiously, made the world of nature the focus of protoscientific research designed to conserve the environment for future generations.

Neo-Confucianism, the last major philosophical force to emerge in traditional Japan, encouraged scientific interest in and ethical concern for the natural world. Prompted by the sophisticated Buddhist metaphysics with its (to Neo-Confucians) repulsive doctrine of emptiness, Confucians reformulated their originally sociopolitical thought along novel metaphysical lines so as to refute the Buddhist challenge. Originally a Chinese movement of the Song dynasty (967–1279). Neo-Confucianism ultimately became a pan-Asian force decisively affecting China, Korea, Japan, Vietnam, and other East

Asian areas up until the modern period. In Japan, it was a dominant force during the Tokugawa period (1600–1867).

Neo-Confucians endorsed common sense, declaring that the natural environment was both substantial and fully real. They believed that there was no other world. Rejecting emptiness, they asserted that everything consisted of a quasimaterial, psycho-physical energy called *ki*. Giving "matter" its rationale was another ontological element, *ri*, or "principle." The fusion of *ki* and *ri* accounted for the diversity within the natural world. The latter was created by heaven and earth, which engaged in constant production and reproduction as its Way. Most Neo-Confucians recognized the complementary forces of yin and yang as the cardinal modes of material being. They also admitted the five elements of earth, wood, fire, water, and metal, as essential processes defining all development within nature. Because nature and man were created by the same elements and by the same forces, Neo-Confucians reinterpreted their earlier sociopolitical ethic of humaneness in mystical terms of forming one body with the universe. This mysticism identified the human body with all that existed. Some even spoke of heaven and earth as their parents, and the myriad entities of nature, organic and inorganic, as their companions. Most Neo-Confucians declared human nature (*sei*), or the original psycho-physical disposition of human beings, to be good, not empty as the Buddhists claimed. Furthermore Neo-Confucians claimed that the nature (*sei*) of the universe, i.e., its moral character, was originally good. The human project, as defined by Neo-Confucians, was to preserve this original goodness by moral self-cultivation and by moral action in the world.

Confucius (551–479 BCE) too respected the natural world. The *Analects*, the most authentic record of his thought, states that the wise person loves water (Chinese: *shui*; Japanese: *sui*), while the humane person loves mountains (Chinese: *shan*; Japanese: *san*). This reveals that early Confucianism linked moral concerns to ecological ones. It is also artistically significant, for the Chinese word for landscape painting is *shansui* and the Japanese is *sansui*, denoting a

combination of bodies of water with mountains or hills, which were the constituent elements in a landscape painting. The latter were not just idealized depictions of nature; they were equally reflections of the moral consciousness of the artist. Furthermore Confucians' and Neo-Confucians, following Confucius' views about mountains and bodies of water, believed that morality involved right behavior toward nature and humanity.

Evidence abounds revealing a practical interest in the world of nature by Confucians and Neo-Confucians in Japan. By the late-seventeenth century, forests throughout the archipelago had been depleted due to an overexploitation as a result of a boom in the construction of castles and urban residences. Confucian scholars diagnosed the environmental crisis and called for its cure. Yamaga Sokō (1622–1685), for example, argued that forests should be conserved to ensure future productivity. Sokō admonished loggers to harvest lumber only in the proper season, not to overcut, and to reforest areas they had cut. One of Sokō's disciples, Tsugaru Nobumasa, daimyo of Hirosaki domain in northeastern Honshū, claimed that the three fundamental concerns of a feudal lord were for (1) his family line, (2) his heir, and (3) his mountain forests.

In his *Daigaku wakumon* (Dialogues on the Great Learning), Kumazawa Banzan (1619–1691) argued that humane government involved afforestation, river dike repair, and other conservation practices that would maximize agricultural productivity. Noting the crisis at hand, his disciples declared that "mountains and rivers are the foundations of a country." Full of hope, despite the depleted forests that were all too evident to him, Kumazawa claimed even that bald mountains could be covered with trees again if oats and other cover crops were planted so as to retain a thin layer of soil long enough for a forest ecosystem to reappear. Ultimately, the *Dialogues on the Great Learning* advocated harnessing samurai energy for the sake of the agricultural ecosystem: Kumazawa argued that samurai should be allowed to return to the countryside to labor as farmers rather than required to live in castle towns where they fell prey to urban vices. Kumazawa's

proposals were so radical, however, that they were not heeded. Generations after his death, however, his more environmentally-oriented ideas, as advocated by others, did find favor.

Kaibara Ekken (1630–1714), influenced by the Neo-Confucian call to investigate the principles of things, authored the first systematic botanical study in Japan, the *Yamato honzō* (Flora and Fauna of Japan, 1709), describing and classifying over 1,550 trees, plants, flowers, birds, fish, seashells, etc., into some 37 categories. Ekken's "Preface" declares that because heaven and earth produce and reproduce myriad lifeforms, scholars must study their principles. Many later studies in herbology, botany, pharmacology, and zoology were influenced by Ekken's *Flora and Fauna*. He also encouraged the research of Miyazaki Yasusada (1623–1697) which culminated in the conservation-minded *Nōgyō zensho* (Agricultural Encyclopedia, 1696). In his preface, Ekken observed that a sage government, which nourished and educated the people, was facilitated by studying the *Agricultural Encyclopedia* because through it people could understand how to assist heaven and earth by cultivating the productive forces of nature.

Some late-Tokugawa intellectuals were influenced by notions of Western science as introduced to Japan via Dutch traders permitted at Nagasaki. Satō Nobuhiro (1769–1850), exposed to Western science but also influenced by Shintō, advocated techniques of agricultural management, based on the scientific study of natural law, to improve agriculture. He argued that this would realize the divine aim inherent in creation. Rejecting such clever short cuts, Ninomiya Sontoku (1787–1856) insisted instead on following the natural, creative cycles of heaven in agriculture, and repaying the virtue of heaven with conservation techniques which would rejuvenate nature. Miura Baien (1723–1789), influenced by Western science, slightly modified the Neo-Confucian project of investigating things by advocating the investigation of the rational order (*jōri*) of heaven and earth in a disinterested, objective way.

Given the dense population which appeared during the Tokugawa, and its heavy taxation of the fragile ecosystem of the archipelago, one

extremely poor in natural resources, Japan could easily have become, as Conrad Totman has suggested, an eroded moonscape rather than a verdant archipelago. In the seventeenth century, Japan was well on its way to a state of deforestation. It was saved largely by Confucian and Neo-Confucian scholars who called for systematic, scientific action. Yet it would be far-fetched to deny credit to Shintō and Buddhism, although admittedly they were less conspicuous in enunciating a conservation program saving Japan's forests, and thus its mountains, rivers, and fields.

Following the Meiji Restoration of 1868, when Japan embarked upon a course of rapid Westernization, concern for the natural environment lessened as the new Meiji state presided over the beginnings of industrialization by fostering polluting industries such as railroads. Though anathema to many, the goal of the Meiji state was to match, if not surpass, the industrial prowess of the Western nations which had imposed unequal treaties on Japan during the nineteenth century. Voices of protest against the noxious side effects were either ignored or muffled until Japan had effectively modernized. Widespread water pollution caused by the Ashio Copper Mine in Tochigi Prefecture from the late 1870s resulted in a major ecological disaster and a political scandal which simmered for nearly a century, pitting farmers against private industry and the government. Though notions of "the supremacy of agriculture" (*nohon shugi*) circulated in the late-Meiji, these were frequently no more than ideological currents.

The leading twentieth century philosopher of nature was Watsuji Tetsurō (1889–1960). Watsuji's *Fūdo* (Environment, 1935) criticized Heidegger's *Being and Time*, arguing that space, i.e., natural setting, and not just time, was crucial to human culture. Watsuji correlated the latter with three environmental zones: monsoon, desert, and pastoral. Japanese culture, he claimed, emerged from a monsoon zone where climatic vagaries produced passive, forbearing, inconsistent, sentimental, intuitive, and temperamental traits.

Since 1945, a decreasing number of Japanese have chosen to remain in the countryside close to nature. Just as the Meiji state rushed to

modernize, so did postwar Japan race to renew its industrial sector oblivious to air and water pollution during the 1950s and early 1960s. In Minamata, Kyūshū, a chemical factory was finally held responsible for mercury poisoning, 15 years after the poisoning first occurred in 1953. By the 1960s, Tokyo became internationally notorious for its air pollution. Citizen's protest groups rallied in the 1970s and 1980s, forcing the government to regulate pollution. Since the 1970s, environmentalists have argued for "environmental rights" (*kankyōken*), basing their claims on the 1947 Constitution which guarantees Japanese a "wholesome and cultured life."

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Environment and Nature: The Natural Environment in Native American Thought

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We are the land ... that is the fundamental idea embedded in Native American life ... the Earth is the mind of the people as we are the mind of the earth. The land is not really the place (separate from ourselves) where we act out the drama of our isolate destinies. It is not a means of survival, a setting for our affairs ... It is rather a part of our being, dynamic, significant, real. It is our self ... It is not a matter of being "close to nature" ... The Earth is, in a very real sense, the same as our self (or selves) ... That knowledge, though perfect, does not have associated with it the exalted romance of the sentimental "nature lovers", nor

does it have, at base, any self-conscious "appreciation" of the land ... It is a matter of fact, one known equably from infancy, remembered and honoured at levels of awareness that go beyond consciousness, and that extend long roots into primary levels of mind, language, perception and all the basic aspects of being ... Paula Gunn Allen, *Laguna Pueblo* (1979a, pp. 191–192)

This is how one Native American presents her understanding of the indigenous understanding of nature. As will be explored in this article, many Native Americans present similar understandings. Their reciprocal relationships with nature permeated every aspect of life from spirituality to making a living and led to a different way of seeing the world, a more "environmental" way of seeing the world. But is this a true picture? Increasingly, there has been debate over the nature of the Native American's relationship to the land, both past and present. This article will examine this debate as well as examine the way in which Native Americans view nature. Readers should note that as I draw upon materials from cultures across North America, and as, depending upon the location, different political terms (i.e., Native American, First Nation, etc.) may apply, I will be using a more anthropological term, Aboriginal, to refer to various indigenous cultures resident in North America.

Caveats

Discussing any aspect of Aboriginal cultures requires caution, caution which has not always been employed when discussing Aboriginal relationships with nature. Clear distinctions need to be drawn.

The first necessary distinction is that much is disguised in the concept of "Native American," "Indian," or "Aboriginal." The peoples who ranged, then and now, from the Arctic Ocean to Mexico and between two oceans encompassed a vast diversity of language, custom, practice, and belief. They evolved to take advantage of different natural resources, to deal with dramatically different landscapes and climates and evolved again as they migrated (sometimes voluntarily, sometimes under pressure from other

groups) to different landscapes. To somehow lump this vast, rich diversity into a singular term is to fool ourselves into thinking we understand something about which we have no clear grasp. It is to misunderstand the nature of people we are interested in understanding. Yet we do that lumping all the time. It leads to difficulty as when we misunderstand why two native tribes may choose different, conflicting courses of action: as is the case for Scotland and England, proximity and the lumping in as “British” does not necessarily result in shared goals. Indeed the title of Native American or Aboriginal is most equivalent to the idea of “European.” There *is* something distinctly European when compared with North American, but there are limits to the understanding we can draw from the term.

Yet there may well be an “Aboriginal” perspective when it comes to understanding the relationship with nature, and Aboriginal peoples as well as nonnative writers frequently make this argument. This article itself will present the case for a sense shared across different native cultures, but I would urge the reader to use caution when thinking about “Aboriginal peoples.”

The second necessary distinction is between the modern Aboriginal cultures and historical cultures. When many writers discuss the Native perspective of nature, there is a tendency to lump together cultures from across the recorded historical period. The problems with this approach should be obvious: none of us live like our ancestors did 200 years ago. Modern Aboriginal cultures face different challenges than did their ancestors, and many of those challenges affect how they can now relate to the land. Further, there is always a question of how well “traditional” philosophy and spirituality manage to translate into the modern world. Care must be taken not to conflate what is known about the beliefs and behaviors of the historical cultures and those of today, although both might be instructive. While Aboriginal peoples inherit their past, they must live in the present.

Finally, I think it is worthwhile making the distinction between listening to what Aboriginal people say for themselves and what others write. Both bring different agendas to the table, and it is

useful to recognize that agenda when assessing the information presented. The Aboriginal person speaks with the voice of cultural experience, an intimate understanding of Aboriginal reality an outsider can never hope to achieve. Often they are privy to information or perspectives an outsider could not easily obtain. However, people from within cultures often have difficulty examining those cultures critically and are sometimes constrained about raising controversial issues. Non-Aboriginals do not have similar constraints and can be as critical as they wish. However, they will almost always lack that essential grasp, that innate understanding of a group of people, and the way they think that a cultural resident will have. As such, it can be easy to misinterpret what is going on in a culture as modern critiques of anthropological findings are demonstrating. In terms of trying to grasp the nature of the Aboriginal relation to nature, both past and present, it is most useful to explore both Aboriginal and non-Aboriginal writers, keeping in mind the perspectives of both.

Aboriginal Relationships with Nature

Although they varied significantly among different cultures, Aboriginal relationships with the natural world tended to preserve ecological integrity and appear to have done so over a significant period of time. These cultures engaged in relationships of mutual respect, reciprocity, and caring with an Earth and fellow beings as alive and self-conscious as human beings. Such relationships were reflected and perpetuated by cultural elements including spirituality, culture, modes of production, and ceremonial ritual.

In the songs and legends of Aboriginal cultures, it is apparent that the land and its creatures are perceived as truly beautiful things. There is a sense of great wonder and of something which sparks a deep sensation of joyful celebration. Above all else, Aboriginal cultures were, and are, life affirming; they respected and took pleasure in the life to be found around them, in all its diversity, inconsistency, or inconvenience. Hughes (1983) points out that only the newly

arrived Europeans considered the land to be a “wilderness,” barren and desolate. To Aboriginal peoples, it was a bountiful community of living beings, of whom the humans were only one part. It was a place of great sacredness, in which the workings of the Great Spirit, Creator, or Great Mystery could always be felt.

Standing Bear (1933), a Lakota, wrote that Aboriginal people felt a special joy and wonder for all the elements and changes of season which characterized the land. They felt that they held the spirit of the land within themselves, and so they met and experienced the elements and seasons rather than retreating from them. For Standing Bear and the Lakota, the Earth was so full of life and beings that they never actually felt alone.

There was no such thing as emptiness in the world. Even in the sky there were no vacant places. Everywhere there was life, visible and invisible . . . Even without human companionship one was never alone. (Standing Bear, 1933, p. 14)

This statement echoes a central belief consistent across many Aboriginal cultures – that the Earth is a living, conscious being. The Koyukon of central Alaska, for example, see the Earth as something alive and powerful and, therefore, something which must be treated with respect:

For traditional Koyukon people, the environment is both a natural and supernatural realm. All that exists in nature is imbued with awareness and power . . . all actions towards nature are mediated by consideration of its consciousness and sensitivity. The interchange between humans and environment is based on an elaborate code of respect and morality, without which survival would be jeopardized. (Nelson, 1983, p. 240)

The belief in a conscious, living nature is not simply an intellectual concept for Aboriginal cultures. For most, perception of the landscape is important in determining perception of self. Aboriginal cultures and histories are based in the land, and their lives are inseparably intertwined with it. In a most real sense, it is their life. This interconnection between person and land is not merely a thing of historical significance. Present day Aboriginals continue to acknowledge their ties to the land. I once invited a Carrier healer to speak to my university class.

After an hour of discussing botanical and medicinal characteristics of the different plants with the students in western scientific terms, she suddenly stopped, looked at them sternly, and said, “These things are sacred! Never forget.” Similarly, Utes in the Southwest faced with the question of mining on their lands are deeply troubled, for the land is more than a mere resource, as several individuals have tried to explain:

The land is a living body with spirit and power, which contains tribal genealogy. It is necessary for the people to remain in the place in which they have always been, as guardians, and as an inseparable part of that place and space.

The tribe does not want to diminish the land, but not because of money issues. But because you diminish *us* when the land is eaten away (emphasis in original). (Romeo, 1985, pp. 160–161)

At the Tellico Dam congressional hearing in 1978, Jimmie Durham, a western Cherokee, tried to express what his people felt for a land they could no longer even live upon, but wished to preserve nonetheless:

In the language of my people . . . there is a word for land: Eloheh. This same word also means history, culture and religion. We cannot separate our place on earth from our lives on the earth nor from our vision nor our meaning as a people . . . So when we speak of land, we are not speaking of property, territory or even a piece of ground upon which our houses sit and our crops are grown. We are speaking of something truly sacred. (Matthiessen, 1984, p. 119)

As Roland Willson, Chief of the West Moberly First Nations (northern British Columbia), states:

To be a proud First Nations person, you have to be connected to your culture. You have to know where you came from, and where and what are the important parts. What was the value of that person, and why, and why is my culture important today, and why is making dry meat, and picking these berries, critical to our way of life. The whole tone of government is economics and jobs, and training and forcing people into this economy, and there is not an appropriate amount of attention placed on maintaining [our way of life]. We're the ones fighting. We can see our land base eroding. (Booth & Skelton, 2011, p. 294)

In Aboriginal relationships with a living, conscious world, reciprocity and balance were

required from both sides. Balance was vital: the world exists as an intricate balance of parts, and it was important that humans recognized this balance and strove to maintain and stay within this balance. All hunting and gathering had to be done in such a way as to preserve the balance. Human populations had to fit within the balance. For everything that was taken, something had to be offered in return, and the permanent loss of something, such as in the destruction of a species, irreparably tore at the balance of the world. Thus, offerings were not so much sacrifices, as non-Aboriginals were inclined to interpret them, but an appropriate acknowledgment of a great gift. In this way, the idea of reciprocity emerges. From the Aboriginal perspective, as Hughes describes it, “mankind depends on the other beings for life, and they depend on mankind to maintain the proper balance” (Hughes, 1983, p. 17).

The respect and approval is two way: humans both give and receive value and self-worth from the natural world. Part of the idea of reciprocity is the necessity and importance of interaction. Participation in reciprocity is vital; a failure to interact, or a breakdown in interaction, leads to disease and calamity. Thus, everything that is used in everyday life is used for its part in that interaction; it becomes a symbol of sacred interaction and relationship between the people, the plants, the animals, and the land. Rituals such as those used for healing are not designed to ward off illness or directly cure the ill person. Rather, they are designed to remind the ill person of a frame of mind which is in proper relationship with the rest of the world, a frame of mind which is essential to the maintenance of good health.

An old Keres (Pueblo) song goes like this:

I add my breath to your breath
That our days may be long on earth
That the days of our people may be long
That we may be one person
That we may finish our roads together
May our mother bless you with life
May our Life Paths be fulfilled. (Allen, 1986, p. 56)

The reciprocal relationship embodied in this song, the sharing of breath is the sharing of life, is one of the central insights into Aboriginal

worldviews. One does not act in isolation, but must act with respect towards the others one shares the universe with. Involved with a *living* universe, the Aboriginal person is engaged in a constant dialogue with a network of relations, human and nonhuman, and natural and supernatural. Sam Gill explains that Aboriginal peoples hold a “person to person” relationship with the environment as the power of life itself is personified and inextricably linked with, and identical to, the natural world (Gill, 1989, p. 30). This sense of relationship is explicit in every aspect of life. Consider Ojibwa Winona LaDuke’s (1990, p. 16) comments on the ordinary, mundane activity of hunting and gathering:

Whether it is wild rice, whether it is fish, whether it is deer or turtles, when you go and take something from the land, you pray before you take it. You offer tobacco; you offer a prayer to that spirit and to the creation of a part of that. *You take those things because you have a relationship with all the other parts of the creation. That is why you are allowed to take those things.* You take that and you give something back as a reciprocal arrangement, because that is how you maintain your relationship (emphasis added).

As countless sacred rituals, ceremonies, songs, and teaching stories make clear, maintaining the relationship between human life and nonhuman life is the heart of Aboriginal spirituality. The Sun Dance of the Plains cultures, which has attracted considerable interest for its more gruesome aspects (including a long government ban on its performance), is not about the ability to endure pain. It is about humanity’s willingness to offer blood and spirit towards the maintenance of the balance of life, as Brown’s observations make clear:

The Sun Dance . . . is not a celebration of man for man; it is an honoring of all life and the source of all life, that life may go on, that the circle be a cycle, that all the world and man may continue on the path of the cycle of giving, receiving, bearing, being born in suffering, growing, becoming, giving back to earth that which has been given, and so finally to be born again. (Brown, 1978, p. 12)

A sense of embeddedness in the rest of the world has profound implications for how one chooses to live and interact with others. It is

also one reason why the displacement of Aboriginal cultures from their lands, and the subsequent damage to the land, was and is so socially and psychically devastating. As Allen points out, the despair that appears in many writings by Aboriginal authors is the despair of having lost “that perfect peace of being together with all that surrounds one,” a loss that is irreplaceable (Allen, 1979a, p. 192). Peter Matthiessen agrees that this understanding is found consistently across a wide diversity of cultures:

It is not a matter of ‘worshipping nature,’ as anthropologists suggest: to worship nature, one must stand apart from it and call it ‘nature’ or ‘the human habitat’ or ‘the environment.’ For the Indian, there is no separation. Man is an aspect of nature . . . (Matthiessen, 1984, p. 9)

Or consider part of a sacred chant of the Navajo Nation, designed to remind the person every day of their connections with life:

The mountains, I become part of it . . .
The herbs, the fir tree, I become part of it.
The morning mists, the clouds, the gathering waters,
I become part of it.
The wilderness, the dew drops, the pollen . . .
I become part of it. (Brown, 1989, p. 20)

N. Scott Momaday, of Kiowa descent, describes living apart from the land with horror: “Such isolation is unimaginable” (Momaday, 1979, p. 166). As Allen confirms, all poetry, ceremony, song, and story remind Indians of their part in a living evolving whole by virtue of their willing participation (Allen, 1979b, p. 226).

Part of Aboriginal relations with nature is encapsulated in traditional spirituality. Traditional Aboriginal spirituality has been the target of attack and suppression by the European invaders since 1492, and it continues to be a significant political, legal, and emotional minefield. After 500 years of suppression, some have legitimately questioned whether there is such a thing as “traditional” Aboriginal spirituality. Much knowledge and practice was lost through genocide and through the devastating plagues that swept the New World after the arrival of the Europeans. Many Aboriginal peoples were forced, or chose, to convert to European

religions, and their descendants remain faithful practitioners of Catholicism or some form of Protestantism. In both the United States and Canada, what “traditional” practices remained were outlawed and remained illegal until recently. Yet in spite of everything, the Aboriginal peoples themselves state that unique, viable spiritual practices continue to exist and flourish.

One key question is, what are spiritual practices intended to do? For many Aboriginal people, spiritual practices were part of an ongoing dialogue with the world. Lakota Deloria (1973, p. 102) describes it thus: “The task of the tribal religion, if such a religion can be said to have a task, is to determine the proper relationship that the people of the tribe must have with other living beings.” Spiritual practices become a way of learning how to live well and, in this case, to live well with the natural world. They are methodologies for reaching an appropriate level of consciousness, or mindfulness, of the world. Further, these practices, which interlink behaviors, feelings, and ethics, are completely identified with the very survival of the people and the land.

Aboriginal peoples saw that all that existed shared in sanctity as they were all fragments of God. While they did not “worship” nature, they recognized that all life around them was sacred, for “each form in the world around them bears such a host of precise values and meanings that taken all together they constitute what one would call their ‘doctrine’” (Brown, 1985, p. 37). When Aboriginal cultures defined themselves in terms of community, their definition of community included the natural community. Spirituality requires that humanity and “the rest of creation (be) cooperative and respectful of the task set for them by the Great Spirit” (Deloria, 1973, p. 96). That task is dwelling with balance and with harmony.

Respect in the American Indian context does not mean the worship of other forms of life but involves two attitudes. One attitude is the acceptance of self-discipline by humans and their communities to act responsibly towards other forms of life. The other attitude is to seek to establish communication and covenants with other forms of life on a mutually agreeable basis. (Deloria, Foechner, & Scinta, 1999, p. 51)

Deloria (1973) has given a particularly thorough consideration to the linkage between place and spirituality, contrasting it with Christian practice. Christianity, he notes, although originating in a particular land (the Holy Land), can and does exist almost anywhere on the face of the earth without extensive modification of the central creed, i.e., the Christian god is “portable.” Traditional Aboriginal spiritual practices, however, cannot without damage be moved from a given landscape. Rather, they have evolved to incorporate and reflect particular elements of the chosen land. Where would the Navajo Nation be without the Four Mountains, or the Lakota without the Black Hills? When poet Paula Gunn Allen writes “We are the land . . .,” her statement, to her, is literal truth. It is who she is as a Laguna (Allen, 1979a). The same sense of identification is true for Kiowa N. Scott Momaday, who writes of giving himself to the “remembered earth” (Momaday, 1979, pp. 164–165), or for Lakota Black Elk and Standing Bear, who speak of the devastating loss of the Black Hills to gold miners (Standing Bear, 1933; Neihardt, 1932/1975). The land is who an Aboriginal person is and it affects his/her responses to the world. Consider Ronald Goodman’s interpretation of what, to the American government, was merely a question of land expropriation, but to the Lakota was an attack on their spiritual integrity:

Traditional Lakota believed that ceremonies done by them on earth were also being performed simultaneously in the spirit world. When what is happening in the stellar world is also being done on earth in the same way at the corresponding place at the same time, a hierophany can occur; sacred power can be drawn down; attunement to the will of Waken Tanka can be achieved.

Our study of Lakota constellations and related matters has helped us appreciate that the need which the Lakota felt to move freely on the plains was primarily religious. (Goodman, 1990, p. 1)

Such an indelible bond with the land, however, is clearly a deliberate construction by the tribes. Aboriginal groups have been migrating across the North American continent for the last 40,000 years. Some are very recent arrivals; the Navajo only migrated into the American Southwest from Alaska and the Yukon about 600 years

ago (one of the last non-European induced migrations in North America) (Dickason, 1992). They are not then “native” to the area. They have, however, reconstructed their religion to reflect the new land in which they dwell, in part by borrowing from earlier residents such as the Hopi. From this, Deloria draws a conclusion of interest: he believes it is possible for a cultural group to “consecrate” a particular landscape, if they are capable of seeing themselves in terms of that landscape (Deloria, 1973, p. 295). A similar situation occurred among the Lakota. When pressures from the Europeans forced them to relocate from their territory around the Great Lakes, they “reinvented” themselves, including their culture and spirituality, from being “woodland” to “plains” cultures (Dickason, 1992). What we think of as the Lakota culture, horses, feathered headdresses, etc. are readaptations to a new environment. Their spiritual practices were recreated as well within the radically different landscape.

While such discussions of spirituality and land can seem rather romantic, modern Aboriginal cultures are working to embed the linkages of culture, spirituality, and land within some very applied modern practices. Recent reviews of modern Canadian Aboriginal land-use planning and forestry, for example, demonstrate that these “western” natural resource practices are being used by Aboriginal governments to protect both critical lands and resources as well as culture and spirituality, in unique blends of culturally appropriate tools and techniques (Booth & Muir, 2011, 2013, respectively). The linkage of land, spirituality, and living in contemporary times remains an Aboriginal way of life.

For the Aboriginal person, all living can be spiritual practice. Thus, material possessions are symbolic of sacred relationships. Moccasins remind the wearer of their connection with the earth, with the plants and animals on it, and so of the nature of reality itself. A pipe becomes a teaching tool, a history of the people, and a reminder of how all in the world are related. When smoked in a sacred manner, it is offered to “all my relations” (Lame Deer & Erdoes, 1972, p. 12, pp. 150–253). A caribou leg bone scraper is a reminder of history, of culture, and how

intimately linked is all of life. Activity which maintains life is also part of the ongoing sacred process; for an Aboriginal person, the acts of hunting or weaving or building a house are also religious activities. Toelken (1976) also points out that Aboriginal cultures rarely distinguish between their religious life and their secular life. Instead, there is nothing in life that is *not* religious. Everything from hunting to healing is a recognition and affirmation of the sacredness of life. In the weaving of a basket is the creation of the whole world. In a proper life, there is never a sense of disconnectedness from the Earth. As Peter Matthiessen suggests:

... the whole universe is sacred, man is the whole universe, and the religious ceremony is life itself, the miraculous common acts of every day. Respect for nature is respect for oneself; to revere it is self-respecting, since man and nature, though not the same thing, are not different. ... (Matthiessen, 1981, p. 12)

In all traditional Aboriginal spiritual practice, the sense of the earth as alive was part of a sacred understanding of life and human obligations to life, as Deloria discusses:

Coming last (in creation) human beings were the "younger brothers" of the other life forms and therefore had to learn everything from these creatures. Thus human activities resembled bird and animal behaviors in many ways and brought the unity of conscious life to an objective consistency. (Deloria et al., 1999, p. 50)

This idea reoccurs in contemporary Aboriginal cultures as well. Allen sees the distinguishing characteristic between western and Aboriginal thinking as the "magicalness" in Indian perception. This is not a childish magicalness but a perception of everything in the world as alive, viable, and subject to the need to grow and change. An Indian, she says, is one who:

assumes that the earth is alive in the same sense that he is alive. He sees this aliveness in nonphysical terms, in terms that are familiar to the mystic or the psychic, and this gives rise to a mystical sense of reality that is an ineradicable part of his being. (Allen, 1979b, p. 233)

The vital importance of maintaining essential relationships has serious implications for how Aboriginal cultures deal with their fur-clad

relatives, the animals. The idea which appears over and over is "kinship" with other living beings, as Allen comments:

All are seen to be brothers or relatives (and in tribal systems relationship is central), all are offspring of the Great Mystery, children of our mother, and necessary parts of an ordered, balanced and living whole. (Allen, 1979b, p. 225)

Brown (1985) comments that nonhumans are the links between humans and the Great Mystery. To realize the self, kinship with all beings must be realized. To gain knowledge, humans must humble themselves before all creation, down to and including the lowliest ant. Nature is a mirror which reflects all things, including that which it is important to learn about, understand, and value throughout life. Further, many tribes acknowledge that humans found a world to come in to and a way of making a living as the result of conscious, caring gifts from the animals. The creation myths of tribes such as the Arapaho or the Iroquois tell of how the Creator created the world with the help of animals, from mud brought up from beneath endless waters by a muskrat or rested on the back of a willing turtle. Sacred objects are donated, as when eagle grants the use of his feathers, and food is found because holy animals offer their flesh as a gift (Harrod, 1987, p. 51).

However, some anthropologists such as Harrod (1987) or Hultkrantz (1981) see a tension inherent in the problem of having to kill animals with whom one had a deep, intimate relationship. Looking at the Plains cultures, Harrod observes that such tensions are apparent in creation myths. The Blackfoot, for example, tell of a time when humans were hunted by the buffalo. To change this, the god taught the people to make bows and arrows and then to hunt. In compensation for becoming food, the buffalo and other animals became spiritual helpers which the Blackfoot were to obey. In this fashion, and through other rituals, the tension inherent in eating social equivalents is partially resolved (Harrod, 1987, pp. 44–45, 53–54).

However, as the anthropologists start to suggest, relationships with animals can be complex. Modern Aboriginal communities have individuals who do not subscribe to more

“traditional” approaches and so can be highly disrespectful hunters. At times, what an Aboriginal culture views as “respectful” may not match non-Aboriginal sensibilities, with preferences for non-fur-wearing, vegetarianism (a popular bumper sticker in many Aboriginal communities reads, “Vegetarianism is an Indian word for lousy hunter”), or the safe anonymity of plastic wrapped meats with no hint of industrial feedlots or slaughterhouses. Nor can anyone visiting an Aboriginal community see respect in how domestic dogs are frequently treated. A non-Aboriginal might well be uncertain about Aboriginal relationships with animals, but careful consideration is warranted.

Most Aboriginal legends speak of other species as beings who could shed their fur masks and look human. They once shared a common language with humans and continued to understand humans after the humans had lost their ability to speak to the animals. The animals partook of the sacredness of life and were often the descendants of the powerful beings who had lived on the earth before humans. An animal was something more than its furry, four-footed shape, more than what was seen by human eyes. It was, says Nelson (1983, p. 31), a personage and a personality with a lineage far older than humanity’s. Laird describes animals this way:

It is to be remembered that the pre-human Immortals (the gods, if you will) were Animals Who Were People. These Forerunners, these Ancient Ones whose bodies shimmered as it were between animal and human forms, these denizens of the elder dream-world, have long since taken their final departure; yet they remain as the visible animals of this everyday world ... Mythic Coyote, supertrickster and pattern-setter for mankind, is not [coyote], raiding fields and howling on the hills before dawn - and yet in a certain mystical sense, he is. (Laird, 1976, p. 110)

Even into the present, most Aboriginal people (although not every individual) respect their relationship with animals and believe that the respect and caring go both ways. Thus, communication is possible, as Yukon Indian Irene Isaacs explains:

You can tell them and they do it, that wolf. You tell them, “Kill something for me!” And then the wolf will. Then you come, and they are going to kill

a moose and you’re going to find it and have moose meat. They do that, wolves. So they understand Indians. And other animals, that’s what I tell my son about that too. You’ve got to treat animals good. (McClellan, 1987, p. 280)

Martin, discussing subarctic bands, also notes that a sympathy builds up between the hunter and the animal persons who are hunted, a sympathy which pervades human life. At all times, there is a mutual obligation felt, an obligation to be courteous. An animal is not killed unless the hunter obtains its consent in the spiritual world; the animal must be willing to surrender itself to the hunter. Hunting gives meaning to the hunters’ lives; it gives a sense of identity. It is the animal who grants this sense of identity (Martin, 1978).

According to Nelson, the Alaskan Koyukon believe that animals and humans are distinct beings, their souls being quite different, but that animals are powerful beings in their own right (Nelson, 1982, 1978). Consequently, a complex collection of rules, respectful activities, and taboos surround everyday life and assist humans in remaining within the moral codes that bind all life. Hunting, therefore, is conducted with respect and with ritual from the moment the hunt is conceptualized until the animal’s remains are properly disposed of. Animals are not offended at being killed for use, but killing must be done humanely, and there should be no suggestion of waste. Nor can the body be mistreated: irreverent, insulting, or wasteful behavior could result in the future loss of the species, which would no longer make itself available for killing. Even gathering must be done respectfully. Yukon women gathering roots are pleased by the find of caches of roots already collected by mice. However, they are careful to leave some for the mice. Otherwise the mice are likely to come raiding Indian supplies during the winter (McClellan, 1987, pp. 139–140).

In my own research with Beaver cultures in northeastern British Columbia, I talk regularly with hunters who speak of the necessary respect with which a proper hunter must approach an animal, being considerate of its habitat and the animal itself. Others outright empathize with animals, who they might hunt for food and cultural nourishment, but whom they worry about when

they are hurt by industrial development. As Max Desjarlais, an elder asked, "And that poor animal, the house it lives in, how is it going to live? What is it going to do?" (Booth & Skelton, 2011).

The practical consequences of such relationships with animals are profound. Species were not endangered or exterminated, for exterminating a species would have meant the elimination not only an essential life, but a kindred being. Hughes (1983) believes that the "ecological consciousness" of the Aboriginal was in part due to their sense of kinship with the rest of the world.

The need to both respect *and* use animals continues today, although it can engender modern controversy. Just last week, I spoke with a university student who was angered about an Aboriginal community working to protect and increase a herd of caribou, just so that they could once again hunt (and eat) caribou. To him, this seemed self-serving and immoral. To the community with which I work, it is a deeply moral act, a reciprocal act of restoring ecological integrity to benefit both caribou and Aboriginal. On an international scale, whaling, for example, is a similarly controversial subject. When a west coast Washington tribe, the Makah, decided to return to their traditional practice of whaling in 1999, it provoked outrage on the part of environmentalists and even ordinary people; it prompted immense television coverage, the attempted intervention of the Sea Shepherd Society, and required the protection of the US Coast Guard for the hunters (Blow, 1998). However, as Tom Mexsis Happynook, chair of the World Council of Whalers, argued, whaling represents a modern practice of responsibilities which integrate the native culture into the environment, which "maintain the balance within the environment and ecosystems":

For the Nuu-chah-nulth hunters the taking of any life was looked upon as the most sacred responsibility that we have had bestowed upon us, because of this my grandfather taught me the hunters had to pay dearly for the honour of taking a life. This especially applied to the whaling chiefs because they hunted the greatest and largest mammal on earth.

People have a very important role to play in the environment which is to help maintain the balance through our relationship with the ecosystem; that

one of the most important tools we have at our disposal to meet this obligation is respectful, responsible and sustainable utilization of the resources (the gray whale population on our coast is a perfect example of that responsibility). (Happynook, 1999, p. 3)

Non-Aboriginals see an intelligent, sympathetic endangered species. Whaling cultures see the same but also a creature with which they have had a profound relationship for millennia, the hunting of which underlies who they are as a culture.

This argument has a scientific basis as well. For example, the Inuit in northern Canada have long argued that they had a better sense of the whale population, through yearlong observation, than did the visiting government whale biologist and pushed for a larger harvest quota. Subsequent non-Aboriginal research has begun to confirm the greater accuracy of traditional ecological knowledge in this instance (Wohlforth, 2004). It is worth recognizing that the sense of relationship, of reciprocity, and of participation in the world encapsulated in Aboriginal spirituality, and as reflected in how they interacted with animals, had a very practical ecological link for many Aboriginal cultures, as Deloria describes:

The Indian principle of interpretation/observation is simplicity itself: "We are all relatives." Most Indians hear this phrase thousands of times a year as they attend or perform ceremonies. . . this phrase is very important as a practical methodological tool for investigating the natural world and drawing conclusions about it that can serve as guides for understanding nature and living comfortably within it. "We are all relatives" when taken as a methodological tool for obtaining knowledge means that we observe the natural world by looking for relationships between various things in it. That is to say, everything in the natural world has relationships with every other thing and the total set of relationships makes up the natural world as we experience it. (Deloria et al., 1999, p. 34)

Sounds remarkably like the modern science of ecology. But were Aboriginal people ecologists?

The Ecological Aboriginal?

In the last two decades, the academic discussion has moved slightly in focus from what view of

nature Aboriginal peoples had in the past or present to how this might translate into action. The key question appears to have become, were Aboriginal peoples truly the first environmentalists? Were they “ecological” Indians? Or were they, as Berkes terms it, “intruding wastrels” destructive of their ecosystems, surviving only because of they moved around and had fortuitously small populations (Berkes, 1999, p. 145). Or are they “fallen angels,” former noble savages whose ancestors lived in harmony with nature but whose descendants threaten fragile wildlife populations and at-risk wilderness? This is a challenging debate within ecological and anthropological circles, one to which entire conferences have been devoted (although less so lately). A critical discussion of this issue is provided in an Extra to this article. As this Extra indicates, “using” Aboriginal cultures as ecological “models” is difficult and potentially misleading. That said I still wish to consider how they have adapted to the land and whether the adaptations could be considered ecologically successful. While most Aboriginal peoples, I think, would have considerable difficulty in fitting themselves into a category as shallow and narrow as “environmentalist,” I believe that non-Aboriginals, with their distinctly more destructive relationships with the land and planet (global climate change, anyone?), could learn a thing or two from others, including Aboriginal cultures.

It must be remembered that for most Aboriginal cultures, the land and its residents have many more shades of meaning than non-Aboriginal societies are willing to consider. The land is a source of sustenance and was exploited for that purpose. However, the land also holds other meanings for past and present Aboriginal cultures. Nelson remarks of the Alaskan Koyukon, principally hunters and gatherers, that their land:

is permeated with different levels of meaning - personal, historical and spiritual. It is known in its finest details, each place unique, each endowed with that rich further dimension that emerges from the Koyukon mind. (Nelson, 1983, p. 245)

To picture Aboriginal cultures as people who passed through the land leaving no trace, as some environmentalists are apt to do, is to deny an

ecological reality and, in passing, to damn Aboriginal cultures with faint praise (with the implication that they were incapable of making such a mark). As Hughes remarks of the Northeastern cultures,

Like all human cultures, the forest Indians were agents of change in nature. For at least 10,000 years, and perhaps much longer, they had lived within the forest ecosystems, hunting, fishing and gathering with skill and experience. Their land was not a wilderness, but a woodland park which had known expert hunters for millennia. (Hughes, 1977, p. 7)

That the lands remained productive was in part due to Aboriginal lifestyles that were more or less mobile (even the farmers moved to new areas when the soil was exhausted), as Cronon (1983), Merchant (1989), and Krech (1999) document, although some cultures, such as the Haida, occupied their lands for millennia (Dickason, 1992). It may have also been the result of a sense of stewardship. Many cultures deliberately took (and still take) steps to ensure that human-induced changes did not damage their source of livelihood. Among the Yukon Indians, these steps took the form of a belief in ownership of certain areas.

This kind of ownership meant that a headman and the people who traveled with him had the first right to use the products of the local land and water, but they also had the duty of taking care of these resources ... It was part of their job to see that people did not overhunt, overtrap or overfish the area, as well as to see that as far as possible everybody got enough to eat ... (McClellan, 1987, pp. 151–152)

Among the Cree, efforts to conserve resources took the form of dividing the land into regions, with a hunting camp in the center. The camp was occupied until both animal populations and resources such as firewood and green bedding boughs were reduced. Old campsites were cleaned prior to leaving to avoid offending the spirits, who would send away the animals if the land was not cared for (Tanner, 1979, pp. 74–75). Such concerns did not mitigate the ecological impacts; the game population and the campsite recovered because the Indians moved elsewhere. However, the concern for the spirits’ goodwill, in combination with a mobile population, may have limited irreparable damage, at least where overall

human population numbers were low. Such land stewardship practices can still be found in modern Aboriginal cultures across northern Canada and Alaska, as well as elsewhere, where individuals and families are given explicit responsibility for specific lands and their ecological health.

Of great concern to Aboriginal cultures, for obvious reasons, was the conservation of game animals. Harrod notes the presence of several Trickster stories among the Plains cultures, in which the Trickster character exploits trusting animals to satisfy an insatiable appetite. In this pursuit, he is foolish enough to eliminate almost all the animals, usually missing just one:

That Trickster is foolish and even a dangerous hunter appears in the theme of the "last animal" which runs through the narratives. As a consequence of escape, often brought on by a momentary lapse in Trickster's character, an animal survives to continue the species. Clearly the hunting techniques of Trickster are not affirmed; rather, the foolishness and potentially disastrous consequences of such activities are underlined in these stories. (Harrod, 1987, p. 63)

There appears to have been a real concern, expressed through such stories, that the animal populations not be decimated. Recent anthropological work among the modern Cree and Koyukon, among others, has uncovered what researchers feel are deliberate conservation practices. Tanner (1979) and Berkes (1999) observe that the Cree are constantly assessing plant and animal population levels. Long- and short-term changes in populations are understood both in spiritual terms (the activities of the Animal Masters) and in terms of environmental factors (food supplies, water, weather patterns, forest fires, and hunter activities). The Cree govern their hunting activity on the basis of these observations. Modern Inuit observe whale populations assiduously to determine appropriate hunting levels (Wohlforth, 2004). The Treaty 8 First Nations I work with in northeastern British Columbia had their elders declare that, after a dam was built that destroyed huge amounts of habitat, caribou, an extremely important animal, would no longer be hunted. That hunting moratorium has been honored for more than 50 years.

Among the Koyukon, conservation activities are also based on their keen observation of the ecological dynamics of their lands. The people regulate their harvests in a number of ways to ensure that plant and animal populations remain healthy. The Koyukon may consciously avoid taking more individuals than they believe can be naturally replaced, or they may take special measures that they hope will enhance the productivity of a species. They avoid killing female waterfowl, bears, and moose in the spring when they are breeding. Hunting activities are usually spread over as wide an area as possible. Young plants and animals are usually not harvested, but are allowed to mature. Trappers are very cautious about where and how many animals are harvested (Nelson, 1983, pp. 221–223). For example, trappers are careful when trapping the sedentary beaver.

While such practices are noteworthy, Nelson is careful to point out that there is no objective data to prove that these intentional limitations actually achieve their conservation goals. He does, however, feel that the Koyukon could be considered to be practicing a "conservation ethic." Tanner is also unable to document the impacts of the Cree's conservation practices on resource populations. Berkes, however, makes an extensive case for the conservation ethic of modern Cree, although he notes it was not without many mistakes and misapprehensions.

A final issue to consider is the modern need for Aboriginal cultures to make a living from the land upon which they live. This often involves necessary, and not always satisfactory, compromise between traditional beliefs regarding nature and resource extraction. Forestry is a common industry on many Aboriginal lands in both Canada and the United States. One well-known, long-term industrial forest operation has been undertaken by the Menominee of Wisconsin. The Menominee have been logging on their reservation for over a century and still have a robust and healthy forest ecosystem. Their forester, Marshall Pecore, argues it is a unique balancing act.

It is said of the Menominee people that the sacredness of the land is their very body, the values of the culture are their very soul, and the water is their

very blood. It is obvious, then, that the forest and its living creatures can be viewed as food for their existence. . . . Their story is one of successful equilibrium between harvesting and using only what the land can provide, and maximising the jobs and other economic benefits that flow from a sustained-yield harvest (cited in Davis, 2000, pp. 55–56).

However, it is also not always easily achieved. One group I work with, Tl'azt'en Nation, runs a commercial forestry operation and has done so for 20 years. They feel they have been less successful in integrating traditional values and, correctly my analysis suggests, blame it on the restrictions surrounding forestry in British Columbia, as a community member notes indicates:

There's a conflict right there. That one is really a conflict that we're conscious of - trying to look at a bottom line and manage in a traditional way - and we haven't really been able to marry those two successfully and our teachings . . . they're still there but . . . you know there's a real major conflict in thinking and ideology right there along with our teachings, when you go into the bush to take a plant for medicine, you return something back. And then in logging you go in there and clearcut an area, you don't put anything back except new trees . . . I have a concern about that, and how we do that I'm not sure right now except to try to build those traditional teachings and principles into your management plans, push those, work those. Some of those don't necessarily, are not necessarily acceptable by the (British Columbia) Ministry of Forests, so it's an ongoing struggle there too because you have different thinking about how that forest should be managed. (Booth, 1999, p. 33)

Similarly, the West Moberly and Sauteau Nations of northeastern British Columbia, in planning for their community forest, seek forestry operations in which traditional values including wildlife and plant protection, ecological integrity, and spiritual opportunities were as important, if not more so, than strictly economic returns:

The forest is important to me because it's not just about First Nations' Treaty Rights, it [is about] trying to protect the wildlife, the medicinal plants, the berries, and just the environment as a whole and if we don't try to slow [industrial development] down, there's going to be big impacts in the future and it is going affect our kids. (Booth & Muir, 2013, p. 153).

However, modern Aboriginals need to make their own compromises, in matching cultural

practices with modern demands for jobs and revenue:

Conservation and development-policy-making and -planning often seems to assume that we, the Aboriginal peoples, have only two options for the future: to return to our ancient ways of life or abandon subsistence altogether and become assimilated into the dominant society. Neither option is reasonable. We should have a third option: to modify our subsistence way of life, combining the old and the new in ways that maintain and enhance our identity while allowing our society and economy to evolve. (Erasmus, 1989, p. 229).

Conclusions

Are Aboriginal peoples ecologists? Environmentalists? Or peoples with a unique understanding of the natural world that might or might not have translated into a better way of living with the earth. Readers will need to draw their own conclusions. However, I agree with Berkes (1999, p. 182) when he notes that, "A fundamental lesson of traditional ecological knowledge is that worldviews [and beliefs] do matter."

The challenge is to cultivate a kind of ecology that rejects the materialist tradition and questions the Newtonian, machinelike view of ecosystems . . . The indigenous knowledge systems of diverse groups, from the Dene of the North American subarctic to the Fijians of the South Pacific, provide an alternative view of ecosystems. This is a view of an ecosystem pulsating with life and spirit, incorporating people who *belong* to that land and who have a relationship of peaceful coexistence with other beings.

Aboriginal views of nature, as articulated in this article, attract a great deal of interest as well as controversy. There is a fascinating psychological question as to why, as a society we are attracted to them, even if they are not part of our cultural heritage. Perhaps we need to believe there are ways of seeing the world that might lead to the preservation of functioning ecosystems. Perhaps this is the same basis from which others are driven to criticize the concept of the ecological Indian: we do not have to feel as guilty for our behavior if we are all equally, inherently, destructive of nature. The problem I see is not that we are able to be inspired by Aboriginal

cultures, or that they drive us to justify our own actions against ecosystems, but that in doing either we lose sight of the people themselves and the complex nature of the challenges they face. We need to allow ourselves that inspiration, the critical question as well, but we need to always remember the *people* who articulate a reality that perhaps all humans can understand.

Once in his life a man ought to concentrate his mind upon the remembered earth, I believe. He ought to give himself up to a particular landscape in his experience, to look upon it from as many angles as he can, to wonder about it, to dwell upon it. He ought to imagine that he touches it with his hands at every season and listens to the sounds that are made upon it. He ought to imagine the creatures that are there and all the faintest motions in the wind. He ought to recollect the glare of noon and all the colors of the dawn and dusk.

I am interested in the way that a man looks at a given landscape and takes possession of it in his blood and brain. For this happens, I am certain, in the ordinary motion of life. None of us lives apart from the land entirely; such isolation is unimaginable. We have sooner or later to come to terms with the world around us - and I mean especially the physical world; not only as it is revealed to us immediately through our senses, but also as it is perceived more truly in the long turn of seasons and of years. (Momaday, 1979, p. 164, 166.)

Extra: The Ecological Indian?

During the last two decades of the twentieth century, the academic discussion became focussed upon two questions: what view of nature did Aboriginal cultures have in the past or present and what might this mean for non-Aboriginal cultures. The key question appears to have become: were Aboriginal peoples truly the first environmentalists? Were they “ecological” Indians? Or were they, as Berkes terms it, “intruding wastrels” destructive of their ecosystems, surviving only because they moved around and had fortuitously small populations (Berkes, 1999, p. 145). Or are they “fallen angels,” former noble savages whose ancestors lived in harmony with nature but whose descendants threaten fragile wildlife populations and at-risk wilderness?

This interest in Aboriginal relationships with nature has an old history. Influential members of

the early American conservation movement were deeply impressed by Native Americans and their relations with the natural world (Cornell, 1985). This question however came under intense consideration with the 1960s environmental movement. Former Secretary of the Interior Stewart Udall (1973) articulated this best in his influential article entitled *Indians: First Americans, First Ecologists*. Interest burgeoned and works such as *Black Elk Speaks* (Neihardt, 1932/1975), *Rolling Thunder*, and the now controversial speech of Chief Seattle became cultural icons. The story of Chief Seattle’s speech is somewhat instructive in how eagerly and uncritically the public embraced the idea of the Aboriginal environmentalist. While Seattle, a Duwamish chief, did indeed make a highly articulate speech to the US government on the appropriation of his tribe’s land, what has become known as Seattle’s speech was actually a highly liberal adaptation written by a European as narration for a 1970s film (Kaiser, 1985). (A copy of the speech and more on the controversy can be found at: <http://www.geocities.com/Athens/2344/chiefs4.htm>.)

Many Aboriginal peoples were not unwilling to have this part of their culture articulated. Many writers of the 1970s and 1980s articulating the Aboriginal culture and nature relationship were themselves of Aboriginal descent, including Vine Deloria, Jr., Paula Gunn Allen, John Lane Deer, Winona LaDuke, and N. Scott Momaday.

By the 1980s, however, the issue came under academic scrutiny, and the picture was no longer clear-cut. Anthropologists and historians marshalled on both sides. People like Hughes, Nelson, Cronon, Gill, Toelken, Brown, and others presented plausible cases for cultures which, while not gentle nature lovers, nonetheless maintained functioning ecosystems through cultures which integrated nature into spiritual and living practices. Many were examining historical cultures, although Gill, Brown, Toelken, and Nelson were working with modern cultures. Making the case that Aboriginal cultures were not model ecological citizens were scholars such as Callicott, Martin, and Krech.

The debate never resolved and academic interest moved on, so the question is not as hotly

debated currently, but it still rears its head in debates over natural resources extraction, Aboriginal lands, and who governs. Both sides over time made some persuasive cases. The “good ecological” Aboriginal arguments are simplified, based on two threads. The first thread is the ecological knowledge and “philosophy” contained in Aboriginal culture past and present. This has been discussed in the section on Aboriginal views of nature. The second thread is the ecological state of North America when European explorers discovered it. While research has demonstrated that the landscape was not unmanipulated by human residents, nonetheless after an occupation of between 10,000 and perhaps 40,000 years (Dickason, 1992), North America looked like an Eden to European arrivals. Forest cover was extensive. Wildlife, including large carnivores, appeared in astonishing numbers. It was a sharp contrast to the humanized, ecologically impoverished landscape that European explorers left behind. This is the crux of the argument of those who argue that Aboriginal cultures offer models of human-nature relationships well worth admiration and study.

Those who argue against the concept of the “ecological Indian” also draw on evidence from the pre-European era. Shepard Krech III was one of the leaders in the move to debunk the myth of the ecological Indian, and he does so in his 1999 book (Krech, 1999) based largely on historical activities. He also does so by defining the truly ecological Indians clearly as ones who did *not* change, damage, or irrevocably alter their ecosystem. By doing so, he clearly defines what we (or at least the scholars debating the ecological Indian myth) think of as ecological or environmental behavior: the opposite. By this definition, as Krech successfully argues, the historical Aboriginal was not ecological or an environmentalist. There is considerable archaeological evidence, for example, that indicates many cultures did indeed damage their ecosystem through overuse of resources. Krech cites the midwestern Cahokia culture which flourished between the twelfth and fourteenth centuries. They apparently denuded their landscape so severely they needed

to import wood. The earlier southwestern civilization of the so-called Anasazi may have also collapsed as a consequence of overuse of resources (Krech, 1999, pp. 76–77). Other cultures constantly altered the landscape deliberately. Cultures in the eastern woodland and the prairies fired habitats, deliberately, to alter vegetation to attract different browsers or to force animals into more easily hunted areas (Krech, 1999, p. 105) or to produce berries. While these fires were prompted by considerable ecological knowledge of fire succession stages, these fires often got out of control and were highly destructive. Along the east coast, there are still areas burned down to rock (Patterson & Sassaman, 1988). Krech also cites the hunting of bison through massive drives into pens or over cliffs, with subsequent waste of considerable meat. As Krech does point out, there is equal evidence of careful use of all resources as well. However, what is clear in all his careful scholarship is that Aboriginal peoples used, altered, and in some cases damaged nature. By non-Aboriginal definition, they are unecological, as non-environmental as European descended cultures (i.e., the dominant North American culture today). Krech confirms earlier arguments put forward by scholars such as Callicott and Martin.

Both sides make careful sophisticated arguments that interested readers should approach in their entirety and draw their own conclusions. I remain uncertain as to utility of the debate itself (not that I disagree with debate). I have done a lot of work with a Canadian Aboriginal cultures (the politically correct Canadian term is First Nations) in north central British Columbia. One has given me a nickname: the Blonde Woman. It is said with liking. I am grateful for the name, it means people are willing to talk to me when I show up at their door; the name came with trust. What I find fascinating, however, is that it reflects the most visible feature by which I am defined as *non-Aboriginal*. I have never met a blonde Carrier native; my bloneness defines me as completely the outsider. By its measurement, I am most clearly not Aboriginal. That definition of who is and is not is important, even crucial to people. But the Band I work with does not make the usual

corollary mistake; they do not stereotype me as *the other*, and their focus on my bloneness reflects that too. It is the least important non-Aboriginal characteristic they could focus on. Instead they let me prove myself as an individual, good or bad, trustworthy or not. They do not stereotype me. It is not a courtesy we tend to return.

To talk about the “ecological” or “non-ecological” Aboriginal is to talk of stereotype. Part of the stereotype is to assume that all Aboriginal cultures or people are alike and can be characterized as part of that larger group. One bad (or non-ecological) Indian therefore manages to spoil the bunch. To be fair, we do this to other groups as well, one bad poor African American inner-city dweller casts a shadow on all, but this does not make it a good practice. If we wish to assess an Aboriginal group’s ecological goodness, we should assess only that group within its ecosystem, history, and circumstance. However, this glosses over a larger problem.

When we are assessing an “ecological Indian” status, we are doing what my Band does *not* do to me, blonde hair notwithstanding: we hold each Aboriginal group up against our concept of Indianness and, usually, judge them lacking. Even those disputing the ecological Indian concept are rebelling against an ingrained stereotype of the Aboriginal as nature child at home in the wilderness. Those images are as old as Christopher Columbus (Berkes, 1999; Berkhofer, 1979; Francis, 1992). There are two key problems with this stereotype. The first is that there is something like an essential Indian or Indianness. The second is the imposition of a thoroughly non-Aboriginal concept of ecological or “good” nature-human relationships.

Take the first problem identified: it is part of the problem I identified early in this article that we take for granted there is something that is an “Aboriginal.” I once sat in a university class taught by a Cherokee. After a discussion on blood quantum, a US government measurement of whether an individual could legally qualify as an American Indian, a student asked the professor “How much of an Indian are you?” It seems to me that we spend most of our time requiring

Aboriginal people always to be answering that question. We continually measure Aboriginal people or cultures by whether they meet our definition of Indian, whether blood quantum or environmental mysticism, lifestyle or economic choices, rather than allowing Aboriginals to be people, individuals, and members of a community. Our ecological Indian is a stereotype of our expectations of an Aboriginal person; they are not real humans with real human, situationally unique problems, opportunities, and choices.

The second problem is that when we allocate goodness as an assessment of ecological or environmentally correct behavior, it is based on a western definition of ecological or environmental goodness. As Allen and Deloria Jr, among others, point out this definition derives more from “the exalted romance of the sentimental ‘nature lovers’ [or] self-conscious ‘appreciation’ of the land” (Allen, 1979a, p. 192).

The non-Aboriginal concept of nature, and consequently good environmental behavior, is based upon a relationship that is largely separate from a day-to-day intimate interaction with that nature. It is something outside of our everyday lives, in the sense that when we think about nature it is not the bits of grass and single struggling trees along the sidewalks in our cities, or the squirrels and cockroaches that survive with us that we think about. We imagine *Sierra* magazine vistas, forests, steams, and charismatic wildlife which we may manage actually to experience once or twice a year at best. As a result of separateness, and of the ability to make a living that is removed from the land, nature becomes a sacred, remote concept. Nature is something we are deprived of, often yearn for, and do not understand or know as anything other than a desire. Worse, the undeniable ecological crisis of modern culture creates an image, a truthful image, of nature as fragile, threatened, in need of protection (although this does *not* mean most of us are willing to either change our lifestyle or voluntarily stay out of natural areas). So the day-to-day use of nature by many Natives is seen as unecological, particularly if such use includes making a living through exploiting resources through mining, trapping, logging, damming, or hunting whales. However, as Berkes

(1999, p. 154) notes, wilderness is a questionable ecological concept; there are few landscapes on earth that were not manipulated by human cultures. Aboriginal perceptions of nature still usually include an intimate understanding of making a living from that nature. Part of living means making a living, and we all make a living from the land. Some of us can hide that fact from ourselves better than others. If nothing else, an Aboriginal perception of nature and the human relation with nature is *honest*. But it does mean that it is often difficult to call Aboriginals environmentalists or even ecological, if by that we mean they did not live with, change, and use nature.

Using people to demonstrate a point often involves forgetting that the examples are flesh and blood. Beliefs do not translate perfectly into practice. And the definition of what *is* an ecologically sound practice has changed with the circumstances. Much depends on the natural context: population densities, existing ecological damage, and outside conditions. Today, there is disagreement over whether “traditional, real” Indians drive pickup trucks, snowmobiles, and powerboats and use assorted firearms to hunt. There are bitter disagreements over “traditional” harvests, for example, the Inuit harvest of the seriously endangered bowhead whale using modern mechanical killing devices.

Time also plays a factor, particularly when looking at Aboriginal practices. What was ecologically acceptable 600 years ago, such as stampeding herds of the incredibly numerous bison off cliffs, is not acceptable now when bison are endangered. A less dramatic example might be the hunting of eagles for ceremonial feathers, claws, etc. American Aboriginals are occasionally prosecuted under endangered species laws for these spiritually necessary practices. Yet while eagle populations are on the upswing, they are far from secure, as even Aboriginal peoples acknowledge. Who is the more “ecologically sound” citizen, the spiritually motivated Aboriginal person or the pragmatic US Fish and Wildlife Service officer who arrests them?

Finally, there is the question of which Indian you chose as a “model”: the safely dead “traditional” Indian or the living descendant. The dead

no longer have a voice to protest over how they are used. The living are facing very difficult questions on existence in the modern world. Environmentalists often seem to prefer the dead Indian; modern Aboriginal people too often make difficult partners. On some issues, Aboriginal communities have welcomed the help of resource-rich environmental organizations. On other issues, for example, oil and mineral developments on the southwestern or Alaskan reservations, Aboriginal tribes have been on opposite sides from environmentalists. Or consider the bitter divisions that resulted after Greenpeace successfully lobbied against the trade in harp sealskins. Many northern tribes lost much of their yearly income with the loss of the sealskin market, and they are angry in their condemnation of Greenpeace’s cultural insensitivity. A similar issue has erupted as animal rights activists are increasingly successful in making the wearing of fur “politically incorrect.” While some furbearers are ranch-raised, many are still trapped by northern Aboriginal communities who stand to lose a significant source of income. White middle-class environmentalists are often slow to recognize the imperative of feeding children on reservations with 60 % unemployment and chronic poverty. They also raise legitimate questions on the use of animals.

To conclude, there is no easy answer regarding this issue, academically. To the living, flesh and blood Aboriginal person, the debate is also academic, as they struggle to reconcile the invasiveness of western culture and their often fierce desire to hold on to older cultures, whether “ecological” or not, if only for their children and grandchildren’s sakes.

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Useful Websites

Turtle Island. <http://www.turtleisland.org>

Environment in Ancient India

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The most ancient scriptures in the world, the *Vēda* (derived from the Sanskrit root “*vid*” which means to know) are treasures of vast scientific knowledge. They contain several references on the weather cycle, rainfall phenomena, hydrologic cycle, environmental protection, ecological balance, and related subjects that indicate a high level of awareness possessed by the seers and people of that time. Hymns in the four Vedas, *R̥gvēda* (RV), *Yajurvēda* (YV), *Sāmavēda* (SV), and *Atharvavēda* (AV), reveal full cognizance of the undesirable effects of climate change; skew in the weather patterns, water pollution, distortion in ecological balance, and environmental degradation; and appropriately caution against them.

While describing and hailing the five gross basic elements of nature, water, fire (or energy), substratum (sky, space), air, and earth, of which all living and nonliving bodies are made up, the vast Vedic and post-Vedic Sanskrit literature presents in great details the theory of evolution of universe(s) and earth, the science of rainfall, climatology, meteorology, hydrology, environment, and water use and management, among many spheres of their enquiry.

The seers recognized that changes caused because of indiscreet human activities could result in abnormal behavioral patterns of seasons, rainfall, crops, or atmosphere and degrade the

quality of the water, air, and earth resources. The sages prayed to the deities responsible for maintaining the requisite balance in the functioning of all entities of nature. People realized that their conduct toward different objects of the universe had to be righteous so as not to disturb the cycles of nature and to be able to “rejoice in all the moods of Nature and experience the unseen divine glory manifested in various forms.” People were so aware, even in that ancient time, that in a hymn of *R̥gvēda*, a clear reference to the presence of a protective layer, which we know now as the ozone layer that filters the harmful ultraviolet rays of the sun and protects the earth, is seen.

Pañcamahābhūta as Creative Elements of the Universe

The whole material world is believed to have developed from five prototypical gross elements called *pañcamahābhūta* or *pañcatatva*. These are *Ṛthivī* (earth), *Āpa* or *Jala* (water), *Agni* or *Tēja* (fire, energy), *Vāyu* (air), and *Ākāśa* (ether, space). These five *bhūta*’s constitute the physical universe. A Vedic *mantra* “*Ṛthivyāpastējōvāyurākāśāt*” indicates the sequence of the initial appearance of the five basic gross elements (Sharma, 2007). Thus, first appeared space, from which appeared air, from that fire or energy, from which came the water, and then the earth. The hymns in the four Vedas were visualized and compiled by various enlightened sages or seers (*ṛṣi*) through an estimated time span from 6500 BC to 1500 BC. They covered various aspects of scientific truths regarding psychological matter (consciousness) pervading the physical matter (electrons) which is present in the whole material creation/universe in different forms and as “*kṛṣṇa raja*” (dark matter) in deeper space beyond. In unmanifested form, it is present as *agni* (fire) on the earth, in violent form as *Vāyu* (air), as a prominent driver in mid-sphere as *Indra* (deity of atmosphere), and in a dominating factor in celestial sphere in ionized or luminous form as *Sūrya* (sun) or galaxial clusters.

The seers of Vedic times were great visionaries who perceived the creation of the universe in a scientific manner and revealed the mysteries of cosmic evolution with profound wisdom and theories which were, perhaps, too advanced until a few years back for the world to understand (Sharma, 2009b). It is only now that with the advent of quantum mechanics and string theory propounded by physicists, the ancient theories revealed in the *Upaniṣad*'s can be revisited. The later Sanskrit scriptures also present scientifically the concepts of cosmology, rainfall, climatology, meteorology, hydrology, water management, and environmental protection in great detail. Those who have not had a right exposure to the knowledge contained in the four Vedas think that they are religious scriptures! The truth is far from this.

Various Philosophical Thoughts on the Gross Basic Elements of Nature

Several schools of philosophical thought like Buddhism, *Cārvāka*, *Sāṅkhya* (cosmology), *Yōga* (psychology), *N'yāya* (logic), *Vaiśeṣika* (physics), *Mīmāṃsā* (language), and *Vēdānta* (reality) have existed in India since ancient times. They perceive the cosmos and material objects closely (and rather differently in some cases) with their logic (Sharma, 2007).

The *Vēdānta* and the *Sāṅkhya Yōga* schools state that the material constituting the subtle elements (*tanmātrā*) is seen only in a transformed state in the gross elements of the earthly objects. The *Sāṅkhya* philosophy offers a framework for all the levels of manifestation, from the most subtle to the most obvious.

The *N'yāya-Vaiśeṣika* system defines substance as that in which qualities and actions are inherent. According to it, there are nine primary substances, the five *Mahābhūta*'s (ether/substratum, air, fire/radiation, water, and earth), time (*kāla*), space/direction (*dik*), inner self or spirit (*ātman*), and mind/internal sense organ (*mānasa*). The first five are called physical substances, and each of them has a peculiar quality as

mentioned earlier. There is a psychological sense with the physical sense organ, which is a part of the physical body. While we can perceive earth, water, and fire, the other two, air and ether, can be inferred from their qualities. Four of the primary substances (called *dravya*), *Ṛṭhivī*, *Jala*, *Teja*, and *Vāyu*, are divisible, and their elementary indivisible units are called *paramāṇu* or *kana* (quanta) (Sharma, 2007). These four *dravya*'s together with *ākāśa* (substratum, sky) constitute the five *bhūta*'s (gross elements).

The *Vaiśeṣika* system of philosophy presents the closest parallel to the chemical/physical approach to describing matter in its elementary and composite forms, the qualities (*guṇa*) of the fundamental quanta (*kana*), and the primary substance (*dravya*) of the universe. The inclusion of space and time corroborating modern cosmology and the use of the substratum/sky (*ākāśa*) as distinct from it are worth noting. Mind and the self are included in the *Vaiśeṣika* system whereby the world can become a perceivable entity.

"Aṣṭa Vasu" as Protective Forces of Nature

An ancient treatise, "*Śatapatha Brāhmaṇa*" (14.16), lists eight "sources" (or deities) of illumination and enlightenment as – "...*Agniśca ṛṭhivīca vāyuśca antarikṣaṃ cādityaśca dyauśca candramasca nakṣatrāṇi caitē vasavaḥ*." The *Aṣṭa Vasu*'s are *Agni* (fire, energy), *Ṛṭhivī* (earth), *Vāyu* (air), *antarikṣa* (space), *āditya* (sun), *Dyaus* (heaven, firmament), *candramas* (moon), and *nakṣatra* (constellations). Another scripture *Viṣṇu Purāṇa* mentions these, respectively, as *Āpas*, *dharā*, *anila*, *anala*, *dhruva* (pole star representing the space or ether dimension), *soma*, *pratyūṣa* (recurring dawn representing the sun), and *prabhāsa* (star light of the constellations). These are called "*Aṣṭa Vasu*'s." All these that include the gross basic elements also are nature's forces as well as lunar mansions, said to be protecting and sustaining us (Sharma, 2013). They are also considered the attendant deities of *Indra*.

Elements of *Prakṛti* (Matter) as Deities

The utmost reverence for the entities of nature saw its deification in ancient Indian culture where these were regarded as deities. All those forces that were facilitators of rain, like sun (also known as *āditya*) and wind, were prayed to as deities. A deity was also assigned to each of the main cosmic elements/phenomena. Thus, *Indra* is the god for water (and heaven), *Maruts* are considered gods of winds, and *Aryamā*, *Mitra*, *Varuṇa*, and *Soma* are the facilitators of water. *Aditi* means motherland, the planet earth, and the universe. Fire (*Agni*) was also regarded as a deity. In Vedic cosmology, the earth (*Pr̥thivī*) symbolizes the main supporting platform, and the upper sky or heaven (*Dyaus*) symbolizes the perennial source of energy and sustenance (Narayanan, 1995). These two together provide the environment (*paryāvaraṇa*) between them and constantly work to preserve it. Thus, while eulogizing the earth and heaven for their different attributes, the Rigvedic hymns vividly describe *dyāvā-pr̥thivī* (heaven and earth together) jointly as “full of water,” “decorated with ornaments of water,” “abundantly blessed with love of water,” or “conservator of waters” (Sharma, 2009b). In Atharvaveda also, the seers treat earth as mother, upper sky or heaven (*dyaus*) as father, and the atmosphere between them as brother and seek forgiveness for any inadvertent harm that may have been done to these “relatives”:

If atmosphere, earth, and sky and if father and mother we have injured, may this house-holder's Fire lead us from that to the world of their perfectly restored state. May mother earth, worshipped like Aditi, brother atmosphere save us from imprecation; may our father heaven be weal to us from paternal guilt; having approached my relatives, let me not fall down from their grace. (AV 6.120.1–2) (Joshi, 2002).

The verses wish for a clean and unharmed earth and an unpolluted environment to which no injury should be done. Particular reference to “paternal guilt” may be noted that indicates the seer's wish against harm even to the upper layers of atmosphere. In recent times, we have seen and heard of damage to the ozone layer high up in the

atmosphere that protects us from the harmful ultraviolet rays. Naming the dense enveloping layer as “*mahat ulbam*,” a prayer has been made to the concerned deities to alleviate any harm to the upper sky, *dyaus*, the father. The hymn says:

Great and very dense is the covering enveloped by which, Agni, you have entered into the waters. Agni! Jātavēda! one deity (Sun) has beheld all your manifold forms. (RV 10.51.1)

A seer of that time praises heaven and earth (*dyāvā-pr̥thivī*) by saying:

You are surrounded, Heaven and Earth, by water, you are the asylum for water; imbued with water, the augmenters of water, vast and manifold; you are the first propitiated in the sacrifice, the pious people pray to you for happiness, that the sacrifice may be celebrated. May Heaven and Earth, the effusers of water, the extractors of water, facilitators of the functions of water, divinities, promoters of sacrifice, bestowers of wealth, of renown, of food, of male posterity, combine together. (RV 6.70.4–5) (Arya and Joshi, 1997).

Another hymn says: *Your mother (earth) and father (celestial sphere) together make the world inhabitable. May the celestial sphere provide you with rains and other factors that promote life on earth* (YV 23.24) (Arya, 1999).

Preservation of Nature's Elements for Enhanced Quality of Life

The protection of environment in the Vedic period was understood to be closely related to the protection of heaven (atmosphere/firmament), earth, and other elements between them. Thus, the ancient sages prayed for maintaining the requisite balance in the functioning of all entities of nature – the mountains, lakes, heaven and earth, the forests, the waters in the firmament, and so on (Sharma, 2009a).

I invoke the vast and beautiful day and night, heaven and earth, Mitra and Varuṇa with Aryamā, Indra, the Maruta's, the mountains, the waters of the earth, the Āditya's, heaven and earth, and the waters of the firmament. (RV 10.36.1) (Arya and Joshi, 1997)

Hoping the seasons would maintain their cycle, the waters remain pure, and rains would

be in abundance and the actions of human beings pious, the seers aspired for a long life:

That pure eye (of the universe), beneficial of the gods, rises; may we behold it for a hundred years, may we live a hundred years. (RV 7.66.16)

In YV 36.24 also, the seers pray for a long and healthy life – “May we hear, may we speak, may we be independent, for a hundred years. . .”

The people of the ancient Indian culture tried not to harm any entity of nature so as not to disturb the ecological balance. They were taught to maintain harmony.

Ecological Balance: The Key to Blissful Living

Many of the modern concepts of taking a holistic approach to ecological balance are reflected in the ancient literature. Protection of rivers, lakes, and other water bodies, environment, ecology, as well as flora and fauna is their main message. It was well understood that wrong actions by individuals and society could harm the cycle of nature and its functions. The importance of preserving and conserving nature’s resources was an unwritten ethical prescription since the bounties of the seasons and bliss of nature were well recognized and prayed for (Sharma, 2005b). Here are some examples:

Rejoice in all the moods of Nature, experience the unseen divine glory manifested in various forms. Spring is the season of flowers and scented breeze which gladden the hearts; summer follows and has a beauty of its own. The rain with its dark clouds and dazzling flashes, bathes the entire earth with its splendour, autumn and winter too possess their peculiar charm and beauty. (SV) (Arya, 1996).

Maintain us in well-being in summer, winter, dew-time, spring, autumn, and rainy season. Grant us happiness in cattle and children. May we enjoy your unassailed protection. (AV) (Joshi, 2002).

We offer our reverence to Nature’s great bounties, to those who are old, and to the young, may we speak with the force at our command, the glory of all divine powers. May we not overlook any of them. (RV 1.27.13) (Arya and Joshi, 1997).

The winds bring sweet (beneficial) rewards to the sacrificer; the rivers bring sweet waters; may the herbs yield sweetness to us. May night and morn be sweet; may the region of the earth be full

of sweetness; may the protecting heaven be sweet to us. May vanaspati (vegetation and crops) be possessed of sweetness towards us; may the sun be imbued with sweetness; may the cattle be sweet to us. (RV 1.91.6–8) (Arya and Joshi, 1997).

Theories on Different Planes

The Vedic sages explored all aspects of science. The psychological, physiological, anthropological, metaphysical, and ethical aspects were covered as *ādhyātmika* (spiritual or relating to self or soul); astronomical aspects were dealt with under *ādhidaivika* (proceeding from the influence of atmosphere or plants); and geological, geographical, social, political, and economic aspects of study were described under *ādhibhautika* (relating to created beings or derived from primitive elements). All of these are terrestrial aspects. The Vedic visionaries visualized the laws of nature beyond time and space. The meteorological and atmospheric phenomena are described in detail in the ancient Indian scriptures which corroborate modern thinking.

Nurturing Mother Earth

Ṛṥhivī, the other basic element, was also revered for the enormous bounties it gave for the sustenance of life. In the olden times, earth was literally treated as mother. A hymn says, “*Mātā bhūmih putrōhaṃ ṛṥhivyāḥ*” (AV 12.1.12).

This hymn has a very deep meaning. It reminds us of our responsibility not only toward our motherland but also to the planet earth at large. The *mantra* refers to earth differently as “*bhūmī*” and “*ṛṥhivī*” and says that while my motherland is my mother, I am also the son of the planet earth. This is in the spirit of “*Vasudhaiva kuṭumbakam*,” the entire planet as a family. The people therefore said: “*Ṛṥhivīm mā hinsīḥ*” (YV 13.18), i.e., do not harm the earth (Sharma, 2009b). The hymn in Yajurveda also says – “*Antarikṣam mā hinsīḥ, māpō mauṣadhīḥ hinsīḥ*,” meaning “do not harm the atmosphere, do not harm the waters and do not harm the vegetation.”

The people vow in the following hymn not to overexploit earth's resources thereby injuring its "vital organs" and promise to replenish it in return:

Yat tē bhūmē vikhanāmi kṣipraṁ tadapi rōhatu
mā mē marma vimṛgvari mā tē hṛdayamarpipam.
(AV 12.1.35)

Keeping an eye on the need for the earth to remain healthy, the visionaries wished it well without a thorn so that the people would have a pleasant habitation and a blissful life by sharing its development for peaceful sustenance (YV 36.13). It was well understood that the well-being of mother earth depended on the preservation and sustenance of the environment and the upper layers of the atmosphere, sometimes addressed by the seers as "earth's heart" ("*Yasyā hṛdayam paramē vyōman*"). Only a healthy earth could spread its benevolence to the people, so the sages of Atharva Veda (AV 12.1.8) (Joshi, 2002) say:

The earth that was formerly water upon the ocean of space, which the wise seers explored and understood by their skills, whose heart is in the high sky, immortal, surrounded by truth, shall bestow upon us brilliance and strength and grant us supreme sovereignty

The seers offered their reverence to nature's great bounties and hail all the divine powers pledging not to violate their commands (RV 1.27.13).

Balancing the *Bhūta's* (Elements) for a Fulfilling Existence

The *yajña's* or sacrifices are not the killing of animals. The Vedic *mantras* and Brahmanic *yajña's* all signify parallelism between spirituality, astronomy, and physics. The *yajña's* helped not only in rainmaking but also in cleansing the environment by their disinfecting sacrificial fire and by destroying harmful disease-causing bacteria (AV 6.32.1) (Sharma, 2013).

Ancient Indian philosophy has always advocated a peaceful coexistence not only among human beings but also with every entity of nature.

People sought the blessing of the sun for their happiness, hoped every part of the earth would be prosperous, and wanted mountains, waters, and rivers to be propitious (RV 7.37.8). The importance of vital healing air, fresh unpolluted waters, and healthy flora on earth that the people wished for is clearly mentioned in the hymn of Yajurveda (11.39). The people wished the earth to be strong (YV 13.18). They also wanted no harm to be done to the waters as well as to the plants and crops (YV 6.22).

The sages were aware of undesirable actions by humans that could pollute the waters or harm nature's balance, whereby the waters could be unfit for drinking. The very thought of this unwise action propels them to ask for forgiveness:

Whatever the offence which we men commit, Varuṇa, against divine beings; whatever law of thine we may through ignorance violate, do not you divine Varuṇa, punish us on account of that iniquity. (RV 7.89.5)

The people of Vedic times did not hesitate to seek pardon of the deities of nature if inadvertently or ignorantly, their callous actions violated the laws (RV 7.89.5). The prayers asked for freedom from hunger for humans, for abundance of fresh water and food, a healthy atmosphere to live in, and for an overall prosperity by wishing winds to bring sweet rewards for the worshipper, the rivers to provide fresh and clean water, and the herbs to provide nourishing yields (RV 1.91.6; YV 13.27). The forests, all vegetation, herbs, biodiversity, crops, and the land were accepted as an important part of the ecology of the area, and therefore protection, preservation, and sustenance of these were sought in prayers (AV 20.141.8).

Climate Change and Vedic Thoughts

Because of industrialization, the increasing number of vehicles, and indiscreet human actions, it is estimated that the level of the two most significant greenhouse gases, carbon dioxide and methane, has increased to an extent that was never seen during the past 650,000 years, resulting in

a global temperature rise between 0.6 °C and 0.9 °C over the past century. Higher temperatures will lead to phenomena like more frequent droughts, change in weather patterns, more intense rainfalls, heat waves, and sea-level rise. The Vedic people took precaution against such eventualities, as has been shown in the previous hymns.

Climate change is a long-term significant change in the average weather, comprising a large number of factors such as average temperature, precipitation, wind patterns, and change in average state of the atmosphere that a region experiences. The broad causes of climate change include the dynamic processes on Earth (such as volcanoes, shifts, river meanders), external forces (such as solar-lunar inputs, solar flares), and anthropogenic factors, like human activity (such as land use, deforestation, emissions, agricultural practices).

The Vedas have several references on weather cycles, rainfall phenomena, hydrologic cycles, environmental protection, ecological balance, and related subjects that directly indicate the high level of awareness possessed by the seers and people of that time (Sharma, 2009a).

Solar flares occasionally change, affecting the temperature. Lunar outputs have an effect on the ocean tides. Scientists believe that a change in solar output of only 1 % per century would alter the Earth's average temperature by between 0.5 °C and 1.0 °C, as per climatic models. The ṛṣi's knowing the effect of solar flares or "flames of fire" emitted by sun wished *Aśvina*'s protection from any excessive intensity of sun's seven rays (RV 8.73.9).

The harmful ultraviolet rays coming from the sun are protected by the ozone layer in the sky. The ancient Indian seers were aware of the existence of such a protecting layer as they give a clear reference (mentioned earlier) to this by a prayer for *Agni* and *Jātavēda* (RV 10.51.1) who are represented by the sun for protection against any harmful rays. Reference is also available in *Rigveda* (RV 7.101.2) which depicts that the sun's intensity varies in different seasons and accordingly the solar flares also change. This is a remarkable observation. The rays of the sun are

said to be most powerful at dawn in the spring, at noon in the hot season, and in the afternoon in the autumn (Sharma, 2005a).

Ancient Indian ecological philosophy was so holistic that every entity was assuaged to quietude – the atmosphere, the earth, the waters, the crops, and the vegetation (YV 36.17 and AV 19.9.14). The seers recognized that any changes caused due to indiscreet human activities could result in malevolent behavioral patterns. Being conscious of this possibility, there are ample hymns and verses in the Vedic as well as post-Vedic Sanskrit literature, asking nature's entities to be benevolent to mankind.

Epilogue

Unfortunately today, the scientific community has no or very little appreciation of the Sanskrit language in which the Vedas exist, while the Sanskrit scholars do not have a science background. India's treasure of knowledge in the form of Vedas however needs to be revisited. The civilization paid greatest attention to maintaining a balance between the ecological entities and their related phenomena, so as to protect the environment. Water and the rivers were ordained to be treated with great respect to keep them pollution-free. We can appreciate how the old practices and theories of water management and ecological preservation of ancient India are more relevant today, after thousands of years.

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Ethnobotany

Richard Evans Schultes

There are numerous definitions of ethnobotany. The simplest is that it concerns the study of the uses of plants in societies. The term was first employed by John Harschberger in 1895. It was used narrowly in reference to the use of plants by aboriginal people. More recent authors believe that ethnobotany should consider not only the uses of plants but the entire range of relations between humans and plants.

Ethnobotany is a distinct field of research with a strongly interdisciplinary outlook. A number of subdivisions have developed, such as archaeoethnobotany (often called paleoethnobotany), ethnopharmacology, ethnoecology, and ethnomycology. There is even a possible subdivision which could be called “horticultural ethnobotany.” With this rapid proliferation of interests, ethnobotanists have widened the

definition to encompass the study of uses in aboriginal societies, native technological manipulation, classifications of the plants involved, indigenous nomenclature, agricultural systems, magicoreligious and mythological concepts connected with plant uses, and the general sociological importance of the flora in indigenous societies.

Ethnobotany itself is certainly not new. The earliest humans must have been incipient ethnobotanists. They must have classified plants in their surroundings – those of little or no utility, those which were useful in many practical ways, those which alleviated pain or otherwise ameliorated illness and those that caused illness or even killed outright. They must have wondered at the unwieldy effects of the few hallucinogenic or psychoactive species, and they could explain their extraordinary properties by assuming that they were endowed with spiritual power from supernatural forces.

It was not long before the knowledge and manipulation of the properties of plants became associated mainly with certain individuals, and the early medicine men or shamans ultimately acquired great powers over many aspects of the life and beliefs of the general population. Members of the general population, often especially women, were likewise conversant with the properties and uses of their food, medicinal, and other economic plants of daily use. Many peoples around the world are very knowledgeable about their ambient vegetation as a result of inherited knowledge, the result of hundreds of years of experimentation.

Modern ethnobotany can be of great value to many fields. Human health, new and better medicinally valuable phytochemicals, the domestication of new crop plants for food and industrial purposes, better understanding and use of plant biodiversity, and general environmental conservation – all might well reap significant advantages from proliferation of ethnobotanical investigations.

The world’s flora, estimated to contain some half million species of flowering plants, have been analyzed with modern chemical techniques

only on a limited scale. Tropical rain forests, which contain a greater part of the world's plant species, have been the least chemically studied even though they are extremely rich laboratories. The Amazon Valley, for example, has an estimated population of 80,000 species of angiosperms. When this wealth of species in other rain forest areas of the world is considered the opportunities for great advances in our knowledge of phytochemistry are obvious. If we consider only alkaloids, for example, the increase in our knowledge is significant. In 1950 we were aware of 2,000; in 1970 the number had increased to 4,000, and in 1990 it had reached 10,000.

If enough material of 80,000 species must be collected for chemists from such a difficult and extensive area for travel, transportation, and availability of resources, it is obvious that the task can never be completed, especially by random collecting. Ethnobotany can be a significant help.

More and more tribal peoples are succumbing to acculturation or westernization as a result of road and airport building, dam construction, increased missionary pressure, heightened tourism, or disruption from their centuries-old dwelling sites. In many areas of the great native Amazon Basin knowledge is disappearing even faster than the forests. When an Indian can get from a missionary, tourist, or commercial agent our effective and easily used drugs, this native knowledge disappears rapidly. Of the numerous subdivisions of the field of ethnobotany, none is more important than ethnopharmacology – the search for new medically valuable plants.

In the small area of the northwestern Amazonia (Colombia, Ecuador, and a small part of western Brazil), more than 1,600 species of biodynamic plants used by the Indians as medicines are considered to be an adjunct of routine cures by medicine men, or poisons (as in the manufacture of curare or arrow poisons). If chemists concentrate on those plants which Indian use has demonstrated to be in some way bioactive, understanding of the chemistry of the flora of the region can be accomplished more efficiently.

Another example of the value of ethnobotanical research lies in the Indians' familiarity with minor variations in plant species. This may be of great help in one phase of the study of biodiversity. One of the enigmas that botanists and other specialists have not had much success in understanding concerns the native's easy recognition of varieties of many of the plant species of their forests. These variants are so well established in the Indians' classifications that they usually have distinct names, in spite of the botanists' inability to see any distinguishing morphological characteristics. This skill is manifest not only in the few cultivated economic plants but also in their classification of many wild plants of no utilitarian, ceremonial, magical, or mythological importance. The Indians can usually tell at once and frequently on sight and often at a significant distance, without feeding, tasting, smelling, crushing, tearing, or other physical manipulation, to which category a plant belongs. While it is of interest to the anthropologist and psychologist, it is of extremely practical importance to chemists and botanists.

Yoco (*Paullinia yoco*, Sapindaceae) is a gigantic liana from the bark of which numerous tribes of the Colombian Amazonia prepare a very strong stimulating drink taken in the early morning before eating solids. The drink has 3 % caffeine. There are native names for at least 13 of these lianas. While several give a creamy white drink, others a slightly reddish brown product, there are no discernable morphological differences in them. Often several of the named "kinds" grow in relatively close proximity, so it cannot be due to ecological differences. Nor is it due to different parts of the liana.

Another example is ayahuasca or caapi (*Banisteriopsis caapi*, Malpighiaceae), a forest liana the bark of which is the source of an interesting vision-producing hallucinogenic drink employed widely by many tribes in the western Amazonia. Since the source plant was identified and botanically described as a species new to science in 1853 by the British plant explorer and ethnobotanist, Richard Spruce, many specialists and amateurs have written about it. We are

certain now that one species of *Banisteriopsis* is used. There is now no doubt also that Indians can visually identify at a distance different “kinds” of the *caapi* liana. There is a long list of these variants, and the natives maintain that they are employed to prepare drinks of different strengths or in connection with various ceremonies or dances because of longer or shorter intoxications or because of special magicoreligious needs. There is one of the named variants from which a drink may be prepared according to the kind of animals the hunter wants to find and kill.

Could the ability of the Indian to recognize various types of *B. caapi*, often at a distance, be due to slight differences in the bark of the liana, presumed chemical diversity (which could not be seen), variation in leaf shape, ecological factors (growing in dense or open forests), or other dissimilarities? None of these can be considered logical explanations of the uncanny ability consistently to identify the named type of the liana. It remains an enigma which deserves further study.

Whatever the explanation of this perspicacity, specimens of 18 “kinds” of the ayahuasca vine were collected by Dr. E. Jean Langdon, an anthropologist who worked amongst the Siona in the Colombian Amazonia. They were submitted for botanical identification by a botanical specialist, Dr. Timothy Plowman, and almost all were referred to the single species, *B. caapi*. As Dr. Langdon states: “Further exploration between the conjunction of botany-chemistry-culture warrants further investigation.”

This example of the unexplored horizon awaiting scientific investigation is typical of many other unexplained examples of the wealth of aboriginal concepts of natural phenomena awaiting technical solution around the world.

Ethnobotany, if intensified, can contribute extraordinarily to many fields of modern science, technology, and sociology, but time is of the essence in view of the worldwide uncontrolled acculturation of indigenous societies. As Prince Philip, former president of World Wildlife Fund, has pointed out: “The tropical forests and their traditional inhabitants are under very severe pressure from human encroachment, and it is sadly

inevitable that many of these plant species and the tribes which understand their use are rapidly disappearing forever.”

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Ethnobotany in China

Georges Métailié

Ethnobotany is the study of the links that human beings, as individuals or societies, have maintained and maintain with plants. China is a country with more than 50 different national minorities, with very different traditional cultures, languages, food habits, etc. Chinese ethnobotany could thus be the juxtaposition of the different ethnobotanies of all the ethnic groups living in China. On the other hand, one generally understands “Han” when one says “Chinese.” This term, which is the name of the second dynasty after unification of the empire (206 BCE–AD 220) is also the name of the main ethnic group in China, with about 96 % of the population. It is the ethnobotany of the Han Chinese that we are going to present here.

With 3,692,000 mile², China is about the same size as the United States. Its relief can be roughly compared to stairs going down from the western plateaux to the plains of the east and the south. Its climate is under the double influence of a huge continental mass and the strong impact of the summer monsoon: generally the winters are cold to very cold – except for the extreme south-east – and dry. The summers are very warm with high rainfall and moisture. The diversity of climates and reliefs has probably favored a particular richness in vegetation. With about 25,000 species of higher plants, 2,600 species of ferns, 2,100 species of mosses and liverworts, and some 5,000 species of fungi, China has the third richest flora of the world after Malaya and Brazil.

In Chinese mythical history, the beginning of the relation between man and plants is so strong that it is considered the first step into “civilization.” Speaking of Shennong, the Divine farmer, one of the three mythical emperor creators of the Chinese civilization, one says that “before him, men did not know cereal grains, they ate animals and drank their blood. Then Shennong tasted the

herbs, sorted cereals, and taught the art of tilling to the people. Then he tasted herbs again and sorted simples to save the people from illness.” Eventually, the Yellow Emperor, successor of Shennong, taught cooking and medicinal prescriptions. In the Chinese tradition, the access of mankind to civilization was achieved when man became a tiller and a gatherer; agriculture supplied what was needed for basic food, and gathering gave access to the complementary plants, medicinal, and pot herbs. Actually, the local biodiversity appears to have been rather well appreciated and exploited all through Chinese history, because China is one of the main centers of domestication of plants and possesses a very rich *materia medica*. The local richness did not prevent a great interest in plant introduction. However, introduced plants, like corn, sweet potato, tomato, and potato, have been used mainly as complementary food and never caused any fundamental change in food habits, as happened in Europe, for instance, with American plants. Among the 116 botanical species cultivated as vegetables today in China, at least 37 would have been locally domesticated. Also, considering the cultivars – which are the form under which these species are cultivated – their number amounts to several thousands. As for trees and shrubs, more than 300 species are exploited today – even if they are not all cultivated – for their fruits, eaten fresh or, more frequently, after transformation or preparation.

There is a traditional opposition between crops cultivated on dry lands – millets, wheat, barley, sorghum – in Central and Northern China, and rice and various tubers cultivated in irrigated fields of the south. Nowadays, thanks to agricultural hydraulic development, rice is also cultivated in northern parts of the country, where climatic conditions permit it. On the other hand, corn, following irrigation development, replaced traditional millet crops. The ordinary diet consists of large amounts of a basic food, called *fan*, made from steamed or boiled grains, such as rice, millet, or sorghum, or various kinds of noodles made from wheat, pulses, rice, etc. It is

accompanied by *cai* (dishes), generally made from vegetables and soya bean in the form of *tofu*. Among these dishes, fish or meat, important for special occasions, are still not very frequent in everyday life, especially in the countryside.

As for clothing, even if today synthetic fibers, wool and silk have become more and more important, in the sixties, in mainland China, cotton was the only material used for common suits and even shoes. In the countryside, some work clothes, sun hats, and raincoats are still frequently made of ► bamboo or palm leaves. They combine several advantages: since they are not heavy, they provide good shelter and allow the air to circulate freely. The use of wood for buildings is entirely limited by the resources of the environment: it is a wooden framework which bears the roof of the traditional standard Chinese house, the nonweight-bearing walls being made of brick or tamped earth. However, from its shoots eaten as a delicacy, to the chopsticks used to eat, from the scaffolding, drill-hafts and brine conduits of the salt-fields in Sichuan to irrigation flumes, and from ordinary furniture to the most exquisite pieces of wickerwork, bamboo is probably the member of the vegetable kingdom which plays the most important part in the material life of the Chinese.

Traditional Chinese medicine uses as *materia medica* some 4,773 products of plant origin, 740 of animal origin, and 82 minerals.

Chinese people are also very interested in the beauty of plants. Varieties of some 12 ornamentals are particularly valued: tree-peony (*Paeonia suffruticosa* Andr.), Japanese apricot (*Prunus mume* Sieb. et Zucc.), hybrid roses, camellias, rhododendrons, Wintersweet (*Chimonanthus praecox* Link.), Chrysanthemums [*Dendranthema morifolium* (Ramat.) Tzvel.], orchids (*Cymbidium* sp.), daffodils (*Narcissus tazetta* var. *chinensis* Roem.), hybrid gladioli, pinks (*Dianthus caryophyllus* L.) and Indian lotus (*Nelumbo nucifera* Gaertn.). Besides a great number of other “traditional” ornamentals like bamboos or cockscombs (*Celosia argentea cristata*), new varieties appear frequently.

Grafted succulents became very popular and, more recently, Kaffir lilies (*Clivia* sp.). Just for the pleasure of watching new flowers or to be photographed in front of a blossoming magnolia or plum, crowds of people will visit public parks in the spring, while in autumn it would be unthinkable not to go and admire the red leaves of maples in the nearby hills of the city of Nan-king, for instance.

Plants obviously play a very important part in the life of the Chinese people, but one may wonder whether there is any particular kind of relation which would define a “Chinese ethnobotany.” A first striking point, which can be well appreciated in agriculture and horticulture, is the closeness of the human-to-plant relation. This is obvious with a crop like rice where, after the nursery stage, every seedling in the paddy is transplanted to the field where it will ripen. Propagating other plants like yams or taros also necessitates the individual handling of every cutting. The sowing of all the plants cultivated in gardens, like cucurbits and beans, is individual, and even for crop plants like millets or wheat it is remarkable that a sowing machine allowing seed by seed control has existed at least since the thirteenth century. Grafting seems to have begun during the first centuries AD but it became very important in horticulture as early as the sixth century and was much used for fruit and flower production. Professional horticulturists have used grafting since the Song dynasty (960–1279) when it was believed it could create new varieties of flowers (tree-peonies and chrysanthemums) for amateurs who would pay fortunes just to watch the most beautiful. Another example of individual treatment of a plant is the technique of tree-potting (*penzai*, *bonsai* in Japanese): to keep the tree in small proportions, it is necessary to prune its branches and roots every year and to look after it day after day.

In ancient China, scholars also developed a very exclusive relation with plants. They would rank them from the most precious to the lowest. Following their personal taste, men of letters would develop real “friendships” with the ones

they appreciated most and which would live in their studios, along with “the books and the cithar (zither).” Joseph Needham and Li Hui-Lin have shown that this interest in special plants led to various monographs on them. Plants have also been a favorite theme for literature and poetry. Since the thirteenth century several encyclopedic books have been composed entirely with quotations from texts dealing with plants. One famous book, published in 1231, *Portraits of the Plumflower*, is devoted only to the Japanese apricot (*Prunus mume* Sieb. et Zucc.). The author, Sun Boren, through a hundred ink drawings, each accompanied by a poem, evokes the feelings that he experienced watching the flower, from its bud stage to the fall of the last petal. Actually, in the painting of flowers, Chinese artists were more concerned with emotion than representation. Using a brush and black ink, they were looking for the essence, more than for the true form of, bamboos, pine trees, orchids, or plum-flowers. Zou Yigui (1696–1772), a famous painter, criticized the Western paintings he had seen at the imperial court as being too realistic, and he considered their authors not painters, although they possessed skill, but simple artisans.

In ancient China, plants as medicine were not distinct from minerals or animals and belonged to a system of classification where the whole *materia medica* was separated into three ranks, *san pin*, for nonpoisonous products, good for the health and used to “nourish life,” to very active products, generally highly toxic and used only under very strict conditions. During the sixth century, ► [Tao Hongjing](#), a famous physician, developed this classification: within each of the three grades, plants were subdivided into herbs, trees, grains, potherbs, and fruits. At the end of the sixteenth century, another physician, ► [Li Shizhen](#) (1518–1593) in a famous book called *Bencao gangmu* (Classified Pharmacopoeia, 1596), changed the basis of this classification. Considering almost obsolete the three ranks system, he reorganized the whole *materia medica* “from the lowest to the most precious,” from minerals to man. He kept the five categories

mentioned above for plants but in a new order – herbs, grains, vegetables, fruits, and trees – and divided those into 33 subgroups following various criteria like ecology, taste, and toxicity. Besides this learned system, created and used by physician-scholars, there was a folk taxonomy not exclusive from the previous classification, where the ethnobotanical data were distributed into six ranks. Following Brent Berlin's vocabulary, they are:

- *Kingdom* marked by two words meaning plant, *caomu* (herb tree) and *zhiwu* (planted thing);
- *Life-form* with three main taxa, *cao* (herb), *mu* (tree) and *teng* (vine) and the ambiguous statute of *chu* (bamboo) “neither herb nor tree”;
- *Intermediate* where groups are named by juxtaposition of terms used for taxa of generic rank, like *tao-li* (peach-prune), *song-bai* (pine-cypress);
- *Generic* marked by monosyllabic terms like *tao* (peach), *xing* (apricot), *zao* (jujub);
- *Specific* where one finds some of the monosyllabic terms also used for generic taxa but with a narrower meaning like *xing* (apricot: *Prunus armeniaca* L.). However, terms of this rank are generally polysyllabic. They may be *secondary plant names*, lexical extensions on the basis of a generic term, like *yinxing* (silver apricot: *Ginkgo biloba* L.), or *jiazhutao* (narrow bamboo peach: oleander, *Nerium odoratum* Soland.). They may also be *primary plant names* like *Lu meiren* (the beautiful lady of Lu: poppy, *Papaver rhoeas* L.), *mudan* (male cinnabar: tree peony, *Paeonia suffruticosa* Andr.);
- *Varietal* a system, already described in the first encyclopedia *Erya* (third-second centuries BCE) is still effective today.

The long tradition of observation, culture, and use of plants along with a fair knowledge of plant life never led to a systematic approach. Among the rich literature about plants one cannot find anything like a primer of botany. Up to the middle of the nineteenth century, plants, in China,

were considered in their cultural environment. Besides horticulture, agriculture, or art, concern with plants was philological: considering plant names with obscure meanings occurring in ancient texts, literati would try to find which plants would fit these names. To do so, they compared textual evidence or interpretation with the results of inquiries they made among their contemporary countrymen. Chinese traditional scholars' plant knowledge can be described as cultural botany.

See Also

- [Agriculture in China](#)
- [Bamboo](#)
- [Food Technology in China](#)
- [Li Shizhen](#)

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Ethnobotany in Ethiopia

M. Mesfin Tadesse

Ethiopia is located in the horn of Africa between 3°N and 15°N latitude and 33°E and 48°E longitude. Generally the central parts of the country are mountainous with the highest mountain peak, i.e., 4,620 m, being at Ras Dejen (Ras Daschen) in the Semien Mountains. The coastal areas are low-lying plains. An area in the northeastern part of the country called the Afar depression is about 115 m below sea level.

Botany

The beginning of an organized study of the plant resources of Ethiopia can be traced to about 1,850 when Achille Richard (1847–1851) described the first flora of the country. *Tentamen Florae Abyssinicae* consists of descriptions of about 1,700 species of plants from particularly the northern parts of the country. This was followed, a 100 years later, by the work of Cufodontis (1952–1972), *Enumeratio Plantarum Aethiopiae Spermatophyta*. Almost 20 years after the completion of this checklist, the *Flora of Ethiopia* and later on the *Flora of Ethiopia and Eritrea* was started. This is still in progress although most of the volumes have been published (Edwards, Tadesse, & Hedberg, 1995; Edwards, Demissew, & Hedberg, 1997; Edwards, Tadesse, Demissew, & Hedberg, 2000; Hedberg & Edwards, 1989, 1995; Hedberg, Edwards, & Nemomissa, 2003). What was and is being attempted in the above-cited publications is the documentation of the higher plants of Ethiopia and Eritrea, with the *Enumeratio* also providing information on plants found in Somalia.

Ethnobotany

The focus of this article is not on the total plant life of Ethiopia but only on the cultivated plants,

i.e., the domesticated, wild and semi-wild food and medicinal plants. This usually falls under the umbrella of agronomy in agriculture and ethnobotany in plant biology. In order to understand the origin of ethnobotany in Ethiopia more completely, one has to look into the beginnings of agriculture. This, however, is a broad subject and will not be attempted here. (Ed. note: see Alexia Smith's article on Ancient Methods of Agriculture in this volume.)

Cultivation and domestication of plants have taken place in a number of spots in the world. Although naturalists like Darwin (1868) and De Candolle (1882) had written about cultivated plants, the first person to provide extensive documentation was the Russian scientist, Vavilov (1935), between 1926 and 1937. Vavilov considered the Ethiopian highlands as one of the eight centers of origin of cultivated plants with the major plants being Abyssinian hard wheat, poulard wheat, emmer, Polish wheat, barley, grain sorghum, pearl millet, African millet, cowpea, flax, sesame, castor bean, garden cress, coffee, okra, myrrh, teff, pea, and indigo.

In an overview of the origin of agriculture, Harlan (1998) wrote:

From our review of the agricultures of the world, they seem to be centered on the Near East, Ethiopia, sub-Saharan Africa, China, Mesoamerica, highland South America, and lowland South America. Each has its own suite of cultivated plants. People associated with them, their cultures and religions, are closely intertwined with the main crops they grow. This appears to be the pattern on a global scale.

This view does not differ very much from the patterns described by Vavilov. A little bit has been added here and there but the overall conclusions are very similar.

It is believed that the first cultivated plants were selected from wild plants for their desired values and then domesticated (i.e., manipulated for purposes of mass production, a process of selective breeding). Domesticated plants are often associated with humans and do not occur in the wild, e.g., maize, tobacco, soybeans; others are still found as wild or semiwild plants, e.g., coffee, niger seed (noug), etc. Here I will select

only five of these plants from Ethiopia to illustrate their use and how some of them spread to other countries. Further reading material is also provided after the references.

***Coffea arabica* L.: Rubiaceae (Bunna in Amharic)**

The southwestern Ethiopian highlands (in Illubabor and Keffa) are believed to be the centers of proliferation and probably also of origin of *C. arabica* (Ferne, 1966; Meyer, 1965a, 1965b, 1969; Richard, 1847–1851). As early as 1848, Richard considered arabica coffee as spontaneous in forests in Ennarya and Keffa and introduced elsewhere in Ethiopia. Other contenders of origin are the Boma Plateau in adjacent southern Sudan (Thomas, 1944), Mt. Marsabit in Kenya and the highlands of Yemen. From all the available evidence and from theories regarding the place of origin of plant and animal species, it is believed that arabica coffee originated within the confines of present-day Ethiopia in general and the Keffa-Illubabor region in particular and then it was taken first to Yemen.

The coffee seeds or seedlings that were taken from the Ethiopian highlands were planted in the irrigated fields and terraces in Yemen (Old Arabia Felix). It appears that Yemen had been the only supplier of cultivable coffee to the world, and the Netherlands the first European country to acquire the first planting material from Aden in 1690. But it is also known that earlier on, in 1616, a coffee plant was taken to Holland from Mocha (Haarer, 1962). The Dutch started planting coffee in Sri Lanka (formerly Ceylon) in 1658. Wellman (1961) wrote that the Portuguese had also introduced coffee into Sri Lanka before 1600. Wrigley (1988, p. 39) indicated that “Baba Budan, a Muslim saint,” is believed to have taken a few seeds (seven according to Wellman) into India (Malabar) around 1600. Plants were shipped from Malabar to Java in 1696. These supplied the first commercially grown beans to Europe. In 1706, a coffee plant was sent to the Amsterdam Botanical Garden from Java and seeds and seedlings that were produced from this single

introduction were distributed to the major botanical gardens in Europe (Haarer) and South America.

How did the drinking of coffee spread? This aspect is closely related to the brewing of coffee but as there are conflicting views on where the brewing started, it is also assumed that there will be similar hypotheses about the spread of coffee drinking. May be it is best to start with how coffee was utilized at first.

From a questionnaire survey made in 1989–1990 by the author in many coffee growing areas in Ethiopia, it appears that the earliest use of coffee in Ethiopia was in the form of small balls from roasted ground beans. These were then mixed with butter and kept in the mouth, between the cheek and the jaw, while making long journeys. While at home or in the vicinity of home, roasted coffee beans that were dipped in butter were chewed. This practice goes together with other rituals such as thanksgiving, celebrating the birth of a new child, etc., in this part of Ethiopia even to the present day. It also appears that this habit did not cross the borders of present-day Ethiopia. Similar modes of use have been reported for other species of plants, e.g., the early use of coca (*Erythroxylon coca*) in the Andes of South America (Brucher, 1989, p. 175; Simpson and Ogorzaly, 1986, pp. 363–364).

Genetically, *C. arabica* is tetraploid, meaning that it has four times the original (haploid) number of chromosomes. It is believed to have originated by polyploidy, a process of speciation by doubling chromosomes, from a diploid ancestor. However, up to now no diploid plant has been found in the wild and the parents that might have given rise to it are assumed to have become extinct.

***Brucea antidysenterica* J. F. Mill: Simaroubaceae (Waginos in Geez, or Yedega Abalo in Amharic)**

The root barks of this plant have been used since a long time ago in northern Ethiopia to treat dysentery. Today, there is a lot of useful information on the medicinal value of this species. Antitumor

chemicals and cytotoxic antileukemic alkaloids have been isolated from it (Fukamiya et al., 1986).

There is an interesting story about how this species became popular. According to Pankhurst (1982) a Scottish traveler called James Bruce who stayed in Ethiopia from 1769 to 1771 was attacked by dysentery when he was about to leave Ethiopia. He tried to cure himself with the help of the medicines he had brought along from Europe but was not successful. When observing that he would not be able to make it to Europe traveling through the hot landmass of Sudan and Egypt, the Chief of Ganjar of Shanquilla informed him to take a well-established local drug known as *Waginos* (Geez name, the root of the current Amharic and Tigrigna languages of Ethiopia) or *Yedega Abalo* (name in Amharic, the official language of Ethiopia). The root bark of this plant was cleaned, dried in the sun, and ground into powder. James Bruce was then made to take two spoonfuls of the powder with camel's milk. After the sixth or seventh day, Bruce regained his health and was able to continue his journey to England. On his way back, he took some of the powder and fruits of *Waginos*. He used the powder whenever he or his companions fell sick on the way. The fruits were delivered to a botanist at the British Museum of Natural History called Daniel Solander, who, noting that it represented a species not known in Europe then had it planted in several British gardens. The plant was later named by Miller *Brucea antidysenterica* to commemorate James Bruce with the specific epithet indicating the medicinal property of the plant (More information on the chemical constituents of *Brucea antidysenterica* may be obtained from the *Journal of Natural Products*, e.g., Fukamiya et al. (1986) and Imamura et al. (1995); *Current Medicinal Chemistry*, e.g., Jung et al. (2000), and medicinal databases).

***Hagenia abyssinica* (Bruce) J. F. Gmel:
Rosaceae (Kosso in Amharic)**

This is a large tree with smooth flaking bark known from Ethiopia, Kenya, and Uganda. The plant produces male and female flowers on separate clusters. The female flowers, known as

Kosso, are used in eliminating tapeworm from human intestines. First the flowers are sun dried and an infusion of half an ounce is prepared in a glass of water. This should be drunk early in the morning before breakfast. The patient is not allowed to take food during the day, and, if the bowel movement is not free during that day, a physic should be taken at night.

Here there is also an interesting story on how the plant was introduced into the international world of medicine as an age-old tested medication. According to Pankhurst (1975), "the first foreign medical man to interest himself in Kosso" was a French physician called Dr A. Brayer around 1816. Brayer's first acquaintance with Kosso was from a contact he had with an old Armenian merchant called Karabet in Constantinople (now Istanbul) who told him that the "...Ethiopians cured themselves with the aid of the flowers of a plant which...was known by the word which also signified the taenia itself." The plant was then called *Brayera anthelmintica* Kunth to commemorate the physician, Dr Brayer, and also to indicate its anthelmintic (antiworm) properties. Today, the chemistry is well known and the active compounds are Brayerin (a bitter, acrid resin), volatile oil, and tannin.

Since *B. anthelmintica* described by Kunth in 1824 is preceded by *Banksia* (*Bankesia*) *abyssinica* described by Bruce in 1790, the first name applied to the Kosso plant, today we use the later specific epithet transferred from *Banksia* to *Hagenia* (1791) following the International Code of Botanical Nomenclature. The genus name *Banksia* was published in 1781 by the son of Carolus Linnaeus (often called the father of botany) for an entirely different plant and thus could not be used in conjunction with the specific epithet of the Kosso plant. Hence, the next available genus name in the *Rosaceae* is *Hagenia*.

***Guizotia abyssinica* (L. F.) Cass.:
Asteraceae (Noug in Amharic)**

This is an annual herb that usually grows between 50 and 100 cm, but it may grow up to 2 m. It produces small yellow flowers at the apices of

branches and stems. The marginal flowers are 6–8 in number (rarely up to 15) and strap-shaped, while the central flowers are numerous and tubular. It is from these centrally located flowers that the oil-producing fruits are obtained. The fruits are black, a few millimeters long, up to 1-mm wide and without hair when fully mature. Six out of the seven species in the genus (Mesfin Tadesse, 2004) are found in Ethiopia; it is assumed that the genus originated in Ethiopia.

Noug has been domesticated in Ethiopia for a long time. The oil is used in cooking and as a source of candlelight. The cake is used as part of animal fodder. The plant was introduced in India, where it is also grown as an oilseed crop plant, and in other countries. In Australia, it has been found growing around overseas shipping containers areas. In the United States (Wisconsin), the Winnebago Company introduced it as wild bird seed, and in Ohio (Butler County), it was found as a weed in flower beds, near where bird feeders had been over the preceding winter. In Ethiopia, it is grown as an oilseed crop on a rotational basis with cereals and pulses. “It constitutes about 50 % of Ethiopian and 3 % of Indian oilseed production” (Getnet & Sharma, 1996). Today it is reported as being used in paint and soap production as well.

James Bruce was the first person to take the fruits of *Guizotia abyssinica* to Europe. The earliest name applied to plants grown from these fruits in gardens in Paris was *Verbesina oleifera* by Buchoz in 1775, probably as part of a polynomial (cf. Baagoe, 1974, p. 3). Consequently this name is invalid, but it indicated the property of the plant as used then and now. A plant cultivated in Sweden from among the fruits supplied by James Bruce formed the basis for the first valid name applied to this oil-bearing plant, i.e., *Polymnia abyssinica* L. f. (1781). For a thorough analysis on how the present name was adopted, the reader is referred to the works of Baagoe.

***Eragrostis tef* (Zucc.) Trot.: Poaceae (Teff in Amharic)**

This is one of the economically most important members of the grass family in Ethiopia. It is an

annual plant widely cultivated in Ethiopia as a staple cereal crop, but it also occurs as an escape from cultivation. It is easily recognized by “its panicle of oblong, nonshattering spikelets full of plump grains retained within the swollen florets” (Phillips, 1995). A large number of cultivars have been recognized based on the color of the grains with the major types being white, red, or black.

The genus *Eragrostis* consists of about 350 species (Phillips, 1995). *Eragrostis tef* is an allotetraploid ($2n = 4x = 40$) and its origin is as yet unknown although it is closely related both morphologically and genetically to the widespread and weedy *Eragrostis pilosa* (Ingram & Doyle, 2003).

The grains of *Eragrostis tef* are finely ground or milled and Ethiopians prepare thin and flat pancake- or chappati-like “bread” called *injera* or *yetef injera* from the flour. Injera is utilized throughout highland Ethiopia and currently also it is being utilized in certain low-lying parts of the country, e.g., among the Somali population in eastern Ethiopia. Outside of Ethiopia, the Borana people (Oromo ethnic group) of northern Kenya use the grains as a staple food.

The chaff is also used mixed with clay in the construction of wall material for mud houses in Ethiopia. It is also used as feed for domestic animals. Thus no part of this plant is wasted. This latter use of the plant has recently gained ground in other countries. Teff is now widely grown in South Africa and Australia for hay production and in India as a green fodder. It is also grown as a health food product and as forage for livestock in South Dakota and Montana (Stallknecht, Gilbertson, & Eckhoff, 1993) in the USA. The immigrant Ethiopian community in the USA also utilizes the grains of plants mostly cultivated in Idaho in the preparation of injera.

The specific epithet *tef* is taken from the Amharic vernacular name Teff. The first cultivated teff plant in Europe was in the botanical gardens at Firenze (Florence) in Italy from grains collected by James Bruce in Ethiopia. It was subsequently named *Eragrostis tef* by Zuccagni in 1775. A large number of studies have been published on the biology and chemistry of

Eragrostis tef (Ingram & Doyle, 2003; Ketema, 1997; Bekele et al., 1995 (as Bekele, Endashaw in ref.), as examples).

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Ethnobotany in India

N. C. Shah

Ethnobotany is the use of plants in material or abstract form among ethnic communities or tribal people. Sometimes, it is regarded as ethnographical or anthropological or tribal botany. India is a vast country with a variety of topographies, climates, vegetation, and people. When discussing ethnobotany in India, we can consider two groups of people, those living in small cities or rural villages and tribal peoples who live in remote villages. India has a population of 102 million, out of which about 50 million people belong to 550 tribal communities. There are 325 total

languages with a large number of dialects spoken within the country, of which 18 are official including English, Sanskrit, and Urdu.

Ethnobotany is a combination of ethnography and botany. Ethnographers describe the people of a region including their race, language, and their uses of plants:

- Food and its methods of preparations
- Medicine
- Extraction of fatty oils
- Edibles and non-edibles
- Condiments and spices
- Seasoning material for food
- Drinks and beverages
- Incense
- Household furniture
- Agricultural tools
- Utensils

In abstract form plants can be used in socio-religious and socio-cultural ceremonies, in worship, songs, sayings, similes, riddles, proverbs, and in mythology.

In the study of ethnobotany, native or regional names are collected with their phonetically correct pronunciation known as *transcription*. The native or cultural names are deciphered, etymologically and philologically with the help of local guides or linguists. This adds interesting information about the plant. As an example, in Ladakh, *Erigeron alpinus*, a small herb, grows near the glaciers and is locally known as *Kukling kukling chi bhandu*. It is said that a particular type of insect eats only this plant. An interesting folk tale is attributed to the naming of this plant. Once, the insect that eats it did not get this plant, and when he was coming back after the day's toil, another insect asked him whether he got his favourite plant to eat. He replied, "Kukling kukling chi bhandu" (Yes I got it but it was too bitter) (Shah, 1994a). The botanical names of the plants, with their synonymy and family, habit and habitat, distribution within the region, and phenology (time of flowering and fruiting), are usually given.

Ethnobotany in India started when the British botanists came to India and searched for plants to

study and also noted the native uses of the plants. Roxburgh (1832) described the use, the vernacular names, and the botanical identification of plants. Describing the use of *Tylophora asthmetica* leaves for asthma and their roots for dysentery are part of his ethnobotanical contributions (Shah & Kapoor, 1976).

In 1873, Sir George Watt studied the economic plants of the Manipur and Burma (Myanmar) border for 10 years. In 1883 he was put in charge of an exhibition on Indian economic products sponsored by the then government of Bengal (now West Bengal and Bangladesh). Plant exhibits from all parts of the country were obtained and, after he obtained proper botanical identification, vernacular names and information on various uses, they were exhibited in Calcutta. This was the first workshop on Indian ethnobotany. Sir Watt published, with the help of the material from the exhibits, his monumental work, *Dictionary of the Economic Products of India*, with an index of 3,000 vernacular names and various uses from different parts of India. He also supplied the plant product names in different languages including Arabic, Persian, Sanskrit, Hindi, Bengali, and the South Indian and tribal languages and dialects such as Bhils, Gonds, Nagas, Santals, and Bhotias. In his publication he reported various uses of plants such as indigenous dye plants, such as *Indigofera tinctoria* (Neel), *Saccharum officinarum* (Ganna or cane sugar), and 190 plants as indigenous detergents and substitutes for soap, as well as 500 fodder plants from different parts of the country. He also mentioned sacred and traditional uses of plants, which had no economic significance. He listed *Butea frondosa*, describing its traditional and medicinal uses, the use of its wood and twigs in *Homa* or sacrificial fire and its leaves as plates in the Hindu thread ceremony for eating (Watt, 1889–1896). His work is the first true collection of ethnobotany in India.

Actual study on ethnobotany was initiated by Dr. S. K. Jain, who conducted ethnobotanical surveys in Madhya Pradesh and reported various uses of plants (Jain, 1963a): as medicine and food (Jain, 1965a); for making musical instruments by the Gonds tribe of Central India (Jain, 1965b),

and in magico-religious rites, taboos, and beliefs among the Adivasi of Bastar in Madhya Pradesh (Jain, 1963b, 1964).

Thereafter, there were a number of sporadic studies (Jain & Tarafder, 1970; Shah & Joshi, 1971). In the first work, the use of medicinal plants by the Santal people, earlier reported by (Bodding, 1925, 1926), was explained. In the second work, the ethnobotany of the Kumaon Himalayas was reported with various uses of plants, such as for medicines, food, condiments, or incense, along with the etymology and philology of the vernacular names and a brief introduction to the tribal people and their communities.

The subject of ethnobotany was made official in 1982 after the establishment of the Society of Ethnobotanists. A newsletter was brought out and seminars, symposia, training courses, and workshops were held. Later on, in 1990, a journal *Ethnobotany* was published. In 1983 an All India Coordinated Research Project on Ethnobiology was initiated at the Regional Research Laboratory in Jammu. It was a multi-disciplinary, multi-institutional, and action-oriented research program for generating and documenting the multi-dimensional perspectives of the culture, traditions, and knowledge of tribal life.

Work on the ethnobotany of different regions and tribes was published for Central India, Madhya Pradesh, Bihar, Orissa, North Eastern India, Arunachal Pradesh, Assam, Meghalaya, Maharashtra, Nilgiris, etc., in the proceedings of seminars and training courses and in other compilations (Jain, 1981, 1987, 1990). The work was summarized by Binu, Nayar, and Pushpangadan (1992), Maheshwari (1996), and Jain (2001). There are a number of institutions and universities where ethnobotanical field work was conducted: Botanical Survey of India, Howrah; Regional Research Laboratory, Jammu; National Botanical Research Institute, Central Institute of Medicinal and Aromatic Plants and Central Drug Research Institute at Lucknow; Tropical Botanical Garden and Research Institute, Trivandrum. Many Ph.D. theses were awarded in ethnobotany at a number of universities such as University of Calcutta, University of Kumaon, and University of Rajasthan.

Ethnobotany in India can be explained under the following headings.

Food Plants

Three species of *Amaranthus*, *A. caudatus*, *A. hybridus* ssp. *hybridus* and ssp. *cruentus* are cultivated for their seeds. They have been grown along the whole length of the Himalayas, from Kashmir to Bhutan above 1,500–3,000 m and also on the South Indian hills. Amaranths are fast-growing, cereal-like plants that produce high-protein grains in large, sorghum-like seed heads. The origin of *A. caudatus* is the Andes in South America and of *A. hybridus* is Mexico and Central America. However, the crop has declined to almost a vanishing relic in its homeland, and more Amaranth grain is now produced in Asia especially the hill regions of India, Nepal, and Bhutan than in America (Shah, 1987).

The young leaves and seeds are used as food. These are called *Marca*, *Scu* or *Cu* or *Kedari-cua* (Himachal Pradesh and Uttaranchal), *Bustanfroz* (Kashmir), or *Ramdana* (Hindi). The etymology of *Scu* and *Cu* is obscure, *Kedari-cua* meaning *cua* of Kedarnath, *Marca* possibly after the name of Marca, a Bhotia tribe. However, it is interesting to note that *Amaranthus* sp. is called *scul* in Mexico (Berlin, Breedlove, & Raven, 1974, p. 158), which is phonetically very near to the local names *Scu* or *Cu*. In the Himalayas the seeds are parched and then made into flour for making bread or *capati* and the young leaves are used as vegetables. It is one of the commodities Hindus use for breaking the day's fast in Uttaranchal and other parts of the country, and it treated as sacred (Shah, 1987).

Fagopyrum tataricum is cultivated in higher altitudes, from 2,500 to 3,500 m, throughout the Himalayan region. Known as *Fafar* (Bhotia) *Fagopyrum esculentum* is cultivated from 1,500 to 2,500 m throughout the Himalayan region and in the Nilgiri hills. The leafy vegetable is known as *Oogal*; the seed grains are known as *Kotu* (Kumaoni), *Kannuja*, *Palti* (Garhwal and Bhotia), *kotu* (Trade name), and buckwheat (English). Its flour is used by the Bhotias in

various sacred functions and ceremonies. They believe that it warms the body. The nuts are also used for making local drinks and are also traded to people in the plains. They have a high commercial value as the flour is baked or fried into bread and eaten by Hindus to break their fast (Shah, 1987).

Tribal communities throughout the world use yams, *Dioscorea* spp. In the Kumaon region, the bulbils and root tubers of *Dioscorea bulbifera* (Gethi) are used as food. There is a Kumaoni saying, “Khaunhi ne gethi kamar bandhi peti” (“*Dioscorea* is not available in his house to eat and even then the person poses himself as a big guy”; Pandey and Pande (1999).

Another species, *Dioscorea melanophyma* known as *Tarur* or *Tikhun* (Kumaoni), is the staple food of the Rajis. This tribe is apparently of non-Aryan affinities and is commonly known as Ban Raut, Ban-Manus. Earlier they were known as cave dwellers, but they now live in well-built houses in the Pithoragarh district, Uttaranchal. The present population of the tribe (in 1993) is 556.

The Rajis are known for their craftsmanship in making wooden utensils (bowls) from the wood of a small tree, *Boehmeria rugulosa* (Genthi). Net bags are made for collecting the wild growing root tubers of *Dioscorea* from the fibres of *Boehmeria macrophylla* (syn. *B. platyphylla*), known as *Gargilla*, with a special digging tool known as *Bheku* (Figs. 1 and 2). The Rajis believe that eating *Tarur* rhizomes alleviates hunger (Shah, 1987, 1994b). In Uttaranchal and other parts of the Indian Himalayas, another crop which is cultivated on non-irrigated land is *Eleusine coracana*, commonly known as *Ragi* or *Madua* (finger millet). In Uttaranchal, also growing in the wild, are *Urtica parviflora* and *U. dioeca*, Himalayan stinging nettle and stinging nettle, which are collected along with other fodder grasses and locally called *Shishuna* (Kumaoni) and *Kaldiya* (Gahwali). Its young offshoots are used as a vegetable. The Himalayan stinging nettle and finger millet are both designated as poor man's food.

There is a saying in the Kumaoni language, “Madua ka roti shishona ka sag, Khale rankara yo



Ethnobotany in India, Fig. 1 A Raji boy showing *Japi*, a net bag made up of fibre from *Gargilla* (*Boehmeria platyphylla*) and also holding *Bheku* a digging tool for *Dioscorea* spp. (Photo by N. C. Shah)

tero bhag” (O lad! what a pity on your poor fate that you have to eat the cooked vegetable of stinging nettle with a bread of finger millet). *Shishuna* tastes like spinach. Another interesting seed crop, which is cultivated throughout the Kumaon region, is *Glycine max*, locally known as *Bhat mas* or *Bhat*, black soy or black bean. This is a most interesting crop, introduced from China as the wild Soya bean, *G. soya*. It is found only in China from Heilong to Taiwan to Tibet, Japan, Korea, and Russia (Shah, 2002, 2006).

The local name was possibly coined because of the sound, Bh..a..tt, which emerges when the black bean is parched (Shah, 1987). Various recipes are prepared, such as *thatwani* or *rasa*, *dubka*, *curkani*, and *jaula*. They are prepared in an iron bowl known as *karahi*. These recipes are very nutritious and they are prepared in every house of Kumaon (Shah, 2002, 2006). Hymowitz (1969) conducted a survey in Kumaon to collect a germplasm of the species,



Ethnobotany in India, Fig. 2 A Raji girl stripping fibres from *Gargilla* (*Boemehria platiphylla*) to be used for knitting a net bag known as *Japi* (Photo by N. C. Shah)

when he noted that kwashiorkor, a disease caused by protein deficiency, was not found amongst the children of the Kumaon hills.

Incense, Condiments, Seasonings, and Narcotics

Burning of incense has long been part of Indian culture. It is not clear why the incense is burned. *Aquillaria malaccensis* (*A. agallocha*) is a tree found in Arunachal Pradesh and Assam. The fungal-infected highly aromatic wood is used as incense and known as *Agru* after which the common Indian name *Agar batti* (incense stick) was coined. In ancient times, it was an important commodity of export from India and it is the costliest aromatic wood in the world. The current

rate for the wood is ca. US \$2,000 per kg, and now it is banned both for collection and export.

Nardostachys jatamansi, *Jatamansi*, or spike-nard, was known not only in India, but also in Assyria, Egypt, Greece, Rome, and Arab countries as an important import from India. It was known for its various uses such as incense, a nerve tonic and for its use in hysteria, epileptic fits, heart palpitations, etc. The rhizome of *Nardostachys jatamansi* grows in the high Himalayas in Uttaranchal, Nepal, Bhutan, South China, and Tibet. It is used by the Bhotias as incense and for medicinal use. It has religious as well as cultural sanctity. In Kumaon a song is sung in its praise usually in fairs and festivals (Shah, 1987, 1994d). In Mesopotamia, it has been recorded in cuneiform-shaped script (Speiser, 1951). Its association with Alexander the Great has also been established (Rücker and Glauch, 1967), and it was mentioned in the holy Bible (Modenke, 1954). Akbar the Great used it as a royal perfume (Jarett, 1948), and the Monpas (Arunachal Pradesh) (Dam & Hajra, 1981), Santals and other tribals of South India also recorded using it (Jain & Tarafder, 1970).

Jurinea dolominaea (syn. *J. macrocephala*) is locally known as *Dhup* in Kashmir and the Punjab Himalayas and *Guggul* in the Kumaon Himalayas. *Dhup* means incense. The rhizomes and roots are collected and traded, to be used mostly in sacrificial fire or *homa*. The herb was also used in royal cosmetic preparations during the reign of Akbar the Great (Shah, 1994a).

Cannabis sativa is commonly known as *Bhangālu*, *Bhangāu* (Kumaoni), *bhanga*, *gangika* (Sanskrit), hemp or marijuana (English). *Bhangāu* or *Bhangālu* are derived from the Sanskrit word *Bhang*. The root of these words, “ang” or “an”, recurs in all Indo-European and modern Semitic languages (De Candolle, 1886, p. 148). In Uttaranchal, local people recognize two types of *C. sativa*: the cultivated one, known as *Ghar-bhangau*; and the wild one, *Kath-Bhangau*, which usually grows near habitations, mostly near cattle sheds known as *khattas*. *Kath* and *Ghar* mean wild and domestic. *Ghar Bhangau* are cultivated tall plants, 1.5–4 m high, grown mainly to procure edible seeds and fibre; *Kath Bhangau* are wild, comparatively short,

0.5–1.5 m, and are used to collect hashish and crude resin. In Uttaranchal, their seeds, seed oil, stems, fibre, leaves, inflorescence, and resin are used (Shah & Jain, 1988). The fibre is used for making cordage or ropes and the pith of the stem is used as torchwood. The seeds are used as food (Shah, 1997a, 2001).

The plant is also used as a narcotic. The plant produces three types of narcotics. (1) Hashish (*bhāng*) consists of the dried leaves and flowers of male and female shoots. In the northern plains, a preparation of *bhāng* is used as a beverage and sold Varanasi, Lucknow, and Allahabad. (2) *Ganja* consists of dried inflorescence specially from female plants without any leaves. (3) *Attar* or *charas* is the crude resin, which appears on the stem and inflorescence and is the strongest part. Cannabis is often seen growing around abandoned and dilapidated houses and is used abusively. When the Kumaoni people want to curse someone, they say, “Teri kuri bhāngau jam jo”, which means, “May hemp grow in your house”, i.e. “May your house be ruined and damaged to such an extent that Cannabis will grow there”. People of Garhwal also name their male children after the intoxicant resin, *attar* obtained from the plant such as *Attar Singh* (Shah, 1997a).

Liquor Producing Plants

There are a number of cereals which are used for producing liquor with or without fermentation in the Himalayas and other parts of the country. Some are *Hordeum vulgare*, *Juar*, or barley; *Eleusine coracana*, *Madua*, *Ragi*, or finger millet; *Echinochloa frumentacea*, *Jhungra*, *Madira*, or Japanese barnyard millet; and *Panicum miliaceum*, *Ceena* (*Kangī*), or common millet.

There are also trees from which liquor is produced. Most important among them is *Madhuca India*, commonly known as *mahua*. The fleshy pericarp is fermented and liquor is produced by fermentation. This is a common practice in central parts of India among the tribal and village people. The dried fleshy pericarp is ground to produce flour and bread is produced. The seed of this plant is used to produce edible oil.

Another tree is *Caryota urens*, known as *Mari*. The sap is collected in a pot which is hung and tied to an incised tree. The sap so collected is known as *Toddy*. It is used like a beer or it is fermented and then distilled to yield an alcoholic liquor.

Medicinal Plants

Rauvolfia serpentina is generally known as *Sarpagandha*, the local people used the roots in folk medicine in snakebite and to calm troubled people, in Bihar it was called *Pagal ki Dawa* (“the medicine of the insane”). The drug was adopted first in the Unani system of medicine and consequently in Ayurveda. Because of the alkaloid reserpine found in the root, antipsychotic and hypertensive properties are attributed to it, and it was included in modern medicine in the early 1950s (Shah, 1995).

Recently, scientists at the Tropical Botanical Garden and Research Institute (TBGRI) found that the Kani tribes of Kerala use *Trichopus zeylanicus* ssp. *travancoricus* (*Trichopodaceae*), locally known as *Arogyapacha*. It is used as a health food to maintain vitality and as an immunomodulator to increase resistance against diseases in the body, as is ginseng. The extract of the leaves was commercialized by a pharmaceutical company and exported to Japan, Germany, Malaysia, and Indonesia. From the net profit obtained from the sale, 2 % was shared between TBGRI and the Kani tribes of the region. It was the first model in the world of recognition of an Intellectual Property Right (IPR) pertaining to ethnobotanical and medicinal plant knowledge (Bagla, 1999).

Socio-religious and Socio-cultural Plants

Plants have so deeply influenced the life and culture of the people of the Indian subcontinent that a number of plants are worshipped like deities (Gandhi, 1989; Gupta, 1971). In India, there are two kinds of worship: *Havan* or sacred fire, which means the act of oblation and sacrificial

offering to Gods and Goddesses through fire. The Aryans used to offer their deities animals, butter and milk, cakes of barley, and the Soma plant, a divine plant not yet convincingly identified. A number of plants have been considered, such as Ephedra, Sarcostemma, Cannabis and Amanita muscaria, the fly agaric mushroom. (Mehdhasan, 1963; Shah, 2005; Shah & Badola, 1977). The latest speculation points more clearly to Ephedra as the likely species. People now usually use *Ephedra* species. There are a number of plant materials which are used in the oblation. These are cereals, sugar, raisins, dates, coconut, sesame (*Sesamum indicum*), and a number of medicinal and aromatic plants. *Puja* is a pre-Aryan practice and ritual, in which cooked food, vestments, ornaments and other materials like flowers, leaves, and water are offered to deities. The people burn incense and wave light in front of an idol, e.g. Arti. They also chant mantras. The word *Puja* is derived from the Dravidian word *pu* meaning, flower, and *ja* meaning, “to do”, so it is a flower ritual or *pushpakarma* (Shah, 1994c).

There are many plants worshipped by the Hindus in India. *Ficus religiosa*, commonly known as *Peepal* (sacred banyan), is worshipped on every Sunday on every Somvati Amavasya of the year that is on the non-lunar day of the Hindu month known as Shravan, usually falling in July or August. Each part of this tree is considered sacred. In most Hindu and tribal communities, the bride is first married to a tree and then to the bridegroom. A Hindu never cuts the tree and cutting is equated with killing a Brahmin (Dube, 1995). Every part of the plant is also considered medicinal, and Santals. Bodding et al. reported 16 therapeutic uses of the plant parts (Jain & Tarafder, 1970).

In the month of Jeth (May–June), on a day with a full moon, the *F. benghalensis*, commonly known as *Vat* (banyanan tree), is worshipped. In Bhado (August–September) on Durva-ashtimi day, *Cynodon dactylon*, Hindu women worship the *Doob* grass and they also fast on that day. Doob grass is always used in performing *Pooja*. *Ocimum sanctum*, *Tulsi* (holy basil), is the highest venerated plant among the Hindus; it is believed to be an incarnation of a Goddess. It is

always kept in every house and worshipped daily. It is used in cough and cold and fever as a household remedy. Some claim that it can cure cancer. *Curcuma longa*, *Haldi* (turmeric), is used as an important condiment in every house and in various religious ceremonies. It has a number of therapeutic properties, some of which have undergone scientific studies (Shah, 1997b). There was a lot of hue and cry when some NRI Americans (Non-Resident Indians living in the United States) patented the use of turmeric for healing fresh wounds, which is quite a common use in India. After a long fight in the American courts, the Council of Scientific and Industrial Research (CSIR), New Delhi won the case after they presented documentary proofs of its uses in fresh wounds from old medical treatises. Last, but not least is *Azadirachta indica*, the Neem tree. All parts are regarded as medicinal for day-to-day ailments and diseases. It is sometimes called a “home tree doctor”. It is not worshipped, but it has socio-cultural significance. On the first day of the Hindu calendar year known as *Samvatsar*, which is a festival usually falling in March, early in the morning a few leaves of Neem are eaten with a belief that the person will remain healthy throughout the year (Dube, 1996).

The Indian subcontinent consists of separate linguistic communities each of which share a common language, traditions, and culture. If we want to learn the use of plants by a community, then we have to probe through their language as a tool.

A. Barrea, one of the first promoters of ethnobotany in Mexico, states:

The best ethnobotanist would be a member of an ethnic minority who, trained in both botany and anthropology, would study the traditional knowledge, cultural significance, and the management and uses of the flora. And it would be even better for him and his people if his study could result in economic and cultural benefits for his own community. (Martin, 1995)

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Ethnobotany in Mesoamerica

Richard Evans Schultes

The ethnobotany of Mesoamerica is extremely rich. The region is the original home of many useful plants. Amongst the numerous species, maize (*Zea mays*), avocado (*Persea americana*), henequen (*Agave fourcroydes*), maguey (*Agave cantala*), and chili pepper (*Capsicum frutescens*) immediately come to mind. All of these are inherited from aboriginal peoples who domesticated them long before the arrival of Europeans.

Perhaps the ethnobotanical aspect most typical of the region was the medicinal and ceremonial use of psychoactive or hallucinogenic plants. The Indian populations of Mesoamerica discovered and still employ in their magic and medicine many species with psychophysical properties. Even more significant is the evidence that from ancient times these plants have been considered sacred. That explained why the few plants with these unworldly effects amongst the half-million species in the world have such weird effects when ingested; they must be endowed with spiritual power, according to the belief of the aboriginal people. They are capable, through visual, auditory, or other hallucinations and related bioactivity, of allowing the medicine men or even

ordinary individuals to communicate with ancestors or the spiritual forces who govern the affairs of the world below and who are able, if not propitiated, to inflict sickness, suffering, death, or calamities on people or on whole tribal groups.

We know much today about the use of bioactive plants for magico-religious and medicinal purposes from archaeological finds, ancient monuments, petroglyphs, codices, missionary reports, and other early publications. It is obvious from all of these and other sources that the use of plants capable of producing physiological and psychological alterations has had deep significance amongst native peoples in many parts of the world, especially in Mesoamerica.

In view of the great importance of psychoactive plants in the life of Indians of Mesoamerica, a brief discussion of the cultural importance of several of the numerous psychoactive plants employed by the Indians of Mexico and Guatemala in ancient and modern times will best indicate this particularly significant aspect of Mesoamerican civilizations.

Peyote (*Lophophora williamsii*)

The hallucinogenic peyote cactus has a long history in Mexico as a sacred plant employed in numerous medicinal and ceremonial ways. Peyote is a low, spineless cactus. It is still used ceremonially by Indians in central and northern Mexico, particularly the Huichol, Tarahumare, and Cora. The Huichols each year make a sacred pilgrimage to the peyote deserts and cut off the tops of the peyote plants, leaving the roots in the ground to regenerate tops. The tops are dried and taken back for use throughout the year. It is the dried top, known as the “peyote button” that is eaten during their ceremonies and dances.

Early reports, mostly by post-Conquest ecclesiastical writers, usually condemned the use of this innocuous hallucinogen as the work of the devil, and they tried, unsuccessfully, to exterminate this pagan religious ceremony. One report equated the eating of peyote to cannibalism. One of the early writers intimated that the Chichimecas and Toltecs were acquainted with peyote as early

as 300 BCE, but the accuracy of this dating depends on interpretation of native calendars.

Recently, however, excellently preserved archaeological findings in Trans-Pecos, Texas, and Coahuila, Mexico, have confirmed ceremonial use of peyote. Identifiable remains of peyote buttons in great abundance and in a context suggestive of ritual use have been dated by Carbon 14, and they span 8,000 years of intermittent human occupation. In Coahuila, ceramic bowls dated from 100 BCE to AD 200–300 depict significant use of peyote; four peyote-like ornaments and a hunch-backed man holding a pair of peyotes are depicted in these bowls. There can be little doubt that peyote is the most important psychoactive plant still utilized in the dry regions of Mexico.

Of the many alkaloids (30 or more) in the peyote cactus, only one, mescaline, is responsible for the richly colored, kaleidoscopically moving visions induced when peyote buttons are ingested.

Red Bean or Mescal Bean (*Sophora secundiflora*)

Together with the archaeological cache of peyote in Texas, two other plants were discovered. One is the red bean or coral bean (*Sophora secundiflora*); the other is a suspected psychotropic plant known today as the Mexican buckeye (*Ungnadia speciosa*).

An early Spanish explorer of Texas, Cabeza de Vaca, mentioned mescal beans as an article of trade amongst Indians of the southern regions of North America in 1539.

Sophora secundiflora was employed in northern Mexico until recently in certain ceremonies, but, as in the southwestern United States its use as an intoxicant has disappeared. According to the Stephen Long expedition of 1820, the Arapaho and Iowa tribes were using the large red beans as medicine and a narcotic. A well-developed mescal bean cult existed amongst at least 12 tribes of the United States. There are so many parallels between the peyote cult and the former Red Bean Dance that the origin of the ceremony must have had a southern or Mexican origin.

The active principal of *S. secundiflora* is cytisine which is common in the legume family. This alkaloid belongs to the same group as nicotine; it is a strong poison, attacking the phrenic nerve controlling the diaphragm. Death can occur from asphyxiation. It may possibly be because of the great danger in cases of overdosing with the red bean that its ceremonial use has disappeared. It is of interest, however, that the “road-man” or leader of the peyote ceremony today always wears a necklace of the red beans during the peyote ceremony, undoubtedly as a reminder of a once sacred plant.

Ololiuqui and Badoh Negro (*Turbina corymbosa* and *Ipomoea violacea*)

Early Spanish ecclesiastical chroniclers, writing at the time of the conquest of Mexico or slightly later, described the medico-religious use of a brown lentil-like seed which the Aztecs called *ololiuqui*, coming from a plant known as *coatlxouhqui* (snake plant), indicating a vine with heart-shaped leaves and a tuberous root, clearly a member of the Morning Glory family. Its present botanical name is *Turbina corymbosa*, but it has also been known as *Ipomoea sidaefolia* and *Rivea corymbosa*.

We know much about the preconquest use of this hallucinogenic plant. Furthermore, there are clear, although crude, illustrations of ololiuqui in the codices. The plant is depicted in mural paintings showing the water goddess with a stylized vine reminiscent of this sacred vine.

But even more scientifically meaningful is the report and illustration of ololiuqui in a most extraordinary book: *Rerum Medicarum Novae Hispaniae Thesaurus, seu Plantarum Animalium, Mineralium Mexicanorum Historia* (Medical Thesaurus of New Spain or the Story of the Plants, Animals, and Minerals of Mexico). Shortly following the conquest, the King of Spain sent his personal physician, Dr. Francisco Hernández, to live with the Aztecs and study their medicines. His notes did not appear as a book, however, until 1651, although some of Hernández' notes were published as early as

1615 by Ximénez, who wrote of *ololiuqui*, without identifying it, because, he stated “it will not be wrong to refrain from telling where it grows, for it matters little that this plant be here described or that Spaniards be made acquainted with it.” Another report, dated 1629, stated that “. . .when drunk, the seed deprives of his senses him who has taken it, for it is very powerful.” Still another source said that “it deprives those who use it of their reason. . . The natives communicate with the devil. . . and they are deceived by the various hallucinations which they attribute to the deity which they say resides in the seeds” (de Alarcón, 1629).

Besides being a hallucinogen, *ololiuqui* was used as a magic potion with reputedly analgesic properties. Aztec priests, before making human sacrifices, rubbed the victims with an ointment of the ashes of insects, tobacco, and *ololiuqui* to benumb the flesh and lose all fear. The seeds were venerated and placed in idols of the ancestors.

Mexican botanists identified *ololiuqui* correctly in the last century, but doubts arose, since intoxicating chemical constituents were unknown in the morning glory family. In 1911, a German specialist, Christian Hartwich, suggested that *ololiuqui* might be a species of the Solanaceae, and in 1915, an American ethnobotanist, William Safford, assuming that the chroniclers had been misled by the Indians, definitely identified it as a species of the solanaceous genus *Datura*. There were voices of protest. Not until 1939, however, were actual specimens collected in Oaxaca and used in Mazatec rituals.

It is now employed by more than six tribes and in many Oaxacan villages the morning glory is planted “as an ever present help in time of trouble.” When employed ceremonially as a medicine, the patient must himself collect the seeds, and they are ground and made into a beverage by a virgin, usually a child.

In 1960, the seeds of another morning glory, *Ipomoea violacea* (formerly called *I. tricolor*), was identified as a sacred hallucinogen amongst the Zapotecs of Oaxaca. These seeds are black – thus the local name *badoh negro* – and larger than those of *T. corymbosa*, with which the

badoh negro, usually employed alone, may be mixed. It has been suggested that these black seeds represent the ancient Aztec narcotic seed called *tlitliltzin*, a term in Nahuatl derived from the word for black with a reverential suffix. An early chronicler, Pedro Ponce, had written of “*ololiuqui*, *peyote*, and *tlitliltzin*,” indicating that three different inebriating agents were represented (Wasson, 1963).

The seeds of both *ololiuqui* and *badoh negro* contain a number of ergoline alkaloids, chemically related to the synthetic D-lysergic acid diethylamide (LSD).

Toloache (*Datura innoxia*, *D. discolor*, *D. Wrightii*, *D. kymatocarpa*, *D. ceratocaula*)

Species of *Datura* have a long history in both hemispheres as a genus valued as medicines and hallucinogens. The main center of ceremonial use of *Datura*, however, lies in the Southwest of the United States and Mexico where a number of species are employed. All are known as toloache in Mexico (Fig. 1).

Today, many Indians believe that they can acquire supernatural helpers through the drug, and much secret knowledge is thought to be gained during the ceremonial intoxication. In tribes of northern Mexico boys who are studying to be medicine men must undergo *Datura* intoxication once a year. Modern Tarahumare add *D. innoxia* to *tesquino* (a drink prepared from maize) to make it strong and to induce visions. Some Mexican Indians consider toloache an hallucinogen inhabited by a malevolent spirit, unlike *peyote*.

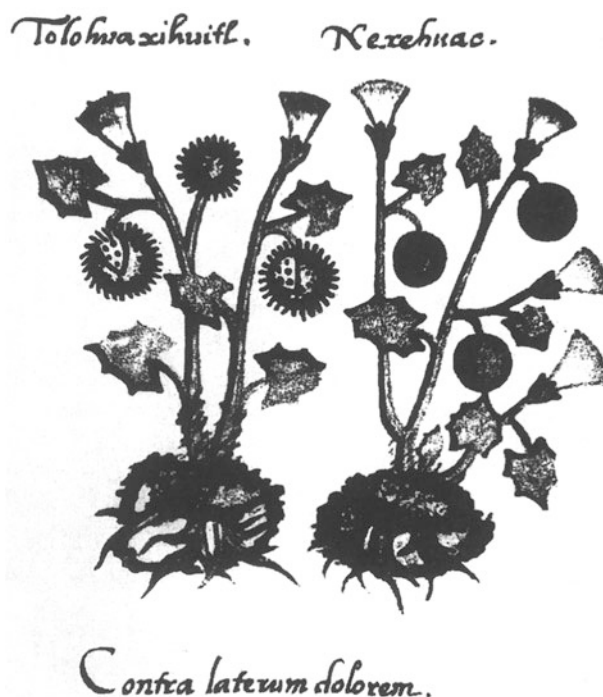
All species of *Datura* owe their activity mainly to their active constituent scopolamine.

Puffballs (*Lycoperdon marginatum*, *L. mixtecorum*)

More ethnobotanical research must be carried out on the use of two species of puffballs amongst the Mixtec Indians of Oaxaca. The first of these two

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Fig. 1 Two species of *Datura*: *D. Inoxia* and *D. ceratocaula* (From *The Badianus Manuscript; an Aztec Herbal of 1552*. Edited and translated by Emily Walcott Emmart, 1940. Reprinted by permission of the Johns Hopkins University Press)



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species is known by the Mixtec name *gi-i-wa* (fungus of first quality), the second as *gi-i-sa-wa* (fungus of second quality).

Lycoperdon mixtecorum causes a state of half sleep in which voices and echoes are heard and, according to the natives, voices respond to questions posed to the spirits.

There is a puffball, still unidentified, reportedly employed by the shamans amongst the Tarahumare.

The active chemical in these fungi with auditory activity has not been identified. There are, however, medical records attesting to this physiological activity amongst patients who ate puffballs in North America and were rushed to hospitals hearing voices.

Mushrooms (Teonanacatl) (Conocybe, Panaeolus, Psilocybe, and Stropharia Species)

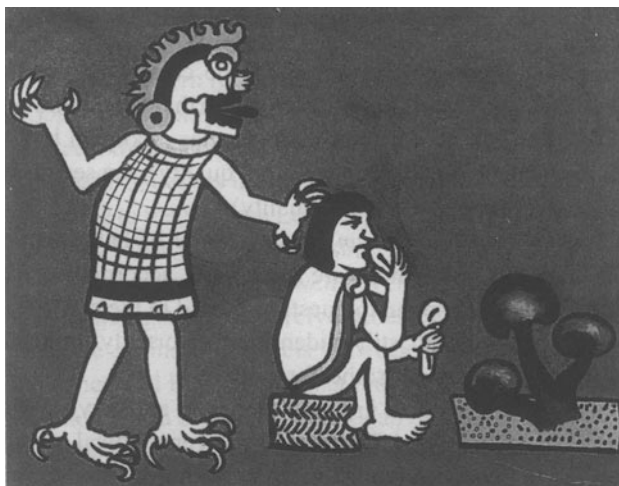
Undoubtedly the most important hallucinogenic plants employed from ancient to modern times from central and southern Mexico and Guatemala

involve a number of species of several genera of mushrooms.

The Spanish conquerors of Mexico were disturbed by the religious and ceremonial use of “diabolic mushrooms” known by the Nahuatl name *teonanacatl* (divine flesh). As with other native religious rites, the early clerics tried to stamp out such a loathsome religion that venerated mushrooms. It has been said that there was little that Christianity could offer comparable to the supernatural power of *teonanacatl*. One of the early Spanish writers reported: “They possessed another method of intoxication which sharpened their cruelty; for it they used certain small toadstools. . . they would see a thousand visions and especially snakes. . . and in this wise with that bitter victual by their cruel god were they hassled” (Sahagun 1829). The King of Spain’s personal physician, who studied the medicines of the Aztecs shortly after the conquest, reported in a more scientific vein three intoxicating mushrooms that “cause not death but madness that occasionally is lasting, of which the symptom is uncontrolled laughter. . . There are others which, without inducing laughter, bring before the eyes

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Fig. 2 Teonanacatl (“flesh of the gods”): the Aztec sacred, hallucinogenic mushrooms. Painting by a Mexican artist of the sixteenth century, showing an Aztec-looking devil encouraging an Indian to eat the fungus (From the *Magliabecchiano Codex*, Biblioteca Nazionale di Firenze, Italy. Used with permission)



all kinds of things, such as wars and the likeness of demons.”

There is plentiful archaeological evidence indicating a long use of teonanacatl. Frescoes from central Mexico made at least 1,700 years ago unmistakably refer to these intoxicating mushrooms (Fig. 2). Clay figurines from Jalisco about 1,800 years old have mushroom effigy “horns.” In Colima, a clay artifact dated between AD 100 and 300 illustrates figures dancing around a mushroom. Stylish mushrooms decorate the pedestal of the statue of Xochipili, the Aztec god of sacred flowers whose body is decorated with a number of intoxicating plants. This statue was discovered on Mt. Popocatepetl and dated about AD 1450.

In Guatemala, however, the deep roots of mushroom use in ceremony go back to the famous “mushroom stones” dated between 300 and 900 BCE. Consisting of an upright stem with either an anthropomorphic or animal figure and crowned with an umbrella-like top, they are now thought to have been associated with the sacred Mesoamerican ball game ritual (Fig. 3).

It was nearly five centuries after the arrival of Europeans that serious ethnobotanical research on the sacred mushrooms of Mexico began. Since in this period of time the ceremonial use of these fungi had not been seen, W.E. Safford, an American ethnobotanist suggested, in 1915, that the Aztecs had misled the chroniclers and that,



Ethnobotany in Mesoamerica, Fig. 3 Animal effigy mushroom stone. Highland Guatemala, Protoclassic Period (100 BCE–AD 300). Collection of the Museo Nacional de Guatemala (Photograph by G. Kalivoda, courtesy of R.M. Rose)

since he assumed that the dry brown top of the peyote cactus superficially resembled dried mushrooms that *teonanacatl* and *peyote* were synonymous and referred to the same plant.

Unfortunately, this “identification” received some acceptance, despite voices of protest. It was not until specimens of the mushrooms were collected in the Mazatec country of Oaxaca that the first of many species – *Panaeolus sphinctrinus* – was botanically identified. Later ethnobotanical and anthropological research in a series of expeditions to the same region has led to the identification of more than 30 species of *Psilocybe*, *Stropharia*, and *Conocybe* ceremonially employed by at least nine tribes in southern Mexico.

Intensive research on these fungi has led to a tremendous increase in ethnobotanical, mycological, chemical, and anthropological knowledge and to an extensive bibliography. Not only have many new species of mushrooms been described, but also chemical investigation of these plants has led to the discovery of the active alkaloids, psilocybine, and psilocine.

This relatively recent discovery and research on what perhaps is a most significant aspect of Mesoamerican ethnobotany has been certainly an important factor in stimulating ethnomycological and even general ethnobotanical investigation in Mesoamerica as well as in other areas in both hemispheres.

See Also

► [Crops in Pre-Columbian America](#)

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Ethnobotany in Native North America

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Native American peoples developed a sophisticated plant-based medical system in the ten millennia before the European conquest of America. Although there were significant differences between the systems developed by the many native groups, about which many fine works have been written, there were also many broad similarities which will be detailed here. There are approximately 28,000 species of plants in North America. Native Americans used about 2,500 of them medicinally (Moerman, 1996, 1998); a convenient database of all of these plant uses is available at <http://www.herb.umd.umich.edu>. The utilized portion (the medicinal flora) is a distinctly nonrandom assortment of the plants available. The richest sources of medicines are the sunflower family (*Asteraceae*), the rose family (*Rosaceae*), and the mint family (*Menthaceae*). By contrast, the grass family (*Poaceae*) and the rush family (*Juncaceae*) produce practically no medicinal species. This remarkable volume and extraordinary selectivity demonstrate without any doubt the falseness of demeaning claims which suggest that Native

American medicines were chosen at random, that they “just used everything and stumbled on something useful once in a while.”

Health and Disease

To understand the character and effectiveness of a medical system, one must understand the health status of the people who use it. Native American peoples generally did not suffer from the heart and circulatory diseases of modern times; their diets were rich in fiber and carbohydrates and low in fats. They lived vigorous lives which provided hearty exercise on a daily basis. They experienced little cancer. Cancer is largely a disease of modern civilization. Although the situation is obviously very complex, an apparently necessary condition for cancer is carcinogens which are largely products manufactured by industrial societies (organic chemicals and dyes, nuclear radiation, etc.). Even into the current day, there is evidence that the Navajo have lower rates of cancer than the surrounding people (Csordas, 1989).

In addition, they suffered little from the classic infectious diseases which ravaged European society over the past two millennia. In large part, this seems to be due to the fact that most such diseases (plague, typhoid, smallpox, cholera, etc.) are zoonoses, diseases of animals which, under conditions of domestication, underwent massive evolutionary change and subsequently affected the human keepers of these animals. Native Americans never domesticated animals to any significant degree (the guinea pig and llama of Peru were apparently only coming under domestication in the few hundred years before European contact). Once these diseases were introduced into North America, they devastated native populations which had no immunity to them. However, until the sixteenth century, while Europeans underwent successive epidemics which regularly killed a quarter or half of the population, Native Americans were spared this devastation.

What medical problems *did* Native Americans face? In the southeast and southwest, there is evidence of a decline in health status after the

invention of agriculture when the diet became simpler, which apparently led to some deficiency diseases. Hunting and gathering peoples avoided that problem, but they, like Europeans, may have experienced some zoonotic infections particularly from beaver and some trichinosis from bears. These would have been direct zoonoses which individuals contracted directly from the infected animal, not remote zoonoses which, once passed to one human being, were subsequently passed from person to person. Like rabies, a terrible disease for the individual who contracts it, these direct zoonoses are not serious threats to a whole society because they are not contagious in the ordinary sense of the term.

Native Americans probably paid a price for the vigorous life they led. Accidents, sprains, broken bones, cuts, lacerations, and the like were common. There was a range of arthritic conditions, some probably the result of injury like those just mentioned and perhaps some similar to rheumatoid arthritis. There is ample evidence that native peoples engaged in warfare; this would have been a source of serious medical problems. There was a range of occasional problems associated with menstruation, pregnancy, childbirth, and lactation which required attention. Living in smoky houses, it is not surprising that they had a broad range of treatments for irritated eyes: they also treated colds, headaches, cold sores, and bruises, the normal insults of daily life everywhere (Vogel, 1970).

Drugs

To address this range of problems, Native Americans inevitably resorted to drugs based on various plants. There were some nonplant substances used medicinally. *Castoreum* from beaver was utilized for various conditions, and some minerals and clays were used as well, but by far the preponderance of medicinal substances came from plants. Every Native American group for which we have any information had a botanical pharmacy. While some were quite small (the Inuit had few plant resources on which to rely), most were quite elaborate with hundreds of plant drugs used for a broad range of conditions.



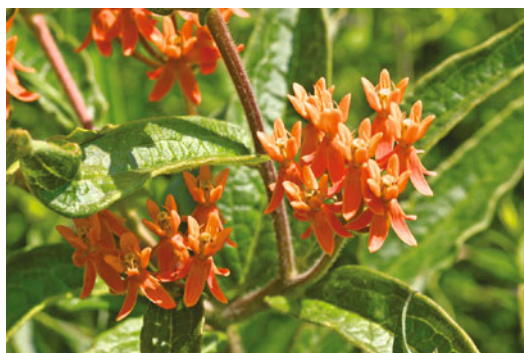
Ethnobotany in Native North America, Fig. 1 Poppy, *Papaver somniferum* (Copyright D. Moerman. All rights reserved)



Ethnobotany in Native North America, Fig. 2 Nightshade, *Solanum americanum* (Copyright D. Moerman. All rights reserved)

This straightforward proposition raises a number of much more challenging questions. Native American healers, even into the early twentieth century, regularly knew the identity of 200 or 300 medicinal plants which they could readily distinguish from the 3,000 to 5,000 species which grow in any particular area. Among 100 sophisticated and well-educated modern Americans, it seems unlikely that very many could identify 200 species of plants of any kind unless they were professional botanists (or perhaps gardeners). How did nonliterate people, without reference to botanical keys or floras compiled by professionals, maintain this extraordinary amount of knowledge (Berlin, 1992)?

Another challenging question is this: Why is it that plants might be of medicinal value in any case? Why do poppies (*Papaver*) (Fig. 1) or nightshade (*Solanum*) (Fig. 2) induce unconsciousness? Why does willow (*Salix*) bark tea relieve headaches? Why does wormseed (*Chenopodium*) kill intestinal parasites? Why does milkweed (*Asclepias*) (Fig. 3) cause vomiting? Although there are many obstinate details yet to understand, the broad outlines of an answer to this question may be sketched. Plants often produce substances of a variety of sorts to protect themselves against browsers (most often insects or worms, but also vertebrates), to defend their space against other plant competitors, or for a wide variety of other particular purposes. These substances share one character: they are somehow biologically active.



Ethnobotany in Native North America, Fig. 3 Milkweed or butterfly weed, *Asclepias tuberosa* (Copyright D. Moerman. All rights reserved)

In using them as medicine, people appropriate these (usually) defensive chemicals to induce reactions which they desire. They are usually toxic; they are therefore customarily used in moderation (e.g., by “prescription”).

Sometimes the answer to particular questions seems fairly straightforward: the toxic cardiac glycosides in milkweeds (*Asclepias* spp.) discourage browsing by insects, worms, deer, or other vertebrates. However, for people who want to induce vomiting, to clear their systems of foul humors or the like, such plants are ideal medicines. Similarly, the substances in wormseed which deter various worms from eating the roots also kill intestinal parasites in human beings. There are nonhuman analogues to these uses of drugs which are of great interest. In the

case of milkweeds, an insect, the monarch butterfly, might be said to use the plant medicinally as well. By virtue of a complex evolutionary adaptation, they manage to tolerate the milkweed toxins, sequestering them throughout their bodies, making themselves in turn unpalatable to predatory birds, notably blue jays (Brower & Glazier, 1975). In a case similar to the human use of goosefoot as an anthelmintic, there is evidence to indicate that occasionally chimpanzees, when they appear not to feel well, seek out the leaves of a particular species of *Aspillia* which has anthelmintic properties. Otherwise, the species is ignored (Wrangham & Goodall, 1989).

Some cases are less clear-cut. Salicin is a substance found in the leaves of most species of willow; the chemical is named after *Salix*, the genus of willows. This water-soluble substance washes off the leaves during rain and acts as an herbicide on plants growing around the tree. It is also the chemical precursor of acetylsalicylic acid, a synthetic drug which we know as aspirin. Various naturally occurring salicylates (also found in certain birches, in the common ornamental *Spiraea*, and in wintergreen) have the same general biological effects as aspirin (named after *Spiraea*) relieving headache and reducing inflammation and fever. The advantage of aspirin is that it is less toxic than the natural chemicals. All of the salicylates seem to work as a result of their inhibiting effect on a class of substances known as the prostaglandins which are involved in all these biological processes. The prostaglandins are also involved in the maintenance of the mucous layer in the stomach and intestine; this is why aspirin (and the other salicylates) can cause stomach upset. What is not clear is why a herbicide should have this effect on mammalian biochemistry. Many similar cases remain to be understood.

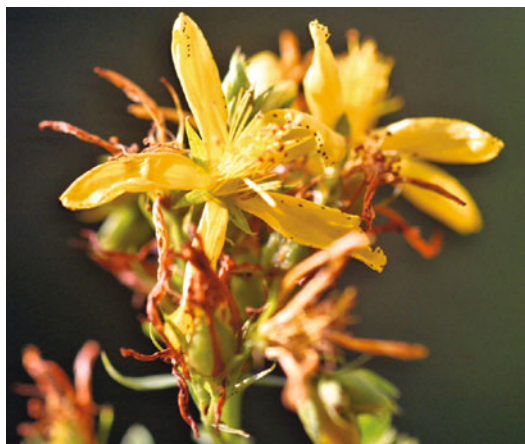
Psychological Drugs

There is little evidence of Native American use of drugs for recreational purposes. In addition, there is only very little evidence indicating the use of drugs in religious or other ritual.

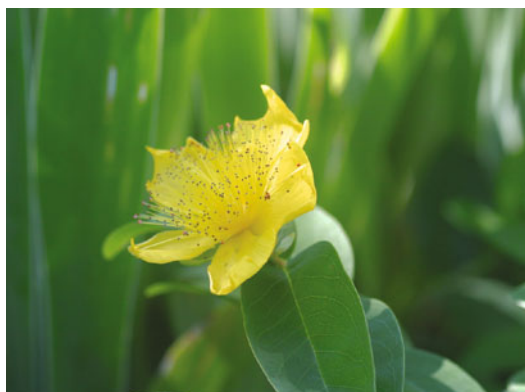
This differentiates native North American peoples from indigenous peoples of Mexico, Central and South America, and many other places as well. The one significant Native American use of a consciousness altering substance involves peyote in the Native American Church. This, however, is a recent development of the twentieth century with no obvious precursors. There are a number of highly active drugs available for such uses, among them various members of the Solanaceae family (particularly nightshade and jimsonweed) as well as a number of hallucinogenic mushrooms, most notably *Amanita muscaria*. The one drug of this sort which was widely used was tobacco (*Nicotiana* spp.). Uncured native tobacco is a much more powerful drug than the highly processed modern variation. In Mexico, powerful tobacco concoctions were ingested in a number of ways to induce substantial transformations of consciousness. This seems not to have happened in the north of the Rio Grande. All accounts of its use in North America indicate that it was utilized very sparingly: individuals sat in a circle and shared the smoke from an ounce or so of tobacco. Its function was clearly more symbolic than biological. There may be a few exceptions to this generalization, but they are all either controversial or very poorly documented. When Native American peoples wanted to transform consciousness – in the vision quest, for example – they did so with disciplines like starvation, concentration, isolation, and sleep deprivation.

Some Interesting Medicinal Plants

Here are some notes on several interesting plants used medicinally by native peoples of north America. St John's wort, *Hypericum hypericoides* (Figs. 4 and 5), is a very useful plant. Recently, a number of double-blind controlled trials have shown that several substances in the plant work to reduce mild to moderate depression. There is little evidence to indicate that native peoples suffered from this common modern scourge; Vogel's authoritative account, *American Indian Medicine*, never mentions it except as a possible effect of



Ethnobotany in Native North America, Fig. 4 Wild St. John's wort, *Hypericum perforatum* (Copyright D. Moerman. All rights reserved)



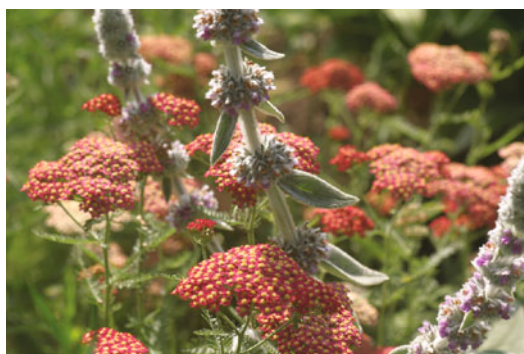
Ethnobotany in Native North America, Fig. 5 Garden St. John's wort, *Hypericum* sp. (Copyright D. Moerman. All rights reserved)

European *Arnica montana* taken internally (Vogel, 1970, p. 261). Instead, it was used primarily by peoples of what is now the Southeastern United States (Alabama, Cherokee, Choctaw, Houma, Natchez) for a variety of purposes: an infusion of the whole plant taken for dysentery, decoction of the root taken for severe pain especially in childbirth, and an infusion of the leaves used as a wash for sore eyes. For an interesting review, see Gupta and Möller (2003).

Another important plant is yarrow, *Achillea millefolium* (Figs. 6 and 7). With 258 recorded uses as a drug (Moerman, 1998), it is the most



Ethnobotany in Native North America, Fig. 6 Wild yarrow, *Achillea millefolium* (Copyright D. Moerman. All rights reserved)



Ethnobotany in Native North America, Fig. 7 Garden yarrow, *Achillea millefolium*, with garden sage, *Salvia officinalis* (Copyright D. Moerman. All rights reserved)

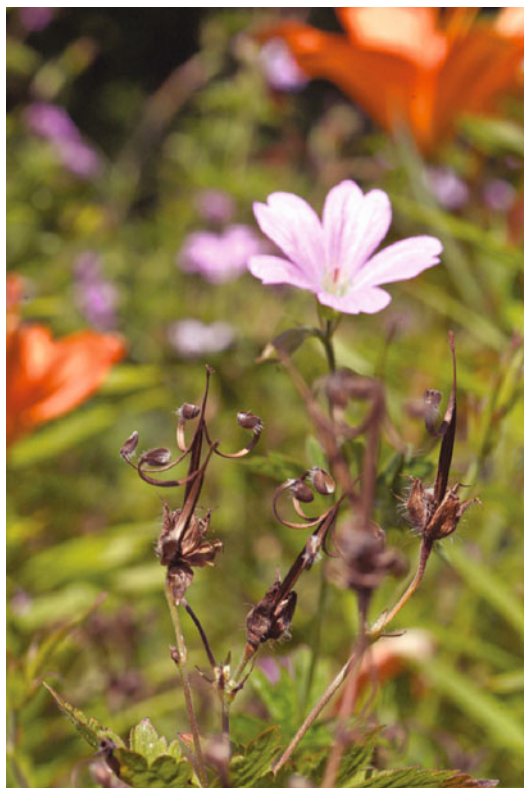
utilized of all Native American medicinal plants (second: *Acorus calamus*, sweet flag, with 219 uses; third: *Artemisia tridentata* ssp. *tridentata*, basin big sagebrush, with 166). Yarrow is one of the most widespread plants in the world, found over most of the northern hemisphere, and in temperate regions of the southern hemisphere as far south as Peru and Tanzania. Wherever it grows, it is used to treat wounds, infections, burns, swellings, sores, pimples, insect bites, and other problems of the skin. The ancient Greeks attributed the discovery of the virtues of *Achillea* to Achilles after whom it is named. He, trained in the arts of medicine, war, and diplomacy by his tutor, Chiron the Centaur, used it to heal a festering wound in an old enemy



Ethnobotany in Native North America,
Fig. 8 Cranesbill or Wild Geranium, *Geranium*
maculatum (Copyright D. Moerman. All rights reserved)

to establish an alliance against the Trojans. Native Americans also used it internally for a range of conditions: as a diuretic; for fevers, colds, coughs, and internal pains; and for diarrhea, among others (Applequist & Moerman, 2011).

Finally, among the 49 American species of cranesbill, or wild or hardy geranium, the one most favored as a medicine by native peoples was *Geranium maculatum*, the spotted cranesbill (Fig. 8). A favorite of a number of Midwestern tribes, Menominee, Meskwaki, and Ojibwa used it for diarrhea, sore gums, and toothache; its use by the Iroquois can show us some important elements in the medical thinking of non-western peoples (Herrick & Snow, 1995). As it goes to seed, *Geranium maculatum* develops a series of very distinctive hooks from its peduncle which hold newly formed seeds (Fig. 9). These hooks, for the Iroquois, were distinctive and important, putting it in a special category of plants with “hook-like or ensnaring features,” along with a number of other plants like the Canadian anemone, *Anemone canadensis*, which has spiky hooks on its seeds, as does the purple avens, *Geum rivale*, and a number of other species. The Iroquois utilize most of these for conditions of eversion, or looseness, or escape, like cold sores or diarrhea. The idea is that the hook-like, ensnaring quality of the plant will engage, or grab, or capture the looseness and pull it back, and so a tea of



Ethnobotany in Native North America,
Fig. 9 Cranesbill or wild geranium, *Geranium*
maculatum; hooked seeds (Copyright D. Moerman. All rights reserved)

the roots is used to wash a chancre sore, and a poultice of dried root is applied to the unhealed navel of an infant. And so the ethnopharmacologists are happy when they find that the geranium root contains substantial quantities of tannin which is a strong astringent, hence “validating” this usage. But the wild geranium has more uses than that. Suppose one suspected that his wife were having a flirtation with another man. Putting a bit of geranium root or flower in her food or drink might capture her and bring her back. Likewise if you are trying to sell some baskets, you could sprinkle them with geranium root tea to ensnare a buyer (and I can attest that books with drawings of wild geraniums included in them sell better than ones that don’t). There is more to medicine than chemistry (Moerman, 2002). In addition, no garden is complete without



Ethnobotany in Native North America, Fig. 10 Horticultural hardy geranium (Copyright D. Moerman. All rights reserved)



Ethnobotany in Native North America, Fig. 11 Horticultural hardy geranium (Copyright D. Moerman. All rights reserved)

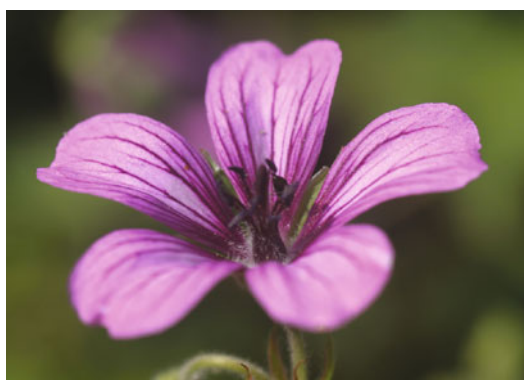
an assortment of wild geraniums (Figs. 10, 11, 12, 13, and 14).

The medicinal knowledge of native North American peoples is extraordinary. Just how this knowledge was developed remains a mystery. Native American peoples came from Asia; the flora of Asia is in many ways similar to that of North America (Duke & Ayensu, 1985). It is quite likely that the first migrants to the New World brought with them detailed knowledge of medical botany, much of which was applicable to this new flora.

Most remarkable, however, may be this: I am unaware of any significant medicinal use of any indigenous American plant species which was



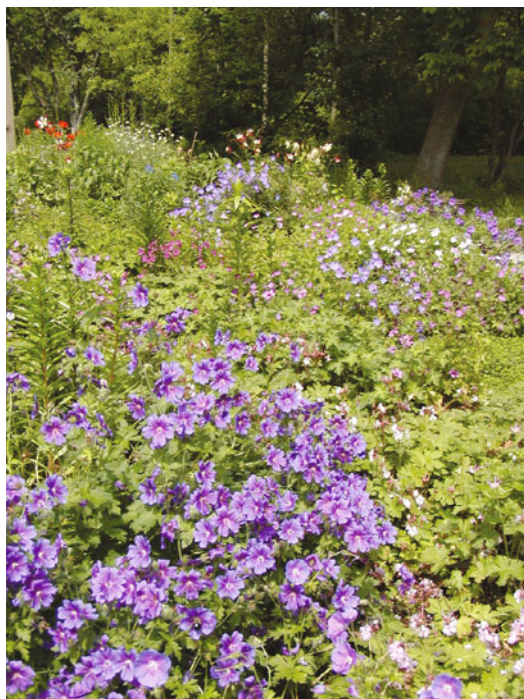
Ethnobotany in Native North America, Fig. 12 Horticultural hardy geranium (Copyright D. Moerman. All rights reserved)



Ethnobotany in Native North America, Fig. 13 Horticultural hardy geranium (Copyright D. Moerman. All rights reserved)

not used medicinally by one or another Native American group. An interesting example involves recent research on taxol, a substance of great medical value found in the common yew, *Taxus brevifolia*, and the Canadian yew, *Taxus canadensis*. Taxol has shown substantial effect in the destruction of tumors in a number of forms of cancer, particularly ovarian cancer, until now a highly refractory form of the disease. Native Americans did not use yew to treat cancer (see above), but they did use it for a variety of other conditions, among them skin problems, wounds, rheumatism, and colds.

In general, if one were interested in finding potentially useful botanical chemicals from the North American flora, it would clearly be wise to focus first on that portion of the flora which had



Ethnobotany in Native North America,
Fig. 14 Spring garden dominated by horticultural hardy geraniums; also columbines, *Aquilegia canadensis*, and poppies, *Papaver somniferum* (Copyright D. Moerman. All rights reserved)

been used by Native Americans. Their experience and knowledge can yet guide our scientific efforts to enhance human health.

See Also

► [Medicine of Native North Americans](#)

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Ethnobotany in Pakistan

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Ethnobotany is a very broad discipline and covers all types of human-plant interactions. It is the study of how the people of a particular culture and region make use of plants. However, there are also other definitions, such as the use of plants in early societies. According to Heinrich and Bremner (2006), ethnobotany investigates the relationship between humans and plants in all its complexity and is usually based on a detailed observation and study of the plants used by a society, including all its cultural beliefs and practices associated with that use. In Pakistan the field of ethnomedicine is quite virgin. The indigenous use of plants is a common practice, but ethnobotanical studies are still on a documenting level (Shinwari, 2010).

Ethnobotanical studies generally identify locally important plant species and document traditional knowledge for the discovery of crude drugs and modern-day drugs. Medicinal plant products have been used successfully for various ailments both externally and internally. Despite the increasing use of synthetic drugs, plant materials have persisted as the treatment of choice as they have no or fewer side effects (Halberstein, 2005).

Medicinal plants are also important for the livelihoods of poor communities all over the world. One cannot separate poverty from threats to biodiversity conservation. Pakistan is a developing country with 150 million people. Each child born inherits an average debt of Rs. 4,400 (US \$80). About 32 % of Pakistan's population has a monthly income of Rs. 650 (US \$11). Infant mortality is 83.3 per thousand (compared to Thailand's 28, Indonesia's 41, Bangladesh's 60). Global borrowing, shrinking incomes, diseases, lower average ages, and greater mortality are all moving the majority of the world's population to desperation.

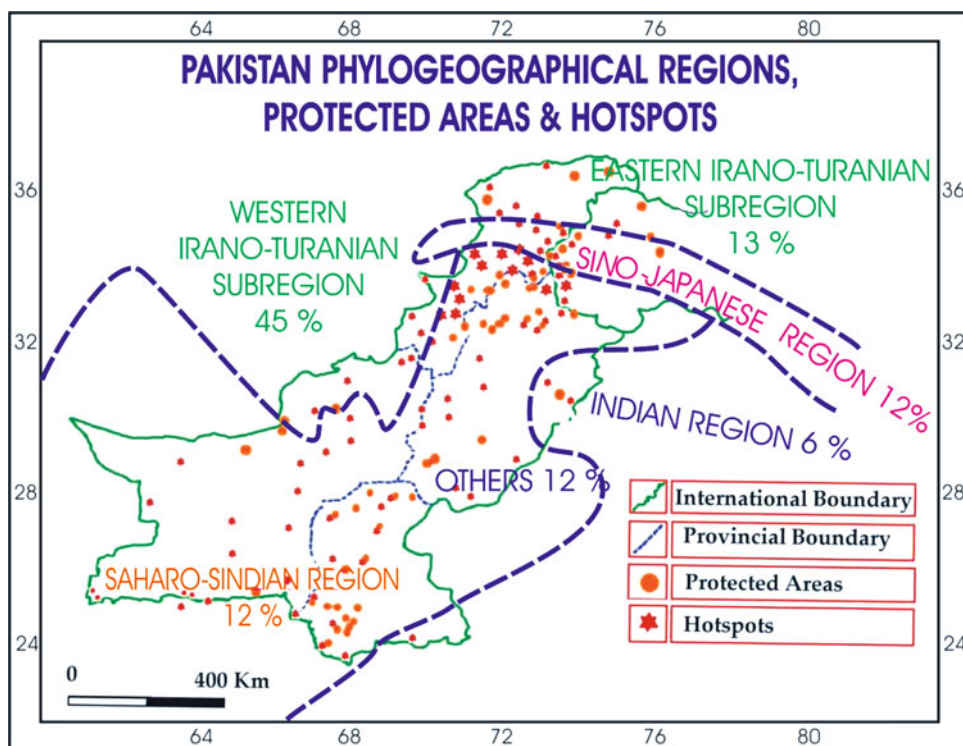
Pakistan has varied climatic and ecological zones and topography along with vast floral diversity. It contains nearly 6,000 species of flowering plants of which 70 % are uniregional (Shinwari, 1996). Among these, 2000 are considered to have therapeutic potential, but so far a large proportion of them are not explored for their medicinal values. In active trade of these plants, there are about 456 medicinal plants, which are used to manufacture more than 350 classical formulations. There are 39,584 hakims, 130,000 homeopaths, and 455 aids registered in Pakistan where about 457 Tibbi dispensaries and clinics provide medication to the public. Among these, 95 dispensaries have been established under the provincial departments of Local Bodies and Rural Development. There are 300–350 herbal/Tibb-e-Unani-manufacturing companies and around 300 companies manufacturing homeopathic medicines (Hussain et al., 2009; Shinwari & Qaiser, 2011). Pakistan has four phytogeographical regions: (1) Irano-Turanian (46 % of species confined to Pakistan), (2) Sino-Himalayan (10 %), (3) Saharo-Sindian (9.5 %), and (4) Indian element (4.5 %). Despite

the Saharo-Sindian region being the biggest area, the diversity of species confined to this area is lowest for any phytogeographical region (Ali & Qaiser, 1986; Fig. 1).

Ethnobotanical plant resources can be divided into two broad categories:

1. Ethnobotanical resources: plants used directly by local communities for food, forage, fiber, timber, medicine, ceremony, symbol, or income.
2. Phylogenetic resources: plants processed or manipulated to extract genes or DNA for crop improvement, cells for tissue culture, or chemicals as precursors of pharmaceuticals.

Approximately 25 % of drugs prescribed worldwide come from plants, with 121 such active compounds in current use (Rates, 2001). There are 252 drugs considered as basic and essential by the World Health Organization, of which 11 % are exclusively of plant origin, while the majority of synthetic drugs also have plant precursors. Local communities in different regions of Pakistan have centuries-old knowledge concerning traditional uses of most of the plants in their areas. Not only in Pakistan but also worldwide, the people of remote areas used to get self-defense against many pathogens due to different organic and inorganic chemicals present in herbal biodiversity (Nadeem, Shinwari, & Qaiser, 2013). Some of the important plants are commercially harvested for the extraction of various types of active ingredients. Even though the systems of *Unani* and *Ayurvedic* medicines are largely based on plants, the precious wealth of indigenous knowledge is in danger of being lost. Many Pakistani scientists have documented this natural treasure of the country in a number of national and international journals. They demonstrated local names, flowering periods, parts used, complete recipes, and the sicknesses cured by these plants (Nadeem et al., 2013). Documentation of traditional knowledge on medicinal plants is still carried out in many parts of the world. The main reasons for such efforts to continue are poor transmission of the knowledge to younger generations, the potential use of this knowledge in the



Ethnobotany in Pakistan, Fig. 1 Pakistan phylogeographical regions, protected areas, and hot spots

exploitation of plant pharmaceutical industries, and the need to conserve rare or highly demanded plant species in traditional medicine (Ong, Zuki, & Milow, 2011). The use of traditional knowledge must also reflect the values embedded in the traditions upheld by elders, especially with regard to medicine. Practitioners know that respecting plants is essential to the efficacy of medicines, which should be seen as having curative energy that draws its medicinal qualities from a relationship between the plants and the people (Juden, 2003).

Pakistan occupies a unique position among developing countries as it has a good potential within the variety of medicinal plants due to its varied climatic and edaphic factors, which reflect diversity and valuable medicinal plant heritage (Ali & Qaiser, 2005). Overharvesting of medicinal plants for commercial purposes has threatened their abundance and even their occurrence. Detailed surveys were conducted to document species of priority for commercial harvesting.

Priority species chosen by the Ministry of Food, Agriculture, and Livestock (MINFAL) and two major herbal facilities in Pakistan (Hamdard and Qarshi) are listed in Tables 1, 2, and 3.

The plant hotspots of Pakistan are spread over 13 natural regions from alpine pastures to mangrove forests. More than 10 % of the flora are endangered (Shinwari, Gilani, Kohjoma, & Nakaika, 2000; Shinwari, Gilani, & Shoukat, 2002; Fig. 2). This is because of environmental problems including population pressure, poverty, poor quality of the natural resource base, breakdown of social institutions, lack of land-use plans, and lack of enforcement of existing rules.

Global efforts to conserve and protect the natural environment are a recent phenomenon, though efforts to conserve economically important natural resources have a long history. Ethnobotany and conservation are inseparable and conservation is one of the most valued tasks of ethnobotanists. In addition to conservation techniques, communities also need to be educated on the importance of

Ethnobotany in Pakistan, Table 1 Some recent studies on the documentation of ethnobotanically important plant species in Pakistan

Location	Province	Number of ethnobotanically important species	References
War-affected region	Northwest of Pakistan	107	Adnan et al., 2014
Tehsil Kabal, Swat	KP	140	Ahmad, Ibrar, Barkatullah, & Ali, 2011
Chail valley of district Swat	KP-Pakistan	50	Ahmad et al., 2014
Patriata, New Murree	Punjab	93	Ahmed et al., 2013
Swat	KP-Pakistan	106	Akhtar, Rashid, Murad, & Bergmeier, 2013
Kurram Agency	FATA KP-Pakistan	21	Hussain et al., 2012
Parachinar, Kurram valley	FATA KP-Pakistan	26	Hussain et al., 2013
Kabal valley, Swat	KP-Pakistan	209	Ilyas et al., 2013
District Lodhran	Punjab-Pakistan	89	Ismail & Nisar, 2010
District Kohistan valley	KP	26	Jan et al., 2010
Poonch valley	AJK Pakistan	56	Khan, Khan, Mujtaba, & Hussain, 2012
District Bannu	KP-Pakistan	50	Khan, Mehmood, Khan, & Jaffar, 2013
Neelum	AJK Pakistan	40	Mahmood, Malik, Shinwari, & Mahmood, 2011
Hazar Nao forest	District Malakand KP	90	Murad et al., 2012
Banda Daud Shah	District Karak KP	58	Murad et al., 2013
North Waziristan	FATA KP-Pakistan	88	Qaisar et al., 2013
Swat	KP-Pakistan	12	Sarwat, Shinwari, & Ahmad, 2012
Kohat Pass	KP	60	Shinwari, Qureshi, & Baydoun, 2011
South Waziristan Agency	FATA	50	Ullah et al., 2013
Central Punjab	Punjab-Pakistan	35	Zereen, Khan, & Ajaib, 2013

conservation of local ecosystems and, with that, their socioeconomic conditions.

There is a rising trend to shift resources from allopathic to traditional healthcare systems. For example, in Japan, the Society of Oriental Medicine Studies was established by 98 members interested in Kambo (traditional Japanese medicine). Today, it has about 10,000 members of whom 80 % are allopathic doctors. Back in

1967, health insurance companies approved only four Kambo prescriptions. Today, there are more than 200 approved prescriptions.

There is a need to cultivate medicinal plants (MPs). In Lucknow (India), medicinal plants worth Rs. 90 million are grown annually. In China, in the year 2000, the total output value of the pharmaceutical industry was 233 billion yuan (US \$28 billion). By the year 2010, the share of

traditional Chinese medicine in the international market is projected to improve from 3 % to 15 %. Pakistan exports of high value plants generated over US \$10.5 million annually in 2012 (Sher, 2013).

Ethnobotany in Pakistan, Table 2 Priority species by MINFAL

Scientific name	Local name
<i>Apium graveolens</i>	Ajmood
<i>Carum copticum</i>	Ajwain
<i>Cassia angustifolia</i>	Sana-Makki
<i>Cassia senna</i>	Sana-Makki
<i>Curcuma zeodaria</i>	Aania Haldi
<i>Foeniculum vulgare</i>	Sonf
<i>Hyocyamus niger</i>	Ajwain Khurasani
<i>Lawsonia inermis/alba</i>	Barg-e-Hina
<i>Matricaria chamomilla</i>	Gul-e-Baboona
<i>Nigella sativa</i>	Kalonji
<i>Rosa damascena</i>	Gul-e-Surkh

Major Issues Pertaining to Medicinal Plant Cultivation, Conservation, and Income-Generation in Pakistan

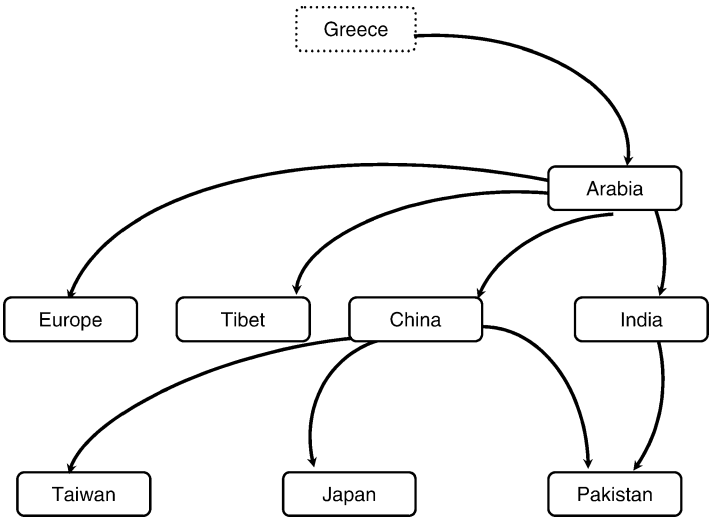
Following are the major issues concerning medicinal plants in Pakistan:

- Potential of medicinal plants: commercializa-
tion, economic growth, and prosperity
- Increasing demand of herbal medicines
globally
- Illegal collection/extraction from wild
populations with the reduction of many valu-
able species
- Traditional healthcare system and extinction
scenario
- Policy issues relating to promoting large-scale
cultivation and conservation

Ethnobotany in Pakistan, Table 3 Species, prices, quantities, and values of medicinal plants (Hamdard Laboratories (Waqf), Pakistan)

Scientific name	Common name	Average price (Rs. per kg)	Quantity collected (kg)
<i>Lavandula officinalis</i>	Ustukhuddus	320	3,000
<i>Achillea millefolium</i>	Baranjasif	285	6,000
<i>Viola odorata</i>	Gul-e-Banafsha	550	2,000
<i>Carum carvi</i>	Zeera siya	495	2,500
<i>Onosma bracteatum</i>	Gul-e-Gaozaban	290	1,500
<i>Berberis aristata</i>	Zarishk	238	2,000
<i>Polypodium vulgare</i>	Bisfajj	250	4,000

Ethnobotany in Pakistan, Fig. 2 Trade chain of medicinal plants showing its possible origin from Greece



Ethnobotany in Pakistan, Table 4 Species, prices, quantities, and value of medicinal plants (Qarshi Industries (P) Limited, Pakistan)

Scientific name	Common name	Average price (Rs. per kg)	Quantity collected (kg)
<i>Plantago ovata</i>	Ispaghol Musallam	225	2,300
<i>Achillea millefolium</i>	Saffron	30,000	5
<i>Viola odorata</i>	Gul-e-Banafsha	550	2,000
<i>Carum carvi</i>	Zeera siyah	400	2,500
<i>Lavandula officinalis</i>	Ustukhuddus	320	3,000
<i>Onosma bracteatum</i>	Gul-e-Gaozaban	290	1,500
<i>Berberis aristata</i>	Zarishk	238	2,000
<i>Polypodium vulgare</i>	Bisfaij	250	4,000

Ethnobotany in Pakistan, Table 5 Medicinal plants of Pakistan

Total species of higher plants (medicinal and nonmedicinal)	About 6,000
Species used as medicine	(10 %) > 600
Species available in the market	>300
Wastage from collector to consumer	>50 %
Price difference from collector to consumer	>100 %
Availability of quality material	Questionable
Trained collectors	None

Twelve percent of Pakistani flora is used in medicines, and more than 300 medicinal plants are traded (Table 4). The ten leading Dawakhana (herbal manufacturers) of Pakistan annually consume more than 2 million kg of 200 medicinal plants (Table 5). Some of the medicinal plants in the Unani system seem to have originated in the medicine of ancient Greece (Fig. 2).

Almost all medicinal plants in Pakistan are wild. Local collectors are sometimes unaware of the best collection procedures. Medicinal plants from the sites of collection to the national and international markets pass through various middlemen. Consequently, the prices of the crude drugs increase more than 100 % along the trade chain. The flora of Pakistan is also threatened because of rapid infrastructural development (roads, building construction), population explosion, spread of irrigation systems, and pollution.

Twenty-two species of medicinal plants worth Rs. 14.733 million were traded in 1990; in 2002, this value rose to more than Rs. 122 million. In 1990, 95 species were consumed worth Rs. 36 million, while in 2002, medicinal plants

worth Rs. 218 million were consumed (Shinwari et al., 2002).

Deforestation in the Himalayas is generally attributed to demographic pressure and other related effects: (1) increase in demand for land for cultivation, (2) livestock population, and (3) use of the remaining forest to meet growing needs for fodder, fuelwood, and timber. On the other hand, social issues, such as social relationships, perceptions and values about natural resources as seen by different social groups, issues of access to and control over resources, and issues of power in relation to deforestation, have rarely been discussed in current literature as possible driving forces to deforestation (Saxena et al., 2001).

Thousands of Afghan refugees have taken shelter in Pakistan. They are dependent on plants for their daily domestic needs. The Ghamkol area, Peshawar road in Kohat, for example, was rich in *Berberis lycium* and *Delphinium kohatense*. The Ghamkol Refugees Camp was established in the early 1980s. Today, *Berberis lycium* and *Delphinium kohatense* are lost from the area (Shinwari et al., 2002). Because of such trends, many of the species, especially those having medicinal values, are becoming threatened (Tables 6 and 7).

According to Chaudheri and Qureshi (1991), nearly 37 % (266 species) of the total of 709 endangered species are endemic to Pakistan. A recent study has revealed that there are over 600 endemic species of Indo-Pakistan (Shinwari et al., 2002; Table 8). The center of evolutionary radiation is Kashmir, northern Balochistan and Chitral (northern Pakistan).

The rapid loss of floral and cultural diversity and the poverty of 30 % of the people in Pakistan make it urgent that we find solutions to their problems and to take active roles in making decisions about the management of natural resources and about the legal status of their traditions and knowledge.

WWF-Pakistan is playing a leading role toward conservation and sustainable management of plant resources. Keeping in view the floristic richness, local uses, danger of loss of knowledge, conservation status, and endemism, the Ethnobotany Project (then headed by one of the authors of this report) introduced ethnobotany as a subject at M. Sc., M. Phil., and Ph. D. levels in various universities.

Ethnobotany in Pakistan, Table 6 Annual consumption of important medicinal plants used by ten leading Dawakhana (Data from 1990, published by NIH-Pakistan)

Category	Average consumption (million kg)	Total value (million Rs.)
20 species used >10,000 kg year ⁻¹	0.33	5.6
80 species used >1,000 kg	0.26	8.2
100 species used <1,000 kg	0.05	1.4
Total 200 species	0.63	15.2
Estimated production 4-2 million kg	1.27	30.4

A project initiated in 1997 as a collaborative effort between WWF-Pakistan and the people and plants joint program of UNESCO, WWF, and the Royal Botanical Gardens, Kew, had the aim of developing an applied ethnobotany project to investigate the status of fodder and fuelwood management at Ayubia National Park (ANP) and in its periphery. The project, currently known as Ayubia Ethnobotany Project, also aimed at providing recommendations for improvement of fodder and fuelwood management systems, as well as implementing some activities to contribute toward greater sustainability of plant resources at ANP and in the surrounding forests. The overall objectives of the people and plants program in Pakistan were to (1) strengthen the capacity for work in applied ethnobotany in Pakistan through a program of training of young professionals and students and (2) achieve better integration between conservation and development at selected field sites.

The work conducted at ANP and in the surrounding forests was thus developed in order to provide a model, where the aim is to improve the management of forests including fuelwood and fodder resources outside the National Park. The aim was also to encourage agreements between communities from local villages and the Forest Department for joint management of forests in which communities have certain rights of use. This would reduce pressure on plant resources in the National Park.

Ethnobotany in Pakistan, Table 7 Total flora and medicinal plants of the hot spots of Pakistan and their current status

Region	Size of flora (number of species)	Total number of medicinally important species	Threatened flora (number of species)
Chitral	±1,600	800	150
Kashmir	1,500	900	200
S. Waziristan	425	323	??
Sindh	1,185	700	100
Hazara	1,759	>1,000	??
Swat	1,550	500	87
Balochistan	1,330	700	>150
Kurram Agency	1,200	>600	>100

Ethnobotany in Pakistan, Table 8 Endemic plants of Pakistan (Modified from Ali and Qaiser (1986))

Area	Number (%)
Endemic in Kashmir (both the sides of the divide)	Over 600 (37 %)
Endemic in Alpine-Hindukush	76 (20 %)
Endemic species in Pakistan	Over 400
Bi- or triregional	Over 100
Uniregional	Over 300
Irano-Turanian	125
Sino-Himalayan	115
Saharo-Sindian	60
Mountainous areas	78 %
Other regions	22 %

Major Developmental Issues in Pakistan

Pakistan is the tenth most populated country in the world with 144 million people. Major national developmental issues are to alleviate poverty through increasing agricultural productivity and through improvement of other sectors such as industrial development and trade and tourism (UNEP & WTO, 1998). In the forestry sector, programs of afforestation have been implemented to try and meet the country’s timber and fuelwood needs. Timber harvesting through (unsustainable) logging is threatening environmental quality including supplies of some resources required by local communities (WWF-Pakistan, 2000). Local cultural and social systems are progressively fading and with them local knowledge of resource management (Shinwari, Khan, & Khan, 1996). National healthcare support at the village level is poor due to lack of facilities and qualified staff. The use of medicinal plants is therefore a necessity in many rural areas.

Women are usually responsible for fuelwood, fodder collection, and water carriage besides a host of agricultural activities. Access to fuelwood and fodder and other nontimber forest products (NTFPs) is also decreasing due to decreases in forest cover and also mismanagement of existing forests. Besides being overwhelmed by fuelwood and fodder

collection tasks, education of young girls is also affected by lack of schools for girls. As is generally recognized in South Asia (Gururani, 2002) and based on our own assessment of the situation at ANP, the link between women and resource management requires particular attention (Aumeeruddy, 1996).

Conservation Priorities

Forest cover represents only 5.2 % (4.58 million ha) of the country’s area, but the country is highly dependent on trees as well as on NTFPs (Shinwari & Khan, 2001). Scarcity of biological resources is a major concern because it represents the livelihood for a large portion of the population. Biodiversity is endangered through increase in population, timber harvesting beyond the productive potential, overgrazing in forest undergrowth as well as in pastures, unsustainable collection of NTFPs such as medicinal plants, for trade, and unsustainable collection of fuelwood (Government of Pakistan, 1998). Fuelwood is still the main source of energy in Pakistan with 90 % of the rural population and 50 % of the urban population mainly relying on it.

International NGOs such as IUCN and WWF are working on natural resource management with a strong emphasis on the role of local communities. IUCN has been involved in recording traditional management of medicinal plants in Bomberet Valley in Chitral (Ali & Khuwaja, 2003). Among local NGOs, the Aga Khan Rural Support Programme is regionally recognized for its experience related to natural resource management involving local populations in afforestation programs, cultivation of medicinal plants, and social forestry. International agencies such as the European Union (EU) and a German aid agency (GTZ) are also involved in major projects in close collaboration with the Forest Department: the European Union project “Environmental Rehabilitation in NWFP and Punjab” and GTZ “Joint Forest Management” project in Mansehra (NWFP).

Priorities for Capacity Building in Ethnobotany

Ethnobotany is a multidisciplinary science encompassing botany, anthropology, economics, and linguistics that study the way in which a society relates to its environment and particularly to the plant world. These relationships can be social, economic, symbolic, religious, ritualistic, commercial, or artistic (Aumeeruddy-Thomas & Pei, 2003). In the early 1980s, there was an increased focus on local management practices by ethnobotanists as a result of greater global concerns about the environmental crisis. A great number of ethnobotanists were then engaged in studies to understand the rationale for such practices, the functioning of local institutions relating to management practices, and their impact on the conservation of biodiversity (Aumeeruddy-Thomas, 2004).

An introductory workshop was organized in September 1996 that showed that ethnobotany in Pakistan had mainly focused on people's use of medicinal plants with relatively little concern for other plant resources. However, the practicalities related to resource management and aspects related to tenure, ownership, rights of access, and methods of harvesting have not yet been investigated. Consultation during the workshop with conservation managers, academics, NGO representatives, and practitioners such as *hakeems* (traditional doctors) showed that there is much interest in using ethnobotany as a tool to learn more about people's needs and perceptions, in order to design better conservation approaches (Table 9).

Ayubia National Park: An Example

ANP was chosen for the project in applied ethnobotany because it is representative of many situations encountered in other forested areas in NWFP-high pressure on resources due to high energy needs (because of prolonged winters and nonavailability/scarcity of alternate sources), mismanagement due to unclear access and tenure

regimes, and a high level of conflict between local communities and the Wildlife and the Forest Departments.

People heavily influence most of the vegetation in and around the park. The vegetation of ANP, which seems fairly well preserved in places, is dominated by coniferous species principally blue pine (*Pinus wallichiana*) and spruce (*Abies pindrow*) mixed with scattered broad-leaved tree species such as oak (*Quercus dilatata*), *Aesculus indica*, elm (*Ulmus wallichiana*), *Prunus padus*, etc. Populations of broad-leaved trees have declined. Blue pine and fir have colonized large areas, leaving seemingly little space for broad-leaved species to grow and relatively poor vegetation in the understory. Outside the park, forested areas are almost entirely composed of fir in the northern aspects and blue pine elsewhere.

Conservation and Developmental Issues at ANP

Forests are important in the Himalayan foothills for catchment's protection. At present, poorly regulated collection is leading to degradation of the resource base, both within and outside the park. Tree populations are decimated and regeneration is highly affected. Women have to walk very long distances to collect fuelwood and fodder, and a situation of conflict persists between the women and the park guards. Guzara forests (outside the park) do not have a clear tenure regime, and wild plant resources have greatly declined due to mismanagement, the absence of clear rules of control and access to resource. A critical social issue at Ayubia is that women are the main harvesters and users of natural resources but are also the least represented in decision-making processes. It is men who control the influential networks taking decisions regarding access to resources, tree planting, or timber harvesting.

Unlike in many other traditional societies, there is no well-developed classification or folk taxonomy. Moreover, knowledge and practices especially relating to fodder and fuelwood are

Ethnobotany in Pakistan, Table 9 Leading organizations involved in medicinal plant research and conservation (Adapted from Shinwari and Qaiser (2011))

Name of organization/academics	Resource person	Type of work
Khyber Pakhtunkhwa province		
Botany dept., Peshawar University	Prof. Farrukh Hussain	Taxonomic, ecological, and ethnobotanical
KP-Agricultural University, Peshawar	Prof. Khan B. Marwat	Ethnobotany
Kohat University of Science and Technology	Dr. Javid Hussain	Proximate analyses
Shaheed Benazir Bhutto University, Dir	Prof. Jehandar Shah	Taxonomy and ethnobotany
Hazara University	Dr. Habib Ahmed	Ethnobotany
Punjab province		
PMAS Arid Agriculture University, Rawalpindi	Dr. Mohammad Arshad	Taxonomy and ethnobotany
Punjab University, Lahore	Dr. Ghazala Nasim	Antimicrobial activities
GC University, Lahore	Dr. Zaheer-ud-Din	Ethnobotany
GC University, Faisalabad	Dr. Tehreema Iftikhar	Antimicrobial activities
Agriculture University, Faisalabad	Dr. M. Ashraf	Ex situ conservation
Sindh province		
Aga Khan University	Prof. Anwar Gilani	Ethnopharmacology
Haroon Ebrahim Jamal Institute of Chemistry, Karachi	Prof. M. Iqbal Chaudheri	Chemical properties of plants
Sindh University, Tandojam	Dr. Tahir Rajput	Taxonomy
Khairpur University	Dr. Raza Bhatti	Ex situ conservation
Karachi University	Prof. Dr. S. Ali	Taxonomy and ex situ conservation
Karachi University	Prof. Dr. Anjum Perveen	Taxonomy and ex situ conservation
Federal Urdu	University Prof. Dr. M. Qaiser	Taxonomy and ex situ conservation
Federal capital Islamabad		
National Agriculture Research Center	Ms. Shahid A. Khalid	Medicinal weeds
Quaid-i-Azam University	Dr. Zabta Khan Shinwari	Indigenous knowledge and commercial utilization
Baluchistan province		
Baluchistan University	Dr. Rasool Bakhsh Tareen	Ethnobotany
International		
International NGO's	Ashiq A. Khan	
IUCN (International Union for Conservation of Nature)		Advocacy, policy issues
WWF-P (World Wide Fund for Nature-Pakistan)		In situ conservation
SDC (Swiss Development Corporation)		Socioeconomic uplift
Leading herbal industries		
Qarshi Industries (Pvt) Ltd. Lahore		
Hamdard Industries, Karachi		
Marhaba Industries, Lahore		
Ashraf Laboratories, Faisalabad		

not linked to cosmology or larger cultural beliefs. Beyond ethnobotanical knowledge, they also have some ethnoecological expertise, such as knowledge of bird nesting or overflying the area and habits and habitats.

Wild Vegetable and Mushroom Collection in the National Park

Types of mushroom collected were mainly different species of morels, locally known as *Kali*

(black) and *Surkh* (red) Guchi (*Morchella esculenta*), Narela, and Begar Guchi (*Morchella* sp.). Kali and Surkh are phenotypic variations of *M. esculenta*, the only mushroom collected for sale. For women, collection is associated with fodder or fuelwood collection trips.

The main vegetables collected are *Kunji* (*Dryopteris stewartii*), *Mushkana* (*Nepeta laevigata*), *Kandhor* (*Dryopteris blanfordii*), *Mirchi* (*Solanum nigra*), and *Tandi* (*Dipsacus inermis*). Parts collected are young leaves for all species. The most collected vegetables are the two *Dryopteris* species, followed by *N. laevigata*. It should be noted that two of these three species are ferns. Collection season for wild vegetables is between April and the end of June (Aumeeruddy et al., 2004).

Conservation Practices

Conservation of plants involves more than plant protection and controlling access to plant resources. Conservation also demands collection of baseline data on social, economic, and ecological parameters, to be incorporated into a comprehensive management strategy. Effective conservation also requires extension activities and education about the importance of plants as well as strategic cultivation initiatives. Moreover, conservation requires the involvement and support of the communities that ultimately depend on these plant resources.

A notable lack of available information on propagation and management of important species limits the increased cultivation of plants. This lack of information is exacerbated by a paucity of quality planting materials. By increasing both the amount of available information and the quantity of local nursery-based stocks, the project hopes to leverage a substantial reduction in the pressure on wild populations of plants. Whatever information exists on the cultivation of plants is not readily available to the farmers who actually could use it.

Selection of species for study must be based on several criteria: degree of endangerment in the wild, actual or potential market value, and the

availability of existing information. To harvest medicinal plants sustainably, training of collectors, training in nursery techniques, and removal of some of the middlemen from the trading chain are essential.

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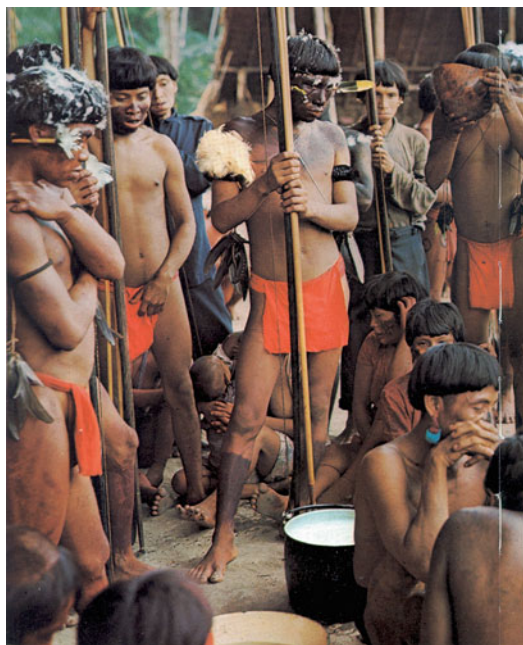
Ethnobotany in South America

Ingrid Roth

Historic Considerations

Ethnobotanical investigation started in Venezuela with the first description of useful plants by Humboldt and Bonplan (1799–1804).

The original population of South America, the Indians, came from Asia about 23,000–10,000 years ago. Today, hundreds of Indian tribes still exist, each comprising a 1,000 people or less and each with its own language or dialect. They accumulated a knowledge of the native flora over centuries or even thousands of years.



Ethnobotany in South America, Fig. 1 Ritualistic ceremony of Yanomami Indians with dances and a banquet (Courtesy Luis Cocco 1970)

Almost every primitive society has its own pharmacopoeia. The Amazon area, extending over Colombia, Ecuador, Brazil, Perú, and Venezuelan Guiana (Schultes & Raffauf, 1990), supports the most extensive tropical rainforest in the world, and rainforests are ecosystems with the greatest wealth of plant species.

The Indians searched mainly for medicinal plants which cured stomach and intestinal problems, inflammations, skin diseases, intoxications, gynecological disorders and parasites. For about 5,000 years, the Indians searched for useful plants and cultivated a large number of them. The most ancient archeological findings of plants used by Indians are Cucurbit seeds about 14,000 years old, and avocados about 10,000 years old. Cultivation of plants and agriculture were started, at the latest, about 5,000 years ago (Brücher, 1989). South and Central American Indian tribes improved the yield and quality of numerous crop plants which today enrich our daily diet. Indians carried out experiments for possibly hundreds of years, but they may also have been

Ethnobotany in South America, Fig. 2 Cacao flowers and fruits emerging from the stem (Roth & Lindorf, 2002)



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accustomed to certain poisonous substances or more resistant to local drugs.

Indians not only supplied us with valuable goods, but also transmitted their language.

On the Origin of Common and Some Latin Plant Names

In tropical regions, plant identification is most difficult. Most of the plant families have their own specialist somewhere in the States, in the Netherlands, or in other countries so that the material has to be sent to them where it may rest for years or decades until identification is settled and sanctioned. In the meantime, one is dependent on the local and common names which – in

many cases – are very useful and unmistakable. In Venezuelan Guyana, there was a peasant without any scientific training who could distinguish most of the 280 collected specimens, even separating the species from one another, relying thus only on common names. A binary nomenclature is frequently used so that sometimes a perfect correspondence between scientific and common names is maintained: *Guamo*, for example, corresponds to the genus *Inga*; and each species also has a species name. *Inga alba* carries the vernacular species name *colorado*, which means colored (*Guamo colorado*). *Inga capitata* is called *Guamo negro* (black Guamo), *Inga rubiginosa* corresponds to *Guamo terciopelo* (velvety Guamo), and so on. The complication which arises from this nomenclature is its regional

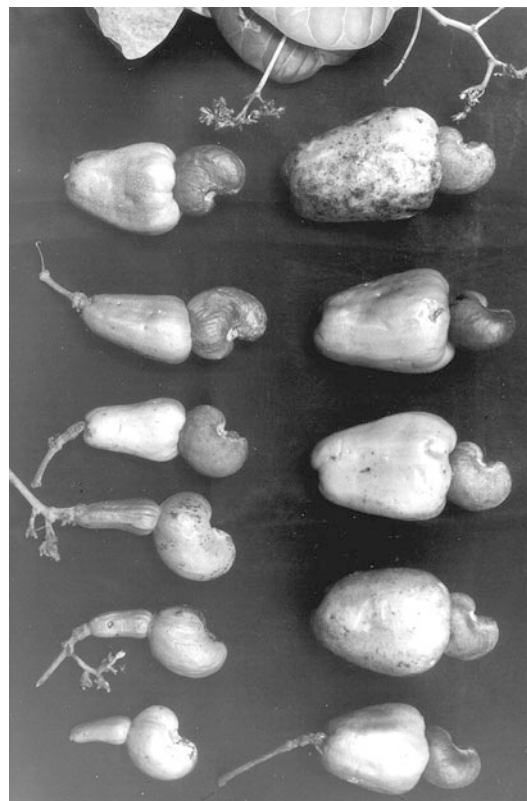
Ethnobotany in South America, Fig. 3 Right: a longitudinal section of cacao fruit with seeds (Roth & Lindorf, 2002)



restriction, so that a species called *Guamo colorado* in Venezuelan Guyana may have a completely different name in other parts of Venezuela. Also, the name *Guamo colorado* may be applied for two completely different species belonging to different families in geographically different regions. Great caution in the application of these names is therefore indicated, and information about the geographical origin of the species in question is indispensable.

Within the mixed-up jungle of common names, this author made the observation that some words were obviously of Spanish origin while others had an Indian sound. After the conquistadores had entered the country, many of the original Indian plant names were altered. A *palo de Maria* (*palo* = pole, stem; in Venezuelan Spanish, it is a tree) corresponding to *Tachiglia paniculata*, or Santa Maria (*Triplaris surinamensis*), San Jose (Saint Joseph = *Jacaranda obtusifolia*), or Nazareno (from Nazareth = *Peltogyne pubescens*) certainly resulted from attempts to Christianize the Indian world. A great part of the common names are thus of Spanish origin, created soon after the

colonizers arrived. Names were given by using personal names such as Don Juan, or recognizing special characteristics of the plants such as *azucarito* (sugary) or *espinas de erizo* (spine of the hedgehog). The Spanish name *sangrito* (bloody, bleeding) for *Pterocarpus* refers to the red secretion from the bark; *cenizero* (ashtray) relates to the old powdery bark; the name *jabón* (soap) comes from the smell of the fresh bark. The name *kerosen* indicates the propensity of the cork to catch fire when lit with a match; the *zapatero* (shoemaker) has a fruit in the shape of the sole of a shoe. Other names refer to characteristic colors, geographical origin (*montanero* = from the mountains, *sabanero* = from the savanna), to similarities and comparisons with animals (*pata de zamuro* = claw of the vulture; *burro muerto* = dead donkey; *cabeza de mono* = head of the monkey); and many other designations which are more remarkable for their oddity than their characterization of the plant. Some names, however, such as *conserva* (canned food), certainly a very recently applied name, have little or nothing to do with the appearance of the plant.



Ethnobotany in South America, Fig. 4 Double fruit of *Anacardium occidentale*: a nut develops from the real fruit; the stalk below transforms into a fleshy pseudofruit (Roth & Lindorf, 2002)

Many species, on the other hand, were compared with the indigenous European plants and some of them recognized more or less correctly by the Spanish colonizers, such as certain Lauraceae of the genera *Aniba*, *Endlicheria*, *Ocotea*, and *Nectandra* which received the generic name Laurel (for example: yellow Laurel, black Laurel). However, it may be possible that some of these names were given relatively recently by people already trained in Botany. Rollet's Laurel, certainly, is a very recent creation in honor of Dr Rollet. *Higuerón* (fig) for *Ficus* is also correct. Most of the comparisons with the indigenous European plant species, however, are very unsuccessful falsifications which have nothing to do with the European genera or species after which they were named. *Cedro dulce* (the sweet

cedar) is *Eriothea*, Bombacaceae; *Crudia*, Caesalpiniaceae, is called *algarrobo* (carob); *Caryocar nuciferum*, Caryocaraceae, became an almond (*almendra*); *Platymiscium*, Papilionaceae, was made an oak (*roble*); and *Swartzia schomburgkii*, Papilionaceae, was transformed into an olive tree (*olivero*). The name *uvero* (grapevine) for *Coccoloba*, Polygonaceae, refers to the clustered grape-like infrutescence of this tree. *Touroulia guianensis*, Quinaceae, is called *palmito*, but it has nothing to do with palm trees, and *helecho* (fern) corresponds to *Dilodendron*, Sapindaceae, which has no relationship with ferns.

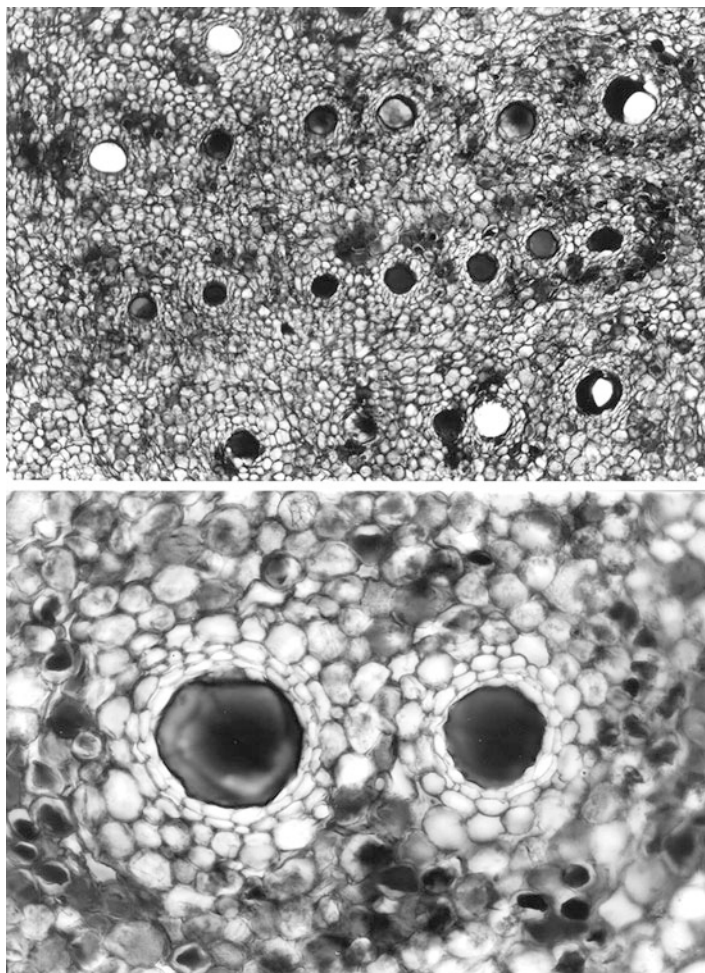
As mentioned above, in many cases we can only guess in which historical period names were given, whether soon after the conquistadores had entered the country (Christian names) or only recently by botanically trained people (as Laurel Rollet). Some species of *Sapium*, Euphorbiaceae, are, for example, designated as *caucho* (rubber), probably a name of Indian origin.

Many of the originally applied Indian names may have been much more meaningful than the later Spanish names. In the jungle of names even some of Arabic origin appear; these were first assimilated from the Arabs by the Spanish people and came from Spain via the conquistadores to South America. *Jebe* (*Lonchocarpus sericeus*, Papilionaceae) is an Arabic name. Checking a complete plant list with over 270 species the author found that about 50 % were of Indian origin. But it is very difficult to find them out. Not all names which mean nothing in Spanish are Indian names.

Within the approximately 370 known Indian tribes, 125 different language families are distinguished, not counting dialects and individual languages. The fact that no fundamental language type unites all these different tongues complicates any investigation. Best studied are probably the Mexican Indian languages. Indian plant names from Mexico sound different from Venezuelan names. In Venezuela, however, philological studies of Indian languages are hardly cultivated. Checking a dictionary of Yanomami, no word referring to a plant name could be found.

Ethnobotany in South America,

Fig. 5 *Anacardium occidentale*, transection of the fleshy false fruit with resin canals (Roth & Lindorf, 2002)



However, some names of very different Indian origin, such as Chibchua, Quechua, Náhuatl, Taino, Caraibic, Guarani, Araucanic, Tupi, or Guaicurü (from Mexico, Brazil, Peru, Chile, and the Caribbean) were adopted in other South or Middle American countries and are now known all over the world. From the Taino came such common words as *maiz*, *tabaco*, and *sabana*. From Náhuatl (Mexico) we have *aguacate* (avocado), *cacao*, chocolate, tomato, potato, and chicle. *Colibri* (a bird) comes from the Caraibic (or Caribic); *ananas* is from the Guarani. Quechua has contributed the words quinine and cocoa, while petunia comes from Tupi.

Some Indian words may easily be recognized by their prefixes or suffixes. The prefix *gua-* always indicates Indian origin, as in *guamo*,

guatacare, *guacharaco* or *guaraunera*; Guatemala is also an Indian name). *-Gua* also appears at the end of the word in *majagua*, or in the middle of the word, as in *masaguaro*. The suffix *-cua* in Nicua or *-guo-* in Purguo is used frequently. *-Guay-* or *-guaya-* in *guayaba* and *guayabito* are other forms of Indian vocal music rich in vowels. Double vowels like *ua*, *ue*, and *uo* are frequently represented in Indian words such as *carruache*, *arahueque*, and *bocsuo* or *merguo*. The *puig* rich in vowels may be a creation of the Caribbean area, being used in Northern South America and the Caribbean Islands. In some words one may perceive the Indian onomatopoeia as in *paují*, a bird name. Double vowels are also characteristic of such words as *copey* (the Christian-Social party of Venezuela has chosen

Ethnobotany in South America, Fig. 6 Fruits of palm trees (Roth & Lindorf, 2002)



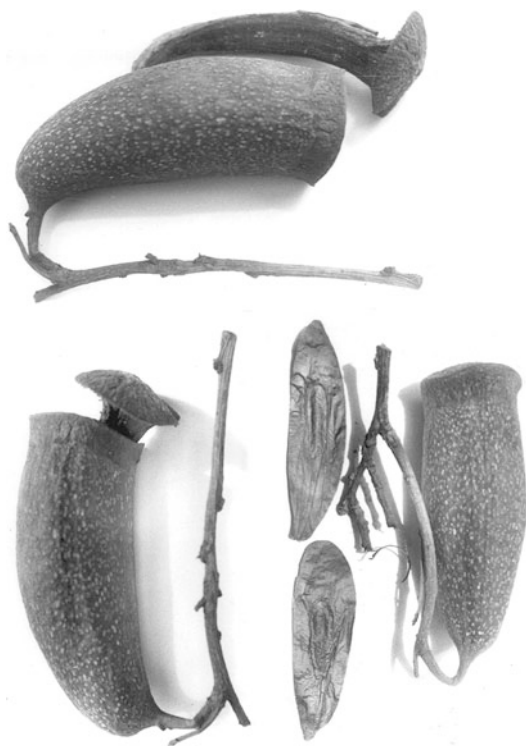
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this as its party name which is adopted from the copey tree, a *Clusia*), *cozoiba*, *cacaito*, or *yigüire*. The ending *-mán* is frequently found in such Indian words as *baramán*, *cajimán*, *samán*. The suffix *-i*, otherwise frequent in certain Indian languages, is seldom found in Venezuelan Indian names. However, the accentuated *ú* is not infrequent, as in *cacú*. The ending *-ey* as in *araguaney* and *merey* also indicates Indian origin. The ending *-tl*, on the other hand, as frequently found in Mexican Indian (Náhuatl, for example), seems to be missing in Venezuelan Indian. A repetition of a word, a twin word, is usually a reference to the Indian in such word compositions as *sun sun*, *marimari*, or *yarayara*; in Yanomami Yare means “gone with the wind” and may be the origin of the name *yarayara*, eventually referring to seed dispersal. Some of the Indian names

became part of the scientific nomenclature. Examples are *samán* (*Samanea saman*), *ceiba*, *simarouba*, *Cacao* (*Theobroma cacao*), and many others. The meanings of the Indian names are unknown. For some cultivated plants or plants of high economic value, however, the significance of the names is known. The name *caucho* or *caoutchouc* (*rubber*), in Indian *cau-uchu*, means the weeping tree which sheds tears of latex. Dozens of English words thus have their origin in one or another Indian language.

Transmission of Information

Botanical knowledge was transmitted to the present population mainly orally. It is based on the experience and experiments of Indians for



Ethnobotany in South America, Fig. 7 Pipe-like fruits of *Lecythis* with seeds (Roth & Lindorf, 2002)

hundreds or even thousands of years. It is estimated that at least 20 alimentary plant species were cultivated on the continent by Indians before the arrival of Columbus in 1492. The Andean Incas trained pharmacognosts specialized in the search for new natural drugs. In the Maya culture, illustrated books called codices were elaborated in which preparations of medical plants are described. The oldest book dates back as far as the tenth century. Dr M. de Cruz had already described 250 curative plants in 1552. The Incas, however, unfortunately did not draw the plants.

Inca Medicine

Inca medicine was divided into a magic-religious branch administered by the priest of the Temple of the Gods and an empirical branch practiced by

the curanderos (healers) (*Primera nueva cronica y buen gobierno* of Felipe Poma de Ayala in 1613) (Albornoz, 1993).

Illness and death were connected with religion and mysticism. Indians believed that they were caused by magical sources. Consequently, shamanistic use of hallucinogenic plants was well developed. Healing was accompanied by ritual dances, dances imitating animals, black magic, exorcism, faith healing and the use of amulets. Astrology was integrated into the healing methods of the ancient Indians. Medicine men collected roots and other vegetable parts in the woods while singing and praying. They applied the theory of signatures, just as Paracelsus did in the sixteenth century, suggesting that each plant resembled the part of the human body which it could cure (Albornoz, 1993).

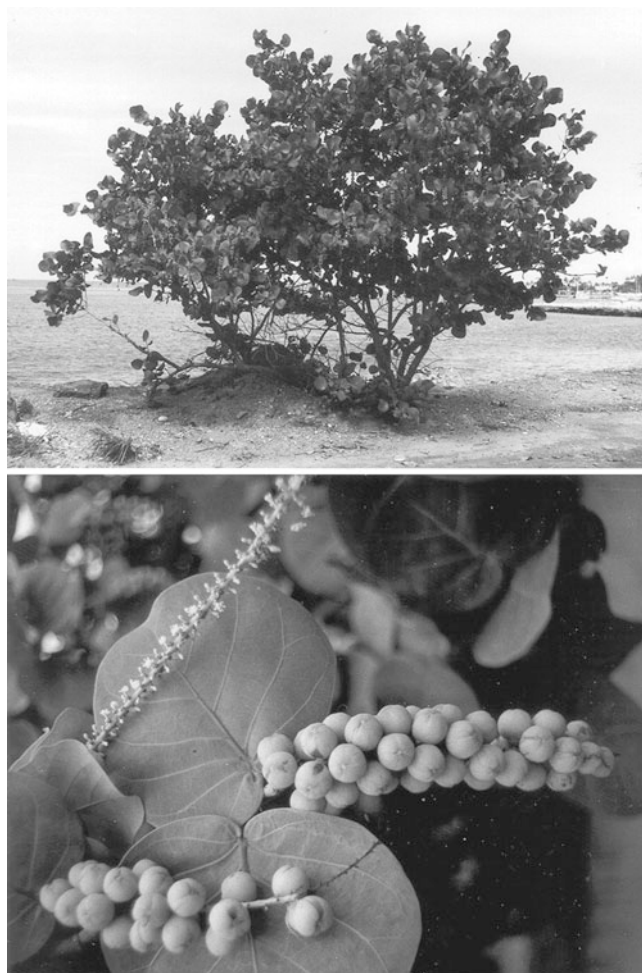
Sick people were cured with massages, suction, vapor blowing, or cataplasms. Shamans acted as intermediates between people and the gods. The Indians used plants in rites and religious ceremonies; the plants are important as they open the entrance to the spiritual world and enable the person to communicate with ghosts and gods and to develop spiritual power (Fig. 1). Species of *Nicotiana* (tobacco) were used to prepare stimulants and narcotics, as well as for medicinal, ritualistic, and hedonistic purposes. Shamans and priests employed nicotine to enter into ecstatic trances. Today, nicotine is also used as an insecticide.

Hallucinogenics of *Ebena* were smoked with blowpipes. The action of the active alkaloids started only a few minutes later, when the spirit abandoned the body to enter the world of ghosts. In this way, shamans expelled the bad ghosts from the body of the patient. *Ayahuasca* (*Banisteropsis*) alkaloids enable telepathy and prophecy. Pictures painted under the influence of ayahuasca are rich in vivid and bright colors, in symbolism and details.

Cacao was called the Food of the Gods (Figs. 2 and 3). The Indians have domesticated it since 2,000 years ago. They developed the art of planting and selecting cacao. The Indian emperor Moctezuma (Montezuma) is said to have drunk

Ethnobotany in South America,

Fig. 8 *Coccoloba uvifera*.
Above: shrub growing at the beach; below:
infrutescences
(agglomerations of fruits)
(Roth & Lindorf, 2002)



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400 cups of hot xocolatl (chocolate) a day. Cacao contains stimulating alkaloids.

Cocaine (*Erythroxylum coca*) has been cultivated in the Andes since 7,000 years BCE. The coca shrub contains the alkaloid cocaine, used as a remedy for hunger and fatigue. Indians masticate the leaves. The hydrochloride of cocaine is used as a local anesthetic. The function of the brain is altered by the use of psychoactive plants. The use of drugs is, however, prescribed by religious instructions of the tribe.

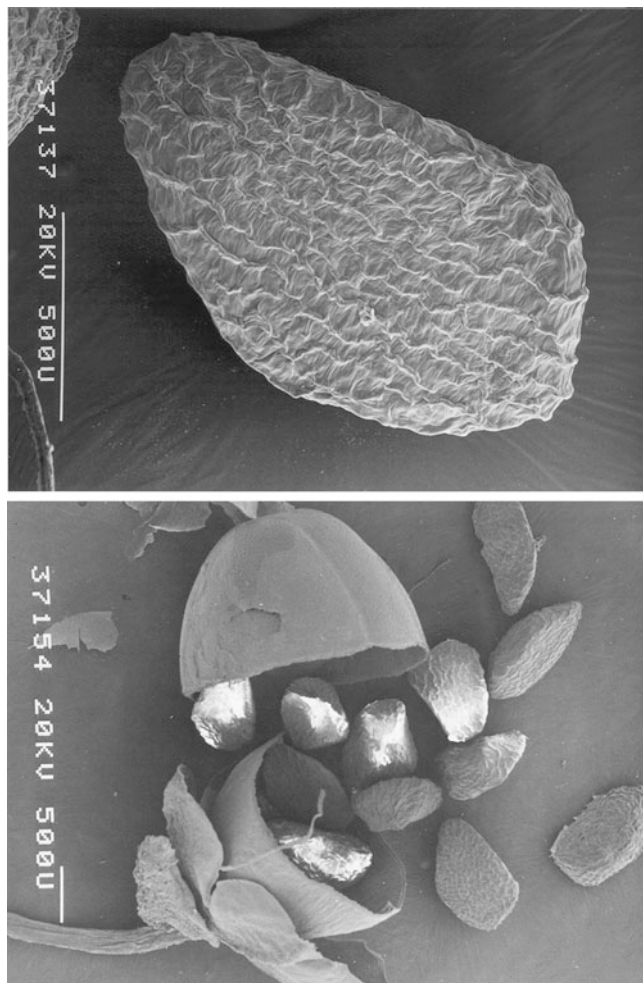
The native population can utilize almost every plant growing in their environment. The discovery of South America brought a large number of new plant species to Europe and in this way profoundly altered European habits. As a

consequence of the discovery of America, such products as maize, cocoa, potato, tobacco, and beautiful orchids improved the European standard of living. *Hevea brasiliensis* supplied the latex rubber.

Utility of South American Plants

Indians used plants to make fermented drinks, syrup, jam, and marmalade from fruits, baskets and cloth from fibers, vessels from calabashes, and housing, canoes, musical instruments, arrows, and bows, furniture and carved objects from timber. For hunting, they used fish and arrow poisons extracted from plants (curare).

Ethnobotany in South America, Fig. 9 *Plantago major*. Above: fruit, below: opened fruit with seeds. The mucilaginous seed coat has laxative effects (Roth & Lindorf, 2002)



Timbers resistant to termites were particularly useful. Some plants supply perfumes or even insecticides. Oils, resins and balsams, wax, cork, gum and rubber, glycosides, saponins, alkaloids, flavonoids, coumarin, tannins, carbohydrates, pectins, lipoids, and tars are found in South American plants. Enzymes, lectins, vitamins, vegetable sweeteners, antidotes, antibiotics, cytostatics, immunostimulants, immunosuppressives, antiallergens, and laxatives may be extracted from many plants, as well as antimicrobial substances, antioxidants, cholesterol-reducing and glucose regulating or anti-inflammatory and antiphlogistic substances. Some plants not only contain a single substance, but some contain as many as 70 different alkaloids or dozens of active substances with similar effects.

A large number of tropical plants have a variety of uses. Most medicinal plants cure quite a few diseases. These plants may also have other uses.

Other not-curative substances obtained from plants are edible plant parts, cloth, material for construction and transportation, condiments, perfumes, soap, stimulants, fibers, cork, tannins, timber, and natural dyes. The Indians also used these dyes to paint their bodies (e.g. red with *Bixa orellana*) and were consequently called red skinned people. Seeds of the cacao tree were used by Indians as currency: with 100 beans one could buy a slave. Further objects of exchange were condiments, timber, and textiles (Figs. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22).



Ethnobotany in South America, Fig. 10 Prepared and compressed bark of fig on which natives painted an Indian motive, the quetzalcoatl, or king of the birds (Roth & Lindorf, 2002)

Preparation of Herbal Drugs

Natives frequently use crude herbs. They put fresh leaves on wounds for disinfection or on the forehead to soothe headaches. Fresh fruits, seeds, and leaves may be eaten raw or plant parts may be cut to pieces, broken, shredded, crushed, ground, or pulverized. For external use, cataplasms are prepared by crushing and grinding. For internal use, a tea, decoction or infusion is prepared.

Women and Beneficial Use of Plants

Women had and still have a good knowledge of useful herbs. They know the places where to find and collect them and how to prepare them.



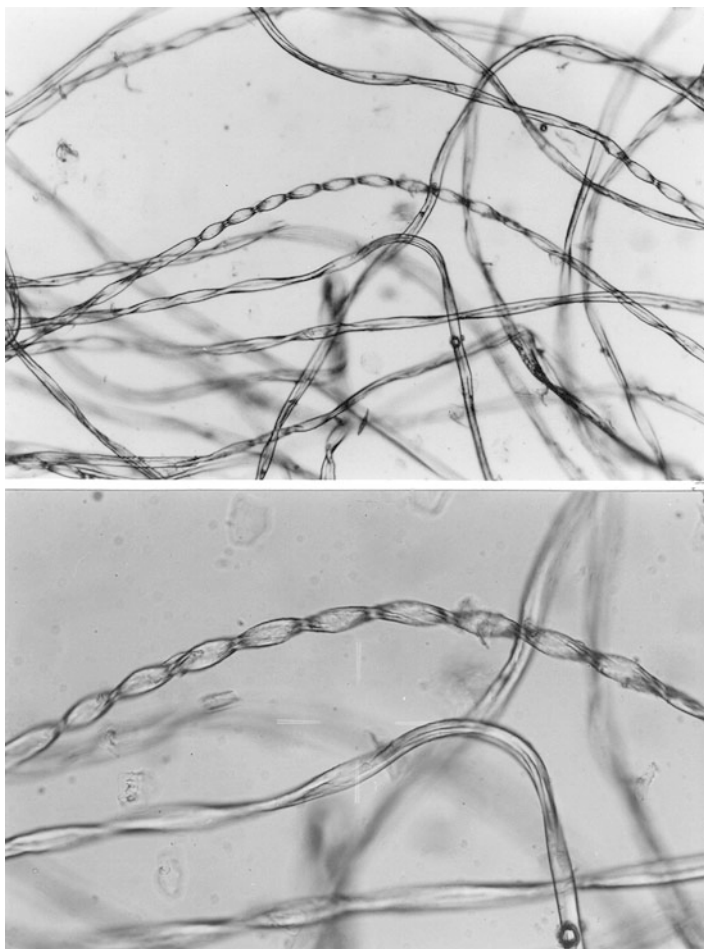
Ethnobotany in South America, Fig. 11 Picture painted by Indians on the bark of a fig (Original)

Mothers pass their knowledge on to their daughters. Many useful plants are cultivated by women in special house gardens around the house (Silva, 1999). Women likewise play their part in agriculture and are aware of the biological diversity of plants. In many places they maintain the agricultural system called *conuco* carried out in the form of small plantations (Royero et al., 1999).

Actual Use of Medicinal Plants

In 1884, the first school of pharmaceutical studies was founded in Venezuela. Although in the twentieth century interest in natural medicine declined abruptly, due to the development of chemotherapy and synthetic products, native people who live far away from urban centers, e.g., in the Orinoco delta or in large forests where no public transportation is available, plants are still the

Ethnobotany in South America, Fig. 12 Fibers of Barbados cotton under the microscope (Roth & Lindorf, 2002)



Ethnobotany in South America, Fig. 13 Woven purse made of cotton fiber with alligator motif (original)



Ethnobotany in South America, Fig. 14 Poncho (jacket) with typical Indian design (original)



Ethnobotany in South America, Fig. 15 Indian basket made of fibers of a palm tree with typical geometric design (original)

best and the most inexpensive medicine available for everybody all the time. In underdeveloped countries, 3.5 million people depend on phytopharmacy. Natural medicines also have the advantage of having been tested by Indians for hundreds of years.

Further Possible Investigation and Recommended Bibliography

The first place to find information about medicinal plants would be the *herbolarios*, open stands where healing plants are offered. They are scattered all over the country and staffed by native experts on healing plants. These people preserve the knowledge of useful plants

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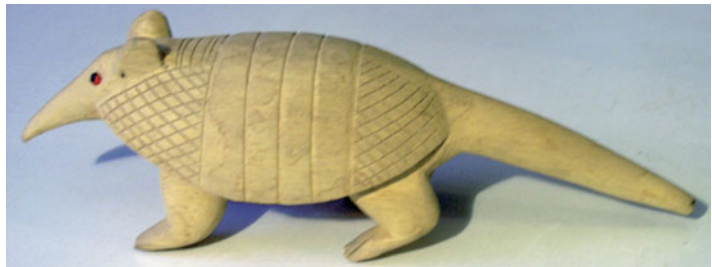
Ethnobotany in South America,

Fig. 16 Rosettes of the Andean plant *Espeletia*. The leaves are very hairy and may be used to manufacture cloth (Roth & Lindorf, 2002)



Ethnobotany in South America, Fig. 17

Balsa woodcarving, representing a daisypod of the rain forest (original)





Ethnobotany in South America, Fig. 18 Opened fruit of a Mahogany tree with brown seeds. Mahogany is a very fine and expensive timber used for elegant furniture (Roth & Lindorf, 2002)

Ethnobotany in South America, Fig. 19 Woodcarving representing a llama with its shepherd (original)

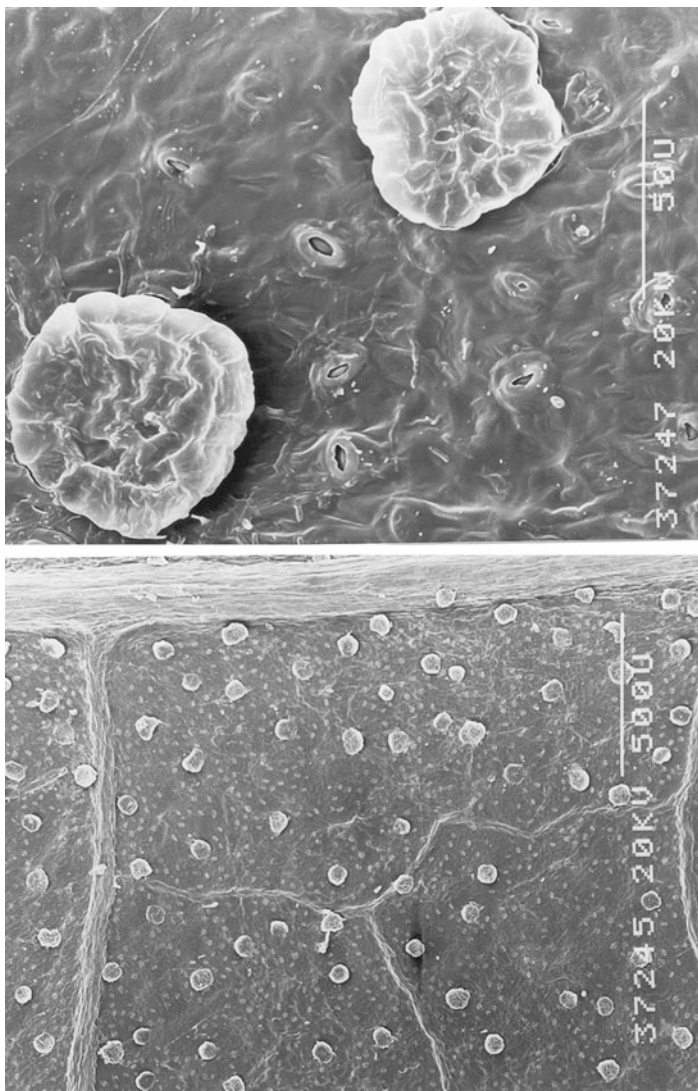


transmitted to them by their ancestors. They know exactly the right plant species, the organs which have to be used, the methods to prepare the drugs and the way to administer the medicine. They also are informed if the plant was collected wild or whether it was cultivated, and they know their vernacular and local names. Drugs of this kind have to be handled with care. Native people are accustomed to these drugs over as many as hundreds of years; other people may react in very different ways. Caution is advisable. The *herbolarios* are often found along highways or at local markets. Perhaps the most authentic information is found with the living Indian tribes, who know not only healing plants, but also narcotics (Schultes & Raffauf, 1990).

In most cases, healing substances are only found in one or another organ, or are enriched in determined organs. When buying drugs at the pharmacological stalls, only plant parts or organs are handed over to the buyer, who then has to find out which plant species is the donor and which taxonomic name the

Ethnobotany in South America, Fig. 20

Bixa orellana leaf with glands in surface view. The seed coat of *Bixa* is industrially used as a dye for food, adding a brilliant *orange* color (Roth & Lindorf, 2002)



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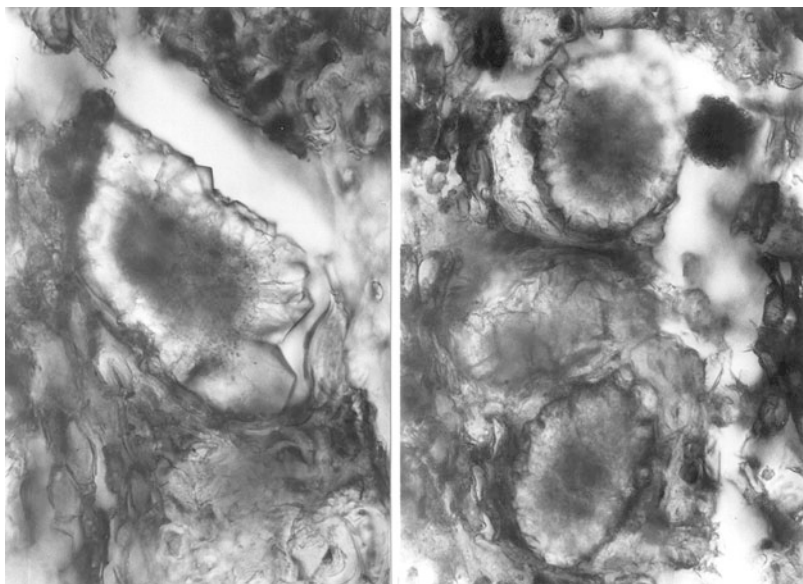
plant has, as plants are usually sold by their vernacular names.

The collection of SECAB is one of the most valuable compilations of medicinal plants which includes the flora of Bolivia, Colombia, Chile, Ecuador, Panama, Peru, and Venezuela. Pittier (1926) contributed a great deal to the knowledge of the useful Venezuelan plants. Gupta (1995) studied 270 Ibero-American medicinal plants. Schultes and Raffauf (1990) deal with the healing forest of the northwest Amazon region. Brucher (1989) treated the genetics of neotropical useful

plants. Interest in tropical useful plants has been growing steadily, so that several books dealing with taxonomic description, chemical contents, pharmacology, use (including recipes), ecological requirements and cultivation of medicinal plants have appeared, written by native botanists, pharmacists, experts on human nutrition, chemists, etc. Uphof provides a good survey of useful and medicinal plants of the world up to 1968. Exhaustive information on South American medicinal and useful plants can be found in (Roth & Lindorf, 2002).

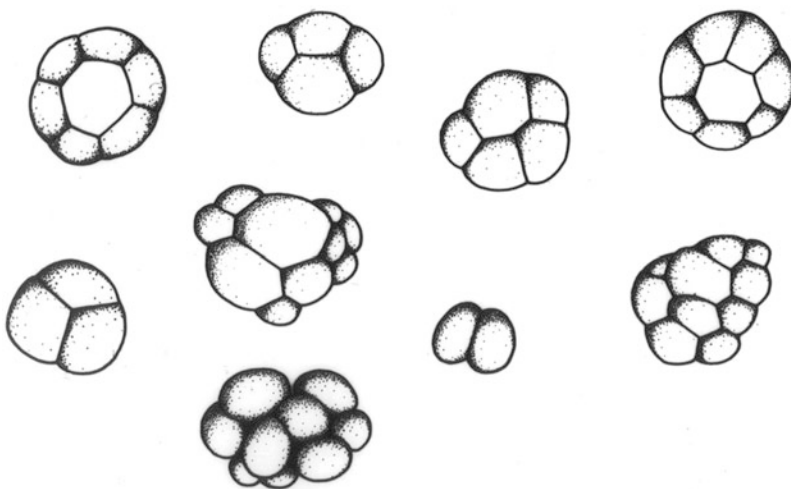
Ethnobotany in South America,

Fig. 21 *Coccoloba* with large crystals of calcium oxalate in the bark (Roth & Lindorf, 2002)



Ethnobotany in South America,

Fig. 22 Compound starch grains of the edible root of *Arracacia esculenta*, a relative of the cellery (Roth & Lindorf, 2002)



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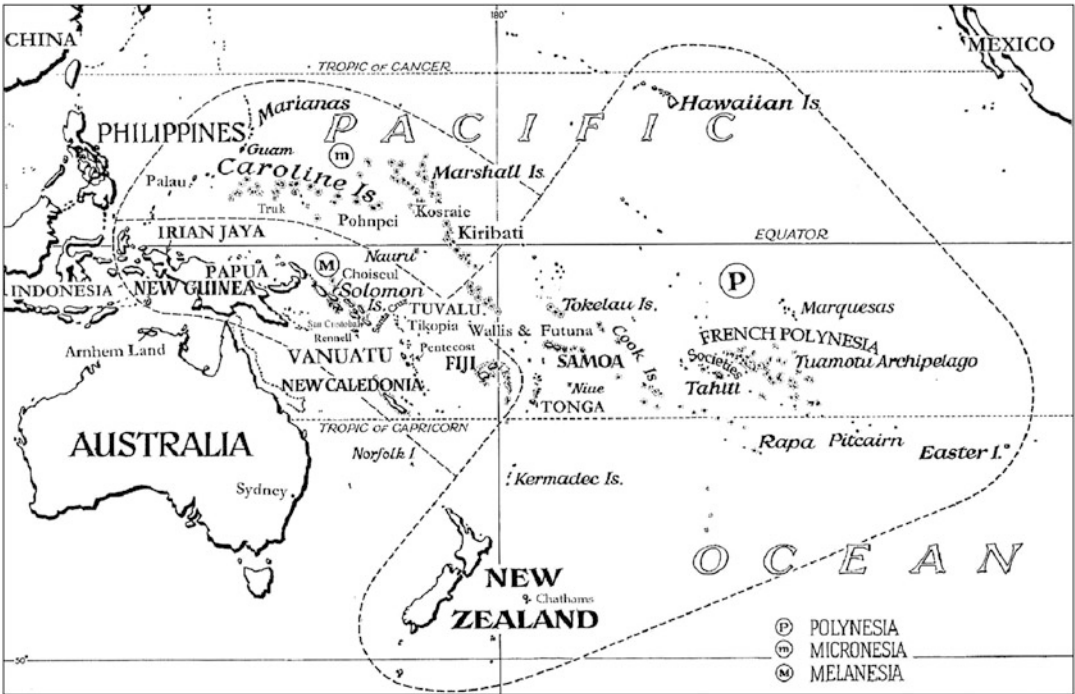
Ethnobotany in the Pacific

Yadhu N. Singh

The island communities of the Pacific, sometimes collectively known as Oceania, are inhabited by indigenous peoples from three major cultural or ethnic regions: Polynesia, Melanesia, and Micronesia (Fig. 1).

Because they lacked a written language of their own at the time of first contact with Europeans in the eighteenth century, much of the earlier information on the ethnobotany of the area has been constructed from the journals and other records of explorers, missionaries, and anthropologists. The increasing westernization of the islands has led to a greater reliance on imported food, clothing, fibers, and other materials, resulting in a decline in the use and specialized knowledge of native plants and agriculture. Fortunately, this influence is greatest in the urban areas and many of the traditional practices continue to flourish in the more rural and isolated communities. Some practices or items of material culture have lost their original roles, but instead have since acquired social, cultural, or historical significance, and consequently are being perpetuated by the present generations. A considerable body of plant lore still exists among the aged chiefs and inhabitants, and several anthropologists and ethnobotanists have strived to document this information. Because of space shortage, only a brief synopsis is presented and the reader is directed to the bibliography for a more complete treatment.

One popular theory on the origins of the Pacific islanders contends that their navigator ancestors migrated eastward from the Indo-Malay area, carrying with them from island to island the plants they needed for food, social, and cultural purposes. The food plants include all of the starchy perennial plants which are propagated vegetatively, including the taro, *Colocasia esculenta* (Fig. 2) and other nourishing *Araceae* of the genera *Alocasia*, *Amorphophallus*, and *Cyrtosperma*; the various yams, *Dioscorea* spp., whose numbers of cultivated species decrease from west to east; the breadfruit, *Artocarpus altilis*, (Fig. 3) of Captain Bligh and the mutiny on HMS *Bounty* (Fig. 4) fame, and for which the greatest number of cultivated varieties are found in eastern Polynesia; the principal bananas, *Musa* spp. (Fig. 5); also sugar cane, *Saccharum officinarum* (Fig. 6), which provides a nourishing drink; and the kava plant, *Piper methysticum* (Fig. 7), the source of the kava beverage which is used for many different activities in the islands (Fig. 8).



Ethnobotany in the Pacific, Fig. 1 Map of the Pacific Ocean showing the three cultural regions of Melanesia, Micronesia and Polynesia (Modified from *Fiji in Color* by Jim Siers, and reproduced with permission from the author)



Ethnobotany in the Pacific, Fig. 2 Taro (*Colocasia esculenta*) plants and tubers

Throughout its long history, the Pacific most certainly witnessed modification of its vegetation as its inhabitants adapted to the new environment and improved their techniques, and as waves of new migrations of humans arrived with new methods, ideas, and plants. Two important plants which fall into this category are the sweet potato, *Ipomoea batatas*, and the manioc or cassava, *Manihot esculenta*

(Fig. 9), being cultigens which were introduced from the American tropics in the last century, and which have become important components of the local diet.

The most widely reported uses of plants in the Pacific are for food and utensils, medicine, ceremony and rituals, general construction, fuelwood, boat and canoe building, cordage and fiber, fish poisons, woodcarving, tools, weapons and traps,

mats, clothing, dyes and pigments, and perfumes and oils.

The dominant food economy is based on the cultivation of the small number of starchy perennial plants mentioned above, which are propagated by vegetative means and which provide tubers and starchy fruits. They are usually embellished for taste, flavor, and variety by various condiments and complimented by seafoods and other plants and shrubs. They include the coconut tree, *Cocos nucifera*, which is unquestionably the most utilized of all plants in the Pacific (Fig. 10).

By 1 count as many as 125 different uses have been reported. Food uses include eating the soft flesh of immature nuts as an important weaning

and adult food; drinking the juice of immature nuts as a nutritious and refreshing local beverage which is often sold and is considered a sacred offering to visitors in Kiribati; using the kernel of the endosperm of the mature nut raw, cooked, or fermented in a variety of ways as a staple food and as a major food for chickens and pigs, as well as an ingredient in locally produced commercial livestock feeds. It is also used for fish and rat bait. The kernel is dried to make copra from which coconut oil is obtained for use in cooking, soap making, as scented oil and in perfumery, and in medicinal potions. The sap from the flower spathe is used to make fermented and unfermented toddy and syrup, which are of considerable nutritional importance in Micronesia and on the atolls. Also, the husks of some cultivars of green nuts are eaten in atoll Polynesia and Micronesia. Other parts of the plant serve as a major source of fuel, for construction and fiber and cordage (Fig. 11). Recently, the fibers from the tree trunk have been pressed into materials suitable for making furniture (Fig. 12).

Young and mature leaves are used for weaving baskets, food containers and parcels, table mats for feasts, to beat water during fish drives, and for pounding and stabilizing banks of taro beds. The shells are used to make drinking cups for water and kava (Fig. 13).

Small bowls, cooking vessels, funnels, storage utensils, fish hooks and lures, and various types of body ornaments were also made of shells. Other



Ethnobotany in the Pacific, Fig. 3 Breadfruit (*Artocarpus altilis*)



Ethnobotany in the Pacific, Fig. 4 HMS *Bounty* model (from Wikipedia). Pitcairn Island stamp depicting the *Bounty*

supplementary food sources include using the pith of the trunk of the sago palm, *Metroxylon* spp., Polynesian arrowroot, *Tacca leontopetaloides*, mature seeds or drupes, aerial root tips, and hearts of meristem of the screwpine, *Pandanus* spp. (Fig. 14), seeds and flesh of ripe fruit of the tropical or beach almond, *Terminalia catappa*

(Fig. 15), seeds of the cycad, *Cycas circinalis* (Fig. 16), and the young fronds of many ferns and tender shoots of a wide range of species.

The beverage called kava, prepared as an infusion from macerated stems and rhizomes of the kava plant, *Piper methysticum*, is probably the best known and most distinctive item of the material culture of the Pacific. It continues to occupy a central place in everyday life in the islands, although its role has been somewhat diminished by time and outside influences. Besides being the social beverage of chiefs, noblemen, and more recently of commoners, it has also been used to welcome distinguished visitors at formal gatherings, at initiation and completion of work, in reconciling with enemies, in preparing for a journey or an ocean voyage, for installation in office, validation of titles, ratification of agreements, celebration of important births, marriages, and deaths, as a libation to the gods, to cure illnesses and to remove curses, as a prelude to tribal wars – in fact, in almost all phases of life in the islands.

Despite the gradually declining reliance on traditional medicine, over 120 different plant species are reportedly used for medicinal purposes. Herbal preparations and potions are used to treat a wide variety of ailments, although not always identified with the equivalent Western disease names. Some of these ailments are shown in Table 1. Among the plant species of most widespread medicinal importance are the beach almond,



Ethnobotany in the Pacific, Fig. 5 Banana (*Musa × paradisiaca*)

Ethnobotany in the Pacific, Fig. 6 Loading a harvest of sugar cane (*Saccharum officinarum*) (Reproduced from inflight magazine of *Air Pacific* with permission)





Ethnobotany in the Pacific, Fig. 7 **a** A kava plant (*Piper methysticum*). **b** Dried kava roots for sale in Suva, Fiji. (Reproduced from inflight magazine of *Air Pacific* with permission). **c** A kava party in Fiji. The bowls (*above*

and *below*) are usually made of *Cordia subcordata* (see Fig. 8). Bowls and cups (*below*) on display at Expo 86 in Vancouver, Canada



Ethnobotany in the Pacific, Fig. 8 *Cordia subcordata* habit, leaves and flowers

Ethnobotany in the Pacific, Fig. 9 Cassava (*Manihot esculenta*) plants and crop



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Ethnobotany in the Pacific, Fig. 10 Coconut (*Cocos nucifera*) tree. Drying coconut flesh to make copra

Ethnobotany in the Pacific, Fig. 11 Coconut fiber coir sinnet (Photograph courtesy of Fiji Museum)



coconut, pandanus, *Vigna marina*, *Centella asiatica* (Fig. 17), *Premna taitensis*, *Ageratum conyzoides*, *Hernandia nymphaeifolia*, *Entada phaseoloides*, *Triumfetta procumbens*, *Morinda*

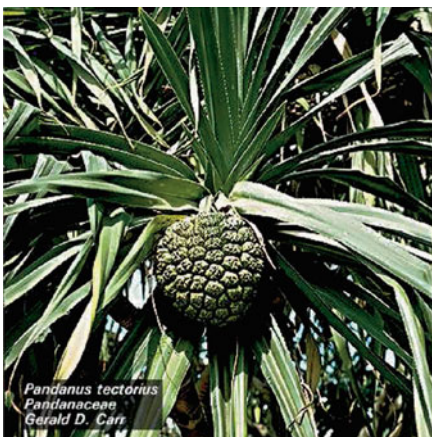
citrifolia (Fig. 18), *Guettarda speciosa*, and *Terminalia catappa*.

Traditional practitioners and midwives continue to play an important role in healthcare

Ethnobotany in the Pacific, Fig. 12 All furniture, including the sofa, coffee table, dining table and chairs were made using pressed coconut tree trunk fiber (Photograph courtesy of Mr. Prakash S. Nagra)



Ethnobotany in the Pacific, Fig. 13 Picture of coconut shell kava cups (Photograph courtesy of *Kava Kauai*)



Ethnobotany in the Pacific, Fig. 14 Screw pine (*Pandanus tectorius*). The hearts of the ripe meristem (right) are savored by many communities (Pictures courtesy of University of Hawaii Botany Department)

Ethnobotany in the Pacific, Fig. 15 Beach Almond (*Terminalia catappa*) flowers and fruits



Ethnobotany in the Pacific, Fig. 16 Cycad (*Cycas circinalis*)

delivery and, with the rapidly rising costs of Western medicine, there is renewed interest in herbal cures and practices. Presently, an extensive literature on the past and current medicinal practices is being assembled by anthropologists and ethnobotanists. However, the active chemical

Ethnobotany in the Pacific, Table 1 Ailments treated with traditional herbal preparations and potions

Arthritis and joint pains
Bleeding
Bone fractures
Cardiovascular disorders, muscular diseases
Cuts and bruises
Diabetes
Gastrointestinal and kidney disorders
General incontinence
Obstetric and gynecological conditions
Pain, fever and inflammation
Parasitic and microbial infections
Postpartum care and nursing
Pulmonary disorders like asthma
Skin disorders
Vomiting and nausea

components have been identified for only a small number of the herbal potions.

Also of medicinal value are species used as fumigants or insect repellants, soap substitutes, shampoos or hair conditioners, and antitoxins. Of the soap substitutes, *Colubrina asiatica* is used almost universally for this purpose. Among those used as antitoxins, or to treat puncture wounds from marine animals or jellyfish stings are *Avicenna maritima*, *Cassytha filiformis*, *Excoecaria agallocha*, *Sophora tomentosa*, and *Tournefortia argentea*. The seeds of *Calophyllum inophyllum*,

the heartwood of *Santalum yasi*, and the leaves of *Vitex* spp. are burned as mosquito repellants.

Tree trunks and timber from about 80 different species have found multiple uses, including for house, canoe, and boat building, tool and weapon making, woodcarving, fishing equipment, food utensils, furniture, games, toys, and musical instruments.

Various items for the tourist industry made from wood and plant materials. From left: warclub, comb, cannibal fork, box and fan.



Ethnobotany in the Pacific, Fig. 17 Gotu kola (*Centella asiatica*)

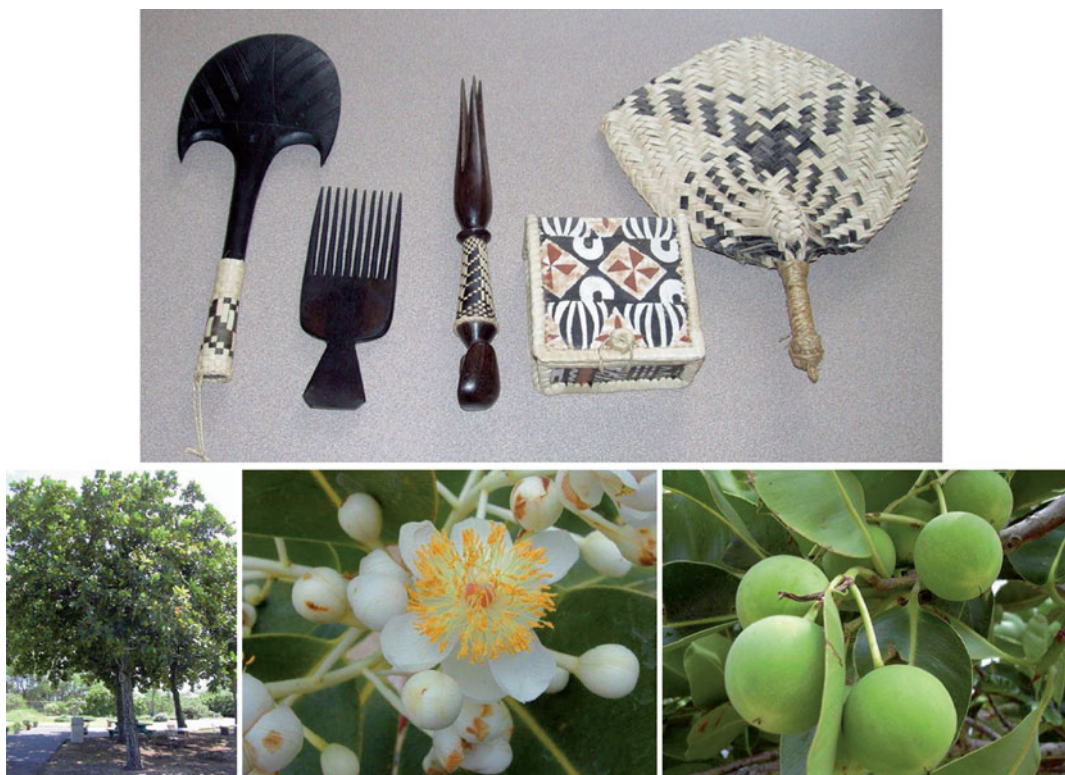
General construction purposes utilize sawn or hewn timber for house poles, beams, rafters, flooring, walls, pilings, bridges, wharves, etc. Some of the more commonly used species include *Bruguiera gymnorhiza*, *Calophyllum inophyllum* (Fig. 19), *Casuarina equisetifolia*, *Cocos nucifera*, *Guettarda speciosa*, *Hibiscus tiliaceus*, *Inocarpus fagifer*, *Intsia bijuga*, *Pandanus tectorius*, *Rhizophora* spp. (Fig. 20), *Terminalia catappa*, and *Thespesia populnea*. For thatching purposes, various grasses, and the leaves and fronds of coconut palms and pandanus are extensively used.

The timber and woody parts of many of the same species are used to construct warclubs, spears and spearpoints, bows and arrows, fishing poles, fish traps, fish hooks (Fig. 21), floats, paddles, digging sticks, needles and awls, adzes and tool handles, tapa cloth beaters, bowls, including kava bowls, ladles, spoons, stirrers, mortars and pestles, coconut huskers, breadfruit splitters, and food containers.

For toys and games, the seeds or fruit of *Abrus precatorius*, *Barringtonia asiatica*, *Caesalpinia bonduc*, *Erythrina variegata*, and others, are used for small balls, marbles and lagging pieces, while the wood of *Gardenia taitensis* is carved into marbles and cricket balls in some Polynesian islands. Pandanus leaves are made into kites and whistles while parts of the coconut palm are made into toy windmills, toy boats, rattles, sledges and clappers. The thin epidermis of pandanus leaves

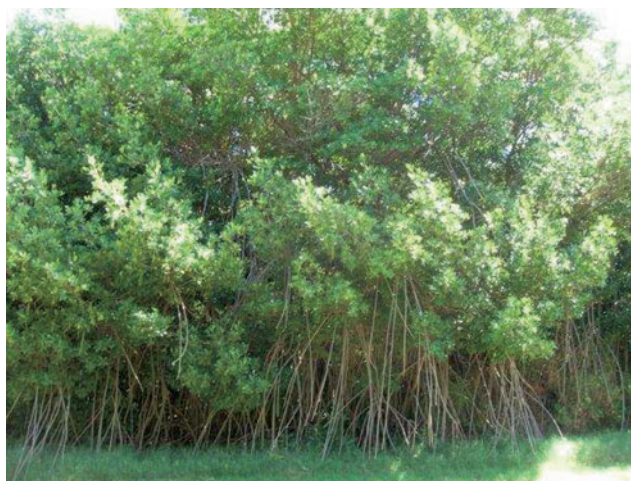
Ethnobotany in the Pacific, Fig. 18 Noni (*Morinda citrifolia*) leaves, ripe and raw fruit, and a commercial noni preparation





Ethnobotany in the Pacific, Fig. 19 *Callophyllum inophyllum* habit, flowers and fruits

Ethnobotany in the Pacific, Fig. 20 Red mangrove (*Rhizophora mangle*)



serves as a substitute for cigarette paper for handrolled cigarettes.

A basket and a mat made using dried pandanus leaves.

Musical drums (like the *lali* of Fiji) and the slit-gongs (of Vanuatu) (Fig. 22), beside being

musical instruments, are still extensively used for summoning people to village meetings or to church services, the most favored species for this purpose being *Cocos nucifera*, *Guettarda speciosa*, *Pemphis acidula*, *Terminalia catappa*, and *Thespesia populnea*.



Ethnobotany in the Pacific, Fig. 21 Coconut fiber coir cord and wooden fishing hook (Photograph courtesy of Fiji Museum)



Ethnobotany in the Pacific, Fig. 22 A lali (arrow, and sculpture, left picture) and a slit-gong from Vanuatu located on the Suva (Fiji) campus of the University of the South Pacific

Ocean going crafts of diverse structures and sophistication were developed to serve specific functions such as for transportation between the islands, for fishing, as racing outrigger or war canoes, and chiefly for voyaging. The components of such crafts, most of which were obtained from plants, include hulls, keel and prow pieces,

outriggers (Fig. 23) floats, booms, ribs and spreaders, planking, platforms, shelters, masts and mastheads, paddles, steering oars, and sails, bound together with fiber cordage.

The hull and keel pieces were composed of extremely strong and durable timber. *Calophyllum inophyllum* has been favored for



Ethnobotany in the Pacific, Fig. 23 Outrigger canoes used in the tourism industry

Ethnobotany in the Pacific, Fig. 24 Coconut fiber coir



the hulls of the larger Polynesian and voyaging canoes. Other species also used for this purpose include *Cordia subcordata*, *Intsia bijuga*, and *Hernandia nymphaeifolia*. Sails were plaited together from pandanus or coconut leaves and other species were used as adhesives and for caulking. Cordage and fiber for lashings on crafts,

housing, weapons, fishing lines, stringing fish nets, and in various handicrafts are obtained from the husk fiber or coir of the coconut (Fig. 24), the bast fiber of *Hibiscus tiliaceus* (Fig. 25), and the leaves of the pandanus. These three materials are also used for straining coconut cream, kava, and other liquids, and for stuffing



Ethnobotany in the Pacific, Fig. 25 Beach hibiscus (*Hibiscus tiliaceus*) habit, flower, and strainer from the bark in use for kava making

Ethnobotany in the Pacific, Fig. 26 Paper mulberry (*Broussonetia papyrifera*) habit and tree trunk



and caulking. The dried fibrous pandanus drupes, coconut coir and *Hibiscus tiliaceus* bast fiber are used as brushes for painting the tapa cloth, other ceremonial clothing, and handicrafts.

Of the various species used in the production of clothing and handicrafts, the most important are the coconut palm, pandanus, breadfruit tree, *Hibiscus tiliaceus*, and the paper mulberry, *Broussonetia papyrifera* (Fig. 26). The leaves of the first two and the bast fiber of *Hibiscus tiliaceus* are used throughout the Pacific for making hats, ordinary and ceremonial mats and garments, fans, and a wide array of handicrafts. The bark of *Broussonetia papyrifera* and the

breadfruit tree are processed to make the cloth called tapa which is best known in Fiji, Tonga, and Samoa (Fig. 27). Dyes, pigments, and preservatives, obtained from a number of species, in particular *Ficus tinctoria*, *Bruguiera gymnorrhiza*, *Morinda citrifolia* and *Rhizophora* spp., are used for dyeing, painting, or strengthening and preserving bark cloth, mats, baskets, and other plaited ware, hats, breechcloths, grass skirts, canoe sails, and for decorating parts of the human body on ceremonial occasions. The dyes and pigments are obtained from the bark and, less commonly, from leaves, roots, flowers, sap, fruit, and seeds.



Ethnobotany in the Pacific, Fig. 27 **a** Tapa making in Tonga. Most commonly the bark of the paper mulberry or breadfruit tree is used. The bark is stripped from young saplings, and the white inner layers are peeled off for the tapa. These narrow strips are soaked in water until softened (in the bowl in the foreground), then they are pounded with grooved mallets, which spreads the bark into increasingly wider strips until they are about 10 in. wide. The edges are then overlapped and glued with cassava root juice, breadfruit, or arrowroot starch to make

wide sheets. Then, on a long log, the tapa is stretched over a series of these design plates, and the tapa is rubbed with dye to stain the surface in areas where the design is raised (*middle* picture). Finally, after the tapa has dried, dark outlines and details are hand painted, using crude brushes made from sticks with frayed ends. A variety of natural plant dyes are used (*right*). Natural brown dyes, for example, have been made from clay and tree sap. **b** The finished tapa cloth (Photographs courtesy of the Government of Tonga)

Although most wood species are used as firewood, some are particularly favored because of their high heat content (*Pemphis acidula*, *Suriana maritima*, *Premna serratifolia*), ability to cook slowly and produce slow-burning charcoal (*Bruguiera gymnorhiza*, *Rhizophora* spp., *Casuarina equisetifolia*, coconut shells), or provide a desired taste to foods. All parts of the coconut

palm are used for fuel, and it is by far the main source of fuel in the atoll countries, as well as in some of the larger low-lying islands.

Sophisticated fishing gear used by coastal communities has been complemented by fish poisons or stupificants, with some ten species being used for this purpose. The fruits, roots, or vines are pounded and the juice is scattered in a



Ethnobotany in the Pacific, Fig. 28 *Derris elliptica* leaves and vines

tidal pool or the lagoon. The suffocated fish rise to the surface and are gathered in baskets woven from coconut leaves. The poisons do not affect the edibility of the fish. The most commonly used species are *Barringtonia asiatica* (fruits), *Tephrosia piscatoria* (roots), and *Derris* spp. (roots and vines) (Fig. 28). The use of these fish poisons has recently been outlawed in many countries.

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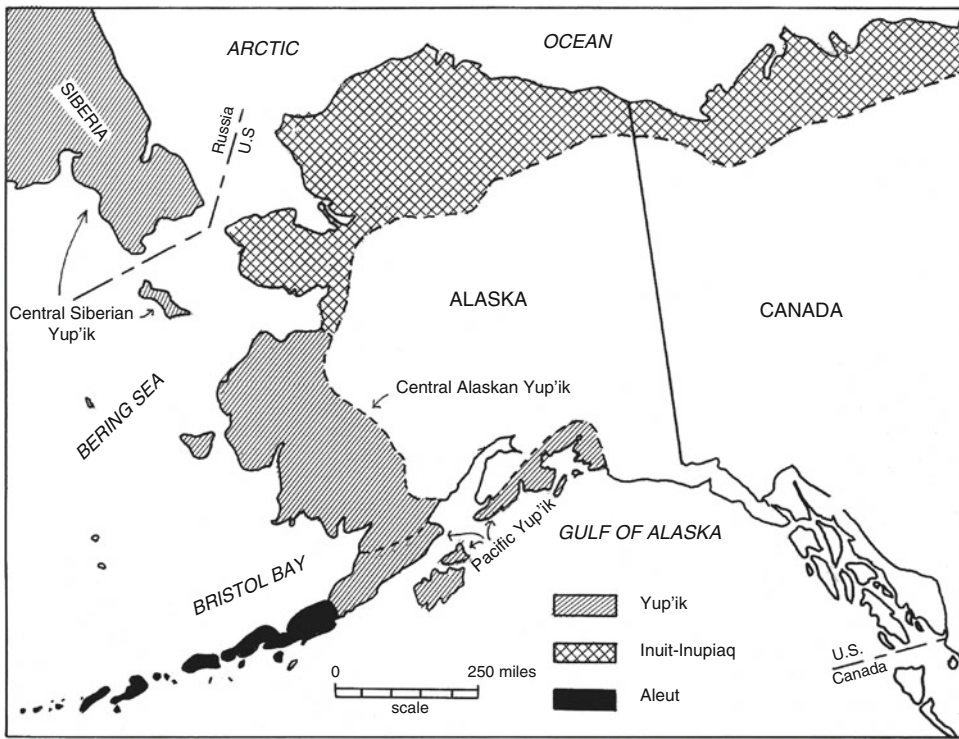
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Ethnobotany of Alaska: A Southwestern Alaska Perspective

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Alaska is the home of many diverse Native peoples who inhabit a wide variety of environments. To survive and flourish in these environments, it was essential for people to be aware of the wide range of plant and animal species in their area on which their survival depended. Published texts on Alaskan Natives, particularly the Eskimo (Lee & DeVoreore, 1968), have stressed the dependence of Native people on hunting in order to survive. While this dependence is undoubtedly true, the awareness and intensity of use of vegetal resources has often been overlooked. While it is impossible to summarize, in a single entry, the use of indigenous plants among all Native peoples of Alaska, this entry focuses on one area of Alaska, that of the Southwest, in order to illustrate the range of knowledge and use of indigenous flora by the Yup'ik Eskimo. This use includes the harvest of plants for food, medicine, and utilitarian purposes. Limited ethnobotanical references for Native peoples in the remainder of the state are also included.

Alaska can be divided into two principal environmental regions based on general landform and vegetation: the interior and coastal regions.



Ethnobotany of Alaska: A Southwestern Alaska Perspective, Fig. 1 Distribution of Yup'ik speakers in Alaska

The interior region is bounded by mountain ranges to the north and south (Brooks and Alaska Ranges, respectively) with a gradual transition in elevation west to the Bering Sea. American Indian peoples largely inhabit the interior. While not being addressed in this entry, the ethnobiology of this region can be found in Carroll (1972), Fortune (1988), Garibaldi (1999), and Kari (1987). The coastal region extends along the border of the state to the north and west where it meets the Bering Sea and along the southern coastal area where it borders the Sea of Alaska. The northern and western coastal areas are generally icebound in winter and comprised of low-lying tundra vegetation. The southern coastal area is generally less affected by the ocean climate with its warmer sea temperatures with vegetation changing from a tundra regime on the Alaska Peninsula to a more forested environment to the east. The coastal region is largely occupied by Eskimoan people that are divided into two linguistic subgroups, the Yup'ik and Inuit-Inupiaq (Woodbury, 1984). (The Aleut

occupy the southern tip of the Alaskan Peninsula and the Aleutian Islands. Their use of indigenous flora is not discussed in this paper (see Bank, 1953).) Yup'ik was spoken aboriginally on the coasts of the Chukchi Peninsula in Siberia and Alaska from Norton Sound south to the Alaskan Peninsula and then east along the Pacific to Prince William Sound (Fig. 1). Inuit-Inupiaq was spoken north from Norton Sound and east across Arctic Alaska and Canada to the coasts of Labrador and Greenland (see Anderson, 1939; Nickerson, Rowe, & Richter, 1973; Jones, 1983 for ethnobotanical information for the Inuit-Inupiaq portion of Alaska). This entry focuses on the ethnobotany of the Yup'ik Eskimo in southwestern Alaska, an area dominated by the Yukon-Kuskokwim Delta which includes both Nunivak and Nelson Islands.

Few early ethnographic studies in Alaska have highlighted the Eskimo's range of knowledge and use of local flora. In fact the opposite was often the case, in that many observers expressed a belief that Eskimos had little knowledge of local

**Ethnobotany of Alaska:
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Fig. 2 Nuniwarmiut elders examining plant specimens
(From *left to right*: Nan Kiokun, Helen Williams, and George Williams, Sr.)



**Ethnobotany of Alaska:
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Perspective,**

Fig. 3 Nuniwarmiut elders examining plant specimens
(From *left to right*: Nona Amos and Walter Amos)



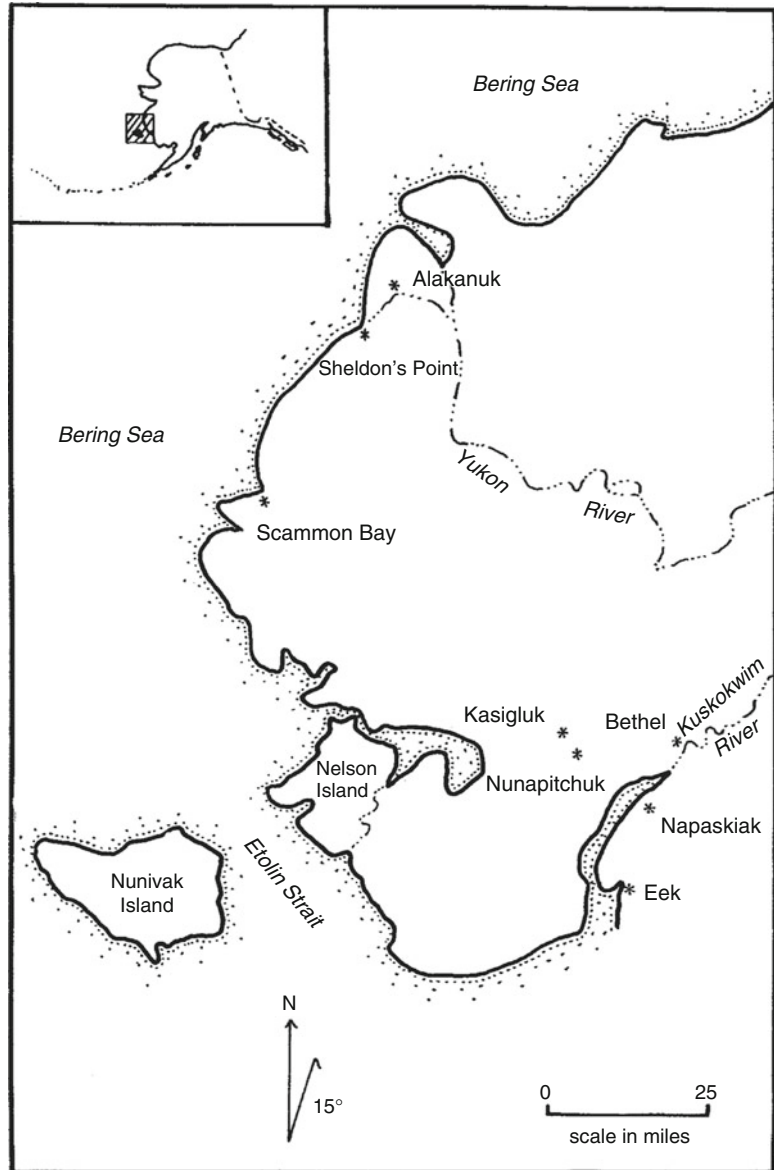
herbs and roots (Whittaker, 1937, p. 115). Young and Hall (1969, p. 43) found that the Western Eskimo were more aware of and made use of more plant species than is generally acknowledged. While the present study summarizes the known traditional use of indigenous plants in southwestern Alaska (central Alaskan Yup'ik), comparative data are also included for plant use among the peoples of St. Lawrence Island and Siberia (Siberian Yup'ik) and the Chugach of Prince William Sound (Pacific Yup'ik), when known. This information was primarily obtained from a 12-year (ca. 1995–2006) collaborative

anthropological project with the Nuniwarmiut of Nunivak Island (see Figs. 2 and 3) and a compilation of published and unpublished sources of ethnobotanical use.

Regional Setting

The Yukon-Kuskokwim Delta (Fig. 4), a geographic and cultural area historically occupied by central Alaskan Yup'ik-speaking Eskimos in southwestern Alaska, encompasses an area of almost 81 million kilometers (31,250 mile²) or

**Ethnobotany of Alaska:
A Southwestern Alaska
Perspective, Fig. 4** Map
of Yukon-Kuskokwim
Delta



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8.1 million hectares (20 million acres). This delta region consists of a vast and largely roadless expanse of low-lying tundra that has attracted limited attention from ethnographers in the past. Native villages are located along the area's major waterways with development largely limited to commercial fishing. The degree of early contact between subcultural groups within the delta cannot accurately be determined due to conflicting early historical data and later movements of peoples throughout the region, but villages are

known to have been linked by extensive trade networks, intermarriage among village residents, and village alliances during times of warfare (VanStone, 1984, p. 224). Ponds, lakes, streams, and sloughs, which made travel throughout southwestern Alaska extremely difficult, cover half of the Yukon-Kuskokwim Delta. Not surprisingly, the immense wetlands provide suitable habitat for millions of waterfowl, small and large mammals, and abundant flora. The seasonal harvest of marine mammals (e.g., seals, sea lion,

walrus) and many species of fish (particularly salmon, halibut, whitefish, and blackfish) remains vital for local survival.

The Yukon-Kuskokwim Delta is subject to a subarctic maritime climate, influenced by the surrounding sea, which produces a relatively stable temperature. Summers are generally cool and windy, with some areas experiencing frequent fog; winters are cold with both wet and dry periods. The region's mean annual temperature is -2°C (30°F) with mean daily temperatures ranging from -25°C (9°F) in January and February to 10°C (50°F) in August (Selkregg, 1976; Swanson, Devony, Jenny, & Dale, 1986). Rain and snowfall are heavier on the mainland than neighboring islands (e.g., Nunivak), with islands experiencing more frequent overcast days with dense fogs. This difference between the mainland and island delta regions is due to the greater effect of the Bering Sea on the island environment. Precipitation is moderate with a mean annual rainfall of 40.6 cm (16 in.) and snowfall of 127 cm (50 in.). Vegetation throughout the region remains similar.

The Yup'ik Eskimo of southwestern Alaska traditionally practiced a hunting, fishing, and gathering subsistence economy that revolved around the harvest of the above-mentioned species, in addition to the numerous plant species that were critically important to survival. Hulten (1966, 1968) has studied the vascular flora of the Yukon-Kuskokwim Delta, Bos (1967) and Palmer and Rouse (1945) that of Nunivak Island, and Young (1968) on St. Lawrence Island. The region's vegetation is predominantly comprised of Arctic tundra containing a variety of lichens, grasses, sedges, flowers, and shrubs. It is similar to vegetation found throughout western and northwestern Alaska. The tallest tundra plants are shrubby willows that can reach up to 8 ft in height along some river courses. Major vegetation types include wet tundra, dry tundra, alpine tundra, and grass-browse (i.e., grass hummock and beach grass-forb). Wet tundra is most prevalent along the coast in poor drained areas, with the dominant cover species consisting of sedges (*Carex* spp.), cottongrass (*Eriophorum* spp.), willow (*Salix* spp.), crowberry (*Empetrum nigrum*),

and various species of mosses and lichens (e.g., *Sphagnum*, *Pohlia*, and *Cladonia*). Dry tundra is found on areas of sloping terrain having good drainage and is dominated by species similar to those found in wet tundra areas, in addition to bearberry (*Arctostaphylos alpina*), Labrador tea (*Ledum palustre decumbens*), woodrush (*Luzula nivalis*), bog blueberry (*Vaccinium uliginosum*), and dwarf birch (*Betula nana exilis*). Alpine tundra, found at higher elevations on hills and mountains, is similar to that in dry tundra areas and is dominated by crowberry, alpine bearberry, Labrador tea, white mountain avens (*Dryas octopetala*), and moss. Grass-browse is generally found interspersed with the dry tundra subtype and along edges of streams and rivers adapted to periodic flooding. This vegetation type is dominated by fescue (*Festuca* spp.), bluejoint (*Calamagrostis canadensis*), willow, lichens, sedge, wild celery, and seacoast angelica (*Angelica lucida*).

Use of Indigenous Flora

Indigenous plants were an integral part of the year-round diet of Eskimo people in addition to their incorporation in other facets of their lives. Contrary to the popular perception of Eskimo people surviving solely on fish and meat, they utilized a large number of local plants for food, medicinal, and utilitarian purposes. An earlier Alaskan study estimated that up to 15 % of the diet of Western Eskimo people (Kotzebue to Alaska Peninsula) is made up of vegetable resources (Young & Hall, 1969, p. 43). While plant resources remained sparse on some offshore islands such as St. Lawrence Island (Young & Hall), on Nunivak and Nelson Islands they provided a significant addition to the Native's year-round diet.

Knowledge of the Native use of indigenous flora in the delta remains limited. Previous ethnobotanical studies are limited to research on Nunivak Island (Fries, 1977; Griffin, 2001, 2004; Lantis, 1946, 1959; Nuniwarmiut Taqnelluit, n.d.); Nelson Island (Ager & Ager, 1980); the Kuskokwim villages of Napaskiak

(Oswalt, 1957), Eek, Kasigluk, and Nunapitchuk (Andrews, 1989; Lantis, 1958, 1959); and several lower Yukon Delta and coastal villages (e.g., Alakanuk, Sheldon's Point, Scammon Bay) by Fienup-Riordan (1986). St. Lawrence Island and the Chukchi coastal area of Siberia are similar in landform with southwestern Alaska in that lands are covered by low-lying Arctic tundra, although the number and variety of plant species differ between areas. Knowledge of the indigenous use of plants in these areas remains limited to few published and unpublished accounts (Ainana & Zagrebin, unpublished data; Young & Hall, 1969, respectively). Ethnobotanical knowledge among Pacific Yup'ik speakers is largely limited to studies among the Chugach (Birket-Smith, 1953; Fortuine, 1988; Wennekens, 1985) in Prince William Sound, Kodiak Island (Graham, 1985), and the Alaska Peninsula (Morseth, 2003). Since the flora of the first two of these areas is very different from that of the Yukon-Kuskokwim Delta (i.e., forest vs. tundra), only information on the use of similar plant species is addressed here. Several recent, regionally based publications have attempted to summarize our knowledge of the indigenous use of plants throughout Alaska (e.g., Biggs, 1999; Garibaldi, 1999; Schofield, 1989); however, the Yup'ik-speaking areas remain poorly documented.

Table 1 provides a list of the seasonal use of indigenous food plants by the Yup'ik Eskimo. This index provides data on the Yup'ik use of 43 indigenous plant species in southwest Alaska. In Table 1, species are arranged in alphabetical order by each species' botanical name. Details regarding season of harvest, plant part used, and if the species was stored for winter consumption/use are provided. In addition, the known range and extent of use of each species among Eskimo peoples is included.

While some researchers believed Eskimos had no knowledge of herbs or roots to combat or relieve sickness (Whittaker, 1937), this has been found to be untrue. Medicinal knowledge of indigenous plants varies from area to area with over 28 plant species used in the Yukon-Kuskokwim Delta. Table 2 provides a list of

medicinally used plants in the region, along with specific references to texts that provide greater detail on the collection, processing, and application of each species.

In addition to the use of plants for food and medicine, many plant species were used for a variety of utilitarian purposes. Table 3 provides details on 13 species used in southwestern Alaska. Data on plant name, season of harvest, and specific use is included.

Native Plant Taxonomy

An examination of general Yup'ik terms (Jacobson, 1984) provides comparative data useful in distinguishing some basic plant terminology distinctions. Yup'ik speakers (including Cup'ig speakers on Nunivak Island who speak the most divergent dialect within the Yup'ik branch) tend to divide plants into basic groups based on how plants were traditionally used, their similarity in appearance, or physical characteristics. For example, on Nunivak Island, the Cup'ig plant named *ciwassit* translates to "wild greens that can be cooked" and is used to denote several distinct species that are prepared in a similar manner (i.e., *Rumex arcticus* [sour dock], *Polygonum bistorta* [bistort], and *Polygonum viviparum* [alpine bistort]). (Cup'ig spellings of all plant species are taken from the Cup'ig Dictionary by Amos and Amos (2003) and have been placed in bold italics. A glossary of Yup'ik and Cup'ig plant names is included in the Appendix.) *Kumarutet* is used to denote all moss species (e.g., *Pohlia nutans*) based on the traditional use of moss as a wick in lamps (*kuman* = lamp, light). Examples of plants grouped by similarity in appearance, characteristics, or setting include (1) *elquat*, term used to designate several varieties of seaweed (e.g., *Palmaria palmata* [dulse], *Fucus* spp. [bladderwrack]); (2) *megtat neqiat*, meaning bumblebee food for several local plant species (e.g., *Pedicularis verticillata* [wooly lousewort], *Sedum rosea* [roseroot]); and (3) *agya an'a(i)*, used for all puffball species (*Lycoperdon* spp. and *Calvatia* spp.). In Yup'ik, *agya ana* translates to meteor and meteors,

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 1 Seasonal use of indigenous food plants among Yup'ik-speaking Eskimo

Scientific name	Common name	Season ^a	Plant part	Storage	Location ^b
<i>Ammodenia peploides</i>	Sea purslane, seabeach sandwort	Su	Leaves	X	Nunivak
<i>Angelica lucida</i>	Wild celery	Su	Leaves, stalk, root	X	Y-K Delta, Ak. Pen., Chugach
<i>Arctostaphylos alpina</i>	Alpine bearberry	Su, F	Fruit		Y-K Delta, Inuit
<i>Boltenia ovifera</i>	Sea potato, sea onion	S, Su	Bulb		Nunivak
<i>Caltha palustris</i>	Marsh marigold	W, S	Entire plant	X	Y-K Delta
<i>Carex</i> spp.	Sedges	F	Root, stem		Nunivak
<i>Cladonia</i> spp.	Lichens	S	Entire plant		Nunivak
<i>Claytonia tuberosa</i>	Wild potato, tuberous spring beauty	Su	Corm		Y-K Delta, Siberia
<i>Conioselinum chinense</i>	Western hemlock-parsley	S, Su	Root		Nunivak, Chugach
<i>Dendroa aggregate</i>		Floats to beach	Branches		Nunivak
<i>Draba borealis</i> or <i>Draba hyperborea</i>	Wild lettuce	S, Su	Leaves	X	Nunivak
<i>Dryopteris dilatata</i>	Shield fern	Su, F	Fronds, fiddleheads		Nunivak
<i>Empetrum nigrum</i>	Crowberry	Su, F	Fruit, plant	X	Y-K Delta, Ak. Pen., Chugach, Siberia, Inuit
<i>Epilobium angustifolium</i>	Tall fireweed	S, Su S	Leaves, young shoots	X	Y-K Delta, Chugach, Inuit
<i>Epilobium latifolium</i>	Dwarf fireweed	Su	Leaves, yg. shoots	X	Nunivak
<i>Epilobium angustifolium</i>	Tall cottongrass	Su, F	Base of stem, greens		Y-K Delta, Inuit
<i>Fucus</i> spp. <i>F. Gardneri</i>	Bladderwrack rockweed	Year-round S, Su, F	Plant, young plant		Y-K Delta, Chugach
<i>Hippuris tetraphylla</i> or <i>H. vulgaris</i>	Mare's tail	S, F	Leaves, stems, roots	X	Y-K Delta
<i>Honckenya peploides major</i>	Beach greens, Seabeach sandwort	S, Su	Leaves, stems	X	Y-K Delta, Siberia, Inuit
<i>Ledum palustre decumbens</i>	Labrador tea	S, Su year rd.	Leaves		Y-K Delta, Chugach
<i>Ligusticum scoticum hultenii</i>	Beach lovage, "wild parsnip/parsley"	S, Su Su	Roots, leaves, stems		Y-K Delta, Ak. Pen., Chugach
<i>Lycoperdon</i> spp.	Puffball	S, Su	Yg. fruiting body		K-Delta? Siberia
<i>Mertensia maritima</i>	Oyster leaf	?	Leaves		Y-K Delta
<i>Oxycoccus microcarpus</i>	Bog cranberry	Year-round	Fruit	X	Y-K Delta, Chugach
<i>Oxyria digyna</i>	Mountain sorrel	S, Su	Leaves	X	Y-K Delta, Siberia, Inuit
<i>Palmaria palmata</i>	Seaweed, dulse	Su, W	Blade		Nunivak

(continued)

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 1 (continued)

Scientific name	Common name	Season ^a	Plant part	Storage	Location ^b
<i>Parrya nudicaulis</i> (?)	Wild cabbage/ celery	Su	Leaves	X	Nunivak
<i>Pedicularis verticillata</i>	Wooly lousewort	S	Flowers, roots		Y-K Delta, Siberia, Inuit
<i>Pohlia nutans/ Webera nutans</i>	Moss	S	Plant		Y-K Delta
<i>Polygonum bistorta</i>	Pink plumes, bistort	S, F	Leaves, root stalk	X	Nunivak, Siberia, Inuit, Ak. Pen.
<i>Polygonum viviparum</i>	Alpine bistort, wild rhubarb	S, Su	Rhizome		Y-K Delta, Siberia
<i>Ranunculus Pallasii</i>	Pallas buttercup	S	Leaves, stems		Y-K Delta
<i>Rhodymenia palmata</i>	Red seaweed, dulse	Year-round	Plant		Y-K Delta, Chugach
<i>Rubus arcticus</i>	Nagoonberry	Su	Fruit	X	Y-K Delta, Chugach, Inuit
<i>Rubus chamaemorus</i>	Cloudberry	Su	Fruit	X	Y-K Delta, Chugach
<i>Rumex arcticus</i>	Dock, sour dock	S, Su	Leaves, stems	X	Y-K Delta, Ak. Pen., Chugach
<i>Salix alaxensis</i>	Alaska willow	S	Catkins, leaf top		Y-K Delta, Inuit
<i>Salix pulchra</i>	Diamond-leaf willow	Su	Catkins, leaves		Y-K Delta, Siberia
<i>Saxifraga</i> spp.	Saxifrages	S, Su, F	Leaves	X	Nunivak, Siberia, Inuit
<i>Sedum rosea</i>	Roseroot, stonecrop	S	Flowers, plant		Y-K Delta, Inuit
<i>Senecio pseudoarnica</i>	Ragwort, fleabane	Su	Leaves, stems, root, top of shoot	X	Y-K Delta
<i>Streptopus amplexifolius</i>	Twisted stalk	S, Su	Fruit, young stalks		Nunivak, Chugach
<i>Vaccinium uliginosum</i>	Alpine blueberry, bog blueberry	Su	Fruit	X	Y-K Delta, Ak. Pen., Chugach
<i>Vaccinium vitis-idaea minus</i>	Lingonberry, low-bush Cranberry	Year-round	Fruit	X	Y-K Delta, Siberia, Chugach, Ak. Pen.

^aSeasonality: S spring, Su summer, F fall, W winter

^bLocation abbreviations include: Y-K Delta Yukon-Kuskokwim Delta, K-Delta Kuskokwim Delta, Inuit-Inupiaq-speaking area, Chugach Prince William Sound, Ak. Pen. Alaska Peninsula

which are traditionally said to turn into puffballs when they land (Jacobson, 1984, p. 48). Still other plant names highlight distinctions within a genus such as *qugyuguat*, which is used to refer to all *Salix* (willow) species except those exhibiting catkins, which are referred to as *qimugkararat*. Further analysis is needed in order to fully understand the Yup'ik's concept and categorization of local flora.

A similarity of plant use and some Native plant names between Yup'ik, Cup'ig, and Inupiaq speakers (i.e., Seward Peninsula) to the

north have been identified. Similarities between some Yup'ik, Cup'ig, and Inupiaq plant names (e.g., *kavlak-kavlag-kavlaq* [*Arctostaphylos alpina* (alpine bearberry)], *paunraq-paunrat-paungaq* [*Empetrum nigrum* (crowberry)], *pekneq-pekner-pikneq* [*Eriophorum angustifolium* (cottongrass)], *tukaayug-tuk'ayut-tukaayuk* [*Linguisticum scoticum* (lovage)]) and food preparations (e.g., *akutaq-akutar-akutuq* [Eskimo ice cream comprised of berries, seal oil, reindeer tallow (Crisco), snow, and sometimes salmon eggs]) highlight extended

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 2 Medicinal plant use among the Yup'ik-speaking Eskimo

Scientific name	Common name	Plant part	Plant application	Symptom	Location ^a	Reference
<i>Achillea</i> spp.	Yarrow	Leaves, stem	Infusion, gargle, poultice, chew, switch	Congestion, sore throat, boils arthritis, uterine evacuation, increase milk after parturition	Nunivak, Chugach	Fortuine (1985), Morseth (2003), Schofield (1989) ^b , and Wennekens (1985)
<i>Alnus</i> spp.	Alder	Leaves, bark, branch	Poultice, switch	Cut/scrapes, arthritis, sore muscles; stool softener	Y-K Delta, Chugach	Ager and Ager (1980), Garibaldi (1999), Morseth (2003), and Wennekens (1985)
<i>Angelica</i> spp.	Angelica	Root, stem	Chew, infusion, switch	General ill health, seasick remedy, sore joints	Y. Delta, SLI	Garibaldi (1999), Hulten (Hulten, 1968), Morseth (2003), and Young and Hall (1969)
<i>Artemisia tilesii</i>	Stinkweed, wormwood	Leaves, branch, seed head, plant	Poultice, switch, infusion/decoction, hair rinse, vapor, chew	Cuts, dandruff, sore muscles, arthritis, stomach trouble, constipation, bleeding	Nunivak, SLI; Y-K Delta, Chugach	Ager and Ager (1980), Fienup-Riordan (1986), Garibaldi (1999), Griffin (2001), Lantis (1959), Oswalt (1957), Overfield, Epstein, and Gaudioso (1980), Wennekens (1985), and Young and Hall (1969)
<i>A. vulgaris</i>	Stinkweed	Leaves	Poultice	Sore joints, gas pains	Nunivak, Norton Sound	Garibaldi (1999), Griffin (2001), and Lantis (1958)
<i>Betula nana exilis</i>	Dwarf birch	Leaves	Infusion/decoction	Boiled for stomach problems, intestinal	Nunivak, K. Delta	Griffin (2001) and Lantis (1958; 1959)
<i>Caltha palustris</i>	Marsh marigold	Leaves	Infusion/decoction, chew	Constipation, diarrhea	K. Delta	Garibaldi (1999) and Lantis (1959)
<i>Dryopteris austriaca</i>	Shield fern	Fronds	Infusion/decoction	Boiled for stomach problems, intestinal	Nunivak, K. Delta	Griffin (2001) and Lantis (1958; 1959)
<i>D. dilatata americana</i>	Wood fern	Plant	Infusion/decoction	Stomach trouble	K-Delta	Garibaldi (1999)
<i>Epilobium angustifolium</i>	Tall fireweed	Leaves, root	Infusion/decoction, poultice	Boiled for stomach problems, intestinal, constipation, cuts	Nunivak, K. Delta, Chugach	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), Lantis (1958, 1959), and Wennekens (1985)

(continued)

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 2 (continued)

Scientific name	Common name	Plant part	Plant application	Symptom	Location ^a	Reference
<i>Equisetum</i> spp., <i>E. arvense</i>	Horsetail	Upper stem, plant	Infusion/decoction, poultice	Internal bleeding, hemorrhages, pimples	Y-K Delta, Chugach	Ager and Ager (1980), Garibaldi (1999), and Wennekens (1985)
<i>Eriophorum</i> spp.	Cottongrass	Flower, cotton, stem, leaves	Chew, poultice	Cuts/scrapes, ill health, sores, inflamed eyes	Nunivak, K. Delta	Garibaldi (1999), Griffin (2001), Lantis (1959), and Oswalt (1957)
<i>Fomes ignarius</i>	Chew ash fungus	Fungus	Infusion/decoction	Constipation, stomach trouble	K. Delta	Garibaldi (1999) and Lantis (1959)
<i>Ledum palustre decumbens</i>	Labrador tea	Leaves, stems, flowers	Infusion, fumigant	Bleeding/hemorrhage, TB, constipation, stomach trouble	Y-K Delta	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), and Lantis (1958, 1959)
<i>Matricaria matricarioides</i>	Pineapple weed	Seed heads, plant top, plant	Infusion/decoction, chew	Colds/flu, stomach trouble, TB, laxative, increase milk after parturition	Napaskiak; NI, Chugach	Ager and Ager (1980), Garibaldi (1999), Morseth (2003), Oswalt (1957), and Wennekens (1985)
<i>Nephroma arcticum</i>	Arctic kidney lichen	Plant	Infusion	Ill health	K. Delta	Garibaldi (1999) and Oswalt (1957)
<i>Oxycoccus microcarpus</i>	Bog cranberry	Fruit	Chew	Pneumonia, stomach trouble	Y-K Delta	Garibaldi (1999)
<i>Picea glauca</i>	White spruce	Needles, gum	Infusion/decoction, chew, salve	Cit/scrapes, cough, chest congestion	Y-K Delta	Garibaldi (1999), Lantis (1959), and Oswalt (1957)
<i>Rubus chamaemorus</i>	Cloudberry	Fruit	Chew	Diarrhea, skin trouble	Nunivak, K. Delta	Garibaldi (1999), Griffin (2001), Lantis (1959), and Schofield (1989)
<i>Rumex</i> spp.	Dock	Leaves, root	Chew, snuff, poultice	Diarrhea, constipation, headache, chill fever	Chugach, Napaskiak	Birket-Smith (1953), Garibaldi (1999), Morseth (2003), Oswalt (1957), and Wennekens (1985)
<i>Salix</i> spp.	Willow	Leaves, bark, catkins, cambium	Infusion/decoction, chew, gargle, poultice	Lung hemorrhage, pain, sore throat or mouth, skin sores, cut/scrapes, eye trouble	Y-K Delta, Nunivak Chugach	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), Lantis (1958, 1959), Oswalt (1957), and Wennekens (1985)

(continued)

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 2 (continued)

Scientific name	Common name	Plant part	Plant application	Symptom	Location ^a	Reference
<i>S. fuscescens</i>	Willow	Leaves, catkins	Chew, swab	Sore mouth, watery eyes	Nunivak	Griffin (2001) and Lantis (1946, 1959)
<i>S. pulchra</i>	Diamond-leaf willow	Leaves	Chew	Sore mouth	Nunivak	Griffin (2001)
<i>Sedum rosea</i>	Roseroot, stonecrop	Leaves, flower, root	Infusion/decoction, chew	Boiled for stomach problems, intestinal, sore mouth, TB	Nunivak, K. Delta, NI	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), and Lantis (1958)
<i>Sphagnum</i> spp.	Sphagnum	Moss	Chew, poultice	Diarrhea, cuts/ scrapes	K. Delta	Fortuine (1985), Garibaldi (1999), and Lantis (1959)
<i>Vaccinium vitis-idaea</i>	Low-bush cranberry	Fruit	Chew, poultice	Diarrhea, eye trouble	K. Delta	Garibaldi (1999) and Lantis (1959)
<i>Valeriana</i> spp.	Valerian	Unknown	Unknown	Stomach trouble, good luck	Y. Delta; SLI	Garibaldi (1999) and Young and Hall (1969)
<i>Nicotiana</i> spp.	Tobacco (introduced)	Leaf	Poultice	Control bleeding	K. Delta	Lantis (1959)

^aLocation abbreviations include: *SLI* St. Lawrence Island, *Y-K Delta* Yukon-Kuskokwim Delta, *K-Delta* Kuskokwim Delta, *NI* Nelson Island, *Chugach* Prince William Sound

^bSchofield’s reference to use of Yarrow on Nunivak Island is believed to be in error based on a misinterpretation of Smith’s arctic pharmacognosia (1973, p. 325)

contact between western Alaskan peoples over time. Further research is needed to evaluate the degree of sharing between these language branches with regard to the recognition and use of indigenous plants.

Plant Harvest, Preparation, and Storage

In the Yukon-Kuskokwim Delta, women and children traditionally gathered most indigenous plants, while the men were harvesting other available resources (e.g., caribou, waterfowl, seal) (Fienup-Riordan, 1983; Lantis, 1946). While fresh spring greens provided a welcome addition to the diet, which in winter was based largely on dried and stored foods, other greens were harvested throughout the year as they ripened and used with some of those stored for winter use. With the melting of the winter’s snow pack, local greens and berries not picked during the previous fall’s harvest begin to appear and were added to the local diet. Depending on the time the ice pack began to break up, Yup’ik families

began to move to their spring camps to harvest available resources. Along the coast, Yup’ik men would journey out along the ice to harvest arriving sea mammals (i.e., seals, walrus), while women would spend much of their time harvesting available plant resources (greens and seaweeds) and shellfish. Early harvestable spring food plants included marsh marigold (*Caltha palustris*), sour dock (*Rumex arcticus*), wild celery, wild lettuce (*Draba hyperborea*), wild parsnip (*Ligusticum hultenii*), wild rhubarb (*Polygonum viviparum*), mountain sorrel (*Oxyria digyna*), Pallas buttercup (*Ranunculus pallasii*), and Labrador tea.

After the completion of the spring hunting season, families would move to summer fish camps. Fish comprised the most prolific and essential subsistence resource for many Alaskan Natives living in the Delta, and its harvest would occupy the majority of the families’ efforts for several months. Traditional indigenous plants would continue to be harvested as they ripened and were eaten fresh or placed in underground caches for temporary storage.

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 3 Utilitarian use of indigenous plants by Yup'ik-speaking Eskimo

Scientific name	Common name	Season	Plant part	Purpose	Location
<i>Aconitum delphinifolium</i>	Monkshood	Year-round	Root	Hunting poison	Chugach, Nunivak?
<i>Angelica lucida</i>	Wild celery	?	Root	Hunting talisman	Siberia
<i>Carex</i> spp.	Sedges	F	Grass	Boot lining, socks	Y-K Delta
<i>Cladonia rangiferina</i>	Lichens, reindeer moss	Year-round	Plant	Seal oil applicator	Y-K Delta
<i>Elymus mollis</i>	Wild rye grass	S, Su, F	Grass	Menstrual pad, basket roof thatching, mats	Y-K Delta Chugach
<i>Empetrum nigrum</i>	Crowberry	Su, F	Leaves	Storage pit liner	Y-K Delta
<i>Equisetum arvense</i>	Common horsetail	S, Su, F	Stems	Play matches for child	Y-K Delta
<i>Eriophorum angustifolium</i>	Tall cottongrass	?	Reeds	Basket, mat	K. Delta
<i>Petasites frigidus</i>	Coltsfoot	Su, F	Leaves	Berry basket	Nunivak
<i>Pohlia nutans/Webera nutans</i>	Moss	S, Su, F	Plant	Diaper, basket lining, fire starter, pottery pad	Y-K Delta Chugach
<i>Rumex arcticus</i>	Sour dock	Su, F	Plant	Navigation aid, cache pit lining, landmark	K. Delta
<i>Sphagnum</i> spp.	Sphagnum moss	Year-round	Moss	Menstrual pad, diaper	Nunivak
<i>Vaccinium vitis-idaea minus</i>	Lingonberry	Su, F	Fruit	Dye	Y-K Delta Chugach

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By late summer/early fall, several berry species (e.g., cloudberry [*Rubus chamaemorus*], nagoonberry [*R. arcticus*], crowberry [*Empetrum nigrum*]) and local greens (e.g., sour dock [*Rumex arcticus*]) were ready to be harvested, and women and children would spend most days on the tundra gathering plant resources.

Most plants were available in a variety of locales, and their harvest did not dictate moving the family to specific camps. Plants that grew in abundance in specific terrain, such as several varieties of cliff greens, usually offered other

resources that could be harvested at the same time (e.g., fish, sandhill cranes). Greens such as *Rumex arcticus* could be found throughout the delta, and old camp sites are said to contain buried cache pits once used for plant storage.

As an example, when harvesting “wild spinach” or sour dock, Nunivak elders state that they would stay in an area until they had harvested enough for their family’s long-term needs (Amos, 1991; Kiokan, 1995). After picking, they would cook the spinach a little bit before placing it into a cache dug underground.

Cook em half way, just for the leaves to just shrivel up and not take much space, and they would dig ditches and line it with a certain type of twigs and grass and put em' in there until the weather gets colder, before the ground get hard, knowing that when it freezes, that *Ciwassit* (*Rumex arcticus*) would freeze in with the earth. So before that time they would go over there again, pull the *Ciwassit* out and this time leave em' on top of the ground. . . They would cover them with grass, probably willows too to keep them together and they would leave them until it freezes. (Amos, 1991, p. 16)

Before placing the spinach in the caches, the cooked leaves would be drained of juice and the pit lined with woven grass mats (e.g., *Elymus mollis*). "Some people rolled them up like a ball and put them away. Each roll was made enough for one meal. They rolled the spinach ball big enough for their dinner or a snack. That's how they took them out of the ground" (Amos, 1989, p. 25). Grass was placed on top before the cache was covered with rocks to insure it would not be disturbed until needed (Kiokan, 1995). Berries were stored in much the same way, except that these pits would be lined with rocks (Kiokan; Whitman, 1995), and raw spinach (e.g., *Rumex arcticus*) was used as an inner lining (Kiokan, 1995). The berries would have no juice when removed, since they would have dried out while being stored underground. In the fall, people would return to their seasonal caches and transport their stored berries and greens to their winter village. Curtis (1930, p. 36) describes berry caches as "a small box-like structure of flat stones lined with grass and covered with sod until air- and water-tight." Examples of such features were discovered during recent archaeological excavations on Nunivak Island (see Fig. 5).

Changes in Plant Use

While recent investigations on Nunivak Island (Griffin, 2001, 2004; Nuniwarmiut Taqnelluit, n.d.) have added extensive details to previous knowledge of traditional subsistence procurement and storage techniques, one must keep in mind that the memories of earlier subsistence use may be affected by historic changes to



Ethnobotany of Alaska: A Southwestern Alaska Perspective, Fig. 5 Rock-lined cache pits at Nash Harbor village, Nunivak Island, Alaska

Native culture. The most obvious change in Yup'ik indigenous plant use, between that found in early ethnographies and at present, is the current lack of knowledge of many previously harvested plants. With the abandonment of many small delta villages in favor of larger villages with established schools where Native children were sent to be educated, and a subsequent increased reliance on western foods, fewer families rely on traditional subsistence resources. Studies (e.g., Nowak, 1975) have documented a link between continued traditional subsistence activities and a family's economic position. With village centralization, the cost of purchasing and maintaining the equipment needed to continue traditional subsistence activities (e.g., boat, four-wheeler, gas) became dependent on having a steady source of income and time to pursue such activities. In time, information on earlier plant use is forgotten, and influences resulting from increased contact with non-Yup'ik mainland peoples can add to or supplant earlier local knowledge. For example, in 1927 Curtis (1930, p. 35) recorded the use of willow leaves (*Salix* spp.) on Nunivak Island as a food and medicinal item. In 1939, Lantis (1959, p. 60) found only one elder on Nunivak who still recalled the earlier use of willow. Today elders routinely deny such traditional use. However, recent influence of northern Eskimos on the island population has resulted in a renewed use of the plant, although contemporary Cup'it elders believe that its use is only of recent innovation. A similar pattern of

traditional versus recent use has been noted for stinkweed/wormwood (*Artemisia tilesii*).

It is easy to assume that observed Native lifeways in the early twentieth century reflect those practiced during the late prehistoric period or before. However, in spite of the evident continuity of tool use and general subsistence practices on Nunivak Island (Griffin, 2001, 2004) and the Yukon-Kuskokwim Delta (Shaw, 1983) throughout the past 500 years, traditional lifeways may have been different, possibly more complex, than those historically recorded. Following increased contact between mainland Native peoples (i.e., trade, intermarriage) and Euro-Americans during the nineteenth century, changes in the use of indigenous plants were probably an ongoing process, influenced by the degree and type of contact, as well as impacts from a serious loss in

Native population resulting from the introduction of western diseases.

Previous research in Native communities within the delta has focused on documenting changes to Native lifeways following the arrival of Euro-Americans to the region (e.g., Fienup-Riordan, 1983; Lantis, 1946). However, these studies have provided little detailed information on traditional use of indigenous plants. The collection of ethnobotanical information was rarely a focus of research efforts, and a systematic analysis of Native plant use throughout the region has yet to be undertaken. Given the incorporation of western foods in Native diets and a corresponding decline in the harvest of many indigenous plants, efforts to collaborate with Native communities need to be undertaken before information on traditional use of area vegetation has been forgotten.

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 4 Yup'ik Native plant name glossary

Scientific name	Common name	Yup'ik	Cup'ig	Siberian Yup'ik
<i>Achillea</i> spp.	Yarrow	punaiyulinu'kait		
<i>Aconitum delphinifolium</i>	Monkshood		cetegnæg	
<i>Alnus</i> spp.	Alder	chufu'koak		
<i>Angelica lucida</i>	Wild celery	ikiituk	ik'itut, ik'iituq, ikkitug	
<i>Arctostaphylos alpina</i>	Alpine bearberry	kavlak	kavlag	
<i>Ammodenia peploides</i>	Sea purslane		tukullegat	
<i>Artemisia tilesii</i>	Stinkweed, wormwood	caiggluk	neqñialngut	
<i>Betula nana exilis</i>	Birch, dwarf birch	chupuaiya'hak	cigur	
<i>Botlenia ovifera</i>	Sea potato, sea onion		arnaut	
<i>Caltha palustris</i>	Marsh marigold	allngiguaq	wivlug	
<i>Carex</i> spp.	Sedges		pekneret	
<i>Cladonia</i> spp.	Lichens	ciruneruat	qelqun'at	
<i>Cladonia rangiferina</i>	Lichens-reindeer moss	ciruneruat	ungagar, ungagat	
<i>Claytonia tuberosa</i>	Tuberous spring-beauty	ulqit	ulpit	ulkik
<i>Conioselinum chinense</i>	Western hemlock-parsley		tuk'ayug	
<i>Dendroa aggregate</i>	Unknown		tukumar	
<i>Draba borealis</i>	Wild lettuce		inguqit	
<i>Dryopteris austriaca</i>	Shield fern	ciilavik	centurkar, ceturga'ar	
<i>Dryopteris dilitata</i>	Shield fern	ceturqaaraat	cilqaarat, ilqaarat	
<i>Elymus mollis</i>	Wild rye grass	taperrnaq	taperrnaq	
<i>Empetrum nigrum</i>	Crowberry	paunraq	paunrat, pauner	pagungak ^a
<i>Epilobium angustifolium</i>	Fireweed	ciiqaaq	cilqaar	
<i>Epilobium latifolium</i>	Dwarf fireweed, river beauty		qilqaarat	

(continued)

Ethnobotany of Alaska: A Southwestern Alaska Perspective, Table 4 (continued)

Scientific name	Common name	Yup'ik	Cup'ig	Siberian Yup'ik
<i>Equisetum arvense</i>	Common horsetail	qetgoq	kenret	
<i>Eriophorum</i> spp.	Cottongrass	melquruaq	melqitutet, pal'it	
<i>Eriophorum angustifolium</i>	Tall cottongrass	anleq	pekner	
<i>Fomes ignarius</i>	Chew ash fungus	kuma'hak		
<i>Fucus</i> spp.	Bladderwrack		elquat	
<i>Fucus gardneri</i>	Bladderwrack		elquar	
<i>Hippuris tetraphylla</i>	Mare's tail	tayaruq	tayarut	
<i>Honckenya peploides</i>	Beach greens	qelquayak	tukullegat	mytknagrak
<i>Ledum palustre decumbens</i>	Labrador tea	ayuq, ai'yut	ay'ut	
<i>Linguisticum scoticum hultenii</i>	Beach lovage, wild parsnip	tukaayuq	tuk'ayat, ciukarat	
<i>Lycoperdon</i> spp.	Puffballs	agyam anaa	agyam an'a(i)	atykyrygak ^a
<i>Matricaria matricariodes</i>	Pineapple weed	atsu'koak		
<i>Mertensia maritima</i>	Oyster leaf	Tumagilir	ciunertur pag	
<i>Nephroma arcticum</i>	Arctic kidney lichen	kus'koak		
<i>Oxycoccus microcarpus</i>	Bog cranberry	uingiar, tumagliq		
<i>Oxyria digyna</i>	Mountain sorrel		quulistar	kugylnik
<i>Palmaria mollis</i>	Seaweed, dulse		elquat, elquarnar	
<i>Parrya nudicaulis</i>	Wild cabbage		inguqit	
<i>Pedicularis verticillata</i>	Wooly lousewort	ulevleruyak	megtat neqiat	kakykak ^a
<i>Petasites frigidus</i>	Coltsfoot	qaltaruq	lal ^a ngagguar	kamgyak ^a
<i>Picea glauca</i>	White spruce	mingkot'moak		
<i>Pohlia nutans</i>	Moss	kuma'hotit	kumarutet	
<i>Polygonum bistorta</i>	Bistort, pink plumes	cuassaaq	<i>Ciwassit</i>	siukl'iak
<i>Polygonum viviparum</i>	Alpine bistort		<i>Ciwassit</i>	siukl'iakyak
<i>Ranunculus Pallasii</i>	Pallas buttercup		aggulunguat	
<i>Rubus arcticus</i>	Nagoonberry	puyuraaraq	puyurarag	
<i>Rubus chamaemorus</i>	Cloudberry, salmonberry	atsalugpiaq	atsar atsakutag	akavsik
<i>Rumex arcticus</i>	Sour dock, "wild spinach"	quagciq	<i>Ciwassit</i>	al'kyhkak
<i>Salix</i> spp.	Dwarf willow	nuwi'longok	inaqac'it	okviuk
<i>Salix alaxensis</i>	Alaska willow		qugyuguat	kukunat ^a
<i>Salix fuscescens</i>	Willow		qimugkararat	
<i>Salix pulchra</i>	Diamond-leaf willow		qugyuguat	kukunat
<i>Saxifraga</i> spp.	Saxifrages		quulistat	siknak ^a
<i>Sedum rosea</i>	Roseroot, stone crop	cuqlamcaraat	megtat neqiat	nunivak
<i>Senecio pseudoarnica</i>	Ragwort, fleabane		qugyugguat	
<i>Sphagnum</i> spp.	Sphagnum moss	uruq		
<i>Streptopus amplexifolius</i>	Twisted stalk		atsarrlug	
<i>Vaccinium uliginosum</i>	Alpine blueberry, bog blueberry	curaq	cur'at	siugak
<i>Vaccinium vitis-idaea</i>	Lingonberry, low-bush cranberry	tumagliq	tumagilir	kitmik
<i>Valeriana</i> spp.	Valerian			ahseukpuk

^aName references same species but possibly different subspecies

The degree of contact between mainland and island Eskimo people, prior to the arrival of Russian and Euro-Americans in the late eighteenth and nineteenth centuries, is unknown but would have largely been limited to trade between neighboring groups during the summer months. Having to rely primarily on locally available resources for their subsistence, the Yup'ik incorporated many indigenous plants into their year-round diet. Contrary to earlier stereotypes of Arctic peoples' sole reliance on a meat-based diet for survival, local flora was routinely incorporated into the Yup'ik diet in addition to Native pharmacology and utilitarian tasks.

There are few Native elders with knowledge of traditional plant use in the Yukon-Kuskokwim Delta, and younger generations have not expressed a strong interest in preserving this data. Except for the continuing harvest of a few popular plant species (e.g., *Angelica lucida* [wild celery], *Rumex arcticus* [sour dock], *Caltha palustris* [marsh marigold], *Rubus chamaemorus* [cloudberry]), much traditional knowledge is not being passed on and will likely disappear with the passing of today's elders. It is important that additional research efforts to record traditional use of plants occur before knowledge of such use is forgotten.

Appendix: Glossary of Native Plant Names

See Table 4.

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Ethnobotany of Amazonia

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Amazonia is a place for myths and legends, and if it has been described for a long time as a “green hell,” it tends now to be perceived as a “green treasure,” with Native people keeping jealously the hidden secrets that may heal the whole planet. The truth is somewhere in the middle. Many people in Amazonia have a really good knowledge of their surrounding biodiversity and its uses, but this knowledge is unequally shared and rapidly eroding. Moreover, how Amazonian inhabitants use plants is a very dynamic field, due to the movements of people and the evolution of their culture. Summarizing Amazonian ethnobotany in a single encyclopedia entry is a challenging goal.

Amazonia is generally understood as the Amazon basin. Nevertheless, from ecological or anthropological points of view, this area is anything but coherent. In this entry, I will speak about the practices of the people from the tropical South American lowlands. This area encompasses the Amazon basin, i.e., the drainage area of the Amazon River and its tributaries, the Guiana shield, the North Brazilian shield, and the southern part of the Orinoco River basin. This region has an ecological homogeneity and a common cultural background. Mankind has been present in Amazonia for at least 10,000 years (Roosevelt et al., 1996). People came down from the north and appear to have spread over the area in a short period of time. According to the first Europeans testimony in the sixteenth century, human occupation in Amazonia was well organized and dense along the Amazon, with cities hosting thousands of inhabitants. But rapidly Amazonian societies faced an intense disorganization and split into smaller settlements. Now, Amazonia is a complex geopolitical region, encompassing more than 250 cultural groups. The majority of them are Native Americans, but many of them are mixed from African or

European descent. These different ethnohistories led to a rich corpus of plant uses that relies on a common Pan-Amazonian basis.

Historical Aspects of Amazonian Ethnobotany

Since the European discovery of South America, in addition to precious metals, plants became rapidly some of the most coveted goods. At the beginning it was simply wood for ships, then dye woods (*pau-brasil*, *Caesalpinia echinata* Lam.), and, finally, plants with medicinal properties (Manzali De Sá & Elisabetsky, 2012). The Jesuits early interest in Amazonian plant uses was followed, during two or three centuries, by a huge interest from the European countries for Amazonian economic botany. This led to many scientific (as well as political) expeditions, due to the dependence of European societies on natural fibers, spices, and remedies. The main part of the inventories was done by European naturalists such as the German C. F. P. von Martius or the French A. de Saint Hilaire, and their missions were scientific as much as diplomatic (Brandão et al., 2008; Brandão, Pignal, Romaniuc, Grael, & Fagg, 2012; Breitbach, Niehues, Lopes, Faria, & Brandão, 2013). The series of “legendary” botanists-explorers ends probably with the American R. E. Schultes, author of *The Healing Forest*, among other books, a milestone in Amazonian ethnobotany.

Between the late nineteenth and early twentieth centuries, there was an intensive exploitation of natural resources. The main natural product exported was rubber (*Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. and related spp., Euphorbiaceae). The close-to-slavery management system of the rubber harvest, the *aviamento*, led to the enrichment of a handful of *seringual* (*Hevea* grove) owners in the main harbors: Iquitos, Manaus, and Belem. Besides rubber, plants such as the *barbasco* (*Lonchocarpus utilis* A. C. Sm. and related spp., Fabaceae) were also exploited for export as agricultural insecticides. These cultivated or wild lianas, also called *timbo* or *cubé*, are traditionally used as a fishing poison.

People crush their roots and drop them into water to stun fishes so that they can collect them easily (Duke & Vasquez, 1994). These plants are rich in rotenoids, a class of isoflavonoid-derived compounds known for their ichthyotoxic properties. They were largely cultivated during the middle twentieth century and exported under the name of *cubé* resin (Fang & Casida, 1999; Schultes & Raffauf, 1990).

Different Faces of Amazonian Medical Ethnobotany

Two levels have to be distinguished when speaking about medical ethnobotany. Each group has its own specialties, and even every single village from the same cultural group has its own knowledge. On the other hand, there are common Pan-Amazonian popular medicines, which are shared from Iquitos to Belem. This common pharmacopoeia originates from a history of exchange between all these Amazonian cultures, as people move constantly from villages to the cities (San Lorenzo, Iquitos, Tabatinga, Manaus, Santarem, and Belem are some of these) to sell local products and return with goods and money. This has been one of the pillars of Amazonian economy (Emperaire, Aubertin, Bahri, & Bressolette, 1996). It consists in harvesting, in a relatively sustainable way, products or raw materials from the forest. Among them, we find *piassaba* fibers (*Leopoldinia piassaba* Wallace, Arecaceae), *babaçu* oil (*Attalea speciosa* Mart. ex Spreng., Arecaceae), Brazil nuts (*Bertholletia excelsa* Bonpl., Lecythidaceae), *açaí* (*Euterpe oleracea* Mart., Arecaceae), *copaiba* (*Copaifera* spp., Fabaceae), and many more. Those products are known by everybody in Amazonia and are found in every market in the region.

On the other hand, specific pharmacopoeias are found in different cultural groups, with some overlapping. It is now estimated that approximately 3,000 plant species are used medicinally in Brazil (Manzali De Sá & Elisabetsky, 2012). Nowadays, the plant uses of many groups in Amazonia are well described. Some of the most consistent works are those by Schultes and

Raffauf (1990), Balée (1999), or Grenand, Moretti, Jacquemin and Prévost (2004), and a good compilation has been established by Duke and Vasquez (1994).

Amazonian ethnomedical practices rely on a kind of dual system, which can be schematized as follows. Illnesses may be caused by spirits. Those spirits, often called “mothers,” are related to places, games, animals in general, meteorological events, or plants. They can harm people, and the main way to be healed is to consult a spiritual healer who will intercede between the malevolent entity and the patient. The therapies often rely on psychoactive plants, such as *tobacco* (*Nicotiana tabacum* L., Solanaceae), *ayahuasca* (a combination of *Banisteriopsis caapi* (Spruce ex Griseb.) C. V. Morton, Malpighiaceae, with *Psychotria viridis* Ruiz. and Pav., Rubiaceae), *toé* (*Brugmansia aurea* Lagerh., Solanaceae) or *chiric sanango* (*Brunfelsia grandiflora* D. Don ssp. *schultesii*, Solanaceae) (Schultes & Raffauf, 2004). But healers (*curanderos* in Spanish-speaking parts of Amazonia) may also be harmful, as they can send their own allied spirits to harm other people. This makes Amazonia look like a complex network of *curanderos*, spirits, and patients, involved in relationships of healing, killing, and revenge. Lay people are also aware of a certain number of magical plants, among which the *piri piri* are probably the most important. They (nearly) all belong to the genus *Cyperus* (Cyperaceae) and are cultivated around the houses and jealously cared for (Plowman, Leuchtmann, Blaney, & Clay, 1990), and their uses are often kept secret so they will not be stolen by neighbors.

However, a majority of daily ailments, considered “naturals,” or at least not from malignant origin, are healed at home or by people who have a particular knowledge of medicinal plants. These practices are still vivid, although primary health centers are now present nearly everywhere and accessing biomedicine is no longer a challenge. Knowledge of these plants is seen as a common phytotherapeutical background and is often shared at the community level. The diseases they heal are mostly perceived as not related to spirits. The complementarities between

these two medical levels, the *curanderos* and the *medicina casera* (home medicine), are the basis of Amazonian medical systems.

Now there is a clear tendency towards homogenization throughout the region, as a global Pan-Amazonian pharmacopoeia is replacing the particular knowledge of each specific group (Lenaerts, 2005). It is characterized by the predominance of cultivated plants around the houses, a small number of highly valued panaceas known with their Spanish (or Quechuas) or Brazilian names (e.g., *ajo sachá*: *Mansoa alliacea* (Lam.) A. H. Gentry, Bignoniaceae), and a high use of these “Pan-Amazonian” plants found in every herbal market (e.g., *sucuuba*, *Himatanthus sucuuba* (Spruce) Woodson and other spp., Apocynaceae, or *copaiba*, *Copaifera reticulata* Ducke L. and other spp., Fabaceae).

Some Important Medicinal Plants from the Amazonian Markets

Among those plants whose knowledge is widely shared throughout Amazonia, there are a handful of important ones, either for their historical, medicinal, or economical points of view, and they can still be observed in the markets. All are known since pre-Columbian times by Amazonian peoples, even if their uses have probably changed since those times. Some of them have been subject to exportation since the seventeenth century.

Andiroba (*Carapa guianensis* Aubl., Meliaceae)

Andiroba's oil is extracted mechanically from the seeds of *Carapa guianensis*, a tall tree from the Meliaceae family, and is sold in the main markets of eastern Amazonia. This fatty oil is principally used as a repellent against insect and tick bites and is the adjuvant of the *anato* red body dye (*Bixa orellana* L.) largely used by Amazonian Indians to paint their bodies. *Andiroba* oil is also claimed to be anti-inflammatory and contains molecules of the class of the limonoids (Silva, Oliveira & Figueiredo, 2009). It is used both on a small scale and industrially to produce soap.

Copaiba (*Copaifera reticulata* Ducke and Related Spp., Fabaceae)

Copaiba oil (or *copahu*), despite its name, is not a fatty oil but a sesquiterpene- and diterpene-rich oleoresin (Langenheim, 2003). It is extracted from several *Copaifera* species, trees from the Fabaceae family (Caesalpinioideae), after tapping (scarifying or piercing) the trunks. The most useful species seems to be *C. paupera* (Herzog) Dwyer, *C. multijuga* Hayne, or *C. officinalis* L. (Fabaceae) (Duke & Vasquez, 1994; Schultes & Raffauf, 1990). The composition and aspects of the oils vary depending on the species, but all are used as strong antiseptics, anti-inflammatories, and for wound healing (Veiga, Rosas, Carvalho, Henriques, & Pinto, 2007). Their commercial exploitation is very important in Brazil, and they have been exported to Europe and United States where they are still present in official pharmacopoeias.

Ipeca (*Carapichea ipecacuanha* (Brot.) L. Andersson, Rubiaceae)

Ipeca (or *ipecac*, *ipecacuanha*) is a small shrub not restricted to Amazonia, as it can be found in the humid forests of Central and South America. As many plants from the Rubiaceae family, it is rich in alkaloids, such as emetin. Its roots were used as an amoebicide but it is now better known as an emetic for people who ingested poisons. Ipeca roots syrup has been widely present in European, US and Canadian pharmacopoeias (Ferreira et al. 2012).

Ojé (*Ficus insipida* Willd.; *Ficus anthelmintica* Mart.; Moraceae)

El *ojé* (or *lombriguera* in Brazil) is one of the most valued anthelmintic [used to destroy parasitic worms] latexes of the Amazon, although it is more used in the western than in the eastern part (De Amorin, Borba, Carauta, Lopes & Kaplan, 1999; Hansson et al., 1986). It comes from tall trees from the Moraceae family. This latex, although controversial because of its high toxicity (Hansson, Zelada & Noriega, 2005), is still widely used by the native population. The latex is drunk pure or diluted with fruit juice or alcohol to get rid of intestinal worms. The properties are due



Ethnobotany of Amazonia, Fig. 1 *Sangre de grado* (*Croton lechleri* Müll. Arg.)

to an enzyme of the protease class called ficin. The use of ojé is often associated with food and salt prohibition (Duke & Vasquez, 1994).

Sangre de Grado (*Croton lechleri* Müll. Arg. and Related Spp., Euphorbiaceae)

The dragon's blood (*sangre de grado*) is a bright red latex (Fig. 1) extracted from several species of the *Croton* genus, medium-sized trees belonging to the Euphorbiaceae Family. The other numerous drugs with the same appellation, extracted from *Daemonorops* spp. (Arecaceae) or *Dracaena* spp. (Asparagaceae), are not American. The main species used is *Croton lechleri* Müll. Arg., but others, like *C. draconoides* Müll. Arg., *C. urucurana* Baill., or *C. palanostigma* Klotzsch, are also used the same way (Gupta, Bleakley & Gupta, 2008). The latex is used externally as a cicatrissant [to close a wound by scar formation] (Duke & Vasquez, 1994; Odonne et al., 2013), due to an alkaloid called taspine (Vaisberg et al., 2007).

Sucuúba (*Himatanthus sucuuba* (Spruce) Woodson and Related Spp., Apocynaceae)

Sucuúba (in Brazil), or *bellaco caspi* in the Spanish-speaking parts of Amazonia, is a small tree belonging to the Apocynaceae, exuding a white and abundant latex. Its external use against leishmaniasis or wounds seems to be widespread (Odonne et al., 2013; Schultes & Raffauf, 1990; Villegas et al., 1997) but it is sometimes sold on Brazilian markets against ulcers or digestive conditions (van den Berg, 1984). Its main compounds are iridoids and triterpenoids (De Miranda et al., 2000; de Silva, Amaral, da Silveira, Rezende & Pinto, 2007).

Conclusion

Amazonian ethnobotany is a multifaceted subject. Traditional uses of plants by the native inhabitants have changed a lot since the colonization of Amazonia by the Europeans. The place of the spiritual traditional healer, using few but powerful plants causing altered states of minds, is still paralleled by a general phytotherapy, individualized by each culture. Nowadays, it is also evident that a general Pan-Amazonian phytotherapy is emerging along the main routes of the Amazon, and it has not been established yet whether it is to the detriment of culture or not. Industrial plants also played a great part in the Amazonia's exploration and history. If rubber and *barbasco* are no longer of importance, the emergence of *açaí* berry-derived products exemplifies the high dependence on foreign fashions.

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Ethnobotany of the Aztecs

Jan G. R. Elferink

Scope

The Aztecs represented the ruling empire in Mexico when the Spaniards arrived there in 1519. It was their culture that came in close – and for the Aztecs disastrous – contact with the Europeans. The Aztecs were a rather young culture. Starting as a small tribe in the thirteenth century, they developed into the ruling culture in Mexico. At the arrival of the Spaniards in 1519, the Aztecs ruled Central Mexico from their splendid capital Tenochtitlan, situated at the place where Mexico City is now located.

Ethnobotany in its broadest sense is the part of botany that deals with the use of plants in religion, medicine, all aspects of social life, and their interrelationships. The Aztecs used a very large number of plants. We know that because a lot were written down in the early years after the conquest. Because of space limitations, only a few aspects of Aztec ethnobotany will be dealt with in this article. The focus is on some plants that were especially important for the Aztecs. The relationship between medicinal plants and religion will also be discussed. A number of publications provide more detailed information about Aztec ethnobotany. These include the works of Ortiz de Montellano, Martínez, several articles in the work of Schultes and von Reis, and the comments by Emmart in the *Codex Badianus*. See also: <http://www.lib.utexas.edu/benson/bibnot/bn-92.html> and http://maya.ucr.edu/pril/reprints_agp/raiceetn.html. For the pre-Columbian use of plants in criminal practices see <http://www.drugtext.org/library/articles/elferink01.htm>.

Sources

A number of sources deal with the use of plants by the Aztecs. These works are more detailed

than for the Mayas or Incas, so we know a lot about their plant use. By far the most extensive source is the work of Hernández. He focused on medicinal plants; he described about 2,000 of them, but he also gave information about a large number of other plants. Hernández was the personal physician of Philip II of Spain. Philip sent him in 1570 to Mexico with a quite clear and specific order: to get as much information as possible from the indigenous herbalists, physicians, and other people involved in medicine. The work of Bernardino de Sahagún, a Franciscan monk, is by far the most valuable source of general information about the Aztecs. His work deals with all aspects of Aztec culture, but it also includes a lot of information about the use of plants. The importance of Sahagún lies not only in the abundance of information which he wrote down. It is especially his reliability, because of the procedure that he followed using Aztec informants. The *Codex Badianus* is an Aztec herbal, written by an Aztec physician in honor of and for Charles V of Spain. It contains colored figures of plants, and a description of the treatment of several groups of diseases. The importance of magic in Aztec medicine is quite clearly illustrated in this manuscript. For understanding the role of religion and magic in the use of medicinal plants two chroniclers are of special importance. These two, Hernando Ruiz de Alarcon and Jacinto de la Serna, wrote their works in the seventeenth century. This might seem late, but the mere fact that they tried to eradicate the ancient customs and beliefs demonstrates that they dealt with the beliefs and attitudes of the ancient Mexicans. In both works ample attention has been paid to the use of *ololiuhqui*, *peyotl*, *picietl* and other plants in medicine and religion. In addition a number of other chroniclers mention the use of plants, but mostly their contribution is modest as compared with those mentioned before (Fig. 1).

The Aztec Interest in Plants

Botanical Gardens

The appreciation of the leading Aztecs for botany, and especially for medical botany, is

Ethnobotany of the Aztecs, Fig. 1

In the Mexican codices plants (especially flowers) are often depicted, such as here in the Codex Nuttall. They are probably connected with medicine, but their exact meaning is often unclear



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demonstrated by the presence of botanical gardens in ancient Mexico. Their wealth in species and choice was so large that the Spanish conquerors were deeply impressed. One of the most important gardens was near the palace of the ruler Montezuma. He did not want any food plant or fruit tree in his garden. Those, he believed, were for slaves and merchants. The garden contained medicinal plants, beautiful flowers, and odorous trees and herbs. Montezuma ordered his physicians to use the medicinal plants for the nobles at court (Cervantes de Salazar, 1971, p. 320). According to Solís the botanical gardens contained herbs for all types of diseases and ailments, and although the Aztec physicians had little knowledge of the cause of diseases, they knew quite well with which plants certain diseases had to be treated. The medicinal plants from these gardens were distributed freely to all those who suffered from diseases (de Solís, 1996, p. 172).

The king of the city-state Texcoco (which had a treaty with the Aztec capital Tenochtitlan) was Nezahualcoyotl; he lived in the fifteenth century. He is described as a constructor, a poet, a wise and clever statesman, and a righteous ruler who codified a number of laws (Clavijero, 1970, p. 115). He was also a special expert on medicinal plants. Those plants which he did not have in his vicinity – Texcoco is situated near present-day Mexico City at an altitude of about 2,000 m – were painted. Hernández used these

paintings when he prepared his treatise on the materia medica of Mexico; in the original version he meticulously copied figures of plants.

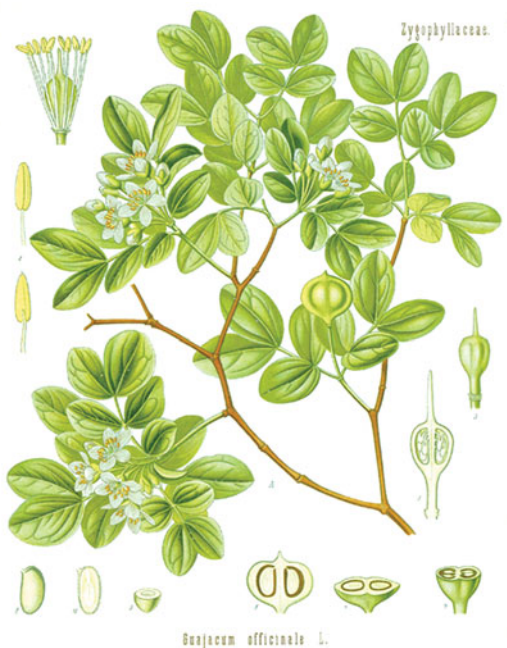
Clavijero (1970, pp. 231, 232) states that there were many botanical gardens in ancient Mexico. He mentions as the most important those of the capital Tenochtitlan, and that of Texcoco, and of the lords of Iztapalapa and of Huaxtepec. Cortés and Bernal Díaz expressed their admiration for the garden of Iztapalapa, and Hernández described a number of the plants from this garden. More important and also much larger than the garden of Iztapalapa was the botanical garden of Huaxtepec. The garden not only contained local plants but also many which were imported from regions far away. After the conquest the Spaniards conserved the garden for many years, and used the medicinal plants in the hospital which they had established in the region (Clavijero, p. 232). Clavijero stresses that many of the plants in this garden were taken from remote areas. The transportation of several types of trees from remote areas to the core of the Aztec empire was only one of the many classes of products which were transported. The conquered tribes had to pay a lot of tribute consisting of a large variety of goods, to the Aztecs. In addition the Aztec merchants, who traveled a lot abroad, transported valuable items (which could be plants) from the region where they practiced commerce, to the capital.

Medicinal Plants

Knowledge of medicinal plants was essential for the Aztecs because their treatment of diseases relied heavily on their use. The principal quality or application of the plant determined their nomenclature. That could be a color, the place where it was found, the beauty of the flower, but also its preferential application against a certain disease. The Aztecs often gave a plant the suffix *patli* when it was used as a medicine; *patli* means “medicine,” but gives by itself no further specification. The reference to a disease or target was often given in the remaining part of the name. In this nomenclature the plant *axixpatli* was a medicine which caused urination (a diuretic). In the same way the plant *atonahuizpatli* was a remedy against fever. In such a name the ability of the plant to act as a medicine against fever is stressed, but it does not necessarily mean that the plant had no other properties. Sometimes a large number of different plants had the same name. The disease *nanahuatl*, probably syphilis or a related disease, was very important in ancient Mexico (Fig. 2). Hernández gives not fewer than eight different plants which were called *nanahuapatli*. The Aztecs also had a medicine called *nanahuaquahuatl* or “tree against *nanahuatl*,” and *nanahuaxochitl* or “flower against *nanahuatl*.”

The Aztecs had a clear idea about the origin of their knowledge of medicinal plants. They were convinced that they had inherited this knowledge from the Toltecs, a tribe that resided in the valley of Mexico before the Aztecs arrived, and to whom the Aztecs were related. About the Toltecs Sahagún writes:

...the Toltecs had much experience and knowledge, they knew the properties and virtues of herbs, they knew which were harmful and poisonous... and through the large experience they had [of these plants] they passed on [the knowledge of] those which are now used for curing, because they were the first physicians, and especially the first of this kind who were called Oxomoco, Cipactonal, Tlaltetecuín, and Xochicauaca who were so competent in knowing medicinal herbs that they were the first inventors of medicine, and the first physician-herbalists. ... (de Sahagún, 1969, p. 10-XXIX).



Ethnobotany of the Aztecs, Fig. 2 It is striking that the *Guayacum officinale* or guayacan was not described as one of the *nanahuapatli* (medicines against syphilis). The guayacan became a major medicine for the Europeans who suffered from syphilis. This picture is from Köhlers *Medizinal-Pflanzen*

The description underlines the importance of medicinal plant knowledge, in a way that demonstrates that medicine and botany could not be separated.

Plants in Religion and Medicine: Divine Plants

The Aztecs venerated a large number of gods, and a number of them had a close relation with plants. The goddess Toci was venerated by all those who had a profession related to medicine (de Sahagún, 1969, pp. 1-VIII and IX). She was the goddess of medicines and medicinal plants. Like other social entities in the Aztec society the pharmacists venerated their own deity. This was primarily the goddess Tzapotlatena. The fact that she had invented the *uxitl*, a highly appreciated medicinal resin derived from pines, was the reason that the



Ethnobotany of the Aztecs, Fig. 3 One of the maize goddesses, named Xilonen, depicted in the Codex Nuttall

pharmacists venerated her. For the invention of the resin she was immortalized and incorporated in the Aztec pantheon of gods and goddesses. Because of the importance of maize as a food plant, some gods were especially associated with maize: Cinteotl, and the related deities Xilonen (Fig. 3). Aztec tobacco or *picietl* was also closely linked to religion. It was believed that tobacco was the body of a goddess called Cihuacoatl (Mendieta, 1973, pp. 66, 67).

Some time after the conquest a number of priests tried to eradicate the ancient beliefs of the Aztecs (de la Serna, 1953; Ruiz de Alarcon, 1953). These priests reported about their activities, and from these reports we can learn how high the Aztecs appreciated a number of plants. In fact, the priests described these plants as divine plants, because they were venerated as (minor) gods. They were invoked by means of incantations or prayers, for help with diseases. Among these were *ololiuhqui* (*Rivea corymbosa*), *peyotl* (*Lophophora williamsii*), *picietl* (*Nicotiana* sp.), *huauhtli* (amaranth, *Amaranthus leucocarpus*), and *yauhtli* (*Tageta lucida*). They had in some way or other a connection with the supernatural. Some of them were hallucinogens, and could be

used to get into a trance to make contact with supernatural powers (Fig. 4). These hallucinogens were used not only for divination purposes, but also in medicine. The religious relevance of the plants varied; the *ololiuhqui* was especially venerated as a kind of god. On the other hand, the *picietl* (tobacco) was used most frequently against a variety of diseases. The *peyotl* was mostly considered in conjunction with *ololiuhqui*, while the *yauhtli* could sometimes substitute for *picietl*. *Yauhtli* (more correctly spelled: *iyauhtli*) was considered an important medicinal plant (Elferink, 1988) (Fig. 5). Hernández mentions more than 20 applications in Aztec medicine. A priest who asked the plant for a cure especially invoked *picietl*. At the same time it was applied to the patient. Occasionally other medicinal plants were invoked for special complaints. For example, the *poztecpatli* was a medicine against bone fractures. It was invoked in an incantation while the priest-physician applied the plant in the form of a plaster (Ruiz de Alarcon, p. 189).

A plant that was not hallucinogenic but nevertheless highly venerated by the Aztecs was *huauhtli*. The connection of *huauhtli* with religion was complex. It derived its importance not from incantations but from a special application in Aztec religion. From *huauhtli* a dough was made that was called *tzoalli*. From this *tzoalli* statues of gods were made. The statues were venerated and subsequently consumed in religious ceremonies as a kind of communion. *Huauhtli* was also an important food plant, and used against diseases such as eye complaints, swellings and pain in the chest.

Some hallucinogenic plants, namely *ololiuhqui* and *picietl*, had still another connection with medicine. They were principal ingredients of *teotlaqualli*. This was an unction that was offered to the gods, for whom it served as food. The Aztec priests smeared themselves with this unction, to dispel fear and to reach the appropriate state of mind to serve the Aztec gods. A few cases are reported in which the Aztec emperor or soldiers were smeared with *teotlaqualli*. It is suggested that the black color of some Aztec deities, as depicted in the codices, was due to an ointment with *teotlaqualli*. In addition to its use for psychoactive

Ethnobotany of the

Aztecs, Fig. 4 Besides the hallucinogens mentioned in the text the Aztecs used *teonanacatl*, the divine mushroom. In the lower part of the picture (Codex Nuttall) the mushroom is depicted, as well as a man who eats it and an unknown deity



Ethnobotany of the

Aztecs, Fig. 5 The Aztecs sacrificed many humans, as depicted here in the Codex Nuttall. On a few occasions they were stunned before they were sacrificed. According to Sahagún the *yauhtli* was used for this purpose



purposes, *teotlaqualli* was applied in medicine under the name *teopatli* (Elferink, 1999).

Some Plants with Special Interest for the Aztecs

Maize

The name maize comes from the language spoken in the Caribbean; the Aztec name was *tlaolli* (*Zea mays*). It was by far the most important food plant of the Aztecs. Its importance can be derived from the large number of Aztec gods that were associated with maize. Its use in medicine was

rather limited, although a number of chroniclers had a different opinion. They were convinced that the consumption of maize products was the cause of the low incidence of kidney and bladder complaints among the Aztecs. From maize a porridge called *atolli* was prepared. It was usually prepared together with other plants, and so a large number of different types of *atolli* were known. The *chillatolli*, for example, was *atolli* mixed with chili pepper. This *atolli* was an aphrodisiac, probably due to the pepper. Hernández describes nearly 20 different types of *atolli*, some of which were applied in medicine. It is hard to say

whether their supposed medicinal action was due to maize or to the other added products.

Picietl

There are few plants which played such a decisive role in Aztec medicine and religion as the *picietl* (*Nicotiana* sp.). *Nicotiana rustica* is often given as identification of *picietl* or Aztec tobacco, but the properties of *N. rustica* do not correspond with those of *picietl*. This refers especially to the mind-altering properties of *picietl*, and these properties especially determined its role in religion, magic, and curing with medical incantations as mentioned before. Many chroniclers have noted these psychoactive properties, so that there is little doubt about this property in ancient times. It is therefore not surprising that diviners used *picietl* to get intoxicated, so that they could make divinations. In addition to magic-religious applications in medicine, *picietl* was just applied as a medicinal plant. Hernández mentions its use against more than 20 different ailments, particularly ailments associated with pain. An interesting application was the use of tobacco as an antidote against the bite of various poisonous animals and the cleansing of wounds with tobacco juice. A particular application of tobacco was the stunning of dangerous snakes with tobacco powder, so that they could be caught for religious purposes (Elferink, 1983).

The Aztecs considered tobacco a sacred plant, and it was highly appreciated because of its use in medicine and its psychoactive properties. In this context it is relevant to realize that the Aztecs did not use the tobacco for recreational purposes as we use tobacco today. The Aztecs did not experience the negative effects of smoking, although they knew too that excessive use was dangerous.

Metl

The name *metl* or *maguey* was used for several Agave species. The *metl* was in more than one respect an important plant. It provided fiber that could be used for preparing clothes, sandals, and other materials. It was used to prepare a good quality of paper. The thorns were used as needles. A specific application of these thorns was the

pricking in the ears or genitals to obtain blood for an offering to the gods. *Metl* was the basis for the preparation of *octli*, today better known as the *pulque*, an alcoholic drink made by fermenting a honey-like secretion of the plant. Although the use of alcoholic beverages was forbidden under normal conditions, *octli* was so important in Aztec society that several Aztecs gods were associated with it. It was frequently used as an offering. Consumption of *octli* occurred mainly during festivities of some *octli*-gods. Both *metl* and *octli* were applied in medicine, the *octli* mainly as vehicle for the intake of other medicines. Pregnant women were allowed to consume *octli* outside religious festivals, because of the supposed strengthening action of the beverage (Fig. 6).

Ulli

Ulli or *hule* was the resin of the *olcahuitl* (or *holquahuitl*) tree (*Castilla elastica*), one of the rubber-producing trees of the Aztecs. It had a number of applications. The *hule* was the product from which balls were made for the ritual ball game. It was further used in a number of religious customs. One of them was related to medicine. If someone recovered from a disease he wanted to honor the god who was associated with the disease. For that purpose he went to a soothsayer-priest to select a suitable day. On that day the former patient burnt in his home pieces of paper on which the soothsayer had painted with *ulli* the picture of the god who had to be venerated (de Sahagún, 1969). The use of *ulli* as an offering to the gods is confirmed by other chroniclers (Durán, 1967: Calendario, V). The *ulli* was sold in the markets by special vendors, who sold nothing except *ulli* (de Sahagún, pp. 10-XXIV). One of the most important medical applications of the *ulli* was to treat dysentery and diarrhea (Hernández, 1959; *Relaciones Geográficas Tlaxcala*, 1984, p. 271; *Relaciones Geográficas México*, 1985, p. 318). For that purpose the *ulli* was often mixed with cacao. It was further used against a number of other ailments such as abscesses, eye diseases, inflammations, intestinal problems, urinary complaints, colic, pain, headache, and eye diseases (de Sahagún, p. 11-VI; Hernández). Hernández describes a peculiar

Ethnobotany of the

Aztecs, Fig. 6 From maize a beverage was prepared that was called *octli* (later it got the name *pulque*). Its consumption was forbidden under normal conditions but during some religious feasts it was taken in large quantities. Here the preparation and consumption of *octli*, as depicted in the Codex Nuttall



application of the ulli, which he apparently had learnt from indigenous physicians. Mixed with axin it was taken to improve the agility and speed of the joints. The informants told him that the bones were loosened in a sense that turns and movements were facilitated so that acrobatic abilities were obtained (Hernández).

Coanenepilli

Another plant, which is often mentioned by the chroniclers because of its frequent use by the indigenous population, is the *coanenepilli*. The name “serpent tongue” refers to the form of the leaves which are bi-lobed (Emmart, in *Codex Badianus*, 1940: plate 59). As might be expected, the name was used for completely different plants, namely *Dorstenia contrayerba*, and a *Passiflora* sp. For medicinal purposes the first one was by far the most important. In the *Codex Badianus* *coanenepilli* was prescribed against obstruction of the urinary tract. An important application of *coanenepilli* was its application as an antidote. For that reason it was called *contrayerba* by the Spaniards. If a snake or a scorpion bit someone, the Indians anointed the bite with the *coanenepilli*, while the juice of the plant was drunk (Relaciones Geográficas México, 1986, p. 150; Relaciones Geográficas Michoacan, 1987, p. 43). Another important application of *coanenepilli* was against fever

(Relaciones Geográficas México, 1985, pp. 280, 306, 312). The Aztec informants of Sahagún stress the ability of the *coanenepilli* to purge: bad humors were expelled by mouth and via stool de Sahagún, 1969, pp. 10-XXVIII).

Shortly after the conquest it was also applied against typhus (de la Serna, 1953, p. 283; Mendieta, 1973, p. 98; Relaciones Geográficas Tlaxcala, 1985, p. 205). The Aztecs desperately tried a number of medicines against the new diseases which were imported by the Spaniards. These diseases decimated the number of Indians, and caused depopulation of large parts of the country (see Chap. XIII). Among the few medicines used by the Indians against these new diseases, the *Relaciones Geográficas* mentions the *coanenepilli*. The frequent application of this plant could suggest that the Indians had some benefit from it. On the other hand, the number of casualties could hardly have been higher than it was, so the new drug had only a limited curative value (Relaciones Geográficas Tlaxcala, pp. 51, 54, 59). The reason for the use of this plant against epidemics was probably that the *coanenepilli* was regarded as a good remedy against feverish conditions. Because the postconquest epidemics were accompanied by fever, the choice for the *coanenepilli* was evident (Relaciones Geográficas Tlaxcala, pp. 84, 205).

Coanenepilli was popular in the combined treatment of diseases with medicinal plants and magic-religious incantations. If someone experienced chest pain because of an accident, the powdered root of coanenepilli was applied, and the patient had to drink a potion of the plant thickened with ground maize. At the same time an incantation was spoken where the coanenepilli was invoked in the name of the god Pahtecatli (Andrews, 1984, pp. 177–178). Combined with magic incantations the coanenepilli was further applied against fever and against cutaneous eruptions (Andrews, 1984, pp. 195–199; de la Serna, 1953, pp. 292, 293, 283, 289).

Iztauhyatl

The *iztauhyatl*, in Mexican folk medicine called *estafiate*, is botanically known as *Artemisia mexicana*. According to the Florentine Codex the plant was a remedy against many diseases (Florentine Codex, 1950–1969, pp. 11–VII). Relapsing fever, cough and anxiety are mentioned. The plant was useful for treating anxiety (de Sahagún, 1969, pp. 11–VII). It was also a part of complex medicines. In the Codex Badianus the *iztauhyatl* was part of a remedy against some diseases which we do not always know exactly what was meant: weakness of the hands, ailment of the fundament, injury of the feet, lassitude, excessive heat, lightning stroke, and phthiriasis of the head (Codex Badianus, 1940: plates 43, 61, 65, 66, 79, 91, 102). Hernández indicates that the name *iztauhyatl* was used for more than one plant. In most cases, however, the plant described as *iztauhyatl* was *Artemisia mexicana*.

Magic power was ascribed to the *iztauhyatl*, and it was considered a sacred herb (Aguirre Beltrán, 1987, pp. 124–126). According to Aguirre Beltrán the name of the plant is derived from *iztahua* (deity of the salt), and *atl* (water). The indigenous physicians called *techichinani*, who cured by sucking the illness from the body, chewed the *iztauhyatl* before they started the sucking of the disease. As a sacred plant the *iztauhyatl* was invoked in cases of troubles in love affairs. The magic power of the *iztauhyatl* was called for assistance when a pregnant woman

or her husband wanted to trespass some rules, such as leaving the house during the night. The result was quite nasty for the child to be born who would cry a lot or become ill. To prevent these dangers the woman had to wear a bag with some copal or *iztauhyatl*, and the man had to wear a bag with *picietl*, when they went out during the night (de la Serna, 1953, p. XIII; de Sahagún, 1969, pp. 5–XIX).

Against one of the most severe epidemics of the postconquest time, mostly referred to as *cocoliztli*, no medicines were available. Among the few which were tried with unknown success were the *iztauhyatl*. Some of the authors of the *Relaciones Geográficas* mention the plant as a remedy; it was put in water, and the water was used to wash the patient (Relaciones Geográficas Mexico, 1986, p. 135).

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Ethnobotany of the Incas

Jan G. R. Elferink

The conquest of America resulted in a considerable enrichment of the number of plants that could be used by Europeans in medicine and nutrition. Important examples are the potato, maize, beans, cacao, chili pepper, quinine, and so on. All these plants were widely used by the pre-Columbian peoples, among which were the Incas. The Incas were only one of the many highly developed civilizations that developed in the Andes and the Peruvian shore of the Pacific Ocean. Like the Aztecs in Mexico, the Incas were a young culture, starting their development in the thirteenth century. When the Spanish conqueror Pizarro arrived in Peru in 1531, the empire of the Incas was enormous, stretching from what is now Colombia in the North, to the middle of Chile in the South.

Information about the use of plants in all aspects of daily life by the Incas (i.e., Inca ethnobotany) comes mainly from the Spanish chroniclers who accompanied or followed the Spanish

conquerors. Unfortunately their information is far more limited than of the chroniclers of the Aztec region. As a consequence we know less about Inca ethnobotany than about Aztec ethnobotany. The chronicler Cobo gave the most extensive description of Inca plants. Some indigenous chroniclers, such as Poma de Ayala, gave some original applications of plants by the Incas. A very late work by Losa contains material that was mostly derived from ancient sources (including Cobo), and thus provides information about the use of plants that is probably of pre-Columbian origin. Besides the information written down by the chroniclers, an increasing quantity of information comes from archeological findings.

Although the amount of information about the use of plants by the Incas is limited, the amount is far too large to cover in a short paper. Therefore only a restricted number of items of Inca ethnobotany will be dealt with. These items come from the use of plants in medicine, and in connection with their role in magic and religion. There is excellent additional information about Inca ethnobotany. These include the works of Yacovleff and Herrera, Towles, Alarco de Zadra, Bastien, Brack Egg, Valdizan, and Maldonado. Unfortunately some of these works are not easily accessible. A very good website about the potential economic applications of Inca food plants is <http://www.nap.edu/books/030904264X/html/>.

Medicinal Plants

The Inca Herbalist-Physician: Hampicamayok

In his description of the Inca physician, Cobo, (1964, p. 256) underlines the importance of the knowledge of medicinal plants for this profession.

... Their physicians were in general old people and highly experienced... They had little knowledge about the nature of the diseases and about their specific names... [They knew] many herbs to cure them. They had more knowledge about wounds and sores... and the particular herbs to cure them. They never used complex drugs, they cured with simple herbs, and between them there were many great herbalists... from whom we learned the virtues of many plants which we now

use in our cures. With these simple drugs they also used to make fomentations and perfumes, which they applied in fever and other ailments. . .

Other chroniclers such as Garcilaso confirm the importance of knowing plants among the Inca physicians. Though Garcilaso is sometimes contradictory in his descriptions of the medical abilities of the Incas he praises the herbalists. There were “great herbalists who were very famous in the days of the Incas. These herbalists learned the virtues of many herbs and taught them by tradition to their sons; they were regarded as physicians. . .” (Garcilaso de la Vega, 1966, p. 121).

The most common name for this type of physician was the *hampicamayoc*, literally “official in charge of medicines” (González Holguín, 1952; Morua, 1946, p. 113; Poma de Ayala, 1980). Calancha states that the (h)anpicamayos, who were called *oquetlupuc* in some coastal regions, were physicians with good reputations (Calancha, 1974, p. 1248).

Besides Cobo some other chroniclers made statements which give an idea of the knowledge about medicines of the indigenous herbalists. Without referring directly to the herbalist, Blas Valera stresses the large number of medicinal plants of the Incas. He says that if they were all known there would be no need to bring herbs from Spain or elsewhere, but that the Spanish doctors set so little store by them that even those which were known to be used by the Indians have in the main been forgotten (Valera, 1992, p. 132). It is not quite clear if the Kallawayas, the traveling herbalists of the Andean regions in Bolivia and Peru, knew the *hampicamayok*. About these Kallawayas (or Callawayas or Callahuayas) a large amount of information is available concerning their role in folk medicine of the last few centuries (Bastien, 1987).

Plants Used in Medicine

In contemporary Peruvian folk medicine a very large number of medicinal plants are used, but the chroniclers described only a relatively small number of them, only a few hundred. That does not mean that the Incas did not use them. It is more an indication that the chroniclers for the Inca region were far less competent than those



Ethnobotany of the Incas, Fig. 1 Maize or *sara* was an important food plant. According to the chroniclers, the consumption of maize products was the reason for a low incidence of gout among the Incas. This and the other botanical pictures are from Köhlers *Medizinal-Pflanzen*

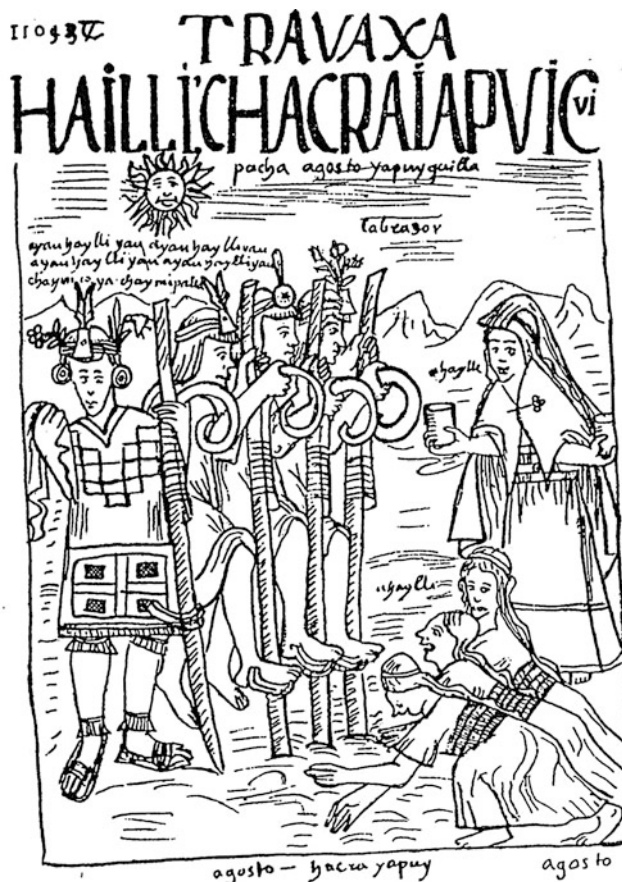
of the Aztecs. Cobo has especially described many Inca plants. Among these were a few that were more important in Inca medicine than others. Maize or *sara* (*Zea mays*) was not only an important diet staple but was also an important medicine, as was the slightly alcoholic beverage called *chicha* that was prepared from maize (Fig. 1). According to several chroniclers the consumption of maize and *chicha* was the reason that they saw very few kidney and bladder complaints among the Incas (Fig. 2).

In the work of most chroniclers only a few plants are mentioned. It seems likely that those few plants mentioned repeatedly by different authors were of special importance and widely used. If this reasoning is correct then *molle* (*Schinus molle*) was one of the most used medicinal plants (<http://www.herrerros.com.ar/>

melanco/elferink.htm). Contreras y Valverde (1965, pp. 11, 12) states that the Indians considered the *molle* as a universal medicine against all their ailments. The differential use of *molle* is a good example to show that Inca physicians were quite aware that the eventual medicinal effect was dependent on preparation and means of application. The tree exudates a resin that was taken as a purgative and against melancholy; the resin in wine was against dropsy (Lizarraga, 1968, p. 81; *Relaciones Geograficas*, 1965: I-349; Vazquez de Espinosa, 1969, p. 432). To cure leishmaniasis the resin and the bark of the tree were boiled in water until the water remained colored, and from this fluid the Indians took a portion on an empty stomach, and a second portion in the afternoon (Cobo, 1964, p. 6-LXXVIII). The dried and pulverized resin was applied against ulcers. Lizarraga describes the resin as an excellent remedy for diseases of the respiratory system; he had tried the resin on himself (Lizarraga, 1968, p. 81). The leaves, cooked and applied in a bath, were used for gout, and the crushed leaves were applied on wounds (Cobo, 1964, p. 6-LXXVIII). The liquid made by boiling the leaves in water was a good remedy for eczema (Garcilaso de la Vega, 1966, p. 504). From the leaves a kind of oil was prepared that was useful for pain in the joints and for ailments of the stomach (*Relaciones Geograficas*, 1965: I-349). A decoction of the leaves was applied as a bath for the treatment of the swollen legs of dropsy patients, and for gout. A plaster of the fruits was supposed to be effective for stomach complaints (Cobo, 1964, p. 6-LXXVIII). The fruits of the *molle* were crushed and the juice gave a beverage that was taken for kidney and bladder complaints (Garcilaso de la Vega, p. 504). The fruit was also used to prepare a kind of *chicha*, which was more intoxicating than the *chicha* made from maize, and which was highly esteemed by the Indians (Cobo, 1964, p. 6-LXXVIII). Besides medicinal properties the *molle* possessed some other qualities. Its wood was preferred as the basis for charcoal. This was the reason that it lost its importance in colonial times. Before the conquest the tree was very common, but a few years after the conquest

Ethnobotany of the

Incas, Fig. 2 Ploughing by special implements as preparation for sowing maize was ceremonially initiated by the Inca ruler and his family, recognizable by the large earrings



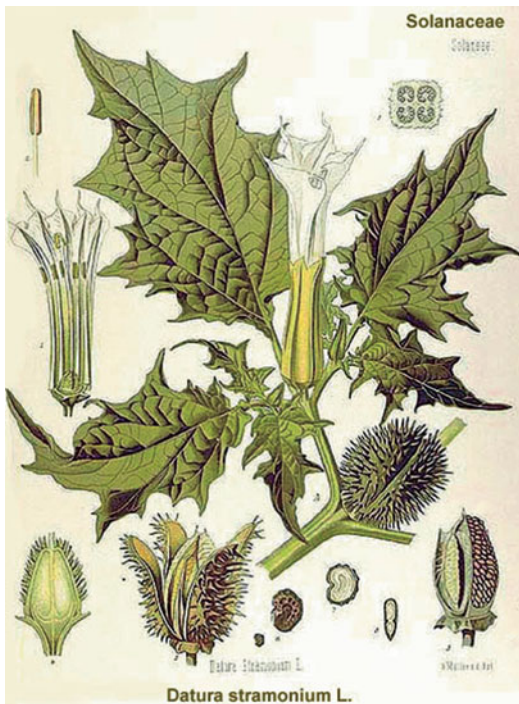
it had decreased dramatically (Garcilaso de la Vega, 1966, p. 504) because of the need of charcoal for brasiers.

Another plant with widespread application was the *quinua* (*Chenopodium quinoa*). The plant was an important food-plant; it was especially attractive because it grew at high altitude. It was also used in medicine for a number of ailments such as stomach complaints, inflammations, spasms, swellings, fever, liver complaints and so on (Calancha, 1974, p. 138; de Losa Avila y Palomares, 1983, pp. 71, 72; Garcilaso de la Vega, 1966, p. 500). Another attractive feature was the possibility of preparing a good quality of inebriating chicha.

The *chamico* (*Datura stramonium*) was a strongly hallucinogenic plant (Fig. 3). In low doses the plant was used against fever, insomnia, inflammations, and to abate pain. According to Cobo the *chamico* was taken to get inebriated.

Higher doses were used in criminal practices, a custom that has persisted till modern times. According to Cobo the chamico was secretly administered to victims who became intoxicated, and thus could be robbed easily. The chroniclers do not report about the use of chamico in religion, in contrast with other psychoactive plants.

Some plants, such as *coca*, *sayri* (tobacco) and potatoes were especially important in social life as food plants or in religion as offerings (<http://www-personal.umich.edu/~jlvoris/thesis.html>). However, all of them were also used as medicine. Chewing of coca leaves was practiced to ease hunger, thirst and tiredness, and this habit became especially important after the conquest (Fig. 4). Coca leaves were applied externally to strengthen broken bones and to cure wounds and ulcers. The decoction was taken against diarrhea and to combat stomach complaints. The dried pulverized leaves were used for asthma. Coca was added to



Ethnobotany of the Incas, Fig. 3 *Datura stramonium* or *chamico* was used in medicine and in malevolent practices

tobacco and chewed maize in an ointment to treat the bites of poisonous animals (de Atienza, 1931, p. 75). Two types of tobacco were distinguished: a cultivated and a wild form. It seems likely that these two forms correspond with *Nicotiana tabacum* and *Nicotiana rustica*, respectively (Wilbert, 1987; <http://www.hoboes.com/html/Politics/Prohibition/Notes/Shamanism.html>). Both were used in medicine, but mostly it is not indicated which form was used. The root of the wild form was called *coro*, and was especially suited for a number of diseases, including syphilis. Tobacco was usually smoked, but the Indians used the tobacco also as snuff (Cobo, 1964, p. 4-LVI). Tobacco was used to treat headache and migraine, and to improve sight. Poma de Ayala states that tobacco, in the form of snuff, was used against fever and cold (Poma de Ayala, 1980, p. 769). One of the main applications of tobacco was to treat bites of poisonous animals (Apuntes, 1987, p. 14; Maroni, 1988, p. 157). The medical applications of potatoes were limited. Cooked



Ethnobotany of the Incas, Fig. 4 The coca plant played a role in Inca religion and medicine. Its use in pre-Hispanic times, however, was strongly regulated by the Inca ruler

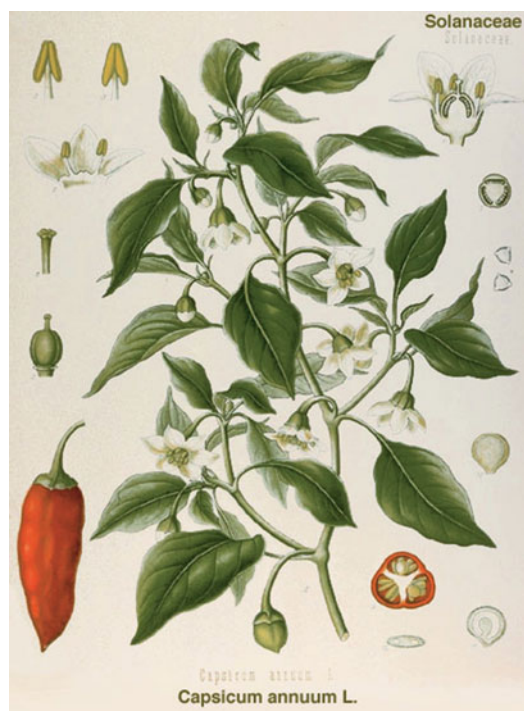
potatoes were applied against gout. Potatoes were freeze-dried for conservation, and the resulting product was called *chuñu*. The *chuñu* was considered an excellent remedy against ulcers, spasms, pain of syphilis, and verruga (Cobo, 1964, p. 4-XIII). The Incas knew many tubers that were very important as food plants. All these plants, among which are potato, *oca* (*Oxalis tuberosum*), *maca* (*Lepidium meyenii*), *ulluco* (*Ullucus tuberosum*) and *añu* (*Tropeaolum tuberosum*), were also applied in medicine. About the economic aspects of these plants an excellent internet source is available (<http://www.nap.edu/books/030904264X/html/>).

Procreation and Plants

A number of plants were used to modulate fertility, or to induce sterility. The use of plants was mostly combined with magic. Among the plants that were applied to induce fertility were the

cabega, the *vilca* (*Anadenanthera colubrina*), the *espinco* (*Medicago hispida*), and the *mocomoco*. Murua (1987, p. 435) states in a general way that the Indians used many plants and potions, not only to procure fertility, but also to induce sterility. In a society where having children was important, the administration of sterility-inducing plants was a severe crime that was punishable by death (Casas, 1939, p. 147; Elferink, 1999). Because those who induced sterility saw few reasons to be communicative, the chroniclers write in general terms about it and give no concrete names of plants. A colonial source reports that the Peruvian Indians considered the consumption of an infusion of the leaves of the *sogue* (*Salix humboldtiana*) a means to cause sterility in women (de Losa Avila y Palomares, 1983, p. 110). It is noteworthy that the Incas used the plant for several medicinal purposes, but that for these applications the infusion of the leaves was not taken orally.

Both plants and magic were applied to increase or to decrease libido (Elferink, 2000). Acosta warned that the excessive consumption of *uchu* or *ají* (chili pepper, *Capsicum annuum*) by youngsters was undesirable, because of the aphrodisiac action of the plant (Fig. 5). This pepper was applied frequently to spice meals. Its use was so common that abstaining from consuming *ají* was considered fasting. Other plants described as an aphrodisiac were the *cuchuchu*, the *siaya*, the *tocoracas* and the *itapallo*. The *añu*, presently better known as *mashua* (*Tropaeolum tuberosum*), has been described as an anaphrodisiac (Cobo, 1964, p. 171; Garcilaso de la Vega, 1966, p. 501). The Inca ruler gave the roots of the plant (it is an important food plant) to their soldiers as food, so that they forgot their wives. A later source describes the plant as an aphrodisiac (de Losa Avila y Palomares, 1983, p. 133). From the plant called *pencácuc* (*Mimosa* sp.) a male and a female form existed. Cobo describes the aphrodisiac properties of this plant, and he states that only the roots of the male form of the plants were stimulating; the roots of the female form had the opposite effect. A comparable peculiar difference between the male and female form of a plant has been ascribed to the *chutarpo*



Ethnobotany of the Incas, Fig. 5 *Capsicum annuum* or chili pepper was an important food plant. It was considered a medicine and also an aphrodisiac

(or *huanarpo*). The male form, *huanarpo macho* (*Jatropha macrantha*), was known to act as an aphrodisiac. The female form, *huanarpo hembra* (*Cnidoscolus peruvianus*), acted in the reverse way, and could be used as an anaphrodisiac to annul the effect of the former (Santa Cruz Pachacuti, 1992). Although the effects of these plants have not been investigated, the description suggests that the plants possessed a magic action rather than a real one. However, in contemporary folk medicine the *huanarpo macho* is still used as an aphrodisiac for men, while the *huanarpo hembra* is considered an aphrodisiac for women and a desaphrodisiac for men (Brack Egg, 1999, p. 145). The *maca* (*Lepidium meyenii*) is a plant that has gained a lot of interest in recent times because of its supposed aphrodisiac and other properties. Because it can stand low temperatures, it was a favorite food plant of high altitudes. Descriptions about its use as an aphrodisiac in ancient Peru are scarce. Cobo, (1964, p. 4-XVI) suspects that the relative

increase of the population in the province of Chincha-cocha was due to the “hot” properties of this plant.

Magic Plants

Plants-Religion-Magic

A few plants played roles in Inca religion because they were used as offerings. Coca and tobacco were most frequently used (Fig. 6). Much information is available about coca and the Incas. The plant was important, but mainly for the upper social classes, because common men were not permitted to chew coca except with the ruler’s permission. In some regions the *espingo* was frequently used as an offering (Arriaga, 1968, p. 211). In many burial mounds of the Chimu (the Chimu kingdom was conquered by the Incas) strings of espingo seeds have been found. Priests used espingo in chicha to get very drunk, suggesting that the plant had psychoactive properties. The identification of the plant is not certain. In an indirect sense maize was the most important plant in religion, because chicha prepared from maize was used by all important and not-important ceremonies as an offering. Furthermore, maize was the basis of *sanco*, a kind of dough or bread that was used in religious ceremonies as a kind of communion.

Maize, coca and potatoes were so important that figures were made from them. These were called *saramama*, *cocamama*, *papamama* (or *axomama*), respectively, and were venerated as objects with supernatural powers. The veneration had a practical background: it was meant to have a good crop of the product from which the figure was made (Albornoz, 1988, p. 165; Arriaga, 1968, pp. 200, 204, 205, 273). The religious importance of these plants is probably connected with the appreciation that the Incas had for these plants: coca as a psychoactive plant, and maize and potato as important food plants. In addition, all three plants were used in medicine.

Divination

Some plants played a decisive role in Inca divination. To obtain an idea about the importance of



Ethnobotany of the Incas, Fig. 6 Tobacco was considered a medicine rather than a recreational drug. Two types of tobacco were used. The wild tobacco was probably identical with *Nicotiana rustica*

divination in Inca society we only have to look at the different types of diviners described by the chroniclers: more than 50 Quechua names are reported. The absolute number of diviners was also very large, as indicated by Acosta (1954, p. 172) and others (Morua, 1946, p. 72; Relación de los Agustinos, 1992, p. 8) who simply state that there were innumerable diviners. Cobo confirms that there were many diviners of several types (Cobo, 1990, pp. 160–163). In every town there were many of them, a statement that earlier was also made by Cieza de Leon (1962, p. LV). Citing another source, Cobo gives the figure of 475 people in Cuzco who had no other occupation than just divining. Intuitive divination was among the principal types of divination, and was often mediated by oracles in the form of *huacas*. A number of (mostly psychoactive)

Ethnobotany of the Incas, Fig. 7 A number of psychoactive plants were used in divination practices. Among these was the *vilca* or *Anadenanthera colubrina*. Vilca was also the name of certain idols. Here the Inca ruler talks with the vilcas and huacas



plants were applied to facilitate contact with the supernatural. Diviners called *yacarcaes*, who recruited spirits from fire, took coca leaves. They pronounced spells with which they summoned the spirit of the person from whom they wanted information. After a few other rituals the “devil” (as the chroniclers describe it) came and without being seen spoke to the attendants. He told them that he was the spirit of the person to whom they wanted to speak (Cobo, p. 169). The procedure was followed in divinations where potential dangers for the Inca ruler or the empire were determined. That could be threat of rebellion or a plot against the Incas. The procedure resembles the one that was used by Inca sorcerers in love affairs. Here tobacco in combination with coca was applied. The person who wanted the

love of another went to these sorcerers with a piece of clothing of that person. The sorcerers used coca and tobacco to get into a trance and raise the spirits of persons who had to become the beloved one.

Vilca (*Anadenanthera colubrina*) was very popular among diviners, who consumed the drug in the alcoholic beverage *chicha* (Cobo, 1990, p. 169), to get intoxicated and attain the right psychic condition to make divinations (Fig. 7). According to Acosta (1954, p. 172) *vilca*, alone or in combination with *chicha*, was applied for all types of divinations. Among the questions which had to be answered, were predicting future events such as the outcome of certain enterprises, whether one would stay healthy or become ill and die. Another purpose

was to find stolen or lost goods. For the same purposes the *achuma*, now better known as San Pedro cactus (*Trichocereus pachanoi*), was used. Murua has described the divination ceremony.

To perform these superstitions and divinations they locked themselves in a house that was closed from within. There they started to drink and to get intoxicated until they lost their senses, and after a day they gave answers to the questions. To reach this effect they smeared their body with certain ointments. The sorcerers first talked with the devil in an obscure place in a way that the people heard a voice, but did not see who talked. They performed many ceremonies and offerings, and answered the questions with yes or no, as they liked it. For this purpose they used vilca or achuma (Morua, 1987, pp. 432–434).

Currently some other psychoactive plants such as *ayahuasca* (*Banisteriopsis caapi*) are used in divination, in addition to those mentioned before. It is not sure however, if ayahuasca was used in Inca times.

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Ethnobotany: Malay Ethnobotany

Is There Such a Thing as Malay Ethnobotany?

Rohani Longuet

It is surprising that in a country as rich in floral species and knowledge as Malaysia, Malay ethnobotany – the knowledge that the indigenous Malays have of their flora – has not been studied as such. Lists of plants and their uses have been compiled, but not many systematic approaches on the perception of the flora by the local inhabitants have been made. That is probably because of the diversity of influences to which the country has been submitted through history. Complexity may be perceived as a lack of unity.

One must distinguish between the Malays living in Malaysia and the rest of the “Malay peoples” who have inhabited not only the Indonesian archipelago, but also areas from the Pacific to the Indian Ocean, from Madagascar to New Zealand and Taiwan. It is possible to cover the subject by considering the particular heritage of the Malays that are presently living in Malaysia. These Malay groups have developed a common indigenous system of botanical knowledge. Their system refers to a worldview and a perception of nature that is steeped in the great Asian traditions, but has a particular local terminology and an indigenous use of native – or imported – species. Such an enterprise is useful because, together with the other Malaysian citizens of various ethnic origins, the Malays of that country have to face the problem of the possible disappearance of their natural and cultural heritage.

Malaysia's Botanical Richness

Malaysia is located at the heart of the Indo-Malesian system, one of the biggest rainforest systems on the planet. Rainforests are defined as “evergreen, hygrophilous (living or growing in

moist places) in character, at least 30 m high, but usually much taller, rich in thick-stemmed lianas and in woody as well as herbaceous epiphytes (Epiphytes are plants that grow on other plants mainly for support. Examples of these in tropical rainforests are orchids and ferns. Epiphytes are sometimes also known as “air plants.”) (Shimper 1903, in Dunn, 1975). Diversity, splendour and luxuriance characterize the original flora of the country.

Malaysia itself is divided into two parts separated by a shallow sea. The West part comprises the Southern Malay Peninsula, and the East part comprises the Northwestern part of the island of Borneo. Almost 95 % of the plants present in Borneo and Sumatra – which belong to the same geological area – are present in the Peninsula, a significant feature for the permanence of botanical knowledge among migrating peoples.

Both parts of the country have a “main range”, a series of hills culminating at 2,187 m in Gunong Tahan for the Peninsula and 4,094 m in Mount Kinabalu for Borneo. From the hills, streams run down on limestone boulders to merge in majestic rivers that end in large estuaries where villages have settled. Up until the 1960s, forest covered 85 % of the soil (Polunin, 1988). A relatively small country, Malaysia has a rich density of species: 8,000–10,000 (compared to, say, 11,000 in India). Botanist Keng calculated that the Malaysian flora has 2.96 % of the gymnosperms and 2.79 % of the angiosperms of the world.

- Three factors have contributed to the floral richness (Deverre, 1985).
- The climate, which is hot and humid, with rain all year round;
- Geological stability from the beginning of the tertiary; and
- The encounter and interpenetration, in the Peninsula, of two kinds of flora, from the Asiatic continent in the North and Malesian flora from the South.

Various floral landscapes create a rich pool of environmental resources for the inhabitants to draw from. There are mountains, hill forests,

lowland forest, fresh water swamps, coastal beaches, saltwater swamps and agricultural lands.

The major botanical families are

1. The Dipterocarps. They are so large that a *cengal* tree in the state of Terengganu needed 11 men to circle its girth.
2. Palms. There are five times the number of native palms than in all of Africa.
3. Eugenias. They align the hill slopes with the bright red of their young leaves
4. Tall gingers, mostly strongly scented.

Malaysia is also home to half of the world species of *Nepenthes*, who digest insects in their receptacles, and to other botanical stars like the *Rafflesia Tuan Muda*, the world's biggest flower, many species of orchids and prehistoric species like the *Gnetum gnemon* and the giant fern-looking *Cycas*.

The Geographical and Historical Components of the Malay Knowledge of Plants

The botanical lore of the Malays reflects the Peninsula and Borneo's floral composition. But Malaysia was at a crossroads of maritime routes that brought in science and culture from three great civilizations: India, China and the Arab world.

First were the years of early trade. The people of the Peninsula collected and sold the fragrant *gaharu* (*Aquilaria Agallocha*), dammars (from various *Dipterocarpaceae*) and camphor (from *Dryobalanocarpus camphora*); this trade was recorded in the Chinese chronicles (Weatley, 1980). The Peninsula remained for centuries within the sphere of influence of the Indianized empires, Funan, Sri Vijaya and Majapahit. Its inhabitants may have benefited from early initiation to Ayurvedic botanical knowledge. Some common village native plants like *gandarussa* (*Justicia gandarussa*) and *patarwali* (*Tinospora crispa*) still bear Sanskrit names.

From China came Buddhist scholars. In the wake of Admiral Cheng Ho, a Chinese

community settled in Malacca. Chinese *sen seh* and settlers established medicinal gardens around temples and houses, sharing knowledge on small tropical herbs such as the *empedu bumi* (*Andrographis paniculata*) (also an Indian plant) *getang* (*Spilanthes acmella*), and the *pegaga* (*Centella asiatica*).

Malays have also benefited from Arabo-Persian medicinal and botanical knowledge that included the value of spices as medicine as well as food flavouring and preservatives. They brought in plants names such as *limun*, *henna* and *halba*.

There was a permanent influx of visitors and settlers: from the South – Achenese, Minangkabau, Javanese, and Bugis; from the North – Pattani Malays and Chams, carrying Chinese, Vietnamese and Cambodian knowledge. For instance, Mohammed Yusoh is a well-known roots and leaves seller from the East Coast of the Peninsula. He claimed to have had Arabic, Javanese and Chinese “gurus.” He was also so familiar with some aboriginal tribes that he was dubbed “Mat Sakai” (Mat of the aborigines). The term *Sakai* has since become derogative, and is now replaced by *Orang asli*, literally the “original people.” The life source of the *orang asli* tribes is the forest. They are the ones who would have transmitted knowledge on dangerous species like the *Antiaris* dart poison, the *tuba* Derris to kill fish or the *susu harimau*, a contraceptive mushroom.

Like pharmacists, aboriginal people provided the medicines; like medical doctors, Malay *bomoh* or traditional healers would tune the prescriptions to their patients. Some Malay peoples – proto – or deutero – Malays like the Jakun – belong to the *orang asli* group. However, generally for the Malays, the forest is considered dangerous. It is a vast, inexhaustible store of resources to be exploited. Villagers on the forest fringes, hunters, martial art gurus, herbalists and animal traders make expeditions in the forest from the base of their village.

One difference between the forest dwellers and the Malay settlers is the level of intervention that the Malays have introduced in nature. They tended to select and “grow” their natural environment in settled villages while aboriginals made

use of everything they needed on the large tracks of forest they knew, without changing the natural composition of species. Malay villagers encouraged the growth of *nipah*, *nibong*, *pinang* and coconut palms. They planted crops on the outskirts of their villages and fruit trees around their houses.

Another example of a transmitter of botanical knowledge is Tuk Ku Paloh – Syed Abdul Rahman (1818–1918), a religious teacher of Arabic lineage and a political advisor to three successive sultans of Terengganu. He planted orchards of *jambu* (*Eugenia* sp.) and *rambutan* (*Nephelium* sp.) fruit trees in his vast ashram-like compound. He even created a spice garden for medicinal use.

Species native to drier and cooler regions were acclimated. In the Northern states, a *Zyziphus* (*bidara*) used in religious rites (also belonging to the Chinese materia medica) is planted around mosques and cemeteries. The pomegranate, dear to Arabo-Islamic tradition and a symbol of fertility for the Chinese, is grown in some Malay gardens against climatic odds.

Concepts and Philosophy of Malay Ethnobotany

Researchers have been puzzled by the apparent contradictory and overlapping beliefs of the Malays. A traditional healer would summon spirits from the animist past, chant a Hindu mantra, wrap up the incantation in a Muslim *doa* prayer and prescribe a plant preparation. The Malays do not seem to have perceived a contradiction in their multi-layered spiritual interpretations of the relationship of man with nature.

Mohd (1995), writing about the passage from animism to Hinduism, suggests that the Malays “merely transferred their beliefs in spirits and in nature to the various Hindu gods.” Subsequently, one could surmise that the belief in Shiva, a Hindu creator god, introduced the concept of a unique force behind nature, separate and above it, perhaps preparing for the Muslim concept of *tawhīd*: the oneness of God.

During the nineteenth century, compilations of medicinal and botanical knowledge were made in *jawi* script or translated, giving lists of therapeutic plants. These, like the *Tajul Mulu* (Medical Book of Malayan Medicine) or the *Ilmu Tabib* contain lists of charms and references that place them in traditional healing systems. The role and the effect of the plants were described according to their relation with the balance between the four elements, the humours and “hot or cold” or “wet or dry” states. Studies are still needed to identify to which tradition(s) they actually owe their formulas.

Today, the idea of an indigenous perception of nature – how the Malay villagers see themselves in relation to the plant world – can be found in interviews with villagers and forest workers, especially in remote areas. They have a strong sense of a reciprocal link between all living things as *insan* (creatures of God). “The growth of trees toward the sky is their prayer to God,” explained an elderly lady. Plant collectors in the forest believe in the “signature doctrine.” Just like the *Qurʾān* Holy Book, nature is knowledge revealed (*ilmu naqli*).

Villagers have long maintained a symbiotic relationship with nature. Plants are found everywhere in art and crafts; twirling *Cucurbitacea* and Ipomeas are found on carvings on *cenggal* wood verandahs (Said, 2000). Flowers enliven the batik sarongs worn by the villagers. In *pantun* poems (Daille, 1990), fragrant flowers of jasmine and *Michelia cempaka* decorate love promises. In cemeteries sweet smelling *Plumeria* species alleviate sadness. The Muslim paradise is pictured as a garden, so gardens also have religious significance. Even today, the Malays try to arrange some flowers to compose a welcoming entrance to their house (Nor, 2003).

Malay Classification and Exploitation of Botanical Materials

In the vernacular system, plants in general – herbs, shrubs, climbers and epiphytes – are *pokok* (which means “tree” – in lay language). The “trees” are subdivided into *akar*, which means roots and

climbers, *rumput* (herbs) and *paku pakis* – “nails” – for ferns.

The Malay floral nomenclature is pragmatic and empiric. It does not refer to a phylogenetic organization of the floral kingdom; nor does it refer to Arab, Indian or Chinese classifications. Plant species receive their names by reference to their aspect (morphology) or their use (ergology/phytopharmacology) (Table 1).

A name sometimes evokes both aspect and use. *Tongkat* is “cane.” In *Tongkat Ali*, it refers to the aspect of the straight growing *Eurycoma*, a shrub with a deep, hard-to-dig root. The word indicates the use: like a cane, it supports failing strength. *Putar* means “to turn” in Malay and Sanskrit. *Patarwali* (*Tinospora Crispa*) is a spiralling climber. That name is also pronounced *putrawali*. *Putra* means “son”; *wali* is “representative.” So the *Tinospora* in Malay is “the whirling plant that helps to get a male descendant.” The pretty *Tetracera* climber is called *mempelas* – sandpaper – as its rough leaves are used to polish wood and metallic surfaces.

There are also specific species names, sometimes derived from the ancient Malay or Melano-Polynesian vocabulary. For instance, the sea Hibiscus is *Bebaru* from the island of Madagascar.

Composite plant names are formed by adding a qualificative identifying the individual species within the vernacular genus: *Limau* is for citrus, *limau purut* is *Citrus hystrix* and *limau nipis* is *Citrus aurantifolia*. A qualificative may indicate the degree of effectiveness of the material, either as a timber or medicine. *Tongkat Ali* is “Ali’s own cane.” Ali’s name, the Prophet Muhammad’s cousin, carries a connotation of effectiveness and strength. Other tonics for men are associated with Ali. Plants good for women refer to Fatimah, the Prophet’s daughter.

Evocative qualificatives are drawn from the animal kingdom: elephants, bear, tigers, monkeys and buffaloes help characterize plants. The aerial *Paku langsuiyir* is the “vampire fern” – an *Asplenium* which hangs its large and long dishevelled leaves on the fruit trees at the back of a house. Information on location, origin or gender is frequent: “Female” often means a

Ethnobotany: Malay Ethnobotany, Table 1 Examples of forest species familiar to the Malays and their vernacular names

Malay names	Translation	Botanical name	Reputed traditional use
Gajah beranak	Elephant giving birth	Goniothalamus	Post partum decoctions
Penawar hitam	Black medicine	Schortechinii	
Tongkat Ali	Ali's staff, sky pointer	Eurycoma longifolia	Febrifuge, sexual tonic
Teja lawang	Specific name	Cinnmonum	All medicinal decoctions
Aji Samat	Haji Samad	Jackia ornate	Tonic
Tengkok biawak	Neck of monitor lizard		
Betek hutan	Forest papaya	Renellia sp.	Nasal and sinus troubles
Setawar hutan	Forest antidote	Costus speciosus	Mostly decoration
Dedawai	Wiry one	Smilax callophyllum	Tonic, diuretic
Tongkat Ali	Ali's staff		
Kacip Fatimah	Fatimah's scissors	Labisia pointiana	Feminine health
Kerbau melawan	Fighting buffalo	Shefflera sp.	Sexual tonic
Gajah tarik	Pulling elephant	Strychnos intai	Tonic, hypotensor
Hujung atap	Tips of roof thatch	Baekia fructescens	Postpartum
Mas secotet,	A spot of gold	Ficus deltoidea	Tonic for women
Telinga kera	Monkey's ear		
Tonkat Ali biru	Blue Ali's staff	Polyaltia bullata	Heart tonic
Cengal	Specific name	Neobalanocarpus heimii	Mostly building material
Resdong	Nose inflammation	Ervatamia	Nasal and sinus troubles
Telinga beruk	Bear's ear	Thothea	Diarrhea, colic
Mengkudu bukit	Hill Morinda,	Renellia speciosa	In medicinal decoctions
Ginseng Melayu	Malay ginseng		
Akar sarsi	Sarsaparilla	Cinnamomum ebracteum	Fragrant, diuretic

large variety and “male” a smaller one (noted by British forester Watson as early as 1928).

Like the *limau*, some plants names correspond a to modern botanic genus: *Uncarias* are *kekait*, some *Eugenias* are *kelat*, a word referring to the tart taste of their wood. The edible *Eugenia* are *jambu*. *Cinnamomun* species are known as *teja* with various qualificatives: *jantan* (male), *bulu* (hairy). The more poisonous ones are often called *medan* and may be used as insecticides. Misleading appearances or similarities are signalled by a repetition: *Annonacea* are *pisang pisang* – false bananas or the qualificative *hantu* (ghost).

Some plants are so specific to some ailments that they are called by the name of what they cure: there is “ring worm medicine” (*Cassia alata*) and the “sinusite trees” (*Ervatamias*). Or they may be known by the illness they cause. *Excoecaria agallocha* (*bebuta*) is the “blinding” or “blind one” because of its latex, which is harmful for the eyes.

Plant collectors and healers are familiar with the principal names and the alternative names of the most famous floral species. The confusion of species perceived by botanists as they noted the existence of synonyms and substitutes is not relevant within the pragmatic system that gives priority to the use of the plants. Plants that share the same use and same look will be designated with the same names. For instance, leaves from the *Leucopogon Malayanus* – an *Epacridacea* – may conveniently replace the other similar looking *Cucur atap* (roof leaves) species, *Baekia* and *Leptospermum*, in the herbalist post-delivery tea (Yusof, 1985).

As the main criteria for designating plants is their use, a few very useful and well-known species change names. *Oriza sativa* is rice (*nasi*) in the plate, *beras* in the shop and *padi* in the field. *Aquilaria Agallocha* is the *tengkaras* timber of the foresters, the *chandan* tree of collectors and becomes *gaharu* when the precious fragrant wood is found in the tree.

The vast range of use of plants in Malay ethnobotany run from the rites accompanying protection ceremonies to the criminal use by thieves sending *Datura* smoke through the floor boards of houses on stilts. There are building materials, dyes, mats, food, flavourings, wrappings and cosmetic, soaps, talcum, perfumes – a complete shopping mall (Table 2).

Coherent, pragmatic and didactic, the Malay system of vernacular botany was based on the villagers' needs. About 20 years ago Malay gardens in villages were good illustrations of the familiarity of their owners with the local flora (see Extra: "Plants on a Day in a Village 20 years ago").

The Future of Malay Ethnobotany

Today, Malay vernacular botany shares the fate of other ancient knowledge in the world. It vanishes because it is written on vanishing material supports. One of these supports is the memory of the elders. Records have been made and translated into modern Malay and scientific botanical terminology; the most recent are those of Pr. Kamarudin Mat Salleh at the University Kebangsaan Malaysia and of Pr. Roland Werner at the University Malaya). However, behind the names, has the frame of mind and the worldview of the indigenous botanists been documented enough? Can translation render the esoteric yet powerfully suggestive context? The second support of botanical knowledge is the flora of Malaysia. In the process of development, the diversity and quantity of plants species are reduced. In consequence "hands on" knowledge of species which were previously common is on the way to being lost.

On the other hand, the relationship of the Malays with the world of plants still runs deep. Beyond the country's political and scientific interest for biotechnology (see extra "Three Malaysian Plants in the Hall of Fame"), it has been found (Nor, 2003; Said, 2000) that modern Malays grow species from their past in the small gardens of their suburban terrace houses. They have a desire to continue combining esthetics, ethnic heritage and function, in the plants they display in their new environment.

Extra: Plants on a Day in the Village, 20 Years Ago

In the Malay village, a young mother woke up on her mat made of *Pandanus*, with the smell of the *Euphorbia* ambers still warm under her special post-delivery sleeping platform. There was a light fragrance from the surrounding *belukar* secondary forest: the astringent *Rutacea Glycosmis*, frothing *Cinnamomum* and camphor. These contained plants prepared for her morning bath. Her newborn had his umbilical cord cut with a ► *bamboo sembilu* and later he would be circumcised with same type of disposable knife.

The mother is having a breakfast of sweet potatoes sprinkled with grated coconut. She will take a tonic *majun* pill made mostly of spices and ginger (*rempah ratus*) mixed with honey collected from nests on the gigantic forest *Compassia* tree. She set aside a large basin of *ubat periok*, a decoction based on *akar kayu* (jungle roots and trees) bought from herbalists at the market (*Annonacea*, *Cinnamomum*, a bitter *Eurycoma*, the slim leaves of *Baekia frutescens*, and a modest beach creeper, *Vitex trifolia*).

The forest smell pervades the house built in cool timber (*seraya* or *cengal* Dipterocarps) with a *nipah*-thatched roof. The midwife performs a thorough massage of the young mother with coconut oil, applying lime juice on her stomach, wrapping her in a tight batik (dyed cloth) corset and finally applying the heat of stones wrapped in large *Morinda* leaves to help the recovery process.

Meanwhile, the men are at sea on a *chengal* made boat. The sails are made of *sekecut* sedge from the paddy fields mounted on bamboo battens from the *belukar*. They pull ropes made of coconut husks and prepare a *gala gala* caulking made of jungle resin and *minyal kuin* oil in case the deck needed it. The seams on the flanks of the boat rarely leak as they are built with strips of the bark of tannin rich *gelam Melaleuca leucadendron* (from the swamps) fixed during the construction on the *pasak* "nails" *Mesua ferrea* (from the forest) that join the planks of the boat. If a new crew member became seasick, he could use an oil distilled from the leaves of the same *gelam* tree.

Ethnobotany: Malay Ethnobotany, Table 2 Some species found in Malay villages and their use

Source	Malay name	Botanical name	Traditional medicine			Food	Building material, dyes, etc.	Ornamental	Cosmetics	Fragrance	Rites	Poems and songs
			M	C	I							
W	<i>Kaduk</i>	<i>Piper sarmentosum</i>	/	/		Vegetable						
F	<i>Nibong</i>	<i>Oncosperma tigillarum</i>					House posts	/				
W	<i>Keduduk</i>	<i>Melastoma malabathr.</i>	/	/		Fruit	Indigo					
W	<i>Bemban</i>	<i>Donax</i>						/				
W	<i>Capa</i>	<i>Blumea balsanifera</i>	/	/			Camphor		Bath			
W	<i>Pulai</i>	<i>Alstonia scholaris</i>					Carving					
F	<i>Putrawali</i>	<i>Tinospora crispa</i>	/	/	/			/				
P	<i>Inai</i>	<i>Lawsonia inermis</i>	/	/	/				/		/	/
P	<i>Kecubong</i>	<i>Datura fastuosa</i>	/	/	/			/				
P	<i>Empedu Bumi</i>	<i>Andrographis paniculata</i>	/	/	/							
F	<i>Cengal Pasir</i>	<i>Hopea odorata</i>					Boats masts	/				
P	<i>Meninjau</i>	<i>Gnetum gnemon</i>				Candied chips		/				
p	<i>Bidara</i>	<i>Zyziphus jujuba</i>	/	/	/						/	/
W	<i>Gelenggang</i>	<i>Cassia alata</i>	/	/				/				
W	<i>Bebuas</i>	<i>Premna integrifolia</i>	/			In fish sauces		/				
W	<i>Bebaru</i>	<i>Hibiscus tiliaceus</i>					Ropes	/				
F	<i>Mengkudu</i>	<i>Morinda elliptica</i>	/	/	/	Leaves, fruit						
W	<i>Getang</i>	<i>Spilanthes acmella</i>	/	/								
P	<i>Belimbing besi</i>	<i>Averrhoa belimbi</i>				Coconut sauces	Cleans blades					

(continued)

Ethnobotany: Malay Ethnobotany, Table 2 (continued)

Source	Malay name	Botanical name	Traditional medicine			Food	Building material, dyes, etc.	Ornamental	Cosmetics	Fragrance	Rites	Poems and songs
			M	C	I							
P	<i>Kenanga china</i>	<i>Artabotrys odorata</i>							/			
P	<i>Bunga cina</i>	<i>Gardenia jasminoides</i>							/			
P	<i>Duku</i>	<i>Lansium domesticum</i>				Fruit						
F	<i>Buluh</i>	<i>Bambusa sp.</i>				Young shoots		/				
W	<i>Dedalu</i>	<i>Loranthus ferrugineus</i>	/	/				/				
W	<i>Sisek naga</i>	<i>Drymoglossum heteroph.</i>										
P	<i>Cempaka</i>	<i>Michelia cempaka</i>						/	In hair oil	/		/
F	<i>Gelam</i>	<i>Melaleuca leucadendron</i>	/				Charcoal, caulking					
P	<i>Penaga lilin</i>	<i>Mesua ferrea</i>					Treenails					
W	<i>Ketola hutan</i>	<i>Aristolochia tagala</i>										
P	<i>Ceri</i>	<i>Lepisanthes alata</i>				Fruit						
F	<i>Terajang</i>	<i>Lapsanthes kunsteri</i>	/				Soap					
F	<i>Asam Jawa</i>	<i>Tamarindus indica</i>	/			Fruit in sauces	Cleans brass					
P	<i>Sentul</i>	<i>Sandoricum indicum</i>				Fruit						
P	<i>Dedap</i>	<i>Erythrina indica</i>						/			“Time to sail”	
P	<i>Jambu air</i>	<i>Eugenia aquea</i>				Fruit						
W	<i>Jambu arang</i>	<i>Erioglossum rubiginosum</i>				Fruit						

P	Jambu batu	<i>Psidium guava</i>	/			Fruit						
F	Jambu golok	<i>Anarcadium occidentale</i>				Fruit, leaves						
P	Limau kasturi	<i>Citrus microcarpa</i>	/			Fruit						
P	Limau nipis	<i>Citrus aurantifolia</i>	/			Fruit						
P	Limau purut	<i>Citrus hystrix</i>	/			Fruit, leaves				Shampoo		
P	Belimbing	<i>Averrhoa carambola</i>				Fruit						
P	Kekabu	<i>Ceiba pentandra</i>							Stuffing floss			
P	Kapas	<i>Gossipium brasiliense</i>							Coton			Funerary
W	Paku langsyir	<i>Asplenium nidum</i>						/				/
W	Rambut pueri	<i>Cassytha filiformis</i>								Shampoo		
P	Bunga raya	<i>Hibiscus rosa-sinensis</i>	/					/				
W	Mata pelanduk	<i>Ardisia crenata</i>	/			Leaves						
P	Binjai	<i>Mangifera caesia</i>				Fruit						
P	Sireh	<i>Piper betel</i>	/	/	/	Masticatory		/				
P	Misai kucing	<i>Ortosiphon stamineus</i>	/	/	/							
W	Terape	<i>Glycosmis citrifolia</i>						/				
W	Teja pasir	<i>Neolitsea zeylanica</i>										
F	Cekur manis	<i>Sauropus andronysus</i>				Vegetable						
F	Beluru	<i>Entada phaseolides</i>										

(continued)

Ethnobotany: Malay Ethnobotany, Table 2 (continued)

Source	Malay name	Botanical name	Traditional medicine			Food	Building material, dyes, etc.	Ornamental	Cosmetics	Fragrance	Rites	Poems and songs
			M	C	I							
P	<i>Pandan</i>	<i>Pandanus</i>				Flavour, colour						
F	<i>Mengkuang</i>	<i>Pandanus</i>				Flavour						
P	<i>Serai</i>	<i>Andropogon citratus</i>				Flavour						
P	<i>Kunyit</i>	<i>Curcuma domestica</i>	/	/	/	Colour, flavour						
F	<i>Bonglai</i>	<i>Zingiber cassumara</i>	/									
P	<i>Halia</i>	<i>Alpinia officinale</i>	/	/	/	Flavour						
F	<i>Nipah</i>	<i>Nipa fruticans</i>				Fruit, salt, sugar						
W	<i>Gurah</i>	<i>Euphorbia</i>					Charcoal					
W	<i>Tapak Suleiman</i>	<i>Elephantopus scaber</i>										
W	<i>Kemunting Cina</i>	<i>Vinca rosea</i>	/	/	/	Fruit		/				
F	<i>Kerekup</i>	<i>Flacourtia jangomas</i>										Songs
W	<i>Setebal</i>	<i>Fagraea racemosa</i>	/					/				
W	<i>Mempelas</i>	<i>Tetracera indica</i>					Sandpaper					
P	<i>Kari</i>	<i>Murraya koenigii</i>				Leaves,						
P	<i>Delima</i>	<i>Punica granatum</i>	/	/		Fruit		/				/
P	<i>Senna</i>	<i>Cassia angustifolia</i>	/	/								/
F	<i>Bogor</i>	<i>Lagerstroemia speciosa</i>						/				
W	<i>Urang aring</i>	<i>Eclipta alba</i>	/	/					Shampoo			
P	<i>Ulam raja</i>	<i>Cosmos caudatus</i>				Fresh greens						

In the village, in the afternoon, sitting on a platform in the garden, the great grand mother is sewing a pillow stuffed with floss from the *kekabu* tree. Her daughter gathers *ulam* greens and *daun serai* (*Cymbopogon*) to perfume the sauces for the next meals. A group of young girls ask permission to take some *inai* leaves from the Henna tree for an elder sister who is going to be married soon. She may look at the *bidara* (*Zyziphus*) and the cotton tree which are used during the funeral rites. A small *jambu* (*Eugenia*) has been planted where foetal membranes of the new grandson are buried. Life stages are written in the garden around the elderly lady. The presence of the plants helps preserve practical knowledge as well as spiritual beliefs. The next generation naturally learns from them.

Extra: Three Malaysian Plant Species in the Hall of Fame

A Criminal Tree?

Recently, for as long as 6 weeks, a battle was fought in the news (*Utusan Malaysia* November and December 2004) around a *Rubiaceae* species, the *Mytragyna speciosa* (*ketum* in Malay). Journalists reported that police officers had felled an old *ketum* tree in Perak, causing a stir among nature lovers. The police explained that villagers had called them as the tree attracted drug addicts to the area. In fact, the police in Terengganu had previously felled hundreds of them. Addicts use the leaves of *ketum* to calm the effects of their drug craving, as it was explained in other articles. The tree is placed, just as in Thailand, on the list of forbidden substances.

The *ketum* or *biak*, endemic to Northern Malaysia and Southern Thailand, was traditionally used by villagers in post-partum teas to ease afterbirth pains and by workers who faced long hours of work in the forest. A few times in the past, it had received attention from researchers in Malaysia and abroad. Other species of *Mytragyna* grow in Africa; they have been studied for their alkaloid contents and are used there in traditional compound medicine for mental illness.

Malaysian scientists agreed that the plant did have a potential as a methadone substitute and that it had a mild analgesic effect. It acts on opiate sensitive receptors in the brain.

Researchers at Chiba University in Japan (*Journal of the Pharmaceutical Society of Japan* October 2003) have published analyses on plants gathered in Malaysia and Thailand. Among the newly identified compounds, one of them, a mytragynine pseudoindoxyl, was found to be much more effective than the same amount of morphine.

Tongkat Ali, the "Malay Viagra"?

This shrub or small tree with a particularly thick, deep and straight root is not easy to collect. It used to be very common on the slopes of forest hills in Malaysia. It is also found in Indochina and Indonesia. But now it is becoming rare, and forest officers mark trees because their fame as a source for a sexual tonic has triggered harvests of commercial proportions.

The bitter tongkat or *Eurycoma longifolia* was studied at Malaysian universities and found to be effective, as traditionally claimed, as a febrifuge (a substance that lowers fever) and anti-diabetic. It has a testosterone-like effect on mice, which produce a plethora of male progeny. It does not seem to have harmful secondary effects. Under Malaysian law, it is on the list of protected and non-exportable species.

With academic endorsement, and following Good Manufacturing Procedure (GMP), entrepreneurs in the country are now using extracts of tongkat Ali in very successful "power" drinks together with coffee and ginseng. To face the oncoming shortage of wild material, the *Eurycoma* is now grown commercially.

Sarawak Tree in the Race to Find a Medicine for AIDS

During pharmacological screenings for anti-cancer activity of medicinal plants from Malaysia, a team of US scientists identified an interesting substance in a species of *Calophyllum* (*bintangor* in Malay). It had prospects as an immune system booster and even as a treatment for AIDS patients.

The scientists formed a research company and entered into a partnership with the state of Sarawak to create a drug from the particular variety of Calophyllum that had been collected and is not very common. The Government participated in funding the first stage of the research in exchange for returns on the sales of the end product medicine for AIDS.

Calanolide – and other compounds from Calophyllum species – have passed the tests on their effects on the HIV virus, and calanolide is at the clinical phase. But the competition is fierce and it has to be shown to be better than other candidates supported with equally motivated teams. More information is available at <http://www.forestry.sarawak.gov.my/forweb/research/fr/ip/eco/calophys.htm>, “The Calophyllum Story.”

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Ethnomathematics

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Ethnomathematics is the study of the relationship between mathematics and culture. It examines a diverse range of ideas including mathematical models, numeric practices, quantifiers, measurements, calculations, and patterns found in culture, as well as education policies and pedagogy regarding mathematics education. “The goal of ethnomathematics is to contribute both to the understanding of culture and the understanding of mathematics, but mainly to appreciating the connections between the two” (D’ambrosio, 1999, p. 146). Ethnomathematics is a new inclusive, pluralistic perspective of mathematics, in this case referring to a great range of numeric traditions and thought beyond that of those practiced in the Western or modern school systems and circulated by professional mathematicians and academics.

Cultural Mathematics or Mathematical Cultures: Permissible Paradigms?

Mathematics as the culture-free or culture-neutral intellectual contribution of Western civilization was first challenged by the twentieth-century scholars attempting to conceive of mathematics within its cultural context and rewrite what had become a single dominant unilateral history of mathematics. Paulus Gerdes identifies the French

psychologist who explored the social origins of mathematics, G. Luquet (1928), and the German mathematician, ethnologist, and pedagogue who had reflected extensively on early mathematical thinking, E. Fettweis, as the first forerunners of ethnomathematics (Gerdes, 1995, p. 19). In 1938 O’Raum is credited as the first scholar to challenge the colonial aims and legacy of mathematics education in Africa (particularly South Africa and current-day Tanzania), proposing a new model of arithmetic based on the students’ tribal context and knowledge base (see Raum, 1938). The scholars R. L. Wilder and Leslie A. White shared a concern with the anthropological explorations of mathematics, which Wilder presented at the International Congress of Mathematicians in Cambridge, Massachusetts, in 1950 and White in his 1947 publication “The Locus of Mathematical Reality.” The mathematician Morris Kline was also one of the initial scholars to establish the connection between mathematics and culture in his 1953 work *Mathematics in Western Culture*, soon followed by *Mathematics: A Cultural Approach* (1962) which also examined non-Western mathematical cultures and methods.

This new perspective on and exploration of mathematics as a cultural product derived from the anthropological ideas regarding culture that emerged in the twentieth century. In his conference presentation (1950), Wilder highlights that it is very uncommon to discuss mathematics in relation to man and his environment in a moment in which the inwardly directed studies of psychology and anthropology had just recently started to gain recognition in the academic world. The conflict (which can trace its origins as far back as the internalist/externalist divide between Aristotle and Plato) impinged on whether or not mathematics was a divine revelation existing outside of man and meant to be discovered or an intellectual exercise existing inside of man and meant to be invented. Whether invention or discovery, mathematics insights were believed to be either a product of one’s own understanding or of divine design, thus neglecting cultural influence. Leslie White, however, is the first to study both arguments of this debate in order to show that culture

is ultimately the generator of all mathematical knowledge. Based on Durkheim's discussion of the relation between "collective consciousness" (i.e., culture) and the human mind, White demonstrates that since mathematics is both outside "man" (conceived as the individual organism) and inside "man" (conceived as the human species), it can be located in no other place but culture – culture being both a man-made construct as well as a mode of life informing all human action.

The Beginnings of Ethnomathematics

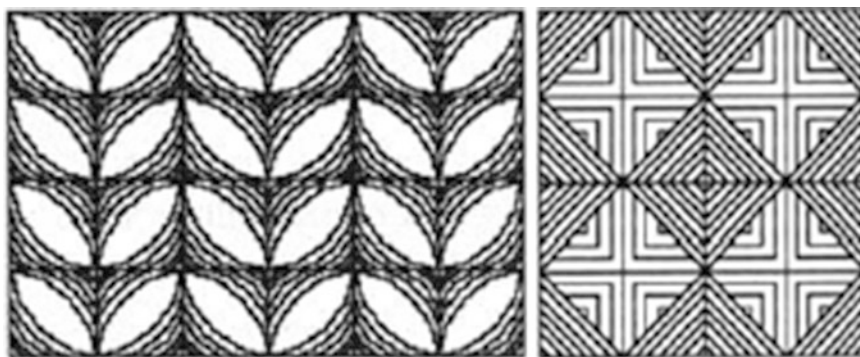
These disperse cultural studies of mathematics were further promoted when they were formally considered part of a new social and intellectual ethnomathematical program as introduced by Ubiratan D'Ambrosio in 1977 during a presentation for the American Association for the Advancement of Science. D'Ambrosio is a mathematician and educator from Brazil who has strongly advocated for a more dynamic and multifaceted practice of mathematics. D'Ambrosio's thinking is strongly influenced by fellow Brazilian intellectual and educator Paulo Freire who promoted a *conscientização* that would allow for a more humanistic education stemming from students' personal experiences and appropriate to their own individual circumstances, making education as a matter of social justice and a means for students to have dialogue, develop consciousness, and politicize (*Pedagogía del Oprimido*). D'Ambrosio applied the principles of *conscientização* in order to appropriate the mathematics practices that have become repressed by Western history and its representation of mathematics. D'Ambrosio even goes as far to say that ethnomathematics serves as a step towards peace: "Mathematics is absolutely integrated with Western civilization, which conquered and dominated the entire world. The only possibility of building up a planetary civilization depends on restoring the dignity of the losers and, together, winners and losers, moving into the new. [Ethnomathematics, then, is] a step towards peace" (Greene, 2000).

Trends in Ethnomathematics: Case Studies and Pedagogy

There are currently two trends within ethnomathematics research: a) the investigation of mathematics practices as cultural constructs of "other" societies (as opposed in some way to Western academic mathematics) and b) the political discussions of mathematics pedagogy, autonomy, and implementation in different cultural contexts. This numeric "otherness" has taken various forms, which Gerdes has extensively categorized as indigenous mathematics, sociomathematics, informal mathematics, mathematics in the (African) socio-cultural environment, spontaneous mathematics, oral mathematics, oppressed mathematics, non-standard mathematics, hidden or frozen mathematics, folk mathematics, and mathematics codified in know-hows (Gerdes, 1995, pp. 19–20). Scholars maintain that these particular expressions of mathematical thought have been systematically excluded from formal, academic mathematics but nonetheless abide by the same numerical principles that unite all forms of mathematical expression and merit investigation.

These studies tend to be anthropological or ethnographic in nature, relying on field study, artifacts, and description to determine how numbers are used and valued by cultural groups somehow designated as outside the Western world. Ethnomathematicians generally accept that the discipline is more creative in its methodological approach, going beyond the limits of history and integrating insights from the fields of anthropology, archeology, literature, linguistics, education, and others.

One of the first studies of another culture's mathematics through an anthropological lens is that of Claudia Zaslavsky. After travelling to Tanzania and encountering local mathematics practices, this teacher from New York decided to publish what she stated to be the first "analysis of African culture from the mathematical point of view": *Africa Counts: Number and Pattern in African Culture*. Since this initial study, the last forty years of scholarship has seen a blossoming of anthropological investigations regarding mathematics practices in diverse contexts.



Ethnomathematics, Fig. 1 Litema wall patterns (Lesotho). Geometrical shapes and symmetry are common topics of study in ethnomathematics (Image by Paulus Gerdes)

The ethnomathematician Marcia Ascher published many collections on diverse mathematical practices around the globe and her work entitled *Mathematics Elsewhere: An Exploration of Ideas across Cultures* exemplifies the main topics and geographic locations discussed in the field, including studies of divination, timekeeping, maps, relationship systems, and models in diverse locations such as the Pacific Islands, Nigeria, Madagascar, and India (Fig. 1).

The political and pedagogical trend of ethnomathematics stems from a conscious protest against the colonial structures that imposed and maintained Eurocentric values and number systems. This process involves a recovery of the third world practices denied credibility and space in the public realm. The pedagogical discussions of ethnomathematics operate under the premise that Western mathematics practices have not and are not always the easiest way for a group of people to learn and understand numbers. In addition, these same standardized practices may not address each student's daily needs or particular value systems in regard to counting and calculating. Because the way mathematics is presented to the youth of any culture dictates how mathematics will be used in societal relationships of that very same culture, many scholars are interested in finally scrutinizing the present state of mathematics education in light of its societal implications.

Alan J. Bishop's study *Mathematical Enculturation: A Cultural Perspective on Mathematics Education* (1988) was one of the most extensive

projects examining the connection between culture and mathematics education. This publication is often cited as the source that proposes six universal numeric activities in which all cultures engage: counting, measuring, locating, explaining, designing, and playing. Bishop considers this project a social project and promotes "the kind of mathematical education which will enable that cultural force [of Western civilization as explored by Kline] to be recognized, absorbed, but also evaluated" (Bishop, 6) (Fig. 2).

Future Collaborations and Resources

The International Study Group on Ethnomathematics (ISGEm) (<http://isgem.rpi.edu/>) was created in 1985 to actively discuss and promote ethnomathematics research. Eventually the North American Study Group on Ethnomathematics (NASGEm) (<http://nasgem.rpi.edu/>) was created as an offshoot of the international group and founded the online *Journal of Mathematics and Culture* which explores the intersection of mathematics and culture while explicitly focusing on pedagogical concerns of ethnomathematics implementation in classroom settings. There are similar study groups based in South Africa, Brazil, and Latin America, including The Latin American Network (RELAET) (<http://www.etnomatematica.org/home/>) which brings together scholars from dozens of countries and houses the indexed *Latin American Journal*

Ethnomathematics,

Fig. 2 Malekula and Tshokwe sand tracings. Sand tracings are found in many cultures and are connected to ideas of graph theory, geometry, and topology (Image by Marcia Ascher)

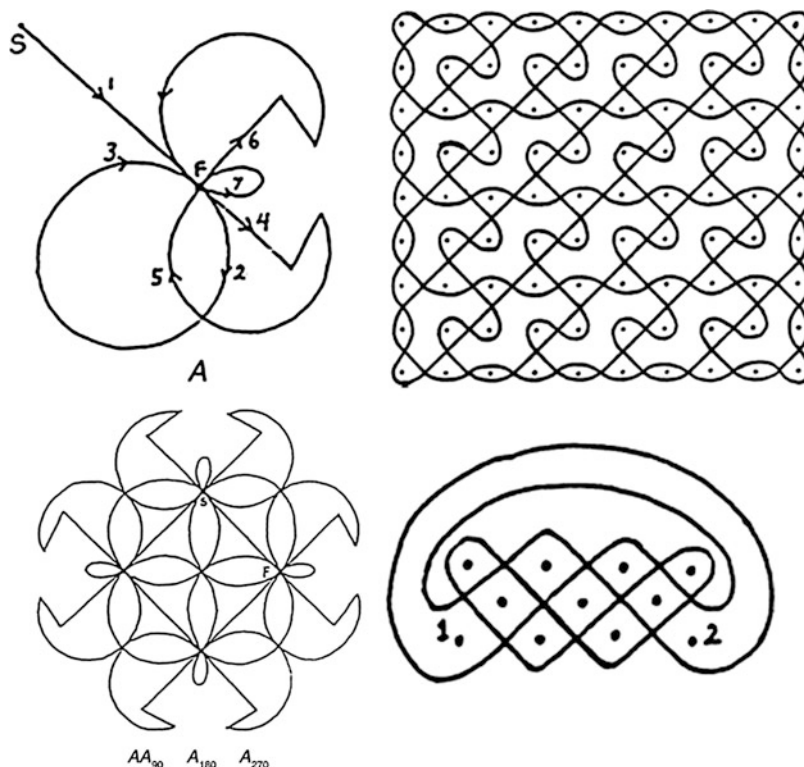
**Ethnomathematics,**

Fig. 3 Gran Bretaña School, Lima, Perú. 5th graders participating in an ethnomathematics seminar organized by author (Photo by author)



of *Ethnomathematics* (<http://www.revista.etnomatematica.org/index.php/RLE>). The members and coordinators of these networks also actively participate in international conference series such as the International Conference on Ethnomathematics (ICEM), the Latin-American Reunion of Mathematics Education (RELME) (<http://www.clame.org.mx/relme.htm>), the

Mathematics Education and Society conference (<http://www.mescommunity.info/>), and others. These forums and resources continually bring together the leading scholars of the field in the hopes of promoting the diverse mathematics methods and traditions that enrich our intellectual past and inform our future understandings of the world (Fig. 3).

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Ethnomathematics of the Inkas

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Under the shade of a tree, some women are sitting. They are watching over several children, but at the same time, their bodies are subtly swaying and their hands are busy moving threads. These women are weaving. As they talk among themselves, calculations are occurring: 40×2 , 20×2 , 10×2 , etc. On their weaving tools, symmetric patterns of geometric and animal figures are slowly emerging, produced from years of experience in counting and understanding symmetric properties. The procedures they follow have been instructed to them verbally as has been done for thousands of years, and they follow it precisely, almost subconsciously. In fact, these

women are doing *mathematics*. They are calculating pairs of threads in blocks of tens (10, 20, and so on) and determining which colors of threads must go in which places so that half of the emerging figures will be exactly copied across an axis of symmetry. These women, and likely some girls who are learning from them, are not writing down equations or scratching out the calculations on a notepad. Remarkably, the weaving is done from memory.

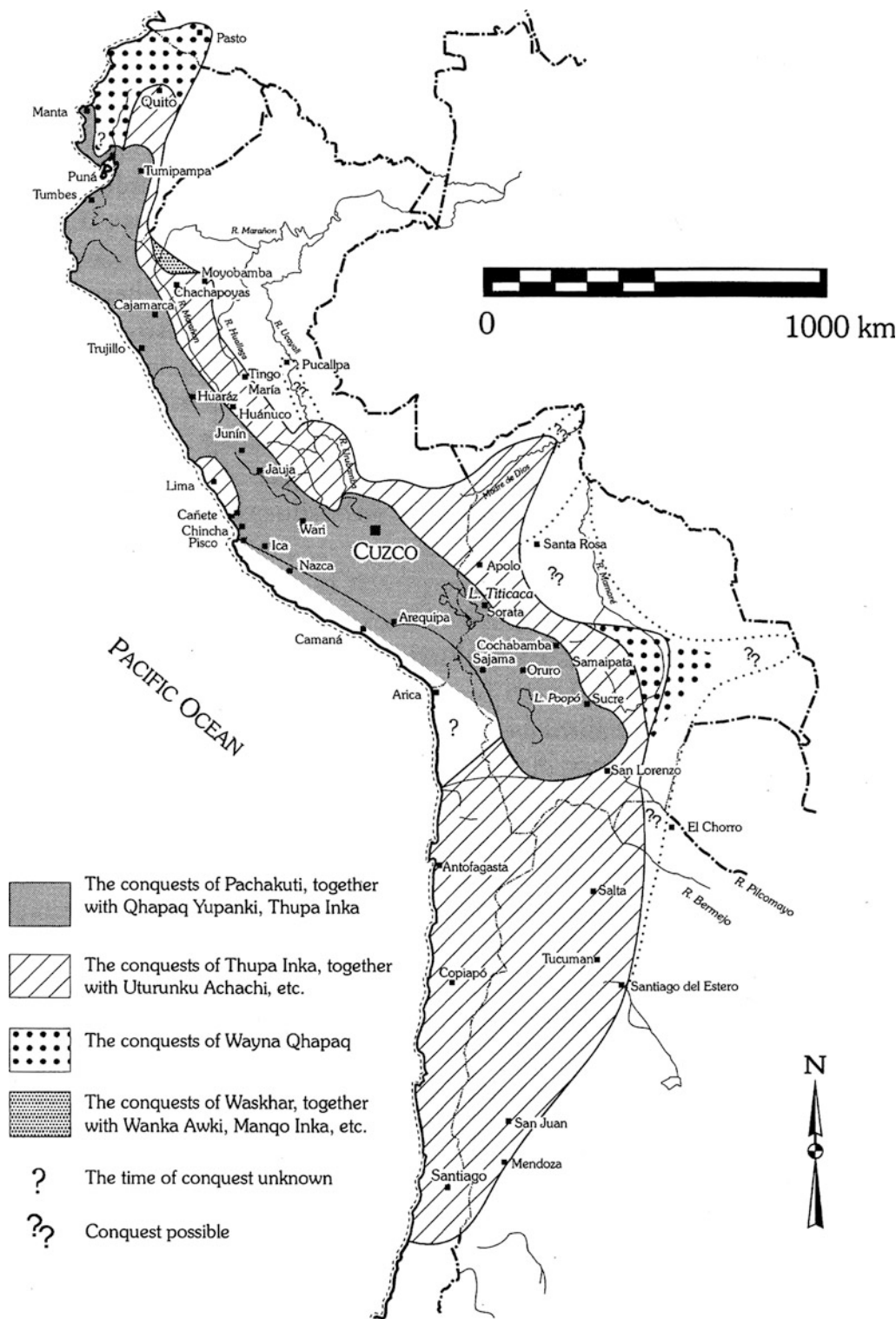
Weaving has existed in most cultures around the world, so the events and hence the mathematics in the previous paragraph could occur almost anywhere. In our case, we are going to consider the mathematics of the South American cultural group of the Quechua-speaking Inkas (Incas). As with weaving, we will see that Inka mathematics is intimately tangled with Inka culture.

Before we can jump into the details of their mathematics, we must take some time to understand who the Inkas were and some small picture of what their culture was like. Backing up even further, the first term we must clarify is “Inka,” by which we refer to a collection of many groups who had a common government, religion, and language but were of distinct cultural origins. When we speak of the Inka Empire, we refer to the territory controlled by the Inka from about 1400 to 1560 (CE). The first Inkas started near Cuzco in present-day Peru and persistently moved on neighboring groups, forming an enormous empire that included part or all of Peru, Ecuador, Bolivia, Chile, Argentina, and southern Colombia (Fig. 1).

We have seen that there is mathematical thought occurring in weaving, but as we proceed, we can also observe factors such as geography that may have influenced the development of Inka mathematics.

Geographic, Climatic, and Environmental Aspects of Inka Mathematics

The Inka territory included regions of widely varying geography: coastal desert, high rugged Andes, the Lake Titicaca inter-mountain area,



Ethnomathematics of the Inkas, Fig. 1 The Inka Empire (From D’Altroy (2003). Used with their kind permission)

seacoast along the Pacific, and jungle on the eastern edge of the Andes as they descend into the vast Amazon basin. From pages 24 to 32 of D'Altroy (2003), we can get a glimpse of the situation, by noting that a 200-km trip by air from ocean to forest in central Peru would cross 20 of the world's 34 major life zones. In addition, the Andes range contains many areas that are rugged enough to be inaccessible even by horseback.

In terms of weather, there are numerous, unstable climate and geological patterns such as earthquakes, droughts, floods, and the corresponding effects of periodic occurrences of El Niño.

These geographic aspects indicate several motivations for mathematics. For example, all successful groups in the dry regions had to have some kind of effective water control in the form of irrigation and aqueducts. Next, those in the high altitudes had to have some form of flexible mountain agriculture, such as terrace farming. Moreover, in many parts of the Inka territory, the groups there had to construct bridges to cross deep canyons and difficult mountain areas. In effect, civil and agricultural engineering were crucial elements of survival. Finally, as in almost any cultural group, knowledge of astronomy is important in terms of predicting planting and harvesting seasons, approximating weather changes, and general time keeping. Mathematics is, of course, part of all of these activities.

A Few Relevant Cultural Groups

As alluded to previously, there were many groups that were part of what we are calling the Inkas, and we would like to mention just a few of them. The relevance is that these groups had their own mathematical concepts and practices, and as the Inkas absorbed these groups into their system, they almost certainly made use of some of that mathematical knowledge. A quite complete general reference on the various groups and their interactions with the Inka is in Moseley (1992).

Of the many competing cultural groups in what became Inka territory, we can first mention the

Moche of the northern Peruvian coast, from about 100 to 700 CE. Later, in old Moche territory, a substantial group called the Chimú arose, forming the Chimor Empire with its capital city of Chan Chan. The Moche-Chimú group was the largest Inka rival, and they inhabited the northern Peruvian coast during the Early Intermediate period to the Late Intermediate period (about CE 0–1470). They practiced river valley agriculture along several of the rivers that descend from the Andes to the Pacific, including the Moche River. The Inkas did not overcome them until 1470.

Another group is the Huari of the central Andean highlands of Peru during the Early Intermediate and Middle Horizon periods (about CE 600–1000). The Huari engaged in advanced irrigated terrace farming and had quite mathematical artwork.

Next, we can mention the Aymara kingdoms of the Lake Titicaca region of the Late Intermediate period (about CE 1000–1400). The Aymara themselves consisted of several groups, e.g., the Colla and Lupaqa groups. Also, the Aymara had their own language group, and some dialects of Aymara are still spoken today. The Aymara also had extensive terrace agriculture as well as domesticated llamas and alpacas.

The last of this sampling of groups that we mention is the Nazca of the southern Peruvian coast of the Early Intermediate period (about BCE 400–CE 500). Some indication of Nazca understanding of geometry and astronomy can be seen in the lines and figures they created in the desert. It is still not clear what the lines represent, but there are connections between many of the lines and both astronomy and ritual of the Nazca. The interested reader can get some idea of this topic in the book edited by Aveni et al. (1990) and in the article on Nazca lines in this encyclopedia. Of course, we cannot exit the Nazca topic without mentioning in passing the inspiration to mathematics teachers in the name of Maria Reiche (1903–1998). Reiche was a German-born teacher who made a daring career move in 1932 by moving to Peru. By the end of her career, she had played a crucial role in the preservation and study of the Nazca culture and lines. See her collected works in Reiche (1993) for more details.

All of the above groups had some knowledge of mathematical ideas. The *kipu* [also called quipu, a mathematical recording device of strings and knots] that is discussed in detail elsewhere in the encyclopedia existed long before the rise of the Inkas and was known, for example, to the Huari and Aymara; see chapter 10 of Quilter and Urton (2002). As the Inkas grew to control the territory, their control and/or interaction with these groups must have played into their own mathematical understanding and development. We could even go much farther and say that this little piece on Inka ethnomathematics is only a peek into the larger realm of mathematical interaction, history, and culture of Andean societies, most of which has yet to be carefully researched.

Understanding Preconquest Inka Culture

Tahuantinsuyu, “Land of the Four Quarters,” is the word the Inka used to describe their territory. We would like to know a little about what Inka culture was like before the arrival of the Spanish in 1532. However, it turns out that it is not so easy to reconstruct an ancient culture.

First, although the Inkas were indisputably advanced in many regards, they did not use a writing system as we know it. In fact, the subject of how the Inkas created and maintained complexity in terms of society, government, and economy without communication through what we would consider a writing system is one of active debate. The *kipu* represents a mathematically based system of information keeping that could well have served in place of writing. Meanwhile, however, it is also the case that the Inka groups made use of oral tradition, whereby information, history, and social practices are passed along via oral descriptions. See Schneider (1994) for a general description of oral tradition. Also, an interesting description of Inka culture and literature can be seen in Lara (1960).

Next, there are problems with accuracy of information on the history of the Inkas. Because the only studies of Inka culture we know of took place after the Spanish conquest, information

about the Inkas is either substantially culturally biased, as in the case of most Spanish chroniclers, or is a study of a group that has changed significantly in nature, as is the case in studying present-day descendants of the Inkas. Thus, accurate information is difficult to obtain. For our purposes, two sources considered to be relatively accurate are those of Pedro Cieza de León and Felipe Guaman Poma de Ayala. In Ascher and Ascher (1981, p. 3), the reader may find a detailed description of original works and translations of Cieza de León’s work, and in the bibliography, here we have listed a reference to the works of Guaman Poma (1980) [1614]. Guaman Poma is particularly known for the many drawings of Inka. From sources such as these, we can explain a few aspects of Inka culture that are relevant to our theme of mathematics.

One feature of the Inkas worth mentioning is that as they expanded into regions of other groups, they allowed those groups a certain amount of local control. There are two advantages to this attitude. One is that the subjugated groups would not be as likely to reject Inka rule. The other, relevant to our theme of mathematics, is that by allowing the conquered groups to retain some original culture, the Inkas could use and improve mathematical and engineering ideas of those groups, such as astronomy and agriculture. This last comment implies that some of the mathematics of the Inkas was probably diffused from other groups.

Also relevant to the development of mathematics in the Inka region is that of economy. Starting with very early organized groups and extending even to the present, trade has been an important factor in the societies in the Inka region. In addition, the Inka economy included an extensive taxation system. Later, we will see that this taxation, among other activities, could be recorded on the Inkas’ *kipus*. A good reference to the ideas of trade and interaction of the various groups can be found in Moseley (1992).

Quechua Number Words

Our first mathematically close look at the Inkas comes by way of discussing Quechua number

words, which reflect Inka numeration. In a study of numbers in cultural mathematics, there are two distinct aspects that we must consider: number words and number symbols (representation). These two concepts are not the same.

The first things we must clarify have to do with Quechua, the language used by the Inka. Until the 1960s, it was commonly thought that Quechua originated and spread with Inka expansion. In Mannheim (1985), Mannheim (1991), Stark (1985a, b), Urton (1997), and Weber (1989), the reader may find explanations and references indicating that Quechua in fact originated in northern central Peru and later split into essentially two branches. For our intentions, we take as our model Weber's description of Huallaga (Huánuco) Quechua, which is often referred to as *Quechua I* or *Quechua B* in the references. As Weber indicates, Huallaga Quechua seems to have suffered fewer changes than some other Quechua dialects, which implies that our discussion here of number words should have some accuracy.

Here is a short list of number words from Huallaga Quechua:

Huk, 1; *ishkay*, 2; *kimsa*, 3; *chuska*, 4; *pichqa*, 5; *soqta*, 6; *qanchis*, 7; *pusaq*, 8; *isqon*, 9; *chunka*, 10; *pachak*, 100; *waranqa*, 1000

The format of more complex number words is the following:

[multiplier] {nucleus} (adder)

The nucleus is always a power of ten. For the examples that follow below, we will employ the above notation, namely, multipliers, []; nuclei, {}; and adders, ().

Example 1: *isqon pachak*: [9] {100} = $9 \times 100 = 900$.

Example 2: *qanchis chunka pichqa*: [7] {10} + (5) = 75.

Example 3: 347,002: [[3] {100} ([4] {10} (7))] {1000} (2).

kimsa pachak chuska chunka qanchis waranqa ishkay.

From the number words and the examples above, we can deduce that the Inkas counted in base ten; i.e., they used a decimal system.

Looking Deeper: Weaving, Symmetry, and Counting

The previous section describes some basic facts about number words of the Inkas. However, that information tells us little about the cultural context of Inka mathematics. Such contexts between mathematics and culture entices us into the field of ethnomathematics. Good places to start in the study of ethnomathematics in general are with Selin (2000), Ascher (2002), Closs (1986), Pacheco (1997), Urton (1997), Zaslavsky (1973), and Gilsdorf (2012). What comes out of ethnomathematical considerations is the understanding of how a particular culture perceives and interprets mathematics. It is often surprising to learn that some cultural activity of a particular group involves elegant mathematics that are not easy to see until we look closely and think differently. Moreover, although modern Western mathematical notation of the mathematics being used may not make sense to people of the group, it becomes clear that they nevertheless understand the concepts. The interesting part is that the Western and non-Western interpretations can be dramatically different. We will next examine some such activities for the case of the Quechua-speaking Inkas.

Let us look more carefully at the situation of the women who were weaving, described at the beginning. The first mathematical observation we can make is to notice the symmetry patterns that evolve from the weaving process. In chapter six of Ascher (1991), we find a careful discussion of decoration and various translations, reflections, and rotations that reveal a cultural emphasis of the Inkas on formality, precision, and repetition. Figure 2a–d shows some examples of weaving patterns of the Inka and some other cultural groups eventually controlled by the Inkas. In Fig. 2a, for example, we can observe many types of symmetry. One such symmetry is horizontal: imagine a horizontal line drawn halfway through the figure. Then we see that the pattern in the upper half is exactly repeated in the lower half. Similarly, if we draw a vertical line down the middle of the figure, then the pattern on the left half is exactly repeated on the right half, so the figure has



Ethnomathematics of the Inkas, Fig. 2 Bolivian textile patterns. From Tamara E. Wasserman and Jonathan S. Hill, *Bolivian Indian Textiles, Traditional Designs and Costumes*. New York: Dover Publications, 1981, Plate 17

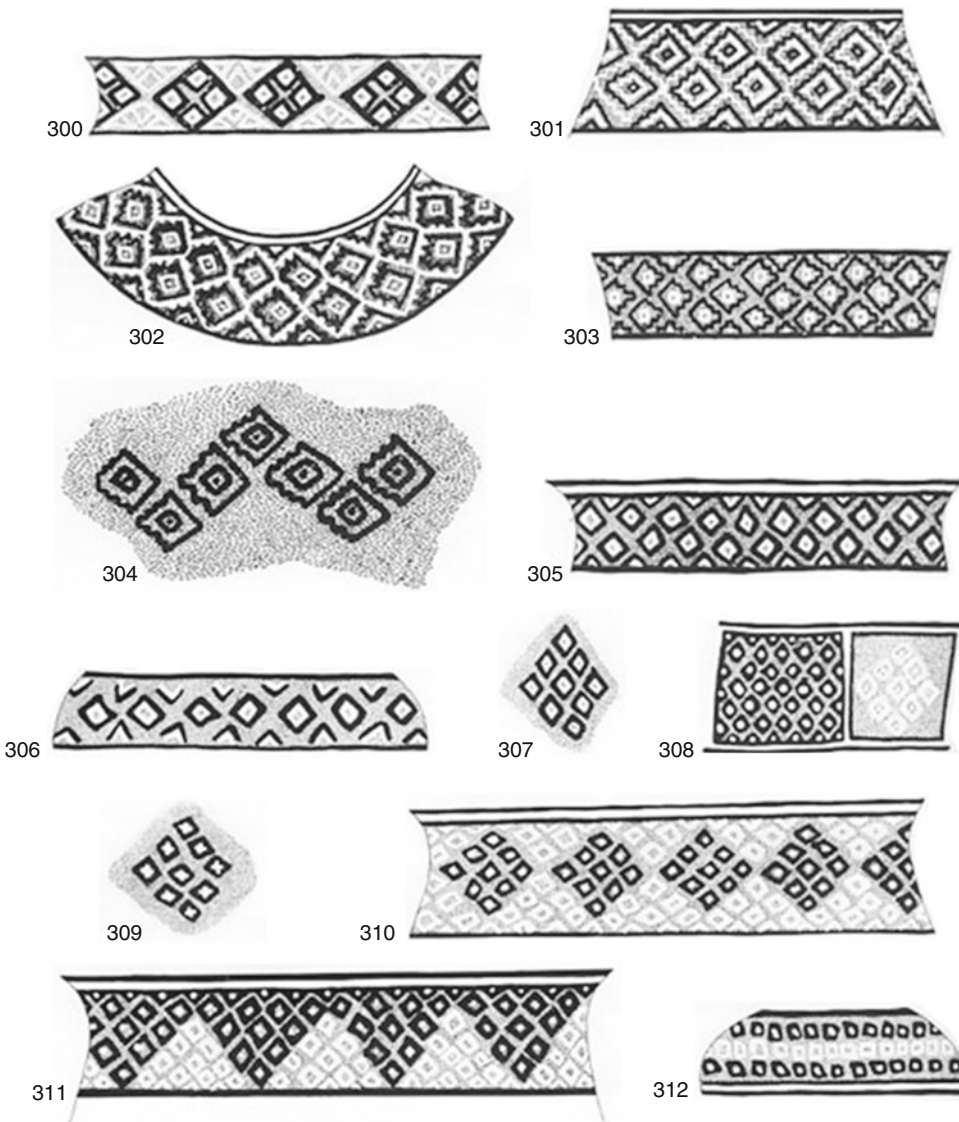
vertical symmetry. Now let us look at Fig. 2b. Except for slight displacements of some of the smaller parts of the figure, it has horizontal symmetry. It does not have vertical symmetry, however: observe that if we draw a vertical line through the middle of the rectangular spiral part of the figure and reflect the figure across that line, then the spirals will appear in a different orientation. That is, we will not see the same pattern being repeated. On the other hand, the rectangular spiral pattern appears again in Fig. 2c, which, although it does not have vertical symmetry, has rotational symmetry. Imagine putting a tack in the middle of the strip pattern and rotating the figure 180° . The rectangular spirals then appear in the same orientation as in the original unrotated figure. Now let us look at ceramics, namely, the item marked “300” from Fig. 3. It has several symmetry properties including vertical, horizontal, and rotational

symmetry. On the other hand, item 311 of Fig. 3 only has vertical and translational symmetry (translational symmetry means the pattern is repeated if we slide the figure to the right or to the left). Next, item “401” of Fig. 4 only has translational symmetry.

Furthermore, symmetry can appear in contexts other than weaving. If you want to look even deeper into more types of symmetry properties, you can read Ascher (1991), chapter 6.

The above is a good practice for learning about symmetry patterns in general, but we must get back to the cultural part of this. We can ask questions like: What can we deduce from the symmetry properties used in a particular cultural group? In the case of the Inkas, we see the repeated preference for a lot of symmetry. This preference indicates a strong sense of order and precision in Inka culture and mathematics. This corresponds with our general knowledge of the Inkas as being a culture that kept careful records via their *quipus*. Detailed discussions of quipus (quipus) can be found elsewhere in this work, as well as in chapter 10 of Gilsdorf (2012).

Here is another question: how do the weavers know how to construct the patterns in order that they have such symmetry? Even in the case of what at first appears to be a simple shawl having several stripes of varying widths, we can ask as to how the weaver knew how to obtain the widths from the threads. Look at Fig. 2a again. In these questions, we are in fact asking about mathematics. The people (mainly women) who weave such items must in fact count (*yupa*, “to count or account”) threads. For the case of stripes, the number of, say, red threads for the first stripe must correspond in some way to the number of red threads that might appear later in the pattern, so that the two red stripes have the same width. The number of threads to be counted in each step of a weaving process is often complicated and must be decided upon ahead of time. Indeed, the weaver must know in advance what the entire pattern will look like. Once the process starts, what is remarkable is that the weaver does the counting of the threads mentally. A detailed discussion of how groups of threads are counted by Inka (Quechua) weavers can be found in

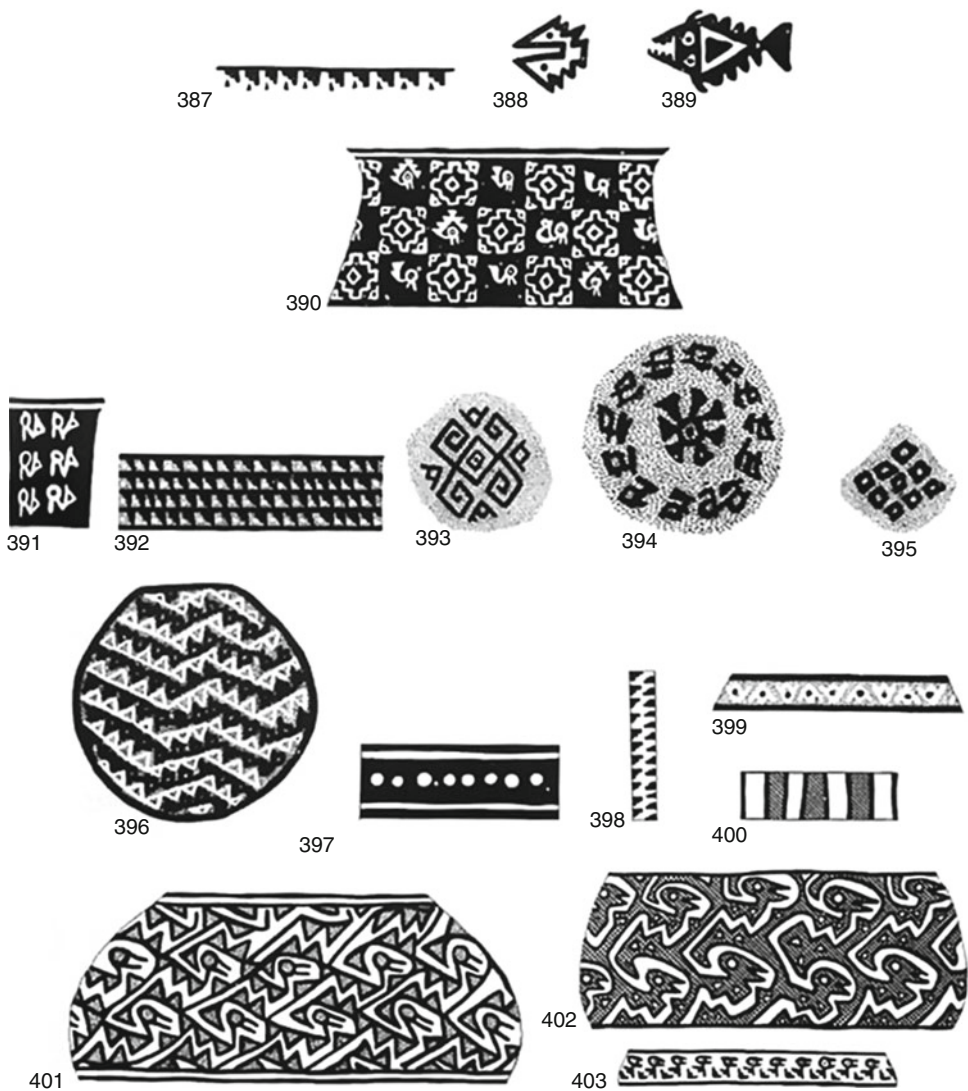


Ethnomathematics of the Inkas, Fig. 3 Inka design patterns (From Menzel (1976), Plate 26. Used with their kind permission)

chapter 4 of Urton (1997). In our context of ethnomathematics, we can observe some mathematical properties in Inka weaving. One such property described in Urton (1997) (see Fig. 6) is that thread counts are usually done in blocks of 10 and 20 and that in general what is being counted are values of pairs of numbers of threads. Notice the influence of the decimal system. The complex geometric or animal motifs are created by a process called *pallay*, “to pick up.”

Gender and Inka Mathematics

If we go back to the first line of this piece on Inka mathematics, it is a group of women that is involved in weaving. Moreover, it is worth mentioning that Urton (1997) refers to master weavers called *Mamas* (a Quechua word, not the word for mother) who are women who most likely started weaving when they were girls and reached a high level of expertise. They are



Ethnomathematics of the Inkas, Fig. 4 Inka design patterns (From Menzel (1976), Plate 31. Used with their kind permission)

generally treated with special respect within their community. The *Mamas*’ abilities in counting and understanding patterns of symmetry and in geometry are part of that expertise. The ethnomathematical aspect of this situation is this: if we asked one of these women to explain geometric or symmetry properties in terms of lines, rotations, polygons, and so forth, they probably would not explain them in such textbook-like terms. Yet, they clearly understand these mathematical concepts. The difference is that

their understanding comes from the perspective of a weaver who must create a cultural product and who wants to include certain patterns. There is more to say regarding the role of women in society and their skills at mathematics.

It is well known that in Western culture, until recently, women have traditionally been left out of mathematical professions. One famous example from the 1800s is that of Sofia (Sonya) Kovalesskia (Also spelled Kovalessky). Who was the first woman to earn a doctorate in

Ethnomathematics of the Inkas, Fig. 5

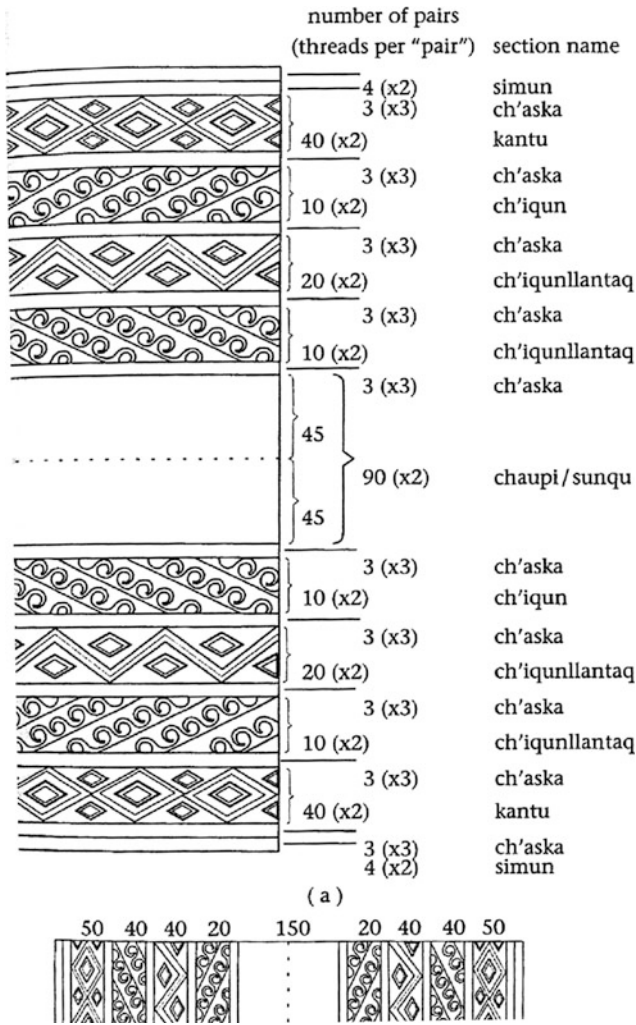
Inka design patterns
(From Menzel (1976),
Plate 45. Used with their
kind permission)



mathematics but could only obtain it through the support of male mathematicians (mainly Karl Weierstrass) and was barred from employment in the mathematics departments in several countries afterward. This was because of her gender. Details of the mathematical life of Kowalewskaja can be found in Burton (2007). More details about tendencies in Western culture with respect to mathematics can be found in chapter 1 of Gillsdorf (2012). Thus, the connection between gender roles of women and their skills in mathematics could get overlooked. Indeed, Berlo (1996) indicates, “In the modern Western world, both textiles and women are marginalized. A priori assumptions about textiles and women allow otherwise sensitive investigators to delimit women’s activities...” (438). So, let us discuss some of this within the context of Inka culture.

There is a definite connection between gender and weaving in Inka culture. Costin (1995, p. 69) describes her archaeological work on pre-Inka Wari culture in which she concludes that *all* females spun thread and made cloth. In addition, in her investigation she concludes, “The ethno-historic documents tell us that most cloth was manufactured in a domestic setting and that women were the primary producers of thread and cloth” (68). This indicates a strong identification between being female and textile production, and the identification was already present before the rise of the Inkas. Costin’s findings and supporting documents allow her to conclude that elite pre-Inka Wari women in fact created wealth for their families through their production of spinning and weaving (69–70). In a later work that focuses on gender roles and cloth production

Ethnomathematics of the Inkas, Fig. 6 Warp counts in Inka weaving. From Gary Urton, *The Social Life of Numbers, A Quechua Ontology of Numbers and Philosophy of Arithmetic*. Austin: University of Texas Press, 1997, Figure 4.6, page 121. Used with their kind permission

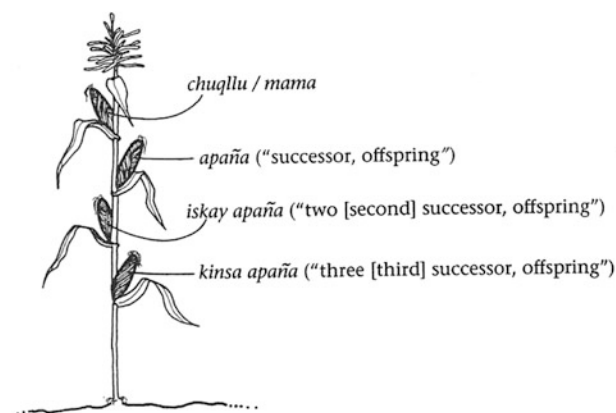


in pre-Hispanic Inka times, Costin (1998) observes that cloth production continued to be a crucial activity and that Inka royalty carefully chose women to be weavers dedicated to making elaborate cloth. The women attained high social status, though at a high cost of being secluded from society in general and having to remain virgins. Nevertheless, the existence of the selection of chosen women as weavers indicates the importance of cloth production to Inka society and reinforces the importance of female gender identity within the realm of cloth production. This importance of gender and weaving also appears in the work of Guaman Poma in which virtually all of his drawings that relate to weaving

show women as the producers of cloth. See Costin (1998, p. 131) for a good sample of drawings from Guaman Poma regarding cloth production. Hence, we can piece together the connections between weaving, mathematics, and gender to conclude that the mathematical skills involved in weaving (thread counts, symmetry, geometric patterns) were extremely important to the Inkas and that the corresponding knowledge base was almost exclusively connected to being female. Finally, it turns out that connections between gender roles and cloth production can be found in other cultures. Two examples are the Aztecs (see Brumfiel 1996) and the Maya (see Hendon 2006).

Ethnomathematics of the Inkas, Fig. 7

“Birth order” and naming of ears of corn. From Gary Urton, *The Social Life of Numbers, A Quechua Ontology of Numbers and Philosophy of Arithmetic*. Austin: University of Texas Press, 1997, Figure 3.3, page 86. Used with their kind permission



A Bit More About Counting, Pairs, and Even Numbers

In Quechua culture, counting is closely tied to important cultural aspects. Kinship and social organization, as explained by Urton (1997), represent one such aspect. On page 85, for example, he tells us that ears of corn on a stalk are carefully named in the order in which they appear, with the first representing the “mother” and others being defined in accordance to the first as offspring of the mother (Fig. 7).

Note that the order of the counting is as important as the counting itself. As for the subject of pairs, it turns out that the Inkas view the property of being even in a count as extremely important. In fact, we could go so far as to say that odd numbers are considered as incomplete pairs. We saw above that the counting of threads in the weaving process is done in pairs of threads. There are many more instances in which one counts pairs in Quechua society. The perception of even versus odd numbers is in fact one of the main themes of Urton’s (1997) book. The cultural impetus for this viewpoint is that the Inkas constantly strive to have proper order in their world. Such order even extends to contexts like social situations. If a person has done something inappropriate, then something must be done by him/her or by the community so that proper social order is regained. This can be thought of as completing an incomplete pair. By the way, notice that this persistence of order and proper organization appeared in the symmetry patterns, too.

A Few Remarks About Astronomy

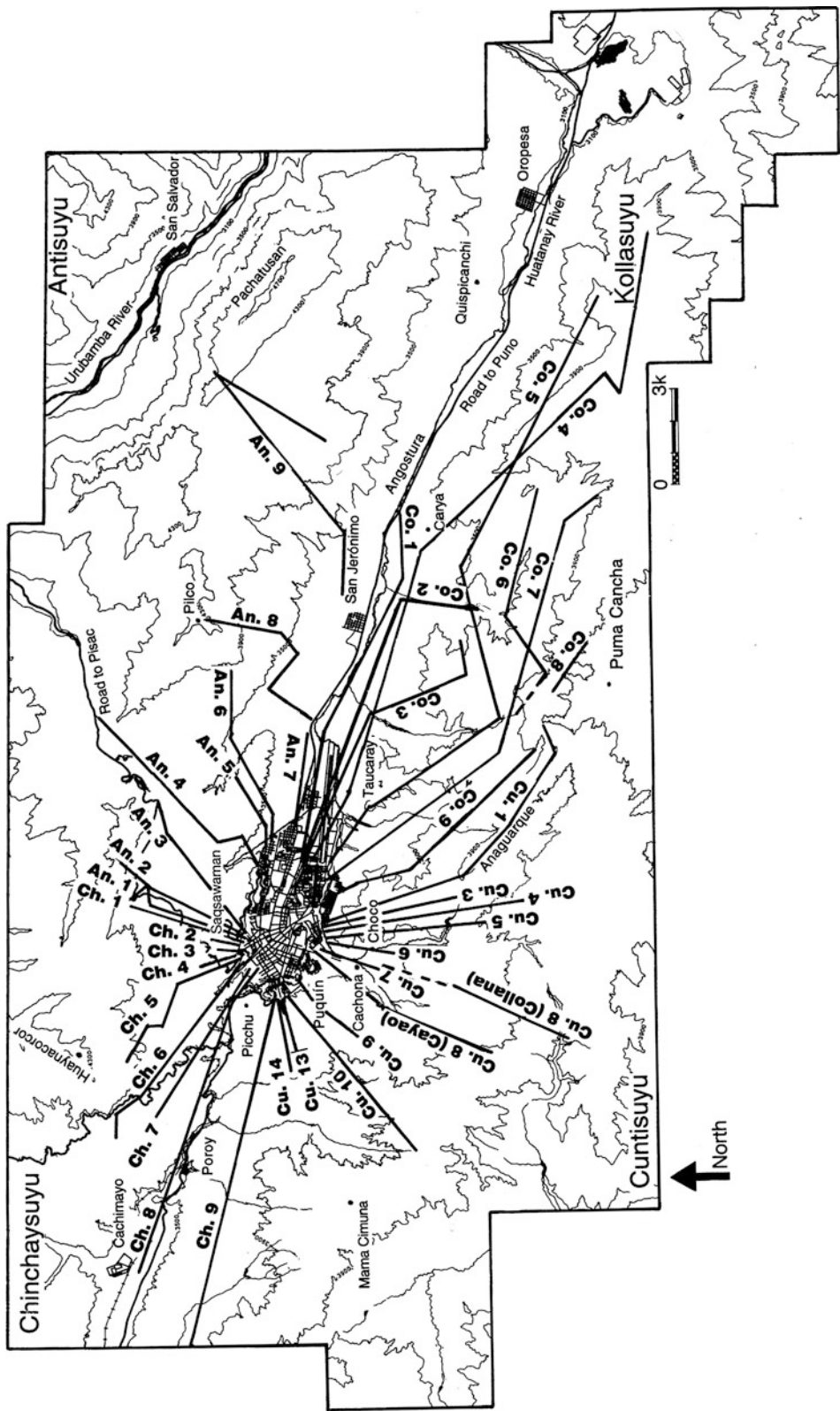
Inkan astronomers knew about the solar, lunar, and Venusian cycles. They had a solar calendar and festival calendar based on 12 lunar cycles, plus adjustments to account for the difference necessary to make a full 365-day year.

Throughout the city of Cuzco, there are remains of some of about 400 markers, called *huacas*, along with imaginary lines called *ceques* (also *zeq’*e**). These lines originate from the center of Cuzco. Figures 8 and 9 show some details of the system, though you will have to read chapter 7 of D’Altroy (2002) to fully understand the figures. These *huacas* had ritual and social significance. Some had connections with astronomy, hence mathematics. In particular, the Inka used several of the *ceque* lines as part of astronomical observations such as the June solstice. Furthermore, the *ceques* and *huacas* were crucial components of the Inkan religious ceremonies, and in fact, the *huacas* are more accurately described as sacred shrines.

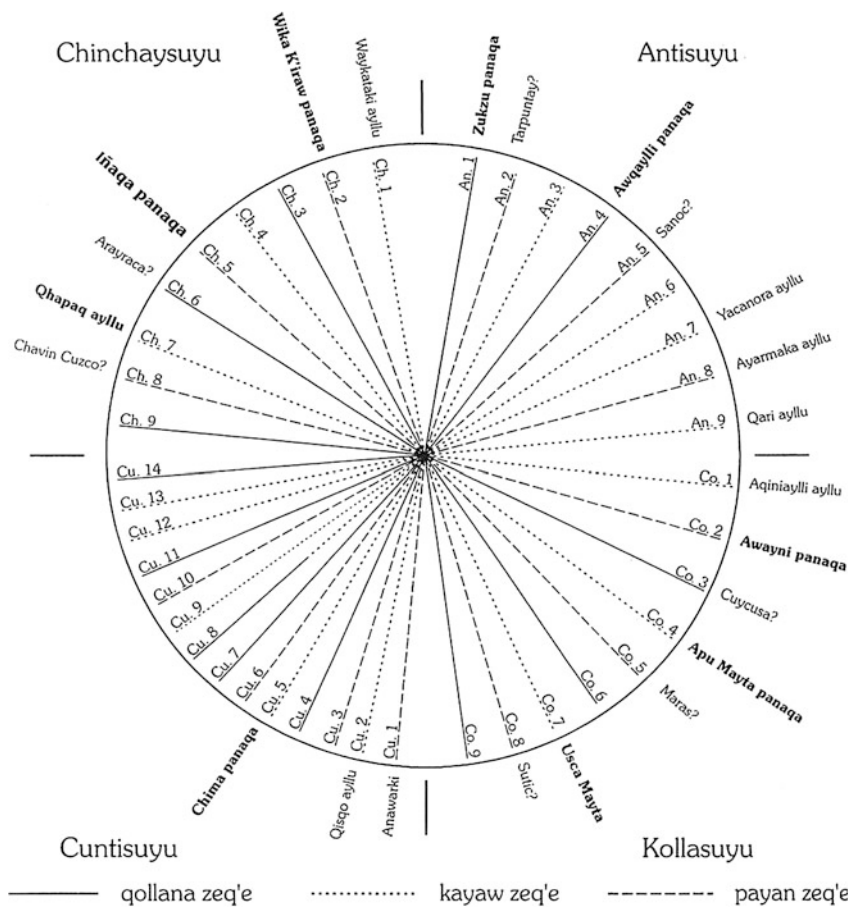
Astronomy and culture quickly become intimately involved with each other. We know that astronomy and mathematics also have a close relationship, so we can conclude here that astronomy, culture, and mathematics of the Inkas are intertwined.

Yupana

The Inka performed rather complicated computations. The *kipu* was a record-keeping device



Ethnomathematics of the Inkas, Fig. 8 Cuzco's ceque system. From Terence D'Altroy, *The Inkas*. Oxford: Blackwell Publishing, 2003. Figure 7.1, page 160. Used with their kind permission



Ethnomathematics of the Inkas, Fig. 9 Schematic diagram of Cuzco's ceque system. From Terence D'Altroy, *The Inkas*. Oxford: Blackwell Publishing, 2003. Figure 7.2, page 161. Used with their kind permission

not used for calculating. In fact, most of the knots on known khipus are tight, implying that the values on them were usually intended to be fixed. This leads us to ask the question: How did they make the computations? The answer to this question is still not completely understood. One possibility arises in the first of the drawings of khipus made by Guaman Poma.

The rectangular grid of solid and unfilled dots appears to be a kind of counting board; however, Guaman Poma gives no explanation of the grid. Certainly there would be reason to believe that the grid has mathematical meaning because of its appearance with a khipu. A curious aspect of the grid is that each row contains 11 dots, something that obviously does not coincide with a decimal counting system. In addition, because Guaman

Poma's work occurred after the Spanish conquest of Peru, the grid does not necessarily represent a device of the Inka.

On the other hand, proposals of mathematical uses of the grid have been given, with the term *yupana* (Quechua for the verb to count) used to denote it, such as those appeared in Mackey, Pereyra, Radicati, Rodriguez, and Valverde (1990) and Higuera and Clara (1994).

The mathematical methods for counting that are presented make logical sense, such as filling the 11th dot as a placeholder for powers of ten. Included are photos of three-level rectangular stone figures that resemble counting grids in some ways that could have served as abaci for counting. There are descriptions by Spanish chroniclers of observations of Inkas counting on

these rectangular forms, but here we encounter the problem of accuracy. A conclusive explanation of the grids and rectangular forms still has not been given. However, the works cited here point toward possible patterns of counting or symbols.

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Faience in Ancient South Asia

Blythe McCarthy

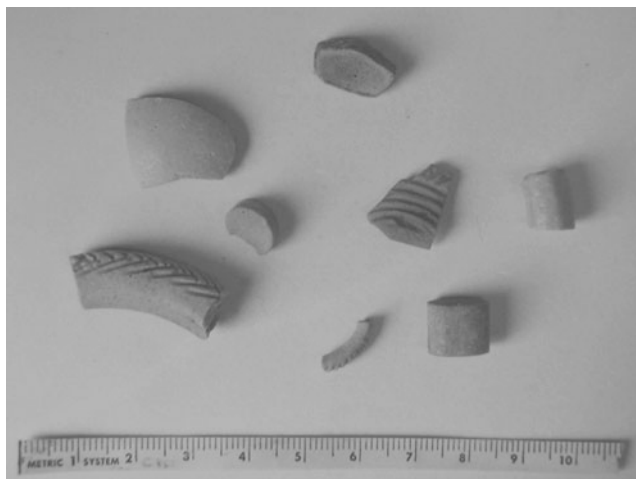
The term faience when referring to ancient materials describes a man-made material of mineral grains, generally quartz or sand, that are bound together by varying amounts of glass, often with a layer of glass (a glaze) on the surface. The material can be very friable and crumble easily or can be hard and dense, depending on the amount of glass present. Several terms have been used to describe this material including glazed quartz frit, glazed paste, glazed composite bodies, blue-glazed whiteware, fritware, and siliceous paste. Faience is however the term most commonly used. Although faience is most often associated with ancient Egypt there was also a well-developed faience industry in the Indus Valley as well as in ancient Mesopotamia. The faience industry in South Asia dates to the third millennium BCE while that from Egypt dates to the first half of the fourth millennium BCE and Mesopotamia from the late fifth millennium BCE (Moorey, 1985; Stone & Thomas, 1956).

Faience using quartz for the mineral grains first appeared in South Asia during the Kot Diji phase (2800–2600 BCE or Nausharo I). It is seen at Nausharo and Mudigak in the form of beads (Barthélemy de Saizieu & Bouquillon, 1997). Beads were primarily small in size and shaped

as cylindrical rings during the early Harappan period, Kot Diji phase; however small tubular, spherical and diamond shaped beads have also been found. There are also beads, lenticular and biconical in shape, from this period at Harappa (Kenoyer, 2000). Some of the faience from the end of this phase appears similar to compact faience seen in the later mature Harappan phase. Beads continue to constitute a large proportion of the faience into the mature Harappan phase (<http://www.harappa.com/indus2/174.html>). There is a concentration of ellipsoidal beads, but larger and more complex beads, such as segmented and multicolor beads, are present as well. Faience beads form a small part of the bead corpus with steatite beads accounting for the majority. At the site of Nausharo only faience beads and small amulets made of faience have been found. In addition to beads, bracelets, buttons, spindle-whorls, gamesmen, animal figures, and small jars made of faience have been found at the sites of Harappa, Chanhudaro, Lothal, and Mohenjodaro among others. Figure 1 shows some fragments of bangle bracelets of varying diameter, as well as vessel fragments. Small faience jars have been found in all faience containing strata at Harappa. Several of the vessels have textile impressions (Kenoyer, 1998, p. 159).

Faience is occasionally found in sites of periods later than the Harappan period. A microbead hoard was found in a black slipped ceramic at the site of Agiabir (Mirzapur), Uttar Pradesh (Singh, 2002) dated to the

Faience in Ancient South Asia, Fig. 1 Compact faience bangle bracelet and vessel fragments from the site of Harappa



Northern Black Polished Ware (NBP) culture (600–200 BCE). Occasional faience beads were recovered in two earlier periods at the site, that of the Narhan culture (1300–900 BCE) and Pre-NBP with Iron (900–600 BCE). Singh states that it was similar to the high strength faience of the Indus Valley civilization. Faience bangles also continue after the Harappan period and may lead to the introduction of glass bangle technology in the early historic period (600 BCE) (Kenoyer, 1994).

Two types of quartz faience have been identified for the Indus Valley Civilization. One, coarse with 50–100 μm quartz grains, is speckled in appearance, with a glass binder and colorant. This material was used for beads and small tokens (Barthélemy de Saizieu & Bouquillon, 1997). A second type is fine with a compact structure, evenly colored with quartz grains less than 30 μm in diameter. This dense, homogeneous form of faience was determined to have been formed by multiple cycles of heating, to a temperature between 1,000 and 1,100 $^{\circ}\text{C}$, and grinding an initial mixture of alkalies (salts), clay, and quartz. This produced faience of uniform color due to a very homogeneous glass phase and very small quartz crystals as seen in Fig. 2. The addition of alkalies in the final step where the objects were fashioned resulted in a thin surface glaze through an efflorescence glazing process (McCarthy &

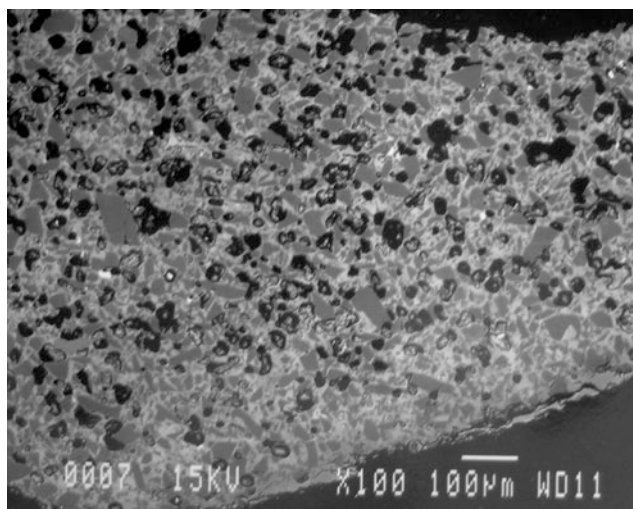
Vandiver, 1990). In this process, the alkalies migrate to the surface during drying, react with the quartz particles at the surface and form a glass (<http://www.harappa.com/indus3/255.html>). This type of faience manufacturing results in a material of higher strength than other forms which may account for its use in bangle bracelets and vessels unlike the other forms of Indus valley faience which are primarily used for beads. Faience can be manufactured in this manner without the addition of glass, i.e., with only salts and sand; however, this forms a glazed material with a very friable interior.

A workshop was found at the site of Harappa in 2001 (Kenoyer, 2003) that included debris from faience manufacture (<http://www.harappa.com/indus3/246.html>). Steatite tablet molds, carved in reverse, were uncovered as were firing containers, kiln supports and a yellow green slag. The clay containers were lined with crushed bone and steatite. (See slides 250–253 at <http://www.harappa.com/indus3/slideindex.html>.)

To date, no traditional kilns have been found that can be linked to faience manufacture. Recent experiments have resulted in a plausible method for the firing of the small faience objects found in the Indus Valley culture. Replication of the containers, setters and faience material similar to that found in the workshop were made and used to fire faience and steatite. The filled containers were set

Faience in Ancient South Asia,

Fig. 2 Backscattered electron image from a scanning electron microscope of a cross section of a faience bangle bracelet from Harappa. The *dark gray* grains are quartz, the *light gray* matrix is the glass phase. The exterior of the bangle runs along the lower edge of the photomicrograph and a thin glaze layer is visible along part of the length at the *lower right*



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in a bonfire. The temperature in the containers reached 935 °C and glazed faience resulted. (See slides 254–257 at <http://www.harappa.com/indus3/slideindex.html>.)

The color of South Asian faience varies. When a pure quartz mineral is used for the grains and there is no colorant in the glass phase a white material results. This may have a colored glaze layer and so appear colored if not broken. If a colorant is present in the glass binding material, such as copper that produces a blue color, or iron oxide particles, that produce a red color, the interior of the faience has that color. When weathered, faience appears similar to weathered glass and the two materials can be easily confused. Colors include white (colored by high calcium), black (colored by manganese), deep blue (colored by copper or cobalt and manganese), yellow, brown and red-brown (colored by iron), and brilliant red. Faience with multiple colors has been used to imitate banded agate and agate or carnelian eyebeads, white with brown, black or red-brown (Barthélemy de Saizieu & Bouquillon, 1994; Kenoyer, 1998). Lead has been found in the glazes of two Indus period faience beads from Nausharo (Barthélemy de Saizieu & Bouquillon, 1995). This is 1,000 years before the earliest known lead glazes, but the small number of beads containing lead may indicate that it was an experiment.

Dayton theorized that spent metallurgical molds made of steatite were used to form the first faience (Dayton, 1989). Bouquillon and Barthélemy de Saizieu identified such steatite faience in four cylindrical beads from the pre-Indus period at Mehrgahr dated to around 3000–2800 BCE where a steatite glazing tradition was in place as early as the Chalcolithic period (Barthélemy de Saizieu & Bouquillon, 1995). This date places the manufacture and use of this material earlier than siliceous faience in South Asia. In this form of faience, ground steatite is used for the mineral grains. The steatite faience makes up less than 1 % of the steatite objects recovered from the site. The compositions of the glazes on the steatite faience are similar to those found for glazed steatite from the pre-Indus period.

The development of faience occupies an intermediate step in the technological progression that led to glassmaking in South Asia. The earliest step was that of heating and glazing of stones (steatite), followed by manufacture of faience, first one of crushed steatite, then of quartz grains, progressing finally to glass manufacture.

See Also

► [Beads](#)

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Farming Technology in Amazonia

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The Scope of This Article

This entry summarizes recent advances in our knowledge of the history of farming technology in Amazonia. Although some reference is made to farming as it is practiced in Amazonia today, the focus is squarely on farming techniques of indigenous Amazonians prior to the European conquest. Limited space has led us to additionally restrict the scope of the entry. First, we will concentrate on techniques and material culture, with little attention to sociotechnical systems. As Pfaffenberger (1992) emphasizes, technology alone does not constitute a human population's adaptation to its environment but rather technology in concert with the social coordination of labor. Archaeologists and geographers have

speculated about the sociotechnical systems of pre-Columbian Amazonian farmers, but there is little firm knowledge. Second, we will focus on how farmers managed the land – light, water, soil, and other resources for crops – and much less on how they managed populations of crops and semidomesticated plants and plant communities. There exist excellent reviews on these topics. Work of Posey (1985), Balée (2013), Erickson (Balée & Erickson, 2006; Erickson, 2008), Clement (2006, 2014), and others has sketched out how indigenous Amazonians domesticated landscapes, favoring the abundance of useful trees and other plants and sometimes even extending their geographic distribution (Shepard & Ramirez, 2011). The extent of such landscape domestication, and its impacts on Amazonian forest ecosystems today, are matters of debate (Barlow et al., 2012). Over time, spatially extensive harvesting of wild plants changed to more intensive tending and cultivation and later to crop domestication. Piperno and Pearsall (1998) and Clement et al., (2010) offer useful syntheses of the domestication of plants in the lowland Neotropics and in Amazonia, respectively. For the quintessentially Amazonian crop manioc, work over the past 15 years has shown how farmers' practices shaped, and continue to shape, the traits of the crop (McKey et al., 2012; Ménard et al., 2013; Rival & McKey, 2008), producing great genetic and phenotypic diversity. Work on manioc has also provided scenarios to explain its functional diversification (e.g., in root toxicity in relation to ecological and cultural variation [Arroyo-Kalin, 2010; McKey & Beckerman, 1993; Mühlen et al., 2013; Perrut-Lima et al., 2014]) and its adaptation to different soil types, including the anthroposol created by indigenous Amazonians (Arroyo-Kalin, 2010; Fraser et al., 2012).

This entry focuses on two major themes that have dominated research on how management of the land by pre-Columbian indigenous farmers shaped Amazonian environments, with consequences that can still be observed today. The first of these themes concerns principally forested environments, while the second concerns peri-A Amazonian savannas.

Environmental Constraints, Anthropogenic Dark Earths, and Pre-Columbian Agriculture in Forested Amazonia

An excellent starting point for any article on farming technology in Amazonia is the book by Denevan (2001), an important part of which deals with the agricultural landscapes of forests and savannas of Amazonia and the techniques – the tools, but also the “soft technology” employed to manage soil fertility, weeds, pests, and the like – that shaped these landscapes. Denevan summarizes the ideas, primarily developed by Meggers (1971, 2003), that for several decades formed the dominant narrative of the human use of Amazonian environments. According to Meggers, large farming populations developed only along the major river valleys, where rich alluvial soils of the *várzea* permitted relatively intensive agriculture, supporting dense and sedentary populations. In the *terra firme* between these valleys, the weathered, acid, and nutrient-poor soils allowed only long-fallow slash-and-burn agriculture (swidden) – similar to that widely conducted in Amazonia today – that sustained only sparse, seminomadic human populations. Tracing how these ideas have been challenged by recent work (summarized for broad audiences by Mann (2005)), Denevan reached several conclusions. First, patterns observed today are likely to be very different from those that existed before the European conquest and the introduction of iron tools. When only stone axes (Fig. 1) were available, clearing forest would have been much more difficult than today (Fig. 2). Once a parcel was cleared, farmers would have attempted to cultivate it as long as possible. In Denevan's view, long-fallow shifting cultivation (Fig. 3) – or at least the great geographic extension of this mode of land use – is a postconquest phenomenon, triggered largely by the European introduction of metal tools (cf. Arroyo-Kalin, 2012; Rostain, 2012). Second, although the alluvial soils of the *várzea* are fertile, farming in this environment carries a high risk of complete loss of crops to exceptional floods. Farmers may have preferred to reside



Farming Technology in Amazonia, Fig. 1 Stone axe with a polished cutting edge still used in the 1960s by an Akuliyo group in Suriname (Photo by Stéphen Rostain)

near floodplains and their aquatic resources, rather than within floodplains, and to farm areas with less flood risk, such as bluffs overlooking river valleys. Third, natural constraints to agricultural production in *terra firme* soils – not only those on bluffs, but also those further from rivers – were overcome by environmental changes induced by humans. Where humans lived, the accumulation of kitchen wastes and other detritus added large quantities of nutrients to the soil, as well as large quantities of charcoal. By felicitous circumstance, the chemical properties of charcoal (black carbon) make it a very stable form of organic matter that can functionally replace clay in retaining nutrient cations against leaching (Glaser, 2007; Glaser & Birk, 2012). Long-term human occupation – with short fallow periods and more intensive, fire-dependent, labor-demanding farming – thus greatly modified soils in ways that favored agriculture, creating anthroposol that have been named Anthropogenic Dark Earths (ADE) (Fig. 4). ADEs have much higher nutrient content and nutrient retention capacity than the highly weathered soils from which they were derived.



Farming Technology in Amazonia, Fig. 2 Xetá Indian cutting a tree with a stone axe, Brazil (Drawing by S. Rostain after a photo in Kozák, Baxter, Williamson, and Carneiro (1979))

In this way, even the acid, nutrient-poor oxisols that dominate *terra firme* environments could be converted into soils quite favorable for agriculture. The carrying capacity of farming in *terra firme* is thus dependent not on natural factors, as Meggers argued, but on the interaction between natural and cultural factors. Most ADEs appear to be a legacy of increasing farming populations in Amazonia during the late pre-Columbian period, ca. 2000–500 year BP (Neves, Petersen, Bartone, & Silva, 2003).

Work since Denevan's landmark book has strengthened these conclusions. The distinction between *várzea* and *terra firme* has been shown to be oversimplified, with the recognition of paleoriverine landforms – paleoterraces and paleovarzea – that lie beyond the active floodplain of Amazonian rivers but below the uplands

Farming Technology in Amazonia,

Fig. 3 Planting of stem cuttings of manioc in a slash-and-burn field, typical of long-fallow shifting cultivation, Wayãpi village of Trois-Sauts, French Guiana (Photo by Françoise Grenand)



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Farming Technology in Amazonia,

Fig. 4 Anthropogenic Dark Earth, or *terra preta*, in the archaeological site of Hatahara on the middle Amazon, near Manaus, Brazil (Photo by Manuel Arroyo-Kalin)



(Coomes, 2004; Dumont, Lamotte, & Kahn, 1990; Irion & Kalliola, 2010; Junk et al., 2011). Books on ADE have proliferated (Glaser & Woods, 2004; Lehmann, Kern, Glaser, & Woods, 2003; Woods et al., 2009). Currently, much work focuses on understanding the occurrence and distribution of ADEs in Amazonia (Bush & Silman, 2007; McMichael et al., 2012, 2014; Schmidt et al., 2014). A particularly important question is whether ADE occurs and is widespread in western Amazonia. In many parts of this region, the absence of a marked dry season precludes the use of fire in forest clearing, and present-day inhabitants often perform “slash-

and-mulch” cultivation, instead of the “slash-and-burn” technique employed today in most of Amazonia (Denevan, 2001). It is currently unknown whether this fire-free (or fire-infrequent) technique resulted in the formation of ADE (McMichael et al., 2014). The “too-wet-to-burn” hypothesis, however, does not hold for a large area of western Amazonia (e.g., most of the Peruvian Amazon below 500 m elevation). This area is little studied for dark earths, and it is too early to conclude that ADE is not widespread (O.T. Coomes, Department of Geography, McGill University, pers. comm.). There are scattered records of ADE from Colombia,

Peru, and Ecuador (Pinedo-Vasquez, Hecht, & Padoch, 2012). Another important current focus is understanding the variation observed among different ADEs. Beginning early in the history of work on ADE, a distinction was made between *terra preta* and *terra mulata*. *Terras pretas* are greatly enriched in charcoal and nutrients compared to neighboring oxisols and contain large quantities of ceramic fragments and other indicators of the proximity of residential sites (e.g., fragments of bones of fish and other animals and other kitchen wastes). Patches of *terra preta* are usually relatively small, from less than a hectare to 20 ha or more, but some reach several hundred hectares in extent. *Terras mulatas* are enriched in charcoal and nutrients compared to oxisols, but not as much as *terras pretas*. Furthermore, indicators of the proximity of residential sites are scarce or absent, and patches often cover large areas, several hundred hectares. Formation of *terra preta* can be explained as the fortuitous consequence of intensive occupation or cultivation, practices of charring organic matter, and the accumulation of various wastes near human settlements. It is debated whether *terras pretas* resulted from continuous occupation over long periods or frequent but intermittent and spatially overlapping short-lived occupations (Arroyo-Kalin, 2012). *Terras mulatas* appear to be associated with larger areas further from villages and were probably burned less extensively. They are less well documented than *terras pretas*, and how they formed is the object of some speculation. According to one hypothesis, *terra preta* arose as a by-product of waste accumulation (“midden model” (Kämpf, Woods, Sombroek, Kern, & Cunha, 2003)). Observing the salubrious effects of charcoal on plant growth in their home gardens, farmers later intentionally tried to reproduce this effect at a larger scale in their farms, for example, by managing fire in ways that resulted in “cool burns” and incomplete combustion, producing less ash and more charcoal (“agricultural model” (Woods & McCann, 1999)). Current work offers little support for the hypothesis that specific techniques were employed to produce *terra mulata*. Instead, recent research tends to support the notion that “cool burns”

were (and sometimes still are) rather generally employed by indigenous Amazonians, in home gardens and outfield farms alike. This work suggests that *terra preta* and *terra mulata* are not different categories, produced by different techniques, but instead reflect a continuum in the intensity of human occupation (Fraser et al., 2011). As locations of villages and their surrounding territories shifted over time, areas nearest the long-term residential-area core developed classic *terra preta*, while areas further away developed soils with less marked anthropic influence. Recent work by Schmidt (2013), building upon pioneering studies of indigenous soil management by Hecht and Posey (1989) and by Hecht (2003), examines how shifting patterns of occupation and location of activities by the present-day indigenous inhabitants of the Xingú River basin generate such a continuum of ADEs.

Since the discovery of the interesting properties of ADEs in Amazonia by archaeologists and soil scientists, research aimed at its applications has skyrocketed. Production of “biochar” is heralded as a way to condition soils, generate biofuels, and mitigate climate change by converting plant biomass into a form of carbon durably stored in soils, thereby reducing CO₂ emissions (Lehmann & Joseph, 2009; Woolf, Amonette, Street-Perrott, Lehmann, & Joseph, 2010). Interestingly, Amazonian farmers have also innovated with “biochar.” In areas of the Peruvian Amazon near Iquitos, increased urban demand has led farmers to increase their commercial production of charcoal, yielding biochar-rich sites for cultivation. This “kiln site agriculture” increases the productivity of the weathered soils, compensating for decreased availability of land and consequent shorter fallow periods in these areas near urban centers (Miltner & Coomes, 2015).

Wetland Agriculture in Seasonally Flooded Peri-Amazonian Savannas

As in forested Amazonia, a late-Holocene expansion – and possibly an intensification – of farming also seems to have occurred in seasonally flooded savannas around the rim of

Farming Technology in Amazonia,

Fig. 5 Complex of pre-Columbian raised fields in seasonally flooded savannas within the Guiana Space Centre (CSG) on the central coast of French Guiana (Photo by Stéphen Rostain)



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Amazonia. In these environments, in addition to acid, nutrient-poor soils, agriculture faces two other important constraints: drought in the dry season and flooding in the rainy season. In the absence of rice or other flooding-adapted crops, one of the ways in which farmers responded to these environments was to construct raised fields upon which to grow their flood-intolerant crops. Here again, the book by Denevan (2001) is an excellent starting point, documenting the occurrence of large complexes of pre-Columbian raised fields in numerous regions of South America, in both lowland savannas and highland interandine valleys. The recent book by Rostain (2012) is another excellent reference.

Raised fields can be defined as “any prepared land involving the transfer and elevation of earth in order to improve cultivating conditions” (Denevan & Turner, 1974). Making raised beds or mounds to serve as planting platforms is a widespread practice of farmers in many environments, but those that farmers construct in wetlands, as they did in pre-Columbian South America, are particularly large and extensive. Along with large complexes such as those shown in Fig. 5, there also occur small groups of raised fields that may correspond to exploitations of family-sized groups (Fig. 6). Denevan (2001) documents the geographic extent of raised fields and the diversity of forms observed throughout South America. In different parts of lowland South America, archaeological raised fields can be as long as 1,000 m or more



Farming Technology in Amazonia, Fig. 6 Small familial complex of pre-Columbian raised fields on the central coast of French Guiana (Photo by Stéphen Rostain)

(in Venezuela), as wide as 25 m (in the Llanos de Mojos of Bolivia), and as high as 2 m (Colombia). Little is known about the functional significance, if any, of this diversity, but some work in French Guiana suggests that fields may have been oriented so as to speed up drainage in

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Fig. 7 Wooden shovel dated to 790 ± 30 years BP and found in a marsh near raised-field sites in Suriname (Drawing by Stéphen Rostain)



more flooded sites and retain moisture for longer periods in less flooded sites (McKey et al., 2010).

European chroniclers left scant anecdotal information on the tools that farmers used to construct raised fields and the methods by which they were managed (De Las Casas, 1560/1986; Gondard, 2008). Gumilla (1791/1963) described how Otomac Amerindians in the Venezuelan llanos built mounds using wooden shovels, and a remarkably well-preserved example of a wooden shovel was found in a marsh near raised-field sites in Suriname (Versteeg, 2003) (Fig. 7). There is archaeobotanical evidence (phytoliths) for cultivation of maize and of squash on raised fields in French Guiana (Iriarte et al., 2010). Microfossil remains of several other crop plants have been found in villages associated with raised-field farmers and were probably also grown on raised fields.

Like the creation and use of ADEs in forested environments, the construction and use of raised fields in seasonally flooded peri-Amazonian savannas has attracted considerable attention as an innovation that enabled indigenous Americans to overcome strong environmental constraints to agriculture (Renard et al., 2012). However, while the formation of ADE, and its use in farming, can still be observed in some parts of Amazonia (Schmidt, 2013), raised-field agriculture is virtually absent from South America today, having been abandoned centuries ago, subsequent to the European conquest, and in some cases much earlier. Attempts to understand how these wetland agricultural systems functioned have thus been virtually completely dependent on inferences from archaeological studies. These studies have

naturally tended to focus on what archaeologists can most easily see, i.e., the conspicuous vestiges of the raised fields themselves. However, focusing on these vestiges has likely given us an incomplete picture of technology and subsistence systems, because farming on raised fields was probably only one component of multi-activity subsistence systems. Raised-field agriculture may be understandable only when it is placed in a broader context of a more complex subsistence system. Bruno (2014) argues this point convincingly for wetland agriculture around Lake Titicaca in the Altiplano (Fig. 8), and it appears likely to hold as well for seasonally flooded savannas in the peri-Amazonian lowlands. In some cases, the importance of other subsistence activities is documented by archaeological evidence, such as the large complexes of earthen fish weirs identified by Erickson (2000) in seasonally flooded savannas of the Baurés region of Bolivia. Other activities, however, may have left no trace.

The limitations of archaeological studies have led to uncertainty and controversy about central aspects of raised-field agriculture, including how intensive and how productive it really was. Some have considered raised-field agriculture to be a way in which wetlands were used intensively but yet sustainably. By combining farming with the harvesting of aquatic resources and by recycling nutrients recovered from the flooded basin back to the cultivated fields, it is argued, raised-field farming supported dense human populations over long periods. Others, though, have questioned this conclusion. As Lombardo, Canal-Beeby, Fehr, and Veit (2011) argue, it is uncertain whether raised-field agriculture was really a



Farming Technology in Amazonia, Fig. 8 Flooded pre-Columbian raised fields near Lake Titicaca in the Peruvian Altiplano (Photo by Stéphen Rostain)

“pre-Columbian green revolution” or simply a “flood risk mitigation strategy.” For example, archaeologists have argued that the size of raised-field complexes indicates that they supported large human populations, but using the area of raised fields to estimate how many people they may have supported is an exercise fraught with uncertainty. Even if we accept measures of productivity of present-day experimentally created raised fields (summarized by Denevan (2001)) as indicative of the productivity of raised fields in the past, it is unknown what proportion of the fields in a region were cultivated at a given time. Were fields cultivated more or less continuously, or intermittently, with long-fallow periods? Did cultivation shift over the landscape with fluctuating water levels (Baveye, 2013)? Were fields used only a short time, being abandoned as new ones were opened? By itself, the impressively large area of raised-field complexes does not allow conclusions about how intensive or sustainable this kind of agriculture was.

Archaeologists have drawn on two other kinds of information in attempting to understand how raised-field agriculture in peri-Amazonian savannas may have functioned. First, a very old type of wetland agriculture, the *chinampas*, still persists – although considerably altered – in the valley of Mexico (Armillas, 1971). Archaeologists have sometimes assumed that findings on the *chinampas* can be generalized to other areas. However, the *chinampas* differ in many important ways from the peri-Amazonian systems (Renard et al., 2012). *Chinampa* agriculture is conducted in lakeshore environments and not in seasonally flooded savannas. Soils in the valley of Mexico are characterized by both alluvial and volcanic influences and are much richer than the acid soils of the peri-Amazonian savannas. Furthermore, in the mid-elevation climate of the valley of Mexico, crop pests and pathogens are much less of a problem than in the hot and humid Amazonian lowlands.

Secondly, archaeologists have gained insights from experiments designed to reconstruct or



Farming Technology in Amazonia, Fig. 9 Experimental modern raised fields near the Tiahuanaco site, Bolivia (Photo by Stéphen Rostain)

rehabilitate raised fields (Fig. 9). These experiments have been instructive, demonstrating, for example, the advantages conferred by the topographic heterogeneity that typifies raised-field systems in buffering variation in crop performance driven by inter-annual differences in rainfall (Erickson, 1992). By and large, however, the experiments have not been carried out over long enough periods to answer the most contentious questions, those concerning the necessity of fallow periods, and the sustainability of yield (Baveye, 2013). The experiments also have other important limitations. It is uncertain how well they replicate the ecological conditions and the plants of these environments in pre-Columbian times, as well as the technical practices employed in constructing and maintaining raised fields and the social organization that characterized pre-Columbian farmers. To the best of our knowledge, none of these experiments has resulted in long-term adoption of raised-field agriculture, but whether this can be ascribed to agroecological limitations (Baveye, 2013) or simply to factors that make raised-field

agriculture unadapted to today's social, cultural, or economic contexts (Erickson, 1994) is debatable.

Forty years ago, two pioneers of research on pre-Columbian raised-field agriculture in the Americas sought inspiration in a survey of contemporary raised-field agriculture in the Old World (Denevan & Turner, 1974). Until recently, however, few have followed their lead. New work on raised-field farmers of seasonally flooded savannas in the Congo Republic and in Zambia (McKey et al., 2014) shows the potential of research on these modern ethnographic analogies to suggest answers to contentious questions about pre-Columbian raised-field agriculture. For example, in the African systems studied so far – characterized, like peri-Amazonian seasonally flooded savannas, by acid and relatively infertile soils – the integration of fallow periods appears to be a constant. In the African systems, large quantities of biomass from adventitious plants and crop residues are incorporated into raised fields, and burning is often discouraged. This “slash-and-mulch” system appears to mirror

geoarchaeological evidence for limited use of fire during the period of raised-field cultivation in coastal savannas of French Guiana, where Iriarte et al. (2012) suggested that raised-field farmers employed a similar method of managing organic matter.

Conclusion

This article has discussed two examples showing how indigenous peoples of Amazonia devised farming systems that enabled them to adapt to severe environmental constraints. These and other farming systems that have stood the test of time (Mollard & Walter, 2008) may provide key insights in the search for ecologically sustainable agriculture (DeWalt, 1994; Koohafkan & Altieri, 2010; Martin, Roy, Diemont, & Ferguson, 2010; Renard et al., 2012). As in ingenious systems elsewhere in the non-Western world (Xie et al., 2011), we are just beginning to understand the ecological interactions underpinning their productivity and resilience. This article shows that indigenous farming technology in Amazonia continues to inspire research on agroecology in the past, the present, and the future.

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Fengshui

Graham Parkes

Along with acupuncture, the best known representative of Chinese science in the West today is *fengshui*. The term is often translated as “geomancy,” though the two graphs that comprise the term simply mean “wind” and “water.” The practices associated with *fengshui* have been informed by ambiguity since their early beginnings – between a practice encouraging charlatanry based on mystification and a set of practical recommendations grounded in sensitivity to the natural environment. This article will ignore the mantic and divinatory aspects of *fengshui*, and the associated panoply of arcane symbolism of colors and animals and planets and stars, all of which distract from its more down-to-earth applications (For a more detailed treatment of *fengshui* is its broader context, see Parkes (2003) and see Geomancy in China in this Encyclopaedia).

It was not until the 1950s that Western scholars began serious investigation of Chinese sciences, as signaled by the first volumes of Joseph Needham’s monumental *Science and Civilization in China*. Needham devotes large sections of his second volume to the philosophies of nature found in Daoism and “the school of Naturalists” (the so-called *Yin-Yang* thinkers), the theory of the five elements (*wuxing*: better translated as “five phases of transformation”), symbolic correlations and correlative thinking, and the system of the *Yijing* (Book of Changes).

We have here for the first time a comprehensive, scholarly, and open-minded account of the philosophical and scientific background from which *fengshui* emerged. The practice of “geomancy” itself, however, Needham relegates to a chapter on “the Pseudo-Sciences,” considering it under the heading “Divination” along with such practices as scapulimancy (prediction of good or bad fortune on the basis of the behavior of ox and deer shoulder-blades when subjected to heat), astrology, chronomancy, cheiromancy, and the like. Operating on the straightforward definition of *fengshui* as “the art of adapting the residences of the living and the dead so as to cooperate and harmonize with the local currents of the cosmic breath [*qi/ch’i*],” he devotes four pages to a brief history and description of the practice (The quote is cited from the article by H. Chatley in Samuel Couling’s *Encyclopaedia Sinica* (1917)). After remarking on its advantages and drawbacks, he concludes that “all through, [*fengshui*] embodied a marked aesthetic component, which accounts for the great beauty of the siting of so many farms, houses and villages throughout China” (Needham, 1956: 2:361).

But if one considers the continuities between the basic features of the Chinese worldviews from which *fengshui* arose – the understanding of the world as a dynamic play of forces, or *qi* energies, rather than an aggregate of material things, with a corresponding emphasis on *becoming* over being, or *process* rather than substance – the scientific components of the practice will become as apparent as the aesthetic aspects.

The historical beginnings of *fengshui* are shrouded – appropriately for such an enigmatic science – in mystery. Marcel Granet cites as perhaps “the first mention of beliefs that are at the origin of geomancy” a passage in the *Book of Songs* (Shijing; ninth to fifth centuries BCE) where the founder of a town is said to have observed “the shadows” (which would indicated south) and also “the surrounding yin and yang.” Feuchtwang remarks in this connection that the application of *fengshui* principles to the layout of towns and cities is apparently much earlier than to houses and graves (Feuchtwang, 1974).

Another indication of an awareness of *fengshui* principles comes from a story concerning Meng Tian, the Qin Dynasty general who supervised the building of the first part of the Great Wall. Construction was begun in 221 BCE: “He . . . built a Great Wall, constructing its defiles and passes in accordance with the configurations of the terrain. It started at Lin-t’ao and extended to Liao-tung, reaching a distance of more than 10,000 li” (Cited from the *Shiji* (Records of the Historian), in the *Cambridge History of China* 1: 62). Thanks to its following the contours of the land, the Wall is traditionally seen as resembling a great dragon, which is an image that comes to refer in *fengshui* to any important topographical formation. Meng Tian is also credited with the invention of the camelhair writing brush, which eventually revolutionized the writing of Chinese characters. Thus in addition to being responsible for a good part of a 2,000-mile long “dragon” in the form of the Great Wall, he facilitated the production of countless smaller dragons – the image that characterizes calligraphy executed with especially vital energy – in the centuries since his death.

In 210 BCE, upon the death of his patron the first Qin Dynasty emperor, Meng fell victim to a dastardly political plot and was ordered to commit suicide. On hearing the news, he is said to have cried out in uncomprehending lamentation over this cruel stroke of fate. Then, on reflection, he said gravely: “I am guilty, and assuredly should die . . . A moated wall of more than 10,000 li; in the course of this work I cannot have avoided cutting through the earth’s veins [*di mo*]: this is my guilt.” He thereupon swallowed a lethal dose of poison (March, 1968, pp. 260–261). The *mo* of *di mo* (“earth’s veins”) corresponds to something in the human body like veins, or arteries, or pulses, but more closely to the acupuncture meridians, since no physical “envelope” for the flow is perceptible.

In a survey of the history of *fengshui* the Ming Dynasty author Wang Wei writes: “The theories of the geomancers have their sources in the ancient Yin-Yang school. Although the ancients in establishing their cities and erecting their buildings always selected the sites

(geomantically), the art of selecting burial sites originated with the *Burial Book* [Zangshu] in 20 parts, written by Guo Pu [276–324] of the Qin Dynasty” (cited in March, 1968, p. 261). Central to the *Zangshu*, also known as the *Book of Funerals*, is the idea that certain sites are blessed with flows of especially vitalizing energy known as *shengqi* (“vital breath,” “life energy”), which is a phase of the larger circulation of cosmic energies: “When the *qi* of yin and yang breathes out it is wind. When it ascends it constitutes the clouds, and when it falls it is rain. It travels on and in the ground and becomes vital *qi*. Vital *qi* travels on and in the ground and engenders the myriad things.” Vital *qi* is further subject to the forces of wind and water: “The [*Burial*] classic says that *qi* rides the wind and disperses. When bounded by water, it halts” (*Zangshu*, cited in Bennett, 1978, pp. 9–10). With respect to a place characterized by multiply dividing streams, the *Shuilongjing* (Water dragon classic) says: “If the wind shakes the willow branches, or if the wind bends the grass whether passing over the position or not, it will mean trouble, and even meandering water will not justify the site. It will bring decay and sickness” (Feuchtwang, 1974, p. 139).

Water molds the natural environs from the outside in obvious ways, primarily through watercourses’ cutting into the earth, but also through precipitation’s sculpting over time the shapes of mountains. Winds, too, move earth, if not mountains, over the long term – in ways less obvious than waters since the movement of air is itself invisible, becoming perceptible only through its effects on water, vegetation, and loose soil. But *fengshui* is concerned with winds and waters in a deeper sense too: with the invisible “breath of the earth” discussed above, and with the “flows” of *qi* beneath the earth that were thought to be responsible for the formation of minerals (Needham, 1970: 3:637, 650).

The art of proper burial consists in choosing a site with favorable life-breath. Guo Pu puts it succinctly by saying: *cheng shengqi*, “burying [is a matter of catching] life-breath” (cited in March, 1968, p. 256). The understanding of *qi*

expressed in the *Zangshu* has been aptly characterized as:

“the breath at the origin of things, forever circulating,” which flows through the whole of space, endlessly engendering all existing things, “deploying itself continuously in the great process of the coming-to-be and transformation of the world” and “filling every individual species through and through”. (Jullien, 1995, pp. 91–92)

The quality of a place, according to Guo Pu, depends on the local *shi*, meaning configurations of earth-energy (which François Jullien translates in this context as “lifelines”): “The vital breath circulates along the lifelines of the terrain and is concentrated at the points where they come to an end.” John Hay draws a helpful distinction between *shi* as “dynamic configuration” and *xing* as “form” or “shape” of concreted objects: “It is the changefulness of *shi* that is lasting, whilst the fixedness of *xing* is transient” (Hay, 1985, p. 53). On the *fengshui* understanding of a landscape, *shi* refers to both the “veins” of earth through which the *qi* flows and also the “skeletal structure” or “spinal column” of the terrain. In order to perceive the dynamic configurations of a landscape, it is necessary to gain some distance for a broader perspective: “The lifelines are visible from a thousand feet away, the particular configurations of the terrain from a distance of one hundred feet” (*Zangshu*, as cited in Jullien, 1995, p. 93). Another way, as Jullien suggests, is to consult an appropriate masterpiece of Chinese landscape painting, the primary principle for which was to “achieve the *shi*” of the landscape (99).

Another important source of ideas behind *fengshui* is the *Huangdi zhaijing* (The Yellow Emperor’s Siting Classic), attributed to the fifth-century thinker Wang Wei. As the title leads one to expect, a central idea in this text is that of *zhai*, meaning “site/siting” or “place/placing”: “All human dwellings are at sites. . . sites are the foundation of human existence” (cited in Bennett, 1978, p. 5). A *zhai* is therefore not merely some location in abstract space, but rather a place as defined both by a particular topography and by the kinds of human activities that take place in it (Western philosophy has generally devoted far

more thought to abstract space than to live place: for a judicious restoration of this imbalance, see Casey (1997)). Since an inhabited place is a dynamic locus of flowing energies, the *Siting Classic* addresses the temporal as well as the spatial aspects of *fengshui* practice: “Every year has twelve months, and each month has positions in time and space of vital and torpid *ch’i* [*shengqi* and *siqi*]” (Bennett, p. 7). Human activities undertaken at times of vital *qi* are more likely to be successful than at times when the *qi* is torpid. The quality of *qi* also varies within smaller cycles, such as the diurnal: Manfred Porkert characterizes *shengqi* as “the quality of energy during the *yang* hours of the rising sun (midnight to noon). . . [which has] a quickening and invigorating effect on active enterprises,” and the opposite for the *yin* hours from noon to midnight (Porkert, 1974, pp. 172–173). The *Siting Classic* also asserts an isomorphism between a *zhai* and a human body, a correlation that is central to Daoist thinking about the relations of the human being to the landscape: “The forms and configurations are considered to be the body; water and underground springs are the blood and veins; the earth is the skin; foliage is the hair; dwellings are the clothes; door and gate are the hat and belt” (Bennett, p. 13).

In spite of the prevalence of all these ideas, it was not until the Tang dynasty (618–906) that *fengshui* theories and practices began to be synthesized and formalized into a distinct school named as such (For example, the *Guanshi dili zhimeng* (Mr. Guan’s Geographical Indicator) attributed to the third-century author Guan Lo, the *Zhangshu* (Book of Funerals) attributed to Guo Pu, and Wang Wei’s *Huangdi zhaijing* (The Yellow Emperor’s Siting Classic); see Needham (1956, p. 360)). Wang Wei’s historical survey distinguishes two schools, one using the “Kiangsi [Jiangxi] method” and the other the “Ancestral Hall” or “Fukien [Fujian] method,” both of which he claims are derived from Guo Pu (March, 1968, p. 261). The latter (founded a century or two later) is also known as the “Compass School” and it emphasizes the importance of the Eight Trigrams of the Yijing and the Five Planets, as well as the

indispensability of the geomantic compass. Since this school's methods are more abstract and less scientific, it seems to have been infected by more charlatanry than its counterpart (A comprehensive account of the practices of the Fujian School, with fascinating descriptions of the geomancer's compass, is to be found in Feuchtwang (1974, pp. 18–95)).

The school employing the Jiangxi method is also known as the “Form and Configuration” (*xing shi*) School, because of its concern with intuiting the configurations (*shi*) of *qi* from the shapes or forms (*xing*) of the landscape. It was apparently founded by an imperial *fengshui* master by the name of Yang Yunsong (c. 840–888). In its consideration of mountains and watercourses the Form and Configuration School lays particular emphasis on the motif of the dragon as a pattern to be found in “all topographical formations” (Feuchtwang, 1974, p. 141), as indicated by the titles of such important treatises by the founder as the *Hanlongjing* (Classic on Arousing the Dragon) and the *Yilongjing* (Classic on Approximating the Dragon).

The dragon is best understood as an image for all vital topographical formations, since some places may simply be “dead” in terms of the flows of *qi*. As a later author, Shen Hao (seventeenth century), puts it:

Surely nothing but the writings of the magic dragon is an adequate figure of the mountain-ridges' permutations. What does not resemble the permutations of the magic dragon does not realize the subtle geomantic essence. Therefore it is said: if it has permutations, call it dragon; if it has none, call it barren mountain. (cited in March, 1968, pp. 256–257)

This is not the Azure Dragon as an image for one of the four directions, which is culturally and geographically specific to China, but “a universal symbol of the powers of nature” and especially of “the power of [self-]transformation.” (Feuchtwang (1974, pp. 149–150). See also the chapter entitled “The Dragon Motif” in Jullien (1995, pp. 151–161)). Since Chinese culture is based on the premise that all events in the world are continually transforming themselves, the

dragon is its perfect emblem. It is also an archetypal image common to a wide range of cultures and mythologies, in some of which its meaning is negative by contrast with its generally auspicious quality in China.

General Meng Tian's concern for respecting the earth is often echoed in the Ming period, which also saw a special flourishing of the art of garden making in China. Fear of damaging the “earth's veins” fueled opposition to gypsum mining in Taihe county in the fourteenth century, and the government prohibited the digging of ponds in ► [Nanjing](#) “lest they damage the *qi* of the earth in the imperial capital” (Clunas, 1996, p. 181). The sixteenth-century author of the *Nongshuo* (Talks on Farming) writes eloquently of “energy arteries running within the earth” and how “earth and bone are like the arterial system of the human body which carries the energy-blood” (cited in Hay, 1985, p. 42). When the body is understood as an organism situated within the larger organism of the environment, its various energetic pulses (*mo*) correspond to the dynamic configurations referred to earlier as the earth's “lifelines” (*shi*).

To fully appreciate sciences based on becoming rather than being, on energy rather than matter, we need to reorient our ways of perceiving our environment. In introducing his discussion of the notion of *shi* as “lifelines” in the earth, François Jullien recommends that we stop regarding nature as “an object of science” in the Western sense: “Rather, we should here perceive nature intuitively, through the sensibility of our bodies and their activity, as the single common principle within and outside us that operates throughout reality and explains how the world is animated and functions. Let us imagine a new ‘physics’ and stop thinking of nature abstractly” (Jullien, 1995, p. 91). If this idea seems too exotic – a physics associated with a transformation in our experience – we might recall that there exists something similar in the Western tradition, with the Hellenistic philosophies of the Stoics and Epicureans. As Pierre Hadot puts it: “Contemplation of the physical world and imagination of the infinite are important elements of Epicurean physics. Both can bring about a

complete change in our way of looking at things. The closed universe is infinitely dilated, and we derive from this spectacle a unique spiritual pleasure” (Hadot, 1995, pp. 87–88).

Just as the breath that animates the human body through bringing oxygen to the blood is invisible (the misty exhalations in cold weather being water vapor rather than air), so the cosmic breath animating the body of the earth cannot be seen, though it can be felt or otherwise sensed. The science of acupuncture, which is closely related to *fengshui*, has been slow to gain acceptance by practitioners of Western medicine. The main reason is that its background assumptions are so different, and there is also that fact that the meridians (*jingluo*) through which the currents of *qi* flow through the human body are invisible, and Western researchers were looking for literal conduits such as veins or nerves.

Corresponding difficulties arise with the idea of energies flowing through the earth (in the broad sense, including watercourses, vegetation, and the other processes of metal and fire) along “lifelines” that are invisible to the eye but can be intuitively discerned by the well-trained practitioner. This notion should, however, be less mysterious to Western physicists since the discovery of the earth’s magnetic field (the magnetosphere), whose energies flow along lines that are similarly invisible. Indeed the Chinese appear to have been the first to understand the phenomenon of magnetism, and texts referring to the “south-controlling spoon” – a piece of lodestone carved into the shape of the Northern Dipper (Ursa Major) – appear in China over a 1,000 years earlier than the first European references to the magnetic compass. These Chinese discoveries naturally took place within the context of *fengshui* (Needham, 1969: 71ff; 1962: 4/1, pp. 229–334).

In conclusion, a brief look at three Chinese arts will help further our understanding of *fengshui*, especially along the experiential dimension: landscape painting, garden making, and the martial arts and their derivatives.

We saw that Guo Pu understood the lifelines of the land as both its “skeletal structure” and its “veins,” and when the Form and Configuration

School of *fengshui* applied the image of the dragon to any important topographical formation, it was on the assumption that the dragon was animated by *qi* flowing through its bones as well as its veins. This idea is associated with the distinction between the “mountain” (*shan*) and “waters” (*shui*) *qi* animating a landscape (*shanshui*), with peaks and ridges as skeletal structure and watercourses as veins, and it is also exemplified in one of China’s greatest contributions to the world’s art, landscape painting (Feuchtwang, 1974, pp. 141–148). François Jullien quotes and comments upon the tenth-century aesthetician Jing Hao on this topic:

Under the painter’s brush, as in nature, “the aspects of mountains and waters are born from the interaction of vital breath and the given layout to which that force imparts dynamism.” In China, the purpose of painting is to rediscover the elemental and continuous course of the cosmic pulsation through the figurative representation of a landscape. (Jullien, 1995, p. 94)

Thus an excellent way of learning to discern the lifelines in a landscape is to study Chinese landscape paintings, which is in itself one of life’s great pleasures.

Another great Chinese contribution to the world of the arts, again associated with *fengshui*, is the art of the garden. We saw earlier that *fengshui* allows for certain kinds of human intervention in order to improve, when necessary, the conditions of a particular site – though the tragic figure of Meng Tian stands as a constant reminder of the dangers of too deep an intervention. As an important adjunct to the dwellings of the living in China – of the well-to-do in particular – the garden provides an opportunity to put the principles of *fengshui* into practice from the ground up, as it were.

The classic garden manual, the seventeenth-century *Yuanye* (Craft of Gardens) by Ji Cheng, talks of the way a well constructed garden, where one has “visualized the balustrades as if they were in a painting”, can “flood the heart with intoxication” and create “a pure atmosphere around our tables and seats [so that] the common dust of the world is far from our souls” (Ji, 1988, pp. 43–44). Chinese gardens would often be laid

out in such a way as to “borrow” features of the neighboring landscape, by offering views from within the garden of a local mountain or lake. A basic premise of the Chinese garden is the microcosm/macrocosm correlation between the human body and the physical environment: the well designed garden sets up a pattern of energies that corresponds to the dynamic configurations of a larger landscape – and indeed energies just as powerful thanks to the amplifying effect of miniaturization (The classic work on this topic is Stein (1990): see, especially, part one: “Trees, Stones, and Landscapes in Containers,” and “Survey of Themes.” For a brief history of the remarkable lithophilia (or petromania?) that has characterized the Chinese tradition, see Parkes (2005)).

For those of us unable to afford the luxury of a garden, there are other ways of cultivating an appreciation for the relations between the body’s energy configurations and those of the environment – through practices such as qigong (literally, “energy work”) and *taiji quan* (“Great Ultimate bare-hands-combat-technique”), one of the “softer” martial arts to have been developed in China. Anyone who is skeptical about the existence of the *qi* that flows through and energizes the body need only try some *qigong* exercises (for example, the set known as the “eight sections of brocade,” often used as a warm-up for *taiji* practice) in order to experience the flow of *qi* in his or her own person. As with yoga, the breath is central to *taiji* practice, insofar as breathing is a manifestation of the cosmic breath in the human body.

Taiji practice brings about precisely what *fengshui* encourages: a greater awareness of the relations between one’s activities and the configurations of the surroundings, whether natural or built. Unless one has the luxury of choosing a place to live and building a dwelling there, there is no opportunity for engaging in the practice of *fengshui* as “siting” and participating in the architect’s decisions concerning the orientation of the house in relation to prevailing sun, wind, rain, and terrain. But one can always change the ways one’s living space is configured in a residence already built, by the simple expedient of

becoming more aware of one’s activities in relation to the surroundings. It is quite possible thereby to improve the positioning of one’s furniture and personal effects without going to the expense of hiring an “expert” consultant. A little common sense combined with heightened sensitivity to one’s environment goes a long way. Opportunities to set up one’s workspace will generally be more limited than in the home, but improvement is usually possible nonetheless.

One might take encouragement from those writers on *fengshui* like Shen Hao who emphasize intuition. Coming upon a place that is right, he writes,

One’s eyes are opened; if one sits or lies, one’s heart is joyful. Here the breath gathers, and the essence collects. Light shines in the middle, and the magic goes out on all sides. Above or below, to right or left, it is not like this. . . . Try to understand! it is hard to describe. (cited in March, 1968, p. 259).

Among contemporary scholars, no one has put it better than François Jullien, who paraphrases Guo Pu as follows:

Not only my own being, as I experience it intuitively, but the entire landscape that surrounds me as well, is continuously flooded by subterranean circulating energy. . . . The most glorious sites will be those where it is most densely accumulated, where the circulation of the breath is most intense, its transformations most profound. . . . By rooting one’s dwelling here rather than elsewhere, one locks into the very vitality of the world, taps the energy of things more directly. (Jullien, 1995, p. 92)

If in response to such an expression of the more sensible tenets of *fengshui* we could become skeptical concerning the modern conceit that we can be at home anywhere, no matter where, and instead practice some environmental science at the personal level, we would surely witness a greater flourishing on the part of human beings and the natural environment on which we depend.

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Fertility in Historical China

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According to available records, the population living in areas controlled by China's Western Han dynasty (206 BC–25 AD) was already

close to 60 million in the year 2 AD. In the next thousand years, China's population size varied greatly between 20 and 60 million, and its reduction was often related to wars, famines, pandemics, natural disasters, and the decrease in the territory administrated by the imperial government. Noticeable population growth took place in the eleventh and twelfth centuries when the Chinese population was very likely to have reached 100 million. This was followed by further fluctuations in its number in the next few centuries. By the early seventeenth century, the Chinese population increased to 100–150 million. It rose further to about 440 million in 1850 (Ho, 1959; Zhao & Xie, 1988) and 550 million in 1950 (Yao & Yin, 1994). For most of the last two millennia, the Chinese had about a quarter of the world's population.

Partly due to its large population size, four interrelated beliefs or viewpoints about China's past fertility level and reproductive behavior existed widely, and they are still held by some researchers and ordinary people today. These beliefs and viewpoints can be summarized as follows: First, “the fecundity of the Chinese was without parallel” and their “birth rate was abnormally high” in the past (Mallory, 1926). Second, this high fertility resulted because the Chinese did not control their family size. Even if the fertility level in some historical populations was only moderate, its reason “was not deliberate fertility control” (Wolf, 1985; Wolf & Engelen, 2008). Third, the Chinese did not control their fertility, because they had a very pronatalist culture. The Chinese not only liked to have children; they liked to have “as many children as possible, preferably sons” (Chandrasekhar, 1967; Hassan, 1980). “Far from limiting the number of sons reared, Chinese families made every effort to maximize the number” (Wolf, 2001). Fourth, anti-natalist ideas were rarely discussed among Chinese intellectuals in the past. “When Chinese officials worried about the balance of population and resources, they did not advocate birth control as the solution” (Wolf, 2001).

Recent demographic investigations have found however that fertility patterns and people's reproductive behaviors in historical China were

far more complex than those portrayed by the above oversimplified views. The above claims do not accurately represent China's historical reality.

Research findings revealed that in comparison with that recorded in the Hutterites and many preindustrial European populations, marital fertility in historical China was not high but only moderate (Coale, 1985). In some historical European populations, total marital fertility rates were often between 8 and 10 children, but they usually varied between 5 and 7 children in most historical Chinese populations studied up to date. This difference arose largely because compared with their European counterparts, Chinese women married relatively young, but they often took a longer time to have their first child. Chinese women also had longer intervals between successive births and stopped their reproduction at younger ages (Lee & Wang, 1999; Zhao, 1997a).

The relatively low fertility observed in many historical Chinese populations was related to many factors. The practice of child marriage, which existed in many parts of China, tended to go against the natural inclination between spouses, because childhood association could lead to an aversion between them and consequently caused a decrease in the incidence of marital sexual relations (Wolf & Huang, 1980). The intensive and prolonged breastfeeding could lengthen the period of postpartum amenorrhea and delay the next pregnancy (Liu, 1992). The comparatively low coital frequency found in some Chinese populations directly influenced the chance of conception (Barclay et al., 1976; Lavelly, 2007). Low standards of living and poor health could also lower the rate of conception and increase the incidence of spontaneous abortion. Furthermore, the moderate fertility level could be related to periodic separation between spouses caused by seasonal migration (Coale, 1985).

In addition to the factors listed above, recent studies have found that people's reproductive behavior was closely related to the sex composition of children they already had and their children's survivorship. In comparison with those who already had both sons and daughters, couples who had only daughters or sons were more likely

to have another child. Their birth interval to that child was generally shorter, and their mean age at last birth tended to be higher. In comparison with those whose first few children all survived, women whose first few children all died were more likely to have stopped childbearing at older ages (Zhao, 1997b). These patterns were observed in normal times and in periods of hardship. During China's 1958–1961 famine, for example, fertility fell far greater among women who already had a larger number of surviving children, especially those who already had both sons and daughters in comparison with women who had a smaller number of surviving children, especially those who did not have sons (Zhao & Reimondos, 2012). Recent studies also revealed that in the past people's reproductive behavior and fertility level were notably affected by the social status of their family, their position in the family, and the composition of their household (Wang, Campbell, & Lee, 2010). These new research findings show that in Chinese history, a considerable number of people might not want to have as many children as possible, but rather considered their reproduction carefully and deliberately controlled their family size.

In addition to the revealing demographic patterns summarized above, recent studies have uncovered a considerable amount of surviving written evidence that recorded people's consideration about their ideal family size and why did they want to control it in the past (Zhao, 2006). For example, *Sheng Zi Bu Ju* or infanticide existed in many areas of China in Song dynasty (960–1279AD), which was recorded by many scholars and officials (Zang, 1995). In discussing this phenomenon, several well-known historical figures noted that "peasants usually wanted to have two sons and one daughter. If more were born, they would be killed" (Su, eleventh century). "People wanted to have only two sons. They drowned all the rest thereafter regardless of their sex" (Zhu, twelfth century). "People kept only one or two children or sons, and the rest would be killed by drowning" (Li, twelfth century). These records unveiled a fact that many people did not want to maximize their family size or the number of sons. In commenting on

the cause of such behaviors, it was noted that “people had children according to their economic ability. Even the gentry behaved accordingly. . . . Rich families had no more than two sons and one daughter. Middle and lower class families generally had only one son” (Yang, around the end of eleventh century). People controlled their family size, because they wanted *Ji Chan Yu Zi* (Yang, around the end of eleventh century) or *Ji Chan Shou Kou* (Fan, around the end of eleventh century), which literally mean having children according to their ability and wealth.

Strictly speaking, the above records should not be regarded as evidence of intentional birth control, because what had been controlled was the number of surviving children. The intention of citing these examples surely is not to suggest that infanticide is the same as the control of fertility, but rather to show that as early as about a thousand years ago a considerable number of people wanted to limit their family size and their decisions stemmed directly from the consideration of their long-term economic interests.

The intellectual discussion of population issues in historical China was also more complicated than that assumed by some researchers. Anti-natalist ideas were discussed among intellectuals in Chinese history. Some of their writings are still available. As early as more than 2,000 years ago, the impact of rapid population growth on the society was already noted by Han Feizi (c. 280–233BC). Such concern was also expressed by other scholars in the next two millennia and showed a notable increase in recent centuries. This increase seemed to have been related to the rapid population growth taking place over this period. In addressing these issues, ideas relating to population growth rate, population doubling time, stationary population, negative effects of having a large population, and the relationship between population growth and natural resources were discussed by a number of scholars. It is particularly noteworthy that Hong Liang Ji (1746–1809AD), an official and scholar, believed that the speed of population growth in the early Qing period had overtaken the growth of means of subsistence. Hong’s ideas and theory

were all very similar to, but developed a few years earlier than, those proposed by Malthus. Because of that, Hong has been widely regarded as the “Chinese Malthus” (Silberman, 1960). Another Qing official and scholar, Wang Shi Duo (1814–1889AD), held more extreme views on population growth. He believed that rapid population growth had led to land being over-cultivated and becoming no longer able to provide adequate subsistence for the people. This led to poverty and social upheaval. According to him, the population had to be reduced by 70 or 80 % in order to solve these problems. On the basis of these judgments, he proposed a whole set of measures, including some extreme, cruel, and inhuman ones, to control the population growth (Zhang & Yang, 1988). People may have different views about these ideas and suggestions, but they have shown that anti-natalist ideas were discussed by Chinese scholars. They understood that population increase and fertility could be controlled through postponing marriage, lowering the proportion marrying, preventing women from getting pregnant, limiting the number of births, and wide use of contraception and abortion. When they worried about the increasing population pressure, they advocated these measures as solutions for China’s population problems.

The Chinese population entered a period of very rapid growth in the mid-twentieth century, because of its remarkable mortality decline and relatively high fertility. By 1970, China’s national population already reached 830 million (Yao & Yin, 1994). This put a great pressure on the country’s economic development. Facing this challenge, the Chinese government started its nationwide family planning program. Like many countries in the world, China has witnessed a great reduction in fertility since the early 1970s. Its total fertility rate fell to below replacement in the early 1990s and then to far below replacement around the beginning of the twenty-first century. Thanks to these changes, the growth of the Chinese population has slowed down significantly. China will lose its title of world’s most populous country to India and start a long-term population decline in one or two decades.

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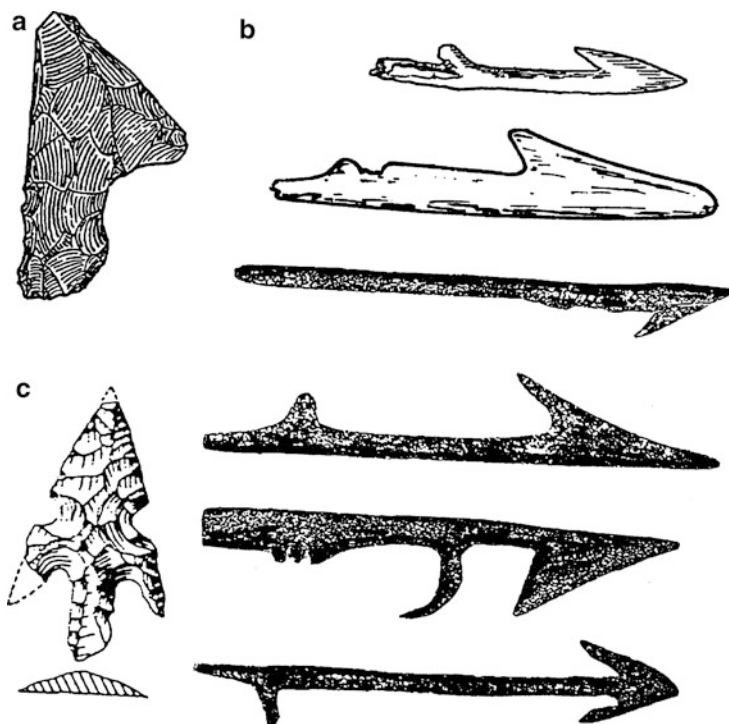
Fishing in Ancient Egypt

Dietrich Sahrhage

Early civilization in the Nile valley developed mainly because of heavy summer rains in the highlands of Ethiopia and around the East

Fishing in Ancient Egypt,

Fig. 1 Ancient gear: (a) points of lances and spears made of flint stone; (b) prehistoric harpoon points made of bone; (c) points of copper harpoons (After Brewer & Friedman, 1989; Petrie, 1920)



African lakes. Every year a huge flood reached Egypt around mid July, carrying to the lower parts of the Nile enormous quantities of fertile silt. This settled as soil especially suitable for agriculture and filled up the Delta, originally a bay of the Mediterranean Sea. The timing and intensity of the floods determined whether people would have wealth or famine, depending on the water supply and agricultural production.

The waters of the Nile, the floodplains, and many pools that remained when water receded or evaporated in autumn, as well as the coastal lagoons of the Delta, contained rich resources of fishes and other aquatic animals which were utilized since prehistoric times. There is much evidence for this from archaeological finds, well preserved in the desert, engravings and wall paintings in tombs and temples, and from hieroglyphic inscriptions.

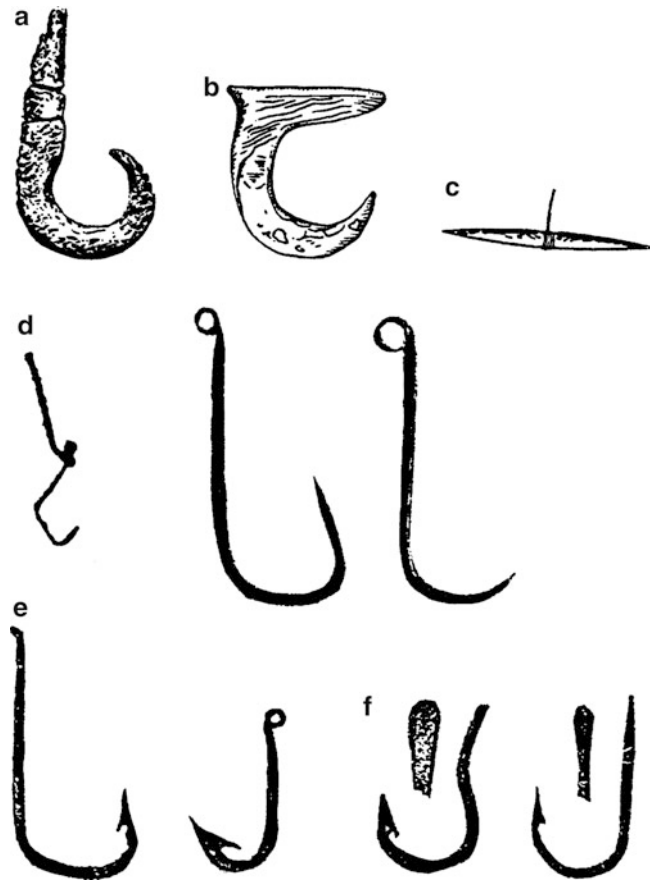
As indicated by bone and shell remains at Kom Ombo near Aswan, hunter-gatherers already fished during the Late Palaeolithic around 15000 BCE for Nile perch, catfishes and barbels, and they collected Nile oysters and African

softshell turtles. Some flint tools have been interpreted as points of lances. After 10000 BCE, as North African savannas deteriorated to deserts due to climatic changes, game became rare, and hunters turned increasingly to fishing, employing gear like spears with stone or bone points, harpoons, and curved fishhooks and gorges made of bone or antlers (Figs. 1 and 2). Hippopotamuses and crocodiles were also harpooned or caught in traps (Fig. 3). The development intensified during the Neolithic (5500–4000 BCE), when Lake Quarun in the Faiyum Depression filled with water and became an important fishing area like the Delta. Around 3500 BCE the first fishhooks of copper appeared and increasingly replaced the stone and bone tools.

The unification of Upper and Lower Egypt around 3000 BCE led to the formation of the Old Kingdom (ca. 2600–2150 BCE) with powerful rulers and an efficient administration, promoting the construction of pyramids and hydraulic engineering for drainage and irrigation to improve agriculture, fishing and

Fishing in Ancient Egypt,

Fig. 2 Hooks for line fishing: (a) bone; (b) antler; (c) gorge; (d) copper hooks, Old Kingdom; (e) barbless copper hooks, Middle Kingdom; (f) barbed copper hooks with plate for fixing a line, New Kingdom (After Brewer & Friedman, 1989; Debono & Mortensen, 1990; Eiwanger, 1992; Petrie, 1917; von Brandt, 1975)



F

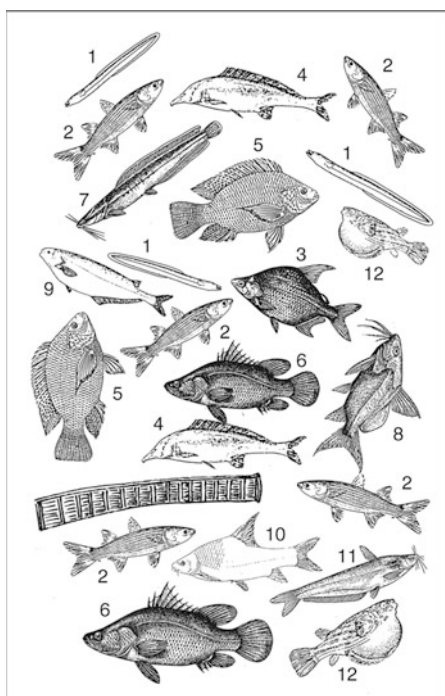
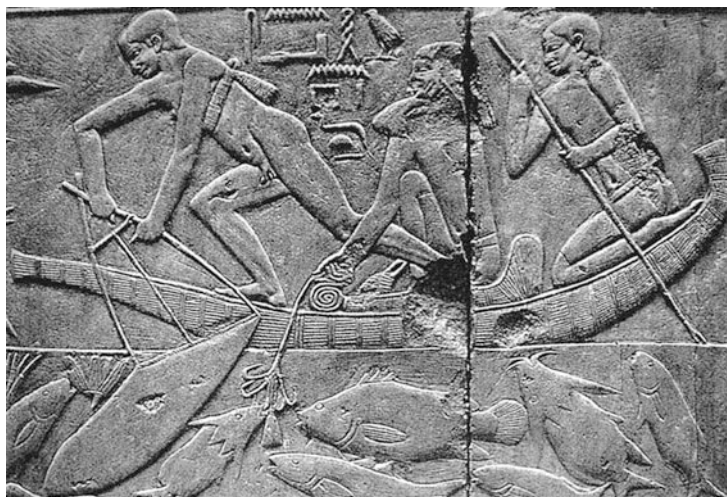
Fishing in Ancient Egypt,

Fig. 3 Harpooning hippopotamus and fishing with hand net. Relief in tomb of Princess Idout at Saqqara, Old Kingdom. The harpoon head was attached to a retrieving line (Macramallah, 1935)



Fishing in Ancient Egypt,

Fig. 4 Fishing with multiple hook and line and with hand net. Relief in tomb of Kagemni at Saqqara, ca. 2280 BCE (von Bissing, 1905)



Fishing in Ancient Egypt, Fig. 5 *Right:* Wall picture in mastaba of Mereruka at Saqqara with various fish species (Duell, 1938); *Left:* Same fish species in modern drawings: (1) eel (*Anguilla anguilla*); (2) mullet (*Liza spec.*); (3) moonfish (*Citharinus citharus*); (4) elephantfish (*Mormyrus caschive*); (5) Nile tilapia (*Oreochromis*

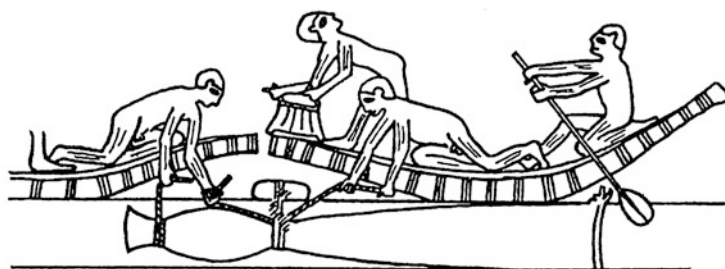
niloticus); (6) Nile perch (*Lates niloticus*); (7) North African catfish (*Clarias gariepinus*); (8) upsidemouth catfish (*Synodontis batensoda*); (9) elephantfish (*Hyperopisus bebe*); (10) barbel (*Barbus bynni*); (11) African butter fish (*Schilbe mystus*); (12) puffer fish (*Tetraodon lineatus*)

Fishing in Ancient Egypt,

Fig. 6 Spearing of Nile tilapia and Nile perch in the papyrus swamps. Wall painting in the mastaba of Kaiemanch at Giza, Old Kingdom (Desroches-Noblecourt, 1954)

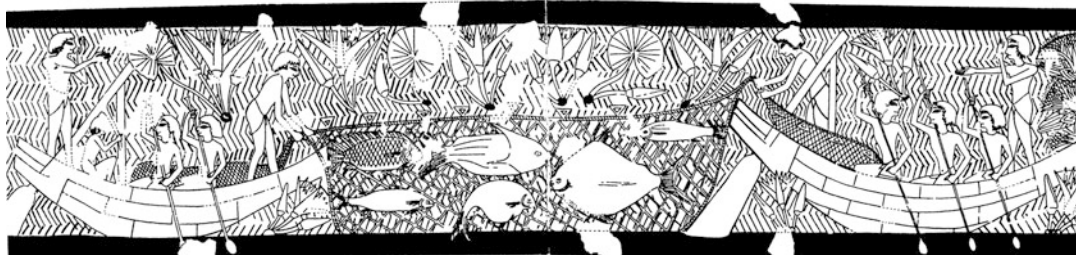
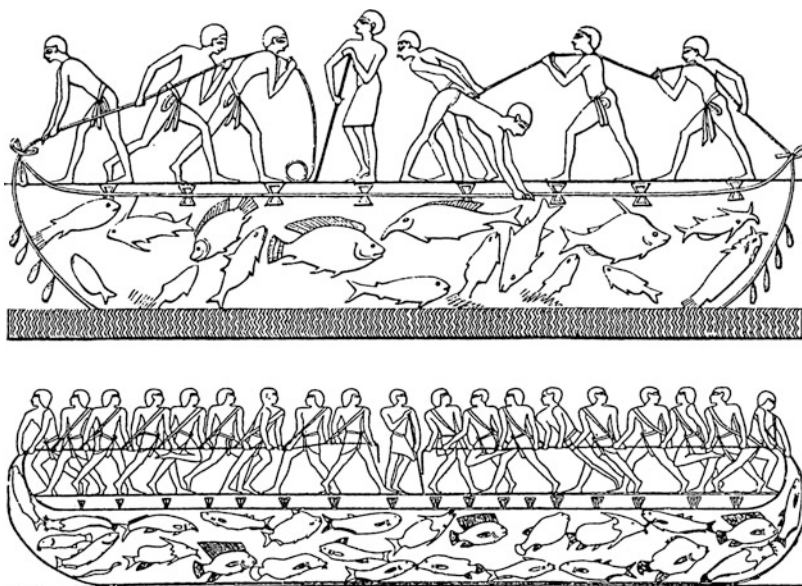
**Fishing in Ancient Egypt,**

Fig. 7 Emptying catches from wicker baskets, depicted in the tomb of Ti at Saqqara (*above*), and setting a large basket (*below*) (Bates, 1917; Loat, 1907)



Fishing in Ancient Egypt,**Fig. 8** Beach seine fishing.

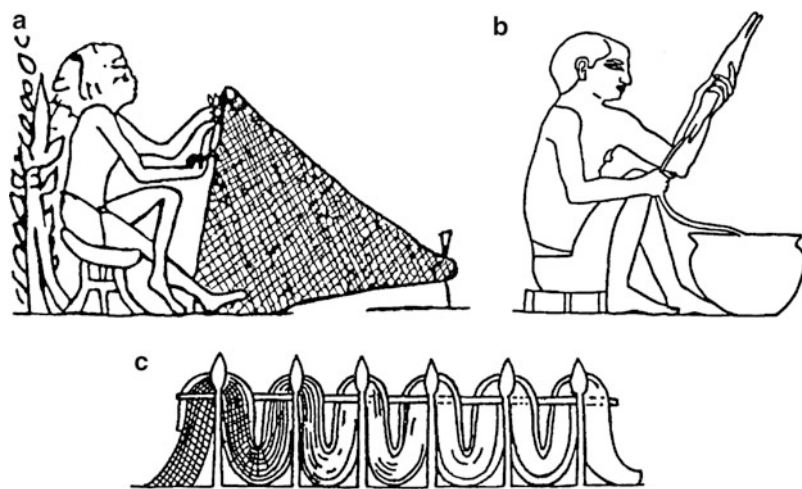
Shown are ropes, floats, sinkers and various fish species (Duell, 1938; Lepsius, 1842–1845)



Fishing in Ancient Egypt, Fig. 9 Seine fishing between two vessels. Wall painting in tomb of Ipuje at Deir el-Medina, Thebes, ca 1290 BCE (Davies, 1927)

Fishing in Ancient Egypt,**Fig. 10** Repairing and drying fishnets:

(a) knitting of net in tomb of Ipuje at Deir el-Medina, Thebes; (b) reloading net needle with yarn in tomb of Ti at Saqqara; (c) stand for net drying in tomb of Kagemni at Saqqara (Bidoli, 1976; Wreszinski, 1923–1936)



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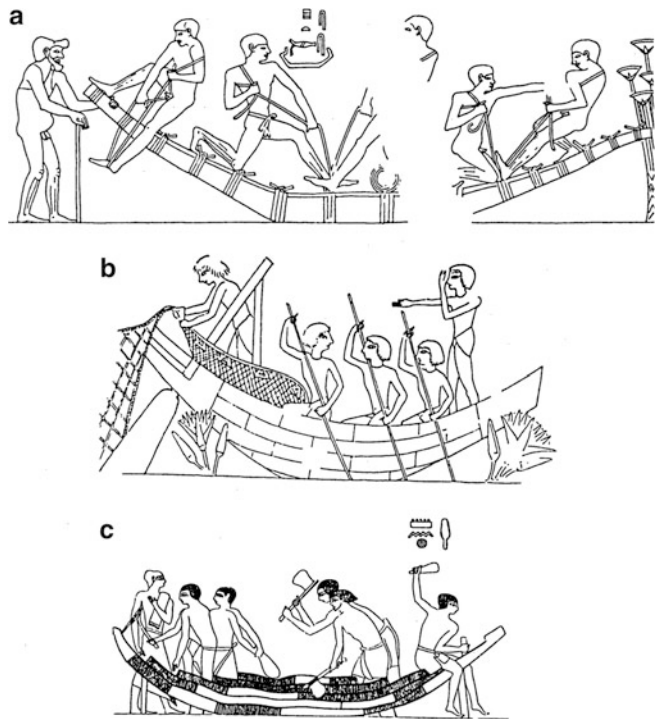
Fig. 11 A small fishnet is pulled between two wooden boats which resemble the original form of papyrus rafts. Model, discovered in tomb of Meketre at Deir el-Bahri, Thebes, ca. 2000 BCE, in Egyptian Museum, Cairo (Photo: Sahrhage)



F

Fishing in Ancient Egypt,

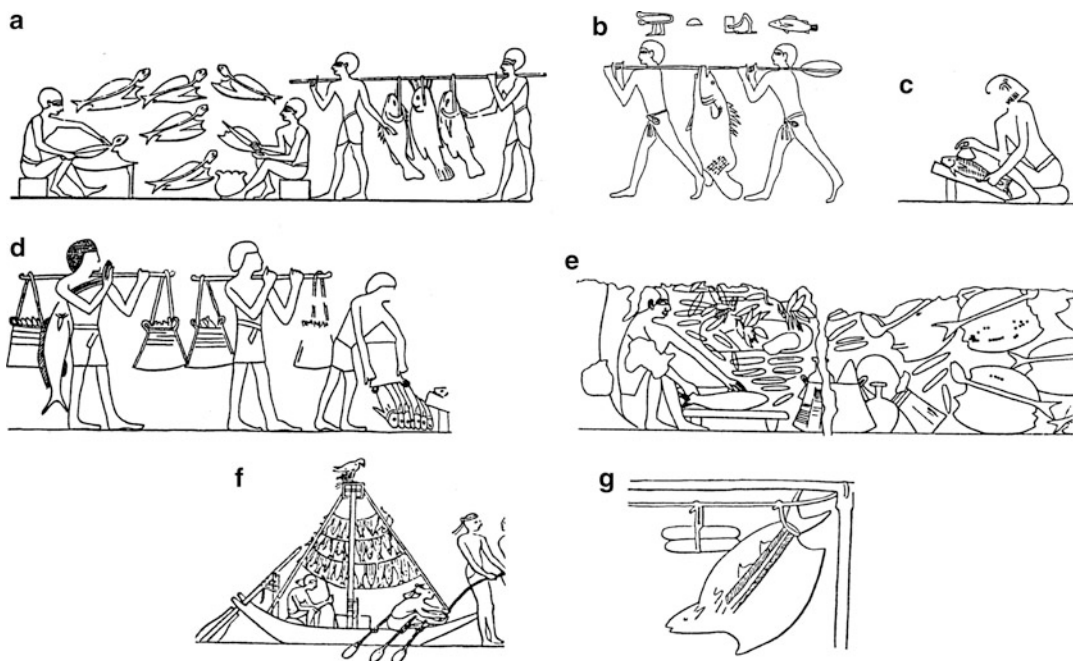
Fig. 12 Fishing vessels: (a) lacing of papyrus rafts. Relief in tomb near Meir, ca. 1950 BCE (Landström, 1970); (b) wooden boat during seine fishing. Wall painting in tomb of Ipuje at Deir el-Medina, ca. 1290 BCE (Davies, 1927); (c) construction of vessel from blocks of wood. Wall picture in tomb of Knumhotep at Beni Hassan, ca. 1950 BCE (Newberry, 1892–1894)



Fishing in Ancient Egypt,

Fig. 13 Miniature from the neck of a silver can found at Bubastis, showing a fish pond (After Vandersleyen, 1975)





Fishing in Ancient Egypt, Fig. 14 Fish processing: (a) transport and clipping; (b) carrying a large Nile perch; (c) removing the fish spine; (d) baskets full of fish for processing; (e) gutting (insects are shown infesting the meat); (f) fish hanging in ship's rigging for drying; (g)

clipped mullet and its roe hanged for drying (Épron & Daumas, 1939; Keimer, 1939; Moussa & Altenmüller, 1977; Petrie, 1892; Taylor & Griffith, 1894; Wreszinski, 1914)

transport. During this epoch artists created very realistic images of fish species and fishing methods in reliefs and wall paintings on tombs, mainly at Saqqara, the necropolis of Memphis (*Mennofer*), the old capital (Fig. 4). The fishes frequently depicted are Nile perch, Nile tilapia, various species of catfishes and elephantfishes, barbels, mullets and eels (Fig. 5). Modern studies revealed about 65 fish species in the Nile waters; some 30 of them can be recognized in ancient images. Presentations of fish and fishing had revivals during the Middle and New Kingdoms (ca. 2000–1780 and 1550–1070 BCE), particularly at Thebes, west of Luxor, and elsewhere. A considerable number of marine species from the Red Sea/Indian Ocean are depicted under ships of the expedition to Punt in reliefs of the mortuary temple of Queen Hatshepsut at Deir el-Bahri.

Famous pictures in tombs show the deceased spearing fish, usually Nile perch and tilapia, in

the papyrus swamps (Fig. 6). Many images illustrate the use of weir baskets (Fig. 7) and of nets, mostly small hand nets and seines, operated both from the beach and from boats (Figs. 8 and 9). Fishermen made and repaired seine nets of flax or other natural fibres (Fig. 10) which were kept vertical in water by floats and sinkers. Trawls pulled between two boats may even have been used (Fig. 11). Cast nets appear in the Late Period. Fishing vessels were papyrus rafts and boats constructed from blocks of wood, since large trunks were scarce (Fig. 12).

As shown in wall pictures, fishes, mainly Nile tilapia, were kept in basins, apparently mostly waters belonging to palaces or temples. A few presentations seem to indicate that fish were also kept in natural ponds, perhaps as storage of living food (Fig. 13).

Fish were gutted and eaten raw or grilled. Large quantities were clipped and dried in the

sun, often hanging on lines. Salted fish also had a wide market both in Egypt and for export (Fig. 14). Some sort of caviar was prepared from mullet roe. It seems that fish for food consisted almost exclusively of freshwater species.

The profession of fishermen was regarded socially as only of a low level. Various images show how they participated in coarse games, knocking each other from the boats with long poles.

Catches usually had to be delivered to palaces or lords of the manor, and fish were often used, jointly with other natural products, as payment in kind for labour. Catches were subject to taxation, and fees had to be paid for fishing rights.

Also well documented is the important role of fishes and other aquatic animals in religion, mythology and medicine. In many provinces different fish species were adored as representing gods, e.g. African butter catfish (*Schilbe mystus*) as a symbol of Hatmehit at Mendes in the Delta, Nile tilapia as a symbol of fertility and rebirth, elephantfish as a symbol of Hathor at Oxyrhynchus and other places, *Lepidotus* (*Barbus bynni*) at Lepidopolis near Abydos, Phagros (mullet?) and puffer fish at Aswan, and Latos (*Lates niloticus*) at Esna. Devotion to fish was often combined with a ban on the consumption of certain fish species at certain times in certain areas, especially by priests in temples. Mainly during the New Kingdom and Late Period thousands of fishes were mummified and buried in large animal cemeteries. Fishes were found as gifts to the deceased in graves, and fish offerings were portrayed on tomb walls, although infrequently.

As described in papyri, extracts from various parts of fish were used as drugs for medical purposes. For curing gout, live electric catfish (*Malapterurus electricus*) were placed under the feet of patients.

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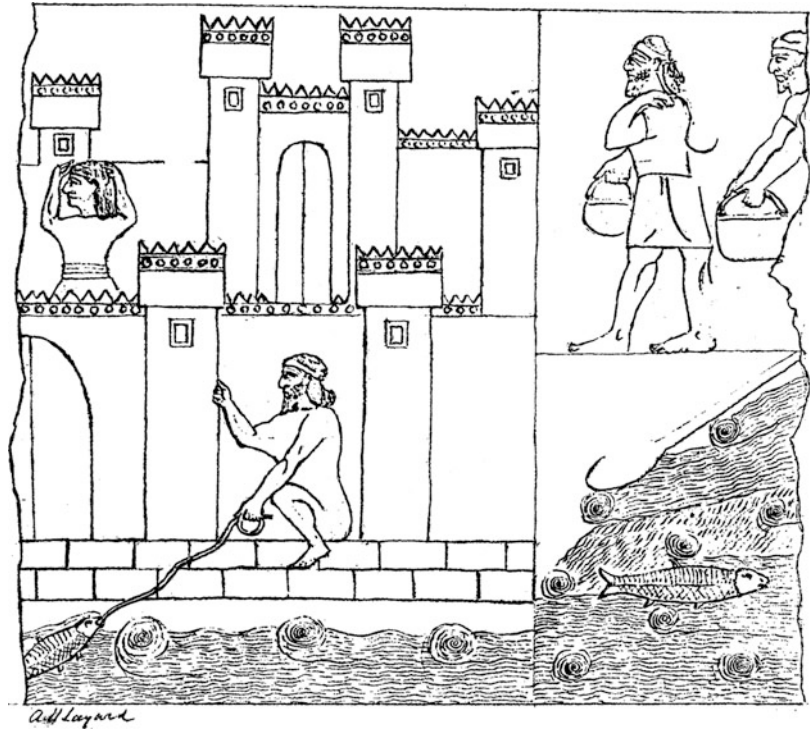
Fishing in Mesopotamia

Dietrich Sahrhage

In Mesopotamia, the region of the rivers Euphrates and Tigris and their tributaries, the formation of old civilizations depended on water for drinking, agriculture, traffic and trade. Living aquatic resources like fish, crustacea, molluscs and turtles contributed substantially to feeding the growing human population.

Fishing in Mesopotamia,

Fig. 1 Fishing with hook and line on the river banks. Drawing after a relief in the Southwest Palace of King Ashurnasirpal II (883–859 BCE) at Nimrud (Layard, 1853)



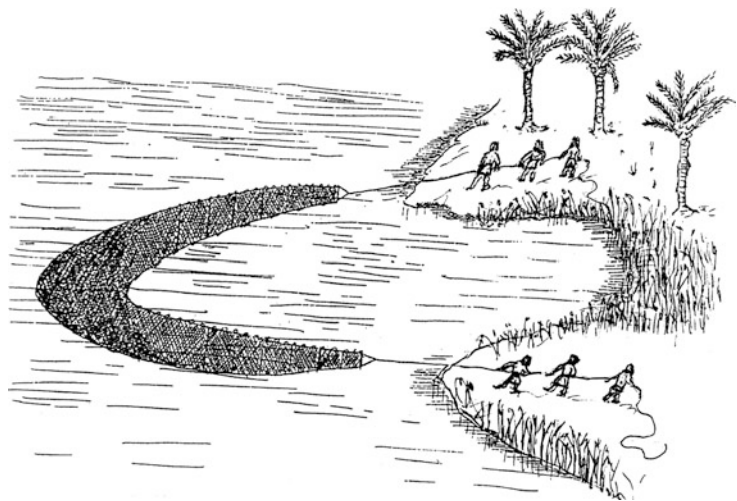
Annual floods, originating from rainfall and meltwater in the highlands of Anatolia and the Zagros Mountains, transported large amounts of pebble and fertile silt downstream; rivers frequently changed their channels, often with catastrophic consequences. During highest water-levels (April–June) wide areas were flooded until water ran off or evaporated in the hot climate. Swamps with reed thickets and lakes (Hors) developed in the depressions. Floods became less dangerous when rivers were regulated with dams and canals, and when irrigation was implemented in the south, from at least 5000 BCE. The many waters were productive areas for fishing.

Investigations have shown that Neanderthals lived in northern Mesopotamia as nomads at least 100,000 years ago. During the Neolithic, after 10,000 BCE, the people formed settlements and developed farming and animal husbandry. The oldest evidence for fishing activities are points

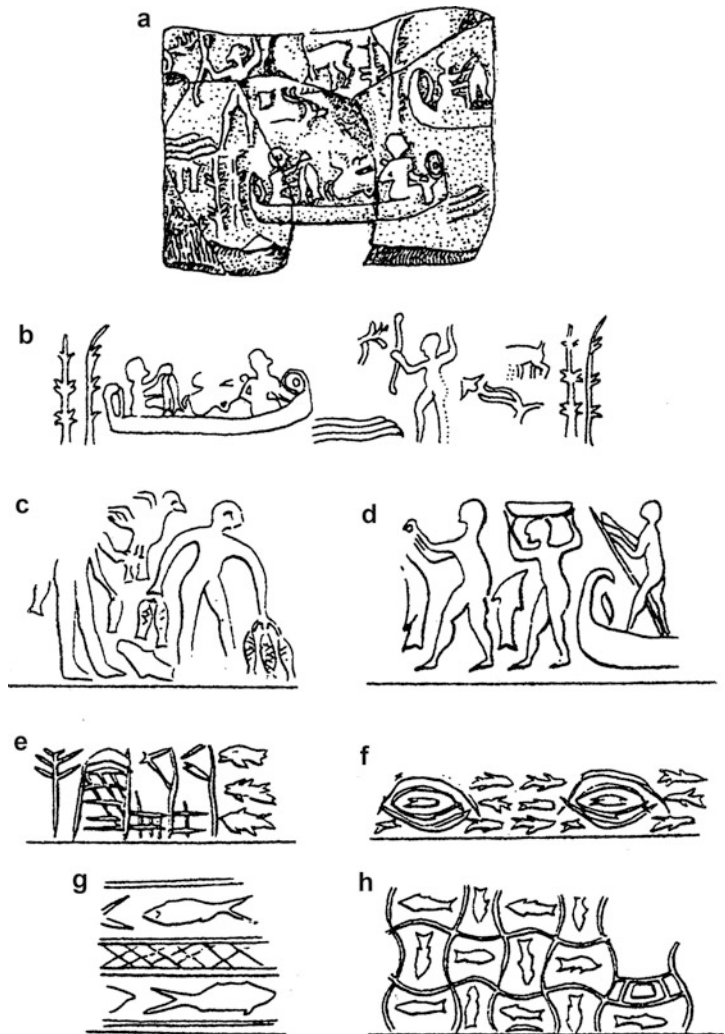


Fishing in Mesopotamia, Fig. 2 Fishing with rod and line. Quare stone of basalt from Tell Halaf, Syria. Height 47 cm (Staatliche Museen zu Berlin-Preussischer Kulturbesitz, Vorderasiatisches Museum) (Used with their permission)

Fishing in Mesopotamia,
Fig. 3 Hauling a seine net
(After Salonen, 1970)



Fishing in Mesopotamia,
Fig. 4 Impressions from
cylinder seals showing
fishing activities. (e, f) May
depict traps, (g, h) Fishes in
front of nets (After Amiet,
1972/1980; Legrain, 1936;
Lenzen, 1960; Van Buren,
1948/1949)





Fishing in Mesopotamia, Fig. 5 Pride of the fisherman: A large barbel (*Barbus esocinus*), probably the prototype of the Apkallu (Photo: H. Pfälzner. Used with his permission)

of spears and arrows of flint and obsidian, fish bones and shells of river mussels (*Unio tigridis*) from around 5500 BCE.

Reports on clay tablets seem to indicate that fish-hedges, traps and baskets were widely used; however any evidence we have has decayed long ago. Fishhooks of stone have only occasionally been discovered, but hooks became more numerous after the implementation of tools of copper around 4500 BCE and bronze (copper-tin alloy) around 3000 BCE. Hook and line fishing is represented in many reliefs (Figs. 1 and 2). According to texts in cuneiform

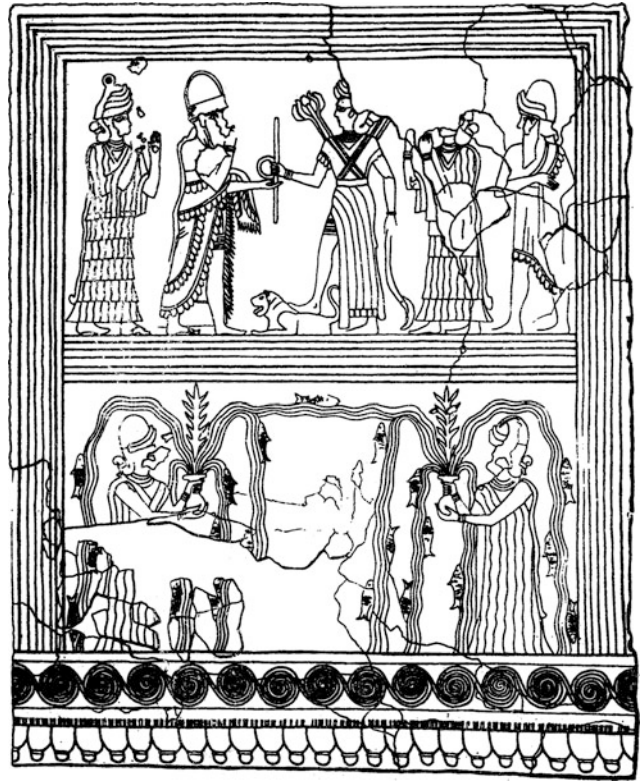


Fishing in Mesopotamia, Fig. 6 Clay tablet from Lagash with text in cuneiform script listing the quantities of various fish species delivered by the fisherman Lugal-sala-tuku to the palace of King Urukagina, ca. 2350 BCE (Staatliche Museen zu Berlin-Preussischer Kulturbesitz, Vorderasiatisches Museum) (Used with their permission)

characters, net fishing was frequently used. Stationary nets were set between stakes and seine nets used from the beach, probably also from reed rafts and boats, to encircle fish shoals (Fig. 3). Cast nets were also known. Impressions of cylinder seals often show fishing activities (Fig. 4).

Mesopotamian graves are much simpler than Egyptian tombs, where fish images, particularly from the Old Kingdom, are presented naturalistically. In contrast, Mesopotamian reliefs, sculptures and cylinder seals show such pictures, but they are fairly stylized. However, rich finds of ancient fish bones from food remains on many sites provide the possibility of identifying a great number of fish species by comparing them with skeletons of modern fishes. Such investigations revealed that various species of barbels, some of very large size (Fig. 5), catfishes and mullets formed the bulk of catches in freshwater areas, whereas sea breams, grunts, croakers, groupers, and many other marine fishes were caught along the

Fishing in Mesopotamia, Fig. 7 Investiture of King Zimri-Lim (1782–1759 BCE). Colored wallpainting from the palace at Mari, central panel. In the lower part streams of water and fishes can be seen (Parrot, 1958)



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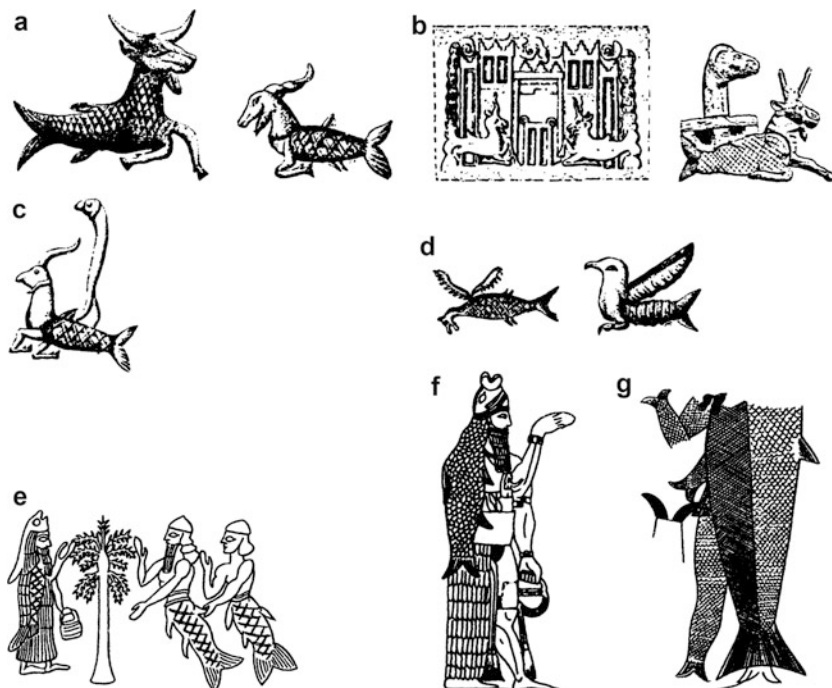


Fishing in Mesopotamia, Fig. 8 Detail of impression from cylinder seal: God Enki (Ea) with running water and fishes. Akkadic period, ca. 2360–2180 BCE. Height 3.8 cm

coasts of the Arabian/Persian Gulf. Frequent finds of marine fish remains far inland prove that these animals were traded over long distances. The same holds true for marine mussels and gastropods, which were converted into ornaments, inlaid work and objects of daily life.

Texts on thousands of clay tablets with writing in cuneiform characters permit a deep insight into many aspects of Mesopotamian matters, especially in the fields of economics, legal affairs, medicine, religion and literature. From these scripts it can be seen what names in Sumerian and Akkadic languages people used for various species of fish. Most of the 324 names collected could not be attached to a certain fish species, but some could, like *kusu* for the dangerous Ganges shark (*Glyphis gangeticus*) which migrates upstream from the Gulf to the north of Baghdad.

The texts also provide information on the organization of fishing, commitments and wages of fishermen, as well as facilities for



Fishing in Mesopotamia, Fig. 9 Mixed figures in Mesopotamian mythology: (a–c) Goat-fish; (d) Dragon and birdlike beings with fish tail; (e) Fish-man and fish-

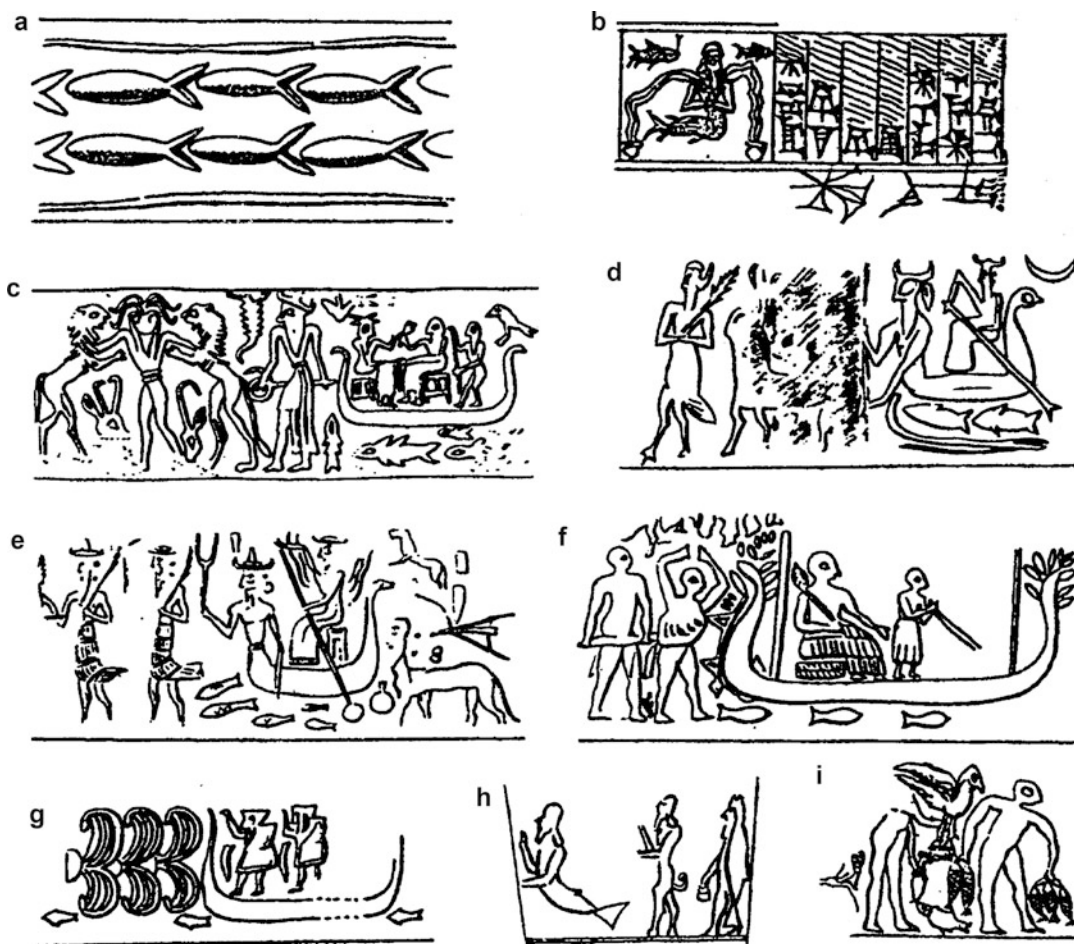
woman; (f, g) Apkallu (After Legrain, 1936; Potraz, 1961; Scheil, 1918; Thureau-Dangin & Durand, 1936)



Fishing in Mesopotamia, Fig. 10 Fish-man on quare stone from Tell Halaf, Syria, ca. 900 BCE. Limestone, ca. 40 × 60 cm (Staatliche Museen zu Berlin-Preussischer Kulturbesitz, Vorderasiatisches Museum) (Used with their permission)

the delivery and distribution of catches. Regulations were most rigid around 2300–1600 BCE, when palaces and temples played a central role for the public production, storage and distribution of foodstuffs and commodities. Detailed statistics were collected regarding the deliveries of fish (Fig. 6). Sometimes temples let out fishing rights to independent fishermen who paid a fee in the form of fish and delivered the rest to trade agents who organized the barter on the basis of silver equivalents for natural goods.

In the vicinity of rivers, lakes and the Gulf, fish were mainly consumed fresh. Because of the hot climate and because fish are perishable, large parts of the catches had to be processed. The fish were gutted, and the marine fish were mostly clipped, dried in the sun, crushed and pressed to blocks suitable for transport over long distances. Freshwater fishes were dried for longer times in the shade. Salting seems to have been less important, but many fish were put into brine prepared from fish guts



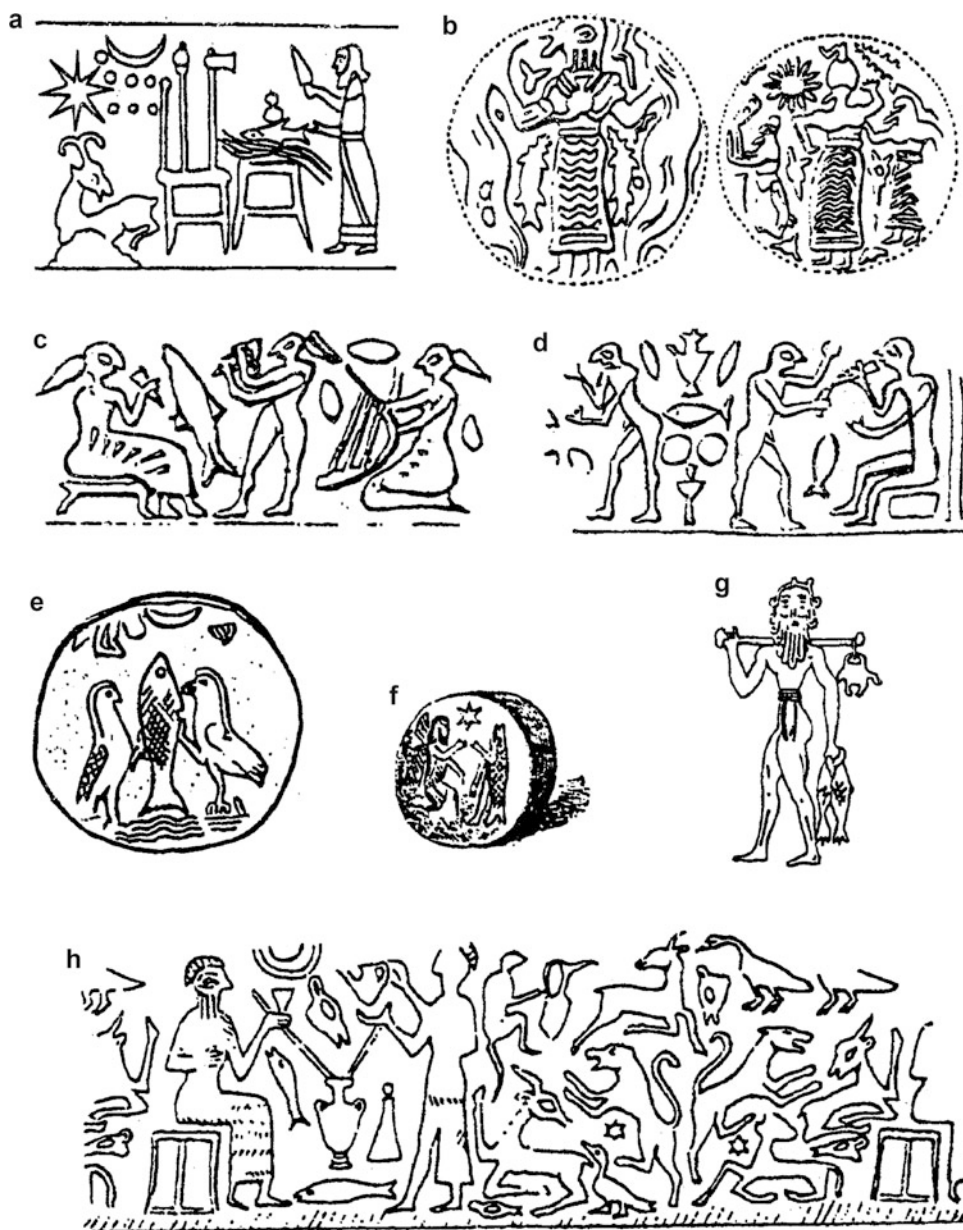
Fishing in Mesopotamia, Fig. 11 Impressions from cylinder seals with mythological scenes related to fishing (After Amiet, 1972/1980; Orthmann, 1975; Weber, 1920)

and crustacea, possibly a forerunner of garum in Greek and Roman times.

Texts on clay tablets also describe medical prescriptions against various diseases in which substances from fish, turtles and seaweeds were considered helpful. Doctors and priests collaborated closely during magic exorcism.

Fish were an important element in Mesopotamian religion and mythology. From the many gods of the Mesopotamian pantheon it was particularly Enki (Ea in Akkadic), the creator of man and god of wisdom, who was adored as the donor of water and fertility. Usually he was depicted carrying a vase

through which water from heaven flowed down to earth (Figs. 7 and 8), while fishes, as symbols of life and fertility, swam upwards in the running water. Enki's attributes were goat-fish and fish-man (Figs. 9 and 10). Frequent figures related to Enki are also men, dressed in the skin of a large fish, probably a barbel (*Barbus esocinus*) (Fig. 5). These figures (priests?) presented in cylinder seals, sculptures and many reliefs, are called Apkallu, which means sage. A great number of cylinder seals show scenes with fishing, boats, fish offering and libation ceremonies (Figs. 11 and 12).



Fishing in Mesopotamia, Fig. 12 Impressions from cylinder seals with scenes of fish offerings and libation ceremonies (After Amiet, 1972/1980; Buchanan, 1966; Heuzey, 1936; Perrot & Chipiez, 1884; Weber, 1920)

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Fishing in the Indus Valley

Dietrich Sahrhage

The ancient civilization in the region of the Indus valley reached its zenith around 2600–1900 BCE. It was characterized by cities like Harappa, Mohenjodaro, and many urban sites which have been excavated or identified by archaeologists in what is now Pakistan and Western India.

It was the regular supply of water that allowed the early development of agriculture and hence the growth of the human population. The main sources were the rainfalls and melting snow from the Hindukush and Karakoram Mountains in the north and monsoon rains from the west. This resulted annually in mighty, though very



Fishing in the Indus Valley, Fig. 1 Steatite stamp seal from Mohenjodaro with pictogram of fish in the script line on top, 3.5 × 3.5 cm. National Museum Delhi (From Jansen, 1986, drawing Bunse, Aachen. Used with their permission)

variable, floods in the River Indus and its effluents with a peak in July and August. The water carried enormous quantities of very fertile soil to the south, which filled the riverbeds and forced streams to change their channels frequently, inundating large areas.

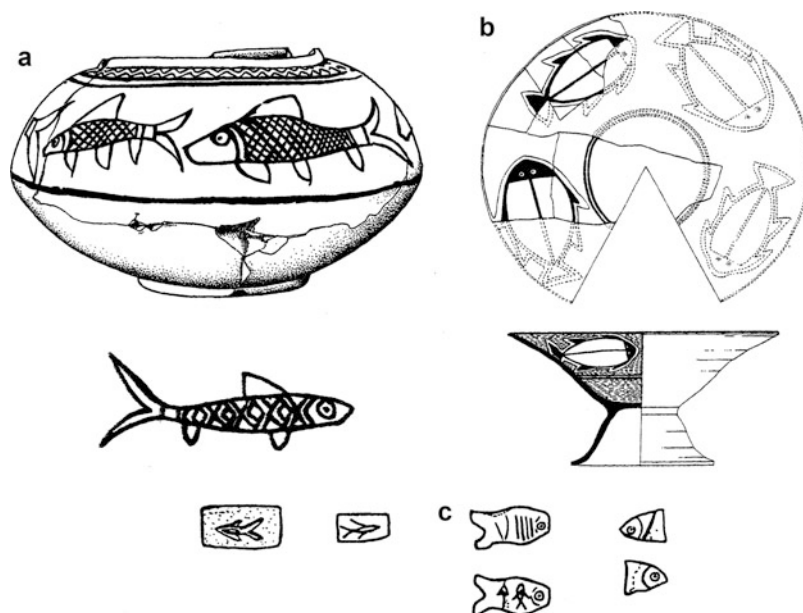
The rivers, numberless lakes and pools, often arising and vanishing, and the waters of the Arabian Sea along the Makran coast were the home for large resources of fish, crustaceans and molluscs. These animals formed a significant element in the diet of people and of the trade in the region.

Since the Indus script and language have not yet been deciphered, and there seem to be no reliefs or wall paintings in temples or palaces, we depend mainly on archaeological finds and on the observation of apparently old practices today for information on fishing and other activities in ancient times.

The importance of fishes in the Indus civilization is evident in many typical seals with a pictogram of fish (Fig. 1). Presentations of fish and fishing also appear on pottery and in the form of small zoomorph ceramic figurines (Fig. 2). Most interesting is a potsherd, discovered at Harappa,

Fishing in the Indus Valley, Fig. 2

Fish images on pottery and in figurines: (a) Red/black ceramic vessel from prehistoric cemetery at Nal (Baluchistan) (Used with their permission), (b) painted dish on stand with fish from Lewan, ca. 3000 BCE (Allchin, 1982/1993), (c) zoomorph figurines with fish design



Fishing in the Indus Valley, Fig. 3

Potsherd from Harappa with painted men fishing with baskets, in front probably seine net (After Vats, 1940 from Jansen, 1986. Used with their permission)

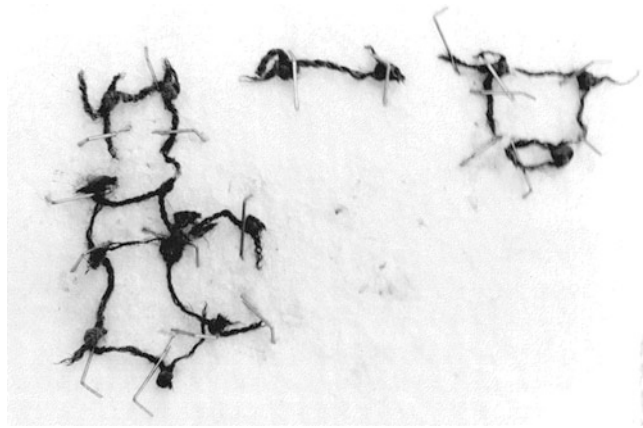


with the drawing of men obviously fishing with baskets (Fig. 3). In the foreground one sees netting which could be interpreted as part of a seine. The existence of such nets is revealed by a great number of typical sinkers, mostly of limestone. Pakistani fishermen still use the same type today. Direct evidence for net fishing is provided by remains of an almost 5,000 year old net discovered in 1972 by an Italian mission at Shahr-i-Sokhta in the Seistan Depression, today in Iran near the border with Afghanistan (Fig. 4).

Finds of ancient fishing gear consisted mostly of spear points, arrowheads and a limited number of fishhooks (Fig. 5). Spears and arrows were certainly also used for hunting. With the development of metallurgy since the fifth millennium BCE, artefacts were made of copper. Fishhooks discovered at Mohenjodaro, Chanhudaro and Harappa were 1–10 cm long. The longest must have been employed in fishing for very large fishes. Hooks were mostly barbed, but barbless hooks were also found. From investigations it

Fishing in the Indus Valley, Fig. 4

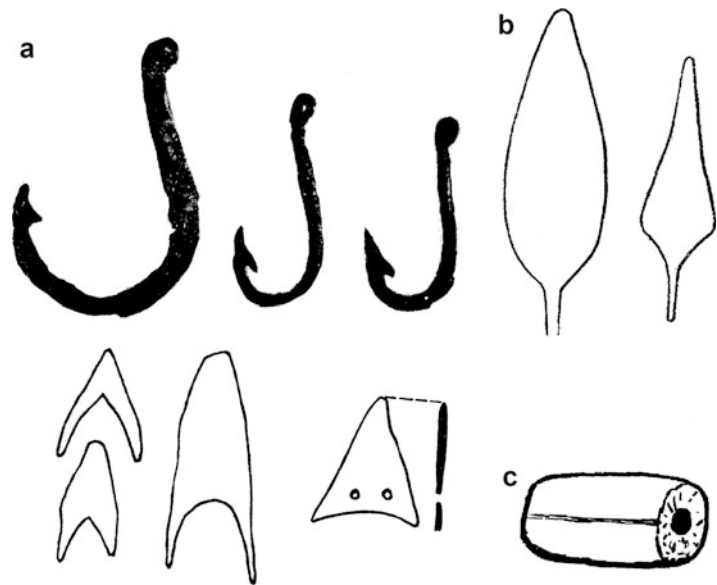
Remains of a fishing net, discovered near Shahr-i-Sokhta in the swamps of the Seistan Depression, third millennium BCE. Netting knitted with reef knots, square mesh 4 cm on average, finely woven fibre, possibly wool (Istituto Italiano per l'Africa e l'Oriente, Rome. Photo: Bonardi. Used with their permission)



F

Fishing in the Indus Valley, Fig. 5

Fishing gear in the Indus civilization: (a) Copper fishhooks from Mohenjodaro (Sarkar, 1953); (b) spearpoints and arrowheads (Agrawala & Kumar, 1993); (c) net sinker of limestone discovered at Mohenjodaro (Marshall, 1931/1973)

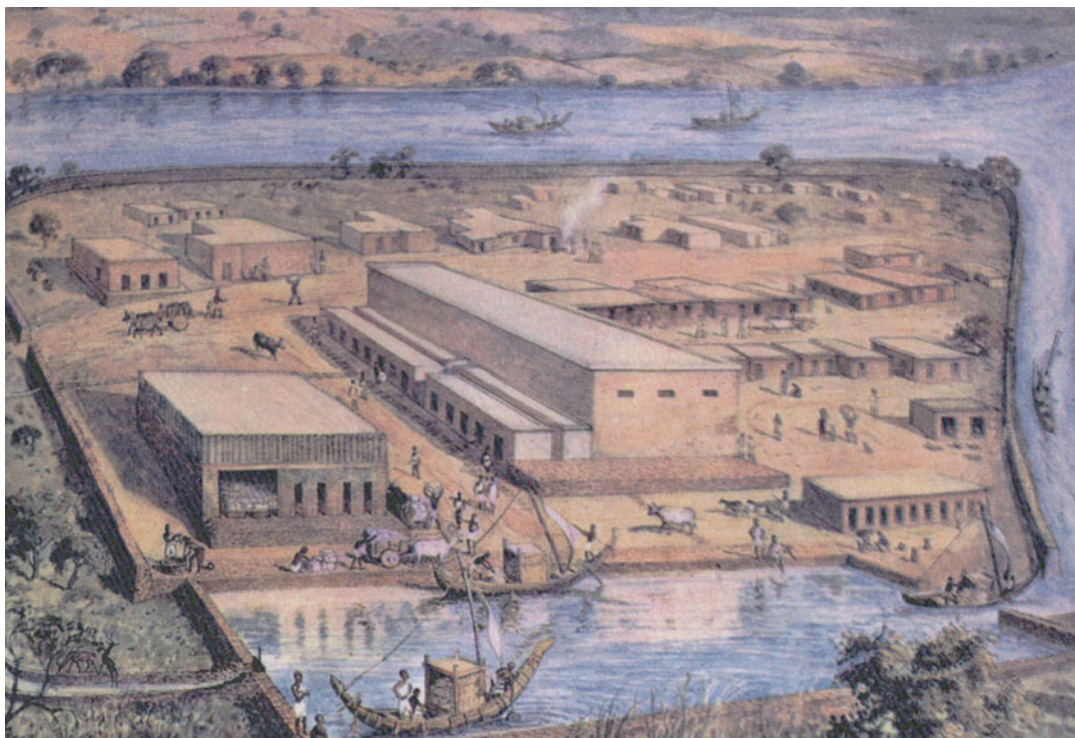


appears that copper was imported from Baluchistan, Rajasthan (Khetri) and overseas from Muscat and Oman (Magan).

In the absence of ancient fish images, skeletal remains are of utmost importance for identifying fish species caught in ancient times. From fish bones unearthed in Mohenjodaro, Harappa and elsewhere it is indicated that catches in freshwaters consisted mainly of carp-like fishes, particularly the large barbels *Catla catla*, Mahseer (*Tor tor*) and the Rohu (*Labeo rohita*), which grow to lengths of over 2 m, and also various species of small barbels which nevertheless are important

due to their biomass. Also the large catfish *Wallago attu* was a major food fish.

The coastal waters of the Arabian Sea provided good catches mostly of giant seacatfishes (*Arius thalassinus*), croakers, grunts, skates and small sharks. This was discovered when a French team with Desse and Desse-Berset in 1989 found thousands of fish bones, together with shells and Harappan potsherds, lying on the Prahag beach near Pasni. Finds of such bones at Miri Qalat, 120 km north of Prahag, and even at Harappa, some 900 km further north, prove that fish had been transported far inland.



Fishing in the Indus Valley, Fig. 6 Reconstruction of the city of Lothal with harbour basin, wharf and store. Large central building ("acropolis") on platform of loam

bricks. In the back living quarters and workshops for copper, marine shells, lapidary and semi-precious stone working industries (Rao, 1973)

In a region with a hot climate this would have been impossible without proper conservation of the catches near the coast. The bone remains on the beach of Prahag gave a hint: they were placed in a number of circles 5–8 m in diameter. It seems that the fishes had been put into round pitches in the sand for salting. In fact, this method is being used by present-day Baluchi fishermen, as Belcher observed at Balakot near Karachi. The fish, mostly silver grunt (*Pomadasyss hasta*), are beheaded, clipped, the halves put into brine for 2–3 days and exposed to wind and sun for drying.

Rivers, lakes, and the Indian Ocean offered good opportunities to catch crustaceans and to collect mussels and gastropods. Whereas the crustaceans remains decayed, the mollusc shells lasted over thousands of years. Already during the Stone Age they were worked into ornaments, amulets and objects of daily life like vessels and spoons. Workshops existed in many Harappan

cities, where craftsmen produced highly artistic objects with fairly uniform techniques and styles. Like precious stone products, mollusc shell products were also traded in the Indus region and far beyond (Kenoyer, 1984).

The central part (columella) of sacred conch (*Turbinella pyrum*) was used to produce hollow cylinders for seals which were exported to Oman and Mesopotamia. Finds of such cylinders, and of Indus stamp seals, in Mesopotamia prove trade connections between Meluhha (as the Indus region was named) and the cities on the rivers Euphrates and Tigris. Cuneiform scripts on clay tablets from Mesopotamia tell that King Sargon I, around 2300 BCE, ordered that ships from Meluhha sail upstream on the Euphrates beyond Ur to reach his capital Akkad for unloading their cargo. After the Akkad period direct connections were discontinued but indirect links via Dilmun on the Bahrain Islands and Oman lasted for many years.

One of the ports for trade overseas was Lothal on the Bay of Cambay, where a basin and likely harbour installations and workshops have been excavated (Fig. 6).

The Indus civilization perished around 1700 BCE for unknown reasons. Possible explanations include climatic changes, tectonic activities with earthquakes, and socio-economic influences like overgrazing, burning of grassland and forests, and the impossibility for rural people to feed the increasing urban population.

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Fishing in the Stone Age

Dietrich Sahrhage

Fishing is one of the oldest activities of man. The hunter-gatherers of the Stone Age not only fed on game and plants but also on fish and other aquatic animals. Living as nomads, they were bound to the neighbourhood of springs, rivers and lakes for drinking water, hunting game at the watering places and using the dense vegetation. No wonder that they soon discovered rich aquatic resources for their food. Also in coastal areas, preferred as migratory routes, they were able to collect and catch many fishes, crustacea and molluscs.

It is striking that fishing gear was developed in different regions of the world to rather similar, sometimes almost identical, forms, although the globe was still only thinly populated. Whether the various techniques were invented independently in different civilizations since human intelligence led to similar solutions (convergence), or whether the experience was distributed by migrations and cultural exchange (diffusion), is an open question.

The oldest indications of fishing, about 2 million years old, are bones of Tilapia and shells of molluscs together with simple pebble tools and human bones left by *Homo habilis* in the Olduvai Gorge in Tanzania, but no fishing gear was found.

It may, however, be assumed that already during the Palaeolithic times humans were able to

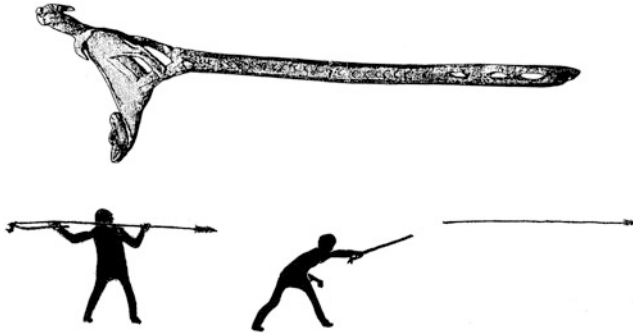
Fishing in the Stone Age,

Fig. 1 Group of Bushmen hunting fish with lances. Drawing after prehistoric rock painting at the Tselike River, South Africa (Battiss, 1945)



Fishing in the Stone Age, Fig. 2 Harpoon of prehistoric fishermen on the coast of southern Peru used for hunting seals and possibly sharks. The harpoon consists of seal bone with a flint point and ligature of leather or

sinew. Shaft is of wood, retrieving line of plant fibre (Lavallée, *Pour La Science* 2001. Used with the permission of *Pour La Science*)



Fishing in the Stone Age, Fig. 3 Atlatl, spear throwing sling from the cave of Mas-d'Azil, Ariège, southern France, about 20,000 years old (After Stodiek & Paulsen, 1996). The 32 cm long stick is decorated at the end with a

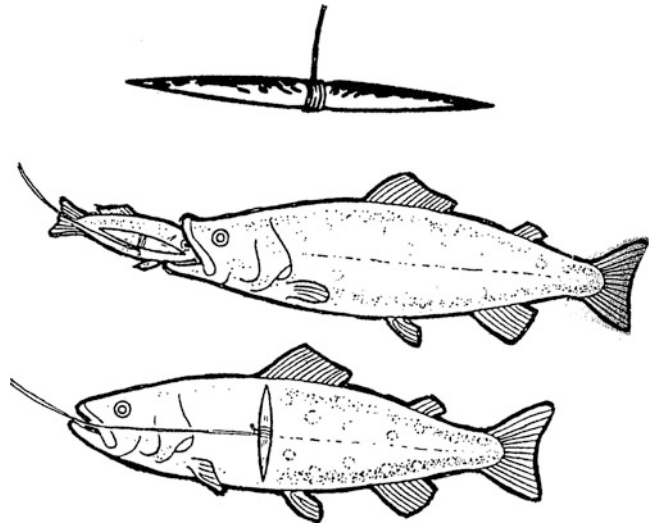
highly artistic sculpture of a fawn and a bird. The end of a spear is put against a spur of the sling, and – as with a catapult – the hunter can propel the spear with a force much greater than that of a hand-thrown spear

develop a palette of simple techniques to reach their goal. Men went hunting for fish with the same gear used for small game, particularly with wooden lances equipped with stone points

(Fig. 1). Women and children collected crustacea and molluscs in shallow waters. People soon managed to catch fish with their bare hands and to build stone walls and wooden hedges to

Fishing in the Stone Age,

Fig. 4 The gorge, probably the oldest angling tackle. In Europe it has been used since the Magdalenian, about 16,000 years ago. The stick is put into the bait. When the prey snaps at the bait, the gorge turns transverse as the line gets tight (Evers, 1988. Used with their kind permission)



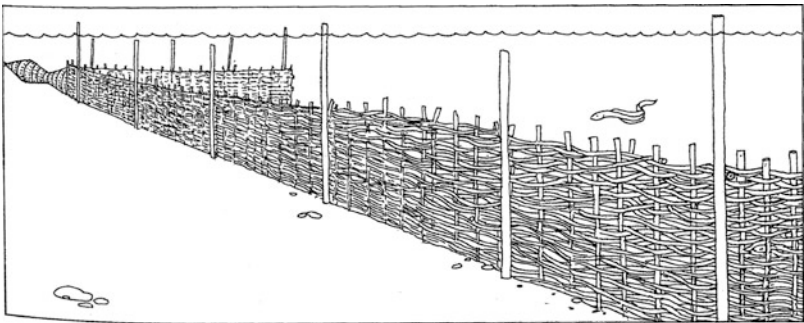
Fishing in the Stone Age, Fig. 5 Above: Curved fishhooks from the Mesolithic period found at various sites in Denmark (The National Museum of Denmark, Copenhagen. Used with their permission); Below: Compound fishhook of seal bone with mussel shell barb from Quebrada de los Burros on the coast of southern Peru, about 8,000 years old (Lavallée, *Pour la Science* 2001, drawing by Bailly. Used with the permission of *Pour La Science*)

improve fishing possibilities. Branches of bushes were stuck into the ground in waters where fishes concentrated to shelter. The hunters also discovered that fish were attracted by light from fire. Most likely they built fish traps similar to those used for game, but any material evidence decayed long ago.

A great step was the invention of the javelin. This tackle was used by *Homo erectus* some 400,000 years ago, as proved by finds in Lower Saxonia, Germany.

Neanderthals (*Homo sapiens neanderthalensis*), living in Europe and the Near East some 200–30,000 years ago, fed mainly on meat, as indicated by their petrified excrements, but fish also played an important role. This was shown by bone remains of trout and salmon on their resting places along rivers in France and Spain.

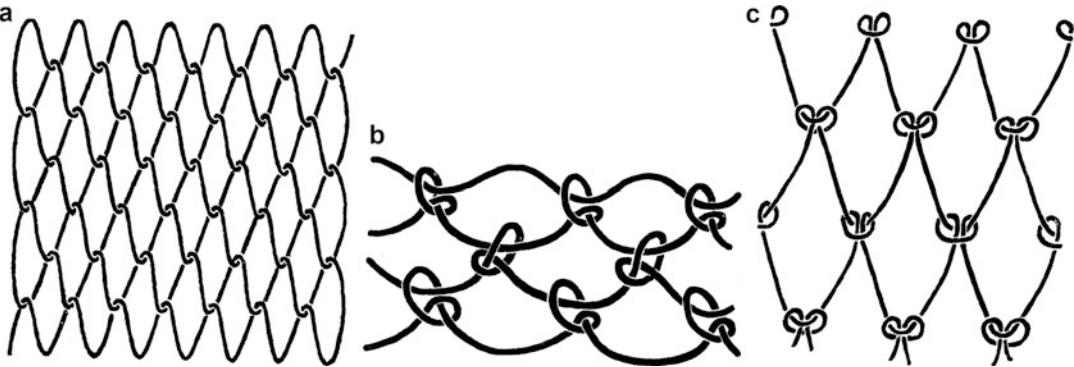
Much progress was achieved after modern man (*Homo sapiens sapiens*) originated. This began about 150,000 years ago somewhere in southeastern Africa and spread out over the globe, reaching Australia around 40,000 BCE and the American continents via the Bering Straits about 15,000 BCE, perhaps earlier. Now more delicate spear points, blades and scrapers of stone, were produced, and later tools of bone and antler.



Fishing in the Stone Age, Fig. 6 Reconstruction of a fish hedge with trap from Oleslyst, Denmark, about 4,500 years old. Hazel stakes in the sea bottom held wickerwork panels over a length of about 45 m. Fish,

mostly eels, swam along the hedge to deeper water and were caught in a weir at the end (Pedersen, 1997; drawing Petersen, Kalundborg Regional Museum. Used with their permission)

Fishing in the Stone Age, Fig. 7 Huge mounds of shell middens were left over from meals of Stone Age people in many places of the world, as here in Otuma on the coast of Peru (Photo: Tulio Cusman, Lima)



Fishing in the Stone Age, Fig. 8 Fish nets with different kinds of knots to produce meshes: (a) knotless nets with simple hanging in; (b) nets knitted with “lake-dweller knots,” (c) nets knitted with “Peru knots” (von Brandt, 1984)

Fishing in the Stone Age,

Fig. 9 Rock painting of a flatfish (flounder?) in the cave of La Pileta near Ronda in Andalusia, Spain, around 20,000 years old, length 1.5 m (Photo: José Bullón Giménez <http://www.cuevadelaPILETA.org>. Used with permission)



F

Fishing in the Stone Age,

Fig. 10 Barramundi fish (*Lates calcarifer*) painted by Australian aborigines about 2–3,000 years ago in “Roentgen” (X-ray) style in the Cockatoo National Park, western Arnhemland (Photo: Tacon, The Australian Museum, Sydney. Used with their kind permission)



Modern humans invented the harpoon, a sharp barbed piece of bone, detachable from the spear shaft, which kept the prey (game or fish) on a retrieving line when it stuck in the body of the animal (Fig. 2). Such gear was found on many locations in the world and has been used frequently up to the present. The oldest harpoon head, found in East Africa, is about 90,000 years old.

Another ingenious invention was a spear-throwing instrument, later called *atlatl* by the

Aztec of Mexico, which was distributed widely over all continents (Fig. 3). The oldest known atlatl was used in northwestern Africa 25,000 years ago; Australian aborigines still hunt with similar tools today. The atlatl was increasingly replaced by bows and arrows, known in Europe since 25,000 BCE, and in America since about 2,500 years ago. Many native people even today fish with this technique.



Fishing in the Stone Age, Fig. 11 Fishing with tamed cormorants. *Above:* An old method used in China (Dabry de Thiersant, 1872); *Below:* Drawing from a ceramic receptacle from the Moche culture, 100 BCE-700 AD in Peru, exhibited in the Museo Amano, Lima (drawing Sahrhage)

Angling may have started during the latest glacial epoch with the gorge, a little wooden stick, pointed at both ends, with a ring furrow for fixing a line (Fig. 4). Curved fishhooks seem to appear only after the Ice Age in the subarctic hunter civilizations of northern Eurasia from where this method spread out to Europe and to the Far East and America (Fig. 5).

With major climatic changes around 12,000 BCE, large parts of the ice cover melted and the sea level rose in all the oceans. Wide coastal areas were flooded and many valleys and depressions filled with water. People

changed their activities increasingly from hunting to fishing with subsequent improvements in catching techniques (Fig. 6). Temporary, and later permanent, settlements on rivers, lakes and the seaside developed where fishing possibilities proved favourable. Dense concentrations of prehistoric fish, seal and whale remains, and huge heaps of shell middens in many places of the world indicate the great importance of aquatic fauna as human food (Fig. 7).

Remains of fishnets lasted only under special conditions in swamps and arid deserts. Knowing how to knit netting marked a major form of progress (Fig. 8). The oldest nets, excavated in Finland and Peru, are 9–10,000 years old, but the history of nets may go back far earlier. In the Czech Republic 27,000 year-old impressions in clay were found which seem to originate from net meshes.

Many rock paintings and engravings certify the role of fish in the spiritual life of Stone Age people, possibly during magic rites in shamanism (Fig. 9). This is evident also from X-ray images found in Europe, northern Asia, America and Australia, showing the inner organs of the animals (Fig. 10).

A sophisticated technique of fishing developed in China, Japan and Peru, where cormorants were tamed to deliver their fish prey to the fisherman who took care of the birds (Fig. 11).

Probably rather early, people started to build vessels for crossing the waters and reaching aquatic resources in deeper areas. For this they used the materials locally available to produce, for example, reed rafts in swamps, dugout canoes in forest regions (Fig. 12), and boats with skin hulls stabilized by wooden sticks.

Various methods of fish preservation were also developed during the Stone Age: drying over the fire or in the wind and sun to produce stable food for the long winter periods passed mostly in caves, and for migrations, as well as salting and pickling.

Most of the basic types of fishing techniques originated in the Stone Age. They are still widely applied.



Fishing in the Stone Age, Fig. 12 Prehistoric dugout canoe, about 8,000 years old, being excavated near Dufuna in northern Nigeria (Photo: Breunig. Used with permission)

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Five Phases (*Wuxing*)

Ang Tian Se

Five phases, or *Wuxing*, is one of the basic concepts used by the ancient Chinese along with *Qi*, *Yin*, and *Yang*, to explain natural phenomena. The term *Wuxing*, formerly translated as “Five Elements” is now rendered as “Five Phases”. The reason for such a rendering is simply that the term *Wuxing* in Chinese did not necessarily mean

“Five Elements” as we understand them today but is a term which implies something dynamic, ever moving, and transforming in a regular pattern through the operation of *Qi* in nature.

Before we trace the origins and development of the *Wuxing* concept, we should bear in mind that early Chinese thought was perennially involved with the relationship of humanity and nature. Humans were seen to hold an integral but not an assertive place in nature. They had to understand nature and live harmoniously with it. To provide a rationale for it, *Zou Zhuan* (Master Zou’s Enlargement of the Spring and Autumn Annals) of the fifth century BCE says:

There are Six *Qi* in nature. When they descend, they give rise to the Five Tastes; display themselves in the Five Colors, and are evidenced by the Five Sounds. When they are in excess, they generate the Six Diseases. The Six *Qi* are *yin* and *yang*, wind and rain, dark and light. They divide to form the Four Seasons, showing the Five Periods in sequence. When they are in excess, they bring about calamities. Excess in *yin* results in cold diseases; excess in *yang*, hot diseases; excess in wind, the diseases of the extremities; excess in rain, the diseases of the stomach; excess in dark, delusions; excess in light, diseases of the heart.

Realizing that nature is vicissitudinary, the early Chinese classified, through their observations and experiences, all the natural phenomena as well as mundane affairs in groups of fives. Classification as such was based on their perception of nature and the society in which they lived. Hence, in several pre-Qin (third century BCE) texts we come across such terms as *Wufang* (Five Directions), *Wushi* or *Wuchen* (Five Periods/Seasons), *Wude* (Five Powers), *Wucai* (Five Materials), and other fivefold categorizations. The oldest reference to the term *Wuxing* without the nomenclature for the set of five is found in the *Guo Yu* (Discussion on the Ancient Feudal States) of Western Zhou in the eighth century BCE.

The person purported to have systematized and stabilized these ideas of categorization was ► **Zou Yan** who flourished between 350 and 270 BCE. He referred to the set of Water, Fire, Metal, Wood, and Earth as “Five Powers”. He cited the rise and fall of past dynasties to put

forward a cosmological theory of monarchy. As a reflection of the order on Nature, the political order was subject to the Five Powers which conquer each other. This sequence later came to be known as the Mutual Conquest Order (*Xiang Ke* or *Xiang Sheng*), wherein Water conquers Fire by extinguishing it, Fire conquers Metal by melting it, Metal conquers Wood by cutting and carving it. Wood conquers Earth either by digging it up or growing out of it, and Earth conquers Water by damming it up and constraining it. Because the Five Powers dominate alternately, it is seen that the process of domination is itself “controlled” by the Power which conquers the conqueror. For example, Wood conquers Earth, but Metal controls the process. There is yet another sequence which is found in the *Chun Qiu Fan Lu* (String of Pearls on the Spring and Autumn Annals) by Dong Zhongshu of the second century BCE. The sequence gives rise to the Mutual Production Order (*Xiang Sheng*), in which the Five Powers generate each other. The sequence begins with Wood which produces Fire (being consumed as fuel). Fire produces Earth (by forming ash), Earth produces Metal (by fostering the formation of metallic ores), Metal produces Water (by liquefying itself when heated), and Water produces Wood (by nourishing the plants). If both the orders of Mutual Conquest and Mutual Production are taken together, it is seen that in the process of destruction of one Power by another, the process of change is somehow “masked” by some other process which produces more of the substrate, or produces it faster than it can be destroyed by the primary process.

Another *locus classicus* of the pre-Qin period which describes the Five Powers as Five Processes is found in the *Hong Fan* (Great Plan) chapter of the *Shu Jing* (Historical Classic). The text gives the names of *Wuxing* in numerical order, followed immediately by their respective descriptions. Thus, we have:

- Water: wetting, descending
- Fire: flaming, ascending
- Wood: (allowing to be) carved, straightened
- Metal: (allowing to be) molded
- Earth: sowing and harvesting

The description suggests five sorts of fundamental processes characterized by their respective quality in nature.

In their effort to understand the physical changes in Nature, the early Chinese tried to establish a viable system in terms of abstract ideas. In the *Wuxing* chapter of *Guan Zi* of the late fourth century BCE, the set of Wood, Fire, Earth, Metal, and Water is fitted to 72-day divisions to the 360-day year in order to show the change of seasons in an evolving manner. The set of five is associated with five types of *Qi* that bring about changes in nature. Then, in another *Wuxing* chapter in *Bai Hu Tong* (Comprehensive Discussion in the White Tiger Hall) of the first century, the word *Xing* is specially used to mean “the activity of *Qi* by the natural order.” In the *Chun Qiu Fan Lu*, too, *Xing* means “activity”. It is clear that *Wuxing* is no longer seen as a set of chemically or physically distinct substances, nor is it a force itself which is capable of performing actions. The *Wuxing*, then, are phases of change brought about by *Qi* in Nature.

See Also

► Yinyang

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Food and the Maori

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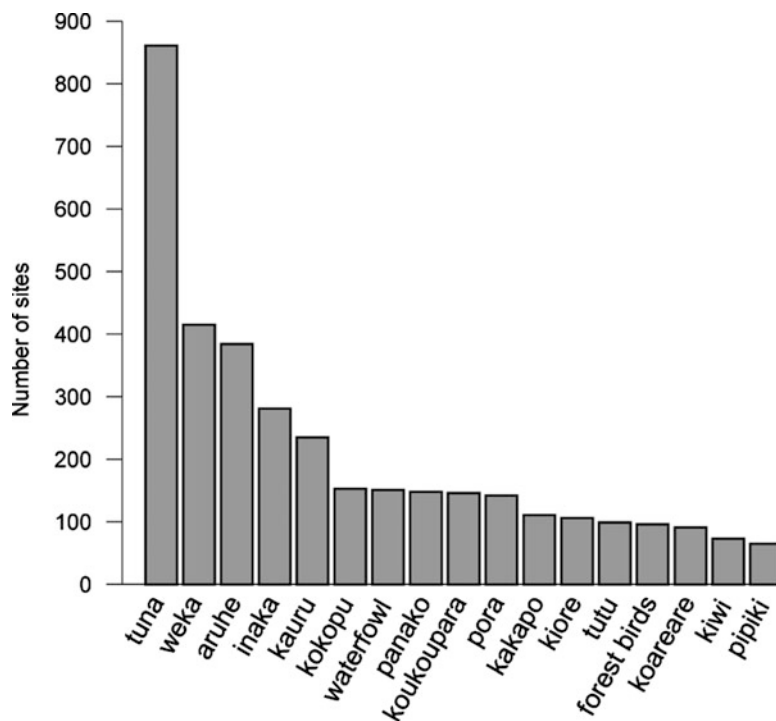
The New Zealand archipelago spans from 35° to 46° South and, accordingly, offers a wide range of soils, climates, and, therefore, growing seasons. The result is a range of diets based on two predominant zones. In the northern three-quarters of the country, kūmera [sweet potato] provides the carbohydrate staple and has achieved a higher status in this area than in any other region of Polynesia; in the southern quarter, kūmera will not grow and a quite different lifestyle evolved, primarily based on hunting and gathering. It is this region that is here analyzed.

In 1879, in preparation for a Royal Commission into South Island land sales, southern Member of Parliament, H. K. Taiaroa, interviewed the oldest folk around to collect details of the regular food-gathering journeys to 1479 sites and the 114 associated foods.

Of the 114 food items, 57 are sources of protein, including 12 of the 20 most commonly encountered (Fig. 1).

Half of all sites were sources of tuna, or eels, the ubiquitous source of protein and fat, available from September until April. Weka is a flightless bird approximately the size of a chicken and a prominent winter standby when it was at its best. Aruhe, or fern root, provided a poor source of carbohydrate, mainly eaten for bulk. Inaka, kokopu, panako, koukoupapa, and pipiki are

Food and the Maori,
Fig. 1 The most
 commonly encountered
 foods



native freshwater fish. Kāuru is an especially rich source of fructose (carbohydrate), extracted from the rhizome of a tree lily known as tī. Kāuru is extracted from the root of the so-called cabbage tree in spring, when its polysaccharide content is highest (greater than either sugar cane or sugar beet). Aruhe, the root of the bracken fern, was a poor sort of carbohydrate and boring to eat, so it was flavored with mineral-rich juices. Tutu juice was high in vitamin B; korari, or flax nectar, was high in niacin and agar, extracted from seaweed, provided iodine. Waterfowl, forest birds, and kiwi, as well as the rodent, kiore, also provided protein and fat. Pora, tutu, and koareare are vegetables and provided vitamins and minerals.

The protein foods were not only the most numerous, but many were available in sufficient quantity to be preserved. Such variety provided choice, and cultural factors emerge. The majority of *kai wairua*, or prestige foods, are protein foods (or combinations of protein and fat). The main fatty foods, tuna and tītī (muttonbirds), both sources of Omega-3 fat, were available in their greatest quantities in late autumn and early winter and were therefore of special value as energy can

be temporarily stored as fat in the adipose tissue for use in the forthcoming period of relative shortage. Subsidiary sources of fat were also popular when preserved. However, it is kāuru that stands out, particularly in the southern three-quarters of the region. As the main source of carbohydrate, great quantities of kāuru were prepared and Tikao (n.d.) details how every hapū, or subtribe, held a *kaihaukai* (a form of ritual feast with the emphasis on reciprocal food exchange) for its neighbors when the kāuru was harvested. There is no record that kāuru was preserved (in fact, Tikao mentions the tendency for it to go moldy (*waitautia*) (n.d., p. 7)). It was harvested in quantity and seems to have been consumed within a quite short time. A feature of kāuru consumption is the number of confections based on it; Tikao mentions fruit juices used as flavorings, as well as a type of jelly made with agar.

Diet

There is little firm evidence to support detailed traditional knowledge of nutritional values; yet

Food and the Maori, Table 1 Approximate composition of shellfish with highest gross energy

Species	Protein	Fat	Carbohydrate	kcal	kJoule
Tuatua	16.7	2.2	6.2	110	460
Bluff oyster	12.9	3.0	3.1	103	429
Pāua	20.8	1.0	0.9	99	415
Rock lobster	21.9	0.8	0.7	97	408
Kina (sea egg)	10.8	5.4	0.6	94	394

Food and the Maori, Table 2 Approximate composition and gross energy of fillets of finfish

Species	Protein	Fat	Carbohydrate	kcal	kJoule
Barracuda	19.3	3.3	*	107	447
Blue cod	18.1	0.8	*	80	333
Snapper	19.4	1.6	*	92	385

the balance in the diet, and particularly the use of tuatua (a type of clam) as a food of last resort, strongly suggests an innate understanding of dietary needs.

The importance of carbohydrates and fats (Speth and Spielmann (1983, p. 13) say that carbohydrate is much more efficient than fat for converting excess protein to energy) in the human diet is well known, as is the necessity for a balanced diet. Pre-European Māori appear to have had an intuitive understanding of dietary requirements. Eating patterns, as indicated by dietary preferences (allowing for some “taste” items), seem to be largely consistent with nutritional needs in that most provide a key dietary element. “[It has been shown that] if the body lacks some chemical, the individual will tend (in an imperfect way) to develop a specific appetite or partial hunger for that food element” (Maslow, 1954, p. 81). Johns (1990, p. 17) comments: “humans develop specific appetites related to nutritional deficiencies such as salt, iron and vitamins.” The Māori language recognizes this aspect. In the idiom used by speakers of Māori and others who use the same idioms, when translated to English: “I’m hungry for a feed of (e.g.) oysters (or ice cream) etc.” Folk who are simply hungry are likely to say “I’m hungry for a kai (or feed).” This is of interest for two reasons. It illustrates that during most seasons, there were dietary choices and, in addition, that the people knew which foods were vital at the time.

Nutritional Balance

Vlieg provides two tables: “proximate composition of shellfish (g/100g wet weight)” (1988, p. 47) and “calculated gross energy of the edible part of shellfish” (1988, p. 50), from which data for the five shellfish with highest gross energy have been extracted and conflated in Table 1 above.

For comparative purposes, the three most favored finfish species (data from Vlieg, 1988, pp. 23–36 and pp. 48–49) are shown in Table 2.

With the exception of tuatua, all are favored Māori traditional foods and even today are strongly preferred, except that tuatua are not particularly popular. But of special interest is the fact that tuatua have the highest energy levels of all (even including finfish). To claim a relationship between dietary preference and nutritional value, the enigma of the tuatua must first be resolved. Perhaps, the key lies in its relatively high carbohydrate level which, in line with Speth and Spielmann’s assertion, would be invaluable in facilitating the conversion of excess protein into energy at times of plant carbohydrate shortage.

Tuatua does feature in archaeological sites, but somewhat enigmatically and sporadically over time. Anderson (1983), who recognizes three periods of food intake, says during “the Early (Moa Hunting) Period: AD 900–1350 . . . Shellfish account for no more than 5–10 % of the total [intake of animal food]” (1983, p. 16).

During the Middle Period, AD 1350–1550, fishing became the major activity and “it provided 31 % of the food represented in the late (14th century) occupation level at Pounaweia and 89 % of that at 14th century Purakaunui” (1983, p. 26). By the Late Period 1550–1800, further adaptations had taken place and shellfish became relatively unimportant. Even at Pounaweia, where fishing was long the major contributor to the diet, dense layers of *tuatua* shell tend to be interspersed with layers having few *tuatua*. This could mean that *tuatua* were only available in some years or were eaten when preferred foods were not available. Shortages of *tuatua* appear unlikely and the latter hypothesis is preferred. It is supported by Leach, Davidson, Robertshawe, and Leach (2001, pp. 22–23) and confirmed by elder Te Mahana Walsh of Kāti Huirapa, who said “the old people only ate *tuatua* when there was nothing else. They didn’t really like it” (pers. com., 1994).

It may be argued, as Carson does in the case of *umu tī* in island Polynesia, that “use only in times of famine still constitutes a food restriction” (2002, p. 346), but when the major determinant is taste, the argument does not hold up. Rather, the avoidance of *tuatua* except in times of hardship demonstrates a range of choices that allowed taste preferences to be indulged.

Underlying this issue is the question as to what such a preference might be based on. According to Vlieg, “The principal carbohydrate in fish (glucose) is not very sweet, and flavour appears mainly due to the presence of non-protein nitrogenous compounds” (1988, p. 6). But Simpson considers that conventional definitions of “flavor” are too narrow in that “Texture and colour have always played a major role” (1982, p. 115) and that aroma is one of that group of properties, usually referred to as flavor, which either attract or deter the consumer.

Sea mammals, which archaeological evidence suggests to have been the major source of fat in the early prehistoric period, were rarely consumed after the mid-fifteenth century (Anderson, 1983, p. 24). Soon afterwards, *umu tī* seemed to proliferate (Anderson, 1983, p. 26), and these foods continued to be of primary

importance until the middle of the nineteenth century (Shortland, 1851, and see the data from H. K. Taiaroa in this article). This is likely to have been the main source of carbohydrate, and *tītī* and tuna, neither of which leave remains that persist in archaeological sites, were likely to have been of considerable importance as sources of fats and oils. The prevalence of *aruhe* sites in the Taiaroa (1880) lists suggests that it, too, was probably of some importance, especially as a food of choice while traveling, due to its being widely available, as well as light to carry. It may also have been a staple in times of food shortage.

Food Values of “Principal Foods”

For current purposes, “principal” foods are those eaten in large quantities and “primary” foods are the primary target of a food-gathering journey. There is considerable overlap between the two. It is instructive to examine the value of items of food that were eaten or stored in large quantities:

Mata, or whitebait, are “essentially similar” to other fish species for lipids (Sumner & Davis, 1977); it has not proved possible to check their carbohydrate values and *makā* (*barracouta*) are “not exceptional in any significant way” according to Pickston, Czochanska, and Smith (1982, p. 25). Accordingly, it would seem that both were taken in great quantities due to their availability, ease of drying, and, perhaps, taste, but probably not for any nutritive reason.

Kāuru is exceptionally rich in carbohydrate. Fankhauser, in his study of the nutritional value of *kāuru*, comments that it was equivalent to taro or yam in carbohydrate content and richer in sugars than either sugarcane or beet (1986, p. 184).

Tuna has a lipid content that increases with the size of the animal, from 6 % in 70 g eels to 22.7 % in 820 g eels (Sumner, John, Hopkirk, & Glen, 1976). “During maturation the eel deposits additional fat evenly along its length” (Wills and Hopkirk, 1975, p. 526). They comment further that other than this increase with size (weight), there is no discernible

difference between the sexes or between the species. Nixon points out that “Two components contained in eel which are of considerable significance for Maaori health are the omega-3 fatty acids and lecithin” (2001, p. 133). She goes on to discuss the dietary significance of these components that offset the known deleterious features of fatty diets, such as high cholesterol, to the extent of having a number of advantages to the human circulatory system. In addition, Graham quoted Dr. M. Cunningham who reported that “whole-fish oil from the eel is found to have a Vitamin D content equal to that of a moderately good Cod-liver oil” (1974, p. 131).

Kiore, too, were preserved in their fat. Taare Te Maihāroa related to Maud Hayter how they were caught in large numbers in the MacKenzie country. They could also be “grilled on a stick,” like a kebab, and eaten bones and all (Aubrey, 1978, p. 52).

Tuatua, as has been pointed out, were rich in both carbohydrate and fat and were readily available, but important only as a “food of last resource” (see Leach et al., 2001 for an extensive discussion).

It is argued that kāuru, titi, and tuna were the most important foods nutritionally and, therefore, should present the best opportunity to assess the relationship between economic and environmental values.

Principal Foods

The term used by most writers for principal foods is “staple,” but views differ among experts on what constitutes a staple food. This may be because principal foods can differ from place to place and season to season. Anderson (1982, p. 61) says that staples such as kāuru, tuna, and aruhe may be de-emphasized in favor of more valuable (or highly favored) foods for exchange. However, the fact that kaihaukai were held for kāuru suggests that it is also in the valued category, and tuna, while available in most areas,

were certainly exchanged by the people of Wairewa and Waihora where there were excesses, as they were seen as “kai wairua.” So, we should not view “staple” and “valuable” as mutually exclusive terms.

There were a small number of foods like Anderson’s (1982) “kāuru, tuna, and fern root” that seem to have been eaten regularly, and as the principle component of a meal. A great number of other foods are eaten less regularly for reasons of availability, preference, or nutritive value, but which still make a significant contribution to the diet. While all lie along a continuum, some foods are clearly more important than others, irrespective of how often they are eaten, and it is from this that the concept of “primary foods” has been developed. Some were eaten in small quantities, and often, others were eaten only occasionally, but in great quantities; either type had its significance. Smith (1985, pp. 400–402), discussing the nutritional requirements of early Murihiku Māori, observes that even quite a small amount of plant food could have provided balance to their diet.

Primary Foods

Primary foods are defined as those of sufficient importance to be the main target for a harvesting trip. They were harvested in quantities sufficient to provide a surplus for storage and trade. Some may be primary foods at one time of year and of lesser importance at others: tuna were a primary food during the heke (Autumn migration) but enjoyed as subsistence foods in spring and summer.

Important primary foods were inaka/mata, which were dried in the sun (as were a number of other foods). Hāpuku (grouper) were caught in Summer and tuaki in Spring – when they were “milky” – and in each case were dried and set aside for winter (Khyla Russel, 1.12.2003, pers. com.). “Kiore were trapped when berries were ripe, which added to the flavour as well as making them easier to catch” (Bradford Haami, 1992, personal communication). They also caught forest birds and makā (barracouta), a seasonal, shoaling surface feeder, of “up to five feet”

(Green, 1975, p. 617) and 8–10 lb (Graham, 1974, p. 315). The main season for makā, March, came at the end of the summer season when the focus had been inland and immediately prior to the muttonbird season (Anderson, 1981, p. 146). Shoals could be of immense size, as Graham records “sometimes densely occupying many acres at the surface” (1974, p. 313). They were caught in large numbers and cleaned and hung on racks to dry in the sun (p. 315). Because abundance of food was largely seasonal, average population density was determined by the seasons of shortage and not by the occasional peaks in supply.

Further south, tītī (muttonbirds) were the most important food, and in early winter, these were traded throughout the area of this study. In mid-winter, when other foods were scarce, weka were caught and preserved in large numbers but apparently not traded.

Helen Leach, who analyzed late-prehistoric food patterns, commented on regional differences within the South Island. While some major seasonal foods are ignored, the regional differences observed are instructive:

... the inhabitants of South Canterbury consumed quantities of fresh-water fish and cabbage tree roots, the Otago natives lived principally on fernroot, birds and seafish; the Westland Maoris ate mostly freshwater fish and preserved birds and their diet included less vegetable matter than in the east. (1969, p. 75)

The differences are largely associated with key local microenvironments, such as bush-covered waterways or extensive wetlands. However, certain cultural preferences have a regional basis, to the extent that some foods are synonymous with a given area. These, too, can be related to local microenvironments: e.g., tuaki (cockles) at Ōtākou and tuna at Wairewa and Taumutu. Such foods are termed manakai and, in some cases, kai wairua. That is not to say that these foods were not available elsewhere, but there they were not the foods of mana (prestige), symbolic of the mana whenua in that district. Accordingly, a gift of food should not be the food, that is, the manakai, of the recipient except under exceptional circumstances.

Complementarity

That precontact Māori had clear notions of dietary need is attested by the traditional eating of complementary foods, and many of these practices have persisted into contemporary times. For example, Paddy Gilroy (28/7/1998 pers. com.), during a public talk about muttonbirding, said, “tūtae-kōau, or wild parsley (*Apium prostratum*) that grows in sand dunes, it has always been boiled and eaten with tītī.” Christina Macdonald mentions that “it has diuretic and anti-scorbutic properties” (1974, p. 115), a comment on the benefits of tūtae-kōau but without identifying why it was complementary to tītī. In the case of kōuka, the so-called cabbage of the tī tree, and tuna, another complementary pair (Williams & Chrisp, 1992), the active ingredient is identified as ascorbic acid, an agent that aids in the digestion of fats. John Moorfield, too, recalls a meal of “blind eel and kōuka” at Tokomaru Bay, in the 1980s (2.4.2001, personal communication). A reasonable inference here is that the people felt comfortable when certain foods were eaten together, whereas heavier foods, on their own, were less easily digested. Perhaps the same principle has led to the contemporary partiality for pork and pūhā (sow thistle).

Extant Foods

Of the principal foods mentioned, only tītī, tuna, and mata/inaka are significant today. Tītī remains the food of greatest overall significance. Pora is extinct, and kākāpō and kiore have been exterminated from the study area. The galaxiids are now threatened species due to habitat reduction and the predations of introduced salmonids. Weka, kiwi, and the forest birds are also rare, due to the combination of reduced habitat and introduced predators. Poisoning for rabbits has also had a significant impact on weka. Tutu has been virtually extirpated due to its toxicity to stock, though there is anecdotal evidence of a small revival of interest in the beverage. Waterfowl are now subject to Fish and Game Council licensing and most Māori harvests conform with the

exigencies of duck-shooting season. Nevertheless, a few families do continue a tradition of taking māunu (this term may apply to fledglings or adult ducks during the late summer molt). One family advises that this practice has been followed since traditional times, but in a limited form. Only one meal per season is taken, comprising no more than three ducklings per brood, to an overall total of six, one each for the members of the family involved. At this quantity, the harvest is a token: no more than an annual assertion of ahi kā (traditional stewardship). Aruhe, kāuru, and kōareare are no longer sought after.

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Food Production Systems in the Amazon

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The following discussion focuses on productive systems found in riverine and interfluvial forest environments, which cover approximately 75 % of the Amazon Basin (i.e., not in wetland, savanna, or shrub environments, such as Cuyabeno, Beni, or Cerrado, respectively). The Amazon has 12 major river basins covering approximately 7.8 million square kilometers,

most of which (~65 %) are in Brazil. Other countries sharing the Amazon are Peru (~10 %), Colombia, Bolivia, and Venezuela (~6 % each), Guyana (~3 %), Surinam (~2 %), Ecuador (~3 %), and French Guyana (~1 %) (RAISG, 2012).

The conventional definition of food production systems revolves around the growing of food plants (Piperno & Pearsall, 1998). This definition, however, is insufficient to describe the main sources of food in the Amazon. Amazonian food production systems, like the Amazon itself, are very diverse. These include activities involved in the growing of food plants, the production of plant foods from foraging for wild and semidomesticated plants (e.g., roots, fruits, nuts), and animal foods, through hunting, fishing, and gathering (e.g., of iguana and tortoise eggs, stingless bee honey, beetle larvae from palms). Historical evidence suggests that the importance and characteristics of each activity have varied from place to place and from period to period. For contemporary traditional Amazonian societies, for example, Carneiro (1970) estimated that the Amahuaca, an isolated group in the central Peruvian Amazon, spent as much time hunting as working on horticulture and that the former generated about 40 % and the latter 50 % of the food consumed. In contrast, the Akuriyo of Suriname seem to have persisted without agriculture, mainly from hunting, fishing, and gathering (Kloos, 1977). In some areas, fishing is an important component of the diet, with families consuming wild fish at least once a day (Dorea, Barbosa, Ferrari, & De Souza, 2003), while in others hunting is more important (Suárez et al., 2009). Beckerman (1987) found great variation in the dependence on horticulture in the diet of 34 indigenous groups, ranging from over 80 % among the Bari and Kuikuru to equal or less than 50 % among the Amahuaca and the Secoya.

Amazonian food production systems developed in three phases: Paleo systems, or systems that dominated before the diffusion of agriculture; traditional systems, or systems that incorporated indigenous agriculture (crops, technology) as a major source of food; and contemporary systems, or systems that incorporate elements of

old-world food production systems. None has completely disappeared or dominated others; they coexist in different forms in today's food production systems. Contemporary systems considered in this article are those used to produce foods for consumption and the production of crops, such as coffee or rice, in small-scale mixed commercial-subsistence, generally family, systems. Medium- and large-scale commercial production and producers of animal products, cattle in particular, and crops, such as soya and oil palm, are not discussed here.

Paleo Systems (Pre-Agriculture)

Humans have lived in the Amazon for at least 11,000 years (Roosevelt et al., 1996). The oldest record of human habitation in the Amazon was found in Caverna da Pedra Pintada, Brazil, dating 11,000 years before present (YBP) (Roosevelt et al., 1996). Physical differences between early and current Amazonians suggest that at least two major waves of occupation occurred, Caverna da Pedra Pintada being an example of the first wave. Early Amazonians seemed to have produced foods from wild and semidomesticated plants (fruits, nuts) and from animals, through hunting, fishing, and gathering. Human groups were probably highly mobile in response to the depletion of preferred preys (Gross, 1975) and the large natural stock fluctuations of animal foods (Sponsel, 1986). Similar to other paleo-American societies of this time, there is no evidence that paleo-Amazonians practiced any significant form of agriculture. Blowguns and darts, spears, and bows and arrows, probably made of palm wood, were used for hunting. Figure 1 (e.g., see www.childrenoftheamazon.com/wp-content/uploads/2010/04/bow-and-arrow-surui-village.jpg). Spears may have had sharpened bone or stone heads. Some groups probably poisoned their arrows or darts with mixtures of animal and plant compounds.

Gross (1975) postulated that animal protein limited human carrying capacity in Amazonia, suggesting that original populations had to be small, dispersed, and mobile. This logical-economic

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Fig. 1 Typical longbow used by traditional indigenous Amazonians (Photograph from: <http://paleoplanet69529.yuku.com/topic/14152/t/amazon-bow-pics.html?page=1#.VRmctuGxVqF>)



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behavior is predicted by optimal foraging theory (Alvard, 1993; Hames, 1987; Kaplan & Hill, 1992). Foraging theory is a branch of evolutionary theory that has been used to examine the behavior of food production and livelihood strategies in a wide variety of taxa including humans. The periodic replacement of extraction areas, primarily for hunting, can be conceived as a strategy to maximize the efficiency of the foraging effort (Winterhalder & Smith, 2000), where frequently moving the foraging area, once low productivity is reached when compared to an expected local optimum, rather than waiting for a zero return to move, ensures a minimum acceptable return per unit of effort. However, Beckerman (1979) argued that for hunter gatherers, fruit trees, producing either nuts or seeds or starchy, oily, or juicy pulps, were likely sources of protein and important components of their diet, allowing higher densities and less mobile populations than Gross' postulate would predict.

All known indigenous groups who dispense of agriculture to produce food are highly mobile, have low population densities, and live in relatively small groups. Theirs are not necessarily remnants of paleo systems because it is possible that they reappeared after a period of agricultural development, as fearful indigenous populations continuously ran away from the diseases and slavery that came with the arrival of Europeans.

They are, however, probably similar in function as the environment and technology available were also similar. For example, the Akuriyo of Suriname (Kloos, 1977) and the Maku and Nukak of Colombia (Politis, 2007; Silverwood, 1972, respectively) persisted mainly from hunting, fishing, and gathering. These groups do not use agriculture as a source of food, changing residence periodically within a relatively stable area, requiring larger areas compared to populations that use agriculture to produce food. Analysis of hunting preferences show that some types of animals are preferred and that for each type, larger prey is preferred (Peres & Palacios, 2007). According to Carneiro (1970), for example, the Amahuaca, a Peruvian group that depends on hunting for a significant part of their diet, hunted and ate most large animals (tapir, large monkeys, peccary, guans) but did not eat carnivores (jaguars, pumas, eagles, vultures) and a few noncarnivores (giant armadillos, raccoons). Amahuaca hunters learned "every significant detail of the life habits of game animals." Individual males carried out most hunting, although meat was often shared with kin and friends. Gathering of nuts, fruits, and other food from forests was primarily done by women.

These are groups that today are extremely rare. If lack of contact with outsiders is a direct indication of their mobility, and mobility an

indirect measure of their dependence on hunting, fishing, and gathering (as opposed to agriculture), there would be approximately 50 such groups in the Amazon today (i.e., the approximate number of uncontacted peoples) with a total population of a few thousands. Of these, the majority are found in the Brazilian Amazon, 20 in Peru, and equal number in the remaining Amazon countries (Pantone, 2008; Watson, 1996). Many of these occur in two or more bordering countries.

Traditional (Precontact) Systems

It is generally accepted that the population of Amazonia at the time Europeans arrived was between 5 and 10 million (Denevan, 1976; Roosevelt et al., 1996). The first European accounts of life in the Amazon by Priest Gaspar de Carvajal, c. 1540–1542, described large areas along major rivers with what seemed to be stable high-density populations, with widespread agriculture, including the husbandry of native animals (e.g., tortoises), separated by unpopulated areas between them. Friar Carvajal's narration also included Amazons, mythical warrior women that gave the name to the region, and other hard-to-believe or too-convenient events, and for these the literal meaning of his story has been doubted many times. In this case, however, the concentrated distribution of the population is consistent with other evidence, such as the concentration of Anthrosols (soils that have been improved by human activity) and of domesticated plants, dating as far back as 2,500 YBP to soon dating as far back as 2,500 YBP to soon after the arrival of Europeans. Most people probably lived on the floodplains of large rivers and depended on a combination of semipermanent agriculture, hunting, fishing, and gathering to sustain semi-sedentary, relatively high population densities (McMichael et al., 2012).

By the end of the sixteenth century, many European visitors described Amazonians as lacking agriculture. Pollen and charcoal records also suggest that populated sites were abandoned in the southern Peruvian Amazon at more or less this time (Bush, Silman, & Listopad, 2007). It is

possible that semipermanent agriculture and dense populations became rare in the Amazon as European diseases and abuse rapidly decimated local populations. To avoid these threats, many of the remaining groups probably regressed to more mobile food production systems, with less intensive agriculture, in the interfluvial hinterland (Cleary, 2001). Murdock (1967) listed the average population of the settlements of 30 Amazonian groups in the mid-twentieth century; of these, 24 had fewer than 100 people.

Agriculture in South America began with the domestication of native plants in various places at various times, with the oldest agricultural sites, dating from 13,000 YBP, found in Norte Chico in coastal Peru (Mann, 2005). In the Amazon, the earliest signs of domestication of plants date to 7,000 YBP, but there are not known indigenous domesticated animals. Widespread animal husbandry, of tortoises and birds, for example, was observed by the European visitors just 50 years after their arrival in America, but these animals also occur commonly in the wild. In the Beni savanna, people constructed large networks of earthen fish weirs suggesting that intensive seasonal fishing was key for their survival (Mann).

By 2,000 YBP, there are clear indications that agriculture was widespread and sustained (Sombroek et al., 2002). Reports of the number of domesticated plants used for food at the arrival of European explorers easily surpass 130, more than half of which are trees (Clement, de Cristo-Araújo, Coppens d'Eeckenbrugge, & Alves Pereira, 2010). The majority seem to have originated in the Amazon, but others probably came from the Andes and even Mesoamerica (e.g., maize, cacao). Manioc or cassava (*Manihot esculenta*) and maize (*Zea mays*) seem to have been key crops since very early in the occupation of Amazonia (Clement, 1999). Manioc, the most important staple in the Amazon, is a root that probably came from and was domesticated in the Cerrado (dry) Sabana possibly as early as 10,000 YBP. Manioc is an incredibly versatile crop used to cook, to make flour, for various types of beverages, and other uses. Peanuts (*Arachis hypogaea*), papaya (*Carica papaya*), pineapple (*Ananas comosus*), avocado (*Persea*

americana), Achira (*Canna edulis*), sweet potato (*Ipomoea batatas*), and passion fruit (*Passiflora edulis*) also originated within the Amazon. In many areas, semidomesticated palms, like the chonta or pejiyabe (*Bactris gasipaes*), were also important (Clement). Clement hypothesized that crop diversity is correlated with sustained human occupation of an area and that the productivity of domesticated plants and semidomesticated animals determined the population density potential of an area; hence higher densities would tend to occur where there has been long human occupation. Some researchers have also assumed that there is a close relationship between crop genetic diversity and cultural development (Vavilov, 1992). Higher traditional food diversity has been associated with greater protein, fiber, vitamin, and mineral intakes (Roche, Creed-Kanashiro, Tuesta, & Kuhnlein, 2007).

Indigenous farmers may have practiced crop selection methods to improve the quantity and quality of their harvest. Kerr and Clement (1980) describe the custom among the Ticuna Indians near Leticia, Colombia, of distributing among households in a group edible crops or fruits that were especially large or flavorful. The Kayapó of the Brazilian Amazon are known to promote the growth of forest patches with high concentrations of useful plants on open lands by a form of composting that uses termite and ant nests mixed with mulch (Posey, 1985a). The Yamuesha, in Peru, collect, trade, and maintain preferred crop varieties while purging the less desirable types (Salick, Cellinese, & Knapp, 1997).

Agriculture also requires the development of appropriate techniques for soil and crop management and storage, some of which are still visible in the archaeological record and surviving traditional food production systems. The best known is probably the development of fertile Anthrosols through controlled burning; this is discussed below. Denevan (2002) reviews traditional techniques used in the Amazon to control pests and weeds, crop rotation and storage, soil and site selection, and ground preparation. As noted above, amazonian farmers also developed techniques to grow wild animals and to fish them in

large quantities. In the first recorded travel of the Amazon River by Europeans, Fray Gaspar de Carvajal described tortoise pens in the settlements the troupe of Spaniards led by Capt. Sebastian de Benalcazar raided for food. Sombroek et al. (2002) report Anthrosols patches every 5 km along the Igarapés River in southeastern Amazonia. Agricultural plots had probably long fallow periods after years of planting, but fallow may not have meant plot abandonment but rather managed forest regrowth to create forests with high concentrations of useful plants (Denevan, 2002). Denevan estimated the population density of the Amazon floodplain could have reached hundreds per square kilometers, compared to 0.1 person in upland forests.

The main tool for clearing forests to establish traditional agriculture was the stone axe. Tools for weeding and planting were also made of wood and stone (Denevan, 2002). Stone axes were also used for obtaining wood for cooking, building houses, and making canoes. Tree felling was aided by ring-barking and controlled burning. Especially large trees were left standing. Other tools were used for picking fruit from trees (e.g., the garabato, a long flexible stick with a notched end), planting (digging sticks and footplows), and undergrowth and weed clearing (macanas, a wooden club). Mulching was probably used to protect crops from direct sunlight, maintain humidity, and control erosion and fertilization. In the Beni savanna, fire was used to maintain and expand the grasslands, where otherwise forest would have developed (Mann, 2005).

The dependency of agriculture on stone tools probably meant that clearing mature forest for setting up agricultural plots was a daunting task. This means that settlement sites were probably kept as long as possible and that, when necessary, secondary, lighter forest regrowths were preferred for clearing. This is consistent with the continued occupation of sites and explains the high concentration of charcoal and nutrients in Amazon's Anthrosols (black and brown soils) discussed below.

The location of the archaeological record indicates that indigenous farmers distinguished the

horticultural potential of the soils at their disposal and managed them accordingly. This knowledge is still evident today. For example, the Shipibo distinguish at least six soil types, generally using plants as indicators (Behrens, 1989). Around settlements, sites with best soils were kept either planted or fallow but rarely allowed to become a forest. Here, production can be sustained over 50 % of initial levels for over 10 years. In poor soils, production falls by more than 50 % in the second year of use. Carneiro (1970) estimated that the Amahuaca, an isolated group in the central Peruvian Amazon that relied at the time almost equally on hunting and horticulture to produce food, moved their settlements once every year or two within a larger but relatively stable area.

In general, Amazon soils are poor, with areas of naturally occurring good soils along rivers rich in sediments (often originating in highland areas, like the Pastaza Fan) or dark (black or brown) anthropogenic soils (Anthrosols, Amazonian dark earths) found in relatively small patches (up to 500 ha) on river bluffs. Lopez and Sierra (2010) compared horticultural systems in isolated Achuar and Shiwiar communities in relatively good riverine soils and poor interfluvial soils in the Western Amazon. Despite similar family sizes (approximately 7.2 and 7.7 persons/family) in both environments, in riverine environments horticultural plots were slightly larger (average of 3.7 vs. 2.7 has), fallows were significantly shorter (average of 6.9 vs. 20.3 years), productivity per hectare much higher (713 vs. 257 kg/ha/month), and, as a result, each hectare planted sustained more people (average of 9.9 vs. 5.6 persons/ha of cultivated land). Similar fallow cycles have been described for the Tukano along the Vaupes River in Colombia and Brazil (Chernela, 1989, in Denevan, 2002).

Anthrosols were probably created and maybe maintained intentionally over many generations (Neves, Peterson, Bartone, & Dasilva, 2003). There are two general types of Anthrosols: black or dark, occurring generally with pottery debris, probably developed over time in settlement areas; and brown, without pottery debris and a tendency to occur around back soils,

probably developed in horticultural areas. In these soils, nutrient leaching is minimal, soil organic matter is typically double, crop productivity can be several times greater, and fallow periods shorter than in the typical Amazon soil (Lehmann, Pereira da Silva, Steiner, Nehls, & Glaser, 2003; Major, Dittommaso, Lehmann, & Falção, 2005; Sombroek et al., 2002). Petersen, Neves, and Heckenberger (2001) reported that Amazonian dark earths in Açutuba were under continuous cultivation without fertilization for over 40 years.

In densely populated areas, households primarily used a form of agroforestry, with small clearings for sun-demanding crops, such as manioc, and canopy management for species that perform better in the shade, such as the pejiyabe (chonta, or peach) palm (*Bactris gasipaes*). Crops were probably planted in cleared areas in clusters and followed determined rotation patterns depending on soil fertility. The agricultural plot of traditional Amazonian farmers was diverse but clearly distinct from the surrounding forest. The Kayapó, in Brazil, for example, have fields arranged into three concentric zones, each with different crops and management techniques (Hecht & Posey, 1989, in Denevan, 2002). The central area is cleared completely and burned for planting sweet potatoes (*Ipomoea batatas*). A second ring is planted with a variety of crops: manioc, maize, beans, and others. Around these, bananas are planted.

Small clearings were probably slashed and charred (as opposed to slashed and burned), which would explain the high concentration of charcoal in Anthrosols. (Slash and burn could not explain the high concentrations of charcoal in Anthrosols without pottery.) The narrations of the travels by Spanish priest Miguel Cabello Balboa show that the practice was present soon after the arrival of Europeans (late sixteenth century) in other rainforest areas of tropical America (Cabello Valboa, 1951). Even today, charcoal production is an integral part of swidden-fallow practices in many areas of the Amazon (Coomes & Burt, 1999; Hecht, 2003; Steiner, Teixeira, & Zech, 2004). For example, the Kayapó also use small, controlled fires to improve the fertility of

their swidden plots (Hecht & Posey, 1989, in Denevan, 2002).

The territory used for extractive productive activities (hunting, fishing, and harvesting) is more difficult to characterize due to the absence of direct evidence and the very limited literature on the subject (the emphasis, perhaps because of the relative ease of study, has been on the analysis of indigenous horticultural systems). Some researchers believe that extensive and continued human use shaped the Amazon rainforest, incrusting it with high concentrations of useful plants (Balée, 1989; Erickson, 2008; Heckenberger et al., 2003), while others believe that while some small forest areas may have been managed, most were not (Bush et al., 2007; McMichael et al., 2012). Some basic assumptions can be made based on observations in contemporary Amazonian societies. First, extractive and similar areas are anchored in the settlement areas. Second, the intensity of extractive uses decreases with distance to the settlements. The objective is to minimize the effort per unit of production. Sirén, Hamback, and Machoa (2004), for example, demonstrated that there is a clear preference for hunting near their settlements among the Kichwa of Pastaza, resulting in a strong negative density gradient of game animals around these points. The maximum hunting distances observed were approximately 15 km from the origin, with almost 70 % of the effort occurring within 6 km and 90 % within 12 km. The availability of domesticated animals has an important effect on the use of wild animals. Apaza et al. (2002) found that lower beef and fish prices were correlated with a drop in the use of wild animals among the Tsimane' of Bolivia.

Contemporary (Postcontact) Systems

Excluding the production systems of existing, very isolated or uncontacted groups, contemporary Amazonian food production systems show two distinctive characteristics:

First, the resurgence of indigenous swidden agriculture that increasingly incorporates imported crops and technologies (e.g., bananas

and rice in horticulture, dogs and shotguns in hunting, outboard engines, metal hooks and tilapia in fishing, chainsaws in gathering). This resurgence is to a large extent a consequence of the rapid growth of indigenous population in Latin America, including the Amazon. In Brazil, for example, the indigenous population more than doubled, from 294,000 to 734,000, between 1991 and 2000 (Fundação Nacional do Índio [FUNAI], 2012), although some of this growth can be explained by changes in the self-identification of census responders. (It is important to note that key Amazonian crops were also exported to other regions. Manioc, for example, rapidly became a staple in Africa. Crosby (2003) called this two-directional flow of crops and production systems the Columbian Exchange).

Second, the rapid expansion, mostly in the past half century, and current dominance of nonindigenous production systems incorporating selected traditional Amazonian crops and technologies into an otherwise imported agricultural system. Of the more than 30 million people living in the Amazon that have nonindigenous origins, approximately 40 %, or 12 million, live in rural areas. Government policies in the second half of the twentieth century promoted the migration of farmers from other regions to the Amazon. For example, almost 97 % of the farms in the late 1990s along the Trans-Amazon Highway in the region of Altamira, in Brazil's Pará State, appeared after 1973, and approximately 70 % of the farmers came from another rural area in Brazil (Brondizio et al., 2002; Morán, Brondizio, & McCracken, 2002). Sierra (2000) describes a similar process for the northern Ecuadorian Amazon. Growing urban centers in the region have also been important incentives of the expansion of food production in the Amazon due to their demand for food products and as input-supply and financial centers.

Contemporary Indigenous Food Production Systems

At the turn of the twenty-first century, there were approximately 320 indigenous groups in the Amazon (FUNPROEIB Andes, 2009). Together they controlled almost 2,000,000 km², or 25.3 %

of the basin, in nearly 2,200 indigenous territories (Red Amazónica De Información Socioambiental Georreferenciada [RAISG], 2012). Indigenous territories represented 21.7 % of Brazil's Amazon, 52 % of the Colombian Amazon, and 65.0 % of the Ecuadorian Amazon. In the early twentieth century, there were approximately 734,000 self-identified indigenous Amazonians in Brazil (FUNAI, 2012), 55,000 in Colombia (World Wildlife Fund [WWF], 2005), 320,000 in Bolivia (Amazonia Boliviana, 2006), 330,000 in Peru (Mayor & Bodmer, 2009), and almost 250,000 in Ecuador (Instituto Nacional de Estadística y Censos [INEC], 2015). Of these, the majority live in rural areas. In Ecuador, for example, almost 60 % of the indigenous population lives outside of cities and towns (INEC, 2015).

Among people living in indigenous territories, traditional subsistence food production systems with small commercial elements dominate. The swidden agricultural system known as slash-and-burn, which has become almost synonymous with Amazonian horticultural systems, probably developed and spread with the arrival of metal tools (machetes, axes), replacing the traditional slash-and-char system. The sudden injection of nutrients by the burning of vegetation allows growing crops in suboptimal sites, but these have to be abandoned after a few years. With metal tools – metal axes, machetes, and later chainsaws – the cost of clearing a patch of forest dropped significantly compared to the costs of traditional cycles adapted to stone tools. The rapid loss in fertility that follows slash-and-burn is offset by much easier forest clearing and land availability.

While access and control of different food sources such as cultivable land, fisheries, or wild game can vary substantially among and within indigenous groups, in general, households usually have exclusive rights to use and extract resources from land they have cleared and planted, but once the land is abandoned, these rights revert back to the community. Hunting areas may be separated, but game animals belong to everybody. Fishing areas rarely belong to one household (Bennett & Sierra, 2014; Bremner &

Lu, 2006). In indigenous territories that are close to markets and easily accessible, commercial production tends to outstrip subsistence production. Food production systems often include the commodification of traditional food crops (maize, manioc) and animals (wild fish, pacú farming) and the introduction of non-Amazonian cash crops (rice), fruits (bananas), and animals (chickens, tilapia). Important land arrangements begin to change. In Rukullakta, for example, a group of 17 relatively accessible Kichwa communities who hold their land communally, over 80 % of the land held by households was inherited, and therefore unused land did not revert to the community, although formal land titles do not exist (Bennett & Sierra, 2014).

A survey of contemporary swidden horticultural systems of 34 Amazonian groups by Beckerman (1987) shows that manioc (*Manihot sculenta*) is by far the main cultivar (Fig. 2). Only 5 of the 34, including the Emberá and Shipibo, had a different principal subsistence crop – bananas and plantain – which were not present in the Amazon until the arrival of Europeans. The Bari recognize at least four varieties of banana and one of plantain (Beckerman). Among the Achuar and Shiwiari of the Western Amazon, manioc occupies more than 80 % of the horticultural area (Lopez & Sierra, 2010) (Fig. 3). Plantain is the second most important crop, with nearly 11 % of the area. Commercial crops, like coffee, make up 3 % of the planted area. The Kayapó from Brazil identify several indigenous tubers and medicinal plants that grow well under the shade of introduced bananas (Posey, 1985b, in Denevan, 2002), and the Yanesha of the Peruvian Amazon have incorporated bananas in the traditional crop rotation cycle, after manioc, which replaces maize, and before fruit trees (Staver, 1989). On the other hand, most indigenous modern systems seem to have lost important traditional production technologies, such as the management of fire and ash for improving plot productivity and sustainability.

Beckerman (1987) also provided estimates of horticultural plot sizes for the 34 indigenous groups. In all but four cases, average plot size was below 1 ha, commonly around half a hectare.



F



Food Production Systems in the Amazon, Fig. 2 Leaves of the manioc plant and typical family garden planted by the Achuar of western Amazonia (Photo: R. Sierra)

Families often have at least one plot within a few meters of their home, but they could walk or canoe 10 km or more to reach complementary plots. Horticultural plots may be next to each other (e.g., Shipibo) or separated by forest in various stages of regrowth (e.g., Bari). Among the Achuar and Shiwiar, mean horticultural plot size is 1.4 ha, with a maximum of 4.9 and a minimum of 0.2 ha (Lopez & Sierra, 2010). The

average distance of the closest plot of a family to their house was 200 m, and the farthest plot was 1.3 km from the home. Larger families have larger cultivated areas, and the size of cultivation plots increases with distance to the community, and the density of plots is inversely correlated to their size. The relationship between family size and horticultural area is related to the age of a family. Younger and older families, with young

Food Production Systems in the Amazon,

Fig. 3 Family gardens surrounding Achuar homes in the Pastaza region of western Amazonia and forest site recently cleared for establishing agriculture in the same vicinity (Photos: A. Weesner (*above*) and R Sierra (*below*))



children or with adult children who probably left the household, tend to have smaller horticultural areas. Middle-aged families, with older kids who can work in the plots, either clearing, cleaning, or harvesting, had the largest horticultural areas. When children are old enough to get married and leave the house to form a new domestic unit, the amount of cultivated area declines. In some cases, parents may redistribute land among their married children, which may reduce the

cultivated area under their control by transferring the rights of use to their children. These patterns show relatively egalitarian rights to land in a community. Other things being equal, and especially soils, all families prefer to have their cultivated areas as close as possible to their home. This preference is predicted by location theory, which says that sources that are visited often are best located near the consumption point. Because it is not uncommon for traditional households to

be made of one husband and more than one wife, smaller plots also allow everyone to have a horticultural area close to home. Generally, management of cultivated areas is the responsibility of married women, which places great value on having easy and fast access to a key source of food.

Contemporary Nonindigenous Food Production Systems

Productive land owned by nonindigenous producers is usually held privately. In the Brazilian Amazon, for example, 77 % of the landowners and 90 % of the land claimed by a person or company in 2006 had a private title, with 90 % of claimers living in their properties (Instituto Brasileiro de Geografia e Estatística [IBGE], 2015). Of these, almost 90 % were family units holding together held 34 % of the land. A survey of three colonization areas in the Brazilian Amazon in the early 1990s by Browder (2002) found average farm sizes of 80.2 ha, 44 % of which were under agricultural use. Pichón (2002) reports average farm sizes in the northern Ecuadorian Amazon to be 46.4 ha. In the early 1990s, almost 5 % of the farmland in the Brazilian Amazon was found in properties smaller than 50 ha, which are likely to be owned by mixed subsistence-commercial nonindigenous producers. Manioc (*Manihot esculenta*) was the most important crop produced, consumed, and probably sold, followed in importance by rice or bananas, both introduced. In farms of this size in the northern Ecuadorian Amazon, Pichón, Marquette, Murphy, and Bilsborrow (2002) reported corn and bananas to be the most important subsistence crops. The area allocated to food production was often less than 10 % of the farm. Commercial crops, such as coffee and cacao, occupied most of the cropland. However, pastures and cattle ranching are the most important productive activity by area. In 2006, almost 60 % of the farmland in the Brazilian Amazon was pastures (IBGE, 2015). Castro et al. (2013) reported a similar proportion for Ecuador. In 2006, there were approximately 26 million heads of cattle in nearly 185,000 farms in the Brazilian Amazon (IBGE, 2015).

At the farm level, production strategies of nonindigenous food producers respond to various factors. For instance, land use intensity increases with increasing access to markets and commodity cycles. In some cases, these markets are outside of the Amazon, such as for cacao. In others, markets are more local, such as for manioc. Crop choices often depend on environmental conditions. For example, along the Trans-Amazon Highway in Altamira, Brazil, Moran et al. (2002) found that cattle ranching tended to be more prevalent in farms with poorer soils, access to water and credit, and higher ownership turnover. In contrast, the importance of permanent crops increased in farms with better soils, more family labor, and lower ownership turnover. Nonindigenous producers often incorporate traditional knowledge and crops into their systems. Indigenous knowledge is used, for example, to select the best soils available in an area (Thayn, Price, & Woods, 2011).

The age of the family also affects productive land uses (McCracken, Siqueira, Moran, & Brondizio, 2002). Initial strategies, during the establishment of a farm by young families with small children in previously forested land, favor the establishment of annual crops, which can be consumed and sold quickly. At this time, land under production expands rapidly. With time, as children become young adults, land use diversifies, including the expansion of family gardens, cattle ranching, and later of perennial crops, which are productive activities that require more time to be realized. Perennial crops also require substantial labor investment, thus reducing the rate of expansion of the area farmed (Castro et al. 2013). As families mature, land use becomes more stable. McCracken et al. (2002) and Browder (2002) estimated that between 80 % and 90 % of labor inputs in four nonindigenous agricultural areas in the Brazilian Amazon in the early to mid-1990s were done by family members. Productive activities showed some segregation by the gender and age of the farm worker. For example, young adolescents and females tend to help with domesticated animal husbandry (and household chores). Older boys increasingly work with cattle. Differences accentuate during

adulthood. For example, adult males played a larger role in the clearing and burning of forest patches to open new agricultural plots, and adult women were more involved with harvesting and food processing.

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Food Technology in Africa

Richard Nnamdi Okagbue

Food processing embodies all treatments applied to foodstuffs after harvest, capture, or slaughter to prepare them for consumption or preservation. Treatments may be single or suitably combined physical, mechanical, chemical, and biological procedures which modify foodstuffs aesthetically, nutritionally, texturally, and organoleptically.

In traditional Africa, food processing is a daily domestic or village-level activity. Women constitute the main workforce and appropriate skills are acquired informally during the process of acculturation. Male professional blacksmiths, stone-cutters and wood carvers, basket makers, and others produce the grindstones, earthenware pots, pans and plates, wooden pestles, mortars and spoons, baskets, knives, calabashes, and gourds used in the processing.

In addition to familiar food plants and animal resources some uncommon products have food uses in certain areas of Africa, depending on their availability and on the prevailing culture and religion. For example, toxic castor oilseeds (*Ricinus communis*) and leaves of the toxic legume *Cassia obtusifolia* are processed into food condiments in Nigeria and Sudan, respectively. *Spirulina*, a “vegetable” microbe, is consumed in Chad, and caterpillars called mopane worms constitute human food in Zimbabwe. Other items include dog meat, cow and goat blood in parts of Nigeria, Kenya, and Zimbabwe, and gall bladder juice, hides, and skins in Sudan and Nigeria, respectively.

First-stage processing is a preliminary treatment used to release valuable seeds and fruits from heavy pods, heads, or husks. Melon pods (*Citrullus vulgaris*), breadfruit heads (*Treculia africana*), and oil palm husks (*Elaeis guineense*) are examples, and they are generally allowed to rot or soften over a period of time. The process may occur in the farm or bush to circumvent transportation and pollution problems.

Retting occurs naturally, but it is aided traditionally by hitting the structure on a hard surface or with a machete in order to rupture it. After about a week, the rotten seed-containing pulp is scooped into a basket. Loose material leaches out, leaving the seeds which are washed and sun-dried.

Sundrying precedes other steps for treating cereal heads to release grains and for shelling legumes and other fruits like the castor seed. Dried millet, sorghum, and rice heads or husks are threshed on hard ground or pounded lightly in a mortar to detach the grains; rice is invariably pounded. Mixtures of grains or seeds are winnowed with flat winnowing baskets. Then manual screening separates the food material from the chaff.

On a large-scale sun-dried pods of legumes such as the cowpea (*Vigna* sp.) are packed in jute bags, and then shelled by being beaten by sticks or trampled upon. One method of separating mixtures of seeds and chaffs is to spread them on a mat across a distance of 4–5 m. The lighter chaffs fall-off during the throwing, and denser seeds are retained on the mat.

Overall, first-stage processing eliminates bulky wastes from harvests and prepares foodstuffs for markets and for further processing. The products mostly remain inedible or unpalatable.

In second-stage processing, foodstuffs undergo textural and organoleptic modification to yield palatable products or flours and oils. Two categories of second-stage processing will be treated—those not involving fermentation and those which are fermented.

Cooking with water, frying in oil, and roasting are commonly used methods. Individual cooked items or suitable mixtures may be pounded into sticky doughs and eaten with relishes. Pounded yam is popular in West Africa, and small amounts are also used for thickening soups or relishes. Ordinary cooking suffices for preparing some cocoyam (*Colocasia esculenta*) varieties but at least one toxic variety is detoxified by prolonged boiling.

Leguminous seeds are generally cooked and consumed with their skins (testas). However, groundnuts (*Arachis hypogaea*) and the bambara nuts (*Voandzeia subterranea*) are often cooked in the pod and later extracted manually.

Smoking is rarely used for preserving plant-based unfermented foods. In contrast, sundrying is widely practiced. Raw or lightly cooked thin slices of sweet potatoes may be so preserved in Zimbabwe, but thinly-sliced cassava is cooked and washed thoroughly before sundrying, to remove the cyanide and guarantee a safe product. In the Chad Republic, mats of *Spirulina*, a microscopic alga which grows in ponds around Lake Chad, are sun-dried for use as a vegetable in local sauces.

Roasting is traditionally carried out with a burning or glowing fire and is commonly applied to tubers and plantains. Among the legumes, only groundnut seeds are roasted. Cowpea seeds are dehulled, without roasting, by first soaking them in water overnight. Placing the container on the surface of water in a deep bucket or pan makes the testas float, and they are skimmed off. Wet dehulled cowpea seeds are pounded further and ground into a slurry which is seasoned and fried in hot palm oil to form palatable balls called *akara* in Nigeria.

Many kinds of dried foodstuffs are processed into flours. In Southern and Eastern Africa, flours from grains are called meals, as in maize meal, and production begins with pounding and winnowing to remove coarse chaffs. The grains or the mortar are then moistened to prevent scattering during a second pounding. The material is then sun-dried for a few hours and finally ground on a grindstone. The finished meal is sun-dried on a mat before storage or use.

Yam and sweet potato tubers are peeled, chipped, and blanched by soaking the chips overnight in hot water before sundrying, pounding, and grinding. In processing cassava flour, chips of peeled and sun-dried tubers are ground.

Many other types of foodstuffs are processed into flour. Shelled groundnuts are roasted and ground for meat seasoning in Nigeria and as a source of butter in Zimbabwe. Various dried spices are also processed into powders.

Cooking oil is extracted from raw or cooked palm fruits and from roasted groundnut seeds. By pounding oil palm fruits in a deep mortar the oil-laden fibrous pericarps are abraded from the kernels which are sorted manually. Batches of the fibrous mass are subsequently warmed in a wide-mouthed earthenware pot to melt the oil. Then suitable portions are pressed between the palms of the hands and the oil flows into a bowl or other container.

Food processing by fermentation is widespread in Africa and various cultures have developed methods of fermenting selected food resources for different purposes. Virtually every kind of foodstuff can be fermented, and suitable processes produce heavy main course meals, condiments, and flavor enhancers, nonalcoholic and alcoholic beverages, meat substitutes, and foods for the elderly, infants, and the convalescent.

Cassava tuber is processed mainly by fermentation to detoxify it by eliminating the cyanogenic glucosides linamarin and lotaustralin and to impart desirable flavors. Important fermented products from grated material include *gari* (West Africa), *attieke* and *plakali* (Ivory Coast), and *oyoko* (Zaire).

Major products of fermenting cassava are *chikwange* (Central Africa), *ntuka* (Zaire), and

fufu (Zaire and Nigeria). The fermentations are retting processes because they soften the tubers. For *chikwange* and one form of Nigerian *fufu* the fermented pulp is mashed and sieved through a basket into a cloth bag; the solids are concentrated by pressing the water out. Meals are prepared by steaming portions of the processed material, and then kneading, boiling, and pounding into a gel. In Zaire the fermented pulp is steamed (*ntuka*), or sun-dried, milled, and cooked (*fufu*).

African cereal-based fermentations result in diverse foods and beverages which satisfy different nutritional needs. Maize (*Zea mays*), sorghum (*sorghum bicolor*), and various millets – pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*) – are the fermentation substrates and products include acidic porridges, nonalcoholic beverages, and opaque beers.

The first step in preparation of acidic nonalcoholic beverages and porridges is soaking the cereals. Subsequent sieving, sedimentation of solids, and decantation of liquor leaves a product which can be molded into various sizes for sale. They are particularly useful for infant weaning and convalescent feeding.

Examples of acidic nonalcoholic drinks are Southern African *mahewu*, Nigerian *kununzaki*, and Sudanese *hulumur*. In *mahewu* preparation, a suspension of maize meal in boiled water (1:9) is cooked and cooled. Some wheat flour is added and the drink is ready after a day's fermentation. Nigerian *kununzaki* uses flour produced by grinding grains soaked in water for 1 or 2 days. Sudanese *hulumur* is prepared by flavoring cold water with flat sheets of fermented and baked sorghum dough prepared with equal amounts of flours from malted and unmalted sorghum.

African acidic alcoholic beverages are produced from malted grains. Malting involves germination of the appropriate grain followed by malt grinding and mashing in warm water to saccharify the malt. Unmalted grain or another carbohydrate source may be added to the mash before fermentation, which may proceed naturally or by induction with a starter from a previous brew.

Clear beers are relatively rare in Africa. Nigerian *otika*, Cameroonian *amgba*, and Sudanese

assaliya are exceptions. *Talla* is an Ethiopian home-brewed beer which differs from the others in some respects. First, it is brewed with barley or wheat, hops, or spices. Secondly, it has a smokey flavor due to the addition of bread darkened by baking and use of a fermentation vessel which has been smoked by inversion over smoldering wood.

Sugary plant juices and saps and honey are the substrates for wine and spirit production. West African palm wines are produced by fermenting saps from oil palm trees (*E. guineense*) and from *Raphia* palm trees (*Raphia* spp.). In Zimbabwe sap from the ilala palm tree (*Hyphaene benguelensis*) is fermented into wine, while in Northwest Africa a wine called *lagmi* is produced from the sap of the date palm. Over-ripe bananas and plantains are also used for wine production in Southwestern Nigeria. For West African palm wines, the best known, fresh juice tapped into gourds contains up to 10 % sugar and has a neutral pH. The fermentation occurs naturally and in 24 h lowers the sugar content considerably, acidity develops, and alcohol builds up so that the wine becomes intoxicating.

Spirits are processed in Africa by distillation of fermented sugary substrates. Zimbabwean *uchema*, Nigerian *ogogoro*, and Ghanaian *ekpeteshi* are distilled from Zimbabwean ilala palm wine and from West African palm wines. Kenyan *chang'aa* and Nigerian *kai-kai* are distilled from fermented cane sugar juice. Generally the alcoholic content of African spirits ranges from 20 % to 30 %.

Food fermentations based on oilseed and leguminous seeds are sometimes called vegetable protein fermentations. West African *iru* or *dawadawa* (from locust bean), *ugba* (from oil bean), various *ogiris* (from melon, fluted pumpkin, *Telfaria occidentals*, castor bean and sesame), and Sudanese *sigda* (from sesame oilseed press cake) are fermented vegetable protein foods, and they are flavor enhancers.

Sudanese *kawal* produced by fermentations of leaves of a toxic legume *C. obtusifolia* and Nigerian *ule* are examples of African food products of leaf fermentation. *Kawal* and *ule* are flavoring materials for stews and other relishes.

Meat fermentation is uncommon in West Africa. However in Sudan virtually every part of a carcass including bones, hide, and gall bladder juice is fermented for food purposes. Fermented gall bladder juice is called *itaga*. It is prepared by adding some sorghum flour or grains to the juice which is then hung up to dry slowly. *Itaga* is pounded and used as a kind of spice for fatty meat dishes.

Fish is processed like meat, and fermentation is also uncommon. It appears to be a last resort for preserving a day's unsold catch. *Bonome* and *guedj* are fermented dried products of Ghana and Senegal, respectively. Fresh fish is allowed to undergo putrefactive fermentation in the open air for 20 h. It is then eviscerated, soaked in salty sea water, and dried in the sun for 2–4 days with or without filleting. Sudan has a variety of fermented fish products including pastes and sauces prepared from fresh water Nile fish.

Many insects, especially gregarious and seasonal types, were traditionally acceptable as food in Africa. Examples are locusts, swarming winged reproductive termites, the large cricket (*Brachytrypes*), and caterpillars of the African silkworm (*Anaphe* spp.). Traditional processing of insects included cleaning and salting, then roasting or tying in parcels and boiling. Although the practice is now restricted to isolated areas of the continent it is noteworthy that in Zimbabwe the commercial product *madora*, also called mopane worms, consists of edible caterpillars. *Madora* is available in markets or in supermarkets. The caterpillars are generally squeezed after capture to press out the digestive fluid, then salted and preserved by sundrying.

The art of fermenting milk is widespread in Africa. Cattle and camels are important dairy animals, and milk fermentation products vary widely. For example, *jben* and *ayib* are Moroccan and Ethiopian cheeses, *nono* is a Nigerian yoghurt-like product, and Zimbabwe and Sudan also have fermented milk products. African milk fermentations occur naturally with attendant souring or coagulation, the milk having usually been collected into clay or earthenware pots or animal skin bags, gourds, or calabashes. They are often churned to produce butter. Moroccan *jben*

is prepared by placing the coagulated milk (*raib*) in a cloth at room temperature and draining the whey. In Kenya various additives such as wood ash, animal blood, urine, and sometimes leafy vegetables may be added to preserve a fermented sour milk called *maziwa lala*.

Scientific Bases of Some Traditional Practices

African traditional food processing is a cultural activity which evolved independently from modern science and technology. Nevertheless valid scientific explanations can be offered for many food practices.

In many traditional fermentations, starters consisting of small amounts of previously fermented materials are introduced into new processes. Scientifically speaking, the starter contains a dense population of relevant microbes which accelerate the new process. Also, most fermentations are carried out in warm conditions, or fermentation time is prolonged in cold weather; these practices are consistent with scientific knowledge of beneficial and adverse effects of warmth and cold on the growth and activities of microbes.

Traditional food preservation with plant extracts is exemplified in the processing of Nigerian palm wine and *nono* with *nche* and *kuka*. Both preservatives inhibit spoilage microorganisms by means of chemicals: *nche* contains phenolics and alkaloids, and *kuka* contains tartarates. Again, the use of small amounts of urine, among other things, for improving the shelf life of Kenyan sour milk has been explained in the context of the lactoperoxidase system which inhibits Gram negative, catalase positive bacteria in milk. Traces of hydrogen peroxide and thiocyanate are known to be present in urine and these may exhibit antimicrobial effects together with lactoperoxidase which normally occurs in bovine milk.

Traditional food softening or flavoring with extracts from ashed monocot heads or husks is exemplified by the use of Sudanese *kambo* from sorghum, Nigerian *ngu* from palm oil husk, and

Zimbabwean products from yellow nut grass (*Cyperus esculentus*) and maize cobs. Ashing concentrates inorganic elements, and high levels of potash in the leachates influence flavor and soften foods by hydrolysis.

African traditional food processing involves diverse food resources, equipment, practices, and products. Productivity is low, and final products often lack good hygienic quality, uniform composition, and predictable shelflives.

Research efforts to modernize food-processing systems have been intensified in African institutions. Production of Southern African opaque beers and *mahewu*, Nigerian *gari*, *dawadawa*, and *poundo* yam have become industrialized, and microbiologically safe processes have been developed for production of Moroccan and Ethiopian dairy products. These developments are encouraging and continuing research efforts will probably assist future generations in preserving Africa's rich traditional food heritage.

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Food Technology in China

H. T. Huang

Agriculture started in China with the domestication of rice in the middle reaches of the Yangtze Valley at about 8000 BCE. Rice was followed by millet (at about 5000 BCE), wheat and barley (1500 BCE) and soybean (1000 BCE). In the classical period (1000–200 BCE), the principal grains of the realm were millet (both panicum and setaria), rice, wheat, barley, and soybean. Much ingenuity was expended by the Chinese to develop methods for processing these crops into attractive and nutritious articles of food and drink.

The kernels of both rice and millet are relatively soft. They were steamed to produce tender, palatable granules called *fan*. Pottery steamers of great antiquity (4000–5000 BCE) have been found in the neolithic sites in Banpo near Xian in the north, and at Hemudu near Hangzhou in the Yangtze delta. It was probably the use of steaming that fortuitously led to the discovery of a

distinctive technology for the conversion of cereal grains into alcoholic drinks.

The Discovery of *Qu* (Chinese Ferment)

The fragrant, fluffy *fan* granules obtained by steaming rice grains were not only appetizing to humans, but also highly attractive as a medium for the growth of airborne fungi, such as those of the genus *Aspergillus*, *Rhizopus*, or *Mucor*. As these fungi proliferate they produce enzymes which hydrolyze the starch in the granules into fermentable sugars. Yeasts then multiply on the hydrolyzed granules and convert the sugars to alcohol. This mixed culture of fungi could be used to inoculate larger amounts of *fan* to produce an alcoholic drink, or dried and stored as a stable solid product known as *qu* (translated as *ferment*) for use in future fermentations. As we shall see, in addition to its role in alcoholic fermentations, *qu* ferment was the foundation upon which a rich array of fermented foods were later developed.

Alcoholic Drinks

The use of *qu* to make an alcoholic drink or wine called *jiu* was probably practiced in China as early as 2000 BCE. The technology for *qu* and *jiu* reached a mature level by the Han Dynasty (206 BCE–AD 220). Extensive recipes for preparing varieties of *qu* and *jiu* (as well as vinegar from it) are given in the *Qimin yaoshu* (Important Arts for the Peoples' Welfare), of AD 544. In making wine, *fan* (steamed millet or rice) was mixed with *qu* and the semisolid medium allowed to ferment until the substrate was depleted. The semisolid mash was then pressed and clarified to give the finished wine. One interesting innovation was the cumulative addition of fresh *fan* to the medium before the substrate was spent. This technique made it possible for skilled brewers in the sixth century to produce wines with alcoholic contents that were comparable or even superior to those of grape wines in the West.

During the Song Dynasty (AD 960–1280) the art of heating the wine before storage, later called pasteurization, was introduced; a red *qu* based on strains of *Monascus* sp. was developed, leading to the production of the so-called yellow or red wine. Although bronze stills were known as early as the Han, distilled spirit did not become commercial until after the Song dynasty. The fermented mash was placed directly on a grid in a boiler and the alcohol carried over by steam distillation. The result was a spirit with a strikingly rich flavor and an alcohol content of greater than 50 %.

Malt Sugar

Sprouted rice or millet, *nie*, was of equal antiquity as *qu* in China and it has been suggested that some of the earliest wines might have been made with *nie* as the saccharifying agent. But soon *qu* displaced *nie*, and the *nie*-based fermentation died out. *Nie* from wheat or barley, however, lived on as the agent for converting steamed millet or rice into malt sugar, the most important sweetener in ancient China. Although its importance declined somewhat when the refining of sugar from sugar canes was introduced from India in the Tang Dynasty (AD 618–905) malt sugar continued to be a popular treat in the Chinese diet until the present day.

Products from Wheat Flour

Since the kernels of wheat are hard, they cannot readily be made palatable by boiling and steaming. Thus, wheat was less popular than millet or rice in ancient China. However, the situation changed during the Han when mills for grinding wheat into flour or *mian* became widely available. The dough made from *mian* could be processed into a dazzling variety of delicious pastas, cakes and breads (including leavened breads). Most of these products were cooked by steaming or boiling. As a result, wheat flour soon

became the staple food in the North while rice remained the staple food in the South.

Probably the best known Chinese food processed from wheat flour is the filamentous noodle, *mian tiao*, which was first made in the second century AD. There is, however, no evidence that Marco Polo ever brought filamentous noodles from China to Italy. Filamentous pasta was already known in Italy before Marco Polo was born. It appears likely that the concept of filamentous noodles had traveled from China to Italy by transfusion along the Silk Road in the tenth to twelfth centuries.

Another important product processed from flour is wheat gluten *mian jin*, an valuable source of protein for vegetarians. It is obtained by the continuous washing of wheat dough with water. The phenomenon was first described in the *Qimin yaoshu* (AD 544), but gluten did not become a popular component of Chinese foods until the Song.

Soybean Processing

Although soybean is an excellent source of protein, it is hard to cook and difficult to digest. Three methods have been developed to process soybeans into wholesome, attractive, and nutritious products. The first is simply to allow the beans to sprout in the dark. Soybean sprouts were known before the Han as a medicament; they did not become popular as food until the Song. Since then sprouts from both soybean and mung bean have remained standard fare in the Chinese diet.

The second method is to process the beans into *doufu* (bean curd). The steps involved are: (1) soaking the beans in water overnight, (2) grinding the beans to a puree, (3) filtering the puree through cloth, (4) heating the milk to near boiling, (5) adding a coagulant, such as bittern, to the cooled milk, and (6) pressing the soft curd in a wooden frame. The procedure is depicted in a mural in a late Han tomb (second century AD), although the product did not become commercialized until the late Tang.

Since then *doufu* has been the most important vegetarian source of protein in the Chinese food system. Soymilk, however, was not accepted as a food until the eighteenth century.

The third method is to ferment the cooked beans with *qu* in a high salt medium to give a triad of relishes and condiments; they are *shi*, fermented bean relish, *jiang*, fermented bean paste, and *jiang you*, soy sauce, probably the best known processed soybean product in the West. When cooked soybeans were incubated with *qu* and salt, the product was *shi*. When they were incubated with *qu*, wheat flour and salt, the product was *jiang*. Both *shi* and *jiang* were already made on a large scale in early Han. Recipes for their preparation can be found in the *Qimin Yaoshu*. Soy sauce was simply the liquid drained from *shi* or *jiang*. It was known during the late Han, but the name *jiang you* did not come into common usage until the Song.

Much of this distinctive food technology was transmitted to Japan during the Tang and later dynasties. Thus, *qu* and *jiu* are known as *koji* and saké in Japan; *shi*, *jiang* and *jiang you* evolve into *natto*, *miso* and *shoyu*; while *doufu* remains as *tofu*. All these products have become integral parts of the food system in Japan, Korea, and Vietnam. They are now gaining acceptance in the West.

However, the best known dietary product from China is actually a drink. Tea was first prepared by steaming, crushing, and drying the leaves of *Camellia sinensis* during the Han. It became widely popular during the Tang, and was disseminated to the West in the seventeenth century. Tea and coffee are now the two major beverages consumed throughout the world.

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Food Technology in Latin America

Judith Vidal

About 5,000 years BCE, native populations in the Caribbean and Latin America developed food technologies which enabled them to exploit their natural biota and become settled. By the time of the Columbian encounter, Indians had evolved unique agricultural techniques suitable for efficient food production in various terrains and climates. Their indigenous staples were cassava (*Manihot esculenta*), maize (*Zea mays*), potatoes (*Solanum tuberosum*), and yams (*Ipomea batatas*), beans, and squash supplemented by fruits and vegetables, fish, turkey, deer, dogmeat, and guinea-pigs, as well as assorted beverages and flavorants.

Food technology began with soil preparation and with the selection of seeds, roots, tubers, or cuttings. The ground was cleared through slash-and-burn and girdling, which is removing a ring of tree bark. Farmers then worked the earth into numerous knee-high mounds several feet in diameter (*montones*), collectively called *conucos*, among the stumps in irregularly shaped fields, or *milpas*, fertilized by ashes and decaying vegetation. These mounds produced less water runoff, and hence less erosion, than traditional European fields plowed in rows.

In the Caribbean, Middle America, and South America, *conucos* were planted with bitter cassava, with a vegetable triad such as maize-beans-squash, or with potatoes in the Andean highlands. In the lake regions of Mexico, floating garden islets (*chinampas*) formed of dense intertwining

roots covered with soil and plants could be paddled over the water. In the Andes, irrigated stone-walled terraces (*andenes*) allowed farming steep grades in narrow strips at higher altitudes dominated by llamas, quinoa, and potatoes, descending in ever broadening tiers to cacao, cacti, and tropical fruits at lower levels, each with its own biota, creating a diverse diet in a small vertical space. Where the parched soil of valleys was unyielding, natives removed the earth's surface in expanses as large as an acre to form *hoyas* (pits) which reached natural moisture and permitted cultivation.

Indians learned to cultivate strains of indigenous flora by taking cuttings, by planting tubers, or by carefully selecting seeds which they planted individually in small holes poked by a planting stick called a *macana* in the Caribbean and a *taclla* in the Andes. These methods produced more uniform quality than European broadcast seeding and resulted in higher caloric production per acre than Old World counterparts of wheat, rice, millet, and barley.

The bitter cassava (also known as *yuca brava*, manioc, mandioca, tapioca, and *farinha*) roots from 2 to 6 in. in diameter were dug up, peeled, and grated. The wet pulp was then stuffed into long mesh baskets and hung from a beam which allowed for twisting to express the poisonous prussic acid. When the toxic juice was removed, the pulp was forced through basket sieves or pounded, and the resulting flour was spread in flat three-foot cakes on hot stone grills or dried and stored for later use. The poisonous liquid was safe to drink after boiling. From Colombia southward down the Pacific coast of South America, a nontoxic sweet cassava was similarly processed and often made into preserves.

The true staff of life for most of Latin America was maize. This Indian corn occurred in hundreds of varieties and colors. Indigenous cultures hybridized the silky tassels by hand to breed the most desired traits. Some kernels were so hard they had to be soaked or chewed before boiling gruels. Women pounded grilled kernels with stones to produce a flour meal for tortillas or other dishes. Dried grain was also stored indefinitely in elevated, aerated storage silos.

Indians of the upper Andes invented freeze-dried potatoes by alternately exposing the tubers to night frost and sunshine. Within a few days all the water was removed, leaving a potato preserve called *chuñu* which could be further whitened or reconstituted by steeping in water. Lightweight and easily transported, the *chuñu* could be preserved indefinitely like cassava or maize. There were over 3,000 types of potatoes, sweet potatoes, ocas, and other tubers. Bean and seed pulses were also important foods throughout Latin America. They too were dried for preservation if not cooked immediately.

In addition to drying, there were several other technologies for preserving foods. These included salting, pickling, fermenting, toasting, and ensiling. Fish was salted as was meat cut into strips. Brine solutions and lime mixtures were also used. Vegetables and fruits were pickled in a variety of herbal vinaigrettes. Fruit and vegetable juices were fermented and distilled into alcoholic beverages which were also used as preserving agents.

Among native beverages, cacao (*Theobroma cacao*) was the most lucrative exchange commodity in New Spain and parts of Peru. Cacao trees were grown by Indians in orchards shaded by large "mother" trees. When the large red pods ripened, they were picked, and hundreds of bitter-tasting seeds were removed by chewing the luscious fruit. The sun-dried seeds were used as money or ground and roasted for a bitter brew restricted to nobles and ceremonial rites. Under Spanish colonization, the chocolate beverage gained widespread popularity in Mesoamerica.

In the Pampas, another stimulating beverage came from a native tea known as *maté*, steeped in boiling water like East Indian varieties. When coffee was introduced to tropical Latin America, it was prepared much like cacao and was widely consumed. All three of these nonalcoholic beverages grew in popularity with the increasing availability of sugar and vanilla which replaced pepper as the preferred seasoning.

In addition to flavor enhancement, many herbs and spices were used to preserve foods and to add medicinal benefits. Seaweed supplemented natural salt sources in Andean diets to protect natives

from goiter. Tropical fruits added vitamin C. Cinnamon, cloves, and capsicum peppers preserved as well as flavored foods. Sarsaparilla was a refreshing beverage which soothed gastrointestinal ailments. Another vegetable product, *guayacán* treated syphilis while *cuasi*, a valuable insecticide, also eased fever symptoms. The most important treatment for malaria came from quinine or *chinchona* which remains a viable cure as well as a popular tonic water.

Alcoholic beverages were consumed in moderation before conquest. In Mexico, the agave or maguey was fermented and distilled into pulque, mezeal, and tequila. Maize was fermented into a beer-like beverage called *chicha* which was popular throughout Middle America and the Andes. *Chicha* could also be fermented from a variety of fruits. Other alcoholic beverages came from fermentation of potatoes, cassava, and tropical fruits such as pineapples and bananas. These were sometimes mixed into brandy called *aguardiente*. None of these beverages became popular in Europe, but rum – fermented from cane sugar – became commercially successful throughout North America and Europe.

Prior to European contact, indigenous populations had few meat sources and no beasts of burden other than the llama and the dog. With the introduction of horses, cattle, oxen, sheep, swine, goats, mules, and donkeys, they gained transportation, meat, and power to plow, haul, and operate mills. They also received protein-rich meat and dairy supplements to their diets. By-products from domesticated and feral herds included fibers, leather, tallow, bones, and horns.

Among the food cultigens brought to the New World, the grape-grain-olive culture remained heavily European. Sugarcane and coffee, however, dominated enormous regions where native labor consumed the stimulants while working plantations. Both commodities were labor-intensive requiring hand planting and harvesting. Sugar works (*trapiches* or *engenhos*) used human, animal, or water power for the crushing mills which released the sugary syrup. Slaves operated a train of boiling vats to purify and clarify the liquid for evaporation. The resulting muscovado sugar was 96 % pure and was

packaged in cones or loaves for shipment to European refineries. Hand-picked coffee beans were spread on patios to dry before roasting and shipping.

Many of the technologies used by indigenous populations are practiced today throughout rural areas of Latin America. Scientists are studying their techniques and lore for insights into environmental protection, expanded food production, and medicinal applications. Global dietary diversity has been accompanied by language enrichment as a result of food exchange. As a result of Latin American food technology, words such as barbecue, olla, mezquite, cassava, tapioca, quinine, banana, palm, tomato, etc. have joined the alimentary menu.

The Indians practiced ecological efficiency and perspicacity unrivaled by the colonial powers who imposed a wheat-wine-oil-meat agriculture in lands more suited to manioc, maize, and potatoes. None the less, dietary diversity has been enhanced throughout the world as a result of native Latin American technologies which first unlocked the secrets of preparing and preserving exotic New World foods which have become staples for subsistence.

See Also

- [Crops in Pre-Columbian America](#)
- [Ethnobotany](#)
- [Potato: Origins and Conservation of Potato Genetic Diversity](#)
- [Sugar in Latin America](#)

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Food Technology in the Pacific Islands

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The range, variety and sophistication of food preserving and commercialisation activities throughout the Pacific Island Nations (PINs) are as varied as the climate, agricultural framework and culture. The techniques so necessary for basic survival have been the foundation of food preservation but the practises have been refined and expanded since European arrival. Countries such as Fiji and the Marshall Islands are now home to highly sophisticated food processing operations sponsored by multinational companies that have been attracted by tax incentives and relatively low wage rates. The ethos of food processing and food exploitation has infiltrated wider communities as the international food standards defined by Codex Alimentarius have been adopted by *inter alia* Vanuatu, Samoa, Tonga, the Cook Islands and Fiji. Countries such as Kiribati and the Federated States of Micronesia remain at the other end of the spectrum but the importance of maintaining food quality has been strengthened by the mandatory conformance to the hazard analysis and critical control points (HACCP) system of quality maintenance for economically important fish exports to the US and EU markets (Beyer, 2000, 2003a, 2003b, 2003c). The welfare of the people of the Pacific nations is nevertheless highly dependent on subsistence farming and traditional preserving techniques (Laban & Swain, 1999) particularly of fish and starchy staples – cassava, taro, plantain, yam, breadfruit and sweet potato (Bradbury, 1987).

Traditional Preserving Techniques

Historically, processing has been confined to practises that will preserve foods to reduce waste and to extend availability, particularly for foods with very short seasons (Atkinson, 1990;

Beyer, 2001; Greenwell, 1947; Kordylas, 1991; Kwatia, 1986a, 1986b, 1988; Parker, 1967; Root Crops Development Newsletter, 1982; Root Crops Processing, 1993). Traditionally, foods have been preserved using techniques that exploit environmental factors (Atchley & Cox, 1985; Atkinson). Sun drying has been used extensively as a means of extending shelf life because of the high ambient temperatures prevalent in the tropics. The process is benign – fish, occasionally pork, vegetables and fruits are merely sliced and laid on racks to dry. If prevailing conditions permit, the foods reach a final moisture content that will inhibit mould growth and the products are edible although not always appetising. In many cases vegetables turn brown, mould may grow before the drying process is completed – or occasionally later if the dried food reabsorbs water as a result of increases in relative humidity during storage. Other products may bleach and become tough.

A number of readily available chemicals have been used to stabilise foods. Salt obtained by sun-evaporation of seawater has been smeared onto root crops to prevent bacterial and mould growth. In other cases, the vegetables are dipped in seawater prior to drying and the salt concentrates during the drying process. Sun-dried lime segments and evaporated lime juice have been used to increase the shelf lives of some root crops and bananas – the vitamin C and the low pH (citric acid) both act as preservatives. Dusting with wood fire ash has been used to prolong the shelf life of breadfruit and yams. In this case, the high pH is hostile to moulds and other bacteria.

Many of these traditional preserving techniques continue to be appropriate for the preservation of root crops in the rural areas. Political upheaval in countries throughout the region has retarded economic progress, and economic empowerment has proceeded at rates below aspirations. Traditional food preservation techniques remain relevant but the end products enjoy declining popularity – particularly among the young. Some of these traditional products continue to appeal to older members of the community and to older expatriates now living in Australia, New Zealand, Canada and the USA.

As a natural evolution, there are isolated instances where those products have formed the basis of export industries. Where markets have persisted for traditionally preserved foods, processes have been standardised with conformity in manufacturing techniques.

Nutritional surveys around the region however indicate that the consumption of traditional foods is decreasing. Such industries as the garment industry and tourism have provided increasing employment for women. As their time for food preparation has become eroded, they have become less tolerant of traditional foods such as yams, cassava and taro in favour of more convenient (often cheaper and lighter) alternatives such as rice and flavoured noodles (FNFC, 1997, 2000; Food Security: The New Millennium, 1999; Hodge et al., 1997; Paterson & Crossland, 1999).

Travel, tourism urban drift television and other lifestyle changes have transformed food choices in the PINs. Although much of the food is imported, local entrepreneurs have copied and modified a number of these imports and form the basis of a wide range of small scale processing operations (Beyer, 2001).

Conventional Preserving Techniques

Dehydrated Products

The cost of removing moisture from foods rises exponentially as the moisture content drops (Brennan, 1994). Thus it is in the processors' interest to remove only that proportion of water that impinges on the keeping quality of the finished product. Not only are processing costs reduced to a minimum but also the product retains some water, which adds to the weight. Unfortunately, intermediate moisture foods (a_w values between 0.35 and 0.6) deteriorate unless they are protected with preservatives, humectants or antioxidants. Only at very low moisture contents (a_w values <0.3) is deterioration kept to a minimum. The exceptions are non-hydrolytic reactions, which usually take place in fats and oils. Rancidity will continue in low moisture foods and may occur even faster than in moist foods because the reactants are very concentrated

by the lack of moisture. It is important therefore that low moisture foods are protected with antioxidants. Antioxidants such as butylated-hydroxy-toluene (BHT) and butylated-hydroxy-anisole (BHA) and even ascorbic acid can be used.

Recent innovations in dehydration and drying are directed towards reducing the relative humidity of the air used for drying by removing the water vapour rather increasing its temperature. So-called heat pump dryers pass heated air, which has previously been used for drying, over cooling coils. The water vapour in the drying air condenses on the cooling coils and thus the relative humidity is reduced. The same air is used repeatedly on this drying cycle. The low temperatures used in this technique cause less oxidative damage and food dried by this means is usually much higher quality. The heat pump dryers are used in some PINs for products where ultimate retail price advantage justifies the capital expenditure and the running costs, which in turn depends on the cost of electricity.

Throughout the PINs some success has been achieved in early trials using secondary air dryers. Secondary air dryers rely on drying an intermediary component – commonly coconut husk using wood-fired drying kilns. Ambient air is then circulated around the pre-dried coconut husk, which removes the water vapour. This reduces relative humidity of the air that is then passed over the food. The food – particularly in the latter stages of drying – is not subjected to high temperatures and therefore suffers less deterioration.

Modern processing techniques have been applied to a number of products including dried cassava dalo, fruit slices and some thinly sliced fish. The sliced product is immersed in a solution containing 150 ppm of sodium metabisulphite (or 200 ppm ascorbic acid). For vegetables they use 1–3 % w/v of sodium chloride (soy sauce is used sometimes especially with fish). The slices are then dried on racks in a heat pump drier. The maximum outlet temperature of the drying air is 55 °C, which is sufficiently low to prevent browning due to caramellisation of the simple sugars. The relative humidity of the outlet air is 55 %, F

which gives a value for water activity of a_w of 0.55. Some sulphite is lost during the later stages of drying as sulphur dioxide.

These products are then shelf stable and do not brown on storage. Residual polyphenolase activity is inhibited by sulphite or ascorbic acid.

Dried granules from the starchy staples have also been developed as the raw material for extrusion. Extrusion technology has been applied to corn and rice starch and combinations of them. During extrusion, granules are forced at high pressure through a heated die. At the very high temperatures and pressures, the starch molecules align in the direction of shear and superheated water boils off rapidly as the pressure on the mass is released. This opens out the matrix to give the familiar honeycomb texture, which is a characteristic of puffed snack foods. Cassava granules in particular perform very well using this technology and preliminary trials have indicated that cassava is a likely candidate for future research and development (R&D) programmes.

Canning

Dalo, cassava, breadfruit and some local vegetables (e.g. *duruka*) and fruits have been canned and exported for some 12 years. The very high temperatures used in canning are responsible for significant damage to the texture and flavour of fruits and vegetables. The products have very soft textures and the heating regimen results in warmed over flavours characteristics of Amadori compounds. These quality characteristics are thus significantly different from fresh items. The market is somewhat resistant to such quality features and sales are consistent but small. Similar products canned in coconut milk are marginally better and sales figures are higher but coconut milk supplies are inconsistent.

Fruit and vegetables processed in retortable pouches (polypropylene/aluminium/foil/nylon/polyethylene laminate) have better quality characteristics because the heat penetrates to the centre of the pouch faster, but the technology is not readily available in the Pacific region (overpressure retort).

Conventionally canned fish (tuna) is the largest single item of canned food produced and

exported from the Pacific region with very large factories in Fiji, American Samoa and the Marshall Islands and smaller factories located in Tonga and Manu Samoa.

An alternative technique (Beyer, 1998) is a multiple pasteurisation technique. Foods are packed in polyethylene/nylon bags and vacuum-sealed in such a layout that the products are not touching and that heat can reach every food surface. They are then immersed in boiling water for sufficient time for the heat to penetrate through the bags so that the surfaces of the foods reach at least 80 °C for 15 s. The pouches are then cooled using cold water to prevent over cooking.

In low acid foods, this is sufficient to destroy the vegetative cells of bacteria but not the spores of thermophilic organisms. However the heat shock is sufficient to encourage germination of the spores. These are then destroyed by pasteurising again 24 h later by immersion in the boiling water bath for enough time for the temperature at the surface of the vegetable to reach 80 °C for 15 s. As an extra insurance measure, the package is heated in the same way on a third day. This is sufficient to destroy surface bacteria. With carefully handled vegetables, the deep tissue will be sterile. Thus this technique should result in pack sterility. In the event that the packs are still not sterile – which would be manifest by blowing – the product can be reheated for a fourth time since the heat penetrates to the same depth each time and damage to the product is still confined to the outer surface. The technique means that relatively little heat is applied to the surface of the vegetable and the damaging effects of the heat penetrate only a short distance into the tissue. The vegetable has the appearance texture and taste of fresh vegetables.

Freezing

In the short period of 30 months preceding May 2000, an export industry in free-flow frozen root crops was established, which peaked in February of 2000. At its maximum volume, 66 tonnes/month of frozen cassava were being exported to Australia (Beyer, 2000). Much smaller volumes were destined for New Zealand. Trial shipments were also sent to Japan, but large-scale exports

were not possible because of cyanide levels that exceed Japanese standards. An unexpected demand has arisen for frozen root crops however, and production level is well below market demand.

Fry Drying

There is now a plethora of small fried snack root crop and plantain producers throughout the PINs. Products are becoming commonplace and some are emerging as export products. Entrepreneurs are encouraged to use these products as a basis for increasing market depth and width through product development programmes described as more appropriate technology and products. By mixing into dough there are many opportunities to:

- Extend using other ingredients
- Improve acceptability by adding flavours
- Improve nutritional value by adding other ingredients such as carrot and tomato (vitamin A)
- Add improvers to extend shelf life
- Produce more consistent products

The cooking medium can have a significant bearing on the acceptability of the final product. Commonly soya bean oil is used, since it is the cheapest of the frying oils. The viscosity of oils is temperature-dependent. Oil temperature should be high as the product is removed. At high temperature, the oil is mobile and drains from the product easily. At low temperature, the oil adheres to the product, thereby increasing costs (oil is commonly very expensive in the PINs). Fried snack foods with high oil contents are more prone to rancidity during storage, they are nutritionally less desirable and the mouth-feel is poor.

Oils used for cooking should therefore be heated to temperatures a little below the smoke point and relatively small quantities of product added to it, to prevent excessive cooling. Used oil should never be topped up with fresh oil since rancidity is autocatalytic – the products of rancidity catalyse the onset of rancidity. Thus used oil should be stored and allowed to settle. It may be washed with water and the (more dense) water

layer drained. It can then be shaken with dried calcium chloride that can be subsequently removed from the oil by filtering (and re-dried for repeated use). The used oil pooled in such a way can be used for several processes after it would normally have been discarded.

Rancidity is accelerated by ultraviolet light, some divalent metals such as copper, (cast) iron and zinc and oxygen. Product keeping quality can thus be enhanced by high quality processing equipment fabricated from stainless steel and by using packaging material (usually incorporating foil) which is opaque to ultraviolet light and which prevents the transmission of oxygen. Vacuum packing improves keeping quality even further.

An antioxidant – an agent that captures free radicals – will also protect the product. Oils are frequently sold with antioxidant added. The antioxidants of choice are BHA or BHT. Unfortunately, these antioxidants are volatile and are lost after only two or three frying cycles so that they do not carry over into the final product. This assists the oil manufacturer because oil must be replaced more frequently, but the snack food is not protected to the same degree. A preferred antioxidant is tertiary butyl-hydroxy-quinone (TBHQ), which is not volatile and which carries over to the product for longer period. This affords antioxidant protection after the product is packaged and will assist in prolonging shelf life.

Current Food Activity

Commercial factors have been responsible for shaping the current status of food technology in the Pacific region. Unlike more developed regions of the world however, the strong cultural foundations have enriched the industry with the modernisation of traditional food preserving methods. Liberalisation of migration policies has resulted in alarming population movements from the island nations to Australia, New Zealand and the USA, however these immigrants have become nuclei markets for exported traditional foods. More than that, they have become ambassadors in the role of introducing new foods to their newfound fellow consumers.

Hence the region has a spectrum of food-related activity not only in the degree of sophistication of the technology but also in the demands of the markets.

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Forestry in India

Deepa Pande

One of the earliest civilizations of the Indian subcontinent was that of the Indus Valley (third or fourth millennium BCE). It was here that cedar (*Cedrus deodara*) and rosewood (*Dalbergia latifolia*) used for coffins was found. A wooden mortar of ber (*Zizyphus mauritiana*) for pounding grain and charred timber of *Acacia* spp., *Albizia* spp., teak (*Tectona grandis*), haldu (*Adina cardifolia*), and *Soyamida febrifuge* were also found. This shows that Neolithic people not only made extensive use of wood, but also understood its particular characteristics for different purposes. This concept today is known as forest utilization.

Evidence of tree worship during the Indus Valley civilization is exhibited by various seals of the Harappan culture which depict the pipal (*Ficus*) and weeping willow (*Salix*) trees. Trees were an essential and integral part of the life support system and considered existing agencies of the creator of God.

Just as forests played an important part in Vedic India, tree worship was also practiced by the Aryans. Because of the human dependence on trees, they were venerated and protected by religious injunctions; their planting was encouraged by a promise of eternal bliss in future life. *R̥g v̄ eḍa* and *Aṭhar v̄ aveḍa*, basic texts of the Vedic period, contain several hymns praising and endowing trees, plants, and vegetation with various divine qualities, highlighting their medicinal significance, and enunciating the policy of conservation or sustainable management. Various *Upaniṣads*, a later group of philosophical treatises that explain the theology of Hinduism, like *Bṛhaḍāruṇyaka*, *Chāndogya*, *Chulikā*, and *Muṇḍakopniṣaḍa*, conclude that trees had life akin to human life. *Maṭsyapurāṇa* and *Varāhapurāṇa* describe the benevolence of trees along with the rituals of tree planting. *Skandapurāṇa* contains a long list of trees which should not be cut except for the purpose of *yajnas* (holy rituals). Whereas planting of trees led to heavenly comforts (*Agnipurāṇa*) indiscreet felling of trees meant torture in hell.

Vedas also contain valuable information about various species of birds. In *R̥g v̄ eḍa* for instance there is a mention of *Garuda* (eagle), *Mayūra* (pea fowl) along with various Himalayan pheasants, partridges, and other species of birds. Surprisingly *R̥g v̄ eḍa* also mentions not only anatomical details of some common birds, but also details about their staple food. For example *Vartika* (partridges) are said to have well-developed bills, legs, and rounded wings; their food consisted of grain, grass, weed, seed, tender shoots, insects, and even white ants. These kindled the sparks of wildlife management during the later period of civilization.

Great saints and sages who understood these texts, passed on their knowledge and wisdom to their disciples. Such education was given in the *Gurukuls* (schools) which were located in the forests. The students lived in the forests and continued their studies. Thus a sense of tolerance and coexistence with various forms of plant and animal life was infused in early childhood. This *Aranya* (forest) culture provided early exposure to nature study and ecology, as well as the policy

of development without destruction in current parlance. Forest and environment consciousness was thus ingrained into the educational system from the very onset.

Even epics and religious texts written later on describe the protective role of trees and their unlimited usefulness. *Rāmāyaṇa* and *Mahābhārata* describe the rich biodiversity and multiplicity of flora and fauna. In *Bhagwaṭgītā* Lord Krishna compared himself to the *Aśvaṭha* (figus) tree in order to emphasize the importance of trees.

Other religions of that time also mentioned the importance of forests and forestry. According to Lord Buddha it was the obligation of every good Buddhist to plant and nurture at least one tree every 5 years.

Moving along chronologically we find that forest management practices were well documented during the reign of Chandra Gupta Maurya (321–296 BCE). Reliable historical documents, such as the *Indika* of the Greek ambassador Magasthenese, the *Arṭhaśāstra* of Kautilya and the *Mudrārākṣasa* of Viśākhaḍaṭṭa vividly depict various aspects of forestry and wildlife. Kautilya's *Arṭhaśāstra*, recognized as the pioneer work in economics in India, indicates the existence of a regular Forest Department headed by *Kūpyādhakṣa* with definite duties and responsibilities for various officers of the department. Some of the important duties of *Kūpyādhakṣa* were to increase the productivity of forests, classification, price fixation, and disposal of various types of forest produce, raising block plantations of important species (e.g., sandalwood), pasture development in saline-alkaline waste lands, and joint management of forests with people dependent on forests.

Forests were legally classified into three main classes: reserved forests, forests donated to eminent Brahmins, and forests for public use. They were classified into six categories on the basis of crown density, luxuriance, growth, and origin. Planted forests were called *Upvana*.

Forest and game laws were stringent and draconian, containing corporal punishment. The death sentence was envisaged for poaching of elephants. Awards were provided to a person who collected elephant tusks from dead elephants

and deposited them with government officials. Kautilya's treatise also dealt at great length not only with the use of various trees and shrubs, but also with the specific use of various parts. For example it indicated that flowers of *Palās*, *Kusuma*, and saffron are used as dyes, *Munja* and *Love* grass are used for making ropes, and fruits of *Aonla*, *Harara*, and *Bahera* are used as medicines.

Emperor Aśoka adopted and improved these practices. Plantation of fruit-bearing shade trees for the benefit of travelers and common people was started on an ambitious scale. Aśoka was the founder of *Abhyāranya*, the *sanctum sanctorum* of wildlife, now known as National Parks and sanctuaries. Aśoka's edicts at Sarnath Varanasi bear ample testimony to the above.

Forestry flourished during the Gupta period (320–800). *Śukranīti*, a well-known work of that time, throws light on the improvements in forest management practices. Seeds of "Social Forestry" were sown during this era. *Śukranīti* dwells on the concept of village forests, choice of species, afforestation and maintenance techniques, fertilization procedures, irrigation schedules, and measures to increase flowering and fruiting in trees. Names of various multipurpose trees such as *Kaḍamba*, *Sīśama*, *Peepal*, *Mango*, *Nīm*, *Coconut*, and *Imlī* are listed in this policy document for planting near villages. Incidentally many of these are also listed in the latest ICRAF (International Council for Research in Agroforestry, in Kenya) booklets. This shows the worth of these ancient publications.

It is thus clear that in ancient India trees were the best friend of people in a hostile environment. They were held sacred, worshipped, and studied in great detail for service to humanity. Forestry practices evolved gradually, in a scientific and rational manner, and are important even today, although in the modern parlance new names have been coined for them.

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Forestry in Japan

Conrad Totman

Forestry may be defined as "the science and art of forming, caring for, or cultivating forests." Another definition is "the science, the art and practice of managing and using for human benefit the natural resources that occur on and in association with forest lands" (The former definition appears in *Webster's New Collegiate Dictionary* (Springfield, Massachusetts: G. & C. Merriam

Co., 1956); the latter in Grant W. Sharpe, et al. *Introduction to Forestry*. 4th ed. New York: McGraw Hill, 1976. 187, quoting the Society of American Foresters). The former, dictionary definition, leaves unidentified the interests to be served by this “science or art.” The latter, autecological definition, with its explicitly human beneficiary, was propounded by the Society of American Foresters around 1970. It fitted nicely the Japanese approach to woodland for centuries down to about 1980. Since then, however, socioeconomic changes have undermined the established rationale of forest policy, permitting advocates of environmental protection to call for a richer synecological understanding of forestry’s proper purpose.

Factors Shaping Japanese Forestry

In Japan, as elsewhere, forestry has been profoundly shaped by its geographical and social contexts.

By global standards the Japanese archipelago is extraordinarily youthful and mountainous. Mostly formed in the past 15 million years, it is characterized by elaborate dendritic systems of acutely upthrust ridges that are covered with thin, immature soils and incised by narrow valleys down which course fast-running streams that eventually debouch onto slender alluvial plains, most of which front the surrounding seas.

Because of the way continental and oceanic weather patterns interact in the northwestern Pacific region, Japan experiences pronounced seasonal differences and a relatively moist climate during most of the year. And its length from north to south assures it substantial variation in mean temperatures, which range from subtropical in the far south to subarctic in the far north. In consequence woodland vegetation is lush everywhere. But it varies from a thin strip of evergreen broadleaf forest along the southern littoral through woodlands of mixed deciduous broadleaf and evergreen firs (which cover most of the realm) to coniferous boreal forest in far northern regions and at high elevations.

Before the introduction of fully fledged horticultural practices some 2,500 years ago, these richly forested islands supported a very modest population of foragers. Once agriculture was introduced, however, the population grew rapidly, and over the course of two millennia cultivators opened much of the archipelago’s lowland to cultivation or other human use. In the process, forest was eliminated from most lowlands and lower slopes of hilly terrain, an outcome reflected in the language. Forest of any substantial dimension is called *sanrin*, literally “mountain-forest,” while the more basic terms for “woods,” *mori* and *hayashi*, which lack reference to mountains, are ordinarily used when talking about small residual groves of trees or parcels of brushwood that have chanced to survive on or near lowland.

Nevertheless, because Japan is so extensively and acutely mountainous, even today about 70 % of it still sustains woodland. Part of this is plantation stands and part mixed, natural growth, some subject to management, some not.

Within this physical context, forestry in Japan has moved, as it has elsewhere, through two major phases, from a long era of exploitation forestry to a shorter era of regenerative forestry. The latter runs from the seventeenth century to the present but can be examined in terms of preindustrial and industrial-age segments.

Exploitation Forestry

For millennia residents of the islands utilized their woodland primarily for fuel and food. With the development of agriculture, however, food came more and more from arable land, and the receding forest provided, instead, water and fertilizer materials to grow the food, fodder for beasts of burden, construction timber for buildings and gadgetry, and fuel for cooking and various industrial tasks, notably metallurgy and kiln work.

During the seventh and eighth centuries CE, political consolidation gave Japan grand capital cities that housed a ruling elite of unprecedented power and cultural pretension. They adopted new architectural styles and construction techniques

that led to a major increase in the consumption of both timber and fuel wood (see Timber-Handling Technology in Japan). These developments led in central Japan to overcutting that created serious problems – flooding and drought, forest fire, wood and fuel shortages, and intensified competition for control of surviving woodland. On the other hand, because the Japanese did not maintain herds of goats and sheep for milk, meat, or wool, Japan's landscape was spared the devastation they have wrought elsewhere.

In the outcome, although the problems caused by overcutting did gradually become more widespread as Japan's population grew and towns proliferated, it was not until the seventeenth century that broadly effective patterns of remediation began to be devised and applied. They emerged then because a sharp increase in wood cutting and another surge in land clearance were having severe downstream consequences during an era when society was well enough organized so that purposeful woodland regulation and management could not only be needed or advocated, but in fact be devised and implemented in a sustained manner.

Regenerative Forestry

Regenerative forestry can be examined in diverse ways. One approach discusses “negative” policies designed to prevent or contain unauthorized exploitation and “positive” policies designed to foster more, better, or different types of forest performance. An overlapping formulation speaks of “protection forestry,” which is designed to protect the woodland itself and other areas and affairs vulnerable to damage caused by unwise forest use, and “production forestry,” designed to enhance the quality or quantity of woodland yield.

In terms of the former approach, local instances of negative forest policy date from the eighth century, when rulers tried to restrict cutting in select locations. Negative policy became visible again during the 1300s–1400s, when some villages in central Japan began regulating the use of their communal woodland, and during the

1500s, when some regional barons (*daimyō*) tried to protect valued groves and stands from unauthorized harvest.

It was from the 1660s onward, however, that the hegemonial Tokugawa shogunal regime (ruled 1600–1868), the 250-odd daimyo, and villages all across the realm began drafting and enforcing, in woodland within their jurisdiction, regulations to control who might do what, where, when, how, with what tools, and how much yield. Those initiatives developed into a wondrously variegated system of multiple-use rights that allowed diverse people to extract diverse goods from designated parcels of woodland throughout Japan.

Regarding timber specifically – which was of particular concern to the rulers – shogun and daimyo not only regulated the harvest in forests they administered as domanial land, but also began stipulating that no good-quality tree of desirable species was to be injured or felled, save with official permission. And that prohibition applied to all formal categories of land, whether of village, fane, or household, even to include trees standing on a villager's house lot.

To enforce their proliferating rules, shogun, daimyo, and village headmen deployed forest wardens, guards, and patrols to catch rule-breakers. They established fines and other punishments, and they developed and applied adjudication procedures for handling those charged with violation of forest law.

These negative policies, together with vigorous programs of riparian management and repair, did gradually achieve major goals of protection forestry, reducing appreciably the extent of erosion and downstream silting, flooding, and damage. But in terms of production forestry, the rate of harvesting on accessible hillsides was so great that negative policies alone failed to sustain fuel, fodder, fertilizer, and timber supplies at the level of demand. And on numerous lower hillsides, especially those facing the agricultural lowlands of central Japan, overuse gradually destroyed vegetation, creating more and more barren hills and ridges known as *hageyama* or “bald mountains.”

Under these circumstances positive policies designed to promote plantation stands, nurture

mixed forests, and revitalize *hageyama* began to be advocated by government officials, village leaders, and Confucian scholars of the “practical learning” (*jitsugaku*) orientation. During the eighteenth century, moreover, land-use arrangements were gradually modified, creating forms of rental forestry that assured users long-term control of select parcels and their yield. These modifications encouraged landlords, entrepreneurial lumbermen, villages, and daimyo to invest time and wealth in programs of woodland planting and nurturing, confident that in due time they or their successors would recoup the investment.

As interest in reforestation spread, the body of silvicultural writings grew apace, enriched by the testimony of practicing tree farmers. It provided detail – mostly practical and biologically sound – on the selection, collection, and preservation of seeds and cuttings, on the preparation and use of seedbeds, on the transport and transplantation of seedlings and rooted cuttings, on the suppression of competing vegetation, on pest control, on restocking failed shoots, and on nurturing the growing stand to produce wood (or other) products with the desired qualities. Writers also offered advice on the use of rotation-cutting schemes, on techniques of stand valuation and harvest, and on wood processing and storage.

By the decades around 1800, and on into the nineteenth century, both plantation stands and managed forests of mixed, multiaged new growth were becoming valued sources of timber throughout Japan. They eased the overall timber shortage that had spawned regenerative forestry in the first place. And while *hageyama* were still common and much woodland was still poorly stocked, the humanly fostered forest did, by enhancing Japan’s volume of standing timber, help equip the realm to handle the traumatic decades that lay just ahead.

Industrial-Age Forestry

During the 1850s–1860s the global wave of early industrial European imperialism finally reached Japan, where it overwhelmed the decentralized

Tokugawa regime in 1868. The new Meiji government saw its primary task as mobilizing sufficient power not only to stay in office, but also to stop further foreign inroads and to repudiate the concessions previously made. Within this new and radically changed context, there were some strong continuities in forestry thought and practice, but the changes seem more noteworthy.

Both protection and production agendas continued to be clearly visible, the balance between them shifting with the ebb and flow of woodland condition and global context. And much of the existing silvicultural knowhow and procedure continued to be applied in planting, nurturing, and harvesting projects.

Even in terms of silvicultural content, however, change gradually occurred. One factor spurring it was new technology, particularly that of the harvest, which placed great new demands on woodland and its handlers (see Timber-Handling Technology in Japan). More strikingly, the practice of forestry became far more systematized. Whereas Tokugawa-era forestry had utilized precedents from China, Meiji leaders took their cues from current practice in industrial societies, Germany most notably. Starting in the 1870s, a number of Japanese studied forestry there and upon their return helped forestry officials develop new policies and launch new programs. By 1883 that government effort had created a school of forestry, a forestry experiment station, a professional association of foresters, and a research bulletin.

In following decades those trends continued: regional forestry associations proliferated, more and more professional meetings were held, technical matters were debated, and new techniques were tried. Students and officials continued going to Germany to study forestry, and German works on the subject were translated into Japanese. New journals appeared; more experiment stations and forestry training programs were established, and the body of trained foresters and published research findings grew apace.

From the outset Meiji leaders had claimed domainial woodland as government forest, and by the 1890s they had created a Forest Agency and subordinate bureaucracy to manage their

newly unified system of national forests, which encompassed more than half of all wooded acreage. Later, authorities also developed programs of guidance and assistance for owners, mostly small-scale, of the remaining woodland.

On government woodland foresters developed both overall management plans and local operational plans. Revealing ever more sophistication as decades passed, the overall plans spelled out policies for afforestation, aftercare, harvesting, and the handling of road construction and other forest-engineering projects. They dealt with the technical tasks of mensuration and the fiscal, spatial, and material requirements of projects. They detailed personnel needs, particulars of organizational structure and of research and operations facilities, and estimates of income and expenditures.

Nor was the planning merely a bureaucratic exercise. Research and training in scientific methods did improve. Forest mensuration, one of the world's more arcane arts, made striking advances. The relatively simple task of measuring acreage gained accuracy as more surveyors were trained and deployed and as surveyor's levels and the techniques of triangulation were introduced and mastered. The much more difficult tasks of estimating stumpage volume and predicting timber yield advanced more slowly as "eyeballing" gave way to increasingly refined techniques of estimation, including the use of sample plots. And foresters began developing yield tables for particular species in select localities.

In their research work, professional foresters also undertook studies of specimen growth, soil acidity and its effects, factors affecting seed-germination rates, and other projects designed to improve forest productivity. They also imported and experimented with seed and seedlings of valued foreign species. By the 1920s they were becoming familiar with the concepts of forest succession and continuous forest, and they were beginning to look more skeptically at such recently touted practices as rotation clearcutting, fixed yield rates, and even-aged monocultures.

Behind – and clearly influencing – this story of forestry's development was a less tidy tale of ups and downs in the actual woodland condition. During the decades from about 1870 to 1900, Japan's forests were ravaged by a combination of pushes and pulls that spurred villagers, entrepreneurs, and government loggers to hack down stands, clear land for cultivation, and otherwise misuse it in ways that produced flooding, erosion, and downstream damage. Decades of later-Tokugawa forest recovery were undone. But from about 1900 into the 1930s governments at all levels and private landholders responded by pursuing remedial policies to control flooding, restock forests, and maximize their rate of sustainable production. By the 1930s, these efforts were yielding results all across the realm: reforestation was being pursued widely, flooding problems had abated, *hageyama* were being revitalized, and the volume of standing timber was gradually increasing.

Then, however, during 1937–1950, industrial-age warfare and its consequences undid the gains, stripping the realm of much woodland cover and again producing widespread and destructive erosion, flooding, and damage. That situation precipitated yet another effort at forest rehabilitation, by far the greatest in Japanese history. During the 1950s–1960s countrywide planting restabilized the hillsides, adding thousands of hectares to the country's hand-planted woodland. By 1980 Japan was again a green archipelago, lushly forested from far north to far south. And today about 40 % of its forest acreage is in plantation stands, most of it trees 30–50 years old.

That outcome has not, however, proven an unqualified triumph. By 1960 the Japanese lumber industry was becoming enmeshed in the global timber trade, and imported logs and other wood products undersold nearly all the domestic competition. In consequence, by 1970 logging had lost most of its profitability, and reforestation and aftercare had become uneconomic, an investment that carried no promise of eventual return. By then, too, shifts to chemical fertilizers, fossil fuel, and motorized machinery had destroyed the



F

Forestry in Japan, Fig. 1 Near Ueda City in Central Japan, March, 1963. By 1950 many of Japan's forests had been stripped of timber, but in following years the hillsides were replanted. By 1980 most of these hillsides

again sported rich young timber stands. In foreground terraced rice fields give way to dry fields which ascend the hillsides as far as gradient allows (Photograph by the author)

markets for green fertilizer, fuel wood, and fodder for draft animals. Woodland had become useless. It was merely pretty scenery.

Since the early 1970s, therefore, tree planting, stand maintenance, and logging work have all been in sharp and sustained decline. Indeed, logging activity today yields only about a quarter of the peak output of ca. 1940–1960. Instead, intermontane regions depopulate as young people in particular leave to find employment elsewhere. And both plantations and mixed forests simply stand and age, increasingly subject to windthrow and snow breakage and gradually losing their potential economic value (Fig. 1).

Because of these developments, Japanese forestry has recently been facing a crisis of purpose. Government committees and other groups have continually, and especially during the 1990s, drafted and redrafted rules and guidelines,

categorizing and recategorizing woodland, giving more emphasis to protection forestry, and formulating purpose one way and another. But at present the basic problem of an uneconomic resource persists, and no coherent and effective policy for addressing it has emerged either within the Forest Agency itself or within government or society more broadly.

So, from a human-centered autecological perspective, Japan's forest affairs currently seem to be in utter disarray. From a broader synecological perspective, of course, it would seem a golden opportunity to encourage the final evacuation of depopulated intermontane regions and their revitalization as more richly diverse biomes. Perhaps even wolves could be reintroduced to manage the population of wild ungulates – deer, wild boar, and serow – that now constitute a widespread nuisance to people. And at the same time, one could pursue at little social cost the gradual,

managed restoration of many plantation stands to wildlife-friendly mixed forest.

However, in Japan, as elsewhere, the former perspective – the human-centered autecological assumption that forests exist to serve human purposes and that they do so best when subject to enlightened human management – continues to prevail despite the small voices that fret about biodiversity, species endangerment, and extinctions. And it seems likely that as the twenty-first century advances, global wood scarcities will revive Japan's plantation-based timber industry and revalidate the production-forest priority before a synecological perspective gains effective voice.

See Also

- [Agriculture in Japan](#)
- [Timber-Handling Technology in Japan](#)

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G

Gaitian

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Gaitian is the Chinese name for a scheme of cosmography, i.e., a description of the overall layout of heaven and earth. The term may be interpreted as “umbrella [-like] heaven.”

The classical description of the *gaitian* view is found in the ► [Zhoubi suanjing](#) (Mathematical Manual of Zhoubi), dating from around the beginning of the Christian era. It seems likely however that it is a systematization of what was the common view of the shape of the heavens at least as early as 250 BCE. Heaven and earth are more or less flat and parallel planes, although they may sometimes be described as gently curved like the cross section of an umbrella. Earth is stationary, while heaven rotates once daily about an imaginary vertical axis through the north celestial pole, carrying the heavenly bodies with it. Day and night occur because this rotation carries the sun beyond the range of the observer’s sight and back again. The rising and setting heavenly bodies are an optical illusion. In winter the sun is further away from the celestial pole than in summer, and is hence more distant from the observer and lower in his sky.

The *Zhoubi suanjing* gives the height of heaven above earth as 80,000 li. The Chinese observer is said to be 103,000 li from the subpolar point, while the greatest and least radii of the sun’s daily orbit round the pole are 119,000 li (summer solstice) and 238,000 li (winter solstice). The scheme gives a fairly good qualitative explanation of obvious phenomena, including the 6-month alternation of day and night at the earth’s north pole. By the second century AD it becomes clear that mathematical astronomers preferred not to think in *gaitian* terms, but were using the so-called ► [huntian](#) (continuous heaven) scheme.

See Also

- [Huntian](#)
- [Zhoubi Suanjing](#)

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Gan De

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As one of the earliest astronomers in China, Gan De, in the fourth century BCE, made many observations of the heavenly bodies, especially Jupiter, which was then called *Suixing* (the year-star). He wrote two books: *Suixing Jing* (Treatise on Jupiter) and *Tianwen Xingzhan* (Astrological Prognostications). Unfortunately these books were lost long ago, and only some quotations from them are extant in the *Kaiyuan Zhanjing* (The Kaiyuan Treatise on Astrology), compiled between AD 718 and 726.

In the *Kaiyuan Zhanjing*, Gan De is quoted as saying: “Jupiter was very large and bright. Apparently, there was a small reddish star appended to its side. This is called ‘an alliance’.” Included in the quotation were a date and rough coordinates, both in the ancient Chinese system.

Zezong, of the Institute for the History of Natural Sciences in the Academia Sinica, Beijing, claims that this record is evidence of the earliest discovery of the brightest moon of Jupiter, Ganymede, in the summer of 365 BCE.

Although Ganymede’s magnitude of 4.6 is somewhat brighter than that of the naked eye’s limit, Jupiter is 760 times brighter and located less than 5.9 arcmin away from this moon. Only people possessing eyes of extraordinary power would be able to see the satellite. Could Gan De have been one of these extraordinary people? We will never know.

Some people claim, on the basis of experiments, that under good observational conditions, the normal naked eye can determine Jupiter and its brighter satellites, especially Ganymede. However, Gan De’s reference to the reddish color continues to be mystifying, because Ganymede is too faint for its color to be perceived with the naked eye.

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Gardens in Ancient Egypt

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Even in damp climates and in a well-dug garden, archaeology can yield significant results (Currie, 2005, Fig. 2, p. 3). Drawings, paintings, and plants provide further information. Our knowledge of ancient Egyptian gardens comes from tomb reliefs, models, ostraca (often bits of broken pottery although some ostraca such as the figured ostraca discovered in the Great Pit at Deir el-Medina at Thebes can also be bits of limestone which was also readily available from the surrounding hillside), texts, and the archaeology itself. Although tomb scenes come from the tombs of the nobility, every house would have at least a little herb plot, often close by in the cultivation, and often a single tree in a pot in the courtyard of the house (Fig. 1).

In ancient Egypt, gardens were surrounded by mud-brick walls, with a gate facing the river. Walls were practical, to protect the garden from more unwelcome wildlife. From the Middle Kingdom, two simple models of gardens have come down to us from the tomb of the chancellor Meketre at Thebes. In front of the little portico of the house is a formal garden. In the center, copper

Gardens in Ancient Egypt, Fig. 1 A modern courtyard garden on the west bank at Thebes (Photograph © the author)



represents a rectangular pool. On each side are little trees representing the sycamore fig.

Trees would have been an important part of any Egyptian garden, a source of shade for people and the garden, for fruit, and for protection. In the tomb of Ineni, four registers show the tomb owner's house and garden. Among the trees listed are date and dom palms, sycamore fig, pomegranate (introduced into Egypt in the New Kingdom), persea, tamarisk, and olive trees. Planted just inside the enclosure wall, tall trees would also serve as a windbreak against spring and autumn gales which sweep across the Western Desert and could be very destructive. A relief from the tomb of Nebamun, now in the British Museum, also shows two rows of date and dom or gingerbread palm trees and sycamore fig trees on three sides of the garden just inside the enclosure wall (Fig. 2).

Trees also lined the causeways of the “mansions of millions of years,” the so-called mortuary temples known best from the West Bank at Luxor. Three rows of seven trees, sycamore and tamarisk, lined the causeway of Nebhepetre Mentuhotep II's “mansion of millions of years” at Deir el-Bahri. Trees and flowers lined the causeway of the Temple of Amun-Re at Karnak. Several different kinds of trees are shown in the Great Temple of the Aten at Amarna (Fig. 3).

Trees were planted in a specially dug hole, filled with fertile Nile silt. In the tomb of Meryre



Gardens in Ancient Egypt, Fig. 2 One of two simple models of the garden of the “Overseer of the Six Great Law Courts”, “Chief Steward” and “Overseer of the Seal” Meketre. (Photograph © Alison Bone)

I at Amarna, trees are shown in individual planting holes with a rim raised to hold the precious water. By a quirk of art style, the rim seems to represent the akhet sign, the “horizon” of the sun

Gardens in Ancient Egypt, Fig. 3 Persea, sycomore fig, cornflowers, mandrake and poppies fill the garden of Ipuy. In the water are blue and white lotus. (de Garis Davies, 1927, Plate XXVIII)



deity, the Aten. Other trees are shown on what appears to be a raised mound, symbolic of the island of creation. Unbaked bricks are shown protecting trees in the Dynasty 18 tomb of Mosi (Wilkinson, 1998, p. 169).

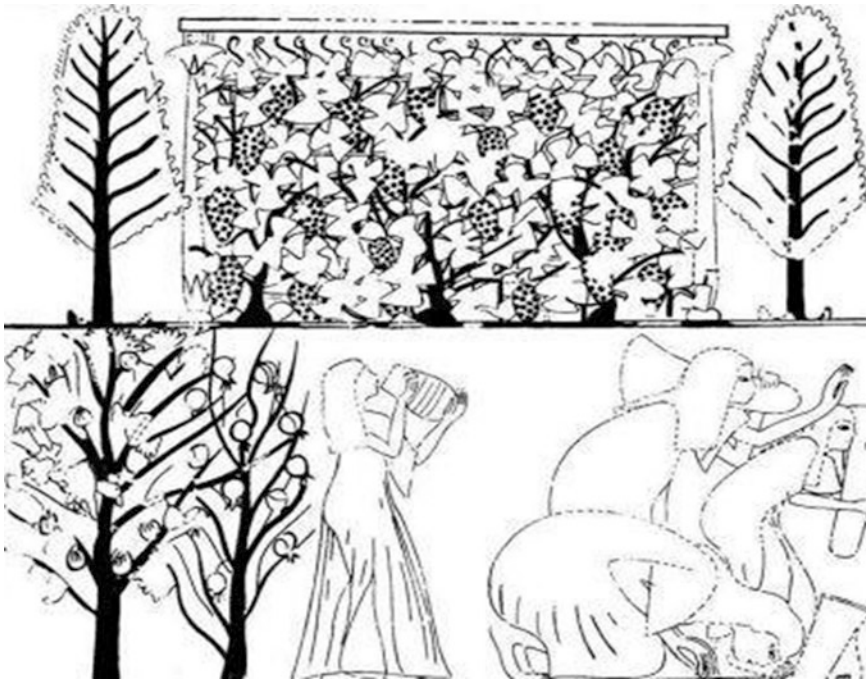
A series of images at Queen Hatshepsut's temple at Deir el-Bahri shows the transportation of incense trees. Ancient Egypt had two words for incense, *snTr* which grows wild in Egypt's Eastern and Western Deserts and *antyu* which came from Punt which the ancient Egyptians called "God's Land" and was an important trading center further south down the Red Sea. Texts and reliefs from the queen's successors also show trees brought from Punt. This may suggest it was not possible to cultivate *antyu* successfully in Egypt (Dixon, 1969).

It is possible that vegetables and grapevines could have been grown under trees. This would certainly be a good use of space but would have been detrimental to the trees and the vines (Eyre, 1994, p. 62). Grapevines, which may not have been indigenous to Egypt, were known and cultivated from at least the Old Kingdom. The grapevine ceiling in the Dynasty 18 tomb of Sennefer on the west bank at Thebes is a testimony to the importance of grapevines, both for their fruit and their shade (Fig. 4).

Watering was both labor-intensive and time-consuming. A scene in the Dynasty 5 mastaba tomb of Mereruka shows servants watering lettuce. Water is carefully poured from pots carried on yokes across the shoulders of the servants. Single pots would also be used to water small plots. It is also possible that individual plants or plants planted in close proximity could have been drip-fed by pottery jars buried or part-buried under the surface (Springuel, 2006, p. 58). Note too "a broken pot found at the base of a tree-planting hole" at Amarna (Leach, 1982, p. 9).

The shaduf, a simple device to lift water from a canal or well, was not known until Dynasty 18. A relief, though damaged, from the tomb of Meryre I at Amarna shows part of a shaduf. Three scenes in the Dynasty 18 tomb of Neferhotep show gardeners directing water from a shaduf to fruit and orchard trees (Butzer, 1976, Fig. 8, p. 44). Rainfall, sometimes heavy, would be a welcome resource (Fig. 5).

In the hot climate of Egypt, evaporation was a major problem. Two shallow lakes were discovered at the Maru-Aten at Amarna. Unfortunately, the original excavators did not investigate how the lakes were filled (Barry Kemp, 2014 personal communication). One possibility is that a well was dug close to the enclosure wall. Despite its



Gardens in Ancient Egypt, Fig. 4 Grapevines form a cool arbour in the palace gardens of Queen Tey (de Garis Davies, 1948, Plate XIX)

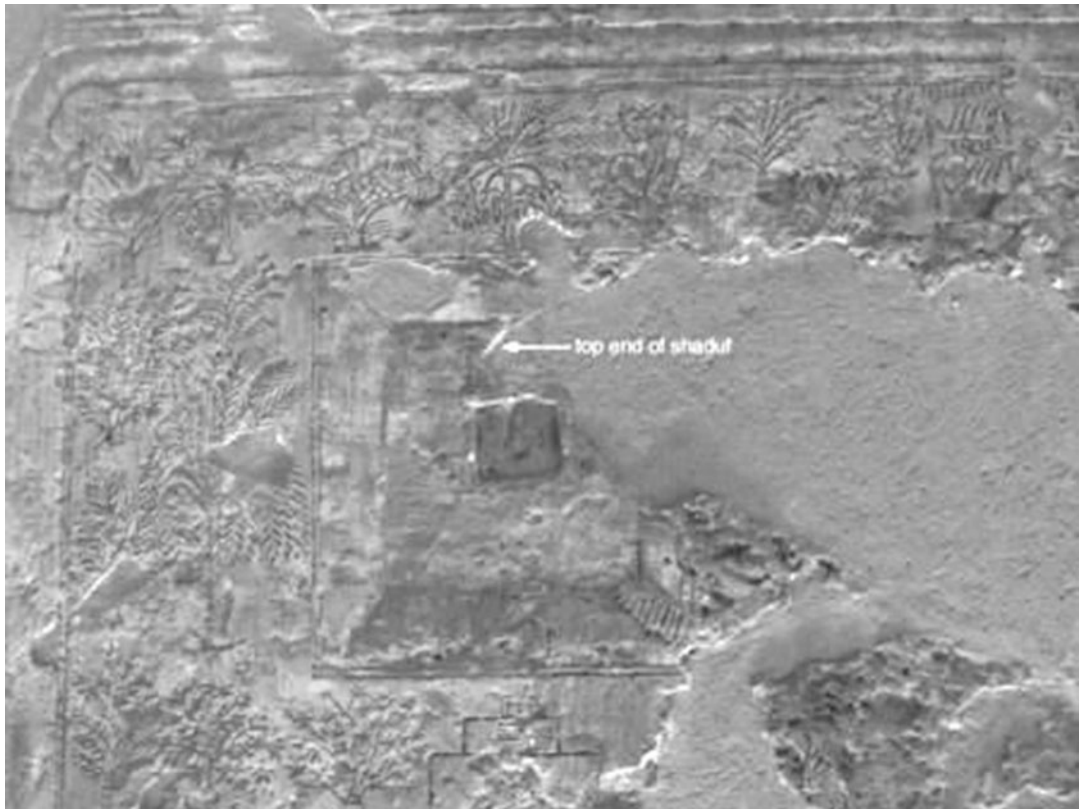
proximity to the river, a number of wells are known from estate gardens. Stone conduits too are known directing water from a well to a pottery workshop (Eyre, 1994, p. 64, n. 44).

It seems, however, that the “lake” in the southern enclosure was not excavated; the shallow depression seen on the ground gave the impression of a shallow lake (Kemp, personal communication). The lake could have been a well. It is also possible each lake was originally excavated deep enough to fill naturally from the water table, the usual way of ensuring a constant supply of water to the sacred lakes of temples. Linear mounds beside the Maru-Aten, much like Birket Habu on the west bank at Thebes but smaller, would certainly suggest the lakes were excavated to some depth.

It is possible too that lotus and papyrus would have grown in the temple’s sacred lakes. This would have helped conserve water by reducing evaporation. In Papyrus Harris I, Ramesses III proclaims: “I dug a lake before it [the Ramesses III temple at Medinet Habu on the west bank at Thebes], flooded with Nun [water], planted with

trees and vegetation like the Delta.” Lotus and papyrus were symbolic. Papyrus was sacred to Hathor, “lady of the west”; the lotus was sacred to the sun deity Re. Tomb scenes always show garden pools with ducks and their offspring, fish, and blue lotus. The symbolism is of birth and new life. Lotus and papyrus would have filled two T-shaped basins in either side of the Hatshepsut temple causeway at Deir el-Bahri.

Water features, whether the sacred lakes within temple enclosure walls, T-shaped basins, or small rectangular pools in private gardens, were clearly important. In the Maru-Aten at Amarna, interlocking T-shaped basins were originally called “fish ponds” by the archaeologists. Fish could certainly have been kept in each pool, but almost certainly, the pools served a dual purpose, the practical storage of water to water the surrounding gardens and just as importantly with a symbolic meaning. T-shaped basins were also found in front of the little chapels of the Workmen’s Village. At Karnak, in the left-side corner of the back wall of the Hypostyle Hall, the king is shown before a T-shaped basin.



Gardens in Ancient Egypt, Fig. 5 One of the earliest representations of a shaduf. Note steps leading down into the pool or well. The author has seen trees and shrubs

growing happily in the sacred lake at Denderah, reaching subsoil water. The tomb of Meryre I el Amarna (Photograph courtesy of Barry Kemp)

Unusually, in the tomb of Meryre II at Amarna, the garden of the tomb owner is shown with a T-shaped pool. Clearly the T shape is important. The symbolism however is much more difficult to know. The author's personal choice is that the T shape is linked to the bark of the sun deity Re (but see Bowmann, 1991, pp. 102–114).

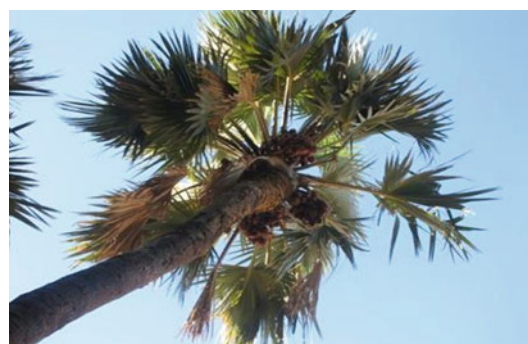
A rectangular pool at the center of the garden would have been surrounded by an herbaceous border. Ancient Egyptian herbaceous gardens were filled with scent and color. Flowers discovered in the tomb of Tutankhamun include leaves and flowers of cornflower, mandrake, poppy, mayweed, wild celery, persea, blue and white lotus, olive, willow, papyrus and reed mace, and the bright red berries of *Withania* nightshade (Hepper, 1990). Daisy-like faience inlay discovered at Amarna is almost certainly the white

flowers of mayweed. Rose petals are known from Hawara dating to the third century BC. Herbs would include the fragrant white flowers of myrrh and the feathery leaves and yellow flowers of dill. Very possibly, at least some of these flowers originally grew wild along the edge of the Sahara and had drifted into the gardens. Fertilizer would be Nile silt and pigeon dung. Some large gardens would be terraced (Fig. 6).

Weeding would have been labor-intensive. Ancient Egyptian hoes would only scratch the surface. Deep-rooted weeds would remain as stubborn as dandelions in grass today.

Temple gardens would have been both practical and symbolic. A relief in the south wall of the sanctuary at Queen Hatshepsut's temple at Deir el-Bahri shows a rectangular garden with formal

Gardens in Ancient Egypt, Fig. 6 One-meter-wide garden plots discovered at Kom el-Nana – el-Amarna (Photograph © Amarna Project)



Gardens in Ancient Egypt, Fig. 7 A date palm growing on the riverbank (Photograph © Ann Keane)

beds surrounded by the sacred persea. In between the persea are lettuces, sacred to the deity Min. Four pools are close by Naville (1906), plate CXLII). Single trees and small flower beds were planted in the courtyards of nobles' tombs at Thebes. Little chapel gardens are also known from the Workmen's Village at Amarna (Stevens & Clapham, 2014) (Fig. 7).

Temple gardens were important both for floral bouquets and for floral and vegetable offerings to the deity. Formal bouquets are known best from New Kingdom tomb scenes at Thebes. A small formal bouquet could comprise blue water lily flowers surrounded by buds, poppy, cornflowers, and, at the top, the fruit of *Mimusops* (persea). Bouquets were hand-tied to papyrus stalks. *Convolvulus*, wound around the papyrus stalks, may represent new birth. An ostrakon discovered at

Deir el-Medina shows either the *convolvulus* or white bryony entwined around a birthing bower. "Stick" bouquets discovered in the tomb of Tutankhamun were simply persea and olive branches. A text from Papyrus Harris I states Ramesses III gave 19,150 large lettuce and flower bouquets to the temple of Amun in just under 3 years (Manniche, 1989/1993, p. 24). This was just a small part of the numbers of bouquets and wreaths offered to the major state deities. Bouquets too were presented to high officials. In a scene in the tomb of the Dynasty 19 official Thay, the tomb owner offers a large formal bouquet to his wife. A similar scene is in the Dynasty 18 Theban tomb of Mosi (Wilkinson, 1998, pp. 168f).

Ancient Egyptian gardens would have been spectacular: the fragrance of herbs and flowers, the cool breeze through the gardens, and the gentle sound of ducks splash in the water. The gardens were clearly a place to show wealth and status for this life and for eternity.

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Gardens in Japan

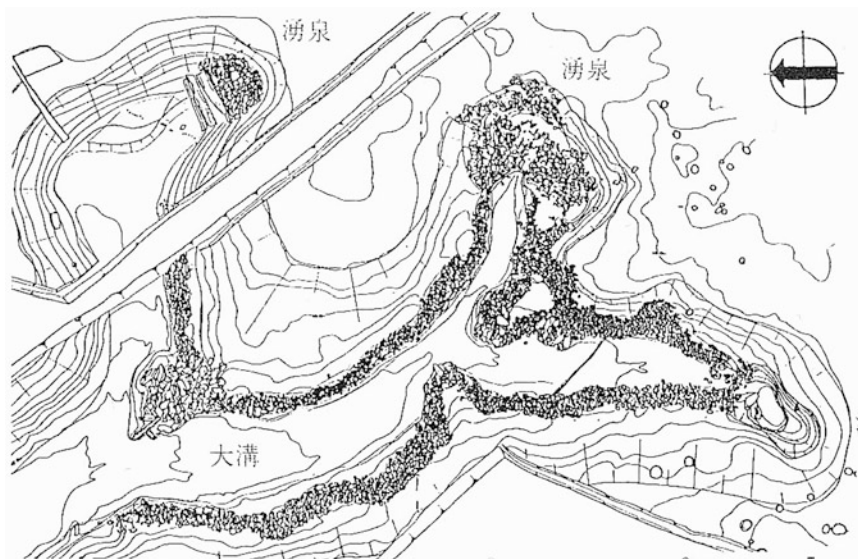
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The Early Centuries

Before a clearly defined native garden art appears in Japan's history somewhere in the eighth century, evidence is found of activities in the field of landscape design. It is mainly through archeology that these early centuries speak to us. At Jo-nokoshi (Mie prefecture) a set of rocks was unearthed that stand upright in a rather naturalistic manner. This group had been put up along three narrow well heads lined with shingles that flow together to feed a small stream. The arrangement has been dated between the end of the fourth and middle of the fifth century. The setting vaguely resembles a manner of handling rocks and shingles seen in a few gardens of the seventh and eighth centuries. One can only guess about the meaning these arrangements would have had for the ones who made it or ordered it to be made (Nara National Research Institute for Cultural Properties & Agency for Cultural Affairs, 2009) (Fig. 1).

Skill in engineering in this early history can be seen in bold burial mounds of advanced design, surrounded by moats. Some square ponds lined with rocks were found, as were quite a few artistic works in carved stone made to have some liquid flow (Asuka Shiryōkan, 1986). These were probably used for rituals involving rice wine or water for purification; similar artifacts are known from the continent. A well-known record, dated 612, speaks of a man who came from Paekche, a Korean kingdom; he built a garden arrangement and made a Chinese style bridge in the garden of the emperor. His name was Michi-no-ko Takumi in the Japanese reading of the Chinese characters of his name (Sakamoto et al., 1965). It underlines how the early history of landscape design in Japan followed the models of the continent.



Gardens in Japan, Fig. 1 Survey drawing of the excavated rocks and shingles at Jo-no-koshi (From Nara National Research Institute for Cultural Properties and Agency for Cultural Affairs (2009), p. 15)

At the mid-seventh-century palace site of Fujiwara-kyō, remains of a winding garden pond have been found. At a slightly later site, parts of an extensive pond garden were unearthed (Higashikage, 2013). The pond had rather heavy embankments in piled-up rock, an island and a fountain-like feature. Most likely it had been part of the seventh-century imperial Asuka palace of the emperor Tenmu (r. 673–686). Though only partly excavated, and much smaller, this garden arrangement resembles in all its details the seventh-century pond garden Anap-ji in Korea.

The Nara Period (710–784)

Nara was founded as an imperial city in 710 AD; it was planned after Chinese geometrical schemes with streets running in a grid pattern. The imperial palace held a central position in the northern part of the city. It is known from scarce records that there were several gardens. None of these remain, but two extensive gardens were discovered and redone after detailed excavation and research.

Southeast of the main palace compound, a detached palace, Tō-in, was constructed in the

early eighth century. The garden of Tō-in, or the East Palace Garden, is one of the gardens mentioned in contemporary records. Extensive archeological surveying gave a wealth of added information. The original pond bottom was paved with large flat stones. Like the Asuka pond, the heavy embankment of the East Palace Garden follows a design of simple curves, again similar to the Korean example. Interestingly, the garden had been rebuilt later in the same century, after a covering of the earlier design with soil. The second, younger pond was paved with much smaller pebbles, and the embankment runs in softer, more expressive curves. Rather than embankments, this second pond was contained with shores or beaches covered with smaller stones, the shingles found on Japan's seashore. Here and there at small peninsulas, rock groups suggested weather-beaten sea cliffs in miniature. A group of rather big and craggy stones is set as a decoration in the shore opposite the remains of a hall, traced from remains of foundation pillars. It is this second phase of the East Palace Garden that shows a clear departure from the continental style and the introduction of clearly native landscape motifs; the typical shingle beaches and

rocky promontories of Japan's natural seacoast would continue to inspire garden designers for centuries to come. The East Palace Garden has been reconstructed on top of the archeological remains. Buildings, bridge, and planting were remade in a hypothetical reconstruction of what could be guessed from what was found in the soil. For redoing the garden, the second phase with its supposedly more native expression was chosen as a point of departure (Kuitert, 1991; Nara National Research Institute for Cultural Properties & Agency for Cultural Affairs, 2009). It was opened to the public in 2004.

A second garden recovered from eighth-century Nara is known as the Palace Site Garden (*Kyūseki teien*) or after its address in the old city of Nara, *Sakyō sanjō nibo kyūseki teien*. The site was probably a private retreat of some courtly family or the emperor himself. It is in walking distance from the East Palace Garden (Tō-in). The most distinctive feature of this garden is a double S-curved, winding stream bed. The bottom of this water feature was paved with fist-sized stones in the old continental manner, but decorative rock groups at protruding curves and beaches covered with pebbles are completely in the native naturalistic manner. Drawing from a natural river, this winding stream has its water running from north to south. It is generally accepted that the garden was used for the so-called winding stream banquet: guests were sitting along the stream, writing poetry. A poem had to be finished before a cup of wine set on a float would reach the poet. This festivity became famous after the Chinese calligrapher Wang Xizhi (303–379) invited 41 men for a winding stream banquet on the third day of the third month in 353. Poetry written on the occasion was compiled in the *Records of the Orchid Pavilion*, a Chinese literary classic, well known in eighth-century Japan. The Palace Site Garden will also have been used for similar winding stream banquets. The rockwork excavated was in such perfect condition that it was decided to reconstruct the garden with most of the original stones. Remains of two sets of wooden boxes were found, set among the stones of the pond bottom; these were probably planting boxes for irises.

A banquet hall was reconstructed departing from the remains of pillar foundations found. As plant material for the Nara garden reconstructions, the Chinese plum (*Prunus mume*) and Japanese pine (*Pinus thunbergii*) are used among other plants (Kuitert, 1991; Nara National Research Institute for Cultural Properties & Agency for Cultural Affairs, 2009) (Fig. 2).

The Heian Period (794–1185)

In 794 the city of Heiankyō, now Kyoto, was founded as a new capital in a plain surrounded on three sides by hills. The city would remain the most prosperous cultural center for many centuries to come. The site for the new city was well chosen and blessed with a lot of pure water and natural springs, giving great advantage for the household and for garden building. Indeed, natural ponds and streams were used in large palatial gardens. In some cases dams were built to contain more spacious garden ponds. At the back and in between the palace buildings, sand was spread out in small court gardens, and a little stream ran among flowers, shrubs, and bamboo planted as decoration. The old glory is perceived in garden remains in Kyoto such as the one at Shinsen-en or at Saga-in, a place now known as the temple Daikaku-ji. At other places, excavations again revealed garden details. Rocks arranged to make a waterfall were found in some sites. These are never high, as gardens were made in the plain.

The noblemen of the capital built their palaces in a peculiar architectural style. After the name of the main hall, the *shinden*, it is called the “shinden style” or *shindenzukuri*. Being planned together with the buildings, the garden developed into a typical *shindenzukuri* garden style as well. Of course, each garden was different, but some characteristics can be defined. Seen from the main hall, white sand was spread in the front part of the garden; beyond it, one found a large pond that could have one or more islands. An arched and a level bridge connected islands and shores. Along the edge of the pond, one could find pebble beaches or standing rocks arranged to suggest a weather-beaten sea cliff. The typical



Gardens in Japan, Fig. 2 Banquet hall reconstructed at the eighth-century rock arrangements of the winding stream at the Palace Site Garden in Nara (Photo by author 29 October 2010)

garden stream mostly ran from the northeastern corner through the garden, often passing under the corridors connecting palace buildings, then among some low garden mounds, before emptying into the pond, usually in the southern half of the garden. Low hills at the back of the garden provided a background on the southern side (Kuitert, 2002, 2007; Mori, 1945). Inner city estates had their gardens fenced in, but fences were low always allowing for views to the hills surrounding the city on the east, north, and west (Motonaka, 1994).

But times were changing, and the twelfth century found the nobles in an unstable political situation. To counter the increasingly pessimistic worldview that prevailed, they built themselves large temples, with gardens referred to as paradise style, or Pure Land (Jōdō) gardens (Mori, Muraoka, Asano et al., 1980). Such gardens meant to reconstruct the Buddhist paradise of Amida in this world and have a temple hall with an image of Amida as a central element. Yorimichi Fujiwara in Uji, for instance, reconstructed his palace and modeled it as a temple named Byōdō-in, set in a large landscape site. Without any fence or bordering

structures, the temple buildings were scattered over the area, one pavilion jutting out over the Uji River. The still extant Amida-dō Hall, now known as the Phoenix Hall, is shown on the Japanese 10 yen coin. After an archaeological survey, medieval repairs were removed, and the original pebbled beach in front of the Hall was repaired in recent years. The shallow slope of this beach indicates how buildings were placed sensitively within the wider river plain landscape, without any forceful, large-scale engineering (Fig. 3).

These early centuries of landscape design in Japan take the continuity of natural landscape as a fundamental quality of garden beauty. This is typical of court noble gardens of palaces and of the temples in the paradise style. Other still extant gardens of the paradise style are in Hiraizumi, Iwate Prefecture, or the Shiramizu-Amida-dō in Fukushima Prefecture, and Enjō-ji and Jōruri-ji close to Nara. Many elements of the palace style remained to be used in these temple gardens as well; ponds and islands are typical. The garden stream of the temple Mōtsu-ji in Hiraizumi is extensive and resembles garden streams as represented in paintings of the period. Around

Gardens in Japan,

Fig. 3 The shallow pebble beach suggests a river gravel bar on which the Phoenix Hall of Byōdō-in was built (Photo by author 24 August 2011)



this time a nobleman wrote a well-developed manual on garden theory – the eleventh-century *Sakuteiki* (Hayakawa, 1973; Hisatsune, 1979; Kuitert, 1998; Mori, 1986; Takei, 1995; Takei & Keane, 2001; Tanaka, 1990; Vieillard Baron, 1997). It set the tradition for centuries to come. The manual stresses the workings of a poetic understanding of nature that is basic to garden making as it attaches importance to a thorough understanding of the topography of the site. Nameless workers, supervised by noblemen, built gardens in this period; a class of gardening priests soon followed (Kuitert, 2002).

The Kamakura Period (1185–1334)

Although a shogun's government of military men was set up in Kamakura, the center of culture remained Heiankyō (modern Kyoto), and all through the Kamakura Period garden art remained under strong influence from the earlier style. Temple gardens built by order of military men followed the pattern of the Paradise style. For instance, Yorimasa Minamoto, after suppressing Hiraizumi in 1189 where he had seen its Paradise temples, was greatly impressed by their magnificence. He started building Yofuku-ji in Kamakura in the same year, and in 1192 the ceremonial services for inaugurating the new buildings were performed. At present on the

designated historic site, the remnants of this garden can be seen (Fukuda, 2011).

Residential gardens of the military class did not escape the influences from the palaces of grander men, but the scale was smaller, and as the meaning as a space for ceremony was also less apparent, more attention was paid to practical use. Also, with a garden space becoming smaller, it became rather a place to look at and enjoy by admiring than a place to enter. Gardens therefore were rather a visual thing in their perceptions and were meant to entertain or impress visitors and guests. Starting from the thirteenth century, garden culture came to receive Chinese influence again, this time through visiting priests. High-ranking priests of the Chinese Song dynasty, like Rankei Dōryū (1213–1278) or Issan Ichinei (1244–1317), given with the Japanese pronunciation of their names, were influential cultural leaders of Japan. Many landscape paintings of the Song and Yuan dynasties were imported as gifts and brought a new vision of an imaginary landscape. The Chinese vision of landscape is still profoundly felt in the artistic composition of rocks arranged for garden waterfalls. For example, at Tenryū-ji and the Golden Pavilion, these rock arrangements probably date to this early period when Chinese priests were around, and the artistic expression of a steep gorge-like valley might very well have been brought in by them (Kuitert, 2002) (Fig. 4).



Gardens in Japan, Fig. 4 Rocks are arranged to suggest a Chinese style landscape painting in Tenryū-ji (From Kuitert (2002), p. 78)

The Muromachi Period (1334–1573)

The new ruling class of military men finally replaced the cultural supremacy of noblemen in Kyoto. Their general, the shogun, would gain control over most parts of the country.

The influence of Chinese culture on garden art was now backed up with a growing trade with China on an unprecedented scale, making a taste for Chinese goods the great fashion. Shogun Yoshimitsu and his palace – of which at present only the Golden Pavilion remains – naturally formed the center of this Chinese fashion. His court was affected by the Chinese mood as can be recognized in the architecture of the Pavilion. The garden is most functional through the pond at which the Pavilion sits. What makes it different from earlier ponds is that there is a large number of small islands that with their pine trees and rocks are reminiscent of the islets off the coast

of Japan. This engineering made for a peculiar view from the Pavilion where important rocks on the islands are in full view; these were once owned by regional leaders now loyal to Yoshimitsu but had been donated or confiscated for the garden (Fig. 5).

The Chinese influence in the fourteenth and fifteenth century shows in the adding of a great variety of pavilions, bridges, roofed corridors, and two- or three-storied buildings to the spacious pond gardens of earlier times. In gardens like at the Golden Pavilion, or Saihō-ji in Kyoto, most, if not all buildings, have disappeared. But the temple Eihō-ji in Tajimi (Gifu prefecture), founded at the end of the Kamakura period, is a typical example where many structures still remain. The garden takes full profit from the dramatic topography of a sharp bend in a natural valley. A small gazebo sits on a sharp, craggy outcrop. Though much smaller in scale, it echoes the continental Daoist love of dramatic rocky landscapes. Garden architecture from these days is adorned with Chinese literary titles that rely on classic literature. Later, in the days of shogun Yoshimasa around 1500, the fashionable and gorgeous Chinese taste came to an end. Growing power and influence of priests and townspeople mingling with the military rulers led to a vision where much importance was attached to sociable meetings and manners. As guests were to be received and entertained, now also by the less wealthy, smaller gardens with a more subdued and intellectual expression came up. It led to a new scenic garden style, at present referred to as “dry landscape” (*karesansui*). However, in those days it was called *kazan*, or *kasenzui*, meaning “imaginary landscape” (Kuitert, 2002; Toyama, 1934). The style strives for an abstraction of landscape by careful placing of rocks. In miniature these can be realistic and suggestive of mountains and waterfalls, while soil left bare expressed water. Sometimes this was strewn with decorative sand. The coarse, white gravel seen today is mostly a later addition. The dry landscape garden is simple in execution and cheap, making it popular for adorning the main hall of small family temples, which as a consequence, also led to an increasing need



Gardens in Japan, Fig. 5 The pond in front of the Golden Pavilion is dotted with islands decorated with conspicuous rocks (Photo by author 10 December 2009)

for intellectualism and stories attached to it. This allowed for quite abstract placing of just a few rocks that still would be called an imaginary landscape. The textbook examples of the style are now Daisen-in the Daitoku-ji monastery (Kuitert, 2013) and the garden in front of the main hall of the temple Ryōan-ji, although the latter garden was rebuilt in the late eighteenth century (Fig. 6).

Among the so-called riverside people (*kawaramono*) living at the very bottom of the social ladder, skilled gardeners called “landscaping riverside people” (*senzui-kawaramono*) became a group of professional gardeners. They become known by name in the records at the end of the Muromachi period (Kuitert, 2002). Gardeners living in and around the temple Ninna-ji have left us a detailed handwritten manual on gardening technique (*Sansui narabini yakeizu*) dating from the 1460s (Egami, 1966, 1967; Slawson, 1987).

The Momoyama Period (1573–1603)

The Momoyama period is a period of transition and sudden wealth after the country’s unification. Gardens at the expansive mansions of the powerful military leaders were in gorgeous



Gardens in Japan, Fig. 6 The imaginary landscape is seen from the room as if it is a Chinese landscape painting (From Sekiguchi (1991), p. 50)

splendor, often employing the ostentatious sago palm tree that was the great fashion of the day. One may visit the garden at the large Reading Hall of the Nishi-Hongan-ji temple in Kyoto,

was aligned with tea pavilions and tea huts or other kinds of garden architecture. Garden mounds, pebble beaches, bridges, stone lanterns, and washing basins were installed to produce scenery that changed with almost every step. This tendency to decorate the garden with numerous details became typical of the later Edo period garden developed by the *daimyo* or governors of the provinces.

These *daimyo* were obliged to live in Edo, currently Tokyo, for 6 months every year. They had their official residences in the city; some were many hectares large. The other half of the year they lived in their own home province where they constructed their gardens in the same manner. *Daimyo* challenged each other all over the country, and above all in Edo, to have the finest of all gardens; it meant that the cultural hegemony of Kyoto gardening came to an end. *Daimyo* gardens first of all served for receiving guests with banquets or to enjoy other garden pleasures, but they also signified the birth of a new garden aesthetic. The scale was large and evoked a concern for scenery; thus, a more bucolic sense is seen in miniature landscapes reproduced. Some gardens have mini Mount Fujis; others have small tea plantations or rice fields which helped in times of economic scarcity. All over the country *daimyo* left us with many good examples. In Tokyo, there are Kōrakuen, Rikugi-en, Shiba-Rikyū, and Hama-Rikyū. In Okayama one may visit Kōrakuen; Takamatsu has its Ritsurin-en, Hiroshima Shukkei-en, Mitō Kairaku-en, or Hikone the Genkyū-en garden (Kuitert, forthcoming; Shirahata, 1994, 1997).

In the course of time, well-to-do citizens also came to possess a garden, and gardening became more popular. Garden books were published and widely read, spreading a stylized mannerism that classified “the” garden in two styles each in three levels of elaboration. The thing to have was, for instance, an “elaborate hillock style garden,” or an “abbreviated flat garden” as these were shown in the picture books (Akisato, 1828; Hishikawa, 1680; Kitamura, 1735). Gardeners became professional specialists, organizing themselves in houses that would pass on the trade for

generations. Propagating and breeding of novel garden plants reached a level matching the modern garden center or even above that when it came to the varieties of ornamental plants (Hida, 2009; Hirano, 2006; Kuitert, forthcoming; Ogisu & Kashioka, 1997). Many of the once prized garden varieties of plants from the Edo period have now become extinct (Fig. 8).

Gardens of the Later Nineteenth and Twentieth Centuries

After the 1860s “the West” was brought to many facets and aspects of Japan’s society, but this did not readily reach the garden. Several western-style gardens were built in Tokyo, often with lawns, winding paths, and a lookout on a hill; an extant and successful example is Shinjuku Gyōen. But in face of Japan’s century-old tradition, these were isolated experiments, at least in the beginning (Kuitert, forthcoming; Ozawa, 1890).

Little by little though, new ideas began to inspire the top end of the garden trade. Among some captains of industry or powerful politicians, the cramped world of the picture book garden was considered obsolete, and a new taste was required, giving room for a more liberal naturalism. Some of these men, like Aritomo Yamagata (1838–1922), had taste for gardening, not in the least because they moved their place of residence often; in a lifetime they developed several estates with different gardeners in different natural landscapes (Yagasaki, 1996). In the course of the 1890s, great progress was made in Kyoto at Murin-an, a garden commissioned by Yamagata and finished by gardener Jihei Ogawa (1860–1933). The garden had meadows of wild flowers set among a pastoral landscape of meandering streams, set before a background of natural hills outside the garden. The meadows and trees and shrubs reflected Japan’s agricultural landscape around Tokyo with its coppice woods. Murin-an had many deciduous trees, rather than the eternal pine trees, but also such novelties as fir (*Abies*) or *Torreya nucifera*. Lawns became *en vogue* for staging garden parties (Fig. 9).

Gardens in Japan,

Fig. 8 Visitors to a gardener's shop inspect the plants for sale (From *Ehon Edo Zakura* 1803 in. Kuitert (1999, p. 58)



The experience gained by gardener Ogawa at this job was put into wider practice in many other and larger gardens in the region around the temple Nanzen-ji in Kyoto. These gardens quickly became famous; most are still extant (Amasaki, 1990, 1992, 2007; Ono, 1987, 2000; Shirahata, 2008). The garden he designed at the Heian Shrine is typical of his work and shows us how he interpreted tradition in a contemporary way. The abundant use of flowers, notably iris, is remarkable, and – as in all gardens by Ogawa – water features are designed with much attention paid to details. Besides Ogawa, we find many other able landscape gardeners. Perhaps Jukki Iida (1890–1977) should be mentioned

here, as one of the men important in carrying the traditions over the Second World War. Iida invented a naturalistic style that could be produced cheaply and quickly, relying on a choice of plant material that would be called ecological today. Like Ogawa the feeling for the naturalistic landscape is central to his aesthetic of mixed deciduous trees (Ga-den raifu shuppanbu hen, 1977; Kuitert, forthcoming; Ogata, 1997). In the meantime landscape tradition had proved to be meaningful in developing urban parks (Maruyama, 1994). Tradition proved effective in large projects like the Meiji Shrine Park and the urban planning of Tokiwadaira (Kuitert, forthcoming).

Gardens in Japan,

Fig. 9 Murin-an shows naturalism achieved with artificial water and mostly deciduous planting (Photo by author 17 October 2013)



A garden artist negating this style was Mirei Shigemori (1898–1978). He was like a producer, working with gardeners rather than being a gardener himself. Therefore, as he was freer from tradition, he found a contemporary new definition of the dry landscape style, employing coarse white gravel and thick, dark green moss (*Polytrichum*). All over Japan he left us many of his at the time avant-garde gardens, some of them with strong lines and forms expressed in concrete (Tschumi, 2007). From an ecological point of view, his gardens are less successful.

The enormous economic expansion of the later decades of the twentieth century brought many commissions and big budgets. Landscaping became a large-scale operation of companies with nameless designers. Experiments with expensive materials such as worked natural stone, often set in concrete, mark this period. Although design was influenced by American

plaza design, the tradition remained meaningful. Ogawa's discovery of the deciduous tree and the coppice wood became common in parks, as well as in the private garden. Rock design remained strong, in some cases adding the strong line of the cutter, as can be seen in the Japanese Garden at the Expo site in Osaka.

The below list of sources gives references to this chapter and functions at the same time as a general bibliography that introduces additional sources for continued studies. Sources are in Japanese, and only in Western languages if they rely (more or less) on primary Japanese sources. Western sources on Japanese garden art have, throughout history, always showed interpretations that should be understood in view of the Western context. Some of these are included, as these are of historic interest, having in turn influenced views on Japan's garden art by the Japanese themselves. Some Western sources, as

Condor 1893–1912, contain interesting photos illustrating gardens and garden styles that have now disappeared.

Any serious researcher should refer to the volumes of *Zōen zasshi*, continued as *Randosuke-pu kenkyū*, and edited by the *Nihon Zōen Gakkai* (Tokyo) to find updated research results. *Nihon teien gakkaiishi*, edited by the *Nihon Teien Gakkai*, has often more detailed reports on individual gardens. One may also check my bibliography in *Themes in the History of Japanese Garden Art*, University of Hawai'i Press, 2002, or my *Gardens and Landscapes in Japan: 1650–1950* University of Pennsylvania Press (forthcoming).

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Gardens of the Islamic World

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The study of landscape and garden design uncovers a deep understanding of natural order and the way it can impact human life. Through the various dynasties across the Middle East, North Africa, Spain, Turkey, India, and Southeast Asia, garden design was directly impacted by climatic responses, sociopolitical context, regional influences, existing topography and landscape, and functional adaptation. While there are numerous sources of poetry, art, and writings embedded in religious symbolism, the design of Islamic gardens and landscapes have served a wide variety of functional uses and also redefined the immediate built environment, surrounding landscape, and urban fabric.

The roots of religious symbolism of gardens traces far beyond Islam, from the Mesopotamians (4000 BCE), Babylonians (2400 BCE), and then to the contextual references of the Garden of Eden as a metaphor for Paradise in the New Testament within Judaism and Christianity. With the spread of Islam as a religion (seventh century CE), the Qurʾān also included metaphors of the Garden of Eden as eight levels of Paradise, filled with lush vegetation and the presence of

water. Although the symbolism of Paradise is rooted in religious aspirations toward the intersection between the metaphysical (represented in form by Nature) and the manmade, water and plant life are two central components that have both symbolic and utilitarian roles within garden design within this region. Although various studies have detailed the spatial configurations based on an inherent sense of geometric order and topography, an equal emphasis should be given to the study of the design of landscape, irrigation and infrastructure systems, and the socioeconomic progress from these agricultural practices.

Throughout the variations in form and function, the presence of water in gardens was a predominant symbol for purification, cleansing, and cooling, often depicted as the “rivers that flow beneath.” Although a vital source for plant life, the scarcity of water in the predominantly desert climates required innovative methods for extraction and distribution. Although influenced by earlier Roman aqueduct prototypes, *qanat* or underground systems of water wells and conduits strategically ducted flowing water from nearby rivers, streams, or groundwater to irrigate and sustain plant life. In addition, the inclusion of water channels and pools was a key climatic response as a passive cooling strategy especially in the tropical, arid desert climates of the Middle East and Southeast Asia.

Pasargadae, the royal hunting park complex of Cyrus the Great (559–530 BCE) from the Achaemenid era (550–330 BCE), was one of the initial traces of laying out landscape, and it set a precedent for garden design. Based on a composition of formal geometric order, this early work provided shade through vegetation and introduced early sophisticated methods of underground water conduits and irrigation infrastructure systems to provide for the diverse plant life. From ceremonial fountains and pools in the early courtyards of Umayyad Syrian royal complexes such as the Qasr al-Hayr (700–730) and Khirbat al-Mafjar (739–74), water continued to manifest through extensive systems of channels as a formal design element as well as the main source for the plant life to thrive. These private walled enclosures consisted of various functions

including a bathhouse, caravanserais, and a plot of land for agriculture (such as olives and other seasonal crops). The newfound capabilities of water access and infrastructure served as a catalyst in discoveries in agricultural and horticultural sciences as well as a supplemental economy and food source, even at a city scale such as under Abbasid rule of Baghdad (750 CE). This surge in agriculture through the advancement of irrigation technology and horticultural practices stimulated economic growth at an urban scale. However, gardens also served a wide range of other functions including pleasure, worship, hunting, leisure, as well as royal encampments, marketplaces, and urban redevelopment.

The relationship between garden and built pavilion elements was further developed in the Sassanid era in the palace of Samarra (849 CE). Other Sassanid palace pleasure gardens such as Firuzabad also further pursued water elements and pools. Palace gardens continued to develop extensively under Umayyad rule, such as the Madinat al-Zahra (936 CE) near Cordoba, Spain. Axial organization of gardens of various scales began to take form, where terraced views strategically placed on higher ground to create greater views of the exterior landscape. Divided by a series of interconnecting pools, colonnades, and pavilions, this complex set a new example for demonstrating the monumentality of palatial architecture and responding to the greater context of the surrounding landscape. These components that emphasized the grandeur and pleasures of royalty continued through Umayyad palace garden complex of Alhambra (twelfth century) in Granada, Spain, with its cross-axial water channels intersecting at a central rectilinear fountain aligned with lush shade trees and diverse plant life, surrounded by a marble colonnade of pavilions (Fig. 1).

In North Africa, gardens continued to vary as a prototype as open meadows within high walls under the Almohad rule (1121–1269) in Morocco. Located in a valley amid the Atlas mountain range, the Agdal Gardens (1157) combined private pleasure gardens with an open rectilinear plan of orange, lemon, fig, pomegranate, and other fruit orchards. Divided by interconnecting networks of tree-lined paths,

Gardens of the Islamic World, Fig. 1 Alhambra (twelfth century) – central rectilinear fountain surrounded by lush plant life and colonnade of pavilion structures



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this vast garden complex depended on two major reservoirs for irrigation supply. Following the addition of the Dar El Beida palace in the early 1800s, the gardens served as places for royal enjoyment and restricted public access.

In Central Asia, following the successor Timur's (1370–1405) shift of the capital to Samarqand during the Timurid era (1370–1507), there was a surge in public projects and garden complexes. Stemming from Timur's nomadic lifestyle, some gardens outside the city boundaries were sites of royal encampment, as well court events and celebrations. In addition to permanent built structures, these gardens included tents, in the form of lightweight tensile structures. These sites of encampments, which were often laid outside the city walls, were also places of shelter and retreat during defeats in battle. However, the more permanent gardens within the main city were utilized for agriculture and economic benefits. These collections of temporary and permanent structures were yet another physical display of the growth of imperial power. While the city of Samarqand already had irrigation access from the Zarafshan River, Timurid gardens integrated waterways to organize geometrically a series of garden spaces with a central pavilion as in the cases of Bagh-i Bishisht (1378) and Bagh-i Shimal (1397). Later Timurid garden examples such as Bagh-i Dilgusha (1396) and Bagh-i Naw (1404) enhanced the geometric order through the use of planting beds ranging in species of fruit trees and plant life bordering the axial walkways.

Babur (1483–1530), Timur's grandson who later became the founder of the Mughal Empire, regarded garden design as a metaphor for the power of the imperial seat and constructed his first garden at Bagh-i Vafa (1508) in Kabul. The strong axial order and quadripartite geometry was an early prototype of the infamous chaharbagh (fourfold) typology. Overlooking the River Kabul, channels of running water divided four quadrants of diverse vegetation, including oranges, fruits, sugarcane, and other fruits. The chaharbagh, translated from Persian as "four gardens," flourished as a typology under Mughal rule, marked by the signature axial symmetry dividing the four distinct quarters by prominent waterways, representing the belief that there were four rivers that created the Garden of Paradise. While these gardens were used for religious rituals, camps, and royal events, the interpretation of chaharbagh began to represent the distinct Mughal funerary tradition, in which the garden that housed the tomb structure personified the resting place of the powerful imperial rulers. Such was the case of the tomb garden complex of Babur. Bagh-i Babur (1528) was located on the northern end of a complex consisting of a series of terraces aligned through an overarching longitudinal axis. Paved walkways known as *khiyabans* symmetrically divided the gardens into four parts, and water channels formed axial paths of the garden.

The chaharbagh typology continued to flourish at a monumental scale, through later Mughal



Gardens of the Islamic World, Fig. 2 Humayun's Tomb (1570) – chaharbagh plan flourished at a monumental scale during the height of the Mughal Empire

imperial funerary complexes such as Humayun's Tomb (1570) and the Taj Mahal (1631). In addition to refining the Persian prototype, Humayun's Tomb displayed the height of the Mughals' introduction of the mausoleum garden, as a key component of the funerary architecture tradition. In the elaborate development of chaharbagh, the core of the geometric order and symmetry of the 30-acre square site are marked by a system of cross-axial channels of running water and intersecting paved walkways, dividing the complex into 36 equal sections, converging at the central tomb structure. While the combination of cypress trees (representing death) and fruit trees (representing life) marked the main axial pathways of the complex, a greater amount of land was left open to create visual intensity and importance to the main tomb structure. This Mughal work also played a pivotal role in redefining the relationship between building and landscape, where the vast gardens and waterways radiated outward from the central monumental tomb structure, highlighting the power and prestige of imperial rulers over the people (Fig. 2).

The later Mughal emperor Jahangir (1569–1627) adapted from the earlier Mughal precedents and further developed the system of waterways, pools, fountains, and pavilion elements, through the royal gardens in Srinagar, Kashmir, at Shalimar Bagh (1641). Diverting

the water of the nearby canal from Lake Dal as the source for running water, the rectilinear plan is divided into four quadrants through its hierarchical water channels. Located on a sloped site, three main tiers (the lowest was a Public Garden, the middle was the Emperor's Garden, and the highest was the Zenana Garden), this terraced garden differed from earlier forms and prototypes, in that it adopted the surrounding mountainous topography. Each tier was unified by a central cascading water channel that dictated the main longitudinal axis and a set of water fountains at each level. Lined with sycamore trees, the central canal also houses arched pavilions (*baradaris*) and niches (*chini khanas*) behind the waterfalls at each terrace level.

Stemming from Babur's interest in plant life, garden complexes had a regionally adaptable species of fruit and flower species, such as citrus fruits, almonds, mangoes, and other Persian crops. Fatehpur Sikri (1569) and the Bagh-i Nur Afza (1620) are two examples of palatial garden complexes serving a variety of functions. The ruler and his establishment benefited from these horticultural experiments. These private royal gardens did have commercial potential, in that people renting garden areas could sell the fruit and flowers to common people. These funds in turn went to support the massive expenditure of the imperial tomb gardens, which was solely

intended for imperial symbolism and monumentality. On the other hand, private pleasure gardens owned by rulers or the nobility contained a wide diversity of flower and tree species and often followed the formal components of the garden plan, as in the case of the Bakhtawar Khan's garden (1667). Some Mughal gardens also served a fourth function in that they were open to the public, such as the Jahanara Garden in Surat (1648), which also included a caravanserai and was open to the public and visitors.

The use of elaborate small-scale pavilion structures and fountains continued to evolve in the Turkish gardens of the Ottoman Empire (1301–1922). While symbolic metaphors were shared with earlier Persian garden traditions, Ottoman sultans differed in that they created many private gardens for enjoyment and pleasure based on existing topographic conditions and irrigation sources, rather than relying on rigid geometric form and typologies. As in the case of Istanbul's royal Topkapi Palace Garden (1453), geometric fountains and pools were centrally placed, surrounded by a series of arched pavilions and a wide diversity of plant life (flowerbeds, herbs, fruits, and vegetables).

The Timurid influences of incorporating gardens on a city scale played a dynamic role in the urban reconstruction of Isfahan during the Safavid era (1502–1736). When Shah Abbas moved the capital from Qazvin to Isfahan, the design of the center city's streetscapes, city centers, and squares played a significant role in the shaping of the urban framework. In a city whose landscape was already fertile and well irrigated, the longitudinal axis of the main city center, the Naghsh-i Jahan Square (1598), was formed by the royal Chaharbagh Street laid along perpendicular to the Zayandeh River and subdivided by palaces, mosques, caravanserais, and arcaded bazaars. Becoming a thriving center for city activities, this prototype at Isfahan set a precedent through the adaption onto a grand urban scale and opened up the garden spaces for a multitude of public civic uses.

Gardens continued to develop and play a vital role in palatial gardens during the Qajar rule (1781–1925), such as the Eram Garden in Shiraz, Iran, which was restored under Qajar rule. While

ideas of formal geometric order, water elements, and pavilion structures continued to be embedded into the plan, an interest for diversifying vegetation surged including orange, pine, persimmon, and cypress trees. The desire for cooling was also addressed by creating channels of flowing water as well as pools of still water that served as a reservoir. However, in contrast to earlier works mostly marked by walled compounds, gardens of eighteenth-century Iran such as the Golestan Palace garden also gave priority to views to surrounding landscape and context. On a residential scale, the aristocratic house had garden complexes in the form of extensive courtyards outside city boundaries such as the Farmaniyeh House, Ghavam al-Saltaneh House, and Massoudieh House. These examples included ideas of pools, plant life, and hierarchical concepts of enclosed spaces and porches.

Between the thirteenth and eighteenth centuries, Arab traders migrated to various regions to the east, and this resulted in new empires and rulers in Southeast Asia, such as the reign of Sultan Hamengkubuwono I (1755–792). The Tamansari Water Castle complex (1758) in Indonesia consisted of a vast complex of gardens for private pleasure, royal defense encampments, hiding grounds, as well as several other smaller plots of landscape. With water as a central element, each of the spaces was linked through a series of geometrically shaped courtyards, drawing toward a central bathing complex.

Gardens have also played a dynamic role in the surge for urban regeneration and renewal of the late twentieth and early twenty-first centuries, in the form of open green spaces and public parks. As a part of the vast urban growth of Tehran in the mid-1900s, public city parks for recreation were created such as Niavaran Park, Laleh Park, and the largest Park-e Shahr. Containing some elements of traditional gardens of water, vegetation, and treatment of landscape, all of these parks were built for recreation and promoting civic life. Another such example is the Al-Azhar Park (1997–2004) in Cairo, which has open green space to rejuvenate the central core of the city while still paying homage to historic monuments, housing districts, and functioning as a part of the

modern infrastructure. Transformed from a central plateau of debris amid a dense historic city, this park reinterprets early Persian garden masterpieces through formal geometrical orchards, pavilions, lush vegetation, and open green spaces tied together by a continuous circulation path and several water pools and fountains. Contemporary gardens and landscape design for political projects such as the Dewan Negeri Johor (2003) and the Sultan Ismail State Parliament Building (2006) in Malaysia pull from early Umayyad design principles of formal geometric order and layers of spatial experiences to convey the changing role of government buildings.

From private enclosures for aristocracy to nodes of various public functions impacting urban growth, gardens emerged as a key facet of the built environment in the Middle East and Asia. Gardens of these regions have shown that they can become powerful illustrations of discovering nature's power and human purpose as they function through the design and adaptation of the landscape.

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Gas: Exploitation and Use of Natural Gas in Premodern China

Hans Ulrich Vogel

Ancient Chinese sources give many references to strange fiery phenomena burning on water or

rising out of the earth. For instance, the *Hanshu* says that in 61 BCE the emperor sacrificed at the “fire well” (*huojing*) of Hongmen (Shaanxi). We do not know the cause of this fiery discharge, but it is clear that this fire well was an object of religious worship, because a fire well temple had been erected there. No mention was made of any use for industrial purposes (Fig. 1).

The first reports on the industrial use of a fire well come from the middle and late third century AD. One of these reports state that there is a fire well in Linqiong, Sichuan province. Once Zhuge Liang (181–234), counselor-in-chief of Liu Bei (162–223), came to see it, whereafter the fire turned stronger. People put pans on the well to boil salt. When brands of common hearths were entered into the well, it at once extinguished and did not burn again. Thus, it is clear that the prosperity and decline of the well was seen as corresponding to political developments. Another source, for instance, interpreted the extinction of the well as an omen for the annexation of Shu by Wei.

We cannot ascertain whether the Linqiong fire well was really a natural gas well, because later texts appear to suggest that petroleum was involved. Whatever the case, there is no doubt that it was productive for only a short period. That later authors referred to this well time and again is because it constituted a strange and interesting historical phenomenon. It is therefore hardly justified to speak of the “systematic use” of natural gas for evaporating brine “on an industrial scale” starting in the second or even fourth century BCE, as Joseph Needham claimed. Moreover, Needham also assumed that deep drilling, which was one of the preconditions for a systematic exploitation and use of natural gas, had already been invented during the first century BCE or AD. Recent research showed, however, that deep drilling originated in the middle of the eleventh century.

After the Linqiong fire well had become extinguished, probably in the late third century, Chinese sources do not mention the use of fire wells for industrial purposes until the sixteenth century. Although they still report on the outflow



Gas: Exploitation and Use of Natural Gas in Premodern China, Fig. 1 Fire wells of different quality, as shown on a mid-eighteenth century scroll. The scroll was photographed by Rewy Alley in Beijing in

1954. The location of the original is unknown (Photograph used with the permission of the Needham Research Institute, University of Cambridge)

of mist (*yanqi*) and hidden vapors (*yingqi*) from wells, it is clear that these discharges were conceived as threats to well salt production. For instance, in the tenth century explosive “hidden gas” was reported from the Ling well, a shaft well in the Lingjing industrial prefecture. Moreover, it is said that in the eleventh century, when workers had been let down into the well for repair work, they were killed. Only by the installation of a so-called “rain basin” (*yupan*) over the top of the well could these difficulties be overcome. From the rain basin water sprinkled down like rain, which carried the gas down into the well. This device was derived from the observation that gas discharge was restrained during rainy days.

Systematic use of natural gas began in the sixteenth century. In the beginning, the number and output of industrially used fire wells appear to have been still limited. Until the end of the eighteenth century a fire well usually could supply

fuel for only one to four pans, though exceptionally productive wells like the Yongtong well existed, which is said to have fed 16 pans. A scroll of the mid-eighteenth century shows interesting details of fire wells of differing productivity probably in northern Sichuan.

The standard situation appears to have been that one well was feeding one pan which was placed directly over the well. A ► bamboo tube inserted into the well served as burner. It was covered by a stone, in case the fire was to be extinguished. The scroll also shows a very productive fire well supplying two pans. The gas distribution device consisted of a large bamboo tube on which a porcelain vessel filled with water was put. The gas was distributed to the pans by two small pipes connecting the burners with the large bamboo tube. Finally, less productive fire wells not only could not feed more than one pan, but had also to be supported with firewood.

The situation changed dramatically with the development of deep drilling techniques in the nineteenth century, when the high pressure gas deposits in the deeper strata of the Ziliujing gas field were tapped. For instance, the French missionary Imbert reported in September of 1827 that a single fire well of Ziliujing could feed more than 300 pans and that the wells were so productive that a part of the gas could not be used and thus had to be burnt off. A new generation of productive fire wells supplying 400–700 pans is mentioned by Li Rong in his famous account of Ziliujing from the end of the nineteenth century. The use of the resources of such highly productive wells necessitated the invention of a number of devices for the control and distribution of the gas flow and for coping with variations in the well's pressure. The utilization of gas was a highly dangerous undertaking which could lead to explosions. That was also the reason why at least in Ziliujing gas was only rarely used for household purposes.

Natural gas was an amazing phenomenon which required explanation. Song Yingxing, in 1637, said that the fire wells contained simply cold water, but not the slightest evidence of the *qi* of fire. One can only see the notion (*yi*) of fire which is bursting forth from the burner's pipe, so that the brine will boil violently. Yet if the bamboo pipelines for conducting the gas are opened and examined, no sign of charring or burning can be seen. "To use the spirit (*shen*) of fire without seeing the solid form (*xing*) of fire – this is indeed one of the strangest things in the world" (Sun & Sun, 1966). Later Chinese authors had less strange ideas of the phenomenon of fire wells. For instance, in 1791, Xu Deqing came to the conclusion that the existence of fire and wind in the earth of high-lying terrains should be regarded as something quite normal, similar to the existence of fresh water sources in marshy and low-lying regions.

See Also

► [Salt in China](#)

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Ge Hong

Ho Peng Yoke

Ge Hong (ca. 283–ca. 343), alchemist, physician, astronomer, and government officer, was the greatest alchemist and physician in fourth-century China. We also know him under several other names, such as Ge Zhiquan, Zhiquan Zhenren, Baopuzi, and Xiao Ge Xianweng. His exact dates are not known with certainty. Some say that he was born between 280 and 286. Other dates given for his birth are ca. 253, 280, 281, 283, and 284. The year of his death has

been variously given as ca. 333, 340, 343, 361, and 364. Chen Guofu's elaborate study suggests the period 283–343 for him. Ge Hong's autobiography is contained in his *Baopuzi waipian* (Exoteric Chapters of the Preservation-of-Solidarity Master), but it says precious little about the author's scientific achievements. His biography is given in the *Jinshu* (Official History of the Jin Dynasty). Since he is regarded by the Daoists as having attained physical immortality, his hagiography is found in abundance in Daoist literature.

When he was young Ge Hong studied alchemy under Zheng Yin and Bao Jing, whose daughter he later married. He also learned much about medicine. He joined the government as an army officer in a military campaign to suppress an uprising in the year 303. After peace was restored he left without seeking reward and traveled widely in search of books. In the year 306 he accepted an invitation from his friend Qi Han to become his military adviser when the latter was appointed Governor of Guangzhou. Qi Han, the author of the *Nanfang caomuzhuang* (Records of Plants and Trees in the Southern Region) was one of the greatest botanists in traditional China, but unfortunately he was soon assassinated. Ge Hong remained for some time in the South and then returned to his place of birth, Nanyang, in Jiangsu province. A belated award came for his past service in the army. He was given the title Marquis of Guannei, and was recommended to the emperor for appointment as a member of the bureau of historiography. He declined the offer, but requested that the emperor make him magistrate of Goulou in South China, which was a rich source of cinnabar that he needed to prepare the elixir of life. Eventually the emperor granted him his wish. Ge Hong then went to live in the Luofoushan Mountain where he carried out his alchemical and protochemical experiments. It was probably there that he completed his famous alchemical work, the *Baopuzi*. Some say that the year was 317.

The *Baopuzi* consists of a *Neipian* (Esoteric Chapters) in 20 chapters and a *Waipian* (Exoteric Chapters) in 32 chapters. Among those in the *Neipian*, chapters 4, 11, and 16 are of special

interest to the alchemists, while the other chapters also contain bits of information on alchemy scattered here and there. Chapter 16 specifically describes the transmutation of base metal into gold or silver. Chapter 1 of the *Waipian* contains Ge Hong's autobiography. The rest of the *Waipian* says nothing about science or alchemy. The relevant sections in the *Neipian* contain names of more than 50 elixirs supposed to have various efficacies – some could only prolong the human lifespan, while others could transform the aspirant to a holy immortal varying from 3 days to 3 years depending on the elixir itself. Ge Hong seemed to be successful in aurification, the process of imparting an appearance of gold to base metals by artificial means. It is interesting that the attributes of the elixir of being a panacea, of being able to translate base metals into gold or silver by means of projection, and of being able to impart longevity and perpetual youth were already mentioned by Ge Hong in the case of some of the elixirs in his *Baopuzi*. Sulfur and mercury were used in many of his elixir recipes.

Ge Hong was an eminent physician in his own right. His *Baopuzi neipian* describes the medicinal values of many plants and minerals. During his stay at the Luofoushan Mountain he also wrote the *Jingui yaofang* (Prescriptions in the Treasury of Medicine), in 100 chapters. Later he added an abridged version, entitled *Zhouhou jiuuzufang* (Handbook of Medicine for Emergencies) in three chapters. Ge Hong's writings contain prescriptions for various types of diseases, including eye trouble, ailments of women and children, and infectious diseases such as smallpox and tuberculosis. They prescribed soya beans, cow's milk and goat's milk for the treatment of beriberi, and for treating bites from mad dogs the recommendation was to apply the brain of the culprit over the wound.

Ge Hong also showed considerable interest in astronomy. The *Jinshu* (Official History of the Jin Dynasty) quotes from a piece of his lost writings on the construction of astronomical instruments by ► [Zhang Heng](#) in the second century. It also narrates Ge Hong's participation in the great cosmological debate of his time. There were then two rival schools, the ► [Gaitian](#) (Canopy

Heaven) and the ► **Huntian** (Spherical Heaven). The former was more ancient and pictured a canopy heaven covering a square earth like a tilted umbrella. The latter visualized the earth as the yolk of an egg floating on water at the center of a spherical heaven that was itself supported by water. The argument used against it was that the sun rising from and setting into water would be quenched of its fire and heat. In supporting the *Huntian* theory, Ge Hong skillfully quoted the hexagrams and passages from the *Yijing* (I Ching, Book of Changes) to silence its critics. Ge Hong also observed the effect of the moon on the water in the sea and on the tides. In his *Baopuzi* he referred to the waves of the sea heaving up and down with the waxing and waning of the moon and the increase in magnitude of the tide when the moon was full.

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Geodesy

Raymond Mercier

Geodesy, the measurement of the earth, is an essential component of both astronomy and geography. The spherical shape of the earth was a concept developed in the early stages of Greek

science, and one finds this concept wherever the legacy of Greek science was taken seriously. Figures for the radius of the earth were reported by Aristotle and a number of other Greek scientists, although a judgment of their accuracy is hindered by our ignorance of an exact measure in modern terms of the units in which the radius was expressed. The coordinates in Ptolemy's geography were fixed by him from various distances measured in terms of *stadia*, converted on the assumption that 1° equaled 500 *stadia*; for Eratosthenes, the degree equaled about 700 *stadia*. On the other hand sources in Latin and Syriac rather later than Ptolemy worked on the assumption that 1° equaled 75 Roman miles, which we can evaluate because the length of the Roman mile is well established, so we know that it is very precise. The radius and circumference of the earth follow immediately from the length of 1°.

In the early stages of Arabic science, especially the work heavily patronized in the early ninth century by the Caliph al-Ma'mūn, various Greek and Syriac sources were consulted with a view to fixing the earth's dimensions. Here the intention was to evaluate the degree in terms of the Arabic mile, which we know to be 4/3 Roman miles, 1,972 m. The Arab scientists of the time, however, were uncertain as to the interpretation of the various figures given in their sources, and they were certainly confused about the true length of the Roman mile. While they were aware that the Roman and Arabic miles were, respectively, 3,000 and 4,000 cubits, they were ready to assume that it was the cubits and not the miles which differed.

Against this background they set about to measure the length of the degree by direct observation of the latitude variations along a north-south traverse in the desert of Iraq. They chose a region south of Sinjār, which is about 100 km west of Mosul. According to extant reports two expeditions were made, one led by al-Marwarrūdhī, the other by 'Alī ibn 'Isā al-Aṣṭurlābī. In one account it is said that they agreed on the ratio 56 miles per degree, but other accounts of the expeditions report 56 2/3, or 56 1/4 miles. There is probably a blending here of observation together with a conversion of the

late Roman figure of 75, since $3/4 \times 75 = 56 \frac{1}{4}$. The accounts are somewhat lacking in circumstantial detail, and probably the methods employed, which must have involved a sufficiently portable quadrant for the measurements of latitude along the route, would not have sufficed to provide more than a rough verification of the received figures, sufficient at least to distinguish between the two different interpretations of the mile.

The great scientist ► [al-Bīrūnī](#) (fl. AD 1030) carried out some work of great value in his determination of a series of longitude differences for stages leading from Baghdad to Ghazna. These were reported in both his treatise on geodesy *Tahdīd nihāyāt al-amākan li-tashīḥ masāfāt al-masākin* (The Determination of the Coordinates of cities), and in his astronomical treatise the *Qānūn al-Masʿūdī*. He also reported his own attempt at a determination of the length of the degree. The latter took place in the Punjab, where the plain to the south may be seen from a peak (479 m) in the Salt Range, some 50 km South West of Jhelum. Al-Bīrūnī says that he measured the dip of the distant horizon as 34 min of arc, from which according to his calculation, he finds slightly more than 56 miles to the degree. He considers however that this should be regarded not as a new result but as a confirmation of the earlier result fixed at the time of al-Mamūn. In fact his procedure was flawed in various ways, for his measurement of the height of the mountain was considerably in error, and a correct interpretation would have required that refraction be taken into account. Moreover we may calculate, taking refraction into account, that he would have obtained a dip nearer to 29 min, so that his whole account is quite suspect. The method has been suggested independently by a number of scientists, but even when carried out with the greatest care, it is doomed to failure because the degree of refraction is unpredictable for a ray grazing the earth's surface.

Al-Bīrūnī's determination of the longitude differences was much more successful. The tables of mean motion in his astronomical treatise were referred to the meridian through Ghazna (near Kabul), and he was naturally obliged to determine

the time/longitude difference between that place and Baghdad. The primary information available to him, as to Ptolemy before him, was provided by travelers who would have converted a traveler's time to a distance. The region between Baghdad and Ghazna is divided up by al-Bīrūnī into shorter stages along two different routes, one passing North through Rayy and Jurjaniyya, and the other South through Shiraz. For each short stage, he calculated the difference of longitude, given the latitudes at each stage, and the distance from one stage to the next. In every case the travelers' distance is discounted to allow for the fact that the real path deviates from a perfect great circle. The problem of fixing the longitude difference is posed and solved correctly in terms of spherical trigonometry, and he gives all the numerical details, so that one can judge the accuracy of his work. In spite of occasional lapses in the calculation the results represent a very considerable improvement over that available in Ptolemy or ► [al-Khwārizmī](#); the final longitude difference between Baghdad and Ghazna is only some 15 min of arc short of the true value. People would not be able to improve on that until entirely new methods were discovered in the late seventeenth century, such as the use of Jupiter's satellites.

See Also

► [Al-Bīrūnī](#)

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Geographical Knowledge in Ancient Sri Lanka

P. Wickramagama

Our knowledge about the early inhabitants who lived prior to the sixth century BCE in Sri Lanka is very limited, but more historical data is available for the period thereafter. Sri Lanka gained a place in the East-West trade and became an important centre in the sea route connecting the Far East and the West. It was known to people outside by several names (Lanka, Serendib, Sihladeepa, Taprobane, Seylon, Zeylon, Ceylon, etc.). Its proximity to the Indian subcontinent meant that people moved back and forth freely in ancient times. The Island has a long history of human habitation from about 130,000 years or more (Deraniyagala, 1998).

The island is divided into two major climatic zones, dry and wet, with a narrow belt in between with transitional characteristics. The Sinhalese civilization flourished in the Dry Zone, despite a severe water shortage during the long dry season. The highly seasonal rainfall meant rain-fed cultivation was possible only during the wet season. Despite this constraint, the main livelihood of the people was rice cultivation, which required considerably more water than any other crop. The need for artificial irrigation to overcome water deficit was understood from a very early stage, and the technology to develop a complex system of reservoirs and canals seems to have evolved out of this necessity. Development of irrigation demanded a high level of knowledge of the terrain as well as the principles of hydraulic engineering.

Sinhalese Cosmology

The ancient Sinhalese are thought to have known a great deal about the earth, its spherical nature, its position among other planets and the universe at large (Gunawardana, 1979). Sinhalese did have

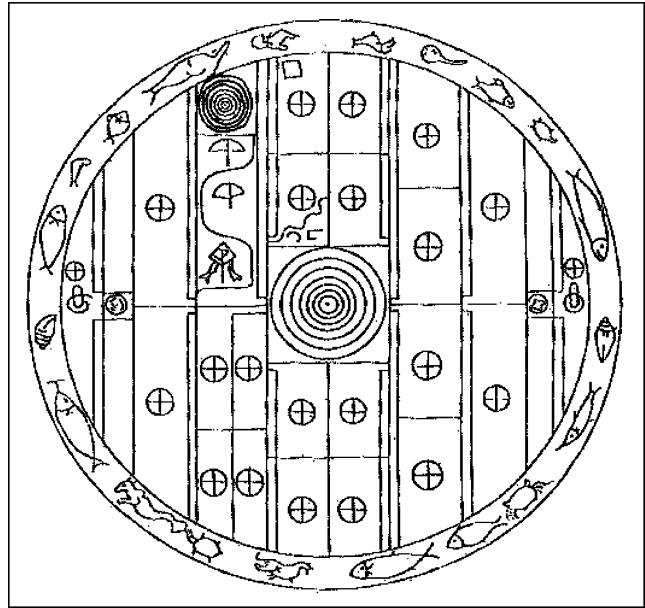
close contacts with various parts of India and the Greco-Roman empire, particularly from the first century AD. Both ancient Hindus and Greeks had certain concepts of the earth, solar system, and the stellar constellations. Astrology played an important role in the ancient Sri Lankan and Indian cultures at a very practical level, and knowledge of astronomy was essential to make astrological calculations. It is possible that there was a considerable exchange of astronomical ideas between the east and the west. Verse 29 in *Sūryasiddhānta* says “This Brahma-egg is hollow; within it is the universe, consisting of earth, sky, etc.; it has the form of a sphere, like a receptacle made of a pair of cauldrons” (Burgess, 2000, p. 285).

Sūryasiddhānta also places the zero meridian (*madyama-rekha*) over Sri Lanka (Burgess, 2000, p. 362).

There is evidence that *Sūryasiddhānta* was one of the astronomical/astrological texts taught in the educational institutions of ancient Sri Lanka. *Girasandesaya*, a message poem, composed in the fifteenth century “describes how students at the Vijayaba Pirivena studied the *Sūryasiddhānta*, plotting the location of various planets by placing sea-shells as markers on a blue board and then moving them in accordance with their calculations” (Gunawardana, 1979). The *Vijayaba Pirivena* was one of the foremost educational institutions of Sri Lanka at that time. It is probable that the Indian astronomical texts were in use in Sri Lanka long before that. Further evidence of this can be found in *Sūryasiddhānta* itself, which speaks about exchange of ideas between students of astronomy in Sri Lanka and elsewhere in South Asia (Gunawardana). At the same time, their links with the Greco-Roman empire means they would have known the ideas of Greco-Roman philosophers. The Sri Lankan ambassadors who visited Rome during the reign of Emperor Claudius are known to have discussed the stellar constellations they observed in Rome and compared them with those observations back in Sri Lanka (Gunawardana).

Another piece of evidence of the Sinhalese cosmology and the shape of the earth is a carving in a cave in Anuradhapura (Fig. 1), which was

Geographical Knowledge in Ancient Sri Lanka, Fig. 1 *Sakwala* from a cave in Anuradhapura (After Bell, 1901)



discovered by archaeologists at the turn of the twentieth century (Bell, 1901), and was named *Sakwala* (earth or universe). It is a circular figure within which numerous symbols are carved and the outermost ring contains aquatic life forms. At the centre of the figure is a carving with seven concentric circles with a dot marking the centre. At this time, there was a belief that this was Mount Meru located at the centre of the world surrounded by seven oceans and four continents. It is possible that the figure with seven concentric circles represent the earth and seven oceans. The same concentric circles occur at the top of the figure as well. The other figures in the interior of the circle have not been identified. Wickramagamage (1995, p. 54) is of the view that this is a *yantra* which may have been used for meditation purposes. There is a seat made of stone right in front of this figure.

Ancient World Geography

The ancient Sinhalese maintained relations with countries in South Asia as well as the countries up to Rome in the west, and up to China and beyond in the east. This was facilitated by its strategic position in the east-west sea route. Seafarers from

the west and east came to Sri Lanka which acted as a trading post in the ancient world (Tampoe, 1995). Two other ports that participated in this trade are Gokannapatuna (Trincomalee) in the northeast and Magama in the south. Manthai (Near Mannar) functioned as the main harbour and as a great emporium in the ancient South Asia region. Sri Lanka sent its own ships to China (Tampoe).

Sri Lankan kings had established links with Greece and Rome as far back as the first century AD. The king of Sri Lanka (Bhatikabaya) explored the possibility of developing direct trade links with Rome. In the year 361 AD, an embassy from Serendivi was received by the Emperor Julian. Similarly, commerce between Sri Lanka and China goes very far back into history. Manthai was involved in transshipment of Chinese goods to the West. China-Sri Lanka trade relations were also reported by the Sinhalese ambassadors to the court of Claudius in the first century AD. Embassies carrying gifts from the Sinhalese king visited China in the first century AD. The relations with China were not confined to trade. There were cultural exchanges between the two countries. The countries with which Sri Lanka maintained relations include Greece, Rome, Egypt, Arabia, Afghanistan, and



Geographical Knowledge in Ancient Sri Lanka, Fig. 2 The world ancient Sri Lankan knew

Persia on the west and China, Korea, Japan, Malay-Indonesian Kingdom in the east (Bandaranayaka, 1998). At the same time relations with India remained at a high level. As Weerakkody (1997, p. 139) has pointed out Sri Lankans themselves had gone to foreign countries on business, and owned ships of considerable size. The Chinese writer, Kien Chang found people from Sri Lanka in Canton. Also a Javanese inscription belonging to the eleventh century mentions Sinhala merchants putting in at ports there (Weerakkody, p. 139). This evidence indicates that ancient Sinhalese knew a large part of the civilized world. The continents of Americas, Africa, and Australia were not known to them. The world they knew in ancient times is depicted in Fig. 2.

Knowledge of the Island

The dry lowlands of Sri Lanka received early waves of immigrants from India and continued to be the main areas of population concentration

up to about twelfth century. Although available evidence shows that the Wet Zone was inhabited since the Stone Age, evidence of major population centres is found only in the western lowlands, where the Kelani Kingdom existed. There are however some references to villages and places of religious importance in the Wet Zone. The Wet Zone highlands were a part of the *Tri Sinhale*, the three provinces the country was divided into. Distribution of stone inscriptions is often taken to indicate the distribution of the ancient settlements in Sri Lanka (Perera, 1978). The high concentration of inscriptions in the Dry Zone lowlands can be interpreted as evidence of ancient settlements in that area, and absence or low density of ancient inscriptions in the Wet Zone (both lowlands and highlands) may indicate that these areas were not densely populated at that time.

A number of villages were involved in various crafts and functions, such as industrial, agricultural, King's service, etc. According to Perera (1978) there were four types of settlements in ancient Sri Lanka:

1. *Gama*: Consisting of paddy fields, gardens, and chena. The people belonged to the same caste.
2. *Nigama*: Larger than *Gama* and a market town where traders met.
3. *Patun Gama*: More urbanized than *Nigama*. Both local and foreign merchants traded. These settlements were situated by the shore and usually had a harbour.
4. *Pura* or *Nagara*: Urban settlements, usually seats of government, with streets. Both local and foreign merchants met.

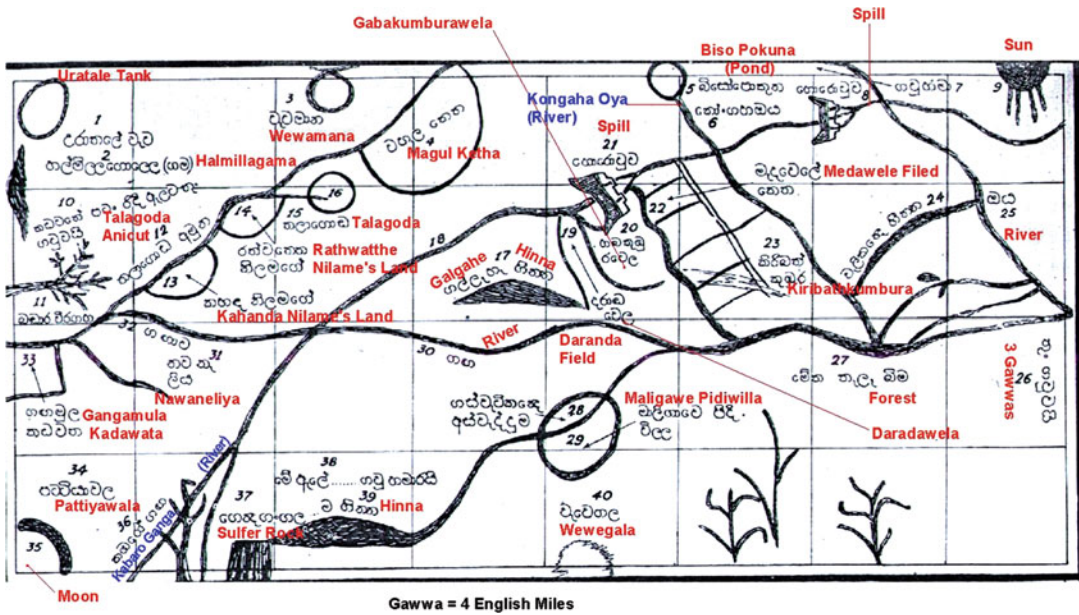
These villages were given names based on a salient characteristic of the village, and it is often its geographic character. There are many village names indicative of land forms, habitats, minerals, or man-made structures such as village tanks. The frequency of a certain name of a landform as a prefix or suffix to the village name indicates the dominance of that landform in the area. For example in the midcountry areas, there are many village names with ‘*deniya*’ which means a valley. This area is characterized by the presence of a ridge and valley topography, and the people have shown a preference to settle in such areas for the reason that they are suitable for paddy cultivation. Some villages are named after a dominant plant or animal species present in the area.

The island has been under one monarch from time to time or split into several kingdoms when there was no strong ruler to unify the country. Unification of the country led to wars which made it essential that the warring armies were acquainted with the terrain. From a very early stage, the different parts of the island were well interconnected by major routes. The chronicles and commentaries speak about five main highways. King Nissankamalla (1187–1196), according to an inscription, fixed *guavas* (2.25 English miles) on the main highways and laid inscribed stone pillars (Nicholas, 1959). Buddhist pilgrims from all parts of the island used to visit Adam’s Peak (*Sri Pada*) mountain on top of which the foot print of the Buddha is supposed to have been placed. Long distances were covered to reach the *Sri Pada*.

The *Sandesa Kavya* (Message Poems), composed in the Kotte period (fifteenth to sixteenth century), were written to dispatch a bird as a messenger with a message to kings and deities. The route to be taken by the messenger is described in detail in poetry, which contains a geographic description of the landmarks the messenger would encounter in its journey.

Cartography

The oldest known map that has survived goes back to the seventeenth century based on a claim by the person in whose custody it was kept (Fig. 3). This map shows “certain lands and the topography including the irrigation system in the valley of the Amban-Ganga, near Elehera, in the District of Matale” (Brohier, 1951, p. 192). It has been drawn on a closely woven fabric (40 × 80 in.). A reproduction of this map has been published by Brohier together with the corresponding portion of the 1-in. map of the area. The two maps show a remarkable resemblance. The scale of the map appears to be about 1 in. to a 1/4 mile, but this is not consistent throughout the map. The distances on the map are given in the Sinhala mile of *gauwa* which is about 4 English miles. The relative position of geographic features is accurate. There is no information about authorship of the map, or for what purpose it was produced. The directions are indicated in the map using the rising sun (east) and the waning moon (west). Brohier is of the opinion that the cartographer of this map was not familiar with the compass. If the author of this map learn the art of mapmaking from the Portuguese who were in the maritime provinces of Sri Lanka since 1505 and the Dutch later, he would have known to determine compass direction. Without more of such evidence, no firm conclusion can be drawn about the history of mapmaking in Sri Lanka. Given the need of such a practice in order to design irrigation canals, paddy lands, and reservoirs, it is conceivable that some form of mapmaking tradition existed in Sri Lanka. Maps may have been drawn on perishable material and therefore no evidence was left for the present generation.



Geographical Knowledge in Ancient Sri Lanka, Fig. 3 Sinhalese cartography (After Broheir, 1959, the English Text by the author)

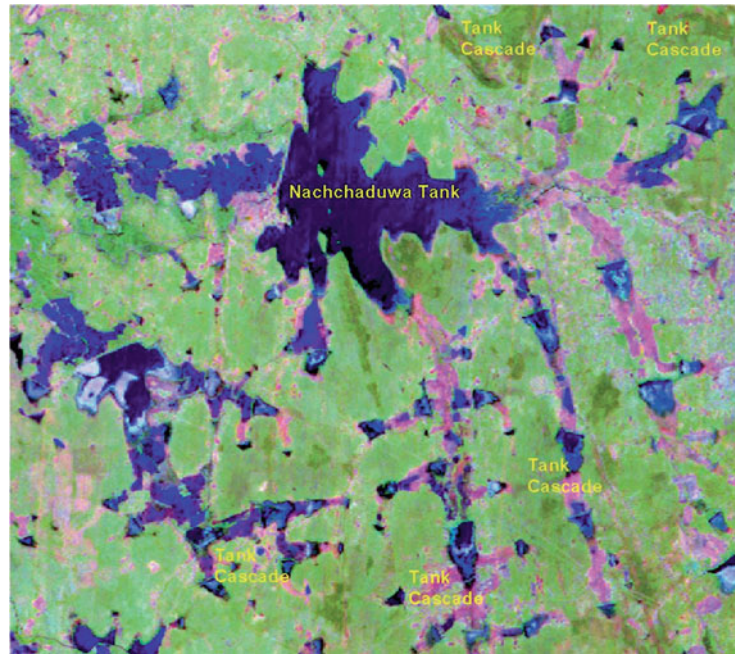
Land Surveying and Design of Irrigation Systems

Without a clear understanding of the characteristics of the topography, construction of large reservoirs, tank cascades, and laying out of canals in an almost flat terrain would not have been possible. These irrigation works and their design can be used as indirect evidence of this knowledge. The early settlers of Sri Lanka chose the dry lowland plains for their settlements despite the severe water shortage during much of the year. This natural constraint was overcome by constructing first what is known as village tanks throughout the settled areas for irrigation as well as domestic use. Later, with an increasing population to be fed, it was discovered that these works were insufficient to last the dry season. This led to the development of large scale irrigation systems such as large reservoirs to store water by damming streams originating in the Wet Zone highlands. To convey water to paddy fields a system of main and distributary canals were constructed. They made decisions on the way canals are constructed, placing of sluices,

and constructing dams in an undulating plain taking advantage of the topography. This point can be illustrated using the example of the trans-basin canal, *Yoda Ela* (Giant's Canal), running from *Kala Wewa* reservoir in the *Kala Oya* river basin to the *Tissa Wewa* of *Anuradhapura* (the ancient capital of Sri Lanka) located in the *Malawathu Oya* basin. This canal has a gradient “for the first 17 miles (27 km) of 6 inches” (Brohier, 1979, p. 8). This shows the extent to which the ancient irrigation engineer understood the hydraulic principles and was able to convey water for long distances efficiently in a gently undulating terrain. Further evidence of the knowledge of the ancient Sinhalese engineer can be illustrated by a case where a branch canal from the *Yoda Ela* constructed by modern engineers some years back was later discovered to have run along the trace of an ancient canal which was used to irrigate the same lands using the water from *Yoda Ela*.

Another example for the extent to which the ancient Sinhalese understood the topography is the construction of village tank cascades in the Dry Zone of Sri Lanka (Fig. 4). “A cascade is a

Geographical Knowledge in Ancient Sri Lanka, Fig. 4 Ancient tank (reservoir) cascade systems near Anuradhapura



G

connected series of tanks organized within a micro-catchment of the Dry Zone landscape, storing, conveying and utilizing water from an ephemeral rivulet” (Madduma Bandara, 1985). They are constructed taking advantage of the topography along the tributaries of Dry Zone streams. There are 127 tank cascades in an area of 1,225 km² covered by the Anuradhapura and Medawachchiya 1 in. topographic maps alone. This amounts to one cascade per square km. Over 85 % of the operational tanks are located in cascades. The tank cascades allowed the optimal utilization of meagre water resources of an area. Each tank is associated with a paddy field, and the excess water from the paddy field returns to the tributary to be input to the tank downstream. The size of the tanks in a cascade tends to increase towards the lower end. The cascade system is reckoned to be one of the most efficient systems of water storage, conveyance and irrigation.

The ancient Sinhalese had a remarkable knowledge of the island as well as the South Asian region, and the countries in the west and the east. Their knowledge was not confined to the knowledge of places, but included such areas as the characteristics of the earth as a planet.

An area that should receive a great deal of attention and in-depth research is the knowledge the ancient Sinhalese had on harnessing water resources of the country. Construction of artificial irrigation systems of colossal magnitude and conveyance systems is a remarkable technological achievement. The most surprising of all is the ability to design these systems with such precision with minimal equipment. They seem to have had an intimate knowledge of the terrain which they utilized to the maximum extent in designing and constructing irrigation systems.

After abandoning these systems for largely unknown reasons, the population moved into the lower parts of the hill country and again used the topography of the terrain to their advantage to protect themselves from enemy attacks. The new settlements were established in the hill country which was completely protected by natural barriers, and entry was possible only through narrow mountain passes which were well guarded.

Although mapmaking would have been an immense help to the designers of irrigation system, no evidence is found on a cartographic tradition in Sri Lanka, except for a Sinhalese map attributed to the seventeenth century. This is

surprising given the fact that locating of reservoirs and construction of canals would have to be carefully designed and planned.

A substantial amount of original material is available for careful examination and study. It would be a rewarding exercise which could reveal depth of geographical knowledge of the people who lived in this island for over 3,000 years.

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Geographical Knowledge in Non-western Cultures

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Cultures differ in their assumptions about the nature of life, the place of their existence, and the place of humanity within their environment. Places, like space and time, are constructed socially and culturally and as such can provide ways to understand the literal and metaphorical geographies of humans. The specificity of place derives from the fact that each place is the focus of unique mixtures of wider and more local relations between social groups, and it is this mixture which accumulates continually to create the distinct place. While distinguishing labels, for people involved in these social relations, such as woman, Canadian, Maori, can be starting points, no one person or one group is exclusively one complete identity, Western, or non-Western, in the end of the twentieth century.

Human cultures are neither essentially coherent nor wholly homogeneous. The borders between nations, classes and cultures have become more fluid. The very notion that the majority of the world's population is defined by not being something (in this case non-Western) infers the continuing power of the past legacy of European and more recently American colonialism or imperialism. The majority of the world's population are non-Western. They did not

originate from Europe's colonial expansion into the Americas, Australia and New Zealand.

This geographical inquiry into the historical experience of non-Western cultures is made from the perspective of a Western woman, a cultural/historical geographer, born in Canada, now residing in Australia. A renewed concept of culture refers not to any unified entity. In a post-colonial world, the idea of an authentic culture as an internally coherent world is no longer tenable. Increasing global interdependence has made it clear that neither "we" nor "they", Western nor non-Western cultures, are neatly separated and mutually exclusive. All of us inhabit an interconnected, late twentieth century world, marked by porous national and cultural boundaries that are enmeshed with power, domination and inequality.

It is however, impossible to deny persisting continuities of long standing traditions, literate or oral, sustained habitation and cultural geographies of non-Western traditions. Human history is rooted in the earth. To understand this history, it is necessary to consider human dwelling and also to realize that European expansion meant the taking of land which was already owned by indigenous residents. With the beginning of European expansion in 1500, most indigenous peoples lived on their lands practicing agriculture, hunting and gathering. While all of these people have expanded geographically into adjacent territories, or into lands near where they once lived, there is no comparison with the great spread of people from European nations. It has been this modern colonialism which forced many indigenous peoples off their own land: Aborigines of Australia, Maoris of New Zealand, the indigenous peoples of North and South America. This compulsion of the Western world to explore, conquer, occupy and own other lands has involved such a long continuous process that it has been called the distinctive Western characteristic.

In contrast, a deep sense of belonging to the land, is central to the identity of indigenous peoples throughout the world, as exemplified by this Maori statement, that while "people disappear, land remains; land doesn't belong to the people,

people belong to the land" (Yoon, 1986). The names many of these First Peoples call themselves, such as Inuit, Maori, Saami, mean "people" and the names of their places mean "land". They literally know themselves as people of the land. "We have opted to become part of the environment", explains Burnum Burnum of Australia. Although differing widely in their customs, culture, economic status, physical surroundings, and impact on the land, many indigenous societies often share a set of values that are in marked contrast to Western priorities. The Cree of Quebec, San of Kalahari and Tukano of Brazil are all connected through a profound relationship and spiritual attachment with the land.

Human beings have created various cultural space and time systems in order to maintain their unique spiritual relationship with the universe. Before the dominance of Western ideas and colonial empires throughout the world, literate societies of Japan, China and India were eloquent in describing their human relationship with non-human species and their place within the greater environment. Oral traditional societies had highly developed constructions of their environments which were transmitted through stories, dance and by paintings to successive generations. For non-Western peoples, although widely different in customs, culture and impact on the land, there was a shared belief in a deep bond with nature, an awareness that all life, rivers, skies, people, ants and rocks were inseparably interconnected. Physical and spiritual worlds were woven together in one web. Humans were not separate from nature but were a part of the nature of the world. Geographical knowledge concerning human and environmental nature is always socially and culturally construed. Through specific examples from non-Western cultures of both literate and oral traditions, an understanding of the diversity of specific geographical knowledges can be explored.

The Mythic Creation of the World

Each culture possesses creation myths which speak of the creative beginnings, an energetic

phase prior to the appearance of physical matter and life. Marriage between the Ancestral couple is common to creation myths of India, Egypt, Mesopotamia, China, Central America and New Zealand. In all these myths, creation is sparked by a cosmic copulation. The intercourse of Geb and Nut in Egyptian mythology and that of Shiva and Paravati in the Indian myth, and Ranginui and Papatuanuku, the primeval pair in Maori myth, reflect creation themes. The vision of the sacred earth as a ledger of cosmology is unique to Australian Aborigines with their creation story written like a book in the earth's topography.

There is evidence of great length and complexity in Australian Aboriginal culture, the oldest continuing society in the world, reaching back to the Pleistocene Age which is based on the remembrance of the origin of life. Aborigines speak of the forces and powers which created their world as Creative Ancestors. During this epoch of world creation called the Dreaming, the Ancestors travelled across a barren flat terrain. Their hunting, loving and fighting shaped the land, deeply marking the surface of the earth and leaving their imprints forming the topographical landscape, making riverbeds and forming rocks and deserts. Before their travels, the Ancestors would sleep and dream the adventures of the following day. In this way, moving from dreaming to action, they had the ability to alternate between pure spiritual powers and an apparition of other forms. In Western scientific language, the earth evolved through a phase of powerful geological and climatic forces which shaped the earth's crust, creating mountains, oceans and rock formations. The main difference between these two myths is that Western scientific description acknowledges only physical forces, while Aboriginal explanation attributes consciousness to the creative forces and to everything created.

The Dreamtime epoch concluded with three fundamental conditions making possible the embodiment of conscious life: the earth's distinct topography, all variety of species of life, and patterns for social relationships. With the completion of this task, the Ancestors grew weary as the world was shaped and filled with species and

varieties of ancestral transformations and they retired into the earth, the sky, the clouds and the creatures to exist like a potency within all that they had created. Their journeys were preserved in stories, paintings, ceremonies and patterns of living and extended a universal psychic consciousness to every living being as well as to the earth and the primary forces and elements.

The Western tendency to view land as material object, existing separately from humanity, allowed for it to be bought, sold and exploited. In contrast, Aboriginal culture shared the identity of the forms, principles and activities by which the natural world was created and saw life and sustenance embedded in the landscape which must be cared for as a friend and provider in continuing reciprocity. "With the birds, the fish, the animals, the plants and all of nature we are still Yorro Yorro, standing up in accordance with the blueprint of Creation", explains Mowaljarlai, concerning the role of men in maintaining the connection between cosmic regions and earthly community life in the Kimberley, Western Australia.

Understanding Nature and Humanity

Generally, the Japanese philosophical and religious traditions represent a holistic ecocentric view characterized by an aesthetic and material oneness with all things. In pre-industrial Japan, the intimate relationship between people and their surroundings can be grasped by the Japanese word *fudo*, which translates into the natural environment. While nature and humanity have been viewed as separate but connected in Western thought, *fudo* refers to the idea that nature and society are inseparable. *Shi-zen* or *Ji-nen* is the Japanese word which most closely corresponds to the European term nature. The connotations of this term signify a concept of nature in which nature is not objectified. Rather, *Shi-zen/Ji-nen* represents the manner of being and becoming of nature, human and environment. *Shi-zen*, originally a Chinese word, was adopted by the Japanese about 1,500 years ago. In ancient Chinese culture, the term had fundamental significance. Lao-Ze wrote: man is based on earth, earth is

based on heaven, heaven is based on the Way (*Dao*) and the Way is based on nature (*Zu-ran*, or *Shi-zen* in Japanese).

The contrast between European and Japanese garden design illustrates the difference in perspectives of nature. In the English garden, a person seeks escape from humanity into a natural space free of artificiality. In the Japanese garden, one tries to express, within a defined space, the totality of mountains and rivers. This is an artistic, human act representing the highest meaning of *Shi-zen*. The English garden is a public place, open to all. The Japanese garden is of a private nature created solely for the few who are artistically gifted. Nature relates equally towards all in the English garden. The *Shi-zen* of the Japanese garden requires those who are able to experience *Shi-zen*. This implies that *Shi-zen* can never be separate, but within the person.

It is the same for Ikebana art and the *Shi-zen* of the tea-ceremony. In the Japanese tea-ceremony, the everyday routine becomes an art form. Sitting in a quiet, small room allows for the mind and body to become alert to the slightest sound, movement of the wind, perfume of flowers, changes in the intensity of light. This time passed within a small room heightens the sense of place by creating a moment of spiritual connection with the environment.

Sense of Place

The sense of place exists in the area where nature and humanity interact and shape each other. Within cultures, information concerning the geographical environment is expressed in certain ways, such as the making of maps, conceptualizing landscapes, and giving places names. In the Pintupi language of Central Australia, a place, or a country, or a camp is called *ngurra*. *Ngurra* signifies both the physical place where people share food, sleep, and dance, and also the metaphysical act of dreaming the country into existence. In this way, the question of Aboriginal identity is obtained by knowing the place. As Kuningga, the ancestral cat, travelled north he crossed plains, identified water sources and, after reaching a

ceremonial site, continued north through a gap in the range. Kuningga's dreaming track weaves north, describing the particular geography of the land and of the natural resources contained within through a song cycle. Thus Kuningga's song can be understood as an oral map of the country. Places where significant events happened, where power was stored, or where the Ancestors had retired into the ground and still remain today are known as *Yarta Yarta* or special sites because of their concentrated ancestral potency.

Certain landscapes create a sense of awe by their presence. In Japan, Mt. Fuji, rising 13,000 ft above sea level, has been depicted in poems, paintings and stories from ancient times. The sheer physical presence of mountains which appeared to connect the earth with the sky allowed for them to be considered Japanese shrines. The word *oyama* sometimes means shrine and is derived from *yama* (mountain). Tadahiko Higuchi in his book *The Visual and the Spatial Structure of Landscape*, described seven prototype shapes for shrine and temple complexes which were translated by Kazuo Matsubayashi. They are:

1. Water-distributing: where water flowed out of the mountain creating a perfect rice irrigation place
2. Bowl: a small, peaceful, plain surrounded on all sides by green mountains
3. Lotus Flower Calyx: the site of a mountain temple surrounded by eight other mountains, which resembled the calyx of a lotus
4. Wind and Water (*fusui*): usually having mountains to the north, hills to the ► east and west, and a sea or river to the south, which was the ideal place to build a city, house or tomb
5. Valley: enclosed by mountains on both sides, which was thought to be the home of the spirits of the dead
6. Thickly forested: a small mountain covered in thick foliage in sharp contrast to its situation near a flat plain, which was believed to be the sacred dwelling of a god
7. Country-viewing: a low hill or mountain standing in the middle of a plain, commanding a view of the surrounding land

The close relationship between the people and their mountainous environment, with each of the types serving a unique purpose, demonstrates the vital reciprocity between humanity and nature.

In Maori tradition, the special relationship between people and their land is revealed, first by the myths explaining the origin of the universe, in which the material world proceeds from the spiritual and the spiritual world interpenetrates the material, physical world of Te Ao Marama, and secondly by the use of dominant landmarks, mountains, or water sources, as symbols of tribal identity. While many indigenous peoples live intimately with nature, the Maori appear to be unique in their formulation of their *pepeha* or popular sayings of tribal identity. Every established Maori community may apply their standard *pepeha* or introduction by naming their mountains, river and tribe at intertribal meetings, now as in the past, actively maintaining the oral tradition and identity of place.

Makeo is the mountain – Ko Makeo te manunga
 Waiaua is the river – Ko Waiauna te awa
 Tutamure is the Ancestor – Ko Tutamure te tangata

Hong-Key Yoon has described the pattern of structure of these sayings which includes the first two phrases for natural identity in terms of landscape and the third for cultural identity in terms of people. The first phrase mentions the most significant landform, almost always a *Maunga* or mountain followed by the second phrase giving the name of a prominent body of water or *te wai*, *te awa* or river, *te awauni* or big river, and *te moana* or sea. The third phrase names the tribe, giving social and cultural identity. Maoris associated intense feelings with the mountains, considering them to be the place of buried ancestral bones, while the valleys and rivers, often serving as tribal boundaries, did not assume as intense a sanctity.

These *pepeha* revealed the symbolic relationship of the people within their place and were combined with the functional territorial boundary delineating home territory, while also perpetuating cultural heritage. Today, the Maori traditions

of respect for place are represented by the Maori Secretary in the Ministry of the Environment. The name of their movement, *Maruwhenua* comes from the understanding of the human responsibility for protecting the land. Mmaruwhenua reflects the saying, "People perish, but the land endures".

Sustaining Natural and Human Place

Indigenous knowledge of nature has ensured the survival of many peoples living in fragile habitats. For example, the Tuareg of West Africa practice nomadic pastoralism in a land so arid that it cannot sustain continual habitation, and the Inuit of the frigid Arctic regions have traditionally depended on hunting and fishing. Modern hunting and gathering depends on cooperation between group members and the formation and maintenance of economic relations with other groups. In Ituri, the tropical rainforest of northeastern Zaire, a mutually supportive, economic relationship has been created between the Efe, who practice a semi-nomadic lifestyle, and the Lese, who live as shifting cultivators. The Efe trade forest products, nuts, construction materials, meat and fish for produce grown by the Lese, and for their pottery, tools and arrows.

In many areas of the world, indigenous societies have classified soils, climate and animal species. Many of these words and descriptions for insects and plants are yet to be known by botanists or entomologists. The Hanunoo people of the Philippines distinguish 400 more plant species in their forests than the 1,200 ones identified by the scientists working in the same location. The Kayapo of Brazil gather about 250 types of wild fruit, hundreds of tubers, leaves, and nuts, and at least 650 plants which are used for medicinal purposes. This vast, complex, indigenous knowledge is now viewed as being important not only to the sustenance of the traditional owners, but to the very survival of the world.

The human relationship to the natural environment has been conceptualized differently over time and through space. At the end of the twentieth century, understanding of the human

experience of nature, from both a Western and non-Western cultural tradition, has become an urgent imperative. The challenge now is to regard humanity and earth in global terms while also seeking an understanding of the social and ecological implications of the whole of humanity planetized. There has been much discussion concerning the damaging perspectives of the Western, anthropocentric approach to nature which has led to actions based on a premise of the separation between mind/body, human/nature and individual/society. This view has been blamed for much of the environmental destruction and exploitation of the world's human and natural resources. At the same time, there have been appeals to consider alternative modes of conceptualizing humanity and nature, such as developing a reverential attitude towards nature and acting in a socially cooperative manner, based on a non-Western, ecocentric perspective.

Cultural expressions, Western or non-Western however, show a universality only at the broad structural level. To go beyond this, it is necessary to explore the specific historical contexts of human habitation in place and through time. Non-Western and Western cultures are historically dynamic. It is important therefore to emphasize the particular and convey the diversity of traditions within and between groups, in order to create mutual understanding.

See Also

- [Ethnobotany](#)
- [Knowledge Systems: Local Knowledge](#)

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Geography in China

Mei-Ling Hsu

The term geography (*di li*) which first appeared in Chinese documents during the Spring-Autumn period (770–476 BCE) literally meant the study of the order and morphology of the land. In the beginning the purpose of such a study was for survival; later it was used to facilitate the production of food and gathering materials for shelter. Agriculture was central to the economy, hence information was collected on climate, land, and water supply, and for crop cultivation and water control, e.g., to construct dikes. Because of these needs, studies in “geography of production” increased. Thus the Chinese have accumulated much geographic knowledge since ancient times.

The two frequently cited geographic classics are *Yu Gong* and *Di Li Zhi*. They demonstrate the importance of geography in delineating major regions in the country and in collecting locational information; these geographical applications facilitated the governing of the ancient Chinese empire. Mapping of large regions and local areas followed.

Yu Gong (The Tribute of Yu, who was a semi-legendary emperor) is a short but brilliant work, written in the Warring States period (475–221 BCE). It presents chapters on mountains and rivers, and on two methods of organizing geographical space: delineating nine physical regions, and allocating five political regions in China. Thus this work presents the earliest examples of regional and systematic geographies.

The term geography was first used as a title of a work in *Di Li Zhi* (Treatise of Geography), a chapter in the *Han Shu* (History of Han Dynasty), by Ban Gu (AD 32–92). It includes three sections, of which the first and third were reprints of earlier works, including *Yu Gong*.

The second section is devoted to the geography of 103 prefectures (*jun/guo*) and their sub-units, the 1,587 counties. Within each administrative unit, some physical, cultural, economic, and demographic features are described. Cities are mentioned. Interestingly, it also describes petroleum as some kind of liquid that can be burnt. However, the major focus of this work is on the history and changes of boundaries of administrative divisions and settlements; such information was important to the governing of a large empire. Unfortunately, too often this particular focus was emphasized at the expense of a more thorough treatment of the physical characteristics of an area, and their effects on the inhabitants and the economy.

The publication of *Di Li Zhi* marked the beginning of a chapter on geography to be included in a dynastic history; this chapter appeared in the second of the 24 such histories. Thus the content and the methodology presented therein became a model that was followed in the later dynastic histories.

Ban Gu's work also planted the seeds of a later development: the publication of local gazetteers (*di fang zhi*) with maps included in these volumes. Beginning in the fifth century, the production of these gazetteers increased in number and gradually became the most prevalent form of geographic writing and compilation in pre-modern China. During the Tang Dynasty (AD 618–907), the scope of some gazetteers began to expand to cover a province and even

the whole country; some of these compilations were multi-volume and were really geographical encyclopaedias. Today they constitute a voluminous geographical and historical literature.

Beginning in the Tang Dynasty, field studies became more important. Perhaps, by this time, long distance travel in China had become more manageable. Noted scholars spent many years away from home travelling and studying the country. They left with us their vivid descriptions and insightful interpretations of the geography of China. Among these books, the best known is the *Xu Xiage Yuji* (Dairy of The Travels of Hsu), written in the seventeenth century. Thanks to the efforts of these scholars, accurate geographical knowledge was accumulated, e.g. of the source of the Huang River, the process of erosion, and the retreat of the sea in the area of today's eastern lowlands. The last of these was studied by Shen Gua in the eleventh century; similar observations to that of Shen's were made in Europe by J. Hutton in the nineteenth century.

Despite the richness of the pre-modern literature, geography was not formally included in the civil examination in imperial China. Only during the late nineteenth century, as the modern school system was developed was geography incorporated as an instructional subject in schools. Today, in Taiwan and on the Chinese mainland, geography courses, which vary in area coverage and degree of difficulty, are taught in every grade in the secondary schools. The two major purposes of this instruction are to provide students with basic knowledge of China and of other countries in the world and to foster the spirit of patriotism.

In historical China, geography and cartography played important roles in scientific inquiry and applications. In this century, the subject geography is taught in schools and colleges, and mapping activities are routinely carried out by government agencies and educational institutions.

See Also

- [Maps and Mapmaking: Celestial East Asian Maps](#)

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Geography in India

Ashok Dutt and Meera Chatterjee

The study of geography as a systematic science was a significant gap in Indian knowledge during ancient times. However, geographical facts were presented in a nonsystematic manner in the whole range of Sanskrit, Pali, and Prakrit literature. Compositions of a geographical character are often found embedded in the religious, legendary and astrological literature of ancient India. Both religious and secular literature contain numerous

isolated references to cities, mountains, rivers, regions, and society, which collectively amount to a considerable addition to geographical knowledge. India is the home of an ancient civilization that originated over 5,000 years ago and attracted many travelers, scholars, ambassadors, and missionaries. Many conveyed impressions back to their compatriots through lively tales, anecdotes, and travel journals. These writings also became important sources of geographical knowledge. The writings of the Chinese, Greek, and Arab geographers are rich sources of information relating to various aspects of geographical science. Various names such as *Bhuvankosa* (Terrestrial Treasure), *Trilokya Darpaṇa* (World's Mirror) and *Kṣetrasamāsa* (Combination of Countries) were used to denote geographic phenomena. Hence, the principal sources of information about the status of geography in ancient India are sketchy because they are obtained from references extracted from nongeographical works, foreign accounts, and inscriptions. The ancient literature developed over the centuries could easily be arranged in a chronological sequence. *Ṛg Veda* (about 1500 B.C.E.) was the first, which was followed by three other Vedas, *Sama*, *Yajur*, and *Atharva*. The *Upaniṣads*, *Purāṇas*, *Jātaka* tales and great epics – *Rāmāyana* and *Mahābhārata* were composed between 1000 and 500 B.C.E. Kautilya's *Arthasāstra* was composed around 300 B.C.E. Other than these, there are writings of different poets and foreign people that also help us to infer the geography of ancient India.

The *Ṛg Veda* is the earliest Indian literature that has been discovered. It mentions many geographical facts such as tribes, rivers, and mountains. According to ► Al-Bīrūnī (Alberuni), an Arab traveler in India, “Veda is knowledge of that which was unknown” (Kazmi, 1995, p. 41). These and associated books contain knowledge about philosophy, mathematics, medicines, navigation, music, and dance. The *Upaniṣads* are works on religious meditation (Tamaskar, 1985). It is difficult to find any direct description of the earth or the world, but, as in the *Ṛg Veda*, geographical phenomena or features are embodied in them. Like the *Vedas*, the *Purāṇas* also did

not deal with geography in a systematic manner; however, they have a lot of geographical facts in them. The scientific material covers a wide range of topics from astronomy, cosmography, and cosmogony to the classical concept of region and regional classification. As defined by Alberuni, *Purāṇa* means “first eternal” and the *Purāṇas* are associated with the names of animal, human or angelic beings. *Purāṇas* not only contain mythical and legendary materials, but also contain scientific information, which is sometimes accurate. Information about astronomical geography can be easily extracted out of the *Purāṇas*. *Jātaka tales* are a huge source of unsystematic geographical information. The legendary stories contained in the *Jātakas* relate the previous lives of Gautama Buddha, the founder of Buddhism. He lived and preached in northeast India between 563 and 483 B.C.E. As there was no written common language, the stories were memorized and handed down from generation to generation by word of mouth. Several hundred years later they were written down in the Pali language; in the process many facts were exaggerated or lost. The *Jātaka* tales were set in some contemporary kingdoms. Kautilaya’s *Arthaśāstra* mentions the names of a few mountains, regions, and tribes. It also provides us with a lot of information about territorial sovereignty and geopolitical principles. The great epics *Rāmāyana* and *Mahābhārata* contain extensive geographical descriptions of north and south India, military geography, family structure and the presence of non-Aryan tribes. (*Mahābhārata* depicts the war that occurred about 900 B.C.E.).

The Aryans, who brought the *Ṛg Veda* from outside the borders of India (possibly from Persia), first settled in northwestern India (Punjab and the Indus plain). They mentioned regional rivers and their branches, such as the Saraswati (extinct), Sutudri (Sutlej), and Sindhu (Indus) (Fig. 1). The rivers, seas and regions had different names in ancient India. A few of them are mentioned in Fig. 1. According to *Ṛg Veda*, Saraswati was the greatest and most powerful river that flowed from the mountains to the sea. The greatest and the holiest river mentioned was not the Ganges, but the dry Saraswati. The latest

studies have shown that the *Ṛg Vedic* Saraswati was a perennial river. The confluence of the Ganges (Gaṅgā) and its tributary Yamuna are mentioned as the eastern boundary of the Aryan settlement. However the Ganges was mentioned only once, whereas the Saraswati was mentioned many times.

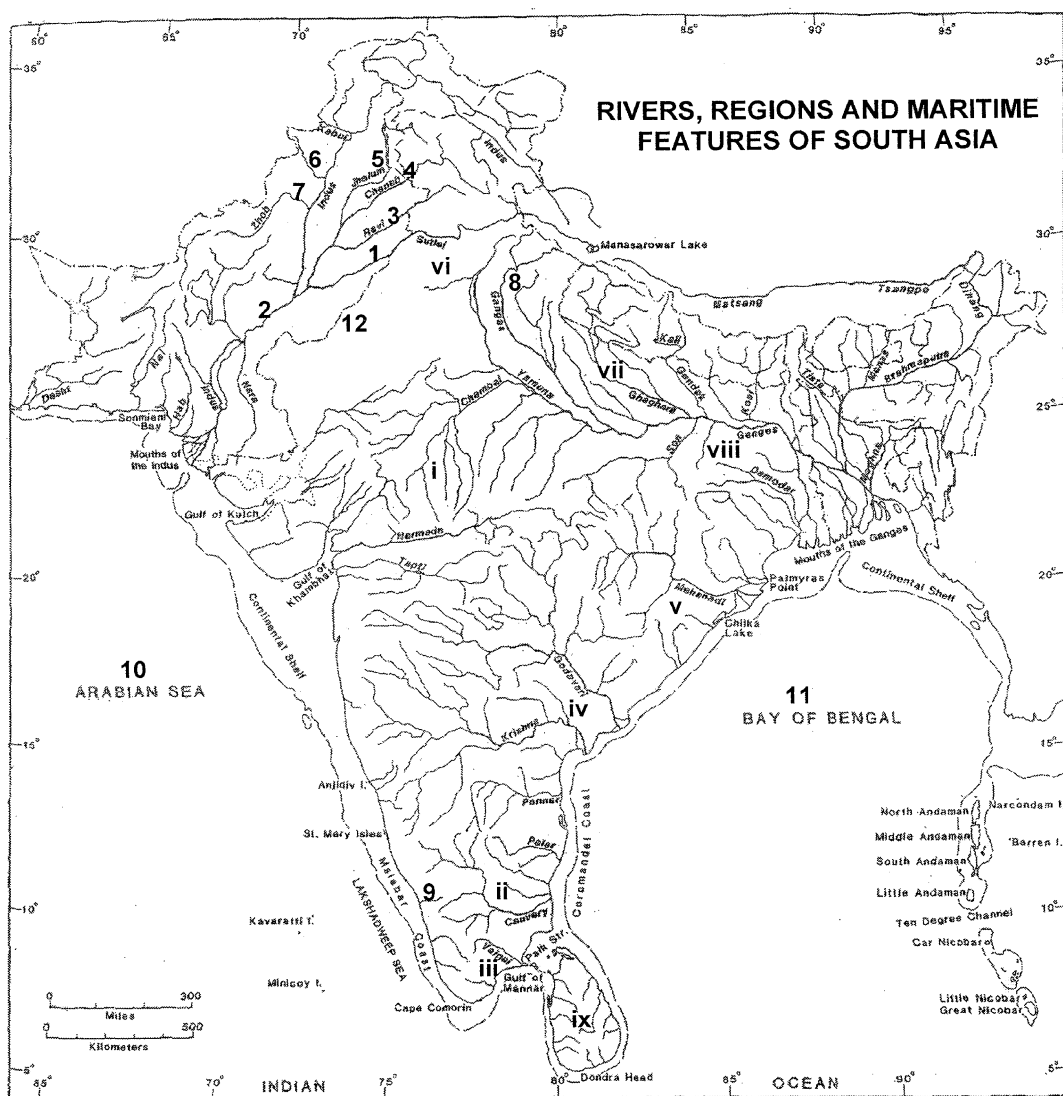
By the beginning of the Christian era, three other Vedas, epics and *Purāṇas* were written, and a more extensive description of Indian geography evolved. The Aryan settlements advanced eastward all the way to Bengal and toward southern India. The latter, though Dravidian in terms of linguistic and physiognomic characteristics, became Hinduized.

Ṛg Veda set the layout of an important aspect of social geography by stratifying Indian society into four different castes. (1) *Brahmins*, who were the interpreters of religious texts and handled all the scholarly literature, (2) *Khasatriyas*, the warriors and the rulers, (3) *Vaiśyas*, the merchants and farmers and (4) *Śūdras*, slaves who did all the hard work including cutting jungles to make land arable. Some of them were designated as untouchables. The following extract is based on *Ṛg Veda* explains the function-based, social hierarchy (four castes).

The *brahmins* form the highest social order, the literate intelligentsia which gave India its priests, thinkers, law-givers, judges, and ministers of state. The *rajanyas*, later called *khsatriyas* or rulers, were the second social order. The Indian counterpart of feudal nobility: from this class was recruited kings, vassals and warriors. The *vaishyas* formed the class of landowners, merchants, moneylenders, while the *śūdras* originally those people conquered by Aryans, were workers, artisans, or serfs. (*Ṛg Veda*, 10.90, as cited in De Bary, 1967, pp. 13–14.)

The caste system still persists among the Hindus. As most of the Muslims and Christians in India are converted from Hinduism, many of them have retained their caste distinction.

Ancient Indians also knew about the land and water ratio on the earth’s surface. Though they did not have accurate knowledge of the ratio, they believed that oceans occupied twice as much area as the land surface on the Earth. In the second

**LEGEND****RIVERS AND SEAS**

- | | |
|---------------------|-------------------------------|
| 1. Sutudri (Sutlej) | 8. Jahanvi (Ganga) |
| 2. Sindhu (Indus) | 9. Kalyani |
| 3. Parusni (Ravi) | 10. Ratnakara (Arabian Sea) |
| 4. Askni (Chenab) | 11. Mahodadhi (Bay of Bengal) |
| 5. Vitasta (Jhelum) | 12. Saraswati (Extinct) |
| 6. Kurumu | |
| 7. Saryu (Zhub) | |

REGIONS

- | |
|--------------------|
| i. Avanti |
| ii. Chola |
| iii. Pandya |
| iv. Dakshina Patha |
| v. Kalinga |
| vi. Panchalas |
| vii. Kosalas |
| viii. Magadhas |
| ix. Simhala Dwipa |

Geography in India, Fig. 1 Rivers, regions, and maritime features of South Asia (Base map from Dutt & Geib, 1998. Permission obtained from the copyright holders.

Anuwaka of third *Brāhmaṇa* of III *Adhyaya* of the *Bṛihadāranyaka-Upaniṣad* it is said, “The oceans surround this earth on every side twice as large” (Tamaskar, 1985, p. 7).

The authors gathered the information on the names of the ancient rivers from various sources)

The Himalayas were mentioned in *Upaniṣads* as the “White Mountains” because their upper reaches are snow clad year-round. The rivers flow out of this mountain chain in an

► east and west direction. They have also been referred to as a powerful barrier for invaders, thus acting as natural borders.

The river Ganges is mentioned in the *Vayu-Purāṇa* as a purifier of sinners, passing through thousands of mountains and irrigating hundreds of valleys thus establishing the importance of rivers in the environment. *Matsya-Purāṇa* also mentions the rivers of Jambū-dvīpa (consisting of most of Asia) and Bharatvarsha or India (the southernmost country of Jambū-dvīpa) rising in the ranges of Himavanta (Himalayas). It was in *Kausītaki* that the southern mountain – Vindhya – was first mentioned, while both *Vasishṭa Dharmasūtra* and the *Code of Manu* referred to the Vindhya by name. *Rāmāyana* and *Mahābhārata* give extensive descriptions of geographic features of both north and south India. When King Dasaratha (in *Rāmāyana*), father of Rama, performed an *Aśvamedhayajña* (Horse Sacrifice) to establish his supremacy over the world, both north and south Indian kings were referred to. In the *Bhīṣmaparva* section of the *Mahābhārata*, Sañjaya, the chariot driver of the blind king Dhṛitarāstra, identified the nations, mountains, and rivers of India. Epics also describe Hastināpur (situated by the side of Ganges), capital of the Kauravas, Indraprastha (situated by the side of Yamuna), capital of Pāṇḍavas, Ayodhyā (in Uttar Pradesh), capital of Rāmā and the city of Mithilā (in Nepal terai). In the *Rāmāyana*, the city of Mithilā, possibly Janakpura in Nepal terai, is referred to as a “city of color and pleasure with people enjoying the business of living.” It had “golden turrets and domes, and lofty towers.” The book also says that, on the eve of Sītā’s *Swayambara* (a ceremony in which the princess selects her groom from among the invited guests), there was a “moat” surrounding (King) Janaka’s palace (Narayan, 1972).

The *Jātaka* tales were set in some contemporaneous kingdoms. The topographic features are embedded in the tales. The Himalayas were mentioned many times. References to small water bodies (ponds) can also be found. Mostly the stories were woven around animals; this referred to the conservation of wildlife. The tales

mentioned the coexistence of carnivores and herbivores, a condition required in nature for a balanced ecology. They frequently refer to thick forests which indicates that the Himalayan and sub-Himalayan zones and parts of the Deccan plateaus were once covered by dense and luxuriant forests. Numerous species of plants and trees were also mentioned. Cultivation and rearing of animals were the principal occupations of the population, although there is a mention of nonprimary activities, such as mining, textiles and trading. The *Rg Vedic* literature talks about the abundance of water in North India brought about by melting of ice caps. Present arid regions like Thar and Rajasthan deserts and the deserts of Sind were once fertile and supported agriculture.

Permanent settlements and agriculture led to trade and other occupational differentiation. Aryans after settling in Pañchāla (Punjab and Haryana) started colonizing the central and eastern Ganges plains and advanced to the Ganges delta in Bengal. From east to west there is a progressive diminution of Aryan traits among the population. As the Aryans advanced eastward, more slaves and śūdras (tribals, vanquished people and Dravidians) were used to clear forests in order to make the Ganges and other plains cultivable. The eastward terrain was inhospitable, wet and disease laden and had limited attraction to the Aryans. They employed slaves and śūdras in vast numbers, who performed the most difficult task of land reclamation. As lands along the Ganga (or Ganges) were cleared, the river became a trade route; the numerous settlements on its banks became markets and trading centers. The cities of Varanasi and Pāṭaliputra (Patna) are two important examples. As the majority of the settlements grew up along the river the probability of their being linear was very high. Trade was restricted initially to local areas, and barter was an essential component of trade, cattle being the unit of value in large-scale transactions, which further limited the geographical reach of the trader. Consequently, markets and the trading process were concentrated in some regions. Custom was law, and kings and chief priests were the arbiters, perhaps advised by certain elders of the community. An Aryan *rājā*, (king) was primarily

a military leader, who took a share from the booty after successful cattle raids or battles. Although the *rājās* had managed to assert their authority, they scrupulously avoided conflicts with *Brahmin* priests as a group, whose knowledge and austere religious life surpassed others in the community. The priests were the educated group of the society and considered superior to other castes, and they also interpreted religious books.

Kautilya's *Arthaśāstra* prescribed a state planned colonization policy for undeveloped (primarily natural vegetation covered) areas with people from foreign lands and kingdoms' surplus labor. Each village was to have 500 families, mostly śūdra cultivators or laborers; villages were to be grouped in a hierarchy of settlements of 800, 400, 200, and 10 units with a large town (*sthaniya*), small town (*dronamukha*) smaller town (*karvatika*), and large village (*samgrahara*) to serve each group, respectively.

Beginning with the *Ṛg Veda* through the *Purāṇas*, cosmological and cosmogonic interpretations of the causes of wind, precipitation, day and night, seasons, and the planetary movements were made. A four-way explanation of the origin of the universe was also given: artistic, mechanical, instrumental, and philosophical. First, the artistic origin refers to god as an artist who skillfully constructed the universe. Second, the mechanical origin is conceived as a sacrifice of the *Ādipuruṣa* (primeval body) who not only had the soul and the nucleus of the universe, but also embodied the Supreme spirit, resulting in the formation of the earth, sky, wind, moon, sun, and other terrestrial elements.

The origin of universe from a primeval sacrifice, in which a cosmic being offers himself as an oblation, is not known in primitive mythological traditions. However, the sacrifice of the male Purusha here is not so much the primordial sacrifice of a world giant or the type *Ur-mensch* found in Norse or Germanic mythology, as it is a cosmogonic idea based on ritual sacrifice itself as the origin of universe. (Based on *Ṛg Veda* 10.90, as cited in De Bary, 1967, p. 13.)

Third, the philosophical concept considered the beginning as an empty space with no atmosphere or sky. The universe was born out of its

own nature, possibly by its own inherent heat. The *Ṛg Veda* also attempted to provide a scientific explanation of the mystery of the origin of the universe. Accordingly, the "creation of universe has started with the origin of water and the cosmic golden egg [embryo, *Hiranyagarbh*] which very well fits in the geological and biological evolution of the earth with the water age, origin of Zoophytes, primeval fishes, reptiles, invertebrates, vertebrates, and mammals" (Tripathi, 1969, p. 3). It also said that water pervaded the whole universe which held fire in its womb. This indicates that during the Vedic age, the civilization was aware of the fact that the interior of the earth was very hot. The fire probably refers to the rising temperature beneath the surface. The importance and dominance of the water were also realized. The *Māhāpurāṇa* further crystallizes the idea that the world endures under its own nature and is divided into hell, earth and heaven.

Fourth, the instrumental origin idea is reflected in the union of heaven and earth caused by the action of different gods, such as fire (*Agni*), sun (*Sūrya*), and *Indra*. "The central idea of various cosmogonic theories of the vedic and postvedic period appears to be (1) existence of the water in the beginning, and (2) creation of the cosmic nucleus – *Prajāpati*" (Ali, 1966). *Prajāpati* is an embodiment of propagation and hence maker of universe. In this concept, they also recognize the supportless movement of the heavenly bodies as iron pieces around a magnet in the sky. Puranic literature mentions solar and lunar eclipses several times although their true mathematical theory was not known. Therefore mystical explanations were advanced.

The demon will obscure the moon and the sun at the end of the dark fortnight and the full moon. Entering the shadow of earth and moon, the swarthy-figured concealed demon will bring adversity to the moon and sun respectively (Tripathi, 1969, p. 39).

The *Upaniṣads* spoke indirectly about the spheroidicity of the earth. The description of the rising and setting sun is mentioned in *Prapathaka III*, *Khanda* 6–10 to the *Chandogya-Upaniṣad*: "So long as the Sun rises in the east and sets in

the west” (sixth *Khanda*) (Maxmueller, 1900). The concept of the rising and setting of the sun was directly related to the shape of the earth. It has been suggested that the sun’s rays did not spread over the earth at the same time, but that they fell by slow degrees, suggesting that the earth was a sphere.

Jātaka tales also mention the rising and setting sun. The whole society seemed to try to have a proper balance with the environment. They frequently referred to the laws of nature which were important for their survival.

The sun gets up each morning
(And the sun is free)
It goes to bed each night,
Why not we?
The clouds, the rain, the earth,
This very Banyan tree,
Obey the laws of nature.
So do we!”
(“The Oldest of the Three” DeRoin, 1975)

There were six seasons: *Vasanta* (spring), *Grishma* (summer), *Varsha* (rains), *Hemanta* (early fall), *Sisira* (late fall) and *Seet* (winter) are recognized in Vedic literature. Seasons are also discussed in the *Upaniṣads*, but they identified only five, as *Hemanta* and *Sisira* were merged. In the region where the *Upaniṣads* were composed (Punjab Plains) it was difficult to differentiate between the two. The year began with *Grishma* (summer) and concluded with *Vasanta* (spring). Wherever it rained sufficiently, crops were produced; this implied regional variation in rainfall. Punjab, where Aryans settled first, is drier than the east (Bihar and Bengal). With the spread of Aryan colonies from west to east, it was possible to draw a comparative picture of rainfall. The correlation between availability of rain water and food production has also been established in the ancient documents, pointing to the absence of irrigation.

The ancient literature also described the racial composition of the population and their geographical distribution. The *Rg Veda* also mentions non-Aryan tribes. It talks about *Dasyus* (Dravidians) not tamed by Aryans, who were considered civilized and supported a patriarchal family system as opposed to the Aryan

patriarchal family. The *Rg Veda* also mentions *Rakshasas* (demons), who were short, dark, thick lipped, fierce in appearance, curly haired and possibly of Negroid origin. They were considered hostile to Aryans. They did not worship fire. *Rakshasas* were engaged in guerilla warfare, attacking Aryans at night and stealing their cattle. Another tribe mentioned in the *Rg Veda* is *Paishachas*, who were ruddy in appearance.

The ancient literature discussed a cyclical human development on the earth. The Hindu view expressed in the *Laws of Manu*, speaks of four ages – *Kṛita*, *Tritā*, *Dvāpara*, and *Kali* with a sharp break at the end of each age. Physical and spiritual deterioration occurs at the completion of the 4-age period with the universe coming to an end and then beginning a new cycle. The *Laws of Manu* also stated that the age of Gods starts with the *Kṛita* (Winning Age).

In the Winning Age [*Kṛita*], religion is entire, standing on all 4 ft, and so is truth; and men do not acquire any gain through irreligion. But in the other [ages], through [such wrong] gains, religion is brought down foot by foot; and because of theft, lying and deceit, religion goes away foot by foot. In the Winning Age people are free from sickness, achieve all their goals, and [have] a lifespan of 400 years; but in the ages that begin with the age of *Treta*, their lifespan grows smaller foot by foot” (Laws of Manu, 1991).

Jainism adheres to the teachings of ► *Mahāvīra* who died in 468 B.C.E. He was a contemporary of Buddha. The Jains also believed in the cosmic cycles, but unlike Hindus they did not foresee any sharp end at the end of the periods (ages). The Jains divided a full cycle into six periods, each with ascending and descending halves. At the end of the sixth period, designated as “very wretched,” human deterioration reaches its peak with a fierce storm wiping out almost all inhabitants. After this a new six-cycle period starts.

As discussed by Tripathi, *Vrhanardiya Purāṇa* provides valuable information on mathematical geography. It gives the radius of the earth as 800 *Yojanas* or 4,000 miles (1 *Yojan* = 5 miles). The diameter was calculated as 1,600 *Yojanas*

and circumference as $1,600/10$ or $1,600 \times 3.162$ *Yojanas*. It provided a formula for calculating the circumference of any latitude parallel to the equator. These facts show that ancient Indian society was indirectly aware of geographical facts and they also made an effort to work on it scientifically (Tripathi, 1969, p. 40).

A section of *Atharva Veda* and the *Aitareya Brāhmaṇa* refers to five geographical divisions of India, which remains valid today. Further details of the divisions are given in the two great epics (*Rāmāyana* and *Mahābhārta*) and the *Purāṇas*. They contain some chapters giving a fairly good account of not only the different territorial divisions of India, but also rivers, mountains, lakes, forests, deserts, towns, countries, and people (Gupta, 1973). India, as mentioned in the *Purāṇa*, is bordered by Himavat or the Himalayas in the north and by the seas in the south, but Puranic *Bhāratvarsha* stretched from the Himalayas in the north to the Southeast Asian archipelago.

The authors of the *Purāṇa* seem to have been acquainted directly or indirectly with the major portion of India. The concept of Hell as described in the Puranic literature covers a geographical region, which is inhospitable and uninhabitable. The road leading to Hell had extreme weather conditions (arid and devoid of water), marshy and swampy land, and very dense forest infested by dangerous animals. They knew that the planet earth had regions which were not conducive for human habitation. So the importance of a favorable environment to survive was known to the people. Living in unfavorable and dull conditions was equivalent to living in "hell." The *Purāṇa* also mentioned favorable sites for human settlements. Availability of water was the decisive factor. According to Tamaskar, sites of settlements during the Puranic age were associated with escarpments, summits of mountains or hills, riverbanks, situation near lakes or tanks, islands, seacoast and forests. Riverbanks were the most important of all the sites. In addition to providing water, they also served as a means of transportation for goods and humans. Modern settlement geography also finds the wet-point-sites as the most favorable for human settlement.

Different geomorphologic features were discussed in the *Rāmāyana*, such as mountains, plateaus, disintegrated rocks, cascades and falls, caves, etc. The mighty Himalayas were divided into three regions – the outer, the lesser, and the interior conforming to the present day classification. The *Rāmāyana* indirectly deals with economic and commercial geography. It mentions the trading relations between different regions, trading items such as horses of Kāmbōja (Cambodia), silk goods and silver in the neighboring islands of Java, gold mines in the west and so on. The epic also provides information regarding prevailing weather conditions.

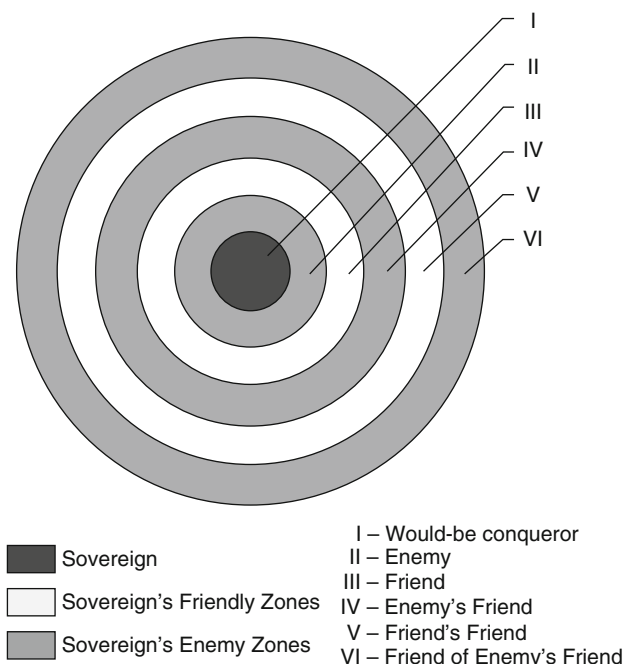
Mist and its disappearance through diurnal rise of temperature, mist and severe cold, cold western wind, water vapor hanging on the surface of the river, dew formation on the sandy margin of the bank and snowfall give a very good description of winter season with some of its geographic paraphernalia. Mountain winds or wind of mountain valleys are also spoken of" (Tripathi, 1969, pp. 103–104).

The *Rāmāyana* indirectly explains the hydrological cycle in its simplest form. It relates solar heating of the ocean, evaporation and cloud formation. It narrates the physical movement of people in different directions. This implies that the transportation and communication system were in a developed stage. There is mention of five types of roads – lanes (*Vithi*), streets (*Rathya*), by-roads (*Uprathya*), roads (*Mahapath*), and National Highways (*Rajmarg*) (Tripathi, 1969, p. 166).

The *Mahābhārata* gives a good account of topography, crops, people's occupations and their political and legal institutions. During that period, India had flourishing international trade with central Asia. This points to the fact that ancient Indians had enough knowledge about sea and land routes and even knew about the air circulation system and the tides. By the time of the composition of the *Mahābhārata* the idea of seven continents, each surrounded by oceans, was firmly established. Four areas are Jāmbū (all of Asia minus the east), Kuśa (Middle East), Śālamali (Eastern Africa), and Puskara (Eastern Asia). The southern part of Jāmbūdīpa was

Geography in India,

Fig. 2 Geo-political zones of Kautiliya (Modified from Tamaskar, 1985)



inhabited by Hindus in the land called Bharata or Bharatvarsha. At the center of the Jambūdhwīpa was the Meru, identified with Pamir knots, and at the northern extremity adjoining the Arctic Ocean was the Uttarakuru. Jambūdhwīpa was surrounded by an ocean, meaning a physical barrier.

Kautilaya's *Arthaśāstra* discusses the principles of territorial sovereignty and geopolitical principles. According to Kautilaya, the seven elements of the state were the king (*Swāmi*), the minister (*Amātya*), the country (*Janapada*), the fort (*Durga*), the treasury (*Kosa*), the army (*Danda*), and the ally (*Mitra*) (Knagle, 1965). *Janapada* meant both the land and the people. The organization of space also extended into the coastal regions and territorial waters. Kautilaya believed that success of any state depended on peace which could be affected by the internal and external forces reflecting centripetal and centrifugal forces of modern political geography, discouraging disintegration and encouraging integration of the state. Kautilaya's sixfold policy dealt with the internal and external problems of the state directly, and the policy revolved around peace, war, preparation for war, neutrality,

seeking shelter and dual political policies. On the basis of political attitudes the neighboring states at the periphery or beyond were conceived as geopolitical zones of enemy, friend, enemy's friend, friend's friend, or friend of enemy's friend with increasing distance (Fig. 2).

According to Kautilaya, "place means earth. In that the region of the sovereign ruler extends northwards between Himavat and the sea, 1,000 yojanas in extent" (Tamaskar, 1985, p. 96). This implies that the natural boundaries for the states were considered important. The right location of the capital within the boundary manifested geographical consideration. Kautilaya emphasized the importance of the strategic location of the capital.

...The king may have his fortified capital, as the seat of his sovereignty (*Somudayasthanam*) in the center of his kingdom in a locality naturally best fitted for the purpose, such as the bank of the confluence of the rivers, a deep pool perennial water, or of a lake or a tank, a fort, a circular, rectangular or square in form, surrounded with an artificial canal of water, and connected with both land and water paths. (Knagle, 1965)

The *Arthaśāstra* also mentioned the importance of developing means of transportation and

communication in order to have political unity within the state. Developed transportation would serve as channels for the army to reach at a time of crisis. In addition to defense it would also help to promote trade and commerce, serving as a lifeline for the state.

The great verse writer, Kalidasa, (designated the “Shakespeare of India”), created *Meghadūtam* and *Raghuvamśa*. They showed a detailed knowledge of hills, rivers, plains, and cities. In *Meghadūtam*, Kalidasa’s description of the path from Ramagiri to the Himalayan gate in the poetry is no less than a geographer’s account. While sending clouds as messengers, the routes, rivers, hills, and cities lying on the way were described. Again, in *Raghuvamśa*, the poet showed in-depth knowledge of Indian geography. The kingdoms as described by Kalidasa show that he had some knowledge of the southern countries of Pandya and Kerala.

Greeks and Persians are the earliest foreign people to leave accounts of India. Greek writings indicate that ancient Indians had knowledge of the shape and size of their country. In 320 B.C.E., Eratosthenes gave India the shape of a rhomboid or unequal quadrilateral which had Indus on the west, the mountains on the north and the sea on the east and south. In 300 B.C.E., Megasthenes, a Greek ambassador of Seleucus Nicator, visited the court of a north Indian King, Chandragupta, and left an account of India on his return. In the *Mahābhārata*, India is described as an equilateral triangle divided into four smaller equal triangles. The apex of the triangle was Cape Comorin and the base was the Himalayas. Cunningham drew a small equilateral triangle by drawing a line between Dwarka (Gujarat) and Ganjam (Orissa) and repeated the exercise on each of the three sides to obtain four divisions of India in one large equilateral triangle. ► [Varāhamihira](#) identified eight divisions. The central division of Pañchāla (Punjab/Haryana) was surrounded by Maghada (east), Kalinga (southeast), Avanta (south), Sindhu-Sauvīra (west), Anarta (southwest), Madra (further south) and Kauṇḍa (northeast).

In the world map of Ptolemy (second century A.D.), a Greco-Egyptian geographer-astronomer,

the true shape of India was distorted. He ignored the southern peninsula and drew an almost straight line from the Gangetic delta to the Makran coast in Baluchistan.

The cause of this mistake is partly due to the erroneous value of 500, instead of 600, Olympic stadia, which Ptolemy assigned to an equatorial degree, partly to an overestimate in converting the road distance into map measurement, but chiefly to the excess which he allowed for the distances of land journeys over those of sea voyages” (Cunningham, 1979).

Though only the southern part of Jambūdīpa was considered Bhāratavarsha, the Indians referred to the latter as the whole earth because the landmass of South Asia surrounded by mountains in the north and seas in the south was not only a physical cul-de-sac, secluded from other people, but was so productive and large that to the people of India it constituted the world. Puranic legend claims that King Bhārata, whose name was identified with the country (Bhāratavarsha), ruled the entire earth, meaning all of India. Such was the case with the emperor Aśoka as inscribed in his Fifth Rock Edict declaring that he was ruler of the world.

During the ancient Indian historical period when the country was shedding its narrow tribal characteristics, turning into a consolidated tribal conglomerate of Aryavārta (land of the Aryans), converging into organized states, no systematic study of geography evolved. On the contrary, during the same period, the Greeks and the Romans explored the geographical features of their known and unknown worlds and provided the basis for modern geography.

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Geography in Mesoamerica

Vincent Herschel Malmström

Unlike the ancient Greeks, for whom all knowledge could be categorized according to a tripartite classification – the phenomenon itself, its place in time (history), and its place in space (geography) – the civilizations of pre-Columbian Mesoamerica viewed all knowledge as religion, some aspects of which found their reflection both in time and space. The most original intellectual creation to emanate from Mesoamerica was the 260-day sacred almanac, known variously as the *tzolkin* among the Maya and as the *tonalpohualli* among the Aztecs. Pre-dating the 365-day secular

calendar, which these people also developed, it ran concurrently with the latter to produce a never-ending series of 52-year cycles ($365 \times 52 = 260 \times 73 = 18,980$ days), giving rise to the Mesoamerican belief that history repeated itself every 52 years.

Though the origin of the 260-day calendar has long been debated, the most convincing explanation for its astronomic underpinnings was first given by Zelia Nuttall in 1928, who argued that it represented the interval between zenithal sun positions at Copán, the major Maya astronomical center located in the mountains of western Honduras. At the latitude of Copán (14.8°N.), the sun passes overhead at noon on August 13 on its apparent southward journey to the Tropic of Capricorn and again on April 30 on its apparent northward journey to the Tropic of Cancer. In 1945, Merrill called attention to the “coincidence” of the August 13 date with the start of the so-called Maya ► [Long Count](#), which in the Goodman-Martínez-Thompson correlation between the Maya and Christian calendars fixes the beginning of the present cycle of the world as August 13, 3114 BCE. (The Long Count represented a meshing of the 260-day sacred almanac and the 365-day secular calendar in such a way that each day was as uniquely and precisely identified as they are in the Julian Day system employed by modern astronomers.) In 1948 a Guatemalan scholar, Girard, contended that the calendar’s birthplace lay along the same parallel of latitude but in the mountains of his country instead. While concurring in the astronomical importance of the 14.8° parallel of latitude, the present writer was forced to reject both Copán and the highlands of Guatemala as the calendar’s cradle, for reasons both of history and of geography. No pre-Columbian site situated along that parallel in the highlands of Central America predates the fifth century AD, whereas the sacred calendar is known to have been in use for several centuries BCE. Furthermore, many of the day-names used in the sacred almanac commemorate lowland tropical animals. The only place where the requisite astronomy, history, and geography come together is at Izapa, on the Pacific coastal plain of Mexico, where a large



Geography in Mesoamerica, Fig. 1 Both Izapa and Copán are situated just south of the 15th parallel of North latitude, the former immediately adjacent to the

boundary between Mexico and Guatemala and the latter in the mountains of western Honduras (Map by the author)

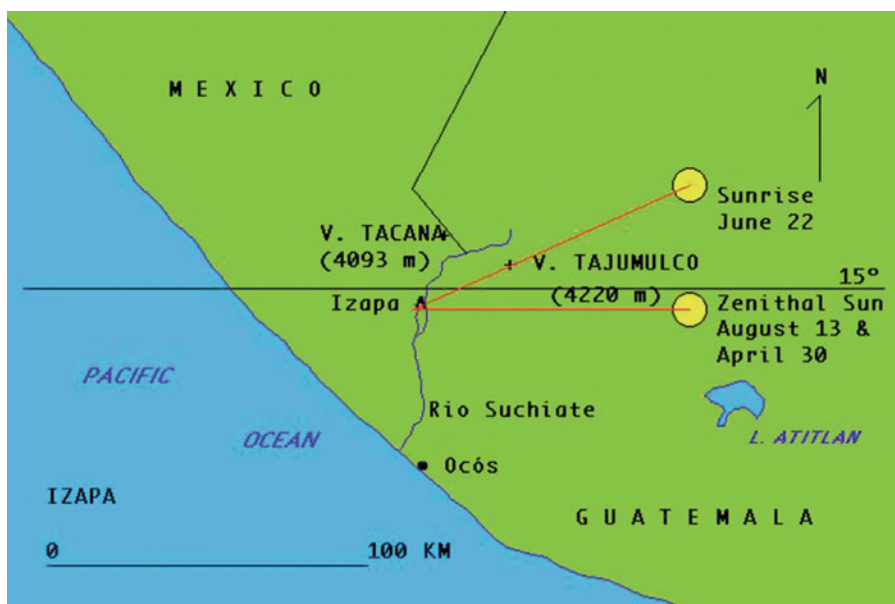
ceremonial center of Formative age (1500 BCE-300 AD) is found amidst a tropical rainforest ecological niche (Fig. 1).

Field work at Izapa in 1974 not only revealed that the entire ceremonial center is oriented to Tacaná, a commanding volcano of 13,428 ft elevation on the northern horizon but also that the highest volcano in Central America, Tajumulco (13,845') marks the azimuth of the rising sun on the summer solstice (June 22) as seen from Izapa (Fig. 2).

This use of prominent topographic features to serve as calendrical markers was subsequently traced to the oldest so-called Olmec ceremonial centers of San Lorenzo (1200 BCE, oriented to Zempoaltepec (11,138') at the winter solstice sunset), La Venta (1000 BCE, oriented to Cerro Santa Martha (4,600') at the summer solstice sunset), and Tres Zapotes (800 BCE, oriented to Cerro San Martín (4,600') at the summer solstice sunrise), but also to the earliest ceremonial centers of the Mexican plateau, including Cholula, Cuicuilco, Tlatilco, and Tlapacoya (Fig. 3).

Significantly, only two of the earliest Maya sites, Uaxactun and Tikal, have mountains within view, but both of them are likewise oriented to the winter solstice sunrise over the highest peak within sight – the first to Baldy Beacon (3,346') and the second to Victoria Peak (3,680'). In each instance, the local site-factor which pinpointed the ceremonial center's location was the availability of water, both for domestic uses and, in the early Olmec centers, for transport, but only when the situational factor of the proper solstitial orientation coincided with it (Fig. 4).

Interestingly, where prominent mountains are not visible on the horizon, the early Mesoamericans substituted architectural alignments for solstitial orientations. The greatest of pre-Columbian cities, Teotihuacán, about 30 miles northeast of present-day Mexico City, combines an intriguing blend of both principles: it is located precisely in line with the winter solstice sunrise over the highest mountain in Mexico – Citlaltépetl, or Orizaba, 18,700' – but the peak itself is obscured by a low ridge of hills on the southeastern horizon. It would appear that



Geography in Mesoamerica, Fig. 2 The unique geographic position of Izapa permitted its priests to calibrate precisely both the length of the 260-day sacred almanac and the 365-day secular calendar – the first by zenithal passages of the sun and the second by measuring the

interval between summer solstice sunrises over Central America's loftiest volcano. The sacred almanac had its beginnings about 1320 BCE and the secular calendar was initiated some 34 years later (Map by the author)



Geography in Mesoamerica, Fig. 3 Throughout the areas they occupied in present-day Guatemala, El Salvador, and Mexico, the Olmecs continued the precedent of orienting a ceremonial center to a solstitial sunrise or sunset, begun at Izapa. On this and subsequent figures,

lines in orange indicate solstitial orientations while those in red mark orientations to the August 13 sunset. Here we see the orientations found at the oldest Olmec sites in southern Veracruz state (Map by the author)



Geography in Mesoamerica, Fig. 4 The flat and relatively featureless peninsula of Yucatán provided the lowland Maya with no mountains with which they could locally calibrate the calendars they had inherited from the Olmecs. However, once within sight of the Maya

Mountains of present-day Belize, the practice was revived at two of their most ancient and important sites in the Petén region of Guatemala, Uaxactun, and Tikal (Map by the author)

a “relay station” was built there to allow the priests of Teotihuacán to calibrate their calendar with the southernmost position of the sun, whereas the entire city itself was meticulously gridded to the sunset position on August 13 – the day the present cycle of the world was believed to have begun (Figs. 5 and 6).

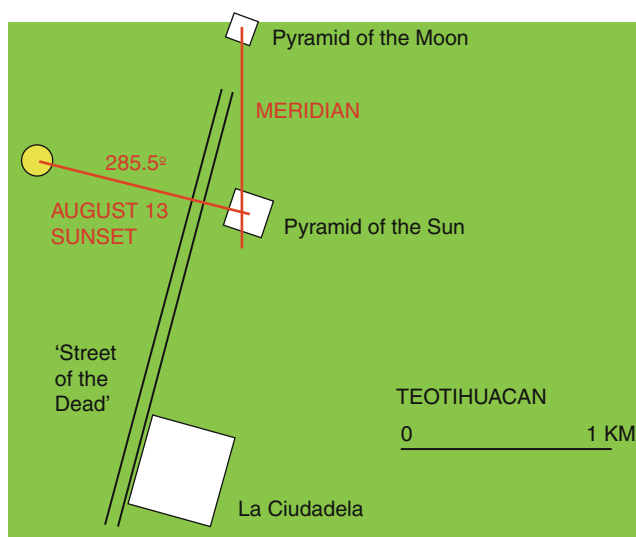
The commemoration of the August 13 sunset is also found in the layout of other ceremonial centers on the Mexican plateau of later, Toltec vintage, but its most widespread use in city planning was amongst the Maya. The location of the earliest Maya ceremonial center at Edzná (dating to 150 BCE) was primarily dictated by the presence of the largest Aguada, or temporary lake, in all of the Yucatán, but its internal layout clearly reflects their religious preoccupation with the August 13 sunset. Similarly, numerous structures throughout the Maya regions of Yucatán and Petén reflect the August 13 alignment, among them the Codz Pop at Kabah, the Pyramid of the Magician at Uxmal, and El Caracol at Chichén

Itzá, to name but a few. The crowning blend of celestial mechanics, time, and space is to be found in the Maya capital of Tikal, where five sky-scraper pyramids, all about 200 ft in height and all constructed in the eighth century, mark the alignments of the August 13 sunset (Temple I to Temple IV), the equinoxes (sunrise Temple III to Temple I; sunset Temple I to Temple III), and the winter solstice sunrise (Temple IV to Temple III) in a sophisticated astronomical matrix. Further, an alignment from Temple V to Temple I not only marks a perfect right angle to the August 13 alignment but one from Temple V to Temple II likewise pinpoints the westernmost point in the rotation of Polaris, which at that time was the closest thing to a polestar which existed, even though it was a full 8° away from its present position (Fig. 7). (Clearly, the repeated use in Mesoamerican ceremonial centers of the August 13 sunset orientation not only forcefully argues for the sacred almanac’s astronomical origin but it also makes any alternative explanation, such as



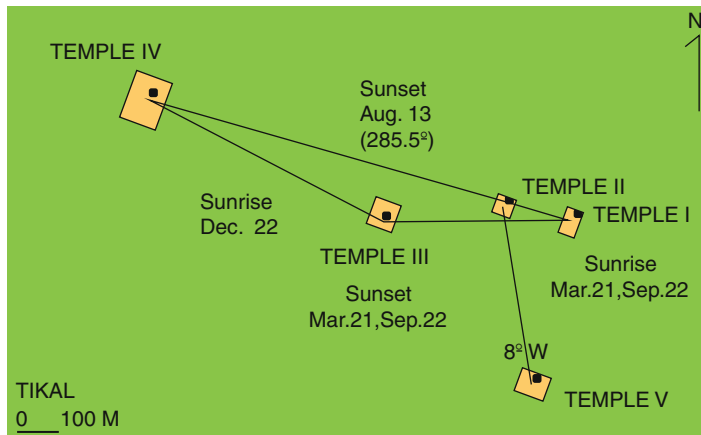
Geography in Mesoamerica, Fig. 5 As the Olmecs carried their calendrical systems onto the plateau of Mexico, they found a plethora of great volcanoes to which they could orient their incipient ceremonial centers. Following the destruction of Cuicuilco about 150 BCE, they founded

what was to become the largest urban center in the New World at Teotihuacán and ensured that it was solstitially oriented to Orizaba, the highest mountain in Mexico (Map by the author)



Geography in Mesoamerica, Fig. 6 At least three key astronomical concepts are built into the layout of Teotihuacán, Mesoamerica's greatest pre-Columbian metropolis. Not only it is oriented to the winter solstice sunrise over the highest mountain in Mexico, but its entire internal structure is also aligned to the sunset position on

August 13. Furthermore, the location of the Pyramid of the Moon and the Pyramid of the Sun, its two most imposing architectural features, precisely defines the meridian, enabling both noon and midnight to be calibrated as well (Photo by author)



Geography in Mesoamerica, Fig. 7 At Tikal, sometimes called “the capital of the Maya,” the planning and construction of five “skyscraper” pyramids, all carried out within about a 50 year period in the late eighth century,

pointedly demonstrates how the Maya combined the spatial arrangement of their architectural structures with key temporal “landmarks” in their religious year (Map by the author)

the length of the human gestation period or the simple permutation of the numbers 13 and 20, untenable.)

In the fifth century, the Mesoamericans appear to have carried out two remarkable geographic expeditions. Although they both had ultimate religious goals in mind, these endeavors probably reflected the closest approach the pre-Columbian civilizations ever made to what we regard as scientific inquiry. The priests of Teotihuacán dispatched an expedition into the northern desert to determine where the “sun stopped” in its annual migration, and in consequence of this, the astronomical center of Chalchihuites was founded on the Tropic of Cancer. Lacking a better means of recording key alignments, they dug trenches through the earth and plastered them with adobe to mark the summer solstice sunrise. (In the tenth century the Toltecs added a trench to mark the beginning of their New Year, February 12.) Perhaps under Teotihuacán’s sponsorship, the Maya carried out a similar expedition at about the same time to locate the place where the 260-day sacred almanac could be calibrated. The result of this venture was the founding of Copán, in the western mountains of Honduras, whose oldest recorded ► [Long Count](#) date is 435 AD. Thanks to its key geographic location, Copán was ultimately to become the Mayas’

principal center for astronomic studies – the late and distant heir of Izapa where the first intellectual stirrings had begun nearly two millennia earlier.

See Also

► [Long Count](#)

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Geography in the Islamic World

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Geography is the study of the Earth's surface as the space within which the human population lives. The internal logic of this study has tended to split modern geography into two parts: physical and human. Such a division was inapplicable in the geography of the Middle Ages, the golden age of scientific inquiry in Islamic civilization (Tozer, 1964). Nevertheless, if we confine the meaning of science and technology to the natural and exact sciences, then a survey of geography in Islam may be divided into three categories: exploration and navigation, physical geography, and cartography and mathematical geography.

Prompted by the sense of Islamic brotherhood, and the quest for knowledge and piety, Muslim scholars engaged in many exploration and navigational activities between the ninth and twelfth centuries (Nafis, 1972). The journeys were not confined to the political boundaries of the Islamic empire but extended to distant regions such as China, Southeast Asia, Southern Africa, and Russia. In Northern Europe, the extent of the Muslims' travels may be gauged from the fact that some ten million pieces of the Islamic state's coins have been found around the Baltic. In Sweden alone 12,000 such coins were discovered at 169 sites.

From extant documents, it may be deduced that no less than 20 geographers were involved in navigation and exploration, resulting in a massive store of information and descriptions of the terra-cognita. Out of these, five may be regarded as outstanding. These geographers are al-Muqaddasī (b. tenth century), Ibn Jubayr (b. AD 1145), Yāqūt (b. AD 1179), Ibn Baṭṭūṭa (b. AD 1304), and Ibn Mājid (b. AD 1400). The contributions of Ibn Faḍlān (tenth century), Ibn Hawqal (tenth century), Mas'ūdī (d. AD 456), al-Bīrūnī (b. AD 972), al-Idrīsī (b. AD 1099), Ibn Rushd (AD 1300), Jawainī (ca. AD 1000), Abdur

Razzāq (AD 1000), Ya'qūbī (d. AD 897), al-Marwazī (d. AD 887), Nāṣir-i-Khusraw (b. AD 1003), al-Māzinī (b. AD 1080), al-Maghribī (d. AD 1274), and Ibn Khurdādhbih (ca. AD 900) are also noteworthy.

Al-Muqaddasī or al-Maqdisī spent 20 years travelling the length and breadth of the Islamic empire. He perceived that it was important to be able to substitute hearsay with personal observations and set out on a series of field trips to gather information and knowledge about places. One of his major works was *Kitāb aḥsan al-taqāsim fī ma'rifat al-aqālīm* (The Best Climatic Divisions), which was regarded as accurately informative of areal differences in climate in the Islamic world. Ibn Jubayr was meticulous in his description of places such as Mecca and Medina in his *The Travels of Ibn Jubayr*, which became a basis for historical comparison with later writings. Yāqūt's *Mu'jam al-buldān* (Dictionary of Geography) was another major contribution, and his extensive travelling within the Islamic empire resulted in a vivid account of the Islamic world before its fall to the Mongols. Ibn Baṭṭūṭa certainly stands out as the most seasoned traveller. In 20 years he journeyed as far as 120,675 km (75,000 mile) covering countries like China, Southern Ukraine, Sumatra, the Malay Peninsula, Kampuchea, Maldives, and the Volga. His detailed accounts of life in these places contributed further to the geographical preoccupation with different areas. However, Ibn Mājid and Sulaymān al-Mahrī were better informed about the Southeast regions of the world. The former's *Kitāb al-fawā'id fī uṣūl 'ilm al-baḥr wa'l-qawā'id* (Principles of Navigation) and the latter's *'Umda and Minhāj* became important references for those who wanted firsthand information on the Malay Archipelago (Tibbets, 1979).

The fact that collectively the Muslim travellers and navigators covered more than two-thirds of the Earth's surface illustrates the Muslim scholars' disdain for armchair scholarship. That distant places were visited for collecting information at a time when vehicles, vessels, and instruments were underdeveloped, and when both land and sea routes were more unsafe than otherwise, serves to prove the inquiring spirit of the Muslim geographers.

In physical geography the contributions made by Muslim geographers in the Middle Ages pertain to their theoretical speculations about the lithosphere, atmosphere, hydrosphere, and biosphere (Arnold, 1926). In cosmology, they came out with new notions regarding the relationship between cosmological cycles and geographic changes. For instance, the Sincere Brotherhood or Brethren of Purity (*Ikhwān al-ṣafā*), an association of scholars whose treatises were considered the standard for scientific knowledge of their day, conceived of the influence of the angle of declination on insolation, the influence of relief on precipitation, and the relationship of precipitation with the origin of streams and springs.

With regard to the lithosphere, the solid part of the Earth, Muslim geographers thought of landforms as being the results of erosion, deposition, and tectonic activities. Soils were considered the results of organic decomposition, and winds (gases in modern usage) trapped underground and seeking outlets were held responsible for earthquakes.

Their theories on atmosphere embraced both local atmospheric phenomena and the distribution of macro-climatic elements. Thus, by envisaging atmospheric processes, such as insolation, convection, and evaporation, they were able to account for the formation of clouds, rainfall, snow, fog, and dew as different forms of evaporation due to differences in temperatures. They also divided the world into three climatic zones: hot, cold, and temperate, based on their understanding of the changing positioning of the sun.

In terms of the hydrosphere, most of the Muslim geographers' works were focused on understanding the causes of tides and the origin of oceans and reasons for their salinity. In accounting for tides, the geographers were divided. Some pointed to the influence of heat generated by the sun and moon; others attributed the tides to the influence of wind on the movement of sea water. Muslim geographers, in general, concurred with their Greek counterparts in thinking the oceans had originated from the remnants of primitive precipitation which did not get dried when matter was formed in the universe. They, however,

differed again with respect to marine salinity. Some ascribed it to the transformation of calm water to salty hard water after prolonged gestation.

Regarding the biosphere, geography in the Islamic Middle Ages saw the categorization of flora and fauna according to the grade of their creation. Thus, al-Jāhīz wrote four classes of animals based on their locomotion: those that creep, walk, swim, and fly.

By contrast, Ibn Maskwaih's division was based on the creatures' stage of evolution, with the lowest stage being occupied by vegetation which did not require seeds to grow and humans occupying the highest stage of evolution. The categorization by the *Ikhwān al-ṣafā* was based on senses, whereby creatures with one sense occupied the lowest level and those with five senses the highest. In spite of these differences, the Muslim biogeographers agreed that the spatial distribution of organisms was governed by climate, topography, and soils.

Yaq'ūbī was noted for his *Kitāb al-buldān* (The Book of Countries) written in AD 891, in which he described in detail the physical characteristics of Baghdad, Samarra, Iran, Turan, and the present Afghanistan. Ibn Rustah discussed the importance of locational and physical environmental factors on the development of cities, such as Medina and Mecca, in the seventh volume of his *al-A'lāq al-naḥṣah* (The Book of Precious Things), an encyclopedia completed in AD 903. Al-Maqdisī described an imperfect spherical Earth, the northern hemisphere of which contained more land than water. He also gave a detailed account of the world climate in terms of zones. Yet the most daring speculation may be ascribed to al-Bīrūnī, who theorized that, based on empirical evidence of its physical environment, the Indian subcontinent might have been a continental shelf before depositions raised it into a landmass. Lastly, al-Qazwīnī (b. AD 1203) produced two books: *'Ajā'ib al-buldān* (The Wonders of the Lands or Geography) and *'Ajā'ib al-makhlūqāt* (The Wonders of Creation or Cosmology), which were notable for their reference to more than 50 authors. The significance of this fact is that the large number of practicing geographers that were cited indicates how active

and prolific physical geography was in the medieval Islamic civilization.

The achievement of Muslim geographers in mathematical geography may be described in various phases of development (Alavi, 1966). An important phase was the establishment of the school of mathematical geography in Shiraz, Persia, after AD 950. This school produced important scholars such as 'Abd al Raḥmān al-Ṣūfī and Ibn al-A'lam. 'Abd al Raḥmān reviewed Ptolemy's *Star Catalogue*, while Ibn al-A'lam compiled an astronomical table which became a main source of reference for centuries. Important developments took place in the school in Cairo toward the end of the tenth century and the early eleventh century. Important scholars from this school included Ibn Yūnus, who prepared astronomical tables and corrected several errors committed by the Greeks Ptolemy and Hipparchus. For instance, according to Ptolemy, the precession of equinoxes occurs at 1° in 100 years, but the correct measure was 1° in 70 years, as calculated by Ibn Yūnus. His book entitled *Al-zīj al-ḥakīmī* (Tables of Wisdom) explained, among other mathematical ideas, the method of calculating longitudes and latitudes.

Among the notable works written in Central Asia of this school was al-Bīrūnī's book entitled *Taḥdīd nihāyāt alamākin* (The Determination of the Coordinates of Cities). Other scholars of high reputation were al-Zarqāllu, Naṣāl-Dīn al-Ṭūsī, and Ulugh Beg. Al-Zarqāllu produced several books on astronomy including the *Toledan Tables*. His other work, entitled *Qānūn* (Canon), was used by European scholars during the Renaissance. Al-Ṭūsī is remembered for his book *Zīj-i-īlkhānī*, which recorded all the notes and observations he made from the observatory of Maragha. His other important writing was on the astrolabe and the problems related to the measurement of time, celestial altitudes, meridians, and the like (Kennedy & Kennedy, 1987). Ulugh Beg was a Tartar prince (AD 1393–1449) who was also noted for the observations he conducted from the observatory in Samarkand. He managed to point out several errors committed by Ptolemy in the latter's tables and made new tables of latitudes and longitudes.

With respect to cartography, Muslim scholars followed two schools: one was based on the cartographical method of Ptolemy and the other on that pioneered by al-Balkhī. Ptolemy's teachings were followed by al-Idrīsī, and al-Balkhī's were continued by al-Istakhrī, Ibn Ḥawqal, and al-Maqdisī. The Muslims' maps were drawn and utilized in conjunction with countries and regions. Idrīsī became famous in the West because of his maps and cartographical work. His maps were valued not so much because of their accuracy but because of the symbols he used to distinguish various physical and cultural forms.

A prominent feature of the achievement of Muslim scholars in mathematical geography and cartography was the invention of scientific instruments of measurement. Among these were the *astrolab* (astrolabe), the *rubā* (quadrant), the gnomon, the celestial sphere, the sundial, and the compass. The portable astrolabe was used by navigators for measuring altitudes up to the seventeenth century. The rubā was used for measuring the value of angles. The gnomon was also used for measuring altitudes of the sun and other planets. The use of celestial sphere was to explain celestial movements, the sundial for calculating daily time and the azimuth (compass bearing) of Mecca, and the compass for finding direction during navigation. In human geography the achievement of Muslim geographers during the Middle Ages may be summarized into two main categories: (1) works which attempt to explain factors deemed responsible for influencing, or even determining the traits, characteristics or qualitative nature of a population or community, and (2) works which describe basic facts (social, economic, political, and cultural aspects) about a society's or a community's life. Viewed from the perspective of contemporary modern human geography, some of these works coincide with discourses on environmental determinism (the doctrine that human activities are controlled by the environment) and environmental possibilism (the view that the physical environment provides the opportunity for a range of possible responses and that people have considerable discretion to choose between them) (Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1992). Others may

be aligned more with traditional regional geography which was heavy in chorography (the study of the areal differentiation of the Earth's surface, i.e., the areal variation of human and physical phenomena as they relate to other spatially proximate and causally linked phenomena) or idiography (a concern with the unique and the particular). Some of the names identifiable with this episode of Islamic human geography were Al-Masudi – for his explication as to how climates differentiate between people of northern and southern hemispheres – and Al-Maqdisi, for his characterization of settlements based on the temperament of their inhabitants.

Modern human geography has since been dominated by thoughts and works of Western human geographers. So much has happened to the secular epistemological thinking of this subdiscipline of geography, and an Islamic preliminary review of it was written by Buang (1992) followed by an outlining of the content of the Islamic perspective by the same author (Buang, 1996). The latter further pursued the cause of the Islamic perspective of contemporary human geography with a paper which attempts to persuade secular mainstream human geography, on the platform of postcolonial studies, to engage epistemologically with the Islamic perspective. Whether acknowledged by the West or not, an Islamic epistemology exists for both natural and human sciences. And since advancing postcolonial geography must also include the decolonization of knowledge, it is timely to consider if an alternate, Islamic human geography has instructive worth with respect to mainstream human geography. This entry sketches a broad outline of an Islamic human geography and shows how it (i) addresses some of the fundamental epistemological questions non-Islamic, largely secularized, geographies of the West have abandoned or silenced; (ii) incorporates a number of ideas within mainstream human geography; and (iii) outlines novel frameworks for synthesizing differences that trouble mainstream human geography. While the showcasing of Islamic geography may not alter its irrelevance to secular and non-Islamic geographies, its illumination confirms its relevance to Muslim

contexts and, by refraction, the situated nature of mainstream human geography. As such, this exploration serves the purpose of opening out the kind of conversation across differences that postcolonialism seeks to advance (Buang, 2013).

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Geography of the Native North Americans

Martha L. Henderson

Native North Americans sustain sophisticated and complex cultures. What native peoples say about themselves with their own constructs of

space and place is essential to understanding native North American populations. This essay attempts to describe geographical data including native spatial organization, relationships with the natural environment, and the location and significance of places. These data and their analysis can shed light on native identity, problems of intercultural relations from a geographic perspective, and the contemporary context of native geography within the pluralistic federal states of Canada and the United States.

North American natives, those living north of the Mexican-United States border, were divided regionally by specific cultural patterns and practices such as language, religion, and relationships with the natural world. Oral traditions and material artifacts about past events provide clues to a native North America. Similar culture groups established territorial boundaries that served to strengthen group identity. Porous boundaries allowed for fluid contact between groups when conditions required. Territories generally conformed to major ecosystems of the continent.

North American ecosystems are roughly divided by landform and vegetation that include a direct reference to climatic conditions of the modern period. The subtropical Southeast extends from the center of the continent at approximately 100° West to the Atlantic coast to its northern limit at approximate 35° North. Corresponding to the west is the Southern Great Plains, Southern Rocky Mountains, and the desert Southwest. Between 35° and approximately 50° North is the temperate zone. In the west, this zone includes the rainy coastal mountain ranges of the Pacific, the cold Rocky Mountains, the dry Central and Northern Great Plains, and the humid Northeast Atlantic region. North of the temperate zone climatic conditions are generally cooler. The northern region was drastically affected by continental glaciations. Except for the Northern Rocky Mountains that extend into Alaska, the northern region has been heavily eroded and generally flattened. Very large lakes and river drainages cut across the rocky surface. Soil development is slowed due to cold temperatures. Trees rarely grow above 55° North. These

basic environmental conditions set the framework for native population habitation of the land mass (World Atlas).

Today, the international boundary between Canada and the United States divides federally recognized tribes but not self-identified culture groups. Historic treaty-making and reservation assignments create a federal geography while native populations recognize a cultural geography that reaffirms a traditional past, present, and future in Indian Country.

Traditional Native Geography

Native geography can be described on the basis of creation stories, location, territoriality and boundary making, resource adaptation and interaction with the physical environment, and place-making. Native-land relations are primarily structured around a set of beliefs that recognize Earth as the spiritual and material center of life. Generally, Natives do not divide their world between the real and the spiritual. The world includes every existing entity and those spirits who occupy them. All aspects of nature are sacred; there is no separation between the universal and human actions. For example, the Ojibway of the Upper Great Lakes region view Earth as "spirit garden." Resource adaptation and cultural patterns are closely linked, one sustaining the other. Spiritual, cultural, and physical collaboration established a balance that supported native populations in sustainable, traditional patterns.

Places usually recognize the spiritual integrity of natural objects or events that magnify the wishes of a creator. The Hopi of the American Southwest named each of their mesa homelands with respect to physical features and conditions of Hopi creation beliefs. Hopi place names not only imply the physical, but also the spiritual conditions of existence. Prior to contact with non-Hopi groups, especially non-Indian groups, each mesa was a world unto itself, anchored in a spiritual and material existence. Recent events within Hopi mesas, such as surface coal

mining by western industrialists, have wounded this sacred ground.

The White Mountain Apache maintained an oral history by telling each other about specific places. Specific places in traditional territory evoked significant events, lessons of survival, life passages, and mystical events. Without these places, the traditional history of the Apache did not occur. The power associated with each place captures the power of place within many native culture groups (Basso, 1996).

Creation Stories

The native populations of the Western Hemisphere constituted a major portion of Earth's human populations prior to European contact during a period of time generally recognized by scholars during the fifteenth century. It is estimated that populations in Central and North America could have been as high as ten million with the same amount in South America. The extent of nonnative knowledge about human habitation in other parts of the world is speculative. It is apparent in some oral traditions that natives knew of white visitors to the Americas prior to the temporal divide of the 1400s.

Northern American natives believe, and continue to believe in, creation stories that do not include a Beringia migration during periods of colder climatic conditions. Recent discoveries in North America of pre-Paleolithic skeletal remains and artifacts stimulate a growing awareness that native occupation is part of a much longer legacy of continental occupation. Native American artifacts have been found across the North American continent in such quantities as to suggest that all parts of the land mass were occupied at the close of the last major glacial period. The post-Pleistocene period is a convenient but tentative temporal divide. Contemporary native peoples are reasserting their own stories of origin, culture, language, and environmental ethics that reset the balance of authority between native peoples, federal governments, and academic researchers.

Location, Territoriality, and Cultural Boundaries

Within each major group were specific groups who established their location around specific physical features at a density that allowed a sustainable population to exist within the entire ecosystem. Local shifts in location, resource acquisition, sacred sites, and interaction zones between groups were not uncommon. These shifts were sanctioned by mutual consent although peaceful readjustments were not always the case. Major stresses such as prolonged drought or loss of a major resource caused location changes and readaptation across ecosystem boundaries.

Natives generally view area based on concepts of territoriality. Territoriality is a common recognition of a physical landscape that supports loosely allied group needs. Acute observation skills, familiarity with local and regional physical characteristics, and recognition of other social groups within the area are consistent attributes of native geography. For example, the Apache utilized an area of the American Southwest generally between the Rio Grande River and the Great Plains. Primarily a mountain people dependent on species found at various elevations during changing seasons, the Mescalero Apache also developed hunting skills that allowed them to take advantage of grasslands species such as buffalo. They shared buffalo hunting with distant Apache relatives. These other Apache groups were permitted to hunt and gather resources in the Mescalero mountain territory when grasslands resources were scarce. The Mescalero Apache held all resources as a common good to be shared when other Apache required assistance.

An important aspect of territoriality is the ability to communicate conditions of space and place. The Inuit are superb cartographers, able to produce maps of territory with accurate scale, a system of symbols, and direction. The maps also convey a sense of space and place where value is placed on animal trails, natural features, and settlement locations. An Inuit map of the north therefore demonstrates Inuit reality as opposed to another culture's maps of northern places.

The continental context of native occupation was well known to native peoples. Means of transportation and navigation technologies existed that allowed for transcontinental exchange as well as regional interaction between groups. Regionally, large game hunting and other resource-sharing opportunities allowed for contact and exchange between groups. Finally, small groups who occupied specific areas achieved a balance between resources and population needs. Expertise in the maximum utilization of all resources supported native populations within a context of spiritual, cultural, and physical balance.

Resource Adaptation

The map of traditional native North America includes recognized areas of group occupation, fluid and sometimes shifting boundaries between groups, and cultural indicators that promoted group identity and survival. Groups of similar culture and subsistence patterns are recognized within each of the major ecosystems of North America. Each major group had unique linguistic, religious, and subsistence patterns. Within each ecosystem were specific groups who maintained their own identity while recognizing their commonalities with similar groups within the ecosystem. Native populations are generally divided into the following large groups: Mississippi temple-mound builders; eastern woodlands hunter-gatherers and cultivators; plains bison hunters; southwest Anasazi; desert hunter-gatherers; west coast foragers, hunters, and fishers; plateau fishers and hunter-gatherers; sub-Arctic forest hunter-gatherers; Arctic marine mammal hunters; and island fishers (Carnegie Museum).

The use of natural resources for survival is generally framed within the context of small Indian populations, exploitation to meet needs, and returning something to nature for the use of an item. Native Americans developed a resource use paradigm that focused on the unity of all beings and their systemic value rather than individual worth. For example, individual animals within a forest ecosystem were recognized in relationship to other plants, soil, water, and air. The

use of a specific animal was always observed with respect to other elements of the ecosystem with an attitude of thankfulness and recognition of the animal as a gift. Reliance upon specific species developed over centuries of adaptation. As native groups entered new areas of North America and as North American physical environments were transformed by primarily climatic events, groups had to adjust, migrate, or face decline.

This is not to suggest that specific species were not singularly important to American Indian groups. The buffalo provided nearly all of the needs of plains bison hunters while west coast fishers relied heavily but not exclusively upon salmon. Given the low population numbers of natives, neither species were threatened with extinction due to overkill. It is reasonable to believe that resource demands and human populations would have remained static if European explorers with different technologies and valued resources had not impacted native culture groups (Native North America).

Perhaps the most striking of examples of native cohabitation is found in the cold deserts of the plateau fishers and hunters and gatherers, and the Arctic marine mammal hunters. Using simple technological devices, native peoples occupied and survived in both areas. The Piute established their primary homes along pluvial spring-fed lakes that survived continental warming. These people developed fishing and hunting technologies that allowed them to utilize birds, animals, and fish that inhabited the lakes and marshes of the Great Basin. While large game animals are scarce in the region, small animals such as antelope and rabbits were easily trapped. Plants, whose life cycles were well known to local Piute groups, were readily available. These food resources were abundant to the point that it is estimated that the Piute had more time available for leisure and social activities than any other native group.

Similarly, Eskimo experienced a high amount of time available for artist expression and social activities because they developed sufficient technologies and skills to maintain caloric intake and clothing needs. The Arctic is one of the richest animal and fish ecosystems on Earth. Native

fishing, watercraft, celestial navigation, and clothing technologies allowed the Inuit and Eskimo to thrive in the high latitudes.

Oral traditions and present practices indicate that management techniques were utilized to create and sustain certain types of ecosystems. Native use of fire to maintain open fields is apparent across the continent. Native burning may also be the primary force that created the grassland ecosystems of the mid-continent. The eastern woodland natives such as the Iroquois practiced burning of areas, known by European settlers as “old fields,” to maintain open areas for large game hunting.

Native cultural ecology places a high degree of respect for living with environmental conditions. The mental constructs of discovery and contact by Europeans overlooked the brilliance of native populations who had, through experimentation and accident, come to live in a state of balance with the physical environment. This balance was radically changed with the permanent migration of Europeans to North America.

Historic Geographies: Cultural Conflict and Emergent Identities

European influences in native North America are generally recognized as beginning in the fifteenth century with earlier contact periods a probability based on archaeological data. Contact between natives and Europeans resulted in major shifts in native geography. European tools, technologies, diseases, and interruption of traditional patterns of resource acquisition and spatial organization altered those natives who experienced direct contact. More importantly, the changes spread within the native population to affect large groups of natives who did not experience direct contact. The presence of English, French, and Scandinavian explorers and their patterns of living spread quickly from the eastern coastal areas inland. Similarly, natives living in the southwest were affected by the presence of Spanish explorers in Central America. The diffusion of European goods, ideas, technologies, and diseases spread quickly across the entire continent.

Once European settlements were established, their demand for resources had an immediate effect on the location and territoriality of native groups. For example, as French fur traders moved into the Great Lakes region, northern Algonquian peoples moved westward into Ojibwa territory. The Ojibwa peoples moved westward into Sioux territory west of Lake Superior. This migration resulted in conflict and warfare between the two native peoples. Eventually the Sioux moved further west and established themselves on the northern Great Plains. When American ethnographers described the Sioux, they called them Plains people who had adapted to living off buffalo, yet this was a very recent location and adaptation for the Sioux.

Spanish *entradas* into the southwest also created a chain reaction of relocation and territorial disputes within native peoples. Coronado's 1540 brutal search for the Seven Cities of Cibola caused Pueblo and Hopi groups to make alliances in order to protect their holdings in the upper Rio Grande valley. In 1598 the Onate and a group of Spanish settlers entered the central Rio Grande valley. Their presence forced Pueblo groups to reestablish themselves in a new configuration of alliance and mutual support.

Some native groups were able to maintain control of their territory and command a more powerful position with colonial and, later, American federal interests. The first treaties between native groups and the Euro-Americans were based on the strengths of two powers entering into treaties as equals. Native peoples agreed to allow Euro-Americans to inhabit certain spaces for mutual protection. In some cases, native treaty-makers did not perceive that what they were agreeing to was conceptualized in a very different way by the Euro-Americans. These natives could not conceive that what the Euro-Americans were doing was acquiring full rights to the land base because the natives did not believe that land was owned or tenured to any one specific group.

Once established, however, Euro-Americans continued to acquire and use land beyond treaty boundaries. This form of disrespect for the treaties caused continue disruption of native use

of resources, attempts to live with the new population, and peaceful relations with other native groups. Native peoples also faced disequilibrium as Euro-American settlement spread westward across the continent. Debilitating diseases, alcohol, and physical attacks rapidly reduced native populations.

Native groups in the west, especially the Nez Perce, quickly adapted to the use of horses. The introduction of horses added speed and the ability to cover large distances to these native cultures. By the time the American and Canadian governments made contact with these culture groups, their strength in hunting and raiding proved them to be powerful forces that stood in the way of the federal governments.

By 1830, native groups across the continent were significantly reduced and very strongly affected by the presence of the American and Canadian governments. Population numbers were greatly reduced and in some cases entire culture groups were wiped out. Both governments carried out major campaigns to exterminate native peoples. Those remaining were required to sign treaties that established reservations for native groups. Groups of differing traditional backgrounds were often placed on the same reservations. For example, the Cherokee of the southeast mound-building culture were forced to walk nearly a thousand miles in the winter of 1839 to a reservation established for them in the southern Great Plains. The walk, known as the *Trail of Tears*, resulted in the loss of hundreds of Cherokee lives. Those who survived the walk found themselves in a completely new physical environment for which they were not prepared. They were settled with other native groups with whom they shared little in common. Such conditions continued to undermine natives' ability to maintain cultural identity until the late 1870s. Populations were required to stay on reservations that were inadequate and unable to supply the needs of traditional peoples. Population numbers continued to decline.

Both American and Canadian governments, with the assistance of well-meaning missionary groups, assumed that native peoples would fit into a Euro-American North America if they

became farmers. Both governments instituted assistance programs and land tenure policies intended to assist natives into assimilating in the agricultural economies of the United States and Canada. These programs ultimately failed although some natives became farmers. The overall process continued to reduce native populations and open native lands for white settlement.

In a reversal of policy, the federal governments instituted new programs in the mid-twentieth century with the goals of creating tribal governance and business programs for native revenues and protection of native cultures. These new programs assisted native groups in developing tribal resources on tribal lands. Some tribes such as the Mescalero Apache, the Confederated Tribes of the Warm Springs, and the Red Lake Band of the Chippewa developed timber and cattle enterprises. The revenues from these enterprises helped to support native educational, health, and social services needs. However, the revenues were never large enough to fully empower the tribes. Tribes continued to be dependent upon federal programs for basic needs. These programs were unequally and generally poorly funded and administered. The distribution and quality of services on reservations was far from adequate.

The federal governments choose to eliminate many of the native programs at the end of World War II. The American government terminated reservations and treaties in many areas of the United States. All tribes, even those who had created profitable enterprises, were disrupted by these termination policies. At the same time, natives were encouraged to move to urban areas and learn skills that would allow them to find jobs and reside away from rural reservations. As a result of these policies, today the highest population concentrations of native populations in both Canada and the United States are in urban areas.

Contemporary Geographies of Native Peoples

The last decades of the twentieth century saw another policy reversal by both federal

governments. Working with native leaders, both governments are now committed to a process of native self-determination. Native groups have recovered some of their powers as established in treaties and have also been able to secure religious, burial, and cultural freedoms through national laws. As natural resources have become scarce in North America, it is increasingly evident that negotiations with native groups are essential in protecting habitats and threatened species, watersheds, major landforms, and critical wetlands. Native peoples continue to develop resources such as fishing and timber to meet their own needs. Native groups have quickly adopted technologies such as geographic information systems to maintain and plan resource management on native lands. Propagation and protection of flora for medicinal purposes have become major foci of native peoples. The Bella Coola and bands of Puget Sound natives have, for example, reclaimed land and protected specific species that play a significant role in cultural identity and health.

Native groups in the United States have exercised the right to develop casinos on native lands. The popularity of gambling and a desire to meet that need with additional casinos has required extensive mapping to identify the exact location of native lands. Revenue from gambling has been invested in resource development and cultural identity programs that support native populations. In some cases, casino revenue has made it possible for native groups to extend financial assistance to other cultural groups including the dominant white culture in local areas. Mutual resource management goals are also being identified and shared by more than one racial and ethnic group.

First Peoples in Canada have recovered major portions of the Northern Territories as part of the new native province of Nunavut (Atlas of Canada). Native peoples who are implementing traditional ideals and ways of knowing administer this province. Place names, the location of sacred places, resource gathering techniques, and social affairs are practices in Inuit traditions. Native groups throughout North America are experiencing a resurgence of cultural identity as the

landscape of North America reflects growing acceptance of a plurality of cultures.

Today, the largest growing populations in North America are native. More than half of all native peoples is below the age of 15. This growth rate requires planning and development of tribal resources. This expanding native population is able to access both the traditional knowledge of their cultural past and the freedom to express their native identity. The new emphasis on native knowledge is ultimately changing the power relationship between federal and tribal governments, the rights of native peoples, and the cultural and geographical record of the native populations of North America. With full recognition of native power and self-identification, this short essay is offered as only an introduction to the multidimensional and cultural diversity found among native North Americans.

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Geomancy in China

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The Chinese word for geomancy is *feng shui*, which means “wind and water,” or *ti-li*, which means “the principles (patterns) of the land.” The term *ti-li* is also the Chinese word for geography, which suggests an intimate relationship between Chinese geomancy and geography.

In Chinese geomancy, a place having certain landforms and orientations is believed to be more auspicious than others. An auspicious place is where vital energy (*sheng-ji*) is accumulated and available to humans who occupy the site. The function of vital energy is to give birth to and support all living things, and it is stored in certain places meeting geomantic requirements, blessing the people who use the site in harmony with the surrounding landscape.

The flow of vital energy underground (often through mountain ranges) is analogous to that of blood through the veins of the human body. Therefore, a geomancer’s job is to find a spot where vital energy is accumulated, in a similar way that an acupuncturist finds a critical spot of the body where a needle can be planted.

An auspicious site (geomancy cave) is sometimes compared with a melon on a vine. The nutrients from the soil are taken through the roots and transported through the vines to be stored in the melon before being consumed by humans. In a comparable manner, the vital energy flows underground through the veins and is deposited in the geomancy cave to be available for humans who use the place appropriately by building, for example, a house or a grave.

The most important geomantic condition of an auspicious site is that it be sheltered by a surrounding range of hills on three sides, with one side open. The range on the left (normally East) side is called “azure dragon”; the right (normally West) range, “white tiger”; and the hill behind an auspicious site is called the main

mountain or “black warrior.” A horseshoe-shaped basin is an auspicious site. The most desired orientation of the site should face south. The land also needs to have access to a watercourse; the most desirable ones flow slowly with many bends.

In geomancy, the people who occupy auspicious sites are believed to benefit from the land by enjoying longevity, accumulating wealth, or achieving fame in the world. Traditionally, geomancers were normally consulted when cities, temples, graves, and other human settlements were built. Professional geomancers are supposed to know how to choose an auspicious site by applying geomantic principles and can be seen as the traditional Chinese version of modern geomorphologists, location or landscape analysts, and architectural planning consultants.

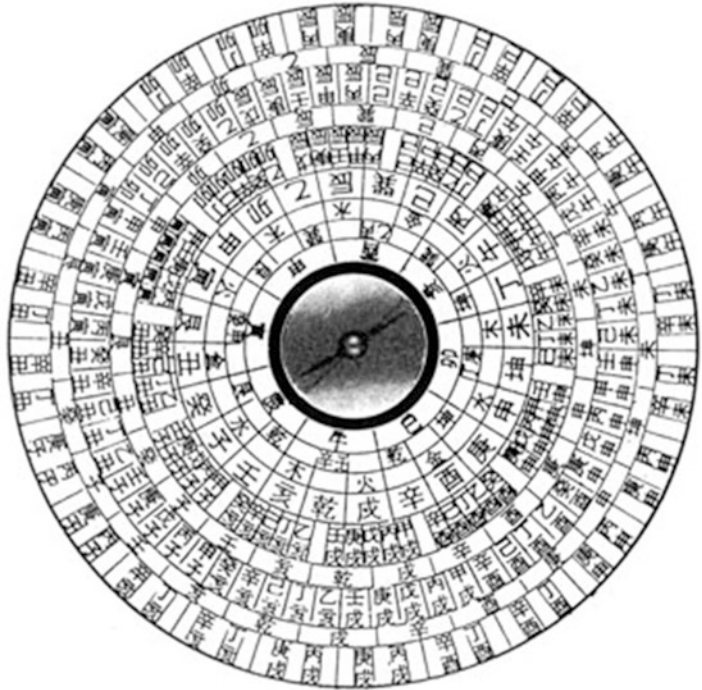
It is virtually impossible to understand the East Asian cultural landscape without having knowledge of geomancy. For instance, important cities like Beijing and Nanjing in China, Seoul and Kaesong in Korea, and Kyoto and Nara in Japan all were chosen and planned geomantically. Thus, Chinese geomancy is defined as “a unique and comprehensive system of conceptualising the physical environment, which regulates human ecology by influencing man to select auspicious environments and to build harmonious structures (i.e., graves, houses, and sites) on them” (Yoon, 1976).

In the evaluation of the quality of the landscape (the environment, place) in geomancy, the following three images are important. First, the landscape is perceived as a magical being which can influence people mysteriously, either auspiciously or inauspiciously. An auspicious site can bless people with a happy life, whereas an inauspicious site can cause people to suffer misfortunes, including disease, bankruptcy, death, and infertility.

Secondly, the landscape is personified and regarded as a system of either a living organism or an inanimate object. Either an element of a local landscape, such as a hill or stream, or the entire landscape itself may be treated as a functioning system of an object such as a cow, a boat, or a flower. Personification of a landscape

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Fig. 1 A geomantic compass currently in use by professional geomancers



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as a beautiful, balanced, and peaceful object normally indicates an auspicious site, whereas personification as an ugly, dangerous, and unbalanced object suggests an inauspicious site. Depending on how a geomancer perceives a local landscape, it may be compared to (personified as) any object in the world.

Thirdly, the landscape is seen as a vulnerable being, which can easily be hurt or remedied by human interference, because the vital energy that flows beneath the surface is extremely vulnerable. Vital energy is only one particular phase of the *yin-yang* energy according to a geomantic classic called *Zang-shu*. When *yin-yang* energy belches out, it becomes the wind. When the wind ascends, it becomes a cloud. When it descends, it becomes rain. When it flows under the ground, it becomes vital energy, but when it emerges out of the ground, it is no longer vital energy (*Guo Bu*). That is why the vital energy of an auspicious site should be utilized without disturbing it, by building a house or a grave in harmony with the surrounding landscape.

In the history of China, geomancy was often more popular for choosing an auspicious site for

a grave rather than for a house, although the same geomantic principles were applied for both cases. All the important principles concerning an auspicious place are in fact about ideal conditions relating to a living person's dwelling site. The analysis of geomantic principles concerning auspicious locations suggests that Chinese geomancy began as an art of selecting a comfortable place to live and then came to be applied to selecting grave sites as well (Fig. 1).

By the sixth and seventh centuries, geomantic principles as we know them today were probably well established in China. Ever since then, geomancy in China has been a powerful part of the art of environmental planning, landscape design, and determining various types of settlement location.

This art was probably diffused to Korea with an early wave of Chinese cultural diffusion. Koreans in turn introduced this art to Japan. Judging from ancient capital sites in Korea and Japan, this art was introduced and practiced in those countries by the seventh century. Geomancy is still practiced in China, Taiwan, Hong Kong, Singapore, Korea, and Japan. In fact,

in Hong Kong, Singapore, and Korea, a number of geomantic institutes were established, and professional geomancers practice their art in planning building structures and in the selection of residential and gravesites.

Geomancy has been adapted to the modern urban environment, and even many Chinese living in cities like America apply geomantic principles in selecting their house sites and designing house structures. In city situations, the main points of geomantic considerations are in place of the landform conditions, street patterns, roof lines of neighbors, the shape and situation of a house section, and the floor plan of a house. In some cases, the furniture arrangement inside a house is decided by applying Chinese geomancy to present day city dwellings.

There have been numerous geomantic textbooks and manuals throughout the history of China, and even now, there are more than a dozen printed editions of geomantic books available for purchase in the Chinese language alone.

See Also

- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [Geography in China](#)

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Geomancy in the Islamic World

Emilie Savage-Smith

The term geomancy comes from the Latin *geomantia*, first used in Spain in the twelfth century as a translation of the Arabic ‘ilm al-raml (the science of sand), the most common name for this type of divination. The practice is to be distinguished from a totally unrelated Chinese form of prognostication based on land forms, unfortunately also called geomancy in English. The origin of this distinctly Islamic art is a matter of speculation, but it appears to have been a well established practice in North Africa, Egypt, and Syria by the twelfth century.

The divination is accomplished by forming and then interpreting a design, called a geomantic tableau, consisting of 16 positions, each of which is occupied by a geomantic figure. The figures occupying the first four positions are determined by marking 16 horizontal lines of dots on a piece of paper or a dust board. Each row of dots is examined to determine if it is odd or even and is then represented by one or two dots accordingly. Each figure is then formed of a vertical column of

four marks, each of which is either one or two dots. The first four figures, generated by lines made while the questioner concentrates upon the question, are placed side by side in a row from right to left. From these four figures the remaining 12 positions in the tableau are produced according to set procedures. Various interpretative methods are advocated by geomancers for reading the tableau, often depending upon the nature of the question asked. The course and seriousness of an illness, the outcome of pregnancy, the location of lost or buried objects, and the fate of a distant relative are among the most popular questions addressed to a geomancer.

The acknowledged master of geomancy was Abū ‘Abdallāh Muḥammad ibn ‘Uthmān al-Zanātī, who lived before AD 1230. Virtually nothing is known of his life, though his name suggests that he was from the North African Berber tribe of Zanāta that was known for practicing other forms of fortune telling, particularly scapulomancy (divination by inspection of shoulder blades). One of the great codifiers of geomancy was ‘Abdallāh ibn Maḥfūf who lived, probably in Syria or Egypt, before AD 1265 and whose treatise is preserved today in several Arabic manuscript copies. Brief discussions of geomancy are included in a Persian encyclopedia composed at the end of the twelfth century by the celebrated theologian Fakr al-Dīn ► [al-Rāzī](#) and in short Persian tracts by the mathematician, philosopher, and founder of the observatory at Maragha in northwest Iran, ► [Naṣīr al-Dīn al-Ṭūsī](#) (d. AD 1275).

The majority of existing treatises on the subject are from the fourteenth century and later, with numerous ones still being written in the nineteenth and twentieth centuries. In view of the relatively few written sources on the topic before the fourteenth century, an intricate metal geomantic tablet, now in the collections of the British Museum, is of considerable importance. It was made in AD 1241–1242 (H. 639) by the metalworker Muḥammad ibn Khutlukh al-Mawṣilī, who also made an incense burner in Damascus about AD 1230–1240. This unique device is of a brass alloy inlaid with gold and silver, with a front plate carrying 20 dials and four

sliding arcs and a back plate engraved with inscriptions, both plates held in a rectangular frame which has a triangular suspensory device on top similar to that commonly found on astrolabes. No writings before or after its construction mention such a mechanical contrivance for establishing a geomantic reading, and there is no other known geomantic device from any culture remotely similar to it. It is evident that the designer of this elaborate device was well-versed in the geomantic literature of his day.

In Iran the term *raml* is applied to two types of divination. One type, frequently described by travelers, employed the throwing of brass dice that were strung together in groups of four. Although these dice are commonly referred to as geomantic dice, they are not marked so as to produce a geomantic figure, and thus the divination using such dice is a form of lot casting or sortilege different from true geomancy. *Raml* is also used in Iran for the traditional form of geomancy, and in modern Persian writings the art often attains an astounding degree of complexity, with successive tableaux generated from previous ones. A large number of lithographed Persian texts were published in India in the nineteenth century.

From the twelfth century until the seventeenth century, geomancy, in a slightly altered form, was very popular in Europe, where only astrology seems to have outranked it in popularity. The Spanish translator Hugh of Santalla working at Tarazona in Aragon appears to have been the first to prepare a Latin paraphrase of an Arabic treatise on the subject, with his slightly younger contemporary working in Toledo, Gerard of Cremona (d. AD 1187), translating another Arabic tract. After the seventeenth century, interest in geomancy faded abruptly in the West, and today it remains relatively unknown there.

There are many non-Western areas where geomancy and derivative methods of divination are still practiced. Geomancy in sub-Saharan Africa and Madagascar, which employs simplified but clearly derivative versions of classical Islamic geomancy, has been the subject of several anthropological studies. The mathematical structure of the practice has also received some scholarly

attention. In nearly all Islamic lands geomancy and related methods of divination are still practiced, in forms varying from the simple casting of a favorable or unfavorable geomantic figure to the complex interpretation of tableaux employing a large number of procedures.

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abstract space and the relationships induced by that partitioning. Historically, as a human activity, it is said by the Roman historian Herodotus (d. 425 BCE) to have begun in Egypt where the annual inundation of the Nile River obliterated field boundaries. In order to preserve the royal system of land distribution and taxation, official priest-surveyors measured the land and reestablished boundary markers. Their land-measuring techniques were imported to Greece and given the collective name “geometry” (*geo*, “earth”; *metrein*, “to measure”). Thus the practices of land measurement became the science of geometry. However, all peoples and societies possess and use some geometrical knowledge. For example, decorative pottery motifs and textile or basket weaving patterns demonstrate a geometric knowledge and facility on the part of their creators. Certainly the blanket patterns of the Ibans of Borneo and the rafter carvings of New Zealand's Maori people reflect an appreciation of symmetry; a complexity of line relationships is evident in the *sona* tracings of the Tshokwe culture in southern Africa, and a mastery of geometrical figures is illustrated in the sand drawings of North America's Navajos. All these non-Western cultures possess “a geometry” but to survey these traditional geometries would present a monumental task and be beyond the scope of this present survey. Therefore the discussion below will view geometry in a narrower sense, i.e., as an exact science and as a subject of acknowledged societal concern either documented by existing historical records or the evidence of archeological excavations.

Egypt and Babylonia

Egyptian geometry was practical in its conception and tied to measurement and the bureaucratic needs of the state. A small collection of surviving papyrus problems provided a limited glimpse into the workings of Egyptian geometry. The ancient Egyptians possessed correct computation formulas for determining the areas and volumes for a variety of plane and solid figures.

Geometry

Frank J. Swetz

Geometry is the branch of mathematics that deals with the partitioning of a physical or

Apparently they deduced such formulas by techniques of “dissection and rearrangement.” Correct formulas for the areas of rectangles, triangles, and isosceles trapezia were employed. Problem 50 of the Ahmes Papyrus (1650 BCE) gives the area of a circle with known diameter d as $A = (8/9d)^2$ from which it is found that the Egyptians of this time used a value $\pi \approx 3.1605$. Problem 48 of the same sequence provides an illustration that has been interpreted as a polygonal approximation for the area of a circle and from which the formula was derived. In total, the Ahmes Papyrus contains 19 problems of a geometrical nature. The Moscow Papyrus (1850 BCE), in its 14th problem, offers a correct computational procedure for determining the volume of a truncated square pyramid of given height h and with bases whose sides measure a and b in length; $V = h/3(a^2 + ab + b^2)$. Problem 10 of the Moscow Papyrus requires the surface area of a “basket” with known diameter and has resulted in a yet unresolved controversy as to whether the Egyptians were considering the basket as a hemisphere or as a semicylinder. If the former interpretation is accepted this would indicate that the Egyptians possessed rather sophisticated geometrical insights at a very early date. Egyptian geometry remained utilitarian in nature and was never advanced to the status of an abstract science.

In a similar manner, Babylonian geometry was also of a computational nature and devoted to solving practical problems. In our context, the term “Babylonian” designates the civilization that occupied the Tigris-Euphrates region in the period 3500–539 BCE and includes the Sumerian, Akkadian, Chaldean, and Assyrian peoples. Knowledge of Babylonian geometry has been obtained from a limited examination of cuneiform texts and mathematical tables. This examination reveals that their authors possessed computation procedures for obtaining the areas of rectangles, right-angled triangles, isosceles triangles, and trapezia with one side perpendicular to the parallel sides. They knew several numerical properties of a circle and approximated the area of a given circle radius r by $A = 3r^2$. A clay tablet from the Old Babylonian Period (1900–1650

BCE) supplies a more accurate value of π as 3.125. The Babylonians could determine the length of a chord l , given the diameter of a circle d and the length of the sagitta in question a : $l = \sqrt{d^2 - (d - 2a)^2}$. Tablet no. 322 in the Plimpton Collection at Columbia University, whose origin is traced to 1800–1650 BCE, provides a list of Pythagorean triples indicating that the Babylonians of this period were familiar with the “Pythagorean Theorem.” A clay tablet excavated at Tell Harmal in Iraq and dated to about 2000 BCE indicates that its users knew some properties of similar triangles and could employ these properties in solving numerical problems involving triangles. Babylonian scribes also could compute the volumes for simple solids and possessed an approximate formula for the volume of a truncated square pyramid of height h and bases of length a and b , i.e., $V = h/2(a^2 + b^2)$. Although several excavated clay tablets bear geometric diagrams, these diagrams serve as illustrations for relevant concrete problem situations and are not theoretical constructions. Apparently for the Babylonians, geometry remained an adjunct to numerical problem solving and did not evolve into a separate discipline.

Ancient India

Geometric activity on the Indian subcontinent can be traced back to the Indus Valley Civilization (ca. 3000 BCE). Excavations at this civilization’s urban centers of Harappa, Lothal, and Mohenjo-Daro reveal the existence of a baked-brick technology allowing for the erection of numerous structures: houses, baths, and market places. This construction entailed large-scale city planning and the use of geometry. Archeological evidence indicates that the Indus peoples were familiar with the basic properties of rectangles, triangles, and circles, and could employ right-triangle principles for planning and structural purposes.

With the arrival and dominance of the Aryan culture in the region (1500–800 BCE), there

developed a sacred Vedic literature of rituals and customs. Part of this literature concerned the construction of sacrificial fire altars of specific shapes and dimensions. Cord stretching techniques were described to obtain the required results. This collection of construction procedures and techniques became known as the *Śulbasūtras* (800 BCE) or “the rules of the cord.” Using cords and pegs, squares, circles, rectangles, and trapezia of specified dimensions and areas could be laid out and constructed by the Vedic priests. Although outwardly religious texts, the *Śulbasūtras* presented a codified system of geometry. Besides obvious geometric constructions, the texts supplied a technical vocabulary for geometrical principles and concepts including a theory of similar triangles. Techniques for transforming shapes while preserving areas considered the quadrature of rectangles and circles, and procedures were also given for doubling the area of a circle and transforming a square into a circle. The principle of constructing a square on the diagonal of a rectangle (“Pythagorean Theorem”) was also known to the writers of *Śulbasūtras*. No formal “proofs” were given but some results were justified by arguments.

The subsequent influence of the *Śulbasūtras* on the latter development of Indian geometry is controversial: early researchers such as G. R. Kaye could discern no influence, whereas more modern writers such as T. A. Sarasvati Amma believe that the *Śulbasūtras* established the foundation for all Indian geometry. Whatever the influence of these Veda texts on geometrical thinking, later developments in this field were spotty and isolated. Geometry became closely associated with astronomy and cosmography. It was dominated by numerical problem solving based primarily on the use of right-triangle principles and was mainly concerned with finding the length of circular chords. The post-Vedic period saw the rise of the Jaina school of philosophical and scientific thought. The Jainas, in their cosmological considerations, held two geometric figures – the circle and trapezium – in high regard. Much of their geometry focused on mensuration problems involving these figures.

In general, they considered geometry important denoting it as “the lotus of mathematics.” The Jainas employed the approximation $\pi = \sqrt{10}$.

The next Indian mathematical text of note to appear was the *Āryabhaṭīya* (ca. 499) of Āryabhaṭa I (476–550). While many of its problems concern the applications of geometry to astronomy, its author also considered the computation of area for triangles, trapezia, and circles, and the volumes of spheres and triangular pyramids. Āryabhaṭa’s formula for the area of a circle is correct; his approximation for π is 62,832/20,000 or 3.1416. However, his results for the volume of a sphere are $V = \pi^{3/2}r^3$. Subsequent mathematical authors would refine and extend Āryabhaṭa’s work. ► [Brahmagupta](#) (ca. AD 628) in his *Brahmasphuṭasiddhānta* (Correct Astronomical System of Brahma) provided sections on *Ksetra* (plane figures), *Khāta* (cubic figures), *Citi* (solids composed of piles of bricks), *Krakaca* (truncated solids), and *Chāyā* (plane figures resulting from shadows). Much of Brahmagupta’s results are limited to triangles and quadrilaterals inscribable in a circle. His most notable findings include:

- The correct determination of the area of a cyclic quadrilateral of sides a, b, c, d , with s as its semiperimeter, i.e., $A = \sqrt{(s-a)(s-b)(s-c)(s-d)}$.
- The length of the quadrilateral’s diagonals d_1 and d_2 :

$$d_1 = \sqrt{\frac{(ac+bd)(ad+bc)}{(ab+cd)}},$$

$$d_2 = \sqrt{\frac{(ac+bd)(ab+cd)}{(ad+bc)}}.$$

- The volume of a cone as one-third the product of its base area and its height.

► [Mahāvīra](#) (ca. 850), a Jaina mathematician, improved upon Brahmagupta’s theories in his *Gaṇitasārasaṃgraha* (Summary Compendium of Mathematical Astronomy), greatly extending

geometric terminology and classification systems. For example, he divided quadrilaterals into five different subcategories: equal sides, opposite sides equal, etc., and triangles into three categories: equilateral, isosceles, and scalene. ► **Bhāskara II** (b. 1114), author of one of the most illustrious of Indian mathematical classics, *Līlāvātī* (The Beautiful), obtained accurate formulas for the volume and surface area of a sphere and obtained close approximations for the length of a circular arc in terms of its known chord. Mādhava of Sangamagrāmma (ca. 1340–1425), a Kerala astronomer, is noted for his work on the circle as well as spherical geometry.

Euclid's *Elements* were known and studied in India in the fourteenth century, but the first complete Sanskrit translation of this work appeared in 1718. The translation was performed by Jagannātha Samrāt at the request of his patron king astronomer Jayasimka of Jaipur.

The Islamic World

The founding of Islam in AD 622 was marked by the flight of Muḥammad from Mecca to Medina. Initially experiencing a period of rapid expansion, it was not until the founding of the Abbasid Caliphate, with the establishment of Baghdad as an intellectual and political center (AD 726) that Islamic civilization could begin to express its own intellectual and scientific traditions. The early Abbasid caliphs were patrons of the collection and translation of foreign scientific texts into Arabic, thus establishing a basis for Islamic science. Although Muslim scholars became the heirs of existing western (and eastern) scientific theories and traditions, they did not remain mere translators and passive communicators of this knowledge. In many fields they became true innovators and amplifiers of their mathematical and scientific inheritance. Geometry was one such field that was enriched by Islamic contributions.

The Greek sources that most influence Islamic geometric thinking were Euclid's *Elements*, Archimedes' *On the Sphere and Cylinder*, and

Apollonius of Perga's ► **Conics**, all of which found their way into Arabic during the eighth to the ninth centuries. Muslim geometers pursued the theoretical problems poised in these texts and used their principles in a wide variety of new applications, particularly the study of optics and the design of mathematical instruments. The earliest documented Islamic geometry appears as a separate section of al-Khwārizmī's *Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa 'l-muqābala* (Compendious Book on Calculation by Completion and Balancing), where rules for mensuration and geometric computations involving areas and volumes are stated. The value of π is given as 31/7. Within 50 years of al-Khwārizmī's work, his successors were involved with far more complex geometric theories.

Thābit ibn Qurra (830–890) discussed the geometric verification of algebraic results in his *Qawl fī taṣḥīḥ masā'il al-jabr bi'l-barāhīn al-handasiyya* (On the Verification of Problems of Algebra by Geometrical Proofs). In a private correspondence with a colleague, he expressed dissatisfaction with the existing Socratic proof of the "Pythagorean Theorem" and went on to derive three new proofs, one of which provides a generalization of the theorem to all triangles. Thābit also wrote on the trisection of an angle problem. His grandson, Ibrāhīm ibn Sinan (d. 946), continued researching this problem and provided for "ruler and compass" constructions of the conic sections in his *Rasm al-quṭū' al-talātha* (Outline of Three Sections). In approximately AD 950, Abū'l Wafā' wrote a book on applied geometry for craftsman, *Kitāb fī mā yaḥtāj ilayh al-ṣāni' min al-a'māl al-handasiyya* (Book on Necessary Geometric Construction for the Artisan), in which he presented several original constructions for conic sections. Around the year 1000 Abū 'Abdullāh al-Ḥasan ibn al-Baghdādī published a comprehensive treatment of incommensurables improving on the theory given in the *Elements*.

One of the recurrent themes in Islamic geometry is the concept of parallel lines and the provability of Euclid's fifth postulate. Ibn al-Haytham (ca. 965–1039), known in the West

as Alhazen, attempted to reformulate Euclid's theory of parallel lines by assuming the constructibility of the lines. He presented his theory in a work entitled *Maqāla fī sharḥ muṣādarāt kitāb Uqlīdis* (Commentary on the Premises of Euclid's *Elements*). 'Umar ibn Ibrāhīm al-Khayyāmī, or 'Umar al-Khayyām (ca. 1048–1126), in investigating the concept of parallelism, developed a series of eight propositions eventually leading to the establishment of Euclid's fifth postulate. 'Umar al-Khayyām's work was based on the possible relationships of the angles of a quadrilateral. In turn, this work was expanded by ► [Naṣīr al-Dīn al-Ṭūsī](#) (1201–1274). He also explored parallelism with the aid of a quadrilateral, but allowed for the existence of acute and obtuse angles within the quadrilateral seeking to obtain a contradiction to his premises concurring the nature of parallel lines. He published his work on the fifth postulate in 1250; it was entitled *Al-risāla al-shāfiya 'an al-shakk fī al-khuṭūṭ al-mutawāziya* (Discussions which Remove Doubts about Parallel Lines).

Eventually the theories of Islamic scholars such as Ibn al-Haytham and al-Ṭūsī reached Europe; there they profoundly affected the nature of geometric thinking.

China and the Far East

Most geometrical considerations in early China were empirically based. However, during the Mohist school of activity (ca. 300 BCE) a deductive approach to understanding geometry was undertaken. Mohist philosophy and scientific theory were based on the use of logic. The Mohist Canon (*Mozi*) (ca. 330 BCE) develops a formalist approach to plane geometry building upon a concept of points and lines. Mohist theories did not become popular, and the development of a theoretical geometry progressed no further.

The earliest extant references specifically on Chinese mathematics are the ► [Zhoubi suanjing](#) (Arithmetical Classic of the Gnomon and the Circular Paths of Heaven) and *Jiuzhang suanshu* (Nine Chapters on the Mathematical Art, ca. 100 BCE). A discussion of right-triangle

relationships is given in *Zhoubi*, along with a dissection proof demonstrating that the sum of the squares of the sides adjacent to the right angle in a right triangle is equal to the square of the hypotenuse. Four chapters of the nine chapters of *Jiuzhang* are specifically devoted to geometrical computations involving areas, volumes, and work with right triangles. Correct procedures for finding a variety of areas and volumes are given; the area of a circle of radii r is noted as $A = \pi r^2$ with $\pi = 3$; but the volume of a sphere with diameter d is incorrectly found, $V = 9/16d^3$. An approximation for the area of a circular segment with chord C and sagitta S is given as $A = S/2(S + C)$. Similarity among right triangles is employed in several problem situations.

In the third century, the scholar Liu Hui wrote a commentary on the *Jiuzhang* in which he provided dissection proofs for many of its geometrical formulas. Liu also employed a circle dissection technique involving a 192-sided polygon to estimate π as 3.141024. He extended the right-triangle theory of the *Jiuzhang* to include more complex problem situations involving pairs of similar right triangles. Using a technique called *chong-cha*, Liu provided proofs for solution procedures and published his findings in an appendix to *Jiuzhang*. Eventually, this appendix became a separate geometrical classic called *Haidao suanjing* (Sea Island Mathematical Manual). ► [Zu Chongzhi](#) (429–500) refined Liu's approximation for π obtaining a value of 355/113 or 3.1415929. Further, using a geometric slicing technique, Zu found the volume of a sphere, radii r , correctly as $V = 4/3\pi r^3$.

In 656, the geometric theory contained in *Zhoubi suanjing*, *Jiuzhang suanshu*, and *Haidao suanjing* was sanctioned by the Tang dynasty as a formal curriculum for its scholar officials. This curriculum was also eventually adopted in Japan and Korea, establishing a limited geometrical outlook based on empirical problem solving. This outlook would remain unaltered until the sixteenth century when a translation of Euclid's *Elements* appeared in the Chinese language. This translation of the first six books of Euclid was made by the Jesuit missionary Matteo Ricci and the Chinese scholar Xu Guangxi.

Pre-Columbian America

Although no written records exist to document the geometric knowledge of the early Native American civilizations, archeological sites testify to their use and understanding of geometry. In particular, the city planning and construction techniques employed by the Olmec, Maya, Teotihuacan, Toltec, and Aztec peoples of South and Central America and the Anasazi of the North American Southwest indicate that these peoples utilized the properties of circles, squares, and rectangles and employed right-triangle theory.

See Also

- ▶ [Abū'l-Wafā](#)
- ▶ [al-Khwārizmī](#)
- ▶ [Āryabhaṭa](#)
- ▶ [Bhāskara I](#)
- ▶ [Brahmagupta](#)
- ▶ [Elements: Reception of Euclid's Elements in the Islamic World](#)
- ▶ [Ibn Al-Haytham \(Alhazen\)](#)
- ▶ [Ibrāhīm ibn Sinān](#)
- ▶ [Jiuzhang suanshu](#)
- ▶ [Mādhava of Saṅgamagrāma](#)
- ▶ [Mahāvīra](#)
- ▶ [Naṣīr al-Dīn al-Ṭūsī](#)
- ▶ [Śulbasūtras](#)
- ▶ [Thābit ibn Qurra](#)
- ▶ [Umar al-Khayyām](#)
- ▶ [Zhoubi suanjing](#)

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Geometry and Architecture in the Americas

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Lost in the history of modern man's beginning is the origin of a universal worldview of a Cosmic Mountain centering the world, the *axis mundi*, topped by the Tree of Life with a bird at its apex and a body of water or four rivers emanating from its roots. The mountain (or surrogate pyramid) can also be viewed as the Earth Mother ("Mountain Mother" is an early epithet for her), the tree as the sky-pole inserted to separate heaven (generally male), and earth (generally female) as the initial act of creation. At the same time both pyramid and tree bridge the two worlds. The bird is the hen that laid the Cosmic Egg. Its halves became the earth and the sky and its contents the geographic and celestial features of the earth, as well as plants and animals. The bird, however, also symbolizes air, the breath of life, and the vehicle of souls. The water is the place of emergence for mankind into the present world following creations and destructions of previous worlds

This entry has been abstracted in part from Spider Grandmother and Other Avatars of the Moon Goddess in New World Sacred Architecture (Journal of the Southwest, special edition, Vol. 54, No 2, 2012).

by a creator attempting to perfect a race a people who live in harmony and pay proper homage to him, or her, and his, or her, dictates. Animal avatars of the gods varied across space, reflecting their natural habitat and totemic recognition over time.

Another image of this antique worldview is the serpent (snake, dragon, or crocodile). In some mythologies a snake or four snakes separate heaven and earth. The snake is therefore interchangeable with the tree as the bridge between earth and firmament. Additionally the Milky Way was viewed as a Cosmic Ocean in serpent form that encircled the earth and periodically destroyed the world in order to begin another.

The belief in a deity who destroyed previous worlds had several consequences. One was the idea of a tiered universe with previous worlds beneath and several above this one. In Buddhist cosmology, for example, both nine and thirteen levels are identified. Multiple worlds also led to concepts of cyclic time, envisioning future worlds to come, and ceremonial calendars demanding the symbolic re-creation of this one in the attempt to keep it in balance (often tied to dynastic changes) to stave off the next destruction. Thus, the construction or reconstruction of any kind of building deemed sacred – be it temple, king's palace, or priest's home – re-created (and still does in some cultures) the world and required a human sacrifice representing the creator, who by one means or another died in order to bring forth life.

The body of water divided into four rivers oriented to the cardinal points partitioned the world into quadrants, thus producing the quincunx with the mountain center as the fifth point. It is what I term the "Cosmic Cross." Its origin as a symbol of godhead at the center and a quadripartite universe is at least as old as 5600–4600 BCE in Anatolia and, enclosed in a circle, became the Pharaonic Egyptian hieroglyph for a town. In China each arm of the cross was represented by a distinct animal equated with the direction or by directional snakes or dragons.

An early representation of the creation story is a pictograph produced by ancestral Bushmen–Hottentots. It depicts a male creator

afloat on the abyssal sea, a bent knee (which becomes the mountain) with a bird perched on it, his phallus ejecting semen to begin life. A similar Egyptian example shows the male Earth God, Geb, in a nearly identical position with an erect penis reaching toward his sister-wife Nut, Goddess of the Air, who arches above him. At his head is the mountain hieroglyph and at his feet the hieroglyph for west, the entrance to the underworld, with the goose that laid the Cosmic Egg. A beautiful example of this worldview is a cult pillar from Knossos, Crete (dated from 2500 to 1400 BCE). The base takes the form of the temple/mountain from which grows the Tree of Life, topped with the double-axe symbol of the Great Goddess and the bird. A parallel, perhaps older, myth of creation has a Spider Mother (avatar of the Moon Goddess) who wove the world into being, defined its boundary, produced progenitors of the human race from her egg sacs, and served as general guide and culture hero to her progeny. Like other creator-gods, her gender changes from culture to culture and her negative side is the ubiquitous trickster – Ananse to the Ashanti of West Africa and Inktemi to the Sioux of North America, for examples. The Spider Mother can be understood as a totemic variation on the Cosmic Egg.

These worldviews are so ancient and widespread in their distribution that I presented a case for a common Paleolithic out-of-Africa origin for them in *Retrieving Tribal Memory* (Schuetz-Miller, 2011a, b, 2012a). This entry examines the continuity of worldview concepts and innovations in how they were manifested in some of the New World's more sophisticated architecture.

Ceremonial Centers of Peru

At about the same time (late fourth and third millennia BCE), Sumerians were erecting ziggurats, Egyptians building pyramids, and the Chinese laying out large sacred compounds. Indians of coastal, mid, and highland Peru began building sizeable ceremonial centers with resident

populations and monumental architecture in what is known as the Preceramic period (prior to ca. 2000 BCE). General characteristics of the temple complexes were large terraced platforms topped with a single or multiple buildings. Access to the summit or linking multiple mounds were projecting or inset stairs and/or ramps. Adobe or stone temples on top were plastered, painted, and sometimes decorated with incised or modeled religious motifs. Floors were of compacted clay and in the highlands were frequently split-level. Some platforms had gallery tombs entered from above for mass burials of men, women, and children. Sunken courts with opposing wedge-shaped inset stairs first appeared in the Supe valley and quickly spread to coastal and highland centers. Some coastal sites were enormous. Caral, for example, covered 65 ha, incorporated six large platforms, each associated with a complex for a class of elites. Within the center were two circular sunken plazas. Numerous outer zones included residential barrios for a lesser class. The coastal complexes, in contrast, dwarfed highland sites. (Data on South American sites are all from Burger, 1992, unless noted otherwise. Bracketed comments are by the author, 2012a, pp. 177–179, 192–204, 227–238, 277–279).

Evidence of ceremonialism is deduced from earlier rooms filled with rubble to provide a foundation for a new structure, sometimes enclosing the entire building to begin a terraced platform. Pits with flues sunk into floors were made for burnt offerings. Dedicatory offerings were found sealed within a room; others were buried between or under floors. And, finally, there were elaborate burials of nobles and/or priests with rich grave goods and sacrificed attendants. Offerings of cotton cloth, gourds [symbol of the womb] filled with food, bird feathers and down [symbolic of people derived from bird ancestors], unbaked clay figurines, bundles of both burnt and unburnt cotton [Moon Goddess as weaver], short sticks carved with chevrons or other geometric designs, pecten shells [attribute of the Moon Goddess], cotton string crosses [*ojos de dios*, protective web of the Spider creatress], a wooden bowl with carved frogs [another early

avatar of the goddess], a ceramic bottle decorated with intertwined snakes [progenitors of the human race in many mythologies], deer antlers [totemic ancestor of people], and a staircase painted with a white serpent [snake as bridge between heaven and earth], and the crossed hands of the Kotosh Religious Tradition point to a peaceful, benign worldview.

Within the ensuing Initial Period innovations in building style appeared: U-shaped temples in the central coast. Adobe cones were set into walls and pilastered rooms became characteristic of north central and northern coastal buildings. New artistic motifs were materialized: fanged monsters, a predominance of arachnid elements [jaguar or puma and spider as avatars of the Moon Goddess], and the earliest evidence of the shamanic use of the psychedelic San Pedro cactus. A painted door to the central room of a temple atop a terraced platform at Cerro Sechín featured a mural of large black felines. The base platform of a later building phase depicted a pair of large fish. The motif suggests the primordial world of a creative couple, such as Chinese Fuxi and Gaomei, frequently depicted as fish, and is consistent with New World mythologies describing a previous world inhabited by fish.

In the highlands great strides were made in construction and engineering that required careful advance planning. One was the ability to cut, move, and finely polish megalithic stone. At Sechín Alto, for example, blocks measuring 1.5 m to the side and weighing over two tons were used to face the terraced pyramid. (The site's central pyramid, by the way, achieved a height of 44 m, the equivalent of a nine story building.) At some sites walls were built with large blocks between stone uprights. The earliest use of volcanic tufa appeared. The apex of Peruvian Initial Period construction was achieved at Chavín de Huántar. Stone mortise and tenon joinery embedded sculpted heads into walls and secured the nearly 15-foot jaguar monster with snake hair colossus known as the “Lanzón” into the floor and ceiling of a small cruciform chamber – the Holy of Holies. Complex systems of stone-lined ventilation shafts and drainage canals, even one extending under a circular

court, attest to skill in hydraulic engineering. Over several 100 years builders enlarged older structures and added new ones, using white granite and black limestone, suggesting a dualistic belief as it was in Southeast Asia. Chavín became a great cult center, attracting pilgrims from great distances, thus spreading the Chavín artistic style. The great highland city-states, under their theocratic societies, transitioned into the Early Horizon under peaceful conditions, setting the stage for the great ceremonial centers around Lake Titicaca and the Inca Empire in the Current Epoch.

About 900 BCE, as highland cities were flourishing during the terminal Initial Period, the majestic coastal centers began disintegrating among evidence of intersocietal warfare. They began to construct citadels on defensible hill sites of the north central coast, multiple-walled enclosures with heavy buttresses, bastions, baffled entrances, and moats for starters. With rare exceptions, new ceremonial centers were not established and some old ones were abandoned during the succeeding Early Horizon. Incised and painted clay friezes depicting dead people with blood flowing from their skulls, warriors, trophy heads, severed limbs, gouged eyes, etc. point to the ferocity of the times.

Building Technology, Archaeoastronomy, and Pre-Euclidean Geometry

From site data and written descriptions from the later Inca period, we glean insight into construction techniques and instruments. Master builders worked from drawings and models. Towns and buildings were laid out with cords (the cord could also be used as a compass). A socketed ceramic device served as a primitive transit used with rods pierced with eyeholes for measuring 90° angles. The needlelike rods resemble those held by so-called Staff Gods, a reminder that geometry and measurement re-created the skyscape and were sacred activities, just as the cord, symbol of the umbilicus connecting heaven and earth was itself sacred. Stone was quarried by drilling slots

into the rock, inserting wooden wedges, and pouring water over them to cause them to swell and split the rock. Ashlars were cut using grooved channels. Stones were dragged with braided sinews or llama skin and set into place with the use of ramps. By Inca times copper axes largely replaced stone ones. Masons mixed straw into adobe to prevent cracking, applied cactus juice to both exterior and interior walls to help the mortar adhere, and added wool or finely ground straw to mortars to produce a glossy finish (Betanzos, 1996, p. 70; Burger, 1992, p. 115; Cobo, 1990, p. 240; Milla Villena, 1992, pp. 120, 152; Schuetz-Miller, 2012b, pp. 334–339).

Through millennia of observation of the night sky, our ancestors accrued a thorough knowledge of the annual progression of stars and planets. It was the single constant in an unpredictable and often hostile world. The appearance of a star or constellation recalled a myth, signaled a time to start or abstain from hunting or fishing, a time for planting and harvesting, as well as providing a ceremonial calendar. The firmament was the realm of the gods and ancestors. Indeed, brilliant stars or planets were deities themselves and if man-made sacred spaces mirrored the heavenly abodes of holy people, they would look favorably upon them. Therefore, it is not surprising to find ceremonial structures oriented with certain asterisms. Numerous sites stretching along most of the vertical length of the west coast of South America, dating back to the Preceramic period, are oriented with the Southern Cross (seen as a condor chasing the Celestial Llama, identified in Centaur with Alpha and Beta as the eyes, or a llama doe suckling her fawn). Summer solstice and equinoctial alignments are evident at other coastal sites. Some Andean centers face the rising of the Pleiades (identified by Barsana as Star Woman who governs the seasons and agriculture). Others appear to be oriented to the zenith and nadir sun directions. The doorway of one temple has sight lines on the rising positions of the sun and Pleiades. Astronomers in the coastal valleys observed the heliacal rising and setting of Orion's Belt (the Desanas recognized Orion as the trickster creator/culture hero with

a prodigious sexual appetite who violated his mother-in-law), the Southern Cross, and several dark cloud constellations. Almost two millennia prior to the erection of the Sun Pillars of Incan Cuzco, a solar observatory was built at Chankillo 400 km north of Lima. Thirteen towers along a north–south axis mark the progress of the sun between winter and summer solstice from observation points within adjacent buildings to the west and east during a time frame of about 300 BCE. Incan Cuzco had an elaborate pattern of 41 radiating sight lines, some astronomical, incorporating both natural and man-made shrines called *huacas*. Machu Picchu and Pisac had multiple observatories, including the former’s Intihuatana for solar observation carved from the living rock.

A system of pre-Euclidean geometry evolved from tracking the courses of the sun and moon. Daily sightings of the rising and setting points of the sun throughout the year produced a circle. The circle was divided by observations of the summer and winter solstices and again by the twice annual occurrence of the equinox. The basic forms of geometry were now established: the circle and the halving of it with the solstices or the equinoxes. The circle could be divided into quadrants by intersecting the half at right angles or by the intersection of the two solstices which approximates a 90° angle. By connecting the points, a square is produced. By connecting diagonally opposite points of the square, two triangles are formed. Connecting the points of a cross dividing the square into quadrants and the corners of the square with the two farthest diagonal points result in an eight-pointed star, a symbol of divinity. It was a geometric system used for designing a single structure or laying out great ceremonial complexes in Mesopotamia, perhaps as early as 4500–4000 BCE (Brunés, 1967; Schuetz-Miller, 2006, pp. 331–332; Schuetz-Miller, 2011a, pp. 212–216).

Pre-Euclidean geometry was used in the Americas as well. Noted previously were enigmatic circular sunken courts with wedge-shaped steps. They are often referred to as “kiva courts” because of their resemblance to Pueblo keyhole kivas. They were likely filled with water to serve

as celestial mirrors or observatories; clay effigy pots made later portray figures holding them or peering into them. According to Milla Villena, the most important celestial event to Andinos was the zenith position of the Southern Cross; the ratio of its width to its length, the square root of 2, was a sacred proportion. My analyses of a kiva court (Figs. 1 and 2) compared to a Pueblo kiva (Figs. 3 and 4) confirm the use of root 2 extensions, as well as the eight-pointed star and doubling the square.

Figure 5 demonstrates that a lateral extension to a central temple was likewise dictated by the square root of 2 (Milla Villena, 1992, pp. 60, 62, 107–108, 121–123; Schuetz-Miller, 2012b, pp. 309–312).

Ceremonial Centers of Mesoamerica

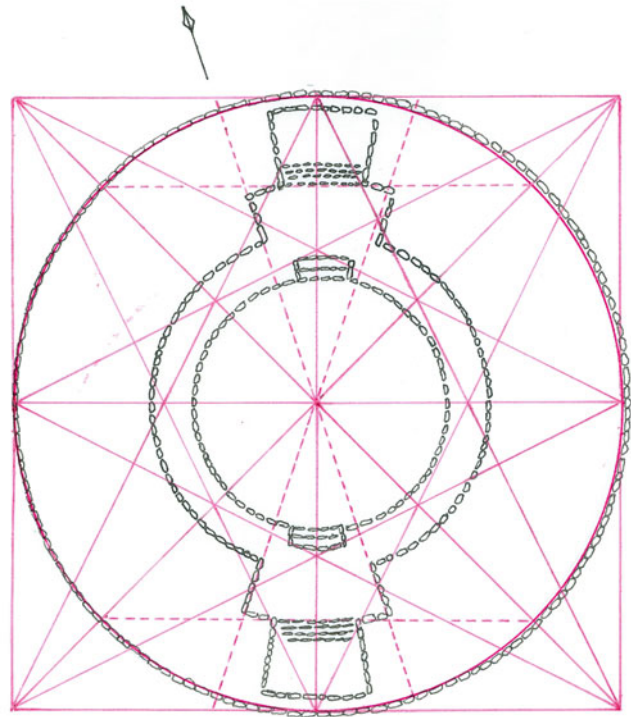
Noted earlier was the inner sanctum constructed as a cruciform chamber with the Lanzón colossus (part jaguar, part snake – both aspects of the Moon Goddess and equated with water – small cruciform symbols enclosed in circles at the corners of the mouth) at Chavín de Huántar.

Recovered from excavations at Chavín was a small mortar carved as a jaguar with cruciform spots. These symbols lead us to Mesoamerica’s first great civilization, the Olmec culture. For years the heartland appeared to have been in the Mexican states of Vera Cruz and Tabasco, its influence (from ca. 1200 to 400 BCE) reaching as far north as Mexico City, as far south as Honduras, and across the Isthmus of Tehuantepec to the Pacific and giving rise to the Maya and Aztec civilizations. However, more recently discovered Olmec sites along the Pacific coast in the states of Guerrero, Chiapas, and Guatemala, with earlier dates going back to 2000 and 1400 BCE, contest the traditional birthplace.

La Venta, built between 1000 and 600 BCE, may have been unique in constructing a replica of a volcano rather than the usual pyramid substitute. A stele at its base represents the Tree of Life and Olmec kings identified themselves with the tree, harkening back to a time when gods were recognized in menhirs [standing stones] and had

Geometry and Architecture in the Americas, Fig. 1

Kiva court, Haldas, Peru. The *left* analysis shows that the staircases were derived from the eight-pointed star. The *right* shows the use of the doubling of the square root of 2 extensions (Based upon a drawing of the site in Milla Villena, *Génesis de la cultura andina*)



tree forms in the Old World. Within a sunken court before the “volcano,” green serpentine mosaic pavements with tasseled edges, representing aquatic vegetation and flowers, re-created the Primordial Sea – an immense effort which was then buried to indicate it was the underworld (Freidel, Schele, & Parker, 1993, pp. 132–137). Also buried at La Venta was an enigmatic tableau of carved serpentine and jade figurines and axes. Like Peruvian temple complexes, Olmec ceremonial sites typically had tall pyramids at north and south ends of a plaza with platforms, once topped with lesser temples, and tombs aligned symmetrically between them delineating the sacred space. Excavated sites show considerable rebuilding of structures under different kings. Since latex balls have been found, at least at one site, ball courts are likely to be found eventually (Stuart, 1993, pp. 88–115).

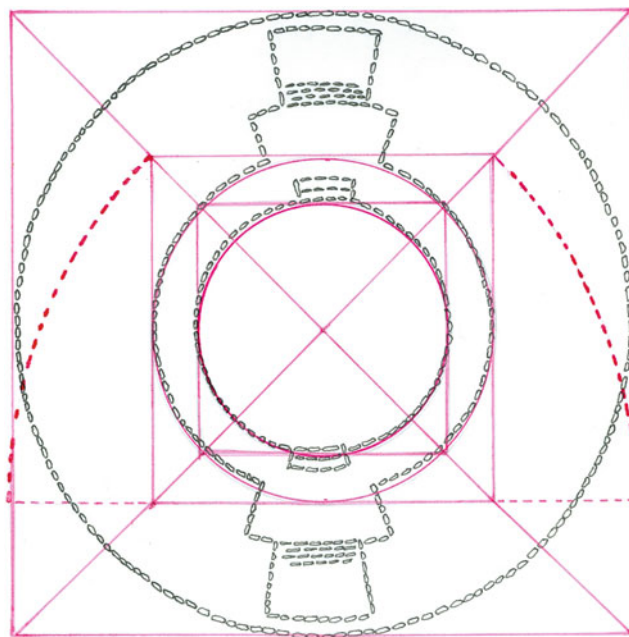
In Olmec art the equal-armed cross represents a deity, either female or male, and is often found associated with a feline. In the Yucatecan and

Cholan languages, the cross is known as the *kan* and *chan*, respectively, meaning “sky,” “snake,” and “four.” Some platforms and tombs at early Monte Alban were constructed in the form of the Cosmic Cross. The Zapotecs appear to have equated the arms with the lesser lightnings (clouds, rain, hail, wind), represented by lizards that were aspects of Cocijio (Lightning), the most powerful force in Zapotec belief. In the southeastern USA, the cross was a popular motif on artifacts produced by the Hopewell, Adena, and Mississippian cultures. Figure 6 depicts Spider Grandmother, an avatar of the Moon Goddess, delineating the world as in a Zuni version: “[Water Strider] stretched out his [sic] arms and legs and touched the horizon at the north, west, south, and east. He was in the middle of the world.” In addition to the gorget [piece of armor surrounding the throat] depicted, others feature the Cosmic Cross, symbolizing the life force, with other avatars of the goddess, such as directional felines, rattlesnakes, and pileated woodpeckers.

Geometry and

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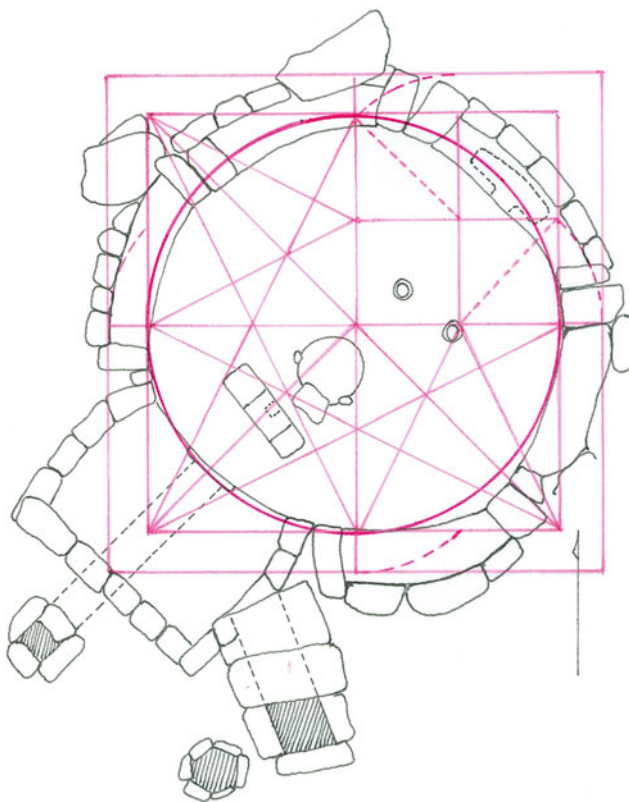
Americas, Fig. 2 Kiva court, Haldas, Peru. The *left* analysis shows that the staircases were derived from the eight-pointed star. The *right* shows the use of the doubling of the square root of 2 extensions (Based upon a drawing of the site in Milla Villena, *Génesis de la cultura andina*)



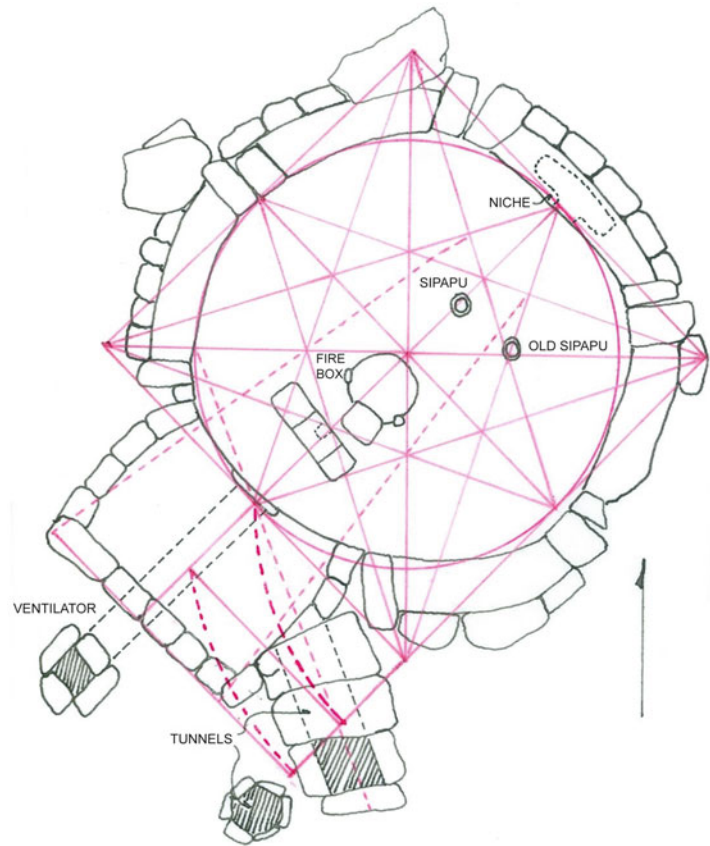
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Americas, Fig. 3 Kiva C, Mug House, Mesa Verde. The analyses demonstrate the use of the eight-pointed star and root-2 extensions (Based upon a drawing in Rohn, *Wetherhill Mesa Excavations*)



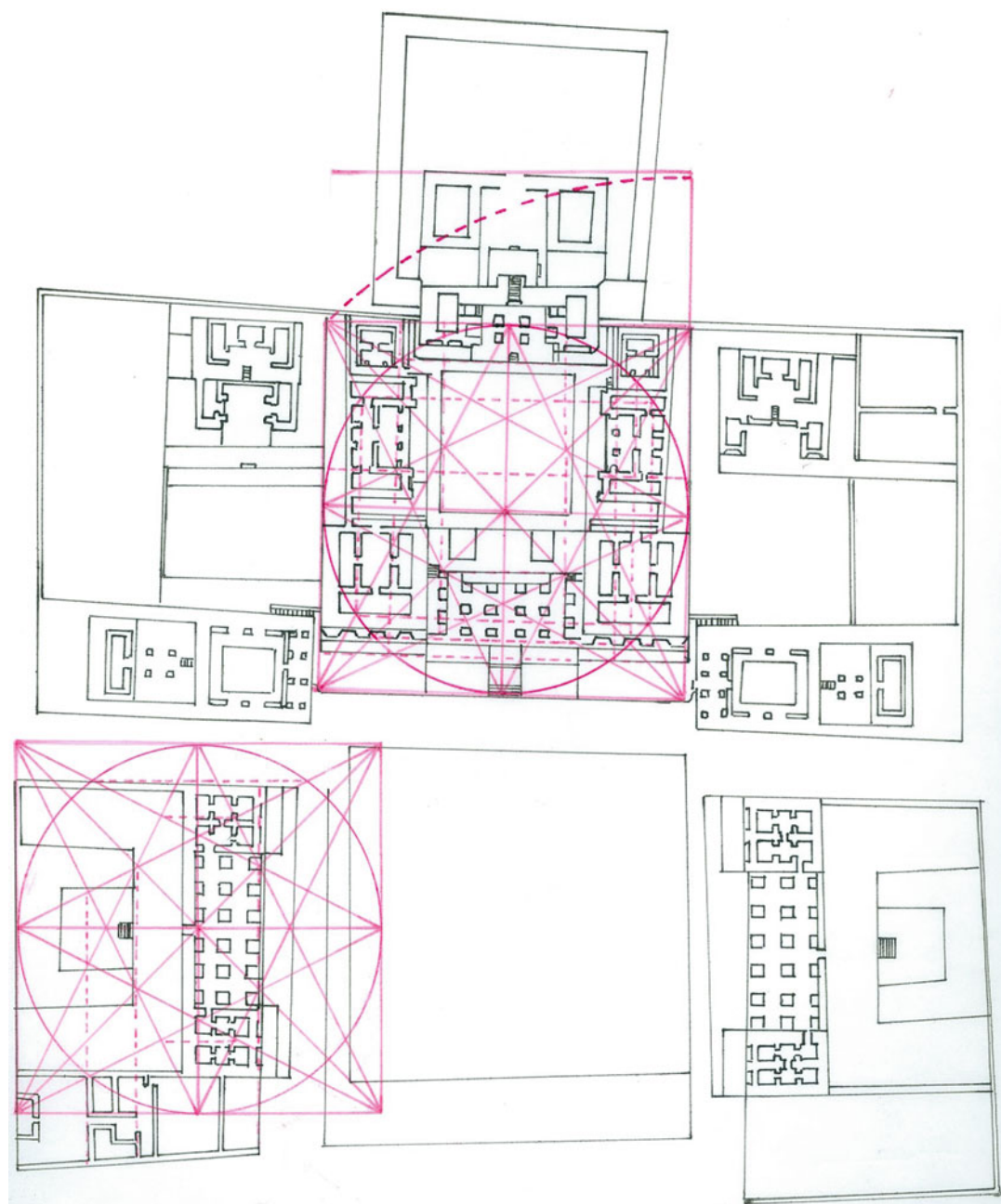
Geometry and Architecture in the Americas, Fig. 4 Kiva C, Mug House, Mesa Verde. The analyses demonstrate the use of the eight-pointed star and root-2 extensions (Based upon a drawing in Rohn, *Wetherhill Mesa Excavations*)



The feline (jaguar or puma) was surely the most prominent avatar of the creatress in Olmec culture. The ubiquitous representations of a fanged, snarling face with downturned mouth, the Witz Monster, and the same images with a cleft head are all the felines as Earth Mother. The latter possibly symbolized either the theme of the mother who had to be sacrificed for her body to become the earth and start the process of creation or the cave opening (both mouth and birth canal) of the Earth Mother as Cosmic Mountain at the center of the Cosmic Cross (Schuetz-Miller, 2012a, pp. 192–200, 211–220).

In this proposed direct link between Chavín, the Olmec of Mesoamerica, and the southeastern USA, important clues are Chavín's sunken court and the plethora of feline and arachnid imagery. While the courts probably served as celestial mirrors, as suggested by Milla Villena, I think

they also symbolized the Place of Emergence through which Spider Grandmother led the survivors of a previous world through a body of water into this, the Fourth World. Impressed into the floor of Chavín's court was a large fossilized gastropod identifying it as the Cosmic Sea (Milky Way, also viewed as a snake) encompassing the earth. Conservative tribes of the Americas retain the creation story in their constructions. Tucanoans envision the earth as an enormous hexagonal spider web outlined by six outstretched snakes. Their longhouse is built over a web wherein dwells the spider. Radial and wheel-shaped patterns of other Brazilian tribes likely reflect the same worldview. Altars in Huichol temples of western Mexico mark the watery underworld of the Mother of the Western Sea who sometimes appears as a spider. Underground kivas of the Pueblo people of the southwestern



Geometry and Architecture in the Americas, Fig. 5 Huaca de los Reyes, Peru. Cupisnique Initial period complex (Drawing based on original map by T. Pozarski in Burger, *Chavín and the Origins of Andean Civilization*)

USA also represent the entry into the Fourth World. The structure is the primordial underworld home when the gods (*kachinas*) are in residence. Their impersonators reenact the

original emergence when they climb out of the kiva for ceremonies (Schuetz-Miller, 2012b, pp. 302–303, 319, 359). Returning to Olmec culture, a sunken courtyard at Teopantecuanitlán



Geometry and Architecture in the Americas,
Fig. 6 Shell gorget, Southern Cult Temple, Mound II,
 Perry County, Missouri (Redrawn from Griffin, *Archeology of Eastern United States*)

(“place of the temple of the jaguar gods”) has two of its four walls adorned with jaguar heads carved of travertine (Stuart, 1993, pp. 108–109, 114). It echoes Chavín’s sunken court in which paired jaguars carved into the walls converge toward the western staircase; the west is the home of the Moon Goddess (Schuetz-Miller, p. 319).

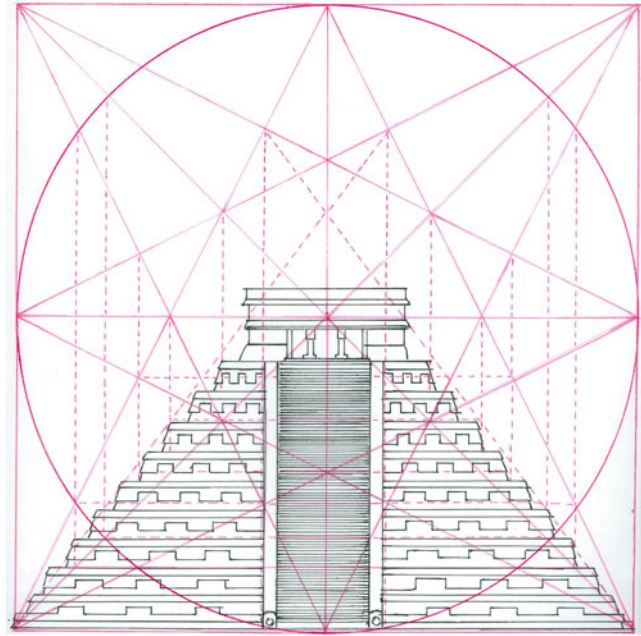
Carrying the concept into the Mayan period, we have the advantage of written records and archaeology, to further our understanding of sacred spaces. Mayan ball courts similarly represented the underworld (Xibalba) where Hun-Hunahpu, father of the hero twins (who became the Sun and Moon), was lured by the evil beings to play ball, was defeated and decapitated. An extraordinary example of the re-creation of this world is found at Copan, Honduras. In its final stage of rebuilding (dedication date January 7, A.D. 738), a mountain/temple was erected at the north end of the plaza, its entry fashioned as the maw of the Jaguar Monster. At the corners of the building, other carved jaguar heads, topped with maize stalks and celestial birds, were embedded. Framing the interior

side of the entrance was a deeply carved Cosmic Monster, an anaconda with a crocodilian head decorated with Venus symbols. The walls of a false ball court below the temple were adorned with carved conch shells; caymans [reptiles] on a platform overlooked it. Centered on the western staircase leading down to the court was a sculptured image, and hieroglyphics identify it as Chac-Xib-Chac (evening star – an aspect of Venus, the first-born of the twins). Flanking the stairs, there is a pair of dancing jaguars – the hero twins celebrating their victory over the Lords of Death. At the center of the court were three markers depicting the severed head of the First Father (Freidel et al., 1993, pp. 146–155); Schele & Freidel, 1990, pp. 322–323, 489 n.44

At Copan we find all the universal symbolism of man’s early cosmic view of the world. At its center are the mythic pyramid/mountain as the *axis mundi* and the temple in the form of the feline monster, the Earth Mother associated with rain, fertility, and childbirth. It has the same significance as the temple at Peruvian Cerro Sechín with its doors painted with felines. The corn stalks represent the Tree of Life atop the mountain and the birds that top them the vital Life Force (air, breath, spirit). The ball court, like Peruvian kiva courts, is the body of water at the roots of the tree and base of the mountain – the entrance to the underworld and the intersection of the four rivers and four quarters of the earth. There is the earth-enclosing ocean in the form of a serpent seen in the Milky Way. And finally there is the association of the feline with shamanism and its persistence to this day in the Olmec heartland and Amazonia (Schuetz-Miller, 2012a).

The Cosmic Cross or quincunx persisted as the model for pyramids throughout pre-Columbian kingdoms. It remains the perceived model of Indian villages in southern Mexico: Lacandon retain the idea in four trails leading from their hamlets – the fifth point – to the cardinal directions; Mayas recognize four Yum Balanobs, Fathers of Jaguars, guarding the four entrances to their settlements. Temples continued to be

Geometry and Architecture in the Americas, Fig. 7 Mayan Temple of Kulkulcan, Chichén Itzá, Yucatan. Profile and plan demonstrating how the temple was laid out in accordance with the eight-pointed star, the symbol of Venus (Based on drawings in Doczi, *The Power of Limits*)



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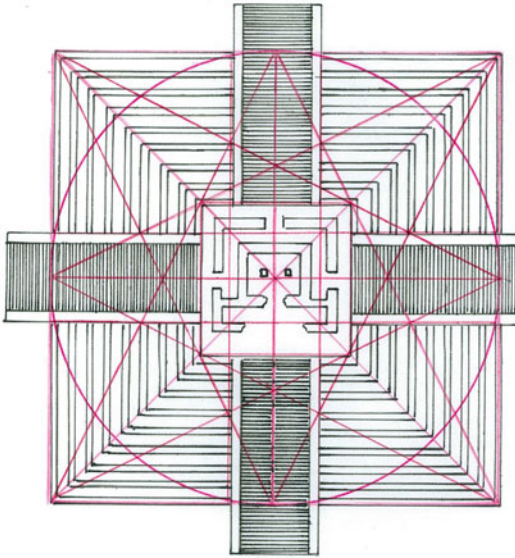
rebuilt, some to terminate a bad cycle and start anew, and new ones erected as tombs for kings claiming descent from the gods themselves. In the ninth century many old kingdoms were crashing, while states across the Yucatan Peninsula and northern lowlands flourished. Chichén Itzá emerged in the eleventh century as the unchallenged ruler of the northern Maya. Analyses of three temples demonstrate the harmonic integration of sacred geometry with the structures and the importance of the eight-pointed star and Cosmic Cross.

Contrary to the Old World's equation of the planet Venus with the Mother Goddess, whose symbol was the eight-pointed star, Mayas identified it with their primary male creator Kulkulcan (Feathered Serpent and Rain God), whose symbol was the five-pointed star (actually half an eight-pointed one). Many Mayan buildings were aligned to track the star, especially at its last appearance on the western horizon – important for predicting its presumed heliacal rising 8 days later. Its heliacal rising, an unlucky omen, was tied to ritual warfare associated with the god

(Aveni, 1982, pp. 1–30; Schuetz-Miller, 2012b, pp. 378–380). Although the Temple of Kulkulcan at Chichén Itzá is known for its western staircase ending in snakeheads, when at sunset during the equinoxes the Feathered Serpent himself appears to undulate down the stairs, there is more than meets the eye. The eight-pointed star and the Cosmic Cross embedded in its structure are evident in Figs. 7 and 8. Its nine terraces are the nine levels of heaven, so cosmic space is transcended as one climbs to the top. Each staircase has 91 steps, totaling 364, and they share one common final step to account for the days of the year. Thus, one transcends time as well (Schuetz-Miller, p. 378; Van Kirk & Van Kirk, 1987, p. 33).

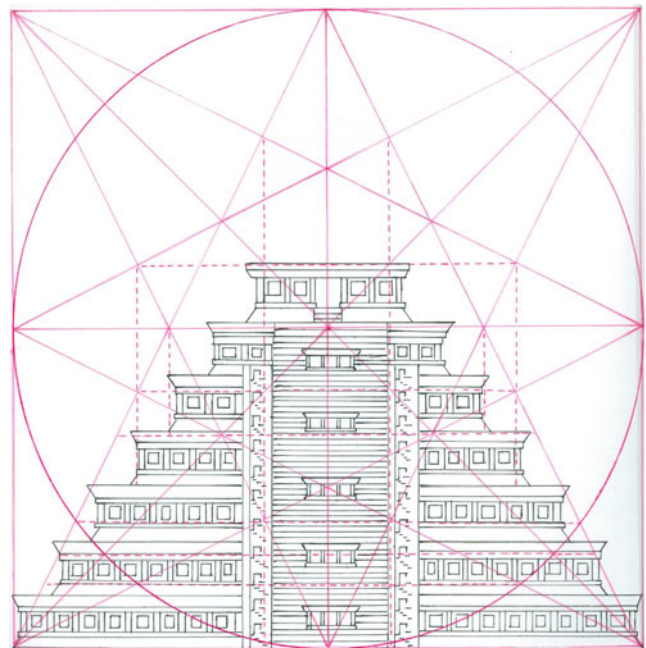
At the Temple of the Niches (Figs. 9 and 10), time is embedded in 365 niches rather than steps. Each side of the stairs is flanked by a ramp with a fret-like motif interpreted as abstract serpent or human vertebrae. The temple at the summit has five carved panels per side, above of which are friezes representing the sky. Zoomorphic motifs on the building include snake, coyote, and

jaguar – in some mythologies the brothers are identified as feline and canine (Schuetz-Miller, 2012b, pp. 380–3810).



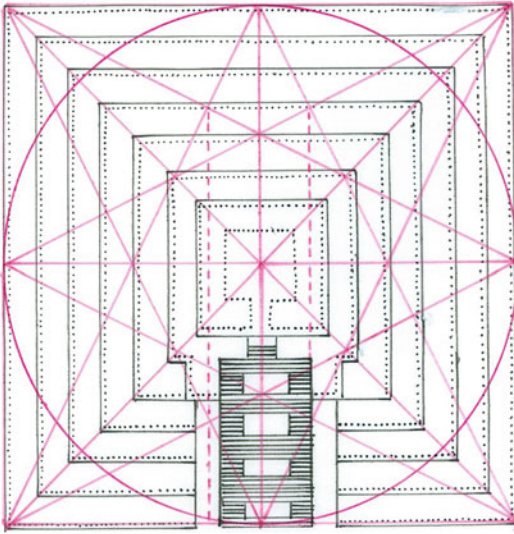
Geometry and Architecture in the Americas, Fig. 8 Mayan Temple of Kulkulcan, Chichén Itzá, Yucatan. Profile and plan demonstrating how the temple was laid out in accordance with the eight-pointed star, the symbol of Venus (Based on drawings in Doczi, *The Power of Limits*)

Geometry and Architecture in the Americas, Fig. 9 Temple of the Niches, El Tajín. Yucatan. Profile and plan demonstrating how the temple was laid out in accordance with the eight-pointed star, the symbol of Venus (Analyses based on drawings in Doczi, *The Power of Limits*)



A final example of microcosm as macrocosm is the Temple of Quetzalcóatl at Teotihuacan (Figs. 11 and 12), which demonstrates the use of the eight-pointed star and halving of the square in its design. The city itself appears to have been planned with the Cosmic Cross as its model. Its eight square miles were laid out as a rectangular grid following a main north–south boulevard beginning with the Temple of the Moon (Moon Goddess, Guardian of the Underworld located in the north) at the north end and the Temple of Quetzalcóatl (son/consort of the Moon, associated with south in his rabbit avatar) at the south. The street was aligned to a slope of the sacred mountain, Cerro Gordo, three miles distant. Forming a Cosmic Cross was an intersecting east–west street that marked the setting of the Pleiades around May 18 at a time when the sun passes directly overhead and coincides with the first annual predawn appearance of the asterism. It further marked the setting of the sun on August 12, the anniversary of the beginning of the last great Mesoamerican calendar cycle, which according to some scholars began on 3114 BCE. Significantly, these and other alignment points are marked with Cosmic Crosses. The Pyramid of the Sun, between those of the

Moon and Quetzalcóatl, was built over a cave, suggesting it was the place of emergence from the previous four worlds of Aztec cosmology



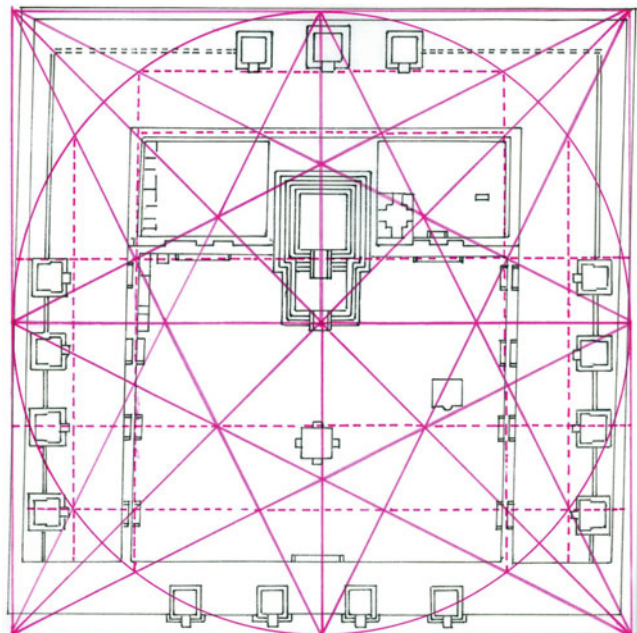
Geometry and Architecture in the Americas,
Fig. 10 Temple of the Niches, El Tajín. Yucatan. Profile and plan demonstrating how the temple was laid out in accordance with the eight-pointed star, the symbol of Venus (Analyses based on drawings in Doczi, *The Power of Limits*)

(Aveni, 1977, pp. 3–9; Schuetz-Miller, 2012b, pp. 381–389; Stuart, 1995, pp. 5–35).

This study had looked at examples of monumental architecture in the Americas from its initial appearance in Peru about 3000 BCE to the period of the Spanish Conquest. It demonstrates the use of a system of pre-Euclidean geometry in their design that embedded the builders' worldview, represented by the eight-pointed star as the symbol of deity, and the Cosmic Cross as a symbol of both divinity and the quincunxial organization of the earth. It was a worldview and a simple geometry, requiring no mathematical skills, shared with the Old World where its use can be traced back into the Neolithic age. This early form of geometry, derived from astronomic observation, was sacred knowledge because it mirrored the celestial kingdom of the gods and ancestors. It was religious belief visualized, not mathematics. It ensured commensurable proportions, was adaptable to any standard of measurement, and was easily taught. Coupled with the rich symbolism of indigenous creation myths, it produced an integration of cosmic view with geometry the equal of any produced in the Old World.

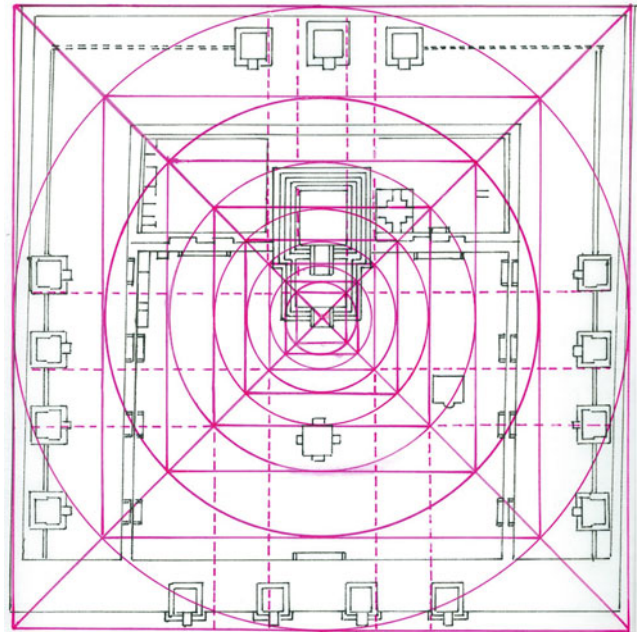
Geometry and Architecture in the Americas,

Fig. 11 Temple of Quetzalcóatl, Teotihuacan, Mexico. Analyses demonstrate the use of the 8-pointed star and doubling of the square (Analyses based on drawings in Millon, Drewitt, and Cowgill, *Urbanization at Teotihuacna, Mexico*)



Geometry and Architecture in the Americas,

Fig. 12 Temple of Quetzalcóatl, Teotihuacan, Mexico. Analyses demonstrate the use of the 8-pointed star and doubling of the square (Analyses based on drawings in Millon, Drewitt, and Cowgill, *Urbanization at Teotihuacan, Mexico*)



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Geometry in Africa

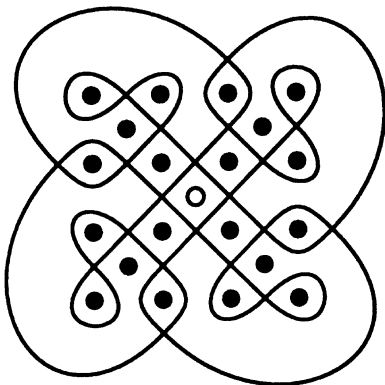
Paulus Gerdes

The *sona* tradition is a part of the heritage of the Tchokwe, Lunda, Lwena, Xinge and Minungo peoples that inhabit the northeastern part of Angola, and of the Ngangela and Luchazi peoples of southeastern Angola and Western Zambia. When the Tchokwe met at their central village places or at their hunting camps, they usually sat around a fire or in the shadow of leafy trees spending their time in conversation, illustrated by drawings in the sand. These drawings are called *lusona* (singular) or *sona* (plural).

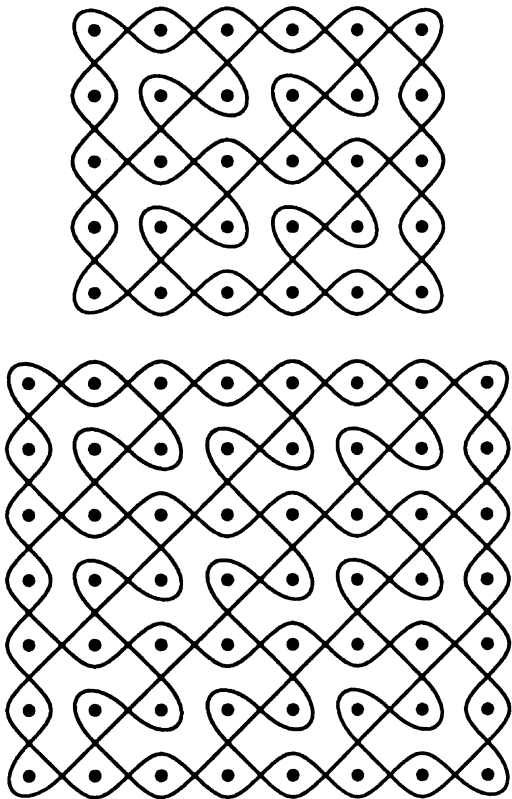
Most of these drawings belonged to an old tradition. They referred to proverbs, fables, riddles, animals, etc., and played an important role in the transmission of knowledge and wisdom from one generation to the next.

Every boy learned the meaning and execution of the easier *sona* during the intensive schooling phase of the circumcision and initiation rites. The significance and creation of more difficult *sona* were known only by specialists, the *akwa kuta sona* (those who know how to draw), who transmitted their knowledge to their sons.

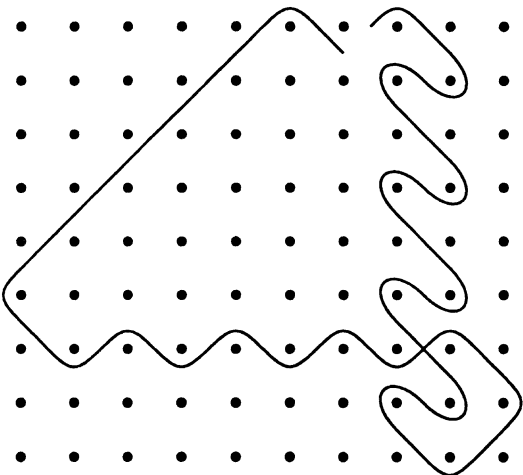
The designs have to be executed smoothly and continuously. In order to facilitate the memorization of their standardized ‘sona’, the drawing



Geometry in Africa, Fig. 1 Monolinear *lusona* with rotational symmetry

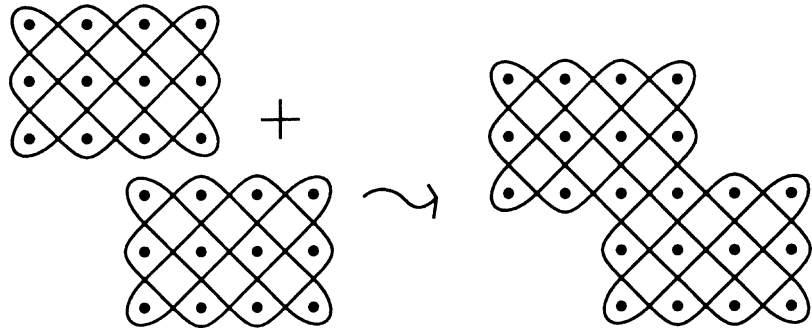


Geometry in Africa, Fig. 2 Two instances of “chased chicken” sona

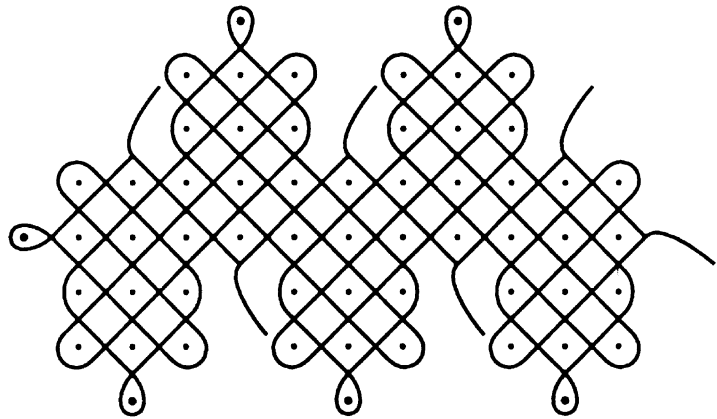


Geometry in Africa, Fig. 3 Geometrical algorithm for “chased chicken” patterns

Geometry in Africa,
Fig. 4 Example of a
 composition rule



Geometry in Africa,
Fig. 5 Representation of a
 leopard with five cubs



experts used the following mnemonic device. After cleaning and smoothing the ground, they first set out with their fingertips an orthogonal net of equidistant points. Then one or more lines were drawn that 'embraced' the points of the reference frame. By applying their method, the drawing experts reduced the memorization of a whole drawing to that of mostly two numbers (the dimensions of the reference frame) and a geometric algorithm (the rule of how to draw the embracing line(s)).

The *sona* tradition vanished almost completely. Tentative designs have been made to try to reconstruct the mathematical knowledge of the drawing experts.

They considered symmetry and monolinearity (i.e. a whole figure made up of only one line) important. Note the example of a *lusona* that is monolinear and that displays a rotational symmetry of order 4 (Fig. 1).

They invented geometrical algorithms for the construction of classes of 'sona'. Figure 2 displays two monolinear drawings belonging to the same class and constructed in agreement with the

same algorithm (Fig. 3). Both drawings represent the marks left on the ground by a chicken when it is chased.

The drawing experts also invented a series of rules for the systematic construction of monolinear *sona*. They probably knew why the rules were valid: they could prove in one way or another the truth of the theorems that these rules expressed.

Figure 4 illustrates one such a rule. This rule serves for chaining monolinear patterns and has been applied four times in the Tchokwe representation of a leopard with five cubs (see Fig. 5).

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Geometry in Chinese Mathematics

Jean-Claude Martzloff

The earliest evidence of a systematic organization of regular shapes reproduced on material objects found in China dates from the third millennium BCE or even earlier. Painted motifs displaying geometrical patterns such as symmetrical arrangements of triangles, lozenges, or circles have been found on pottery pieces unearthed at Banpo (near present-day Xi'an) and other archaeological sites. (Banpo (Pan-p'o) Neolithic dwelling site, one of the most important of its kind, located in the vicinity of Xi'an, south Shenxi, to the north of the present village of Banpo, on a hillock. It was discovered in 1953 while men were constructing the foundations of a plant. It belongs to the Yangshao culture (ca. 6000 BCE). It comprises the remains of the foundations of 45 huts, 200 silos, painted potteries, animal bones, farming and fishing tools, and a necropolis (more than 200 tombs and 37 funerary urns).) These designs demonstrate an early interest in spatial ordering and are perhaps at the origin of subsequent developments even though we are now unable to establish any continuity between prehistoric and historic Chinese mathematics. Nonetheless, several Chinese myths and legends attest that the plumb line, the compass, the carpenter square, and the gnomon (a post of standard height) were commonly used in Zhou China (1121–256 BCE). This last instrument, in particular, was considered so important that the

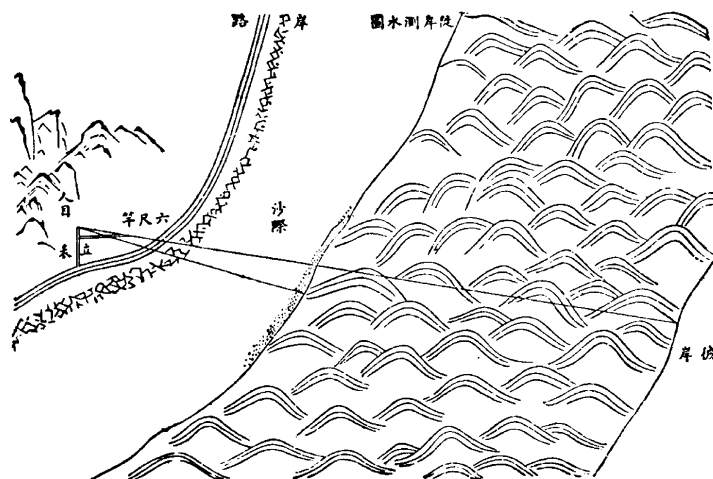
Chinese began founding their astronomical and calendrical conceptions on the determination of the length of gnomon shadows.

Chinese mathematical computations based on the gnomon have been preserved in several important sources from Chinese antiquity such as the *Huai Nan Zi* (The Book of the Prince of Huai Nan) and the ► [Zhoubi suanjing](#) (The Canon of Gnomon Computations from the Zhou Dynasty) (Cullen, 1996). (The prince of Huainan, Liu An, lived under the first half of the Former Han (~206–8), his grand father was Liu Bang (r. ~206 to ~196), the founder of the Han dynasty. The whole text of the *Huai Nan Zi* has been recently translated into French (Le Blanc and Mathieu, 2003).) In these sources, gnomons and their shadows are considered as sides of similar right-angled triangles and properties of similarity are applied to the determination of the height of the sun, at noon, above the flat earth. Later on, the same technique was generalized and used for the determination of earthly distances not directly measurable such as the depth of a well, the height of a mountain, or the distance of an island from the shore. Toward the end of the third century AD, these techniques were edited in algorithmic form in a book entitled *Haidao suanjing* (The Sea Island Computational Canon) (Fig. 1).

Haidao suanjing, one of the Ten Mathematical Manuals (*Suanjing shishu*) of the Tang dynasty (618–907), was composed much earlier by the famous Liu Hui (late third century AD) and commented upon by Li Chunfeng (640–670). From the beginning, it was considered a sequel to the *Jiuzhang suanshu*. Under the Tang dynasty (618–907), it was incorporated in the famous *Suanjing shi shu* mathematical collection composed of ten treatises, just after the *Jiuzhang suanshu*. It was also first officially printed under the Northern Song. None of these antique manuscripts and prints have been handed down to us and the present edition of the text is mainly the result of a late eighteenth-century compilation of incomplete Southern Song dynasty editions, together with excerpts of the text incorporated into the famous encyclopedia, *Yongle dadian* published under the reign of the emperor Yongle (1403–1407).

Geometry in Chinese Mathematics,

Fig. 1 A variant of the *Haidao* technique, taken from Problem IV-3 of the *Shushu juzhang* by Qin Jiushao (1248). The drawing explains the process of “measuring the width of stream from a steeply slanting bank” in order to construct a pontoon bridge in view of military operations (Libbrecht, 1973)



The *Haidao suanjing* is a very short treatise, composed of only nine problems, all concerned with the determination of inaccessible lengths. Word for word, its title means “Sea *hai* Island *dao* computational *suan* classic *jing*”; it should not be taken literally since only the first problem of the collection has really something to do with a sea island, while some others concern mountain distances, the depth of a well, the width of a river estuary. In a word, its real topic is topometry seen under the angle of various special examples, not maritime surveying. In fact, the title is only here to give an idea of what the book contains by alluding to the specific content of its first problem. It is a kind of mnemotechnic device, a reminder.

As for the problems, their textual structure is uniform, composed as they are in the tripartite form of, first, the statement of a little enigma, second the solving technique and last, the commentary. While the problems are rather realistic, the solving technique is announced in a general way and states the succession of arithmetical operations to be performed in order to obtain the answer from the known data of the text, irrespective of the special numerical values various elements are given in the statement of the problem. In sharp contrast with the commentaries of the *Jiuzhang suanshu*, the present one is not devoted to the rational justification of the sequences of calculations. Rather, they only give some specific details concerning the underlying arithmetic.

The statement and solution of the first problem are as follows:

Let a Sea Island be observed. Erect 1,000 *bu* (paces) apart two poles of the same height, three *zhang*, in such a way that both are aligned on an equal level. When moving back 123 *bu* from the front pole and looking from the ground up to the top of the island, the top end of the front pole lies in the alignment. When moving back 127 *bu* from the rear pole and looking from the ground up to the top of the island, the top end of the back pole lies again in the alignment.

Question Find the height of the island and its distance from the front pole?

Answer Height of the island 4 *li* 55 *bu*; distance from the front pole 102 *li* 150 *bu*.

In a quite different spirit, the Mohists – a sect of preaching friars from the fourth and third centuries BCE – approached geometry from a logical point of view and attempted to define the point, the circle, the square, space, and even parallelism (this last point is controversial). Certain of these definitions bear a striking resemblance to those found in Greek mathematics, particularly in Euclid’s *Elements*. Still, there are important differences between both approaches: the Mohist definitions do not concern a single science, geometry, but include optics, mechanics, and

economics. Moreover, the Mohists allow their definitions to incorporate familiar objects from the immediate human environment such as the sun, the bolt of a door, and other very concrete notions. More importantly, the grammatical structure of the Chinese language is such that objects and their properties are not distinguished in any way in the Mohist definitions cf. A. C. Graham, 1978.

Mohist logic did not arouse much interest and was never again studied in China; Chinese geometry developed without concern for geometrical definitions, let alone axiomatic-deductive constructions. But during the Han dynasty (206 BCE-AD 220) Chinese mathematical knowledge was for the first time separated from other domains and recorded in the *Jiuzhang suanshu* (Computational Prescriptions in Nine Chapters, also translated as Nine Chapters on the Mathematical Art). (Generally speaking, *shu* means “technique” or “art.” For example, in terms like *labanshu*, cerography (lit. the art of cerography), *yaoceshu* (lit. the art of measuring from afar) telemetry, *qieduanshu*, amputation (the art of cutting limbs), *fashu* magic arts, *guoshu* (lit. national arts), i.e., Chinese traditional martial arts and gymnastics, *jianshu*, swordsmanship, *jishu*, technology, *mimashu* (lit. the arts of secret codes) cryptography, *meishishu* (lit. the art of fine eating) gastronomy, *suanshu* (lit. the arts of calculation) arithmetic and sometimes mathematics too, *yinshuashu*, printing, *zhanxingshu*, astrology, *zhiwenshu*, dactylography, and so on. From this, the title *Jiuzhang suanshu* could be said to be “the arts of the nine chapters.” However, it is also a fact that the text of the *Jiuzhang suanshu* consists of a list of problems with their *shu*, i.e., their prescriptions – or receipts or “instructions” – which is precisely the special meaning of *shu*, in this context; these *shu*, receipts, are sometimes also called “procedures” in a rather anachronistic way, as if computer listings and algorithms were at stake here. The title *Jiuzhang suanshu* means exactly “the *shu* of the nine chapters,” i.e., “the receipts of the nine chapters” or the “computational prescriptions in nine chapters.”) Composed of 243 problems and almost as many prescriptive solutions

(*shu* = method, device, prescription, algorithm), this very influential manual was eventually revered as a kind of mathematical Bible, so that as late as the seventeenth century certain respected Chinese mathematicians considered that all imaginable problems and computational methods would necessarily be interpretable in terms of the traditional nine chapters of the *Jiuzhang suanshu*.

In fact, the geometry of the *Jiuzhang suanshu* is not precisely an autonomous body of knowledge and consists essentially in a threefold compilation of problems pertaining to planimetry, stereometry, and right-angled triangles. Planimetry is included in the first chapter of the *Jiuzhang suanshu* and comprises a collection of formulae needed to compute the area of fields in the form of squares, rectangles, triangles, trapezia, circles, rings, and segments of circles. Stereometry is found in the fourth and fifth chapters and concerns the computation of volumes or capacities of cubes, parallelepipeds, pyramids, spheres, as well as that of various prisms, dikes, moat walls, ditches, excavations, and cylindrical or prismatic grain silos. Problems on right-angled triangles are found in the last chapter of the *Jiuzhang suanshu* and bear upon Pythagoras’ theorem, where some dimension of a right-angled triangle is sought, given simple algebraic combinations of other dimensions (such as the sum of its base and hypotenuse, its area, and so on). Lastly, the determination of the side and diameter of a square and a circle, respectively, inscribed in the same right-angled triangle are also considered. Nongeometrical subjects are also dealt with in the same chapters (for example, fractions in the first chapter, square and cube roots in the fourth). In addition, various concerns (units of measurement, for example) frequently interfere with the geometrical aspect of problems, so that they seem highly realistic at first sight. In reality, most of them are artificial, since the situations they describe are often the inverse of what would naturally occur in real life: one is often asked to determine the dimensions of a figure given its area or its volume. On the whole, these problems are strikingly similar with those found in the *Suanshu shu* (*Book of arithmetic*) an arithmetical

manual written on ► [bamboo](#) strips from ca. 186 B.C., found in 1983–1984 in a tomb of a Chinese nobleman from the Western Han Dynasty in a site near Zhangjiashan, Jiangling country, Hubei province.

Given that problems on planimetry, stereometry, and right-angled triangles quite similar to the above ones are also well represented in the known corpus of Babylonian mathematics, it would seem that there is no essential difference between Chinese and Babylonian geometry. That is not the case, however, for on the one hand, the solutions of Chinese problems are practically never stated using particular numbers but rather general formulations, and on the other hand, certain Chinese mathematicians have felt the need to justify geometrical results. Remarkably, these justifications would appear quite correct and even accessible to informal proofs in the eyes of modern mathematicians not at all acquainted with Chinese mathematics.

Chinese proofs of geometrical results have been preserved in various commentaries on the *Jiuzhang Suanshu* composed between the third and the seventh century AD by Liu Hui (fl. ca. end of the third century), the author of most of them, ► [Zu Chongzhi](#) (429–500), a famous astronomer and mathematician known for his approximation $\pi = 355/113$, and Li Shunfeng (602–670), an astronomer and compiler of the *Suanjing shi shu* (Ten Computational Canons), a collection of mathematical manuals representative of Chinese mathematical knowledge from the origins to the seventh century. As may be expected, the commentaries do not focus on mathematics alone, but concentrate also on many other aspects of problems needed to understand their original context and pertaining to history, geography, philology, pedagogy, and philosophy. The commentaries are thus intrinsically nonhomogeneous. In their turn, the proofs themselves are often interspersed with numerous digressions and are no more homogeneous than the rest of the commentaries they are imbedded in. Moreover, they frequently rely on all sorts of results (Pythagoras' theorem, for example) not yet proved when they were first used. Reasoning is thus neither constrained by formal modes of

presentation nor by restrictions on what is admissible and what is not. In particular, numerical computations are liberally used, even when strictly speaking they would not necessarily be needed. More surprisingly however, but probably for mnemotechnical reasons, most proofs are formulated in a terse language; deductions are only suggested and based on a limited number of heuristic principles whose formulation is also extremely concise and which are used over and over again.

One of these heuristic principles can be described as a generalized form of the so-called “Cavalieri's principle” (named by analogy with a famous proposition found in Bonaventura Cavalieri's *Geometria Indivisibilibus*; Bologna 1635). (The original text of Cavalieri's *Geometria Indivisibilibus* is wholly accessible from the Biblioteca Digitale IMSS (Istituto e Museo di Storia della Scienza, Firenze) (<http://www.brunelleschi.imss.fi.it/bd/>).)

In its Chinese version, this principle is limited to solids and states that when the areas of the plane sections of two solids always have the same proportion between them, their volumes also have the same proportion. According to another heuristic principle, when a figure is dissected into several pieces as if it were a puzzle, and when the pieces are adequately reassembled, the area (or the volume) of the initial and final figures is equal. This principle is used with standard colored pieces (*qi*) but these are not necessarily the equivalent of concrete pieces of some puzzle since their number is sometimes infinite and involves the idea of carrying the process to the limit. This is the case, for example, in the derivation of the volume of the pyramid, in a way which reminds us of Euclid's proof of the volume of the pyramid (*Elements*, book 12, prop. 5), as the mathematician and historian of mathematics B. L. van der Waerden has suggested (“Liu [Hui]'s proof is very similar to that of Euclid, and it is based on just the same division of a tetrahedron into two prisms and two smaller tetrahedra” (van der Waerden, 1983, pp. 204, 202ff)). This dissection technique is so productive that its usage extends beyond the bounds of geometry. Very often, properties that

we would call “algebraic” (especially when the equivalent of equations comes into play) are manipulated figuratively by means of dissections, so that algebraic relations are directly visualized without any recourse to discursive reasoning or even to particular computations.

As numerous quotations from classical texts (such as Confucius’s *Analects*, the *Yijing* (I Ching, Book of Changes) or Zhuangzi’s works) found in the commentaries on the *Jiuzhang suanshu* suggest, this approach largely depends on Confucian and Daoist ideas. (Also known as *Zhuangzhou* (ca. 370–300 BCE), this Daoist philosopher from the Warring States period is the author of the *Zhuangzi* and can be considered as the master of irrationalism.) According to the Confucian conception, when presenting new knowledge, all the details should not immediately be revealed to students in order to oblige them to make efforts which would result in a deeper understanding. Similarly Zhuangzi favored conciseness of expression, but for a very different reason: he believed that, as sophisms show, discursive reasoning is intrinsically limited and therefore any efficient access to knowledge should necessarily include all imaginable modes of apprehension of reality and not only discursive reasoning. On the whole, these conceptions induced defiance toward modes of reasoning based on language alone; hence the recourse to nonlinguistic modes of communication such as those based on computations or figurative techniques. Still it remains possible that the *Jiuzhang suanshu* and its commentaries are also the result of various other influences which did not necessarily originate in the Chinese world. In this respect it should be noted, for example, that Archimedes and other Greek mathematicians already used equivalents of Cavalieri’s principle many centuries before the advent of the *Jiuzhang suanshu* and its commentaries. Dissections are also attested in antiquity, particularly in Archimedes’ *Stomachion* and even more strikingly, the Chinese proof relating to the volume of the sphere relies, among other things, on the knowledge of the fact that the volume of a solid defined by the intersection of two orthogonal cylinders inscribed in the same cube is equal

to two-thirds of the volume of the cube, a result explicitly stated in Archimedes’s *Method of Mechanical Theorems for Eratosthenes* and in Heron of Alexandria’s *Metrika*. (Cf. E. J. Diksterhuis (1987). The *Stomachion*: “This is a kind of game, played with ivory pieces in the form of simple planimetric figures, the object being to fit these various bits together in such a way that various shapes of human beings, animals or different objects were imitated.” Note that this conclusion is solidly based on quotations taken from several classical authors. In other words, the *Stomachion* is a kind of puzzle in use in classical antiquity, more than 2,000 years before the first mention of the tangrams in China, first in the seventeenth century, and above all at the beginning of the nineteenth century.)

After the seventh century, the Chinese repertory of planimetric and stereometric formulae was continuously enriched. Among the most interesting results from this period, one must cite Hero’s formula for the computation of the area of a triangle given its sides, which was published in Qin Jiushao’s *Shushu juzhang* (Mathematical Works in Nine Chapters, 1247). (On this the indispensable reference always remains U. Libbrecht’s outstanding masterpiece, *Chinese Mathematics in the Thirteenth Century, the Shu-shu chiu-chang of Ch’in Chiu-shao*. Cambridge, Massachusetts: MIT Press, 1973.) Despite its title, this work is very different from the *Jiuzhang suanshu* and is better known for its study of the “Chinese remainder problem” (simultaneous congruences) and its algebraic developments. After the seventh century however, and until the seventeenth, geometrical proofs were never again recorded in Chinese mathematical books. This fact perhaps has something to do with the remarkable development of Chinese algebra which took place during the Song and Yuan dynasties, for algebraic computations have the capacity to generate new results by means of mere computations. Nevertheless, we must admit that we absolutely do not know why some eminent Chinese like Liu Hui or ► [Zu Chongzhi](#) became interested in mathematical proofs endowed with a rather strong Greek flavor,

from the triple point of view of its methods, contents, and results, during a short interval of time, limited to a few centuries, and in a context where Chinese geometry was previously limited to trivial or semitrivial results (such as $\pi = 3$ in the *Jiuzhang suanshu*). (Clavius, *C. Euclidis Elementorum libri XV, Accessit XVI de Solidorum Regularium cuiuslibet intra quodlibet comparatione*. Coloniae (Köln), 1591. Cf. P. M. Engelfriet, *Euclid in China. The Genesis of the First Translation of Euclid's Elements Books I-VI (Jihe yuanben: Peking 1607), and Its Reception up to 1723*. Leiden: Brill, 1998. Review: J. -C. Martzloff. *Euclid in China. Monumenta Serica* 47 (1999): 479–488.)

At the beginning of the seventeenth century, the Chinese became aware of axiomatic-deductive modes of reasoning when, in 1607, the first six books of Christopher Clavius's commentary on Euclid's *Elements* were translated into Chinese by the Jesuit missionary Matteo Ricci (1552–1610) and Xu Guangqi (1562–1633) under the title *Jihe yuanben* (*jihe* = geometry or quantity and *yuanben* = elements, so that *Jihe yuanben* means either “*Elements of Geometry*” or “*Elements of the Measure of Quantities*”) – here, the reader will perhaps deem this story unbelievable. Why, from the very beginning, were Jesuits in China more interested in translating Euclid into Chinese rather than the Bible, papal bulls, catechisms, and other religious texts much more in keeping with a missionary activity? In fact, the answer has to do with the Jesuit educational policy in the context of the Catholic counter-reform. In their *Ratio studiorum* the Jesuits stress the importance of deductive mathematics because of its strong connection with theology: mathematics are extremely important because the kind of knowledge they provide depends both on dogmatic assertions – axioms and postulates – and deductive reasoning leading to truth and certainty. In other words, teaching mathematics to the Chinese was felt like the first and necessary step toward the propagation of religious truths. (Cf. Romano Antonella, *La Contre-Réforme Mathématique: Constitution et Diffusion d'une Culture Mathématique Jésuite à la Renaissance*

(1540–1640). Paris: École Française de Rome, 1999.) Xu Guangqi was a Christian convert and influential high official responsible for the reform of Chinese astronomy undertaken from 1630 onward on the basis of imported European knowledge. It has often been noted that some Persian or Arabic version of Euclid's *Elements* had already reached the Chinese imperial library three centuries earlier, during the Mongol domination of China, but there exists no evidence of any Chinese translation made during that period, and no trace of influence on subsequent Chinese mathematics has ever been detected.

At first, the new geometry was not much studied save by a few converts and Chinese students of Western astronomy who served the Jesuits at the imperial bureau of astronomy. However, as time went on, many Chinese scholars impressed by the successes of European sciences (especially mathematical predictions of celestial phenomena such as eclipses of the sun and calendrical computations) began to study the *Elements* seriously. The majority of these scholars considered that Euclid stood at the very basis of the new Western knowledge. At the same time they also believed that once properly reinterpreted, the results of the *Elements* were the same as those of their nine mathematical chapters; they also thought it desirable to dissociate the content of the *Elements* from its form. Far from representing the very model of logical clarity and the universal basis of all true knowledge, the formal structure of argumentation was judged inappropriate and even noxious. A textual recasting (of the *Elements*) not only affected demonstrations but also geometrical figures, and mathematicians of the first order such as Mei Wending (1633–1721) did their best to dissociate geometrical figures from the demonstrations to which they were attached. Thus, they sometimes redrew figures so as to make the corresponding theorems directly visible. Taking as it were the appearance of “monstrations,” demonstrations changed of nature through the intermediary of tangible figurative representations. At the same time, this major transformation of Euclidean space was accompanied by an extensive “numerization” of geometry. Whereas, in their underlying logic,

Euclid's *Elements* dealt with intrinsic properties of numbers in general, without ever quoting any precise number, even when questions of area and volume were at stake, Chinese geometers made massive use of explicitly mentioned particular numbers, computed if need be with a high degree of precision (Martzloff 1993–1994, pp. 71–72).

Such reactions against the *Elements* were also fairly common in Europe during the seventeenth century, but, in sharp contrast with what happened in China, these European reactions (which often went hand in hand with the rejection of Aristotelianism and scholasticism) were never powerful enough to dominate the mathematical scene, except perhaps in elementary education. In fact, during the seventeenth and eighteenth centuries, China was dominated by a strong reaction against all sorts of speculative reasoning prevalent during the preceding centuries which was designated as the source of Chinese decline. Consequently, numerous scholars advocated the development of concrete sciences (*shixue*), i.e., of applied sciences whose usefulness could be tangibly demonstrated by an increased social welfare. Thus, if mathematics were to be used at all, computational results had to be expressed in the form of easily understandable instructions. In this respect, syllogisms like those of the *Elements* were particularly difficult to use, inasmuch as they also involved numerous repetitions, a characteristic which was also contrary to the canons of Chinese literary composition. In addition, certain critics also wrote that Euclid's *Elements* were written in a cryptic language devised purposefully to obscure simple mathematical results. Many scholars found still another reason to defy geometry; they believed – not without basis – that they had detected an essential similarity between formal discourses typical of the rhetoric of geometrical demonstrations and the scholasticism of the theological speculations widely diffused by the European missionaries. Hence there was a rejection of forms of expression which tended to speculative form.

These ideas remained unchallenged in China until the end of the nineteenth century, but if axiomatic-deductive reasoning was never studied

as such during that period, geometrical results were nevertheless taken seriously as early as the second half of the seventeenth century. In particular, a famous mathematician Mei Wending developed at length the computational aspect of the stereometry of regular and semiregular polyhedrons on the basis of a very incomplete description of these that he had found in the *Celiang quanyi* (Complete Treatise on Measurements), a manual based on Clavius's *Geometria practica* and translated into Chinese ca. 1635. Others tried to recast to content of the *Elements* into the mold of the nine chapters of the *Jiuzhang suanshu*. From the end of the seventeenth century, new Chinese and Manchu translations of the *Elements* were realized under the patronage of the Kangxi emperor. These were all given the same title as the former translation of the *Elements* published a century earlier. However, they were very different from Clavius's commentary since they were all essentially based on Father Gaston-Ignace Pardies (1636–1673) (Ziggelaar, 1971). *Elements de géométrie*, a French manual very different from Euclid's initial text and intended for the teaching of geometry in Jesuit colleges (Ziggelaar, 1971). Pardies' manual (first published in 1671) was so popular that it remained in use in Europe during a whole century and was translated into several European languages. The new translations of the *Elements* all remained in manuscript form, but these eventually gave birth to a final text which was eventually incorporated into a famous mathematical encyclopedia published by imperial order at the end of Kangxi's reign, the *Shuli jingyun* (Collected Essential Principles of Mathematics, 1723). Whereas this encyclopedia remained in use in China for two centuries, the not yet translated part of the first translation of the *Elements* was carried out between 1852 and 1856 by Alexander Wylie (1815–1887) (Fig. 2), a British Protestant missionary, and ► [Li Shanlan](#) (1811–1882), a renowned translator of Western manuals on astronomy, mathematics, botany, and other scientific subjects. This time, the translation was not based on Clavius' commentary but on Heury Billingsley's English translation of Euclid's *Eleane eats* released in 1570 in



Geometry in Chinese Mathematics, Fig. 2 Alexander Wylie

17 books. (Cf. Xu Yibao, “The First Chinese translation of the last nine books of Euclid’s *Elements* and its source” *Historia Mathematica*, 2005, Vol. 32, no. 1, pp 4–32.) After 1760, other elementary Western textbooks on geometry, which have been forgotten since, were again translated into Chinese.

After the 1911 revolution, Chinese mathematics was never again studied for scientific purposes (except by historians) and China gradually made its way into the international mathematical community. Nowadays, there is of course no distinction between geometry developed in China and in other countries.

See Also

- [Algebra in China](#)
- [Pi in Chinese Mathematics](#)
- [Qin Jiushao](#)
- [Zu Chongzhi](#)

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Geometry in India

George Gheverghese Joseph

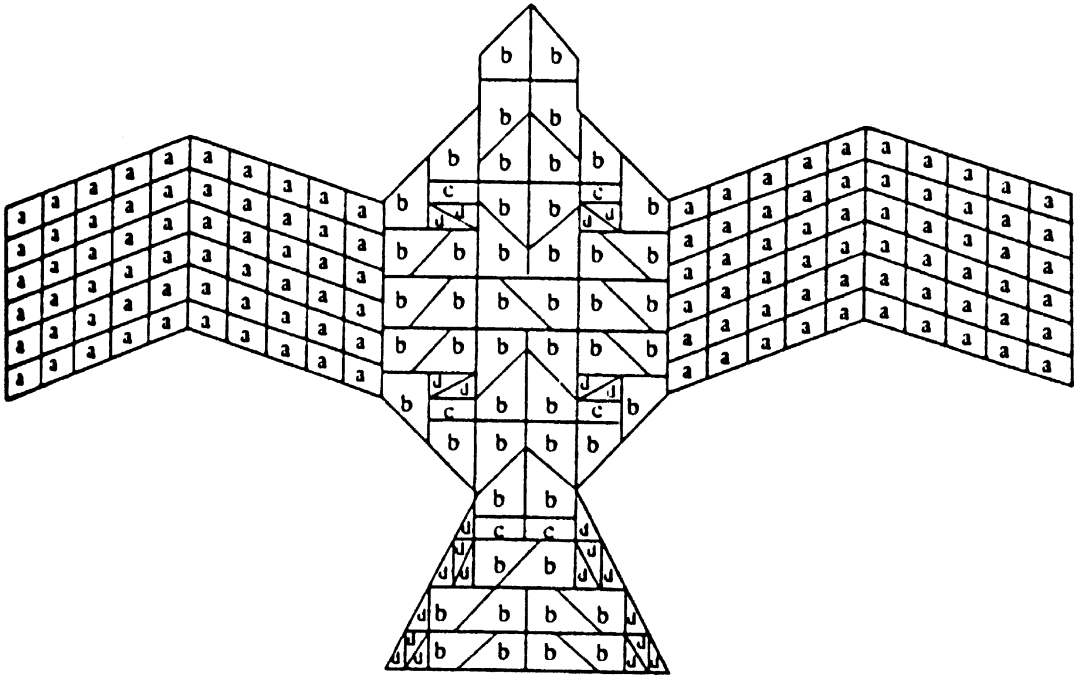
An examination of the earliest known geometry in India, Vedic geometry, involves a study of the *Śulbasūtras*, conservatively dated as recorded between 800 and 500 BCE, though they contain knowledge from earlier times. Before what is conventionally known as the Vedic period (ca. 1500–500 BCE), there was the Harappan civilization dating back to the beginning of the third millennium BCE. Even a superficial study of the Harappan cities show its builders as extremely capable town planners and engineers requiring fairly sophisticated knowledge of practical geometry. An interesting conjecture has been suggested by a drawing on a seal found from Harappa (ca. 2500 BCE): was there an awareness then that the area of a polygon inscribed in a circle approaches the area of the circle as the number of sides of the polygon keeps increasing? This is the basic idea behind techniques that were developed for the mensuration of the circle in a number of mathematical traditions including Indian.

The *Śulbasūtras* are instructions for the construction of sacrificial altars (*vedi*) and the location of sacred fires (*agni*) which had to conform to clearly laid down instructions about their shapes and areas if they were to be effective instruments of sacrifice. There were two main

types of ritual, one for worship at home and the other for communal worship. Square and circular altars were sufficient for household rituals, while more elaborate altars whose shapes were combinations of rectangles, triangles, and trapezia were required for public worship. One of the most elaborate of the public altars was shaped like a giant falcon just about to take flight (*Vakraprakṣa-śyena*). It was believed that offering a sacrifice on such an altar would enable the soul of the supplicant to be conveyed by a falcon straight to heaven (Fig. 1).

It is clear that if in the construction of larger altars they had to conform to certain basic shapes and prescribed areas or perimeters, two geometrical problems would soon arise. One is the problem of finding a square equal in area to two or more given squares; the other is the problem of converting other shapes (for example, a circle or a trapezium or a rectangle) into a square of equal area or vice versa. The constructions were achieved through a judicious combination of concrete geometry (in particular what would be known today as the principle of dissection and reassembly), ingenious algorithms, and the application of the so-called Pythagorean theorem. The essence of the dissection and reassembly method involves two commonsense assumptions. The first is that both the area of a plane figure and the volume of a solid remain the same under rigid translation to another place. The second says that if a plane figure or solid is cut into several sections, the sum of the areas or volumes of the sections is equal to the area or volume of the original figure or solid. The reasoning behind this approach was very different from that behind Euclidean geometry, but the method was often just as effective, as shown in the Indian (and Chinese) “proofs” of the Pythagorean theorem.

In the *Kātyāyana Śulbasūtra* (named after one of the authors) the following proposition appears: “The rope (stretched along the length) of the diagonal of a rectangle makes an (area) which the vertical and horizontal sides make together.” (2.11). Using this version of the Pythagorean theorem, the *Śulbasūtras* show how to construct both a square equal to the sum of two given



Geometry in India, Fig. 1 The first layer of a Vakrapaksa-syena altar. The wings are made from 60 bricks of type “a,” and the body, head and tail from

50 type “b,” 6 of type “c” and 24 type “d” bricks. Each subsequent layer was laid out using different patterns of bricks with the total number of bricks equaling 200

squares and a square equal to the difference of two given squares. Further constructions include the transformation of a rectangle (square) to a square (rectangle) of equal area and of square (circle) to a circle (square) of approximately equal area. The constructions “doubling the square” and “squaring the circle” lead naturally to devising algorithms for the square root of 2 and other numbers, for implicit estimates of π , and for constructing similar figures in required proportions of a given figure.

The composers of the *Śulbasūtras* made it clear that their work was not original but could be traced to earlier texts, notably the *Samhitās* and the *Brāhmaṇas* of which the most relevant text, *Śatapatha Brāhmaṇa*, is at least 3,000 years old. In spite of its obscurities and archaic character the text is valuable for an early discussion of the technical aspects of altar construction. The instructions given in *Śatapatha Brāhmaṇa* (X.2.3.11–14) for constructing a falcon-shaped altar consisting of 95 layers of bricks are as follows:

$$\text{Area of the body (Atman)} = 56 + \frac{12}{7} \sqrt{56};$$

$$\begin{aligned} \text{Area of two wings} = & 2(14) + \frac{3}{7} \sqrt{14} \\ & + \left(\frac{1}{5}\right) \left(\frac{1}{7}\right) (3) (\sqrt{14}); \end{aligned}$$

$$\text{Area of tail} = 14 + \frac{3}{7} \sqrt{14} + \left(\frac{1}{10}\right) \left(\frac{1}{7}\right) (3) (\sqrt{14}).$$

The total area is about 116 square *purushas*, which is an over-estimate of the required 101.5 square *purushas*, arising in part from a rounding off error involved in taking 14 rather than $13 + 8/15$.

A major strand running through the history of Indian geometry and also providing the main motivation for the development of the subject was a recognition of the impossibility of arriving at an exact value for the circumference of a circle given the diameter (i.e., the incommensurability of π). A passage in Āryabhaṭa’s *Āryabhaṭīya* (AD 499) – Verse 10 of the section on *Gaṇita* – reads:

Add 4 to 100, multiply by 8, and add 62,000. The result is *approximately* the circumference of a circle whose diameter is 20,000. (Giving an implicit value of 3.1416 for π . This was the most accurate estimate for π known at that time. About 600 years earlier (ca. 150 BCE), there was an implicit estimate of π as the square root of 10 in a Jaina text called *Anuyoga Dwāra Sūtra*.)

It was the word “approximately” that gave food for thought to commentators of Āryabhata’s work from ► **Bhāskara I** (ca. AD 600) to Nīlakanṭha (b. AD 1445). The first formal proof of the transcendental nature of π was given by the Swiss mathematician Lambert in a paper to the Berlin Academy in 1671. However, about 150 years earlier, Nīlakanṭha’s commentary on *Āryabhaṭīya* contained the following statement:

Why is only the approximate value (of circumference) given here? Let me explain. Because the real value cannot be obtained. If the diameter can be measured without a remainder, the circumference measured by the same unit (of measurement) will leave a remainder. Similarly the unit which measures the circumference without a remainder will leave a remainder when used for measuring the diameter. Hence the two measured by the same unit will never be without a remainder. Though we try very hard we can reduce the remainder to a small quantity but never achieve the state of ‘remainderlessness’. This is the problem. (Adapted from Sarasvati Amma 1979)

Once the incommensurability of π was accepted, the approach of the Indian mathematician was to obtain as accurate a value of this quantity as possible, and the strategy to be followed was expressed thus by Śaṅkara Variyār and Nārāyana Kriyākramakarī (ca. 1550):

Thus even by computing the results progressively, it is impossible theoretically to come to a final value. So, one has to stop computation at that stage of accuracy that one wants and take the final result arrived at ignoring the previous results. (Adapted from Sarma 1975)

The major breakthrough came from the revolutionary idea, most probably that of Mādhava (ca. 1340–1425), that it was possible to obtain an infinite series whose sum would be exactly equal to π and that an increasingly close rational approximation of the quantity could be obtained by taking partial sums successively of higher order. While the question of the slow

convergence of this series was not explicitly discussed, the need for increasing rapidity of convergence was recognized and some remarkable corrections to be applied to truncated series were deduced. The work on infinite series for circular functions provided an impetus to derivation of other infinite series for trigonometric functions, namely arc tangent, sine, and cosine series. Often inductive reasoning (and intuition) built upon geometrical representation helped them to discover these results, but the proof of these results can withstand any rigorous criterion applied to it today. An implicit estimate for π based on infinite-series expansion given by Mādhava around 1,400 is correct to 11 decimal places.

Another area of geometry in which the Indian contribution was significant was in the study of the properties of a cyclic quadrilateral. In the *Brāhma Sphuṭa Siddhānta*, ► **Brahmagupta** (b. AD 598) gives these results:

1. The area of a cyclic quadrilateral is given by the product of half the sums of the opposite sides, or by the square root of the product of four sets of half the sum of the sides (respectively), diminished by the sides.
2. The sums of the products of the sides about the diagonal should be divided by each other and multiplied by the sum of the opposite sides. The square roots of the quotients give the diagonals of a cyclical quadrilateral.

The derivations of these results are first referred to in a tenth-century commentary on Brahmagupta’s work, but find their full expression in the sixteenth century Kerala text *Yuktibhāṣā* by Jyeṣṭhadeva. This makes use of Ptolemy’s theorem that in a cyclic quadrilateral the product of the diagonals is equal to the sum of the products of two pairs of opposite sides.

Notable extensions in this area are contained in Nārāyana Pandita’s *Gaṇita Kaumudī* in the fourteenth century and Parameśvara’s *Līlāvati Bhāṣya*, a detailed commentary on Bhāskaracharya’s *Līlāvati*. In the latter is found a new rule for obtaining the radius of the circle in which a cyclic quadrilateral is inscribed.

The great interest in the cyclic quadrilateral in Indian mathematics arose from the fact that it was an important device for deriving a number of important trigonometric results which were in almost all cases used in astronomy.

In India geometry never became idealized in the way it did in Greece. Geometry was largely concrete and empirical in character. It did, however, have an algebraic character which is best seen in the genesis of trigonometry there. Because of their geometric emphasis, the Greeks used chords in their astronomical calculations, whereas the Indians developed the notion of sines and versines (i.e., $1 - \cos$ of an angle) as early as AD 500. Āryabhata was perhaps the first Indian astronomer to give a special name to these functions and draw up a table of sines for each degree. Approximation formulae were developed for these functions, culminating in the construction of sine tables in Kerala during the fifteenth century where the values in almost all cases are correct to the eight or ninth decimal place, a remarkable degree of accuracy.

See Also

- [Āryabhata](#)
- [Bhāskara I](#)
- [Geometry](#)
- [Mādhava of Saṅgamagrāma](#)
- [Nārāyaṇa Paṇḍita](#)
- [Nīlakaṇṭha Somayājī](#)
- [Parameśvara](#)
- [Śulbasūtras](#)

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Geometry in Islamic Art

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Geometric patterns in two and three dimensions comprise one of the key characteristics of arts and architecture of the Islamic world in many cultural traditions from the central Islamic lands of the Middle East to Spain, India, Indonesia, and sub-Saharan Africa (Bloom & Blair, 2009; Broug, 2013; Ettinghausen, Grabar, & Jenkins-Madina, 2001; Gerdes, 1999; Hillenbrand, 1994, 2009). Although geometry is present, either by conscious human choice in design or as an inherent feature of architectural production in all

cultures, it seems to have assumed a much higher significance in Islamic centers of civilization (Grabar, 1992). Often attributed to a proscription against figural images, this interpretation is not borne out historically with reference to palace wall painting, ceramics, ivory, woodwork, and book illustration rich with pictorial narrative. There are, indeed, other more rational explanations for the emphasis on geometric figures (Allen, 1988; Freedberg, 1989; Belting, 2011) as well as many unanswered questions (Grabar, 1992). From the eleventh century throughout the central Islamic lands, the clustered and segmented vaults of *muqarnas* were used to effect spatial transitions for domes, vaults, and arches, or as a corbel to support balconies and cornices (Bloom, 1988; Tabbaa, 1985), exhibiting elaborations in succeeding centuries (Al-Assad, 1995; Golombek & Wilber, 1988). Simultaneously, one may trace the development of patterns in the plane from the empirical juxtaposition of geometric shapes to more complex arrangements with networks of intersecting polygons, which suggest direct relationships to academic studies of geometry in the Euclidean tradition (cf. Allen, 2004, who argues against such an interpretation). Yet precise intersections between the histories of architecture and mathematics have not been fully elucidated (Berggren, 2008; Bier, 2012; see also, Necipoğlu, 2015). The text of Abū'l Wafā' al-Būzjānī (d. 998) suggests direct links including conversations among artisans and mathematicians, leaving much to speculation (Chorbachi & Loeb, 1992; Özdural, 1995, 2000; see also Sarhangi, 2008b).

Geometry in the Service of Religion: Kaaba, Qibla, Hajj, Awqaf, Salat, and Khatt

Science, mathematics, and material culture also intersect in the service of Islam – in particular, the construction of astrolabes requires carefully placed markings that register a projection of three-dimensional space in two dimensions to find the direction and distance to Mecca through astronomical measurements and calculations

from a specific place (King, 1999). In architecture, geometrical considerations impact determination of *qibla* (the direction toward the Kaaba in Mecca), which orients both prayer space and worshipper for prayer, *salat*. The qibla wall of a mosque or prayer hall is often marked with an ornamented *mihrab*, or niche, which frequently incorporates geometric patterns and forms. And the times of prayer, *awqaf*, are based upon the sun's position. The Kaaba itself (Arabic “cube”), which antedates Islam, is conceptually cubic in form, associated with rituals of circumambulation that comprise part of *hajj*, the pilgrimage prescribed for Muslims in the Qur'ān, and rites outside the formal *hajj* season (*'umra*). Similar practices that entail circumambulation are associated in some instances with local shrines and tombs throughout the Islamic world (Mawani, 2016). Because Muslims believe the Qur'ān to have been revealed in Arabic, both language and script (*khatt*) have assumed elevated status within Islamic cultures, a status that contributed to the development of elaborate calligraphic forms often based upon systems of geometric proportion.

Patterns in the Plane: Symmetry and Periodicity

The presence of geometry is evident in the earliest Islamic monuments, including the octagonal plan and prismatic structure of the late seventh-century Dome of the Rock in Jerusalem (Grabar, 2006). Geometric patterns in the plane or radial symmetry appear extensively in floor mosaics, carved stucco, and wall ornaments at Khirbat al-Mafjar near Jericho (Hamilton, 1959), drawing upon the Late Antique artistic heritage of the late Roman, Byzantine, and Sasanian empires. In the ninth century, periodic patterns in the plane exhibit symmetry in the palaces at Samarra and in other more distant Abbasid centers such as Balkh, with similarities of style noted in architectural stucco, woodwork, ceramics, as well as in objects of other materials, such as rock crystal, inlaid wood, and ivory (Ettinghausen et al., 2001). All such periodic patterns have visible or

Geometry in Islamic Art,

Fig. 1 Nishapur, Iran.

Carved stucco wall panel.

Tenth century. Excavated

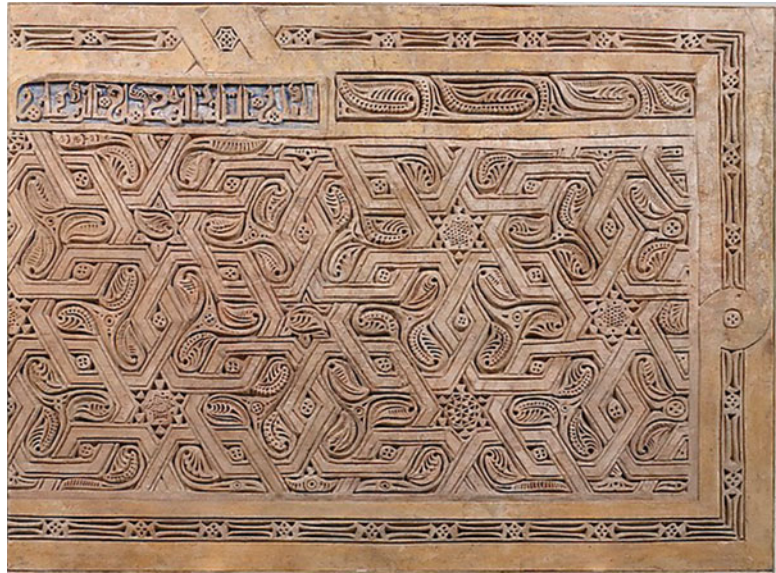
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Rogers Fund, 1940). [www.](http://www.metmuseum.org)

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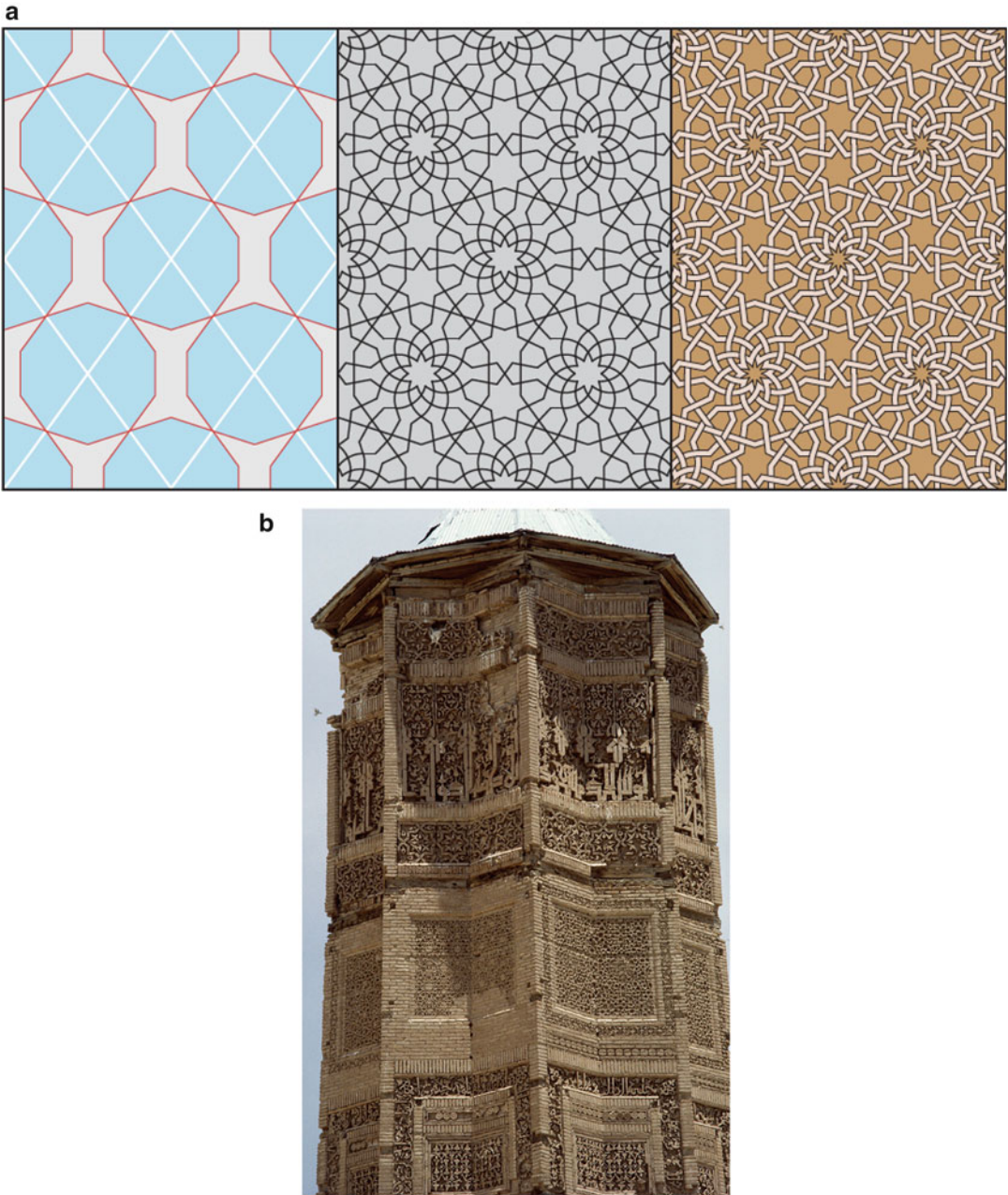
implied square, rectangular, triangular, rhombic, or hexagonal grids and utilize symmetries of reflection, translation, glide reflection, and rotations of orders 2, 3, 4, and 6. At Nishapur in northeastern Iran, a wall panel in carved stucco (Fig. 1) exhibits a plane pattern with overlapping, interlacing hexagons, each spatial unit of the tiling filled with vegetal ornament that is also a characteristic of an Abbasid style. In these early examples of periodic patterns in Islamic art, there is a notable absence of pentagons and decagons, which offer geometric challenges in the spatial dimension. Unlike other regular polygons (equilateral triangles, squares, and hexagons), their interior angles are not factors of 360° . An early complex interlaced pattern with local tenfold rotations set within an implied rhombic grid, as reconstructed by Bonner (Fig. 2a), appears on the stellated octagonal tower of Mas'ud III in Ghazna (Fig. 2b), dating to the late eleventh or early twelfth century (Bonner, 2015). And a pattern with concentric decagrams (ten-pointed stars), also set within an implied rhombic grid, may be discerned in the tympanum of the Gonbad-e Alaviyyan in Hamedan in western Iran (Fig. 3). The use of decagons and decagrams in periodic patterns is highly unusual and may indicate a major achievement in the utilization of geometry for architectural ornament, overcoming

the intransigence of pentagons and decagons to tessellate the plane (see also Nava'i (2012) and Sarhangi (2013a)).

Forms and Patterns Based upon Divisions of the Circle

In Spain, three domed chambers in front of the *mihrab* of the Great Mosque of Cordoba, dating from an extension of the building in the mid-tenth century, exhibit the earliest evidence of ribbed domes, constructed using four pairs of parallel ribs, which interlace to form an octagon and eight-pointed star (Fuentes González & Huerta, 2010). The earliest appearance of a pentagon seems to be in the north dome of the Masjid-e Jomeh, Isfahan, dated to 1088–1089 (Fig. 4), possibly to be associated with the mathematician, Omar Khayyam (Özdural, 1995, 1998). In addition, there are two patterns having local fivefold symmetries (convex and concave polygons) that also appear in the north dome chamber in recessed tympana in the transition zone below the dome.

With a circular or polygonal plan, numerous prismatic tomb towers built of fired brick were constructed in Iran and neighboring lands during the ninth through twelfth centuries. The tradition



Geometry in Islamic Art, Fig. 2 Ghazna, Afghanistan. Tower of Mas'ud III, cut brick. 1099–1115. (a). Interlaced pattern with tenfold rotations set within an implied rhombic grid, pattern reconstruction by Jay Bonner (2015). (b). Detail, registers of brick patterns (note Bonner's analysis

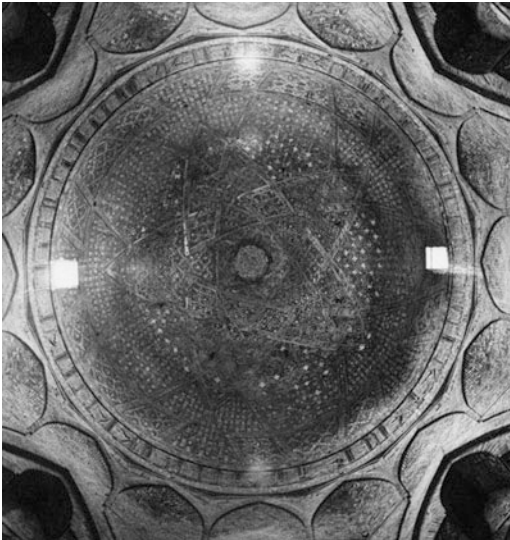
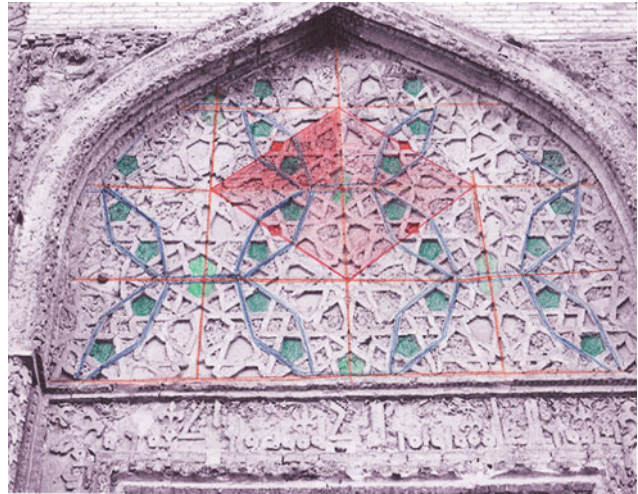
in Fig. 2a is of pattern that is third from top on left flange). (© David Collection, Copenhagen. Photo: Andre Leth. <http://www.davidmus.dk/en/collections/islamic/dynasties/ghaznavids-and-ghurids/architecture/masud-iii>)

continues with great architectural variation (Hillenbrand, 1994), including the extensive use of glazed bricks and ceramic mosaic, which led to

the introduction of tiles. The design of these mausolea begins with a center point and circle; the circle may then be divided into equal segments.

Geometry in Islamic Art,
Fig. 3 Hamadan, Iran.

Gonbad-e Alaviyyan. Cut brick pattern of decagrams set within an implied rhombic grid. Late twelfth century. Analysis by C. Bier



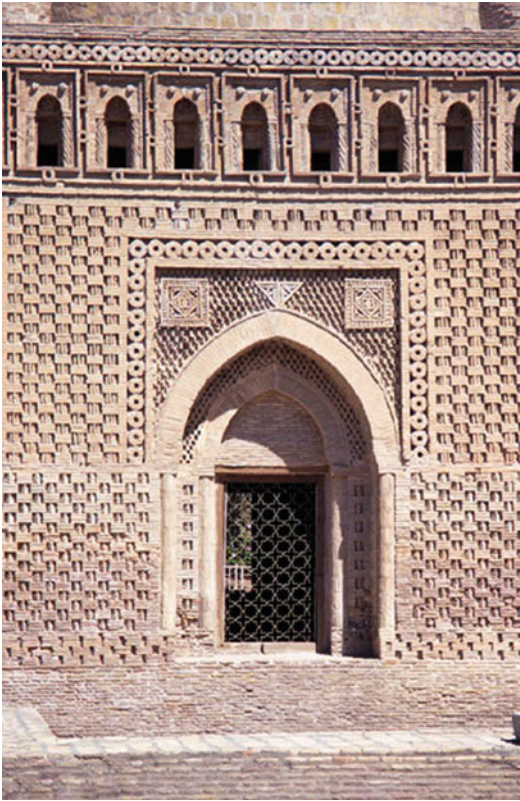
Geometry in Islamic Art, Fig. 4 Isfahan, Iran. Masjid-e Jomeh. North Dome (Gonbad-e Khaq), with central pentagon. 1088–89 (Josephine Powell photograph, Courtesy of Special Collections, Fine Arts Library, Harvard University)

Early examples include the monuments at Radkan, Demavend, Lajim and Kharraqan in Iran, and Bust in Afghanistan. The most common form is an octagonal prism with a variety of conical or polyhedral roofing arrangements (Ashkan & Ahmad, 2012). Several different architectural structures also suggest experimentation with geometry and form; examples include the unique tapering

stellated decagonal tower at Gonbad-e Qabus (dated 1006–1007) with its smooth conical roof and the cubic “tomb of the Samanids” in Bukhara (Fig. 5), with its elaborately reticulated brickwork arranged to display decorative patterns.

Broug (2013, Fig. 1, pp. 21–24) clearly explains pattern families derivative of divisions of the circle into four or eight segments, three or six segments, and five segments in Islamic geometric patterns. In analyzing plane patterns in Islamic art, Bonner (2015) amplifies these categories based upon an elaboration of obtuse, median, or acute angles at points of intersections of bisected lines; he also adds a category for more complex patterns with two-point sharing, introduced in the late twelfth century.

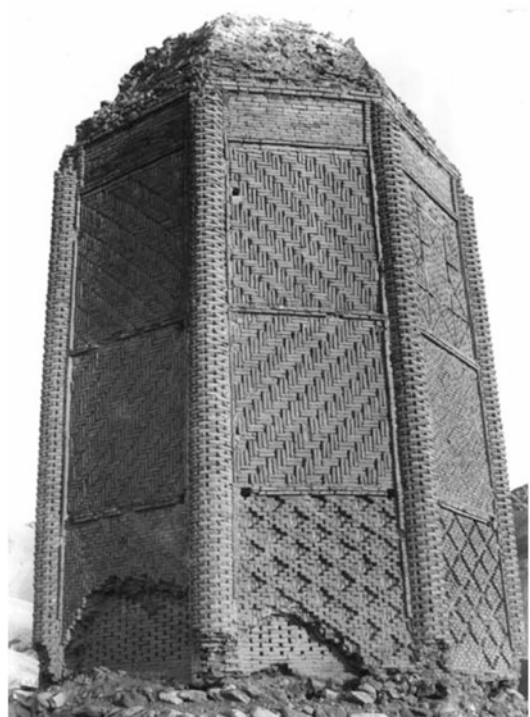
Typically many different geometric patterns appear on a single monument. From the early Islamic period until the mid-eleventh century, such two-dimensional patterns seem to be composed by design algorithms, whether executed in stone or glass mosaic (as in the Dome of the Rock and at Khirbat al-Mafjar) or in brick (as in Bukhara, Demavend, Isfahan, and elsewhere). A unit is repeated according to an organizing principle (today identified as a symmetry group), which results in a pattern. The geometry is emergent. For example, ornamental brickwork relies upon bricks being set in different orientations (vertical and horizontal) or bricks used in proportions of 1:2:3, as at Demavend (Fig. 6),



Geometry in Islamic Art, Fig. 5 Bukhara, Uzbekistan. Tomb of the Samanids, exterior view of articulated brickwork. Tenth century. (Courtesy: © Frank Harold, 1999, <https://depts.washington.edu/silkroad/cities/uz/bukhara/bukhara.html>)

in the earlier tower at Kharraqan (dated 1067), and in blind niches at Gonbad-e Surkh at Maragha. Sometimes the bricks are set with mortar that appears to be intentionally set back, thereby more clearly articulating algorithmic patterns through the play of sunlight and shadow, projection, and recess, as in Bukhara, and on the facades of the two tomb towers at Kharraqan in western Iran.

By the late eleventh century, there seems to be a change, first evident on the entry facades at Kharraqan (Fig. 7) and then on the façade of the Gonbad-e Surkh (Fig. 8), indicated by bricks having been cut to size to create different patterns. Despite its out-of-the-way location off the Hamadan-Qazvin road, the later tomb tower at Kharraqan (dated 1093) provides the earliest



Geometry in Islamic Art, Fig. 6 Demavend, Iran. Tomb tower, showing vertical and horizontal orientation of bricks. Eleventh century. (Robert Byron, 1933–34, © Conway Library, Courtauld Institute of Art, http://archnet.org/media_contents/40177 [Harvard: administered by British Library])

evidence for the introduction of glazed ceramic elements (Pickett, 1997; Stronach & Young, 1966). In the succeeding 100 years, the use of glazed architectural ceramics increased dramatically (Wilber, 1939). Blue-glazed bricks, using a copper colorant for the glaze, were used extensively to cover the long narrow triangular facets of tall pyramidal roofs with polygonal bases, which reflected sunlight from every direction – as noted by the historian, Yaqt (d. 1229), who describes their visibility from miles away serving as a beacon for travelers (Wilber, 1939, p. 23, n.25). A noteworthy early example of the use of glazing to highlight a particular pattern is the mid-twelfth-century tympanum of the Gonbad-e Sorkh at Maragha (Fig. 8). Its arcuate shape encloses three networks of intersecting hexagons, dodecagons, and nonagons sharing the same center point, with nonagons

highlighted in turquoise glaze (Bier, 2012). The composition clearly reflects extraordinary mathematical understanding of how polygons and

polygonal networks relate to one another geometrically. Surrounding the geometric composition, an elegant historical inscription gives the building's date of construction as 4 March 1148 CE and the name of the patron, Fakhr al-Din Abu 'l-'Izz 'Abd al-'Aziz ibn Mahmud, a local ruler also known as Qawam-e Azarbayjan, who 15 years later was host to a famous Jewish mathematician, Abu Nasr Samaw'al b. Yahya al-Maghribi, born in Baghdad (his father was from Spain). Samaw'al retired to Maragha and converted to Islam on Friday, 8 November 1163, as he reports in his autobiography, which was completed in 1167 (Schmidtke, 2013).

From the late twelfth century until the Mongol conquests of the thirteenth century, brick monuments in Iran, Iraq, and Azerbaijan demonstrate an aesthetic predilection for patterns with intersecting polygons, including stars (Pope & Ackerman, 1938/1939). The earlier use of intersecting squares, octagons, hexagons, and dodecagons, as at Kharraqan in Iran (Stronach & Young, 1966) in the late eleventh century and at Chist-e Sharif in Afghanistan (Broug, 2013, Fig. 1.1), of the late twelfth century, is superseded by patterns in which the arms of star polygons are extended to create "petals," and lines are further extended to meet edge extensions of other star polygons by means of point joining. In several instances, such techniques are carried to an

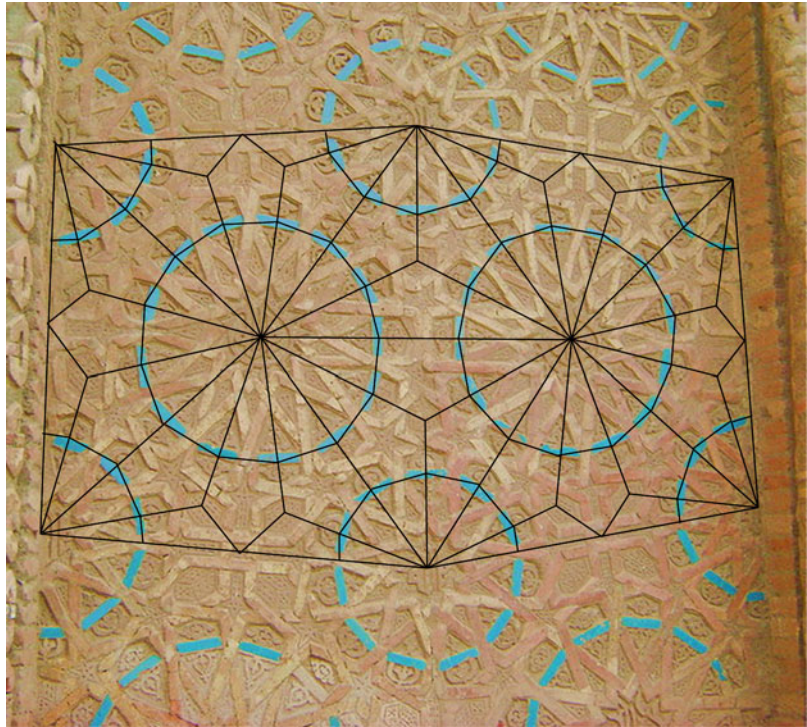


Geometry in Islamic Art, Fig. 7 Kharraqan, Iran. Tomb tower, cut brick façade. Dated by historical inscription to 486H/1092–3 (Photo by Ann Gunter)

Geometry in Islamic Art, Fig. 8 Maragha, Iran. Gonbad-e Sorkh, tympanum of cut brick and turquoise glaze. Dated by historical inscription to 542H/1148. Color transparency (C162) by Hans C. Seherr-Thoss, detail (Hans C. and Sonia P. Seherr-Thoss Photographs of Islamic Architecture, Freer Gallery of Art and Arthur M. Sackler Gallery Archives, Smithsonian Institution, Washington, D.C. Gift of Sonia P. Seherr-Thoss)



Geometry in Islamic Art,
Fig. 9 Nakhchivan,
 Azerbaijan. Tomb tower of
 Mo'mine Khatun, detail of
 cut brick façade with
 turquoise glaze with
 11-gons and 13-gons.
 Dated by historical
 inscription to 1186.
 Analysis by Nathan Voirol

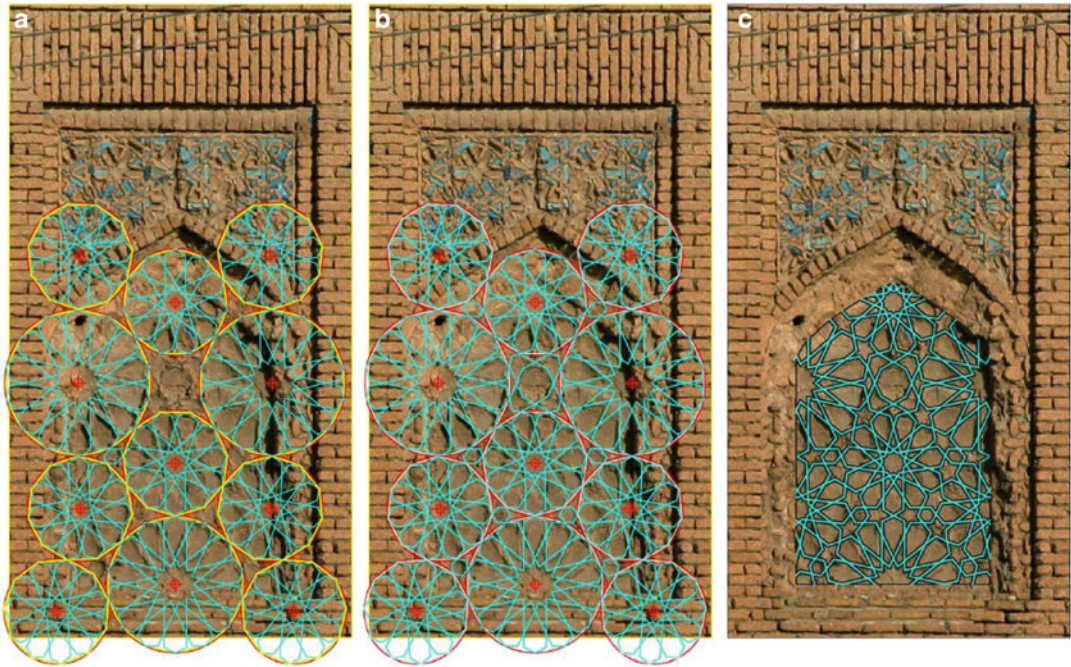


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extreme: the decagonal prismatic mausoleum commissioned by Mo'mine Khatun at Nakhchivan in cut brick (Fig. 9) shows evidence of 11- and 13-gons (dated 1186), and a pattern executed in cut brick on the Choli Minaret at Erbil dating from the late twelfth century (Fig. 10) shows a pattern with 11- and 14-gons as reconstructed (Ajlouni & Justa, 2011). In the citadel at Aleppo, a pattern carved in wood from an Ayyubid panel in the early thirteenth century shows a progression of rayed polygons forming a sequence from 12-, 11-, 10-, 11-, and 12-gons, as analyzed by Herzfeld (1943), which is noted and discussed more recently by several authors (Allen, 1988, p. 53 and Fig. 57; Tabbaa, 2001, p. 96, Fig. 45). Bonner (2015) notes the presence of a more elegant rendition of the same pattern on the portal of a Seljuk monument in Anatolia, the Erkilet Kiosk in Kayseri (dated 1241). The design appears in Schneider (1980, no. 417). Such complex patterns, with or without illusionary interlacing, suggest an extensive array of experimentation with geometric shapes in polygonal networks and an ongoing effort to achieve more elegant refinement.

***Girih*: Grid-Based Patterns**

In the scholarly literature, the term *girih* (Persian, “knot”) has been applied to this ornamental tradition although its first documented appearance is attributed to architects working in nineteenth-century Central Asia (Baklanov, 1947). Necipoğlu (1995) carefully recounts the historical use of this term and consciously applies it to describe an artistic mode that is expressed through diagrams in the Topkapi scroll, which is an undated, anonymous scroll without text. By means of comparative stylistic and contextual analysis, Necipoğlu (1995, p. ix) ascribes this seminal historical document to the Timurid-Turkmen realm of Iran in the late fifteenth-early sixteenth century, but accepts that it is indicative of a much longer developmental evolution of designs used for architectural ornamentation. Other authors use the term *girih* with slightly different inflections (Denny, 2002; Rogers, 1973; Tabbaa, 2001). The Topkapi scroll, published in a 2:1 facsimile edition (Necipoğlu, 1995), serves as a primary source, the data from which has been utilized in numerous



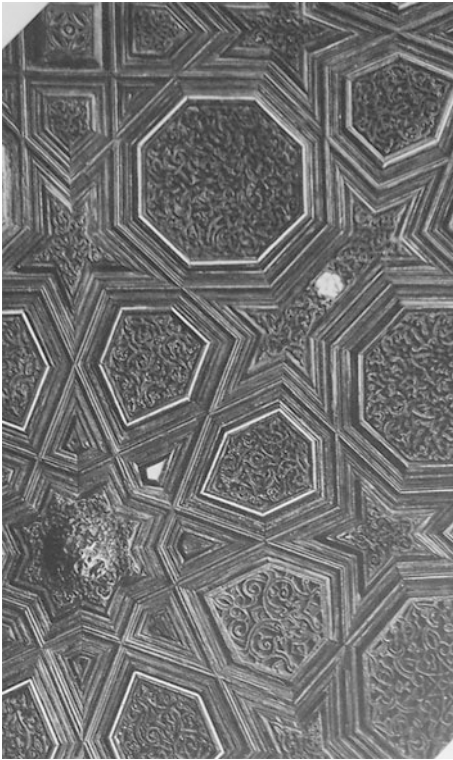
Geometry in Islamic Art, Fig. 10 Erbil, Iraq. Minaret Choli, panel of cut brick and turquoise glaze with 11-gons and 14-gons. Pattern reconstruction, as a sequential process as developed by Ajlouni and Justa (2011, Fig. 4)

contemporary studies in recent years to understand mathematical aspects of pattern construction in two and three dimensions, knowledge of which had been lost. Lu and Steinhardt (2007a) introduced the term “*girih* tiles” for what Bonner (2003) had termed sub-grids that may have allowed for the possibility of modular constructions (see also Sarhangi, Jablan, & Sazdanovic, 2005; Sarhangi, 2008a). The Topkapi scroll illustrates several design templates that demonstrate such sub-grids (see Cromwell, 2010c), in which one-point or two-point matching rules apply. Bonner (2003) associates these patterns with the design methodology he calls the “polygonal technique,” which is similar to the “polygons in contact” identified by Hankin (1925), taken up by Kaplan (2000a, 2000b, 2004, 2005) in relation to the use of computer technologies to generate Islamic star patterns.

In *Encyclopedia Iranica*, the entry for *gereh-sāzi* defines the term as “making knot” and treats it in relation to woodwork (Blair, 2012) and architecture (Milwright, 2012). The section on woodwork focuses on the early fourteenth

century in Iran, but omits reference to its important Zengid and Ayyubid antecedents, which reflect the acknowledged skill of three generations of woodworkers from Aleppo named al-Ma’ali, whose names are inscribed in their works (Mayer, 1958, pp. 48, 63, 65; Tabbaa, 2001, pp. 91, 94, 96). The value accorded such works is affirmed by historical circumstances: the task of installing the famous minbar (Fig. 11) commissioned by Nur al-Din al-Zanji (1146–1174) in the Aqsa Mosque in Jerusalem when the city was restored to Muslim rule after the Crusades fell to his successor, Saladin (Singer, 2008). And the Damascus-born thirteenth century biographer, Ibn Abi Usaibi’a, mentions a carpenter given the title *muhandis* (Arabic: architect or engineer), who had studied geometry with the greatest mathematician of his age, Sharaf al-Dīn al-Ṭūsī (c.1135–1213 CE) (Tabbaa, 2001, p. 88; Mayer, 1958, p.53).

Blair (2012) describes the product of the *gereh-sāzi* technique as geometric interlaced strapwork ornament within a lattice framework and notes that it became “very popular in the



Geometry in Islamic Art, Fig. 11 Jerusalem. Al-Aqsa mosque, minbar (destroyed by arson in 1969). Detail. Carved and inlaid wood, made in Aleppo, late twelfth century. (Photo by K. A. C. Creswell. © Creswell Archive, Ashmolean Museum, neg. EA.CA.5009. Image courtesy of Fine Arts Library, Harvard College Library, http://archnet.org/media_contents/35325 [Harvard: © administered by Ashmolean]).

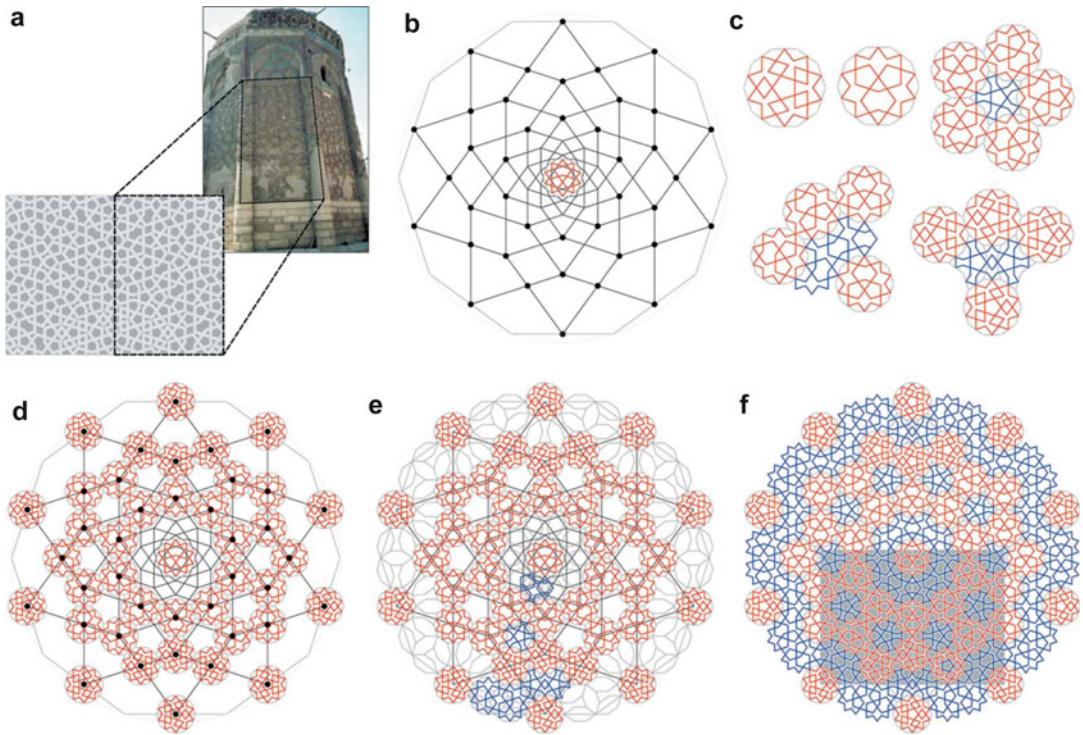
Safavid period.” From the Safavid period onward, colored glass windows, *orosi*, follow similar layouts of geometric patterning (Koliji, 2012b). And the design scrolls of the Qajar state architect, Mirza Akbar, now in the Victoria and Albert Museum, London, attest to a continuation of the tradition into the late nineteenth century (Wade, 2015 <http://patterninislamicart.com/drawings-diagrams-analyses/7/mirza-akbar-architectural-scrolls>).

Periodic and Quasiperiodic Patterns

Contemporary crystallographic interest in quasicrystals and the mathematical study of

quasiperiodic patterns have drawn recent attention to historic two-dimensional designs present in Islamic architecture from late twelfth century Iran (Bonner, 2003; Castéra, 2011; Lu & Steinhardt, 2007a, 2007b; Makovicky, 1992, 2007, 2008), with quasiperiodic octagonal lattices and decagonal patterns also recognized in Spain and Morocco (Makovicky & Fenoll Hach-Alí, 1996; Makovicky, Pérez, & Fenoll Hach-Alí, 1998). Castera (2003) considers self-similarity in *zellij* work in Andalusia and Morocco, and muqarnas, offering information concerning both transformation rules and the recursive process in two and three dimensions; the examples he considers have fourfold symmetry. Debate continues concerning the presence of periodicity – in which translational symmetry is key – in contrast to the long-range global order of quasiperiodic patterns, in which there is a high degree of symmetry without translation (Al Ajlouni, 2012; Bier, 2013; Cromwell, 2009; Saltzman, 2008) (Figs. 12, 13 and 14).

Lu and Steinhardt (2007a) focus on one early antecedent of the quasiperiodicity of patterns being studied today, which are at the forefront of mathematical thinking and identifying its underlying tiling. This pattern, which surrounds the shaft of the decagonal Gunbad-e Kabud in Maragha, had earlier been studied in detail by Makovicky (1992), a crystallographer (see also Makovicky, 2007, 2008 and Bier, 2011). As mentioned above, Bonner (2015) emphasizes that four varieties of pattern families (Fig. 13) may be produced based on the angles of intersecting lines (acute, median, obtuse, and two-point). He also notes that the underlying polygonal structures found in the fivefold system (especially the “ring of pentagons” that typically surround the decagons) very likely informed artists in their composition of more complex underlying generative tilings for patterns with multiple centers of localized symmetry. Based on this interpretation of design methodologies, Bonner (2015) argues that Lu and Steinhardt’s girih tiles (2007a) comprise a limited subset of the larger set of fivefold modules of the Islamic ornamental tradition, namely, only the median pattern family in which 72-degree angles are paramount.



Geometry in Islamic Art, Fig. 12 Maragha, Iran. Gonbad-e Kabud, decagonal tomb tower. Dated by historical inscription to 563H/1196-97. Pattern analysis and

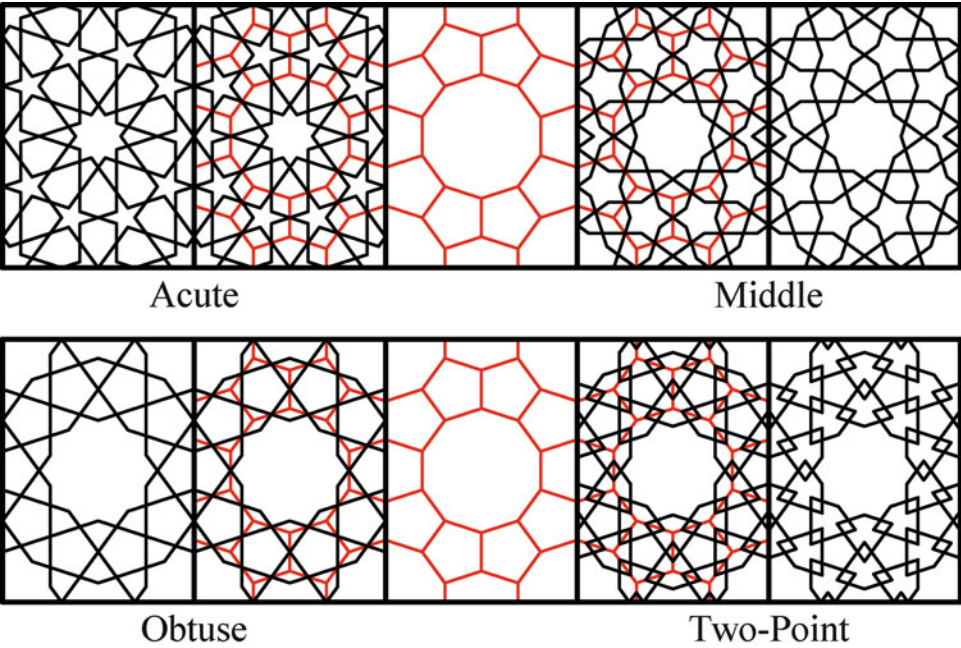
generation by Rima Ajlouni (2012, Fig. 7), showing long-range quasi-periodic pattern with local five-fold and global ten-fold radial symmetries

From the height of the Ottoman Empire in the sixteenth century, two carved and pierced medallions framing the marble *minbar*, or pulpit, of the Şehzade Mosque in Istanbul (Fig. 14) and the Selimiye Mosque in Edirne (both monuments designed by the great Ottoman imperial architect Sinan) also show quasiperiodic patterns (Bier, 2014). Other pierced openwork reticulated marble screens show periodic patterns of intersecting polygonal networks, demonstrating a systematic study of polygonal nets at least 50 years before publication of Kepler's *Harmonices Mundi* in 1619 (Bier, 2014). From the *Risale-ye Mi'mariyya*, a seventeenth century treatise on Mehmed Agha, a chief imperial architect trained by Sinan, we know that architects were trained in mother-of-pearl work (Fig. 15) in the imperial gardens of Topkapi Palace, as a means of learning

the “science of geometry,” which was considered the basis of architectural knowledge (Crane, 1987).

Handasa/Muhandis

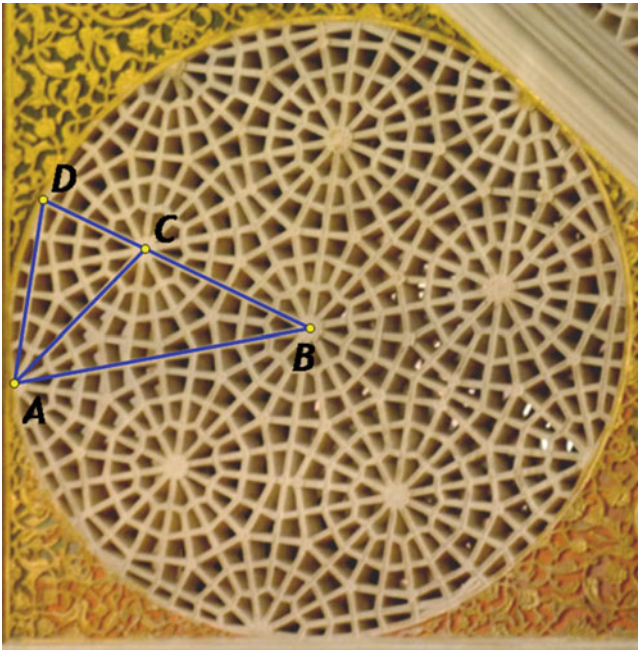
The term *handasa* (Arabic: geometry) is a loan word from Middle Persian, its use dating from before the Arab conquests of the seventh century (Suter, 2014). *‘Ilm al-handasa* is both “knowledge of geometry” and “the science of geometry,” a genitive-possessive construction. The title *muhandis* reflects an Arabic grammatical construction applied to the Persian loan word as if it were an Arabic verb with a quadriliteral root. Although it came to mean architect or engineer, its original primary meaning would have been

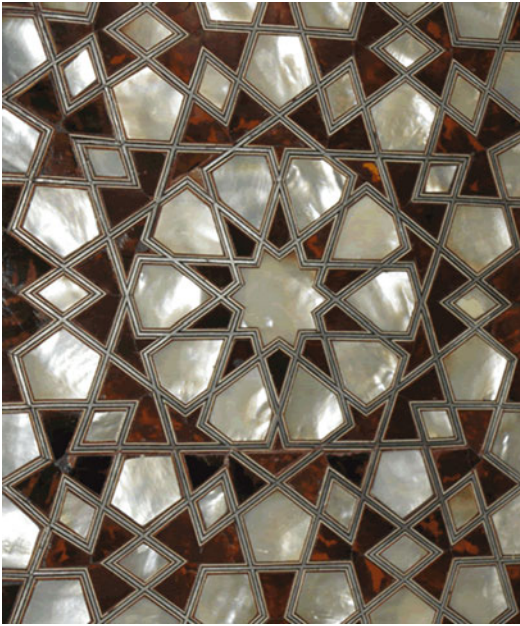


Geometry in Islamic Art, Fig. 13 A polygonal network (for example, with decagons and a ring of pentagons as illustrated) serves as a sub-grid to yield four pattern

families based upon angles of intersection at mid-points (acute, obtuse, median) or two-points. Analysis developed by Jay Bonner (2003)

Geometry in Islamic Art, Fig. 14 Istanbul, Turkey. Şehzade Mosque, circular medallion of minbar. 1543–1548 (Photo and analysis by Mirosław Majewski (2011, Fig. 91))





Geometry in Islamic Art, Fig. 15 Istanbul, Turkey. Detail of mother-of-pearl work, Ottoman, 17th century. (Photography by Roger Von Oech. http://blog.creativethink.com/images/2008/09/14/topkapi_inlay_450.gif)

associated with agency, as “geometrician” or “one who works with geometry.”

In the thirteenth century, a historian of the Delhi Sultanate, Juzjani, extols the palatial architecture of the Ghurids in his hometown of Firuzkuh as being what “no geometrician has made manifest.” Discounting fulsome panegyric, it seems reasonable to assume that this reflects the actual practice of builders and craftsmen – making geometry manifest.

Geometry as Cultural Expression (Geometry Made Manifest)

That geometry itself was held in high cultural esteem is clear from the role it plays in various script styles, both related to calligraphy of the Qurʾān which Muslims accept as having been revealed in Arabic and in the chancery (Blair, 1992, 1998, p. 206; Schimmel, 1984), as well as calligraphic inscriptions on architectural monuments. A particular focus appears in the early

calligraphic reforms of Ibn Muqla (d. 940) (Tabbaa, 1991, 1994, 2001), and the spread of Arabic scripts to other languages must also be noted. Geometry is also referenced in Arabic and Persian poetry (e.g., ‘Unsuri, Sana’i) and in the late twelfth century, Nezami (Soucek, 1975); it also figures in poetic descriptions of palace architecture (Meisami, 2001). A theological dimension may also be inferred; when Sana’i (d. 1131–41), for example, was poet laureate of the Ghaznavid court, he likened “the ability to behold the divine manifestation. . . to the intellectual way of perception of a geometrician” – “You only see with your imagination and your senses when you have not learned about lines, planes, and points” (De Bruijn, 1983, p. 238).

Points, lines, and angles, yielding intersecting lines and patterns in the plane, occur with such frequency in the pre-Mongol monuments of Afghanistan, Iran, Azerbaijan, and Iraq, as to suggest that they concern a visual discourse related to mathematical ideas. The dynamic play with patterns in the plane in the eleventh and twelfth centuries parallels the design innovations in three-dimensional forms including varieties of prismatic structures for tomb monuments, conical and pyramidal roofing arrangements, and the early development of *muqarnas* (Ashkan & Ahmad, 2012; Bloom, 1988; Tabbaa, 1985).

Scholarship on geometry in Islamic art and architecture in the twentieth century has often reflected Western prejudices, including notions that geometric patterns are abstract, repetitive, and nonrepresentational and therefore bear no meaning. Framing the interpretation of ornament as ornamental and decorative is a discourse based in the academic disciplines of the histories of art and architecture, which may have precluded cultural understanding of geometric patterns within their original cultural contexts. One renewed effort to define aesthetics in Islamic art relates optical illusion and aesthetic metaphor and explores decorative patterns of the Alhambra in terms of phenomenology and semiotics (Gonzalez, 2001). Another compares artistry to nature and identifies “reality [to be] less impressive than its artistic image,” as the “quintessence

of the Islamic visual arts” (Behrens-Abouseif, 1999, p. 141), drawing upon the works of al-Farabi, Ibn al-Haytham, and Ibn Sīnā. Belting (2011) also draws upon the theories of vision of Ibn al-Haytham, linking Arabic science to the development of linear perspective and Renaissance art. If Islamic geometric ornament is reexamined within the particular cultural context of its creative formative period in the eleventh and twelfth centuries, it may well be found that it is an expressive rather than symbolic artistic form and may be reinterpreted in relation to other forms of cultural expression – including Qur’ānic inscriptions and *tafsir* (Arabic exegesis or commentary), poetry, and contemporary texts on mathematics. In approaching geometry in Islamic art in this relational manner, we may be able to chart a new course for the study of pattern as lines of mathematical thought expressed visually.

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- al-ḥisāb* (Key of Arithmetic) of Jamshīd al-Kāshī (d. ca. 1430), in the astronomical *al-Qānūn al-Mas'ūdī* (Masudic Canon) of Abū'l Rayḥān al-Bīrūnī (973–1048) and in his treatises on astrolabes, as well as in the encyclopedic *Kitāb al-shifā* (Book of Healing) of Abū 'Alī ibn Sīnā (Avicenna 980–1037). There are also special geometric treatises, commentaries on Euclid, and treatises on geometrical theorems, calculations, constructions, and the foundations of geometry.
- Calculations of areas of plane figures and of volumes of solids were considered in the chapter “On mensuration” of the algebraic treatise of al-Khwārizmī. Many rules in this entry coincide with the rules of Hero's *Metrics* (first century AD) and of Indian mathematicians of the fifth and sixth centuries. For the area S of a circle with radius r , he applies the rule $S = \pi r^2$, where $\pi = 3\frac{1}{7}$, $\sqrt{10}$, 62832/20000.
- The contents of this entry are similar to the Hebrew *Mishnat ha-middot* (Treatise on Measuring), which was believed to be part of the *Talmud* written in the second century AD. Recently Zarfatti (1968) showed that this book was written after al-Khwārizmī's treatise and under its influence.
- Many treatises on geometric calculation were written by Thābit ibn Qurra. In his *Kitāb fī misāḥa al-ashkāl al-musaṭṭaḥa wa 'l-mujassama* (Book on Mensuration of Plane and Solid Figures), he provides many rules for measuring area and volume. For example, there is his general rule for the calculation of the volume V of a right round cylinder, cone, and truncated cone expressed by one formula: $V = \frac{1}{3}h(S_1 + S_2 + \sqrt{S_1S_2})$.
- In his *Kitāb fī misāḥa qaṭ' al-makhrūṭ alladhī yusammā al-mukāfī* (Book on Mensuration of a Conic Section Named Parabola) and other works, Thābit tackles many geometric problems. Among these are the problems of calculating the area of a segment of a parabola, the volume of segments of solids obtained by the revolution of segments of a parabola, and of the area of a surface of an oblique round cylinder. Thābit calculated the area of segments of an ellipse by means of an

Geometry in Islamic Mathematics

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Many original Muslim geometric works are “books” or chapters of great mathematical, astronomical, and encyclopedic works. Geometrical parts are contained in the algebraic treatise of al-Khwārizmī (ca. 780–850), in the *Miftāḥ*

equi-affine transformation of the ellipse onto a circle with equal area. His grandson Ibrāhīm ibn Sinān, (908–946) in his *Kitāb fī misāḥa al-qaṭʿ al-mukāfī* (Book on Mensuration of a Parabola) calculated the area of a segment of a parabola by means of a general affine transformation. Wayjan al-Qūhī (tenth to eleventh centuries) and Ibn al-Haytham (965–ca. 1040) calculated the volumes of segments of solids obtained by the revolution of segments of parabolas that Thābit had not considered.

Al-Bīrūnī, in the mathematical part of his *Masudic Canon*, calculated the sides of a regular triangle, square, pentagon, hexagon, octagon, and decagon inscribed in a given circle. Also, he provided the length $C = 2\pi r$ as the circumference of a circle where $\pi = 3.7305910$ in sexagesimal fractions and 1628631471/518400000 in decimal. Al-Kāshī in his *al-Risāla al-muḥīṭiyya* (Treatise on Circumference) calculated the length $C = 2\pi r$ by means of the calculation of the perimeter of regular inscribed and circumscribed polygons with 3.2^{28} sides. The number of sides was chosen on the condition that the difference between these perimeters for the great circle of the sphere of fixed stars must be less than the “width of a horse hair.” The result was expressed in sexagesimal and decimal fractions as 3.829440472553725 and 3.14159265358979325. In the last case, the calculation is correct up to 17 digits.

The teachers of Thābit ibn Qurra, the brothers Muḥammad (d. 872), Aḥmad, and al-ḥasan Banū Mūsā ibn Shākir, in their *Kitāb al-shakl al-mudawwar al-mustaṭīl* (Book on an Oblong Round Figure), proposed the construction of an ellipse by means of a string attached to its foci (the so-called “Gardiner’s construction”). Thābit himself solved two classical problems of antiquity: the construction of two mean proportional magnitudes between two given ones ($a : x : y : b$), which is the Delic problem of the duplication of a cube (if $b = 2a$) and the trisection of an angle. He also proposed the spatial construction of a semiregular polyhedron with 14 faces, which some now say was discovered by Archimedes.

The great philosopher Abū Naṣr al-Fārābī (ca. 870–950) proposed many geometric

constructions of parabolas, regular polygons, squares equal to three given equal squares, constructions with one opening of the compass, and constructions on the sphere. These were also studied by Thābit’s pupil’s pupil Abū’l-Wafā al-Būzjāni (940–998) in the *Kitāb fī mā yakhtāju ilayhi al-ṣāniʿ min aʿmāl al-handasiyya* (Book on What is Necessary from Geometric Construction for the Artisan).

Ibrāhīm ibn Sinān ibn Thābit proposed many ways to construct a parabola (including al-Fārābī’s one), ellipse, and hyperbola. One of the constructions of an ellipse is based on the compression of a circle; one of a hyperbola is based on a projective transformation of a circle.

Al-Qūhī described the instrument for the construction of conics, which he invented. It is a compass in which one leg varies in length and the second leg can change the angle of its slope to the plane. Many methods for the construction of conics were described by al-Bīrūnī in *Istīʿāb al-wujūh mumkina fī ṣanʿa al-aṣṭurlāb* (The Exhaustion of Possible Ways of Constructing an Astrolabe). In particular, he mentions the “Gardiner’s construction” of Banū Mūsā, the perfect compass of al-Qūhī, and constructions of all three kinds of conics based on projective transformations.

Al-Fārābī revised the order of the first definitions of Euclid. The first definition of Book 1 of the *Elements* was that of a point as “that which has no parts.” Later, Euclid defined a line as “a breadthless length” and a surface as “that which has length and breadth only.” In Book 11, he defined a solid as “that which has length, breadth, and depth.” Al-Fārābī, following Aristotle, defined a solid as the first abstraction from a physical body, a surface as the abstraction from a thin solid, a line as the abstraction from a narrow surface, and a point as the abstraction from a short line. The same order of geometric definitions was used by al-Bīrūnī in the geometric part of his *Kitāb al-taḥfīm li-awāʾil ṣināʿa al-tanjīm* (Book of Instruction in the Elements of the Art of Astrology).

In his *Taḥrīr Uqlīdis* (Exposition of Euclid), Naṣīr al-Dīn al-Ṭūsī added to Euclid’s axioms that of the existence of points, lines, and surfaces,

and the axiom of possibility of choice of a point on an arbitrary line and surface and of a line on an arbitrary surface and through an arbitrary point. There are also analogous axioms ascribed to al-Ṭūsī's version of the exposition of Euclid's *Elements* and in the geometric part of the encyclopedic work of his pupil Quṭb al-Dīn al-Shīrāzī (1236–1311). In both these works, there are also attempts to prove Euclid's first three postulates about the ideal ruler and compass.

In al-Shīrāzī's commentaries to al-Ṭūsī, the rules of the theory of syllogisms from Aristotle's *Analytics* are systematically used.

In many Islamic treatises, the problem of mathematical atomism was discussed. Aristotle's ideas, on which Euclid's *Elements* is based, ousted the mathematical atomism of Pythagoras and Democritus. According to them, finite solids, surfaces, and lines consist of a finite number of "atoms." Pythagoras said these atoms were points without sizes, and the sizes of finite figures were created by the distances between them. According to Democritus these atoms were particles with very small but finite sizes. In medieval Islam, the ideas of mathematical atomism were held by Muslim scholastics, the *mu' tazila* and *mutakallimūn*, who wanted to find a rational explanation for Islam. They believed that time consists of a separate "now" and explained by means of this view that God creates the world anew every instant. Among the *mu' tazila*, there were adherents of both types of mathematical atomism. The first school was headed by Abū'l-Qāsim al-Ka' bī (d. 932) whose nickname al-Ka' bī means "cubical"; the second was headed by Abū'l-hāshim al-Jubbā' ī (820–933). Democritus' ideas were also held by the philosopher and alchemist Abū Bakr al-Rāzī (865–952). The idea of mathematical atomism was also mentioned by al-Shīrāzī in his commentaries on a treatise by al-Ṭūsī.

Islamic mathematicians often attempted to prove Euclid's fifth postulate on which the theory of parallel lines in his *Elements* is based. This postulate is much more complicated than the first four. It asserts that, if a straight line falling on two straight lines makes the interior angles on the same side together less than two right angles, the two straight lines, if produced indefinitely,

meet on that side in which the angles together are less than two right angles. Attempts to prove this axiom as a theorem were made by Archimedes (third century BCE), Posidonius (second to first centuries BCE), Ptolemy (second century AD), Proclus (fifth century), and Simplicius (sixth century). In their proofs, there was the logical error of *petitio principii*, i.e., the implicit use of an assertion equivalent to the one being proved.

The first Islamic mathematician who attempted to prove the fifth postulate was al-'Abbās al-Jawharī (first half of the ninth century). In his *Iṣlāḥ li-kitāb al-Uṣūl* (Improvement of the Book "Elements") he proposed a proof based on the assertion that a straight line intersecting both sides of an angle can always be drawn through any point inside this angle.

Thābit ibn Qurra made two attempts to prove the fifth postulate. His two treatises on parallel lines were written in Syriac and then translated by him into Arabic. The first proof is based on the assertion of the existence of "a simple motion"; i.e., a parallel translation equivalent to the existence of equidistant straight lines and to the existence of a rectangle. The second proof is based on the assertion that, if two straight lines diverge on one side of a line falling on them, they necessarily converge on the other side. From this follows the existence of a parallelogram. An analogous error was made by al-Faḍl al-Nayrīzī (d. 922) in his *Risāla fī bayān al-muṣāḍara al-mashhūra min Uqlīdis* (Treatise on the Proof of the Known Postulate of Euclid).

Ibn al-Haytham also made two attempts to prove the fifth postulate. One attempt was based on the same error as in Thābit's first treatise. In this proof, Ibn al-Haytham first considered quadrangles with three right angles ("the Lambert quadrangles") and three hypotheses about their fourth angle. The hypotheses of acute and obtuse angles were refuted by means of the existence of a rectangle. The second attempt was written in his last years. Here was the first proof of the fifth postulate which was free from logical error. At first the postulate was replaced by another more evident one and was proved by means of it. This new postulate was: two intersecting straight lines

cannot be parallel to a third line. This postulate in the form “if the point A and a straight line a are given, it is impossible to draw more than one not intersecting line through A in their plane.” This is now known as “the Playfair postulate” or “the strong Hilbert axiom of parallels,” after Europeans who later came up with the same axiom.

Also free from logical error was ‘Umar al-Khayyām’s proof of the fifth postulate in his *Sharḥ mā ashkala min muṣādarāt kitāb Uqlīdis* (Commentaries on Difficulties in Introductions of Euclid’s Book). In this work, Khayyām proved the postulate on the basis of a postulate which he called the “fourth principle of the philosopher (Aristotle).” “Two converging lines intersect and it is impossible for them to converge in the direction of divergence.” In this proof, he first considered equilateral quadrangles with two right angles at their low bases (which we now call “the Saccheri quadrangles”) and three hypotheses about their equal upper angles. The hypotheses of acute and obtuse angles are refuted by means of this fourth principle. These two hypotheses, which are analogous to those of Ibn al-Haytham (his quadrangles are halves of Khayyām’s), are fulfilled in hyperbolic and elliptic non-Euclidean geometries, respectively. Ibn al-Haytham and Khayyām actually proved some theorems of these geometries first.

Naṣīr al-Dīn al-Ṭūsī considered the theory of parallel lines. In the treatise, al-Ṭūsī explained the proofs of al-Jawharī, Ibn al-Haytham (only the second), and Khayyām (not completely) and considered the same quadrangles and the same three hypotheses as Khayyām. However, he made the same logical error *petitio principii*. In the book, written after the critical letters of Qayṣar al-Hanafī (ca. 1170–1251), he explained the same proof, but before it he formulated the postulate similar to Khayyām’s, and thus does not make a logical error.

Al-Shīrāzī also made an attempt to prove the fifth postulate based on a logical error: he supposed that the distance between lines which do not intersect is constant.

We saw that in the proofs of the fifth postulate by Thābit ibn Qurra and Ibn al-Haytham “a

simple motion” was used. The application of motion to geometry was used by Pythagoreans who considered lines as traces of moving points and surfaces as traces of moving lines. However, this application was rejected by Aristotle, who considered geometric solids as abstractions from physical bodies, surfaces as abstractions from thin solids, lines as abstractions from narrow surfaces, and points as abstractions from short lines. Following Aristotle, Euclid tried in his *Elements* to avoid the application of motion. Khayyām criticized the application of motion by Ibn al-Haytham.

We also saw that Thābit ibn Qurra and his grandson Ibrāhīm ibn Sinān used affine transformations in their geometric treatises, and al-Bīrūnī also used projective transformations.

An astronomical instrument called an astrolabe was very popular in the Middle Ages. It was based on the projection of the celestial sphere onto its plane. Many treatises on the construction of astrolabes contain descriptions of different projections. In the *Kitāb ṣan‘a al-aṣṭurlāb* (Book of the Construction of the Astrolabe), Aḥmad al-Farghānī (d. 861) described the stereographic projection. That and others were described by al-Bīrūnī in his *Exhaustive Ways of Constructing an Astrolabe*. Al-Bīrūnī applied a stereographic projection for determining the azimuth of *qibla* (the direction to Mecca). He also used the stereographic and some other projections of a sphere on to a plane in his *Risāla fī taṣṭīḥ al-ṣuwar wa tabṭīḥ al-kuwar* (Treatise on the Projection of Designs on to a Plane and on the Map of Spheres on a Plane), which was devoted to problems of cartography.

In the *Elements*, Euclid used the plane geometrical algebra inherited from the Pythagoreans. In this, he represents the products $a \times b$ as rectangles with sides a and b and provides a geometric representation of algebraic equalities. For instance, there is a representation of the formula $(a + b)^2 = a^2 + 2ab + b^2$ by decomposing the square $(a + b)^2$ on two squares a^2 and b^2 and two rectangles $a \times b$. In Archimedes’ *Lemmas* there is an analogous decomposition of a circle with diameter $a + b$ on two circles

with diameters a and b and two “arbelons.” Analogous representations of the formula $(a + b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$ by decompositions of the cube $(a + b)^3$ and of the sphere with diameter $a + b$ were proposed by Abū Saʿīd al-Sijzī (ca. 950–1025).

Apparently, the idea of “geometric” names for powers, square-square for x^4 , square-cube for x^5 , cube-cube for x^6 , and so on, was borrowed from Diophantus’ *Arithmetics*.

Islamic mathematicians used rectangular and oblique coordinates connected with conics: the axes of these coordinates were one of the diameters of a conic and the tangent line at one of its ends. Each point of a conic was determined by half of its chord conjugate with this diameter from a given point to the diameter and by the segment of this diameter from its end (vertex) to the meeting point of the chord with the diameter. They called these coordinates “ordered lines” and “line cut from the vertex,” respectively. (Our terms “ordinate” and “abscissa” came from Latin translations of these expressions.) These coordinates were used by Khayyām in his *Risāla fī l-barāhīn ‘alā masā’il al-jabr wa’ l-muqābala* (Treatise on Demonstrations of Problems of Algebra), which was devoted to the solution of cubic equations by means of the intersection of conics.

Islamic astronomers and geographers following Ptolemy used the geographical coordinates longitude and latitude for the surface of the Earth, and analogous ecliptical coordinates with the same names, the horizontal coordinates azimuth and altitude, and the equatorial coordinates right ascension (or horary angle) and declination for the celestial sphere. Thābit ibn Qurra determined the positions of the ends of the shadows of the gnomon on the plane of a plane sundial by rectangular coordinates which he called, by analogy with the geographical coordinates, longitude and latitude, and by polar coordinates which he called azimuth and length of shadow.

Muḥammad al-Khwārizmī in his geographical treatise *Kitāb ṣūra al-arḍ* (Book of the Picture of the Earth) proposed the classification of curved lines and used the names of different kinds of

lines in his descriptions of rivers, seacoasts, and islands between points with given geographical coordinates.

In addition to their original contributions, Muslims made many translations of Greek works. In many cases, the Arabic version of the work is the only one extant today. The most important Greek geometric work, Euclid’s *Elements*, was translated into Arabic in the ninth century AD by al-Ḥajjāj ibn Yūsuf ibn Maṭar and Iṣḥāq ibn Ḥunayn al-ʿIbādī. The last translation was edited and supplemented by Thābit ibn Qurra (836–901), who was also the translator of other works of Euclid, of many works of Archimedes, of the *Conics* of Apollonius, and of many Greek mathematical works. These, together with a geometric treatise of his teachers the brethren Banū Mūsā and his *Kitāb al-mafrūdāt* (Book of Assumptions) constituted the so-called “middle books” which were studied between Euclid’s *Elements* and Ptolemy’s *Almagest*. Later, many Muslim revisions of other Greek mathematical works appeared.

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [al-Bīrūnī](#)
- [al-Farghānī](#)
- [al-Kāshī](#)
- [al-Khujandī](#)
- [al-Khwārizmī](#)
- [al-Māhānī](#)
- [al-Rāzī](#)
- [al-Shīrāzī](#)
- [al-Sijzī](#)
- [Al-Qūhī \(or Al-Kūhī\)](#)
- [Astrolabe](#)
- [Atomism in Islamic Thought](#)
- [Banū Mūsā](#)
- [Conics](#)
- [Elements: Reception of Euclid’s *Elements* in the Islamic World](#)
- [Geography in the Islamic World](#)
- [Ibn Al-Haytham \(Alhazen\)](#)

- ▶ [Ibrāhīm ibn Sinān](#)
- ▶ [Maps and Mapmaking: Islamic Terrestrial Maps](#)
- ▶ [Mathematics in Islam](#)
- ▶ [Naṣīr al-Dīn al-Tūsī](#)
- ▶ [Sexagesimal system](#)
- ▶ [Sundials in Islam](#)
- ▶ [Thābit ibn Qurra](#)
- ▶ [Umar al-Khayyām](#)

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Geometry in Japanese Mathematics

Yoshimasa Michiwaki

Western mathematics is concerned very much with logic based on proof and demonstration. Japanese mathematics in the Edo period (1603–1867), which is called *Wasan*, has its origin in China, and from the beginning put its emphasis on application, mainly on application in daily life. At the beginning of *Wasan*, experts studied practical aspects of mathematics, such as deriving the areas of figures and the volumes of solid bodies. However, in the developing period, they began to devise questions which provided conclusions based on the beauty of figures and complicated calculation. They especially liked questions on geometrical figures, and they had their own ways of studying. When they studied circles, they tried to increase their number, change their positions, and consider them as ellipses. They also tried to expand into three dimensions. Because of the national isolation policy of Japan, *Wasan* experts were kept in guild-like groups. The study of *Wasan* became

very complicated; practitioners could not concentrate on the main themes but had to act as if their studies were rather like a hobby.

Wasan was formulated in the latter half of the seventeenth century by a Japanese mathematician, Takakazu Seki (or Kowa Seki) with the text *Jinko-ki* as its basis. The interest of *Wasan* experts in those days was to solve the questions left unsolved in *Jinko-ki* and other mathematical texts: that is, to calculate the areas and volumes of planes and solid figures, and also the length of chords and arcs and the area surrounded by them. Takakazu Seki, before he succeeded in systematizing *Wasan*, tried hard to solve those questions, and in the process studied parabolas, hyperbolas, and also the spirals of Archimedes. And he partially succeeded in measuring ellipses.

In the field of algebra, Seki used a determinant of five dimensions in his work *Kaifukudai-no-ho* published in 1683. In the area of geometry, he derived a relative equation between a side of a regular polygon and radii of an inscribed circle and a circumscribed circle. This arose from a theory on regular polygons. He also made great accomplishments in the field of *Enri*: this word may be translated as “circle principle” or “circle theory”, being derived from the fact that the measurement of the circle is the first subject that it treats. He repeated doubling the numbers of the side of an inscribed, regular polygon, and achieved the correct number for π . He devised a calculation method for circles – integral calculation – studying the relation among the chord, the arrow, and the arc. He also worked in other fields, such as the calendar.

After the publication of such works as *Seiyo Sampō*, *Shinpeki Sampō*, *Sampō Kokon Tsuran*, and *Sampō Tensei-ho Shinan*, interest in *Wasan* was very much aroused. For example, *Sangaku* (Mathematical Tablets) were dedicated to shrines and Buddhist temples. Some of these are beautiful, with figures of red, blue, and yellow. The definitions of the figures are not written on the tablets, but the drawn figures (questions) themselves illustrate the things necessary to solve the questions. These questions posed by *Wasan* experts are combined questions, such as a square and a square, a straight line and a circle, a circle

and plural circles (or ellipses). There are questions on the length of a square side, a straight line, and the radius of a circle. There are also questions on the number and areas of circles put into one circle. These questions are expanded from “plane” to “solid” and from “limited” to “unlimited.”

Wasan experts tried to derive the theorems to solve questions, and in the process they reached general laws by something like an inductive method. They sought a general equation with some sort of inspiration. One of these *Wasan* experts, Nushizumi Yamaji, stated in his *Sampo Ruiju* (Vol. 3) the same ideas as in Descartes’ circle theorem but in a different way. A theorem like Descartes’ was introduced in the mathematical texts of the first half of the nineteenth century, such as *Kokon Sankan* by Gokan Uchida.

Wasan in the Bunka and Bunsei period (1804–1818–1829) was at its peak. In *Suri Mujinzo* by Nagatada Shi-raishi, one finds a technique or theorem called *Bosha Jutsu*, which has exactly the same idea as Casey’s. This theorem is considered an extension of Ptolemy’s.

Shingen Takeda wrote *Shingen Sampō*. In the first volume of this work, there is a problem called Clever Ways to Cross the Twenty-Eight Bridges in Naniwa (now Osaka).

Another *Wasan* expert, Zen Hodoji, learned many things through visiting various districts and teaching students in each district. In one of his works, *Kan-shinko Sanhen*, there are questions which are close to the present “inversion” formula. We are not sure how he reached the inversion formula, but the result was correct.

As was stated before, *Wasan* experts were inspired to find a solving technique. *Kyokkei Jutsu* and *Henkei Jutsu* should be introduced here. *Kyokkei Jutsu* is explained in *Sampo Kyokkei Shinan* written by Hiroshi Hasegawa and his student, Giichi Akita. Special figures – *Kyokkei* – are used in this method. Beside this, Hasegawa wrote *Sampo Henkei Shinan* with his student, Teishin Heinouchi. In this, you find a sentence which says that “Questions with reasonable conditions, that is, questions with conditions enough to solve them are called “complete questions” while others with too

many or too few conditions are called “incomplete questions.” Some of these questions can be solved with insufficient conditions, and they are called *Kyoku Dai* (special questions). This book deals mainly with variations of *Kyoku Dai*. Both *Kyokkei Jutsu* and *Henkei Jutsu* deal with figures in special cases instead of general figures, but each technique is different. *Kyokkei Jutsu* has a tendency to make a mistake by trying to get an answer; *Henkei Jutsu* has no such tendency, but you find it difficult to get a *Kyoku Dai*. Each method is unique as a method of geometrical studies.

In the Meiji period (1868–1911), the new education system established in 1872 eliminated *Wasan* studies from public education, and adopted western mathematics.

However, in the Taisho and Showa periods (1912–1928–1988) mathematical leaders such as Tsuruichi Hayashi and Matsusaburo Fujiwara collected materials and wrote theses on various themes of *Wasan*, and its popularity was revived. The History of Science Society of Japan was established in 1941 and Kin-nosuke Ogura, counselor of the society, insisted that Japanese mathematics history be carefully considered. The Mathematics Club, later The History of Mathematics Society of Japan, was established in 1958 mainly to study *Wasan*. Seminar groups appeared in many districts, and magazines and theses were published. In 1979, the *History of Japanese Mathematics before the Meiji Period* (5 Vols.) edited by the Japan Academy was completed. All of the works mentioned in this essay can be found in this set.

See Also

► [Seki Kowa](#)

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Geometry in Mesopotamia and Egypt

Jens Høyrup

This article concentrates on the geometrical knowledge of the scribal traditions, not on what *could* have served for the construction of buildings. It must be observed that high technical precision is often achieved through the combination of quite elementary mathematics and sophisticated non-mathematical techniques. Anyone who has played with rulers and compasses knows that a regular pentagon can easily be made more precise through trial and error than by “exact” construction with all its accumulated errors. It is therefore next to impossible to

extrapolate from the high precision of for example prestige buildings to the particular kind of geometry used in their design, unless some kind of blueprint has survived. Even in such cases, when the tracing of a ground plan has subsisted or the building can be seen to be planned around base lines geared to the standard brick, all that may be concluded is often that *some kind of* geometrical knowledge is involved.

On the other hand, in Mesopotamia as well as Egypt, written texts with geometrical contents have survived, most of which are scribe school problems. Even when unambiguous (which is not always the case), they confront us with a problem of bias: scribal mathematics consisted in calculation; the texts always aim at the determination of a number (an area, a volume, the number of man-days needed to dig a ditch, etc.). Geometrical construction was not the concern of the scribes.

Mesopotamia

The sources for our knowledge of Mesopotamian geometry reach back to the later fourth millennium BCE. The earliest sources are not very informative, but they demonstrate that the length and area metrology, together with the basic techniques for area computation, go back to the first phase of writing. Sources from the third millennium become more copious, in particular towards its end. Sophisticated scribe school problems dealing with complex volumes only turn up in the Old Babylonian period (early second millennium) and disappear again from the horizon after 1600 BCE. Finally, some interesting texts have survived from the later half of the first millennium BCE.

Length metrology may have been created in the same process as writing and written administration. Already in the earliest written documents, area metrology is keyed to the length system – but some of its units appear to be old “natural” (irrigation, ploughing, or seed) measures which have been normalized so as to fit, while others have been created anew. These systems survive until the end of the Old Babylonian period. In the

late period, new quasi-natural measures (seed measures) allowing easier practical computation take over.

The basic volume measures coincide with the area measures, which are tacitly imagined as provided with the height 1 cubit. The system of hollow measures, on the other hand, is perplexingly complex, involving both traditional measures that have been normalized so as to fit the length system, and corrections introduced in order to facilitate practical computation of rations, cylindrical volumes, etc. A Mesopotamian specialty is the multiplicity of “brick measures”, using the terminology of volume measures but referring in fact to the number of bricks, for which several standard dimensions coexisted.

The Old Babylonian texts show us that square and rectangular areas as well as right triangles and trapezia were calculated as we would do it. No unambiguous standard term for the height of a triangle or a trapezium is present, and field plans show us that complex areas, including skew triangles and trapezia, were subdivided into “practically rectangular” quadrangles and “practically right” triangles. No concept of a quantified angle is present, the field plans seem simply to distinguish “right” from “wrong” angles.

In practical mensuration, working in an always slightly uneven terrain and not in an abstract Euclidean plane, what is laid out as a rectangle with traditional methods mostly turns out to have slightly different opposing sides. In this situation, the Mesopotamian scribes calculated the area according to the “surveyors’ formula”: average length times average width. The result always exceeds the true area, but not significantly if the angles of the quadrangle are approximately right. In school problems, where the formula served as a pretext for calculation, it was occasionally used in situations where the outcome was absurd. In practical field measurement, a single instance is known where the error is at least 100 %; whether this reflects general carelessness or the ignorance of a single scribe is not clear (it is even possible that a number written along a side is really meant to be the height, in which case there is no error in the computation but only a somewhat careless diagram).

Most often, the circular area was determined as $1/12$ of the square on the circumference (which is often the dimension most easily determined in practice by means of a piece of string). Translated into our idiom, this means that 4π was approximated as 12, or that $\pi = 3$. Other computations, such as the determination of the diameter from the circumference, agree with this; the Babylonians were thus aware that the circular area was the semi-product of the radius and the circumference.

Simple volumes (prisms, cylinders) were determined as the product of the base and the height – the formulation being that the base was “raised” to the height. Raising is a general term for multiplication based on considerations of proportionality – derived originally from volume determinations but in general use. The idea which underlies volume determination is indeed one of proportionality, since the base was understood as already provided with a standard height of 1 cubit. Similarly, a length could be understood as provided with a standard width of one length unit, and area computations (when not implicit in the construction of a rectangle) were hence also done by raising.

Complex volumes, such as truncated pyramids and cones, were determined by ad hoc methods, not always correctly or consistently. Several texts determine the volume of a truncated cone as that of a cylinder whose diameter is the average of the diameters of top and bottom. One of them determines the volume of a truncated square pyramid in the same way, but adds a correction term that makes the computation accurate (it is not quite sure whether the underlying reasoning is also correct). Other texts determine the volumes of truncated cones and pyramids by raising the average between top and bottom area to the height.

No later than the Old Babylonian period, the Pythagorean theorem was known and used for diagonal calculations. The purpose of a table text making use of Pythagorean triples is not fully decided, but it seems to be arithmetical rather than geometrical.

Already in the twenty-third century BCE, it was known that the square on the parallel transversal which bisects a trapezium is the half-sum

of the squares on the parallel sides. No text tells us how this formula was reached, but it follows without difficulty from consideration of two squares of which one is embedded concentrically in the other. Similar naïve-geometric reflections may have led to the discovery of the Pythagorean theorem; their presence is well attested in the so-called “algebra” texts.

A few texts testify to an interest in geometrical arrangements and in regular polygons; in the actual cases, however, the texts always calculate something (mostly an area). A text with a regular hexagon draws a height in one of the six isosceles triangles from which it is composed and computes its length and uses this in the determination of the area.

The few late Babylonian texts exhibit some changes in the area techniques, such as a more general use of heights in area determination.

Egypt

Third-millennium sources for Egyptian geometry are rare, and even though the precision of the great pyramids demonstrates both architectural and geometrical skill, they tell us little about the geometrical techniques that were in use.

The important mathematical texts – the *Rhind Mathematical Papyrus* and the *Moscow Papyrus* – date from the early second millennium BCE. Together with some minor texts and fragments and with what can be grasped from administrative documents, they present us with a coherent picture. In spite of some unsolved problems of interpretation and the presence of still open questions, nothing suggests that new sources might change our understanding of Egyptian mathematics radically. Nor does Egyptian technology, in spite of its indubitable sophistication, ask for *mathematical* knowledge beyond what we know from the papyri.

The evidence for the length and area metrologies of the third millennium is meager, but sufficient to show that they were intricate; the metrologies of the early second millennium derive from and expand a subset of the third-millennium systems.

In this “classical” period, the most widely used length unit was a “royal cubit” of seven palms. Also in use was a “short cubit” of six palms, together with units equal to the diagonal and semi-diagonal of a square with side equal to the royal cubit.

Area units were derived from the length units. The basic unit for land measurement was (100 cubit)²; for practical purposes, however, the Egyptians would often think in terms of strips with a standard breadth, as the Babylonians might also do.

Volume and capacity units were also keyed to the length system, but in a way that shows them to have originated independently – how else are we to explain that the basic volume unit was not 1 cubit³ but $\frac{2}{3}$ cubit³?

The areas of squares, rectangles and right triangles were calculated from length and width. The areas of trapezia and isosceles triangles were found as the product of height and average width, and the Rhind Mathematical Papyrus explains that this calculation of the triangular area means that the triangle is transformed into a rectangle. It should be noted that the height is a given or measured number, not the outcome of a computation.

The area of the circle was found as, $(\frac{8}{9}d)^2$ where d is the diameter. Translated into modern terms this means that the interesting constant was not π but, $\sqrt{\pi/4}$ which was approximated as 0.888... (where the true value is 0.8862...).

One problem (concerned with a “basket”) has been interpreted as the correct determination of the surface of a semi-sphere (equal to twice the cross section of the sphere). Another interpretation is that the text wants to determine the curved surface of a semi-cylinder, which will then also be correct, and would imply that the semi-circumference of the circle was found in agreement with the determination of the area.

Volumes of prisms and cylinders were found as the product of base and height (multiplied with a metrological conversion factor $\frac{3}{2}$). The *Moscow Papyrus* gives a correct determination of the truncated pyramid as $(a^2 + ab + b^2)(h/3)$ (where a and b are the sides of the upper and lower square and h the height).

Pyramid slopes were measured as horizontal recess, measured in palms, per cubit increased height. Most often, in texts as well as practice, the value is $5 \frac{1}{4}$, corresponding to a ratio 3:4 in pure numbers. Countless attempts have been made to demonstrate that the Cheops pyramid hides knowledge of either π or the Golden section (or both!) in its proportions. The proximity of certain ratios to these “mystical” numbers is, however, a mere consequence of the simple determination of the slope. Moreover, as we have seen, the Egyptians were not interested in the ratio π but in the equivalent number $\sqrt{\pi/4}$. There is no reason to believe that the pyramids testify to occult mathematical knowledge beyond the level revealed in the mathematical papyri. As Otto Neugebauer has pointed out, nothing is less secret than the “secret” knowledge of the Egyptians, the Greek magicians, the Gnostics, etc., all of whom have left an immense number of texts on occult topics, exceeding by far anything these cultures ever wrote on mathematics. Had the Egyptians possessed secret mathematical knowledge, we would certainly have been informed, as we are about the secret spells to be used in the Netherworld.

Even the oft-claimed Egyptian knowledge of the Pythagorean theorem (or at least of the fact that a 3-4-5-triangle is right) should be treated with circumspection. No single text suggests so. One of the arguments in favor of the assumption has been that this knowledge *might* have been used to construct right angles. This trivially correct observation made by Moritz Cantor has since then been quoted as information that they did so. The other is that the pyramid recess of 3:4 could have been chosen for this reason. As we have seen, however, the actual number used by the Egyptians was $5 \frac{1}{4}$; if the vertical distance was measured in cubits and the horizontal in palms, what was then to be done with the hypotenuse?

All of this concerned the mathematics of the scribes. Egypt, however, offers an exception to the rule that non-scribal geometrical techniques cannot be decoded. This exception regards not least the use of square grids, first of all in the pictorial arts but also in architectural planning.

In the pictorial arts the grids were connected to a so-called “canonical system” for the proportions of the human body. That is, whereas scribal geometry aimed at finding numbers from geometrical configurations, the artists determined geometrical configurations from numbers. Quarries and buildings also carry marks in large quantity that inform us about some of the measuring techniques that were used.

General Observations

Histories of mathematics tend to distinguish “exact” from “approximate” formulae. In so far as we are dealing with school traditions built on some kind of didactical argument, this distinction may be defended. Both Babylonian and Egyptian scribal training certainly involved argument, even though it was not deductive. However, when making this distinction we forget that formulae can only be exact with regard to ideal mathematical objects; when it comes to applying the formulae in real-life practice, *all* formulae become approximate.

Histories of mathematics – in particular general histories – also tend to translate into familiar terms. To a certain extent this is necessary, but it hides from view the fact that other cultures may use conceptualizations which are different from ours but just as good and consistent. Speaking of a Babylonian and an Egyptian “value for π ” suggests that the Babylonians, as we, looked for the ratio between the circumference and the diameter of a circle. However, to the Babylonians, the fundamental ratio was the ratio between the area of the circle and the area of the square on the circumference, and the terminology they used demonstrates that they really thought of this as a constructed geometrical square. The Egyptians, for their part, were interested in the ratio between the sides of the squared circle and that of the circumscribed square. Both conceptualizations are fully legitimate, also according to the gauge of mathematical theory, but they are certainly different from ours. If we neglect this, we only use the foreign culture as a mirror where we see – ourselves.

Later Developments

In the first millennium BCE, Egypt was conquered first by the Assyrians, then subdued by the Persian armies, and finally – after Alexander – ruled by a Greek dynasty. We cannot follow the phases of this in detail in the rare mathematical texts, but we observe that the Assyrian or Persian administrators and tax collectors brought some of their own methods to Egypt, such as, for instance, the “surveyors’ formula”. We also see that the practical geometries of the Babylonian and Egyptian cultures served as inspiration for the Greeks when they developed their theoretical geometry. But Greek theoretical development did not influence geometrical practice significantly, in spite of the real or affected efforts of certain Alexandrian mathematicians to educate the practitioners (in particular Hero). The ancient mathematical theoreticians were never sincerely interested in the problems encountered when geometry was to be practised – how to make sure that a ruler is straight, what to do if the compass opening is insufficiently large, how to prevent that the unavoidable imprecision in geometrical construction sums up to something unacceptable (in Euclid’s *Elements*, a circle is never drawn; it is presupposed to have been drawn by an anonymous “helping hand”, as pointed out by C. M. Taisbak). The synthesis between geometrical theory and geometrical practice was only achieved by the mathematicians of the Islamic Middle Ages, from ► [al-Khwārizmī](#) to al-Kāshī.

See Also

- [Algebra, Surveyors’](#)
- [Geometry in Islamic Mathematics](#)
- [Mathematics in Egypt](#)
- [Surveying](#)

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Ghulām Ḥusain Jaunpūrī

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Biography

Abul Qāsim, alias Ghulām Ḥusain Karbalā’ī bin Fataḥ Muḥammad Jaunpūrī (1790–1862), was taught by his father and other contemporary mathematicians and astronomers. He was a court astronomer of the Rājah of Tikārī: Rāja Khān Bahādūr Khān Nuṣrat Jang, son of a Hindu Mahārāja Mitrajīt Singh and of a Muslim mother. Tikari is a town in South Bihar (24° 57 N, 84° 53 E), in India, where Ghulām Ḥusain carried out his astronomical observations, according to his own testimony. Later, he shifted to Banāras (modern Varanasi) and Murshidābād. Actually, he was appointed first Chief Justice (*Ṣadr as-Ṣudūr*) at the court of the Raja of Banāras and later served also Nawāb of Murshidābād. He died on his way to his hometown Jaunpūr, in Dā’ūdpur city, in A.H.1279/A.D.1862.

Scientific Writings: Major Works

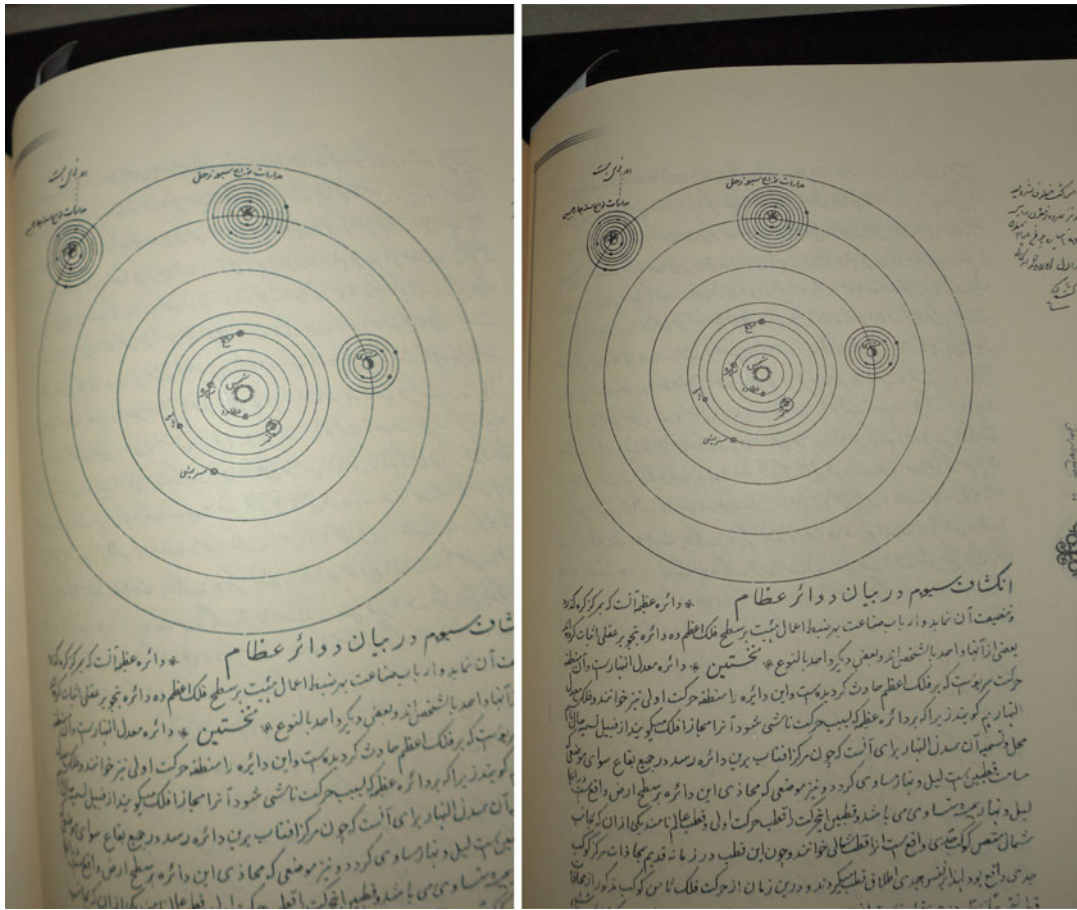
1. “On Problems of Astrolabe for Friendly Companions” (*Anīs al-Aḥbāb fī Bayān Masā’il Aṣṭurlāb*) written in 1818. Its manuscripts are extant in KhB (Patna) with two copies. Ms.1063 is a copy of 1830.

To note are the abbreviations of the various libraries/manuscripts collections: **ASB** (Calcutta): Library of the Asiatic Society of Bengal. **APSCL** (Hyderabad): Andhra Pradesh State Central Library (formerly *Āṣafiyah*). **BM** (London): Library of the British Museum (Oriental Section). **IOL** (London): India Office Library. **KhB** (Patna): Khuda Bakhsh Oriental Public Library. **MAL** (Aligarh): Maulana Azad Library (Aligarh Muslim University). **NMPL** (Murshidabad): Nawab of Murshidabad Palace Library. **PPL** (Lahore): Punjab Public Library, Lahore (Pakistan). **SJM** (Hyderabad): Oriental Manuscript Collection in Salar Jung Museum. This tract is a Persian commentary on the Arabic Treatise on Astrolabe by Bahā'uddīn Al-ʿĀmilī (d. 1621), whose treatises on astronomy and mathematics in Arabic had been very popular in textbooks in Indian Madrasas. The author states that the original Arabic text was too difficult to understand and hence he wrote this commentary, explaining the method of construction and working of the astrolabe. The tract contains also a section on geometrical and astronomical preliminaries.

2. "Compendium of Mathematical–Astronomical Sciences" (*Jāmiʿ Bahādurkhānī*) or "Key to Astronomical Observations" (*Miftāḥ al-Raṣad*) in Persian and written during 1832–1833. It was dedicated to the patron of the author, Rāja Khān Bahādur Khān. The Compendium was lithographed originally in 1835 in Calcutta and reprinted in Tehran in 2008. Its few manuscripts are extant in BM (London) with excerpts only; in SJM (Hyderabad), scribed in 1871; in ASB (Calcutta) in the Curzon collection; and in KhB (Patna). A complete manuscript but undated is also extant in PPL (Lahore), which is excellently written and contains very good diagrams of astronomical instruments dealt in separate chapters. Copies of the printed text are extant, one each in BM (London), NMPL (Murshidabad), and PPL (Lahore) and 3 copies in KhB (Patna), 2 in

MAL (Aligarh), and 2 copies in APSCL (Hyderabad).

- This encyclopedic work comprises six books, each of which is divided into chapters. The chapter on mathematics comprises sections, one for each of its branches, e.g., on trigonometrical functions with solutions of both plane and spherical triangles. The part on astronomy deals with the science of astronomy (*ʿIlm-i Hayʿat*), astronomical tables (*Zīj*), and almanacs (*Taqwīm*). Although mathematics spans over 63 % of the text and the remaining 37 % deals with astronomy, the author emphasized the latter, as is apparent by the second title of this Compendium. Besides the description of Graeco–Arab geocentric model of the planetary motion, he also includes European astronomy, e.g., the heliocentric system of the planets (p.476 *et seq.*) with a clear diagram (Fig. 1), showing also the orbit of Uranus and of minor planets such as Pallas and Ceres, with satellites around the different outer planets. He also explains gravitation (*Jadhb* or *Anjadhāb* in Arabic). In the last book, Ghulām Ḥusain deals with 12 astronomical instruments, each in one chapter and illustrated with a diagram. Two of these are of modern European origin, namely, the compound telescope (*Minzār-i Murakkab*) with a mounting system and reflecting sextant (*Sūdus-i Inʿikāsī*). I may add here that late Prof. Mahdi Ansari Farangīmaḥlī (Aligarh) possessed a unique celestial globe manufactured by Ghulām Ḥusain Jaunpūrī, which is dated 1231 A.H./ A.D. 1816, described by Ansari and Sarma (1999/2000, pp. 82–84).
3. *Zīj-i Bahādurkhānī* (in Persian) are astronomical mathematical tables, which Ghulām Ḥusain compiled during 1838–1841 by the order of Rāja Khān Bahādur Khān to whom it was dedicated. Its second title is "Book for the Benefit of Syllabus/Teaching" (*Kitāb Ifādāt-i Niṣāb*) indicating the purpose of writing this *Zīj*. It was lithographed in India during 1855–1858 at Banaras and reprinted in Tehran, 2009.



Ghulām Ḥusain Jaunpūrī, Fig. 1 This heliocentric diagram (p. 474) depicts the orbits of planets and their satellites (*Tawābī*) according to the following scheme: Sun, Mercury, Venus, Earth (1 satellite/moon), Mars, Pallas,

Ceres, Jupiter (4 sat.), Saturn (7 sat.), Uranus/Jārijis (6 sat.). The author states clearly that the Europeans have been able to observe these satellites with the help of telescope

Ghulām Ḥusain explains the reason for compiling his *Zīj*:

Using the fine and accurate instruments of European scholars, a few of which are available in the Rājā's kingdom, I can find by observation spread over a number of years the discrepancy between the observed (*Marṣudah*) position of the celestial bodies and their calculated (*Maḥsūbah*) ones on the basis of the *Zīj-i Muḥammad Shāhī* [ZMS]. [The ZMS was actually compiled by Mirzā Khairullāh Muhandis in the eighteenth century under the supervision of Raja Sawa'i Jai Singh (d. 1743) by the order of Mughal Emperor Muḥammad Shāh (reigned 1719–1749), cf. Ansari (2007) for details].

And therefore I have compiled this *Zīj* based on our own nine-year long observations of eclipses, occultations of planets . . . , so that any one [interested] can calculate, by using these tables, the longitude of the stars and planets, the occurrence of solar eclipses, crescent visibility . . . year by year for a long time. (p. 2)

This *Zīj* consists of one introduction (*Muqaddmah*) and seven discourses (*Maqālah*), each of the latter comprising several chapters (*Bāb*). The author deals with 15 calendars, which include, besides the usual Islamic calendars, the Indian *Samvat* and *Shāka*, Akbar's *Ilāhī*, and Muḥammad Shāhī calendars. Actually, it is

a reworking or recension of ZMS based on Ghulām Ḥusain's own observations, in which the new elements of European astronomical knowledge were interwoven.

Minor Works

4. "On the Terminology of Almanac" (*Iṣṭilāḥāt-i Taqwīm*). Its manuscripts are extant in KhB (Patna), Curzon collection in ASB (Calcutta). This small tract comprises a preface and 14 short chapters with an epilogue (*Khātimah*). The author explains the technical terms used in the preparation of almanacs and method of their computation. Moreover, he complains about the sad neglect of astronomy in his times.
5. Persian translation of the Arabic version of *De Sphaera* of Theodosius (*Rā'iq al-Nuḥūs Tarjamah-i Ukar-i Thā'ūdhūsiyūs*), a unique MS of which is extant in APSCL (Hyderabad), Storey (p. 2, no. 2.3).
6. A commentary also on Naṣīruddīn al-Ṭūsī's recension of Euclid's geometry (*Tahrīr al-Uqlīdis*) with the Persian title: *Tabṣīrah al-Muhandis*. One manuscript is extant in the ASB (Calcutta), dated A.H.1245/A.D. 1830, and another in the private Library of the Raja of Banaras. This is the only work of Ghulām Ḥusain in Arabic.
7. "Warning to Repudiators" (*Tanbīhāt al-Munkirīn*) is a short tract written in A.H. 1238/AD1833, for which year the title is the chronogram. Its manuscript is extant in Ḥabīb Ganj collection of MAL (Aligarh). It was scribed in A.H.1268/A.D. 1852 and is of only 5 ff. Another manuscript is extant in KhB (Patna), of 10 ff, and was scribed in 1883. The author traces the reasoning underlying the geocentric stationary model of the universe and discusses the proofs of the motion of the Earth according to Pythagoras and European astronomers.
8. "Key to Mathematics" (*Miftāḥ al-Riyādī*). It is a small tract of 38 ff on mathematics extant only in KhB (Patna); it is not dated.

Conclusion

Ghulām Ḥusain was primarily an astronomer and instrument maker. He possessed a small observatory in the Maharaja's castle at Tikari, where he possessed many astronomical instruments of his own making, including a couple of instruments of nineteenth-century Europe, e.g., sextant and telescope. From his abovementioned major works, I list the following important observations Ansari (2002b, pp. 257–258, 259, 260):

1. A comet observed at Banaras during 26 September to 5 October 1825.
2. A partial solar eclipse was observed on Friday, 8 July 1842, with the duration of 10^h 4^m 14^s.
3. A lunar eclipse occurred on October 1838 in Gaya (Bihar), at 8^h 8^m 11^s past noon.

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with a foreword by Farid Ghassemlou, Azad University, Tehran.

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Glass in China

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Glass has always occupied a marginal position in China. From the earliest times, it has exhibited a varied composition reflecting the disparate sources for raw materials, and it was further complicated by the occasional mingling of western glass in the manufacturing process. For instance, chemical analysis of early glass artifacts found in China showed that they had been made with soda (SiO_2) and lime (Na_2O) of western Asian origins. The fact that these specimens came mainly from the coasts of Guangxi and Guangdong provinces in southern China indicated that this glass, in the form of ingots or finished products, was imported through the maritime route. Glass was also shipped in large quantities as cullet (glass lumps and discarded broken vessels), suitable for remelting and making new glass inexpensively. Thus, while it is not always possible to establish the uniqueness of Chinese glass from a chemical standpoint,



Glass in China, Fig. 1 Glass, inlaid “eye bead,” Warring States period (481–221 B.C.), L. 2.8 cm, D. 2.3 cm (Collection, Bristol Museums, Galleries & Archives)

analyses have been able to shed light on its various components and provide us with a time line for its evolution (Figs. 1, 2, 3, 4, 5, 6, 7, and 8).

The glassmaking process itself can be roughly divided into two phases, the first of which was reducing the raw materials to a powder after which they were fused in furnaces capable of reaching high temperatures. In the second phase, the molten glass (called metal) was ladled or poured into molds and pressed, blown, or drawn. The finishing process could be done either at the original glass workshop or carried out elsewhere. Also, it might suggest that a subdivision of labor existed between craftsmen who knew how to mix the raw materials and manipulate the furnaces and other artisans who were skilled in blowing or carving the glass.

The Initial Stage

Studies of Chinese glassmaking were initially limited to literary sources which placed the beginnings of the craft in the fifth century B.C.

Emily B. Curtis is retired.

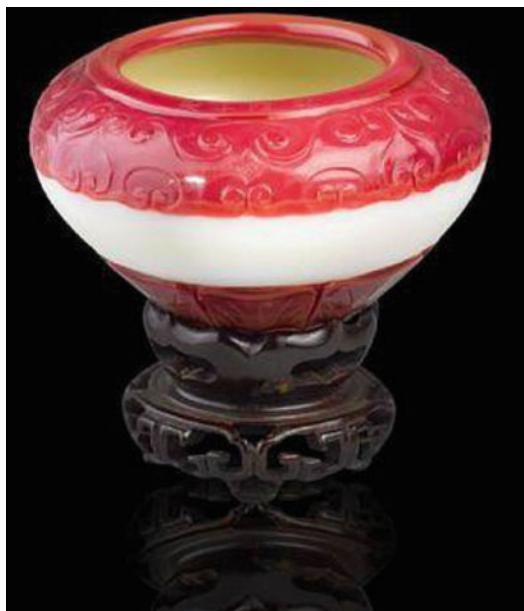


Glass in China, Fig. 2 Glass, press-molded hairpin with dragon head, Ming dynasty (1368–1644), L. 11.0 cm, W. 1.7 cm (Collection Bristol Museums, Galleries & Archives)



Glass in China, Fig. 3 Glass, molded as a recumbent boy supporting his head on his hands, Qing dynasty (seventeenth/eighteenth century), L. 11.9 cm (Collection, Dr. Alan E. Feen)

However, more recent archaeological excavations in China have uncovered evidence which indicates that production may have started in the late Zhou dynasty (1046–221 B.C.). The shapes of the excavated round and cylindrical glass beads indicated a definite influence from jade and stoneworking, and western Zhou glass may well be the first glass made in imitation of jade. However, since the chemical compositions for some of the beads are dominated by SiO_2 , and there are large amounts of crystalline quartz present, some scholars argue that this material is not really glass but faience. The sword decorations generally proved to be transparent glasses of the calcium silicate (X-CaO-SiO_2) or potassium calcium silicate ($\text{K}_2\text{O-CaO-SiO}_2$) variety.



Glass in China, Fig. 4 Glass, brush washer of opaque ivory with ruby-red carved overlays, lip rim with incised four-character Qianlong mark (1736–1795) on rim, D. 8.3 cm (Collection, Dr. Alan E. Feen)

While glassblowing was invented in the Middle East, perhaps in Syria, about 50–25 B.C., this technique developed later in China. Given that Bactrian glassblowers are believed to have been working at Datong, Shanxi province, during the Northern Wei (386–581 A.D.) period, the question arises as to when and if they passed on this technique to Chinese craftsmen. Therefore, the glass vessels from this period, which were found in a stupa in Jingxian, Hebei province, have been considered as important. The cache contained three gourd-shaped bottles, two other bottles, and a monk's alms bowl. All of them were blown of domestic (Chinese) glass. This was an important turning point in the history of Chinese glassmaking, because it made mass production possible and glass products less expensive.

Glass Workshops at Boshan

Written records inform us that glass hair clasps were produced in the Tang dynasty (618–907 A.D.) and that in the Song dynasty (960–1279

A.D.), the majority of women were wearing hair ornaments made from glass. Some examples of rings and hairpins in opaque off-white or turquoise glass may well be products of the glassworks in Zibo, Shandong.

The remains of an ancient glass factory, dating to at least the late Yuan to early Ming, were discovered in 1980s by the edge of the Shaofu River in Boshan (Zibo). The subsequent excavation of this site uncovered pieces of glass, the remains of clay pots, their covers, and some 20 furnace pits arranged in a line. Chemical analyses of the glass shards revealed that they

contained a high level of calcium and a low level of lead. When tested, a sample of blue opal glass was found to contain fluorine, and the lime found in this specimen could be accounted for by the presence of fluorspar. It was determined that the melting furnaces had been fueled by coke, which is also noted in ancient Chinese literature.

Two basic ways of forming glass were employed. Items like hair clasps were made from glass rods or tubes by a secondary process; they were reheated and then formed. Button-like ornaments were made by reheating and molding. These glass objects represented an alternative to jade, a much cherished and more expensive material. They also represented an expanded repertoire since many of the glass objects found in earlier burial contexts were made with shapes similar to their jade counterparts. This imitation was intended to replicate the shape and significance of jades – a major distinctive feature of Chinese glass and also one of the distinguishing marks between Chinese and western glassware. The unusually high concentration of barium oxide (BaO) in the composition of early Chinese glass produced a certain turbidity in the metal which might have been regarded as desirable by the craftsmen since it gave the glass a jade-like appearance. This trait is quite apparent in opaque, white glass artifacts.

Sun Tingquan's *Yanshan zaji* (*Mt. Yanshan Records*) dates to 1665. In it Sun gives a systematic and informative account of the glass materials, properties, coloring, melting times, tools, products, and distribution at Boshan. According to Sun, the glass was made entirely from local



Glass in China, Fig. 5 Glass, aventurine, pierced and cut to resemble a scholar's rock, H. with stand 9.2 cm, nineteenth century (Collection, Robert H. Blumenfeld)

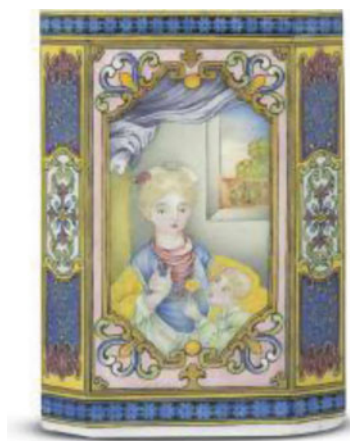
Glass in China,

Fig. 6 Glass, diamond engraved on exterior with four lotus sprays, divided by stylized clouds, D. 12 cm, late seventeenth to early eighteenth century. Plesch collection



materials such as feldspar, fluorspar, quartz, and niter. He also comments upon the creativity of the craftsmen in contending with a lack of sophisticated tools and instruments.

What is of particular note here is that Boshan was a major glassmaking center which, due to a series of natural disasters, had ceased operation by the end of the Ming dynasty. Under the patronage of the Qing emperors, it was able to resume its role as a center of Chinese glassmaking, supplying both materials and craftsmen to the imperial glass workshop; it remains active in present-day China.



Glass in China, Fig. 7 Glass, brush pot, enameled with scene of European “mother and child,” base incised with four-character mark of Qianlong (1736–1795) within a double square, H. 8.5 cm. Shuisongshi Shanfang collection

Glass in China, Fig. 8 Glass with painted enamel, L. 1.6 m., W. 1.3 m., by Xue Lu, Angel is Waiting, 2012



Imperial Glassmaking

Qing dynasty (1644–1911) glass deserves an important place in the history of Chinese glass. In the 35th year (1696) of Kangxi (r. 1662–1722), an imperial glass workshop was established under the direction of Kilian Stumpf, SJ (Ji Lian). Under the patronage of Qing rulers, many new varieties of glass were made, and it was an outstanding period of artistic accomplishment. K_2O and PbO , which were used as fluxes in ancient Chinese glasses preceding the Qing dynasty, proved to be the main fluxes of the glasses analyzed of samples in the Beijing Palace Museum. The raw glass materials used by the imperial workshops included “horse-tooth stone,” saltpeter, borax, white arsenic, and fluorspar. The saltpeter referred to should be potassium nitrate, which was used also as a raw material in the fourteenth-century potash-lime glass in Boshan. According to these findings, the MgO content of the glasses made from the saltpeter was very low (below 0.5 %). “Horse-tooth stone” could be feldspar. Qing glassmaking was also influenced by western technology because some glasses contained B_2O_3 and As_2O_3 , which were introduced as borax and white arsenic, respectively. The colorants included oxides of copper, iron, and cobalt. Spectral analysis showed that the red glass on the cameo samples contained a small amount (about 0.01 %) of gold.

Another important innovation was the application of western technology to make gold ruby glass. This variety can be made when there is colloidal

gold present in the glass batch. The red color is caused by selective light scattering of the gold particles in the glass. This process was successfully transferred from the court to Boshan by 1820 and made its way to Guangzhou (Canton), which brings up the topic of glassworks in other areas of China.

Regional Glass Workshops

Glassmaking in Guangzhou is thought to have commenced in the late seventeenth century.

However, their art glass was not held in high repute by Chinese writers and often fell below the Qing court's standards. Despite this, the city was an important source of skilled artisans who staffed the imperial glassworks, and records of their employment in this capacity date as early as 1708. On the local level, Guangzhou craftsmen were occupied primarily with making sheet glass for spectacles, mirrors, and windowpanes.

Interestingly enough, historians in Yangzhou credit the rise of the craft in their area to the influence of Guangdong glassworkers and go on to attribute the development of a local style of trailing cameo glass to their own artisans. In common with "Peking Glass" at this time, glass-making in either locale did not include the initial process of glass melting, but was solely the fabrication of objects from glass ingots. These ingots were known as *liao qi*, implying glass made with Shandong (Boshan) *liao*. This practice also seems to apply to a very distinctive group of wares (mainly snuff bottles) identified by the term "Yangzhou School."

According to textural references, Yunan specialized in making a type of lampshade (*liaosi deng*) from thin glass rods, which were widely used among the elite. The history of its glass beads is more difficult to chronicle, leaving one to suggest that, since Boshan was known to have exported glass rods to all parts of China, Yunan's glass was fashioned from them.

Glass artisans in Suzhou specialized in manufacturing glass chimes and used recycled glass for making lampshades with painted designs on the interior. Given Suzhou's renown as a center for hard-stone carving, there is the

possibility that its glassworkers also fashioned carved glass objects for the court and the general populace. As to the source for its glass material, this too awaits further research and study.

New Methods of Décor

The influx of western glassmaking technology allowed Chinese craftsmen to produce art glass in a wider range of colors and employ new methods of décor. Among the latter are:

- Aventurine glass – Known in Chinese as "gold star" (金星, *jinxing*) glass; this variety was a specialty of Venetian artisans and a particular favorite of imperial patrons.
- Diamond-point engraving – The use of a diamond point to produce linear drawing on glass was introduced to the imperial glassworks in the late seventeenth/early eighteenth century.
- Enameled glass – In this decorative technique, a mixture of colored powdered glass was allied with an oily medium and fused to a glass object in a furnace. This style of décor evolved during the Qing period.

Other methods of décor which may well have been derived from European examples and glass-makers are:

- Multicolor overlay – A method whereby a blank is overlaid with two or more different colored layers.
- Swirled glass – This effect is achieved by gathering up small colored glass pieces onto a molten lump attached to a blowpipe and fused in a furnace.
- Threaded glass – Molten colored glass in string forms is applied to a hot core to be rolled around inside the furnace for fusion, resulting in parallel segments of contrasting colors.

Contemporary Glassmaking in China

All imperial glassmaking had ceased in 1860. This prompted the Qing court to monopolize the

nation's glassmaking by establishing state-run companies and restricted the procurement of glass ingots from Boshan. These actions severely depressed Boshan's economy, and in 1902 thousands of its local craftsmen staged an uprising. This was suppressed, and Boshans' glass artisans were hard-pressed to make a living until after the fall of the Qing dynasty (1912). Many glass-makers survived in the ensuing years by concentrating on making brightly colored wares, often in imitation of imperial pieces. The situation gradually improved and present-day China is experiencing a renaissance in its arts and crafts. Institutions such as the Shanghai Museum of Glass not only feature exhibitions of ancient and contemporary glassworks but also focus on all aspects of this art which has encouraged contemporary glass artisans to explore and expand the range of their creations.

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Glass in Egypt

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The Invention of Glass

Glass was first produced deliberately and consistently in Mesopotamia sometime between c. 1650 and 1550 BC. There is some scattered evidence for prior glassmaking, largely in the form of beads (see, e.g., Grose, 1989, p. 45), but much of this material was most likely the accidental by-product of other pyrotechnological processes, namely, faience production and metal smelting. The latter sometimes resulted in highly colored vitreous slags, examples of which can be dated back as far as the third millennium BC (Schlick-Nolte & Lierke, 2002, p. 15). The earliest glass vessels were relatively small, the majority being under 15 cm in height, and were employed as perfume and cosmetic containers. Glass also found use as inlay, where it was arranged alongside semiprecious stones such as turquoise and lapis lazuli and precious metals such as gold. Most early glass was highly colored, and the Egyptians particularly favored dark and light blue, yellow, white, and red opaque glasses. Colorless glass was extremely rare prior to the mid-first millennium BC (Fig. 1).

The accidental production of glass during the practice of other high-temperature industries noted above may have provided the early impetus for its production as a material in its own right. Glass was related to several contemporary industries: metal extraction, as glassy slags are often a



Glass in Egypt, Fig. 1 Egyptian core-formed unguent container, housed in the Classical Museum, University College Dublin

by-product of metal smelting; stone working, with many stones and semiprecious stones having conceptual links with glass; and the production of faience, which is also an artificial material and which uses the same basic ingredients as glass, albeit in very different proportions, as shown in Table 1. Largely due to the use of these ingredients, faience is generally credited as the material most likely to have directly given rise to glass (Tite, Shortland, & Paynter, 2002). Given the close proximity of many craft activities in both Egypt and Western Asia during the Late Bronze Age, however, it is quite possible that glassmaking did not develop out of a single one of these industries, but may have been influenced by several.

The Earliest Glass in Egypt

The earliest evidence for glass in Egypt all points to a Mesopotamian origin, and direct parallels with Mesopotamian material can be found among Egyptian glass from the fifteenth century BC.

Glass in Egypt, Table 1 Typical proportions of the major constituents of Egyptian and Mesopotamian faience and glass in the Late Bronze Age

	Silica (crushed quartz) (%)	Lime (%)	Alkali (soda and potash from plant ashes) (%)
Faience	93–98	1–5	0.5–3
Glass	60–67	6–9	16–22

Examples of probable Mesopotamian imports come from the tomb of the three foreign wives of Tuthmosis III. For example, a button-based glass goblet from the tomb is comparable in shape and decoration to items from Nuzi. Similarly, a glass flask (KV 36) from the tomb of Maiherperi, dating to late in the reign of Tuthmosis III, has close parallels in material known from Tell Brak, associated with tablets thought to date to the fifteenth century BC (Lilyquist, 2005, p. 63).

As noted by Moorey (2001, p. 3), the Hurrian-speaking people of the Kingdom of Mitanni are known to have been particularly instrumental in a series of technological innovations during the Late Bronze Age, and it is thought that one of these was the development of glass production. Oppenheim (1973, pp. 263–264) has noted that the terms *ehlipakku* and *mekku* are thought to refer to glasses that are Hurrian and West Semitic, respectively, supporting the theory of northern (upper) Syria as the nexus for glass technology.

How exactly the knowledge of glass production was first obtained by the Egyptians is unclear, but given the atmosphere of secrecy surrounding important craft processes, perhaps the most plausible hypothesis which has been put forward is that foreign craftsmen were captured in campaigns (probably those of Tuthmosis III) and subsequently led the Egyptian glassworking industry (Oppenheim, Brill, Von Saldern, & Barag, 1970; Petrie, 1926, p. 229; Shortland, 2001, p. 219). Most of the earliest vessels known in the Egyptian style, however, were cold worked in the manner of stone, and it is equally possible that the first glass workers to be introduced came slightly later, perhaps during the reign of Amenhotep II, bringing a fully formed knowledge of hot-working glass techniques.

In any case, glassworking was certainly firmly established by the reign of Tuthmosis IV (early fourteenth century BC). This is the first period in which cobalt (responsible for a striking blue color in glasses and accessible in the Egyptian territory) was used extensively as a colorant, suggesting the primary production of glass within Egypt, and coinciding with the establishment of a standard repertoire of vessel forms and heralding the start of the Egyptian glass industry proper.

By the end of the fourteenth century BC, the various regions in which glass was present had developed localized styles, such as the characteristic relief beads of the Mycenaean world, suggesting that glassworking was being practiced locally. The evidence does not, however, imply that glass was being made (fused from raw ingredients) in the Mycenaean territory. Indeed, it seems that the Aegean had become the first – though it was by no means to be the last – importer of Egyptian glass. The discovery of 175 glass ingots in the cargo of a late fourteenth-century BC shipwreck off Uluburun, Turkey, in a shape and size with clear parallels at Egyptian production sites, suggests that glass was being transported from Egypt to Mycenaean Greece, and recent isotopic analyses (Henderson, Evans, & Nikita, 2010) have confirmed that glass was probably entering the Aegean from both Mesopotamia and Egypt.

Egyptian Glass Technology

Despite the links between primary glass production and other applications of pyrotechnology such as metalworking noted above, the very first glass does not seem to have been cast or worked while hot. Instead, the principles of stone working were applied to the production of glass vessels, with glass chunks or ingots being treated as blanks to be laboriously ground and polished. The later appreciation that glass could be manipulated by heat meant that vessels and beads could be produced by casting or by various methods involving coating a removable core of material with glass and applying trails or blobs of another

color of glass onto this base, a practice known as “core forming” (Fig. 2).

When exactly this transition to core forming was established is difficult to determine with precision. In part this is no doubt due to the poor preservation of glass in most climates: the arid Egyptian climate is particularly, and exceptionally, favorable to the preservation of early soda-lime-silica glass. Fragments of core-formed glass vessels have been found at Alalakh in levels dating to 1600 BC, suggesting that the knowledge of core forming was already known in northern Mesopotamia at this early stage (Nicholson, 2007, p. 3).

In any case, the superior preservation of Egyptian glass, coupled with its continued high status throughout the New Kingdom, means that the Egyptian evidence, though slightly later in date, is far more abundant than that from Mesopotamia. From the latter, we have possible – though somewhat difficult to interpret – recipes for the production of colored glasses (see Oppenheim et al., 1970). Egypt, on the other hand, has provided at least one and most likely two examples of early glassmaking sites; these are the earliest known in the world. Primary glass production sites are not frequent finds, and it is often difficult to identify them (one reason for this is the recycling of scrap and waste glass and the lack of significant by-products such as the slags associated with metal production), so the two examples discussed below provide a rare insight into the earliest glass production.

The first of these glassmaking sites was found at the mid-fourteenth-century BC city of Akhetaten, Amarna. Amarna was originally excavated in the 1890s by W. M. F. Petrie, who recorded the presence of semi-fused glass and crucible fragments with adherent glaze at the site, though the location of his hypothesized “glass factories” was not precisely recorded. More recently, excavations at site 045.1 revealed a complex of furnaces or kilns, at least one of which has been argued to have been used for primary glass production (Nicholson, 2007) and which yielded a semi-fused material indicative of an intermediary stage in glass production (Jackson & Nicholson, 2007). Despite this, there

Glass in Egypt,

Fig. 2 Fragments of Egyptian core-formed vessels, 1400–300 BC, housed in the Classical Museum, University College Dublin



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has been significant debate as to whether the evidence from Amarna points to the primary production of glass, to glass coloring, or to the re-melting of glass made elsewhere for the purpose of working it. Following the initial excavation of the furnaces at site 045.1, Nicholson and Jackson (1998) conducted a reconstruction glass-making experiment in a replica furnace, finding that it was possible to directly fuse glass from its raw ingredients in such a structure. It should be emphasized that this evidence alone does not prove that glassmaking was necessarily practiced at the site, only that it could have been. Perhaps more conclusively, Smirniou and Rehren (2011) have reexamined the evidence from Petrie's excavations and have analyzed several examples of "semifinished" glass, strongly indicative of primary production of glass at the site (Fig. 3).

Qantir, in the northeastern Nile Delta, was the site of an industrial estate created in order to serve the building works at nearby Pi-Ramesses, the thirteenth-century BC capital of Ramesses II. The most extensive industrial feature at Qantir is a large bronze-casting factory, but recent excavations have revealed that this was accompanied by a number of works for smaller-scale high-temperature production, perhaps placed together due to their common use of copper. Among these smaller works is evidence for the primary production of red opaque glass. This includes 40 large crucible fragments (and several hundred



Glass in Egypt, Fig. 3 Fragments of glass canes, which would have been heated and wound around the core to produce the vessel's body and its trailed decoration, uncovered during Petrie's excavations at Amarna (fourteenth century BC). All fragments housed in the Classical Museum, University College Dublin

smaller ones), many with traces of red glass adhering to them and the remains of a lime parting layer (Rehren & Pusch, 2005, p. 1756); fragments of uncolored glass; and a complete ingot of red glass colored by adding copper and heating under a reducing atmosphere (Rehren, Pusch, & Herold, 1998, p. 227). The size of the crucibles was standardized and their interior dimensions match that of the ingot from the site. No remains of secondary glass production – that is, working of glass into objects – have been found at Qantir,

and only a few isolated fragments of blue glass have been found in addition to the red glass which dominates at the site (Rehren & Pusch, 1997, p. 136). Red glass must have been difficult to make due to the need to maintain a reducing (oxygen-free) atmosphere, so it is perhaps unsurprising that this site, at least, is specialized in the production of this color of glass.

Other sites yield evidence of secondary glassworking. As well as indirect evidence, such as the presence of regional styles in finished glass objects, glassworking can be indicated by the presence of rods or canes of colored glass used in core forming and decorating glass objects. Such canes have been found at Amarna, Malkata, Lisht, and Menshiyeh (Abydos), in Egypt, and at Tell Brak, in Syria.

The Perception of Glass

Also of interest is the way in which this earliest glass was perceived and valued in Egypt. In the Annals of Tuthmosis III at Karnak, glass is listed directly below gold and silver and alongside precious stones including lapis lazuli and turquoise, the former of which was highly prized and had to be imported from a great distance. The high value of glass seems to continue into at least the fourteenth century, at which time it is found as an inlay alongside these same materials (gold, lapis lazuli, turquoise) in the mask of Tutankhamen.

It is thus apparent that glass was of high value throughout the first few hundred years of its use in Egypt. Less clear, perhaps, is why a substance which was made from relatively abundant raw materials was so highly prized. One explanation

is that the color and material properties of glass were at the center of its value (Duckworth, 2012). For example, the cobalt required to produce the highly prized deep blue of much early glass most likely had to be obtained via dedicated royal expedition. In other cases, difficulty of production may have added value, as with the creation of red glass which required heavy control over the furnace atmosphere. The potential of glass to be worked while hot and its transportation in ingot form may have conceptually linked it with metals, while its visual appearance and the linguistic terms used to describe it suggest that it was also related to semiprecious stones. It is possible that the production of glass itself was ritually significant – a demonstration of human control over the chaos of nature – and that the artificiality and base origins of the material, far from lowering its value, were at the very root of its power as a transformed material.

The Later Glass Industry

An interesting aspect of ancient technology in general, and glass production in particular, is its propensity for conservatism (see, e.g., Sode & Kock, 2001). This makes sense when we consider that the alteration of just one variable in ancient glassmaking could have led to the failure of the entire batch and would constitute an enormous waste of resources, particularly expensive fuel. In addition to being relatively conservative, glass production has traditionally been highly secretive (Fig. 4).

It is the combination of these factors, perhaps, along with the ready availability of the relevant

Glass in Egypt,

Fig. 4 Fragments of millefiori glass vessels, third century BC to first century AD. All fragments housed in the Classical Museum, University College Dublin



raw materials in Egypt and along the Syro-Palestinian coast that are behind the continued significance of these areas in glassmaking from the mid-second millennium BC to the later second millennium AD. Egyptian glass was highly prized in the Hellenistic period, with Alexandria becoming a key center of glass production and remaining so for hundreds of years, as recorded by Cicero in the first century BC and Strabo in the first century AD. Glassmaking flourished under Islamic rule, with the Muslim capital at Fustat, later Cairo, becoming a new center of glass production. By the late thirteenth century, the Egyptian and Syrian gold-painted and enamelled mosque lamps were among the most highly prized objects in the Islamic world (Carboni, 2001, p. 199; Pinder-Wilson, 1991). Knowledge of glassmaking and working would have been handed down within the family, but even within this atmosphere of conservatism and secrecy, there must have been significant scope for innovation and change. Egypt's continued place at the forefront of glass production for millennia is testimony to this.

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Glass in India

Alok Kumar Kanungo

Development of Glass in India

Indian Glass

Foreign travel accounts like Pliny's *Naturalis Historia* (73–77 AD; translated by Bostock and Riley as *The Natural History of Pliny* in 1890), *Periplus Maris Erythraei* (considered to be earlier than *Naturalis Historia*; translated by Schoff as *Periplus of the Erythrean Sea* in 1912) and *Geography of Strabo* (17–23 AD; translated by Jones and cited in Majumdar, 1960, pp. 279, 394) considered Indian glass to be of high quality as it was made of pounded quartz rather than silica. It has long been suggested that this may have been the reason behind the high silica content in ancient Indian glass (Stern, 1987, p. 28). In Gudur (Andhra Pradesh), the government glass factory till recently produced glass from crystal. Dr. Brill of the Corning Museum believes that glassmakers throughout Iran, Mesopotamia, and central Asia (cited in Stern, 1987, p. 28) routinely used pebbles instead of sand as the source of silica. In fact, in a Herat (Afghanistan) factory in 1977, the glassmakers still used pebbles collected in the riverbed as their source of silica.

Although glass was commonly made in the west Asian Bronze Age, there is some

controversy concerning its manufacture in the Indus valley civilization (Glover & Henderson, 1994). Some scholars have tried to trace the origin of Indian glass to the Harappan civilization on the basis of finding glazed pottery and quartz beads. Harappans made glazed pottery, which is ceramic with a thin layer of glass on the surface (Tite, Freestone & Bimson, 1983). Though no true glass has been found in India from the Protohistoric periods at Mohenjodaro and Harappa, the second millennium BCE saw its people able to mould and fuse excellent articles of faience and glazing their quartz beads with frit, a material similar to glass. All three materials—glass, glaze, and faience—consist of silica and lime, although special modern glass need have neither. Glass and glazes always contain soda or some or the other alkali, whereas faience generally contains only very small quantities of soda. In the evolution of glass, frit, faience, and glaze might have signified certain stages of development (Beck, 1934; Biek & Bayley, 1979; Brill, 1963, p. 120; Forbes, 1957, p. 223).

Glaze

There is little doubt that glass was an outcome of glaze. Glass and glazes are chemically identical but they are worked and used differently (Forbes, 1957; Tite et al., 1983). The glazing technique marks the emergence of the first glass or synthetic material (de Barthelemy & Bouquillon, 1994). However, a glaze is a glassy layer applied to a core or base of some other material. This is in some cases mixed with the material before firing and in many cases applied to the body after firing. In the fourth millennium BCE glaze was used extensively within the context of the Badarian civilization in Egypt, the Jemdet Nasr period in Mesopotamia and in the third millennium BCE, the Indus valley civilization. The method of grinding quartz and mixing it with a little alkali before firing and producing faience occurred somewhat later in Egypt, in the early pre-Dynastic period (Forbes, 1957; Lucas, 1926). Marshall (1931, pp. 578, 582, 692) states that the glazing of pottery is an Indian invention and a craft which appears to have been practiced for the first time on the bank of Indus. No

example of it has come to light in Mesopotamia before 1000 BCE, nor in Egypt before the Roman period, although in Nubia there is said to be evidence of glazed ware as early as the twelfth dynasty (1991–1928 BCE). On the strength of the available material at Mohenjodaro and Harappa, Marshall (1931) went on to say that they are so closely allied to glass that it hardly seems possible that glass could have long been delayed. Bhardwaj (1979, p. 31) thought that the four pieces of glazed pottery found at Mohenjodaro were the handiwork of a potter who was well acquainted with the process of glazing and able to carry it to a high degree of perfection. High temperature stoneware bangles and some glazed pottery have also been recorded from Lothal, Bhagwanpura, Sanghol, Banawali, Bara, Ropar, Chanhudaro, Hulas, and Mithathal (Dayton, 1989).

Faience

Faience is nearer to glass in the process of evolution. It is reported from many ancient sites and is likely to have been the predecessor of glass (Brill, 1963, p. 120). In the archaeological sense it is generally agreed that faience consists of a lightly sintered core of crushed quartz grains coated with a translucent blue-to-green glaze, both fluxing due to soda. Such material needs a firing temperature of some 1000 °C and a certain amount of sophistication in making it (Biek & Bayley, 1979, p. 3). Crystalline quartz grains with a small amount of glassy material predominate in the case of faience. A few simple variations, whether accidental or deliberate, would have resulted in true glass (Basa, 1991). Stone and Thomas (1956, p. 37) proposed that glass could be produced by heating faience too much or for too long, while adding a little surplus of alkali. They further suggested that it is most probable, then, that the faience makers found this out by simple observation and so became the first makers of real glass. Forbes (1957) and Bhardwaj (1979) have proposed to call most of ancient objects dubbed faience to be glazed siliceous ware, as they have a body consisting of powdered quartz covered with a layer of glaze. This material has been reported from most of the ancient civilizations

including Egypt, Mesopotamia, and India (Lucas, 1926; Sofianopoulos, 1952). Faience was certainly made in India and fashioned into a variety of objects such as amulets, bangles and inlay, segmented beads, spindle-whorls, fluted disc beads, seals, animal figurines, and pots. In the Indus valley itself the people of Mohenjodaro and Harappa are known to have made extensive use of articles from faience, a composition resulting from powdered quartz grains fused at low temperature with the addition of lime. Some of the articles like beads and inlays were found treated with a glaze or frit which does not materially differ from glass. Marshall (1931, p. 683) and Mackay (1931, pp. 576, 578 and 582) are of the opinion that though no true glass has been recovered from Mohenjodaro and Harappa, the authors of these cultures had perfected a composition which very nearly approached glass. Experiments conducted by McCarthy and Vandiver (1991) have revealed that the Harappan faience has a quite dense body with a continuous glassy phase and a relatively thin skin of glaze. Intentional addition of glass frit and clay are postulated. The Harappan faience bodies are particularly strong, compared with contemporary faience from west Asia and Egypt. A similar technology is not found in Egypt until much later during the New Kingdom, about 1450 BCE.

Brill (1987, p. 2) gives two reasons in support of the belief that glassmaking grew out of faience manufacture. (1) Both processes involve the pyrotechnology of the same materials (silica and alkali), and (2) faience was made for some fifteen centuries before glass was made. In this regard, the data gathered at Mehrgarh and Nausharo are of great interest since they allow the study of the local evolution of the glazing techniques through time, from the Chalcolithic to the Mature Indus period (de Barthelemy & Bouquillon, 1997, p. 63).

Ancient Indian Glass

Bhardwaj (1987) and Singh (1989), on the basis of glazed pottery from Mohenjodaro, have argued that the Harappans were aware of glass making. Bhardwaj (1987) regards a number of vitreous materials unearthed from Mohenjodaro

as weathered unworked glass, but more finds from well-dated contexts are needed before we can be sure that the Harappans had truly mastered the secrets of glassmaking (Singh, 1989), and it is possible that glass could have decomposed to the point where it looked like faience.

Singh (1989) cautioned about the possibility that some glass beads might have been classified wrongly as stone beads. Even if the Harappans had this knowledge it seems to have been lost with the collapse of the urban Bronze Age civilization, and the subsequent finds of glass from the subcontinent come only with the Harappan-PGW (Painted Grey Ware) overlap phase at Bhagwanpura in Haryana, datable to about 1450–1200 BCE (Joshi, 1976). From this time onwards, glass beads and bangles were regularly made in many parts of the subcontinent (Lal, 1987). However, here thorough investigation of faience objects from Chalcolithic sites is required as they are reported to have yielded an enormous quantity of burnt steatite and paste, sometimes also glazed. Here it is important to mention that some of the beads that had been interpreted as shell beads (Casal, 1949; Wheeler et al., 1946) have now been identified as corroded glass (Francis n.d.). Too much soda will yield a kind of glass that will be easily corroded by water, though ancient glasses often have a large percentage of soda to achieve a low melting point (Forbes, 1957). In some cases faience is also wrongly identified as glass; for example faience excavated in Baoji and Fufeng country of China dated to eleventh to tenth century BCE was for a long time considered to be the earliest glass finding of China (Brill, 1995, p. 270).

From the analysis of 38 specimens found at Alamgirpur (undated), Brahmagiri (Megalithic and Andhra culture), Hastinapur (period V, eleventh to fifteenth century AD) and (period III, sixth to third century BCE), Sar Dheri, Arikamedu (ca. 200 AD), Kausambi (200 BCE–200 AD and 100–200 AD), Bihar (first to second century AD), Orissa (200 AD), Rupar (1000–700 BCE and 200 BCE–600 AD), Vankali (Sri Lanka 1200–1250 AD), Brill (1987) comments that if glass found in India has a high alumina content (Al_2O_3) i.e.,

3.5–4.0 % or greater, it probably was made in India and that a low lime content (CaO) can also be considered as evidence of local manufacture. Francis (1985, 1990a, 1990b, 1991, 1994, 2002, n.d.) based on his extensive work on Arikamedu glass beads, argues that glass beads from Arikamedu were made from local glass because of the presence of high potassium that was rare in the western glass of that period. In Egypt and the Roman Empire glass consisted of sodium oxide as alkali, whereas in India and Vietnam, as evident from Arikamedu (India) and Oc-Eo (Vietnam), both sodium and potassium oxide were utilized (Francis, 1990a). Lead as a coloring agent or opacifier in glass is found more in the West than in India. Glass from Khairadih, dated between 700 BCE to second century AD (Singh & Abdurazakov, 1988), Nevasa (Varshney et al., 1988) and Arikamedu (Glover & Henderson, 1994) are found to have low lime content. Furthermore, on the basis of scientific analysis of some of the early glass samples, Francis (n.d.) opines that both imported and indigenous glasses were used for bead production at Arikamedu and other contemporary south Indian sites.

In ancient India fragments of glass slag and other debris of glass production have been noticed at Khairadih, period II (IAR 1981–1982, p. 68; Singh and Abdurazakov, 1990), Kopia (Abdurazakov, 1987; Dikshit, 1969, p. 39; Lal, 1987, p. 45; Roy & Varshney, 1953; Sen & Chaudhuri, 1985, pp. 64–65), Rajghat (Narain et al., 1976; Singh, 1989) and Taxila (Marshall, 1951) in the North; Ahmednagar (Chaudhuri, 1986, p. 97), Bhokardan (Deo & Gupte, 1974, p. 197), Brahmapuri (Kolhapur) (Sankalia & Dikshit, 1952), Nevasa (Sankalia et al., 1960, pp. 355, 383–385), and Paunar (Deo & Dhavalikar, 1968, pp. 82–83) in the Deccan; Sirpur and Tripuri in Central India; Hulas Khera (Tewari et al., 1995–1996); Maheswar (Sankalia, Subbarao & Deo, 1958) and Nagra (Mehta & Shah, 1968, pp. 132–137) in the West; and Arikamedu and Karaikadu in the South. Thus, it is evident that ancient India was not only manufacturing by-products of glass but was also making glass for its use.

Regarding the glass furnace in ancient India, our information is meager. A solitary reference comes from Nevasa, where a glassmaking kiln dated to the period ca. third- and fourth AD was unearthed. It is a circular oven 2'–6" in diameter with 1'–7" depth and is made of burnt clay. Around it an abundance of bichrome glass, slag, lime, cow-dung, etc. was found (Sankalia et al., 1960). At one of the points near the periphery was a channeled projection evidently to insert the pipe for the bellows (Deo, 2000, p. 11). Chaudhuri (1986, p. 99) remarked that most of glass furnaces in ancient India are open-fired type, using solid fuel, and the melting was carried out in a clay pot.

Ancient Literature

Mention of glass (*kāca*) and its by-products, most prominently that of beads, occurs in early *Brāhmaṇical* (Sanskrit) and Buddhist literature. Chaudhuri (1986), Deo (1987, 2000), Dikshit (1964–1965, 1969, Ghosh (1924), and Mukharji (1888), list a few of them; for instance in the *Yajurveda* (c. 1200 BCE) *kāca* is mentioned as one of the articles of which female ornaments were made by means of stringing with gold thread. In *Śatapatha Brāhmaṇa* (c. 800 BCE), the word *kāca* refers to glass beads which were used for decoration of horses in the *Aśvamedha* sacrifice. There are references to women wearing glass beads and to the wearing of or threading of 101 beads of glass. The *Taittiriya Brāhmaṇa* also refers to the wearing of glass. Coming to the Sutra period (ca. 600 BCE), one comes across references to glass beads in the *Baudhayana Srauta Sūtra* and in *Manava Srauta Sūtra*. The *Māhavagga* section of the Buddhist text *Vinaya Piṭaka* (fifth to fourth century BCE) alludes to the use of shoes ornamented with glass as being forbidden to the Buddhist *bhikshus* (monks). The *Chullavagga* similarly forbids the use of glass bowls. One of the earliest South Indian texts, *Manimekalai* (3, 64), refers to *palingu*, meaning glass or quartz in Tamil, which is possibly a corruption of the Sanskrit word *sphatika*, although the prakrit *phalika* (quartz), occurs in the Bhattipruru inscription of the second century BCE (Srinivasan & Banerjee, 1953, p. 113).

Rāmayaṇa refers to the makers of glass, the '*kachakara*'. Kautilya's *Arthaśāstra* (third century BCE) alludes to the making of glass at two places. (1) *Adhikarana* 14, *Adhyāya* 1, *Sūtra* 12, says that in order to punish the enemy, obstacles like the smoke of Puti, Karañja leaves... as in the manufacture of glass, by burning cow dung etc., should deliberately be created. (2) Another passage in the *Adhikarana* 2, *Adhyāya* 14, *Sūtra* 45, though somewhat corrupt, refers to the process of making gold-foiled glass beads. It describes the piercing of glass beads in a molten stage for the purpose of setting ornaments and the setting of glass-fragments (*kṣepana*) in gold ornaments for the preparation of the glass gems. Amongst the various punishments inflicted for stealing, it is ordained that a person stealing articles made of copper, bronze, tin, glass and ivory was to be fined 46–96 *paṇas*. Glass is also mentioned in the *Māhābhārata*, and in *Yuktikarata*. The effects on the human system of drinking water out of a glass tumbler are stated to be the same as those of drinking out of a crystal cup. Some of the Puranas such as the Matsya, the Vishnu, and the Bhagawata, assigned to the Gupta period (third to fifth century AD), refer to *kāca*. *BṛhatSaṃhitā* (sixth century AD) also mentions glass. Apart from these, references to glass vessels for preserving medicines can be seen in texts like *Charaka* and *Śusruta Saṃhitā*. In the *Amarakośa* (seventh century AD) mention of glass vessels, cups and dishes are made. In later period, Somnath Kavi (ca. 1446–1539 AD) mentions spectacles in his *Vyasoyogi Charita*.

Spread of Glass in India

On the basis of glass findings at Taxila and Arikamedu, Marshall (1951) and Wheeler et al. (1946) thought them to be of foreign origin. On the contrary, typical Indian designs on some early glass specimens of Taxila, Mohenjodaro's glazed pottery and evidence of glass in the Chalcolithic level at Maski, and at Painted Grey Ware sites (supposed to be devoid of any foreign association) have led Dikshit (1969), Bhardwaj (1987), and Singh (1989) to argue for indigenous

origin of glass (Kanungo, 2000–2001, 2002a, 2004c). Deo (2000, p. 26) takes a middle path by mentioning that though much of the glass at Taxila was imported into India through its foreign settlers, there is reason to believe that some of the beads are indigenous. It is difficult to say how far early foreign contacts were responsible for the introduction of glass but the stray specimens reported do not point to anything definite.

The *Periplus* mentions Roman export of both raw glass and glassware. The ancient Indian literary records are silent on importing glass from the western world. However, the archaeological data on Roman glass in India strongly corroborates the references in the *Periplus* to glass imports into India (Gupta, 1997). Stern, (1986) suggests that it was convenient for Mediterranean shippers to bring raw glass to India as it served as good ballast for transport vessels. On reaching India, Mediterranean glass found a ready market because of the existence of a highly evolved glass working industry in the subcontinent. On their part, the Indians, besides marketing glass products of Roman glass in the domestic arena, exported the products to Southeast Asia and the Mediterranean. Probably, some of this glass really was imported, but there are good reasons for believing that much of this early glass was actually made in India (Brill, 1987, p. 2).

The Indians learned the technique of glass, probably independently, only around 1200 BCE. Since then evidence of glass has been unearthed from more than 200 ancient Indian sites. Kanungo (2002a, pp. 54–120, 2004b, 2004c) lists 204 sites which have yielded evidences of glass. Glass beads occur in about 150 sites and 36 are claimed to have been manufacturing sites (Kanungo, 2004a, p. 123).

The earliest evidence of glass beads (two well-made unweathered black and white tabular eye beads) in India is reported from Bhagwanpura in the Harappan-Painted Grey Ware overlap phase (period I), c. 1400–1000 BCE (Joshi, 1993). The occurrence of one glass bead in period II (Protohistoric) at Navdatoli shows that glass was not unknown to the people of this period (Deo, 1955, p. 10). The evidence of glass in the Chalcolithic period is very poor, found only at

Maski. During the next cultural phase of Indian history, i.e., Painted Grey Ware, we find that the occurrence of glass is quite common and widespread. It is found at several sites in India, which are widely separated from each other. Glass finds, although limited in number, have been a constant feature in all the levels from the sixth century BCE onwards. However, sites of Ochre Colored Pottery (OCP) culture have yielded only a few beads (Niharika, 1993).

The evidence of stratified eye beads from Northern Black Polished Ware (NBPW) phase, which form the next important stage in the study of glass in India, possibly supports the impression that mature glass came to India from the Mediterranean countries.

The technique of glass manufacture was well known since the seventh to sixth century BCE (Margabandhu, 1971, p. 1219, 1985, p. 327). Once the manufacturing processes were standardized, during the latter half of the first millennium BCE glass objects were produced on a mass scale. The very material and objects made of the glass found during this period bear an eloquent testimony to the fact that the making of glass in a furnace and later remaking and shaping them to beads had been fully understood and utilized to the maximum extent by the artisans of the times (Margabandhu, 1975, p. 73). The site of Kopia in Santh Kabir Nagar district (earlier part of district Basti), dated to about fifth century BCE, has yielded innumerable glass beads, thousands of glass fragments, fragments of clay crucibles with glass sticking to them, big pieces of glass and lumps of unworked glass (Abdurazakov, 1987, p. 38; Dikshit, 1969, p. 39; Lal, 1987, p. 45; Roy & Varshney, 1953; Sen & Chaudhuri, 1985, pp. 64–65). One large block of glass weighs about 76 kg and measures $45 \times 30 \times 22.5$ cm (Lal, 1987, p.45). Unfortunately, a few excavation reports of Indian sites yielding glass objects have discussed the manufacturing techniques involved and none the basis of the same (Kanungo 2000–2001, 2001, 2004a).

From 500 BCE onwards and particularly during the Maurya period, glass objects of all kinds came to be manufactured widely (Lad, 1983, p. 67). In Mauryan (fourth to second centuries

BCE) and Sunga (second to first centuries BCE) periods, beads of all kinds were plentiful including those made of glass (Alkazi, 1996, p. 7). The best evidence is that of glass seals from Maheshwar, Patna, Ujjain and three glass seals from the Mauryan phase at Taxila. The seals are mostly green and pale blue, carefully moulded and subjected to annealing to remove the internal strain. Spool (externally grooved) shaped ear-plugs, beads and bangles constitute the bulk of the glass articles known from specimens from Ahichchhatra, Kausambi, Patna and Rajghat.

The beginning of the Christian era witnessed the ushering of foreign cultural elements into Indian life. This is reflected not only in new shapes, but also in the introduction of new materials like the Mediterranean fine-grained corals and glass (Deo, 2000, p. 6). Use of glass became quite common. Findings at Arikamedu, Nevasa, Taxila and other sites present evidence for this. Excavations at Chandravalli, Karad, Kolhapur, Kondapur, Maski, and Nasik have each yielded valuable materials of high quality from the Satavahana period (first century BCE to early third century AD). Wound and drawn beads are often found (Deo, 2000, p. 27). Beads with white stripes are known to have come from Kolhapur, Kondapur, Maski, Nevasa, Prakash and Ter in the Deccan. These beads are common enough at Tripuri and Ujjain. By the dawn of the Christian era, the use of glass for beads became more popular. Many techniques were adopted for the manufacture of beads and ornaments during this period (Margabandhu, 1985, p. 203).

Abdurazakov (1987, p. 38) speaks of finding fragments of Middle Age glass at nine archaeological sites in India: Ahichchhatra, Arikamedu Assam, Jaipur, Kausambi, Kurukshetra, Nalanda, and Udaigiri. He mentions the evidence of glass and clay pots (used for glass production) at Dargai in Pakistan too.

By the time of Harsa (seventh century AD), glass was no longer a luxury as it must have been in the Satavahana period and was even used by mendicants and aboriginals (Agrawal, 1953, p. 186; Kanungo, 2002b). In Deccan, with the establishment of the Sultanates (twelfth to thirteenth century AD), the country witnessed the

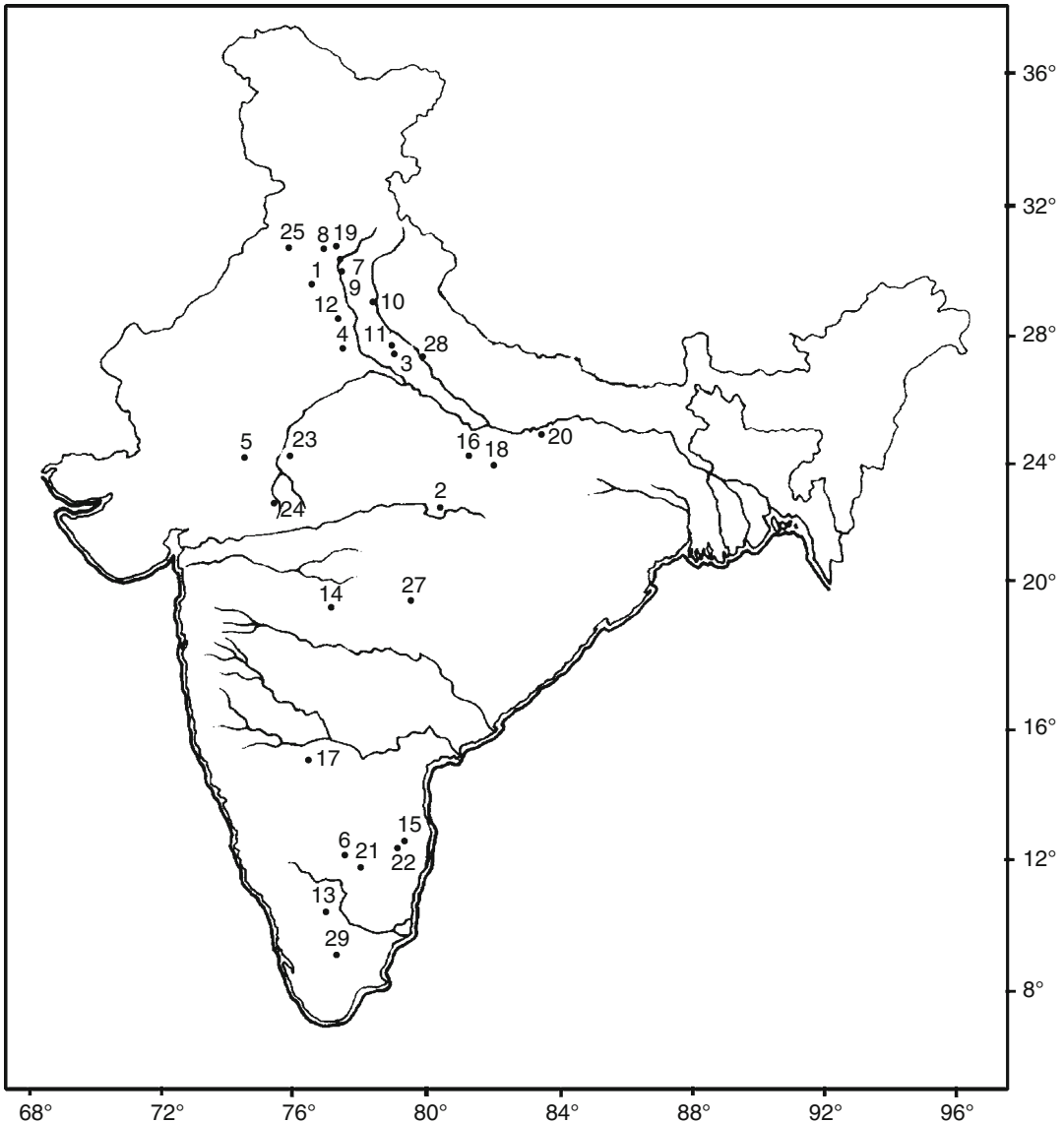
rise of small-scale cottage industries for the fabrication of glass beads, as evidenced by the discoveries at Kolhapur and Nevasa in Maharashtra, and Maski in Karnataka and Sirpur in Madhya Pradesh (Deo, 2000, p. 6). The lacuna in our knowledge about the other contemporary Indian glass objects is almost certainly due to inadequate excavations of historical sites.

Chemical analysis of the specimens of about 18 areas shows that Indian workers were well acquainted with the raw materials and coloring agents used for the preparation of glass. In some of the specimens of Taxila glass, the presence of lead oxide and in some of the Tripuri specimens (200 BCE) the presence of barium oxide has been found. Presence of lead in glass gives rise to the formation of crystal glass and that of barium imparts to glass high resistance to heat.

In comparison with commonly occurring archaeological material such as pottery or metals, the glass in ancient sites occurs less frequently. Glass was never produced, on a very large scale, or over so wide an area as other materials. This is due to the fact that it required advanced technological skills to generate and maintain the required temperature for production of glass for long periods. This very often mirrors the general technological level of society. However, considering the spread of proto glass and its by-products in Protohistoric, its contemporary and later periods there is every possibility that glass might have developed independently in India. Glass seems to have appeared 500–1,000 years later than in Mesopotamia and Egypt.

In the Indian context, literary data and archaeological evidence point to the same time period for the occurrence of glass. Reference of *kāca* comes from the *Brahmana* group of texts which are assigned to the same time period as that of the Painted Grey Ware. Glass becomes more common in the Northern Black Polished Ware period. This is also reflected in literary data of the fourth to fifth century BCE, which abounds in references to glass.

In the early Christian era glass was not only found throughout the country but its by-products like beads were also produced using indigenous techniques. Subsequently, many places emerged



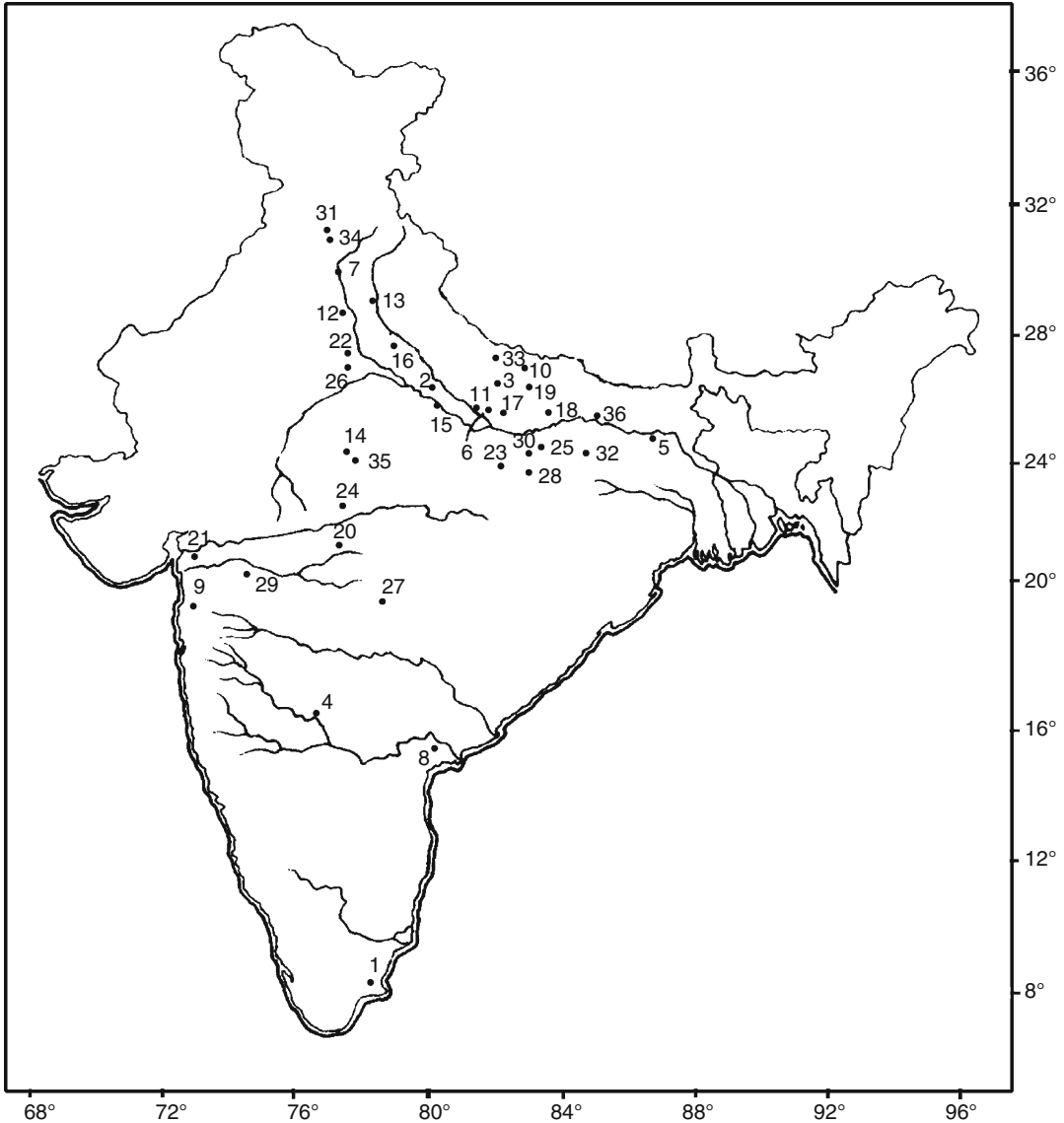
Glass in India, Map 1 Evidence of glass and glass beads in Indian archaeology between 1200 and 600 BCE. 1 Alamgirpur, 2 Amahata, 3 Atranjikhhera, 4 Autha, 5 Bagor, 6 Banahalli, 7 Bhagwanpura, 8 Brass, 9 Daulatpur, 10 Hastinapur, 11 Jakhera, 12 Jhatikra, 13

Kodumanal, 14 Kotra, 15 Kunnattur, 16 Manikpur, 17 Maski, 18 Munahi, 19 Nagiari, 20 Narhan, 21 Pairyampalli, 22 Pallavamedu, 23 Pasewa, 24 Runija, 25 Sanghol, 26 Sarhat, 27 Shirkanda, 28 Sravasti, 29 T-Kallupatti

as production centers of a flourishing glass industry, as it had become by now an article of common use and was no longer a precious and rare commodity. Glass is more abundantly seen at the dawn of the Christian era.

No archaeological site except Nevasa has as yet given evidence of a glass furnace. This is probably

due to the fact that since production of glass requires a high temperature for a long time period, and in earlier days furnaces were generally made of clay, they collapsed or broke down at a fast rate. Thus in the archaeological context, not only does glass need to be classified and recorded, but the debitage also needs to be carefully collected and

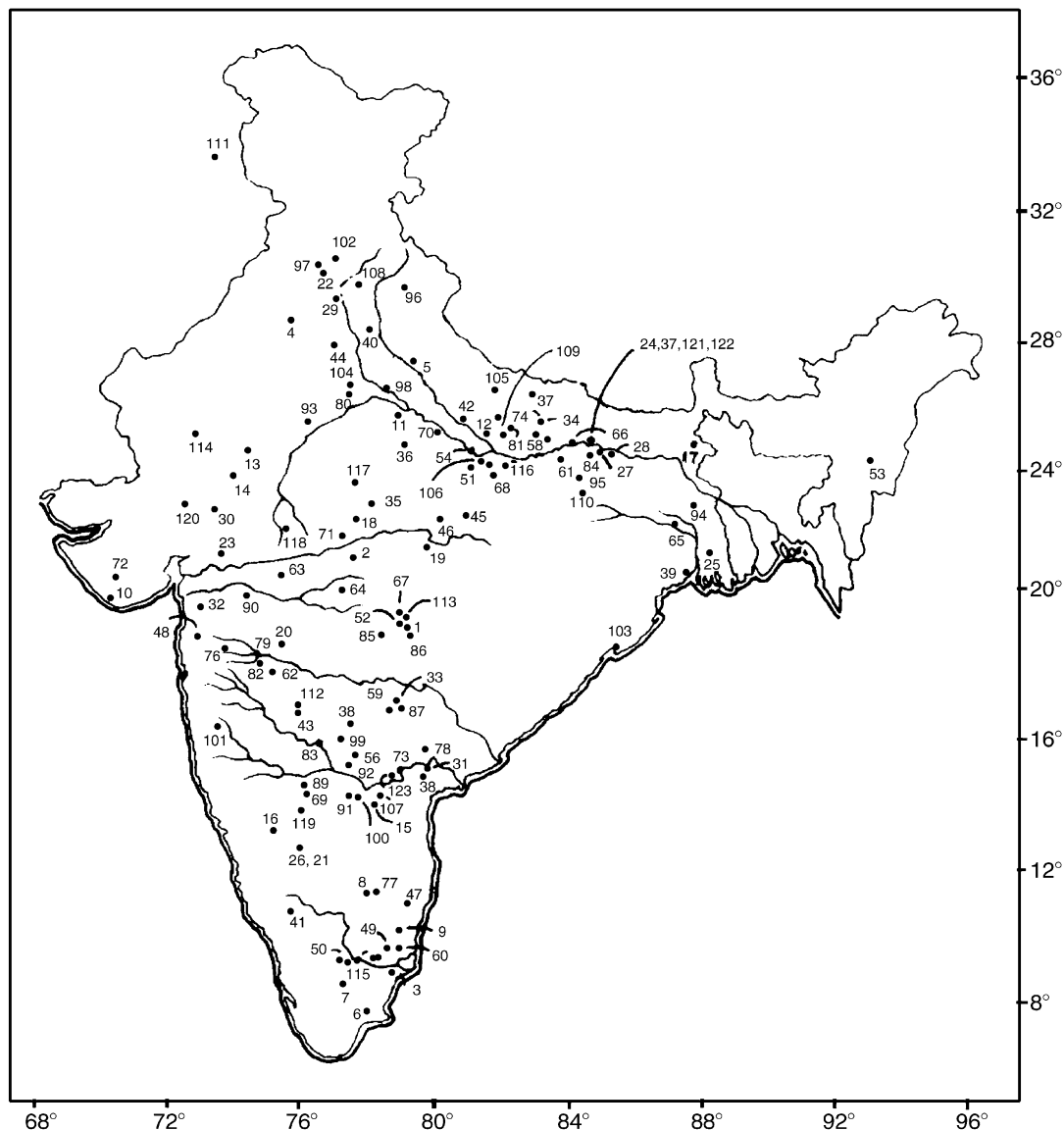


Glass in India, Map 2 Evidence of glass and glass beads in Indian archaeology between 600 and 300 BCE. 1 Alagankulam, 2 Amethi, 3 Ayodhya, 4 Benagutti, 5 Champa, 6 Danwa, 7 Daulatpur, 8 Dharanikota, 9 Dhatva, 10 Ganwaria and Salargarh, 11 Gauriganj, 12 Harnol, 13 Hastinapur, 14 Hulas, 15 Jajmau, 16 Jakhera,

17 Kadipur, 18 Kheradih, 19 Kopia, 20 Kotra, 21 Malvan, 22 Mathura, 23 Munahi, 24 Nadner, 25 Narhan, 26 Noh, 27 Paunar, 28 Prahaladpur, 29 Prakash, 30 Rajghat, 31 Singh Bhagwanpur, 32 Sonepur, 33 Sravasti, 34 Sugh, 35 Tumain, 36 Vaisali

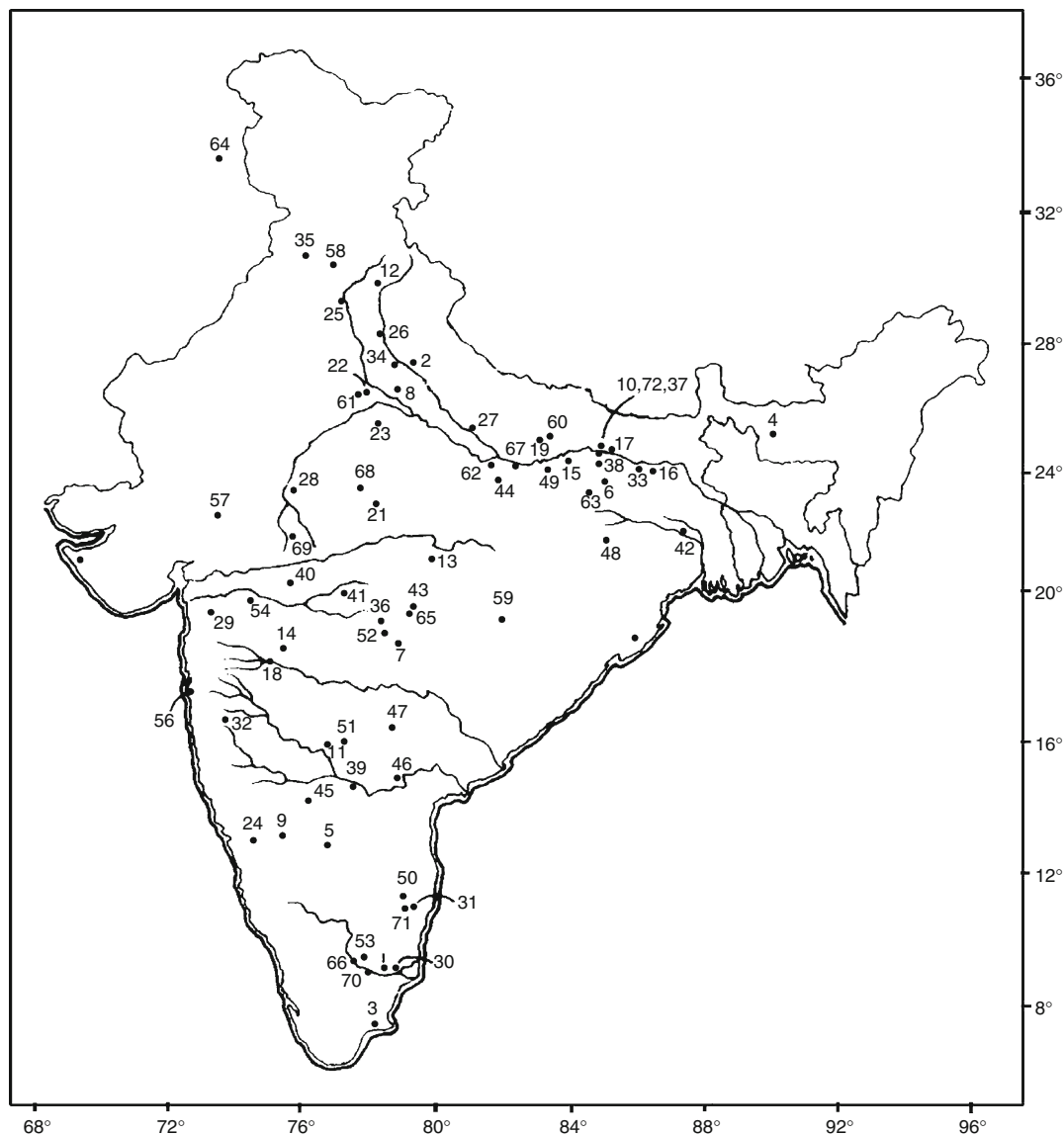
catalogued. (Debitage is the collective term used by archaeologists to refer to the sharp-edged waste material left over when someone creates a stone tool (knaps flint). Debitage is probably the oldest artifact-type recognized by archaeologists; the term is a French one but widely used by archaeologists the world over.)

The evidence of glass in Indian archaeology is spread in both time and space. Though there have been claims at regular intervals by different authors about the glass being introduced to India from outside, sometime in the Indo-Roman period, the evidence from as many as 29 sites gives ample evidence that glass was known



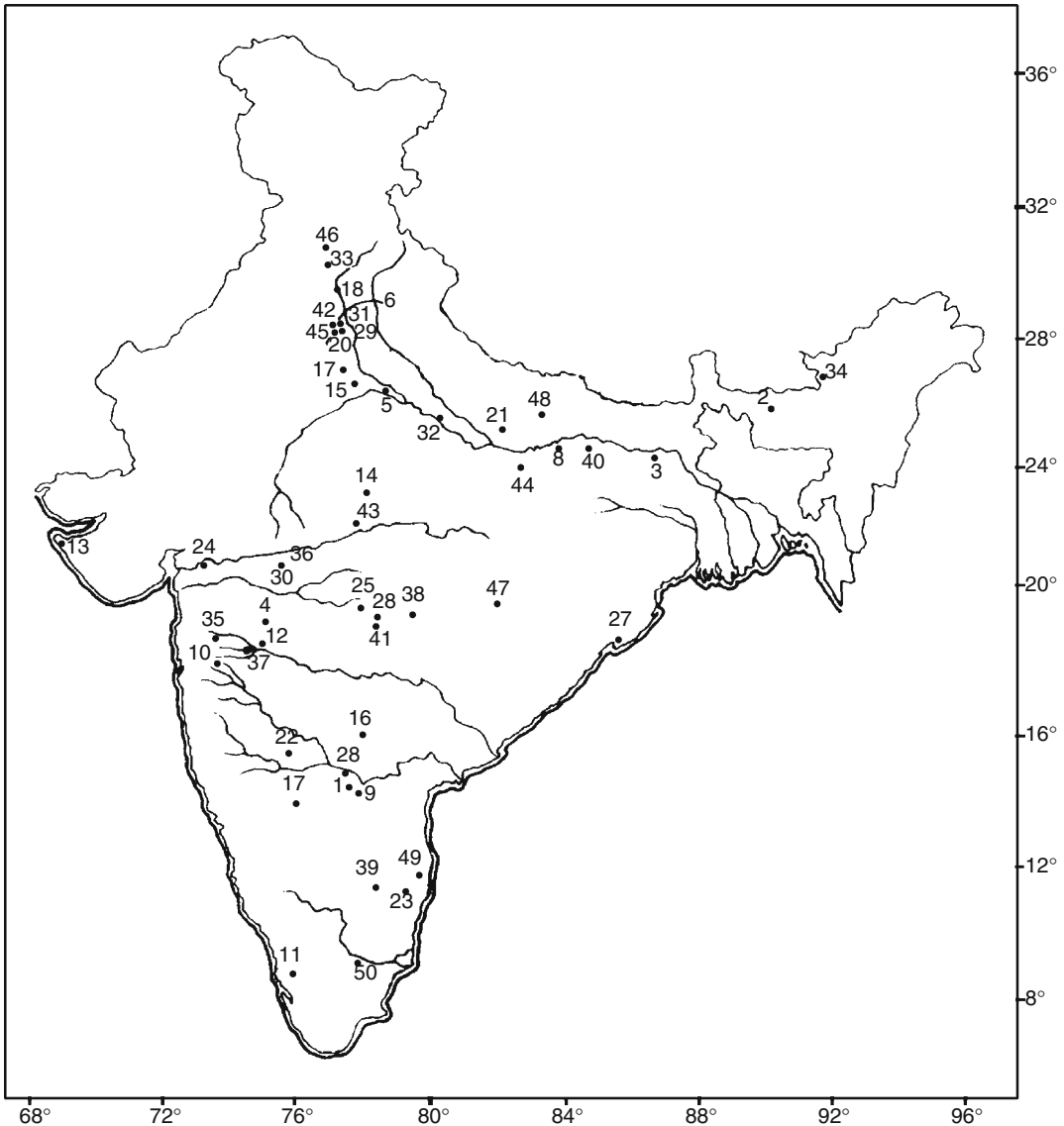
Glass in India, Map 3 Evidence of glass and glass beads in Indian archaeology between 300 BCE and 400 AD. 1 Adam, 2 Adamgarh, 3 Adiyamankottai, 4 Agroha, 5 Ahichchhatra, 6 Alagankulam, 7 Alagarai, 8 Appukalu, 9 Arikamedu, 10 Ami, 11 Aunhan, 12 Ayodhya, 13 Bagor, 14 Balathal, 15 Banahalli, 16 Banavasi, 17 Basarh, 18 Besnagar, 19 Bhita, 20 Bhokardan, 21 Brahmagiri, 22 Brass, 23 Broach, 24 Chandahadih, 25 Chandraketugarh, 26 Chandravalli, 27 Chechar, 28 Chirand, 29 Daulatpur, 30 Devnimori, 31 Dharanikota, 32 Dhatva, 33 Dhulikatta, 34 Dhuriapur, 35 Eran, 36 Erich, 37 Ganwaria and Salargarh, 38 Garapadu, 39 Hari-narayanpur, 40 Hastinapur, 41 Hemmige, 42 Hulas Khera, 43 Irla, 44 Jhatkira, 45 Jhusi, 46 Kakrethta, 47 Kanchipuram, 48 Karad, 49 Karaikadu, 50 Karur, 51 Kausambi, 52 Khairwada, 53 Khangabok, 54 Khartuni, 55 Kheradih, 56 Kohir, 57 Kolhua, 58 Kondapur,

59 Kotalinga, 60 Kudikadu, 61 Kumrahar, 62 Kusan, 63 Maheshwar, 64 Malhar, 65 Mangalkot, 66 Manjhi, 67 Mansar, 68 Masaon, 69 Maski, 70 Matin – Mahadev, 71 Nadner, 72 Nagara, 73 Nagarjunakonda, 74 Narhan, 76 Nasik-Jorwe, 77 Nattamedu, 78 Nelakondapalli, 79 Nevasa, 80 Noh, 81 Orai, 82 Paithan, 83 Pandigadda, 84 Pataliputra, 85 Paunar, 86 Pauni, 87 Peddabankur, 88 Perur, 89 Pikkilhal, 90 Prakash, 91 Pudur, 92 Pydigutta, 93 Raiah, 94 Rajbadidanga, 95 Rajghat, 96 Ratura, 97 Sanghol, 98 Sankisa, 99 Sannati, 100 Satanikota, 101 Satara, 102 Singh Bhagwanpur, 103 Sisupalgarh, 104 Sonkh, 105 Sravasti, 106 Sringaverapura, 107 Srisailem, 108 Sugh, 109 Sultanpur, 110 Taradih, 111 Taxila, 112 Ter, 113 Tharsa, 114 Tilwara, 115 Tirukkambuliur, 116 Tripuri, 117 Tumain, 118 Ujjain, 119 Vadagaon – Madhavapur, 120 Vadnagar, 121 Vaisali, 122 Virpur, 123 Yeleswaram



Glass in India, Map 4 Evidence of glass and glass beads in Indian archaeology between 400 and 1300 AD. 1 Adiyamankottai, 2 Ahichchhatra, 3 Alagankulam, 4 Ambari, 5 Anantapur, 6 Apsad, 7 Arambha, 8 Atranjikhhera, 9 Banavasi, 10 Basarh, 11 Benagutti, 12 Bharat Mandir, 13 Bhita, 14 Bhokardan, 15 Buxar, 16 Champa, 17 Chechar, 18 Daulatabad, 19 Dhuriapur, 20 Dwarka, 21 Eran, 22 Fatehpur Sikri, 23 Gilaulikhhera, 24 Gudnapur, 25 Harsh-ka-tila, 26 Hastinapur, 27 Hulas Khera, 28 Indragarh, 29 Jokha, 30 Kambarmedu, 31 Kanchipuram, 32 Kanheri, 33 Karnachaura, 34 Kashipur, 35

Katpalon, 36 Khairwada, 37 Kolhua, 38 Kumrahar, 39 Kundavelli, 40 Maheshwar, 41 Malhar, 42 Mangalkot, 43 Mansar, 44 Masaon, 45 Maski, 46 Nagarjunakonda, 47 Nagnoor, 48 Nalanda, 49 Narhan, 50 Pallavamedu, 51 Pandigadda, 52 Paunar, 53 Perur, 54 Prakash, 55 Ratnagiri, 56 Sanjan, 57 Shamalaji, 58 Singh Bhagwanpur, 59 Sirpur, 60 Sohgaora, 61 Sonkh, 62 Sringaverapura, 63 Taradih, 64 Taxila, 65 Tharsa, 66 Tirukkambuliur, 67 Tripuri, 68 Tumain, 69 Ujjain, 70 Uraiyur, 71 Vadavur, 72 Vaisali



Glass in India, Map 5 Evidence of glass and glass beads in Indian archaeology between 1300 and 1800 AD. 1 Alampur, 2 Ambari, 3 Antichak, 4 Bahal, 5 Batesvara, 6 Bijai Mandal, 7 Brahmapuri, 8 Buxar, 9 Chagatpur, 10 Chandoli, 11 Chermanparambu, 12 Daulatabad, 13 Dwarka, 14 Eran, 15 Fatehpur Sikri, 16 Golconda, 17 Hampi, 18 Harsh-ka-tila, 19 Hemmige, 20 Jhatkira, 21 Kadipur, 22 Kadkal, 23 Kanchipuram, 24 Karvan, 25 Kaundanpur, 26 Khairwada, 27

Khalkata – patana, 28 Kundavelli, 29 Lalkot, 30 Maheshwar, 31 Makhdum Sahib's Mosque, 32 Matin – Mahadev, 33 Nagiari, 34 Naksaparvat, 35 Nasik-Jorwe, 36 Navdatoli, 37 Nevasa, 38 Pachkheri, 39 Padavedu, 40 Pataliputra, 41 Paunar, 42 Purana Qila, 43 Raisen fort, 44 Rajghat, 45 Salimgarh Fort, 46 Singh Bhagwanpur, 47 Sirpur, 48 Sohgaure, 49 Tiruverkadu, 50 Uraiyur

much earlier and could have been produced locally (Map 1). Besides, there is also stray evidence of glass in Bhagwanpura (Painted Grey Ware-Harappan overlapping), Dwarka

(late Harappan) and Maski (Chalcolithic), which are of much earlier cultures. Likewise there are 34 sites, which have evidence of glass beads in association with the Northern Black Polished

Ware period or in the period in between 600 and 300 BCE (Map 2). However, with the beginning of the early Historic phase, and more particularly in the early Christian centuries, the evidence of glass from as many as 119 sites suggests large-scale use (Map 3). This period is between 300 BCE and 400 AD and is characterized by red ware, red polished ware, russet coated painted ware, red and black slipped ware, black slipped ware and rouletted ware. All the same, during the Medieval Period there is clear indication that glass was becoming quite common as evidenced by its presence at 70 sites in the early Medieval period (400–1300 AD) (Map 4) and 49 sites in the late Medieval period (1300–1800 AD) (Map 5) (for details see Kanungo 2002a, 2004c). Considering such spread of glass and its by-products in ancient India, it is highly likely that around the early Christian era there should have been more regional major producers of glass other than the established site of Arikamedu in the south. In this regard Kopia in the north with its strategic location, abundance of glass, glass beads, crucibles and other debitage on the surface stands apart, and further work followed by a systematic excavation of this site could result in better understanding of ancient glass technology in India.

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See Also

► [Beads](#)

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Glass in the Middle East

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Introduction

Glass, *zujāj*, in Arabic transcription, has been well known in the East since the third millennium (Mesopotamia). It is obtained by mixing a “forming” (silica, mainly found in sand) with a flux (natron) or plant ashes (soda, from *Salsola* soda or potassium ashes) and a stabilizer. Then, the substance is fired at at least 1,000° (Foy & Nenna, 2001; Marin, 1877–1919; Whitehouse, 2002).

Glass from Islamic times is generally found in very small quantities, especially compared to pottery. Fragments constituted of plain glass with a few decorated samples are usually blown or mold-blown; those could be of vessels, windows, bangles, beads, pins, or weights. The paste color as well as the quality, translucent or opaque, may be different regarding location and dating. The glass is most frequently blue, brown, or green but few samples of yellow, or white colors are also identified.

This entry will introduce Islamic glass from the seventh to the nineteenth century in the three main geo-cultural areas: Near East; Iraq, Iran, and Central Asia; and Arabia and Gulf areas. A last fourth will speak of the colored glass bangles known from the Mediterranean to Arabia.

The Near-East

The First Centuries

During the first centuries of the Islamic period (Omayyad: 661–750), the legacy of late Antiquity and Byzantium is really strong (Illustration 1). Glass fragments discovered in Bilad al-Sham as in Damascus and Bosra in Syria, Beirut in Lebanon, and Jerash in Jordan (Dussart, 2000, pp. 91–96) are close to those identified in the archaeological levels of Istabl ‘Antar-Fostat and Tebtunis in Egypt (Foy, 2000a, pp. 151–178). Those may be identified as balsamaria, flasks, and pitchers, and sometimes they are decorated with glass threads applied, pinched, or embossed (Dussart, 1998).

With the Abbasid Caliphate (751–1258) and the Tulunid dynasty in Egypt (808–965), one important novation was the invention of painted luster glass, sometimes attributed to Coptic workshops. It is obtained by putting copper and silver oxides on the surface of the glass object and firing it in an oxygen-free atmosphere. Many painted luster samples have been unearthed in Near Eastern archaeological sites, particularly at Fustat-Misir (Scanlon & Pinder-Wilson, 2001). Another kind of glass is millefiori which had been

discovered in Qasr al-Hayr al-Sharqi in North Syria (Grabar, Holod, Knustad, & Trousdale, 1978).

Monumental mosaics, *fusayfisa*, are a rich expression of glass, particularly in the Near East. The Dome of the Rock at Jerusalem and the Umayyad Mosque in Damascus (Kenney, 2006, pp. 175–200) are from the first centuries. Numerous glass weights or impressed tokens are stored in the museum collections (Launois, 1949).

Glass workshops were located at Tyre on the Mediterranean coast (al-Mas‘udi, al-Muqaddasi in the tenth century: Lamm, 1929, 1930, p. 491; Aldsworth, Haggarty, Jennings, & Whitehouse, 2002, pp. 49–66), Beirut, and Istabl ‘Antar-Fostat (Foy, 2000a).

Fatimid Caliphates (1069–1171) A huge quantity of glass – cups, dishes, jugs, beakers, and lamps commonly attributed to the Fatimid workshops – was discovered in the shipwreck of Serçe Limani in Turkey (Bass, Lledo, Matthews, & Brill, 2004). Beakers and flasks were also found in archaeological sites at Tebtunis and Istabl ‘Antar-Fostat in Egypt (Foy, 2000a, pp. 151–178; 2000b, pp. 239–290). Marvered glass is also assigned to this period. Colored tokens have also been discovered.

Crusader Times (1094–1187) In Akko, Jerusalem, fragments of plain glass were discovered. Some were decorated with prunts [a small mass of glass fused to the body of a glass piece] (beakers); others were marvered (Gorin-Rosen, 2013, pp. 109–116).

Ayyubid Times (1171–1250) This time is well known for the discovery of enameled and gilded glass fragments, unearthed in all the Ayyubid territories (including Bilad al-Sham), but more common in North Syria, Raqqa (Euphrate), Hama, and Mina in Turkey. Fragments are generally identified as beakers; other shapes could be long-necked bottles or flasks.

C. Lamm identified several typological groups of enameled and gilded glass (Blair & Bloom, 2009, pp. 114–115; Carboni, 2002;



Glass in the Middle East, Illustration 1 Animal flask (late seventh–eighth century). Yellow and pinkish, blown glass, applied decoration (Metropolitan Museum of New-York (USA); IAP artstore, Open Access for Scholarly Content (OASC), Met’s Website)

Carboni, & Whitehouse, 2002; Lamm, 1929, 1930). This technique had spread to Venice during the thirteenth century (Carboni, 1998, pp. 101–106; Whitehouse, 2014, pp. 73–78). The origin of the enameled ware could be Iran or Byzantium; the gild process is supposed to have been introduced from Anatolia and Seljuk (Abd el-Ra'uf al Yousuf, 1998: pp. 20–23; Genito, 1977, pp. 12–13). Some beakers are mentioned in medieval inventories and stored in international public collections.

We can also find some thread decoration applied around the long necks of some bottles and marvered decorations on the body of some fragments. Circular impressed weights of inscriptions are always known.

Workshops are well certified by the textual sources. In Syria, Aleppo particularly specialized in enameled glass (al-Qazwini, in the thirteenth century: Lamm, p. 491). In Raqqa, Rafiq, in North Syria, glass sherds have also been found, and other archaeological remains allowed us to conclude that there were glass workshops (Henderson, 1999, pp. 225–240).

Mamluk Times (Bahri (1250–1382) and Burji (1382–1516) Dynasties (Ill. 2 and 3)

Fustat, Quseir el-Qadim, in Egypt had revealed some glass fragments of Mamluk times (Whitcomb & Johnson, 1979, 1982), as have other sites in Bilad al-Sham, Khirbat Faris, Tell Abu Sarbut, and Tell Hesban in Jordan (Illustration 2).

These shapes could be quite different from the earlier ones. There are large dishes or vases and long-necked bottles. Enameled decoration is used as well as the gilded decoration. Mosque lamps illustrate a plain beautiful expression, with a particularly characteristic iconography of calligraphy, written generally in Thuluth.

However, this production is said to have been stopped during the fourteenth century, while Europe, especially Venice and Spain, began to produce those kinds of objects (Carboni, 2007; Whitehouse, 2014). Glass weights are well identified also, as previously.

Regarding glassmaking places, workshops at Hebron, Damascus, and Cairo are also mentioned



Glass in the Middle East, Illustration 2 Beaker with fish motifs (thirteenth–fourteenth century). Glass colorless with yellow tinge blown, applied ring foot enameled and gilded (Metropolitan Museum of New York (USA); IAP artstore, Open Access for Scholarly Content (OASC), Met's Website)

in the sources (Poggibonsi, Schmidt, al-'Umari in Lamm, pp. 492–493).

Ottoman Times (14th–19th) Workshops run by the State became the rule in Turkey, especially in Istanbul, and the guilds played an important role for art crafts. Manuscripts illustrations as in the *Surname-I Hümayun* (Guilds Procession, sixteenth century, stored in the Topkapi Palace Museum Library) display interesting iconography. European connections were strong; Ottoman sultans ordered mosque lamps from Venice (Carboni, 2007; Whitehouse, 2014).

Local provincial workshops continued their activity (Henein, 1974), even if the glass quality was poor. More glass was imported from the Empire, especially from Austria and Hungary. Beykoz glass was a new kind of glass that has



Glass in the Middle East, Illustration 3 Mosque lamp of Amir Qawsun 'Alib Ibn Muhammad al-Barmaki (1329–1335). Glass colorless with brown tinge, blown applied foot enameled and gilded (Metropolitan Museum of New-York (USA); IAP artstore, Open Access for Scholarly Content (OASC), Met's Website)

been manufactured around Istanbul since the nineteenth century (Kucukerman, 1998; Moraitou, 2013).

Iraq, Iran, and Central Asia (Ill 4 to 6)

Ninth to Thirteenth Century, from Abbasids to Seljuk (Ill. 4 and 5)

During the first centuries (Samanid dynasty, for example, from 819 to 999), as in the Near East, art glass production was strongly influenced by the late Iranian antiquity, particularly Sassanid glass production (Illustration 3).

At Samarra, in Iraq, at one time a capital (838–883) of the Abbasid caliphate (750–1258), an interesting glass corpus has been recorded: fragments of flasks, cups, lamps of undecorated blown glass, brown window glass, and decorated glass as millefiori (bowls and pavement floor), deep blue and scratched glass, threads glass

applied, and white glass with circles (relief-cut technique). Some shapes have been interpreted as having medicinal or alchemical uses (Lamm, 1928).

Objects from the Herzfeld excavations (Ernst Emil Herzfeld 1879–1948) are stored among several international museum collections such as the Metropolitan Museum of Art in New York, the Museum Fur Islamische Kunst in Berlin, and the British Museum.

Susa's glass corpus in Iran (Khuzestan), dated from the eighth to the tenth centuries, displays really interesting samples of vessels which are similar to those of Samarra, with some more "Persian" characteristics. Some are also interpreted as having medical or alchemical uses (Lamm, 1928, 1931); a collection is stored at the Louvre Museum in Paris. Another glass corpus was found during the Nishapur excavations, a site located in Khurasan, in Iran (dated from the ninth century to the first part of the thirteenth century); today this is mainly stored in the Metropolitan Museum in New York; it displays fragments of blown, mold-blown glass, with pinched or stamped decorations, glass threads applied, wheel-cut, millefiori, painted luster, or scratched patterns. Some shapes identified are lamps, windows, game pieces, or molar flasks (Kröger, 1995). Colored impressed glass tokens supporting a figurative iconography are known from Ghaznavids (977–1186) palace excavations in Afghanistan (Carboni, 2001).

Regarding glassmaking, a workshop seems to have been identified in Samarra (Northedge, 2005), and Kröger has proposed the possibility of a local one at Nishapur, even if there is no archaeological evidence of local manufacture. Around 17 furnaces have been identified at Sirjan and at Gurgan in Iran (Kröger, 1995).

Mongol Times: Ilkhanids (1256–1353) and Timurids (1370–1506)

Near Eastern art craft workers are frequently quoted as deported by Timur (Tamerlan) in Samarkand, Central Asia, and there are others citations of Near Eastern glass sent to the Golden Horde territory (Kramarovsky, 1998, pp. 20–23). There are also archaeological sources



Glass in the Middle East, Illustration 4 Blue glass fragment from Samarra (Herzfeld Collection, British Museum; Courtesy of the Trustees of the British Museum)

which testify to local production (Abdurazakov, 1972, pp. 161–178). Some long-necked mold-blown bottles with a decoration of mesh patterns are frequently attributed to the twelfth to thirteenth century (Museo Nazionale d'Arte Orientale, Giuseppe Tucci; Doha Museum: Walton, 2013).

Safavids (1501–1736) and Qadjar (1779–1924)

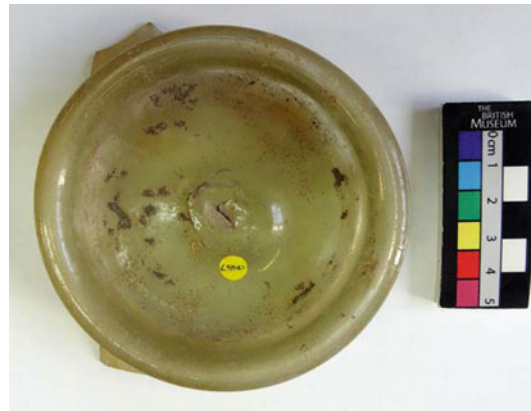
Long-necked bottles as sprinkle containers for rosewater are frequent in the museum collections. During the seventeenth century, textual sources such as Tavernier and Lemans mentioned glass workshops at Isfahan and Shiraz which produced bottles of different colors (Lamm, pp. 500).

Arabia and Gulf Areas (III.7)

Glass finds have been unearthed during excavations of coastal sites at Sharma, al-Shihr (Foy, in process; Boulogne, & Hardy-Guilbert, 2010, pp. 135–148) (Illustration 4). Others have been found in the south of the Arabian Peninsula, around Aden and Julfar in the Persian Gulf (Hansmann, 1985, pp. 76–83; Boulogne & Carter in process) and also in Bahrain (Lombard & al-Sindi, 2013) and in Kuwait. There have also been fragments found in Saudi Arabia, at Masafi, and Yamama (Benoist, CNRS; Schiettecatte CNRS).



Glass in the Middle East, Illustration 5 Green Glass fragment decorated with a star motif, Samarra (Iraq), probably south thronehalls (Herzfeld Collection, British Museum; Courtesy of the Trustees of the British Museum)



Glass in the Middle East, Illustration 6 Yellow green Glass bottom Bottle, Samarra (Iraq), private houses (Sketched by Herzfeld in his Sketchbook 4, p.11 (Herzfeld's Finds Journal); Courtesy of the Trustees of the British Museum)

Finds of the first levels generally display Abbasid styles or shapes, as, for example, little cosmetic containers of fusiform shape (tapered at both ends) and thick deep blue glass or white with embossed patterns of circles. Glass is also recorded among the finds excavated from the



Glass in the Middle East, Illustration 7 Green glass fragment (attributed to Omeyyad times). Discovered at Khadima archaeological site (Kuwait) (D. Kennet excavations at Khadima; Courtesy of D. Kennet)



Glass in the Middle East, Illustration 8 Green glass fragment bangle decorated with yellow prunts (attributed to Samarra, Iraq) (Courtesy of the Trustees of the British Museum)

Glass in the Middle East, Illustration 9 Al-

Yamama glass corpus, al-Yamama (Riyadh, Arabia Saoudi) (Courtesy by Jérémie Schiettecatte CNRS – UMR 8167 “Orient et Méditerranée”)



medieval and later levels; generally those are fragments of thin little or medium concaves back bottles of green glass. Textual sources, particularly of the thirteenth century, talk about some gilded glass imported from the Near East to Yemen; at the same time, others mentioned workshop locations around the area of Aden (Boulogne & Hardy-Guilbert, 2010). Bahrain in the Persian Gulf must certainly have also had workshops.

A Phenomenon from the Near-East to Arabia: Colored Glass Bangles (Ill.8 to 11)

Well known during Antiquity (Spaer, 2001), in monochrome only, bangles dated from Islamic times are both monochrome and polychrome. They have interesting technical and varied chromatic decorations. Some were found in the first levels (Umayyad and Abbasid) of Near Eastern archaeological sites (as Khirbat Minyeh) and some in Qasr al-Hayr al-Sharqi (north of Syria) and Samarra (Iraq) (Grabar, 1978). Most come from medieval and late Islamic levels at sites located in the Near East, the Arabian Peninsula, the Persian Gulf, and sub-Saharan Africa. They also appear in Europe, particularly in Spain (Monod, 1975, pp. 702–718). Amazingly, there are very few from Iranian archaeological



Glass in the Middle East, Illustration 10 Glass bangles (fourteenth–fifteenth centuries), Near-East (Courtesy by J. Schiattecatte, CNRS)

Glass in the Middle East, Illustration 11 Glass bangle (fourteenth–fifteenth centuries), Near-East (Metropolitan Museum of New-York (USA); IAP artstore, Open Access for Scholarly Content (OASC), Met's Website)



Glass in the Middle East, Illustration 12 Glass bangle (fourteenth–fifteenth centuries). Near-East (Metropolitan Museum of New-York (USA); IAP artstore, Open Access for Scholarly Content (OASC), Met's Website)



finds except from South Balochistan. Glass bangles found in Islamic lands are totally different from Byzantine glass bracelets, and until now, we could identify at least two main different groups: Near Eastern and Arabian (with an Indian influence for some). Both groups demonstrate the same stylistic vocabulary combined with a

singular type of colors and variation around the size and profile. Techniques observed on Islamic glass bangles can be compared to this use in glass vessels (enameled, marvering, prunts), and patterns to this of some precious silver bracelets attributed to the Seljuk (Iran) and the Fatimid (Near East) (Hasson, 1987).

A bangle workshop was identified in the city of Hebron (fourteenth to fifteenth century) in the Near East, and Kröger mentioned a glass workshop in Dvin (Armenia), where a lot of bangles dated of the 10th–13th levels have been excavated. Could there have been bangle manufacture in Dvin? (Illustrations 7–10)

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- <http://samarrafindsproject.blogspot.fr/>
<http://samarrafindsproject.blogspot.fr/2014/09/samarra-in-boston.html>
<http://www.cmog.org/>

Glazes in China

Weidong Li

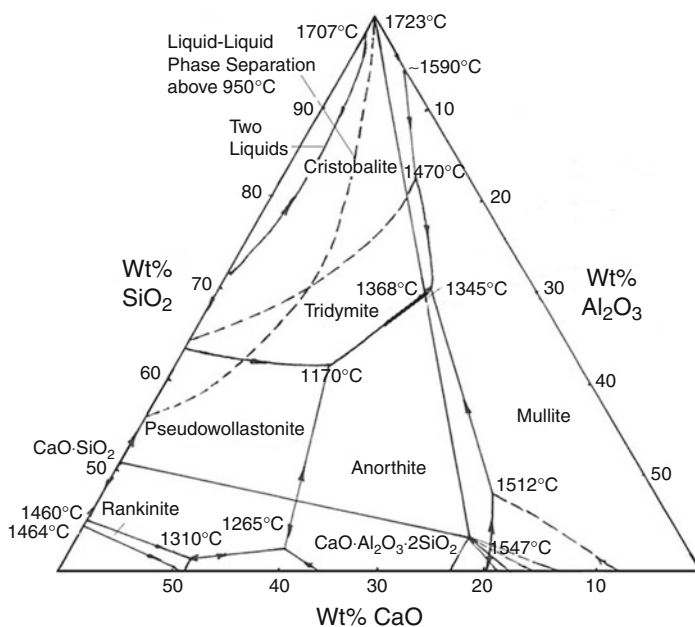
Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China
 Key Scientific Research Base of Ancient Ceramics, State Administration for Cultural Heritage, Shanghai, China

Introduction to Chinese High-Fired Glazes and Low-Fired Glazes

Glaze is a vitreous coating of glass that has been fused to a body through firing; it can color, decorate, strengthen, or waterproof the coated body. Ancient Chinese glaze is both a beautiful and mysterious science that includes high-fired glaze and low-fired glaze. High-fired glaze is applied to

Glazes in China,

Fig. 1 Phase diagram of $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-CaO}$ ternary system (Rawson, 1967)



porcelain or stoneware, whereas low-fired glaze is applied to pottery. Traditional Chinese high-fired glaze falls into the category of calcium glaze, calcium-alkali glaze, or alkali-calcium glaze, which originated from the plant ash glaze from the Shang dynasty (1700–1027 BC) (Li, 1998). Adding calcined plant ash and limestone was advantageous for the vitrification of glaze; the addition serves as a flux, enhances the glaze's stability, minimizes glaze defects, and modifies the fit and bonding between the glaze and body. Chinese low-fired glaze is either lead glaze or lead-barium glaze and originated in the Warring States Period (475–221 BC). Its origin is closely linked with the Chinese lead-barium glass which was invented in the Western Zhou dynasty (1027–771 BC). However, the most famous of the low-fired glazed pottery is the tricolored glazed pottery of the Tang dynasty (618–907 AD). Due to the toxicity of lead, it usually serves as a burial object in tombs.

Physicochemical Basis for High-Fired Glazes

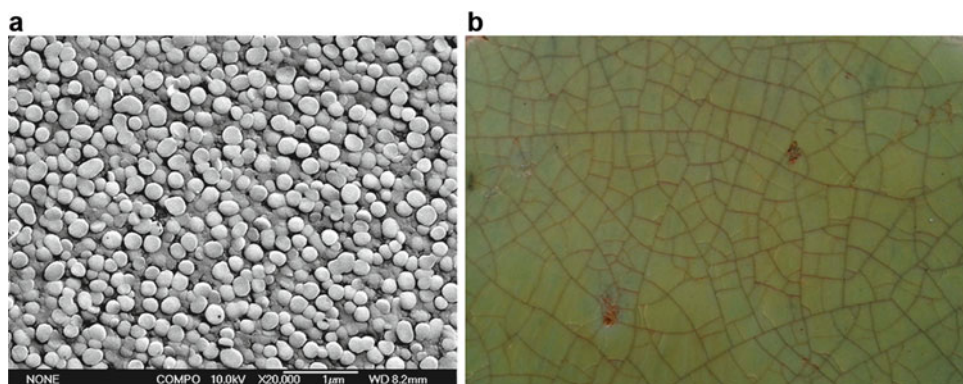
The high-fired glaze category can be divided into two groups: transparent glaze and opaque glaze. Transparent glaze is a homogeneous vitreous

glaze, whereas the opaque glaze contains light scatterers within the glaze, such as microcrystals or phase-separation structures or both. The high-fired glaze has the following principal constituents: SiO_2 , Al_2O_3 , CaO , MgO , K_2O , and Fe_2O_3 , which can be roughly represented with the $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-CaO}$ ternary system by merging MgO and Fe_2O_3 into CaO and ignoring K_2O . The physicochemical basis of Chinese high-fired glazes can be supposed within the confines of the phase equilibrium relationships of the $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2$ system and the metastable liquid-liquid immiscibility region above 950 °C (Rawson, 1967) (Fig. 1).

Phase-Separated Glaze

If the glaze composition falls into the liquid-liquid phase-separation region above 950 °C (Fig. 1), the physical chemistry is adequate for phase separation. Phase separation in glazes is primarily determined by the strong immiscibility tendency between SiO_2 and CaO (Mazurin & Porai-Koshits, 1984).

A celadon glaze from the Qionglai kiln is a high-fired opaque glaze with mild gloss. One thing that can distinguish the glaze from others



Glazes in China, Fig. 2 An opaque celadon glaze from the Qionglai kiln. (a) SEM image, showing submicron droplet phase-separated structure, (b) visual effect of the glaze

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is its extraordinarily high calcia (14.89–19.46 wt % CaO) and magnesia contents (4.24–6.88 wt % MgO). As shown in Fig. 2a, evenly dispersed submicron droplets which are separated out from the matrix serve as the light scatterers, with some of the droplets joining with each other. The droplet or joined droplet size ranges from 0.2 to 0.5 μm , which causes an intensive light scattering and thus results in good opacification (Li, Wu, Li, & Guo, 2002). In this case, chemical coloring effect is dominant, and the submicron phase-separation structure is responsible for the glaze opacification. Figure 3 shows various visual effects of the phase-separated glazes from the Qionglai kiln, Song dynasty (960–1279 AD). Another example of phase-separated glaze is the mild blue glazes from the Jun kiln (Fig. 4), Northern Song dynasty (960–1127 AD).

Crystalline Phase-Separated Glaze

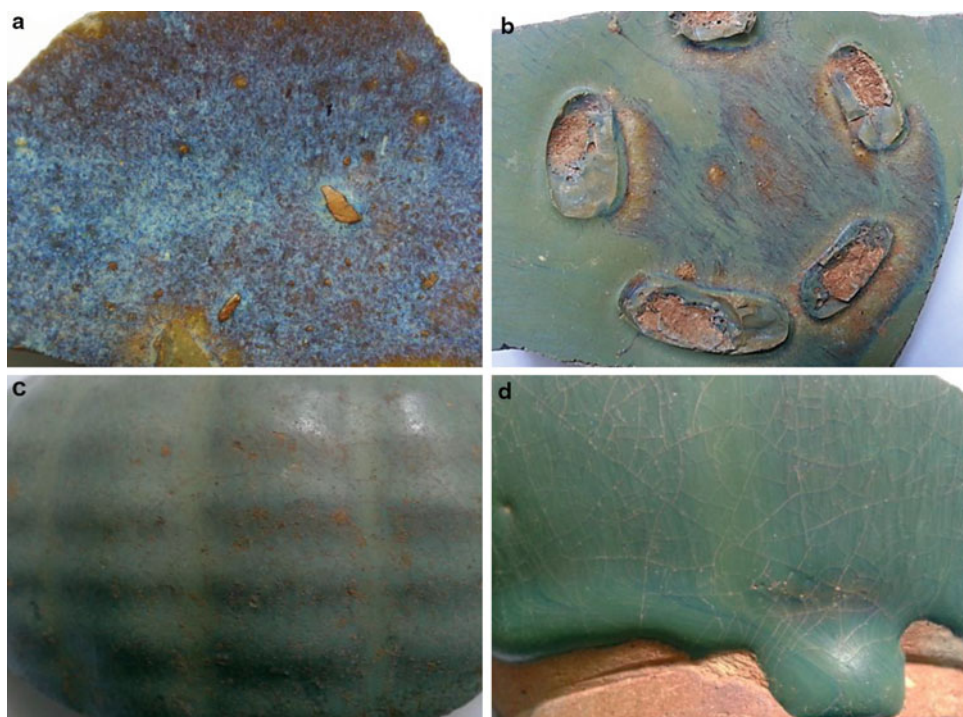
If the glaze composition falls into the primary crystalline phase region of anorthite (Fig. 1), it is limited to the un-equilibrium thermodynamic conditions during the firing process, and consequently, anorthite is the only crystal precipitated from the molten glaze. With anorthite growth, the alumina of the residual glass is heavily consumed; it is then followed by a rapid composition shift as the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio rises dramatically

and enters the metastable liquid-liquid immiscibility region above 950 °C.

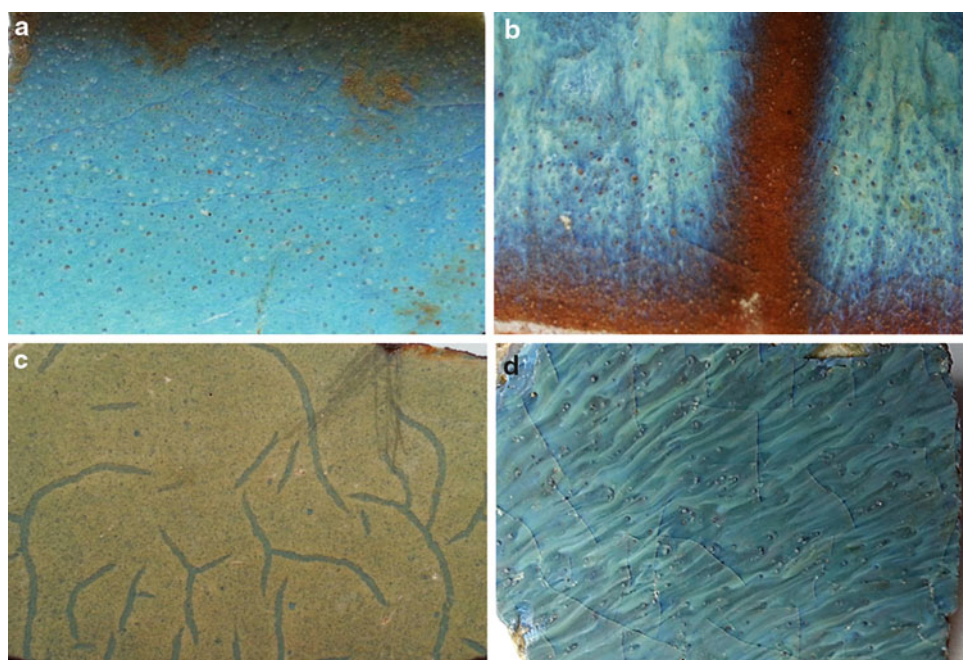
Within the interspaces of the anorthite clusters or around the brims of the anorthite needles or columns, a rough texture characteristic of the nano-sized liquid-liquid phase separation can always be observed. It results from the local chemical variation of the residual glass caused by anorthite crystallization (Li, Li, Deng, Wu, & Guo, 2005; Li, Luo, & Li, 2009) (Figs. 5, 6, and 7). The formation process of phase separation is complicated as it is influenced by the chemical composition variations, the viscosity-temperature relationship of melt, and the firing conditions, such as the temperature and atmosphere. As such, a great deal of variations can be expected. These anorthite crystals pack in different densities and cause varying chemical heterogeneity and, consequently, resulting in various scale phase separations. Opaque green glazes from the Yaozhou kiln (Five Dynasties, 907–960 AD), Ru kiln (Northern Song, 960–1127 AD), Zhang Gong Xiang kiln (Northern Song, 960–1127 AD), and Southern Song imperial kiln (1127–1279 AD) are typical of crystalline phase-separated glazes.

High-Iron Glaze

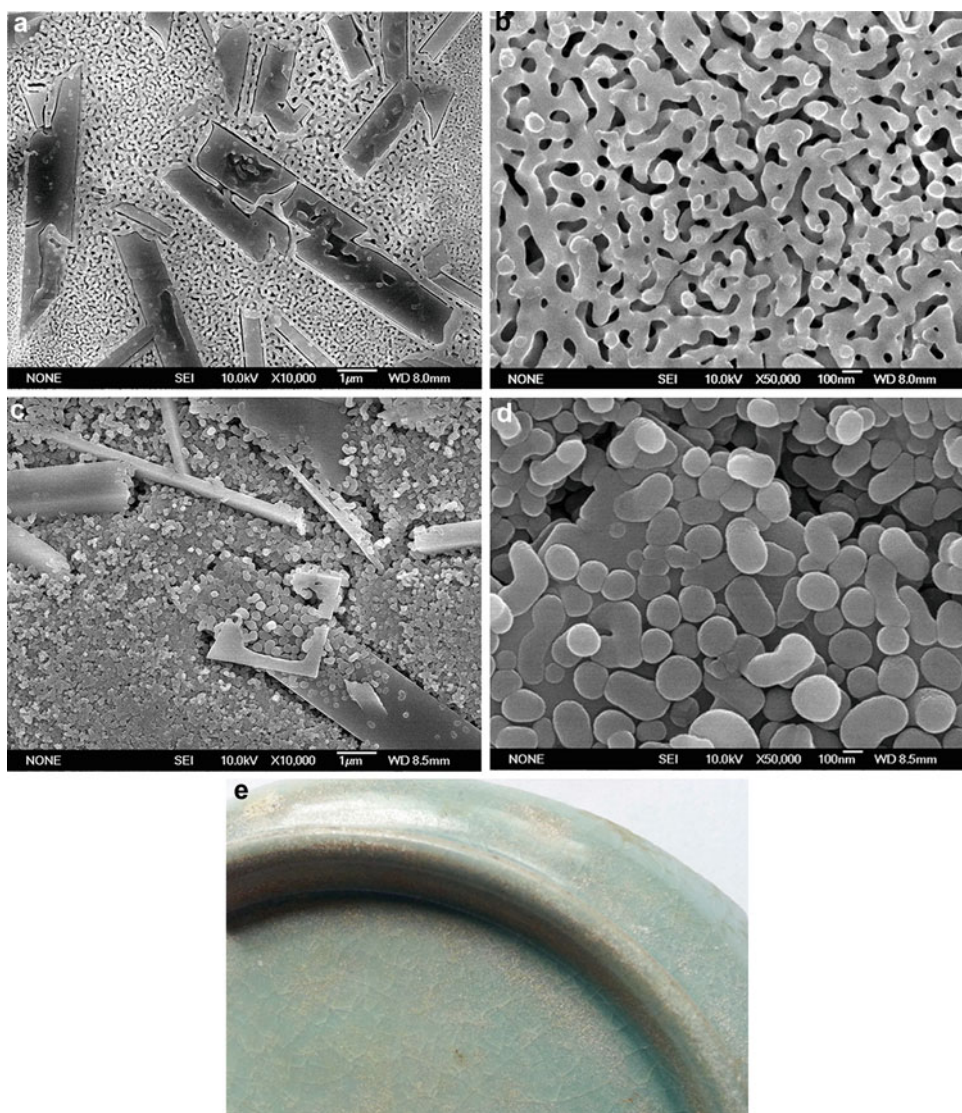
Through its array of complex yet subtle functions, iron is the most impressive element in



Glazes in China, Fig. 3 Visual effects of the phase-separated glazes from the Qionglai kiln, Song dynasty



Glazes in China, Fig. 4 Visual effects of the phase-separated glazes from the Jun kiln, Northern Song dynasty



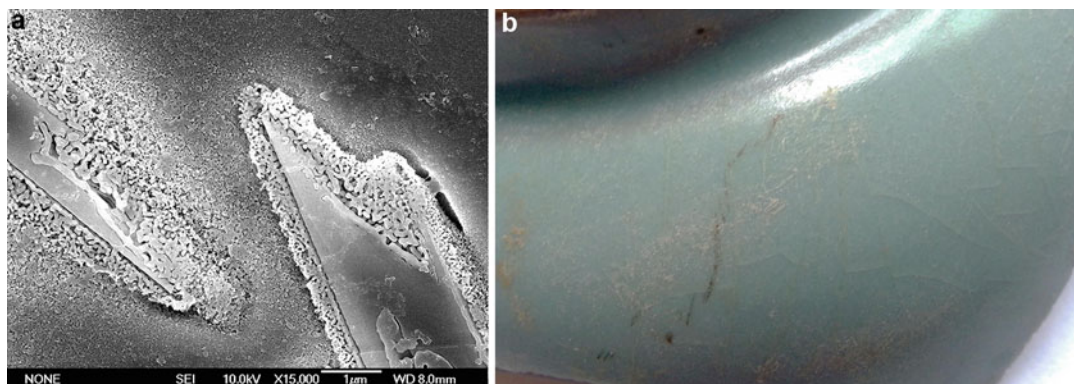
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Glazes in China, Fig. 5 An opaque green glaze from the Ru kiln, Northern Song dynasty. (a) SEM image, showing the liquid-liquid phase separation between the anorthite precipitates; (b) close-up of (a), showing interconnected

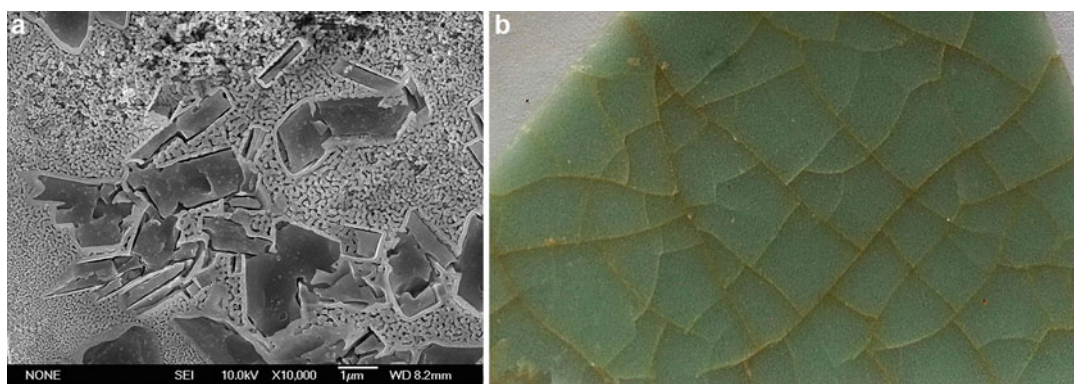
phase-separation structure; (c) SEM image, showing discrete droplet phase separation between the anorthite precipitates; (d) close-up of (c), showing discrete droplet phase-separation structure, (e) visual effect of the glaze

ancient Chinese glaze. It acts as both a flux and a coloring element; it favors the strong immiscibility tendency between SiO_2 and CaO and will precipitate from the glaze under supersaturation. Using the famous Jian kiln ware as an example, Fe is critical for producing the fantastic exterior appearance of the tea bowls from the Song dynasty (960–1279 AD) from the Jian kiln. If Fe

is ignored, the Jian glaze concentrates in the primary crystalline phase region of anorthite. However, in reality, the case is not that simple since the 4–7 wt% iron oxide in the glaze would not be ignored. With glaze composition variation, the microstructure formation would probably result in three distinct possibilities (Li, Luo, Li, Li, & Guo, 2008): (1) precipitation of anorthite



Glazes in China, Fig. 6 An opaque green glaze from the Ru kiln, Northern Song dynasty. (a) SEM image, showing interconnected phase separation around the brims of anorthite crystals, (b) visual effect of the glaze



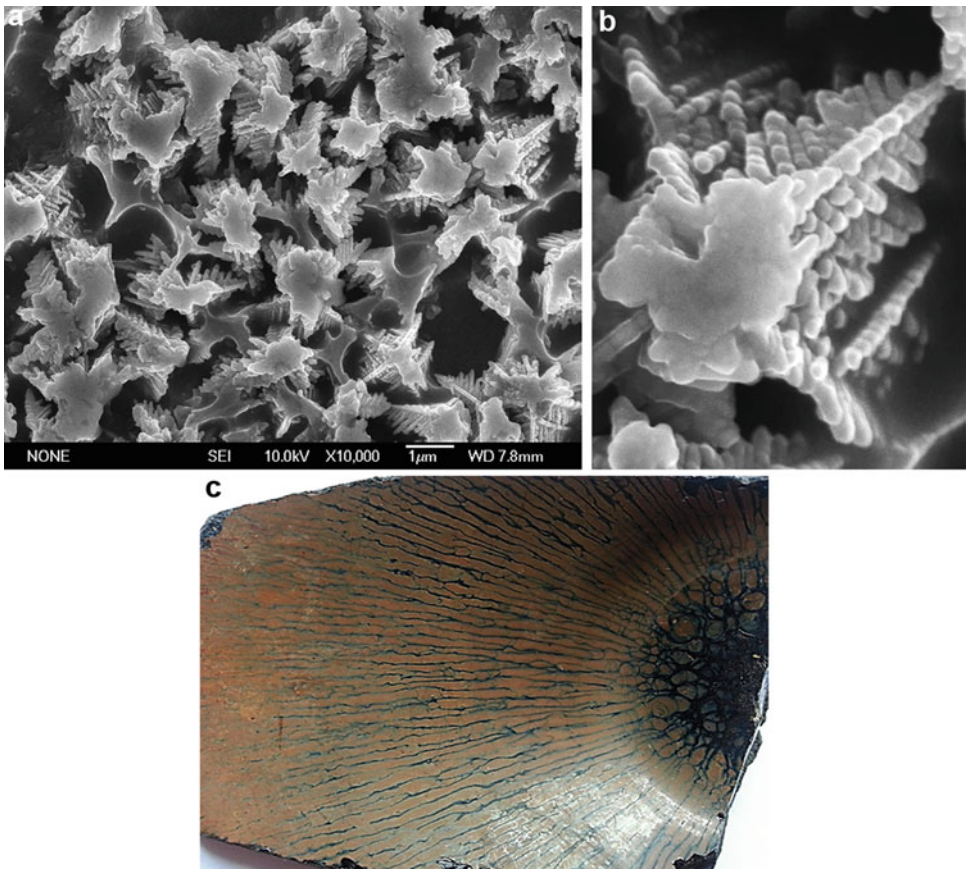
Glazes in China, Fig. 7 An opaque green glaze from the Lao Hu Dong imperial kiln, Southern Song dynasty. (a) SEM image, showing various scale interconnected phase-separation structures, (b) visual effect of the glaze

accompanied by an intercrystal phase separation and the subsequent precipitation of iron oxide, (2) precipitation of iron oxide favored by phase separation, and (3) formation of homogeneous amorphous black glaze. Furthermore, the glaze microstructure is highly related to the composition and firing schedule. Figures 8, 9, 10, 11, 12, and 13 detail the typical microstructures and visual effects of the high-iron glazes from the Jian kiln.

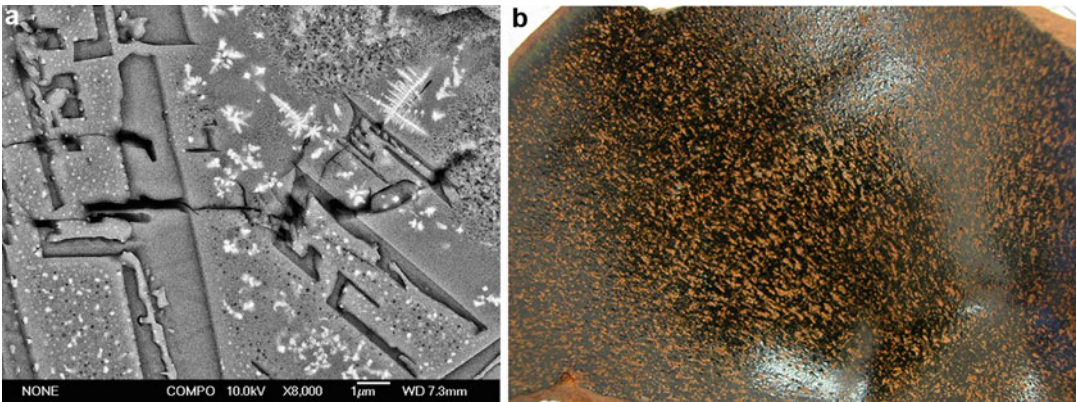
Transparent Vitreous Glaze

If the glaze composition falls into the primary crystalline phase region of tridymite and with

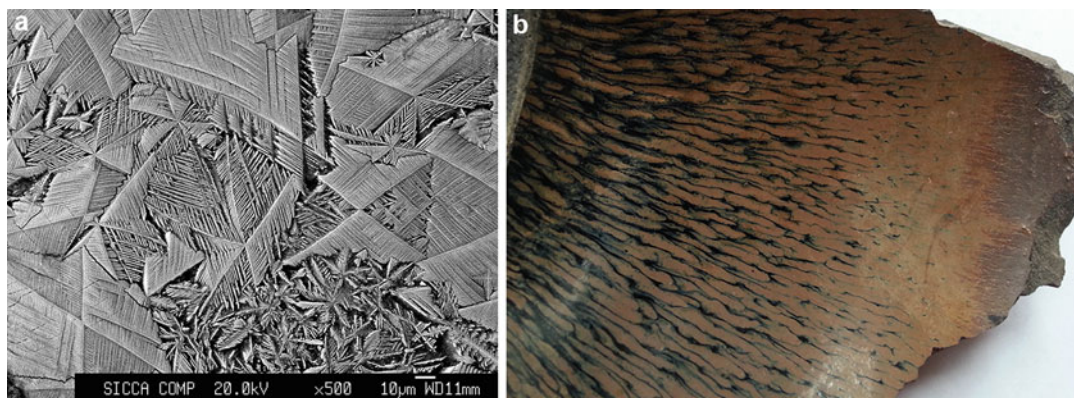
mole ratio of $\text{Al}_2\text{O}_3:\text{SiO}_2$ between 1:11.5 and 1:7 (Fig. 1), limited to the unequilibrium thermodynamic conditions during the firing process, no crystal will precipitate, and thus, a transparent vitreous glaze is formed. An interaction layer consisting of a dense anorthite microcrystal growth reaching into the glaze usually forms at the glaze-body interface due to the diffusion of aluminum ions from the body into the glaze (Li, Luo, Sun, Liu, & Zhao, 2011) (Fig. 14). At this interaction layer, an anorthite-accompanied phase-separation structure can always be observed. Many Chinese ancient kiln sites produced transparent-glazed wares, such as the Yue kiln, Yaozhou kiln, Xing kiln, Ding kiln, Gongyi kiln, Longquan kiln, Dehua kiln, etc.



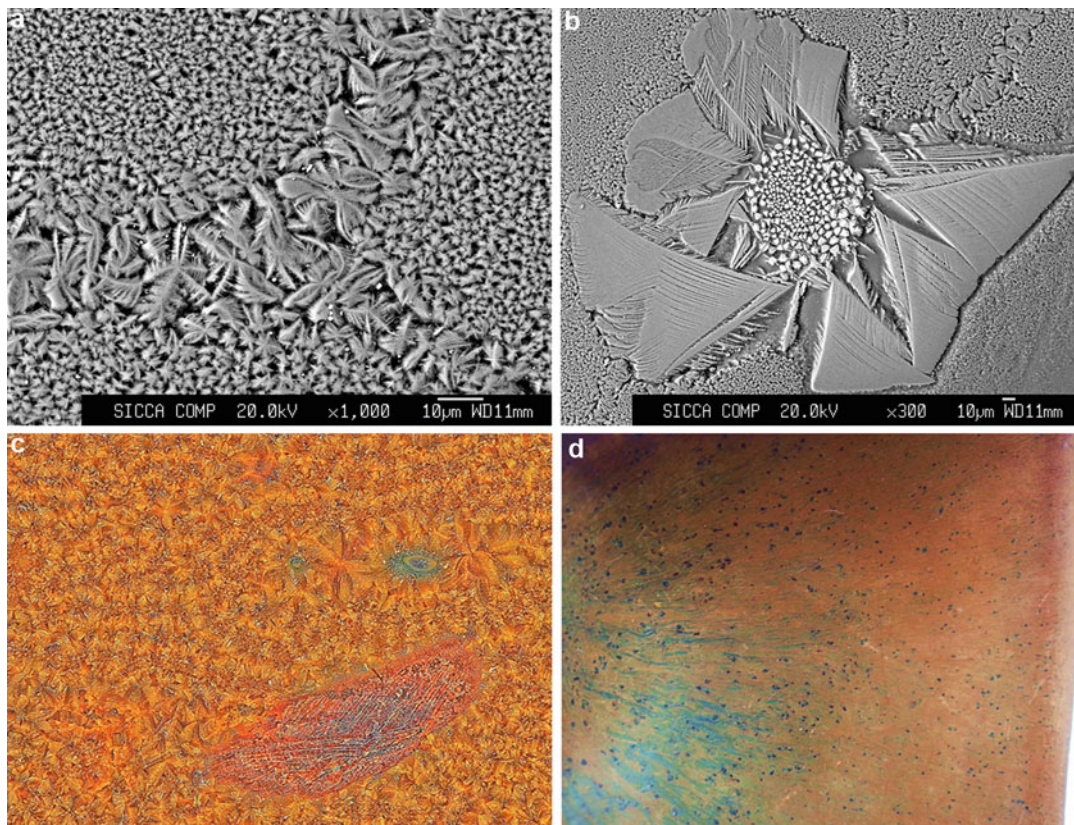
Glazes in China, Fig. 8 A shining brown hare's fur glaze from the Jian kiln, Song dynasty. (a) SEM image, showing well-organized dendrite hematite piling up in parallel with the glaze surface, which is forming shining, reflective streaks above the surface; (b) close-up of (a, c) visual effect of the glaze



Glazes in China, Fig. 9 A brown glaze with yellow speckles from the Jian kiln, Song dynasty. (a) SEM image, showing the anorthite precipitation accompanied by an intercrystal phase separation and the subsequent precipitation of iron oxide, (b) visual effect of the glaze

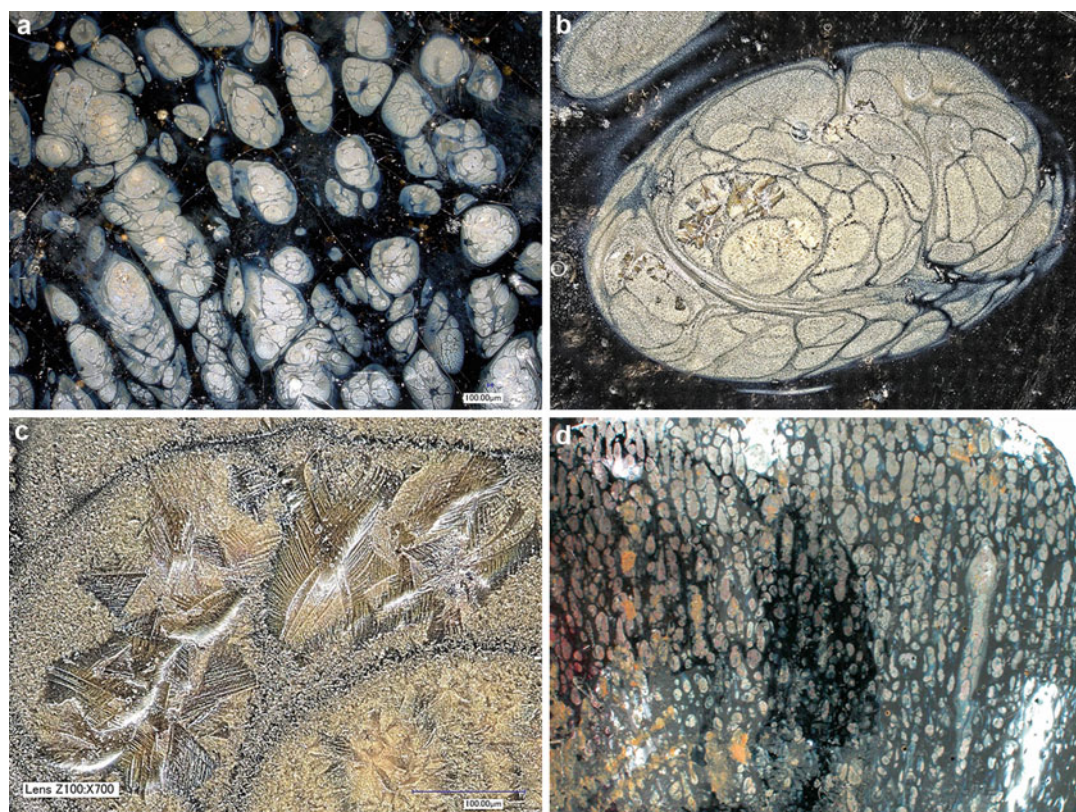


Glazes in China, Fig. 10 A brown hare's fur glaze from the Jian kiln, Song dynasty. (a) SEM image, showing hematite crystals precipitated on *top* of the glaze surface, (b) visual effect of the glaze



Glazes in China, Fig. 11 A brown hare's fur glaze from the Jian kiln, Song dynasty. (a, b) SEM images, showing iron oxide crystals precipitated on *top* of the glaze surface;

(c) OM image, showing iron oxide crystals precipitated on *top* of the glaze surface, (d) visual effect of the glaze



Glazes in China, Fig. 12 An oil spot glaze from the Jian kiln, Song dynasty. (a) OM image of oil spot, showing iron oxide crystals precipitated on *top* of the glaze surface, (b, c) close-ups of (a, d) visual effect of the glaze

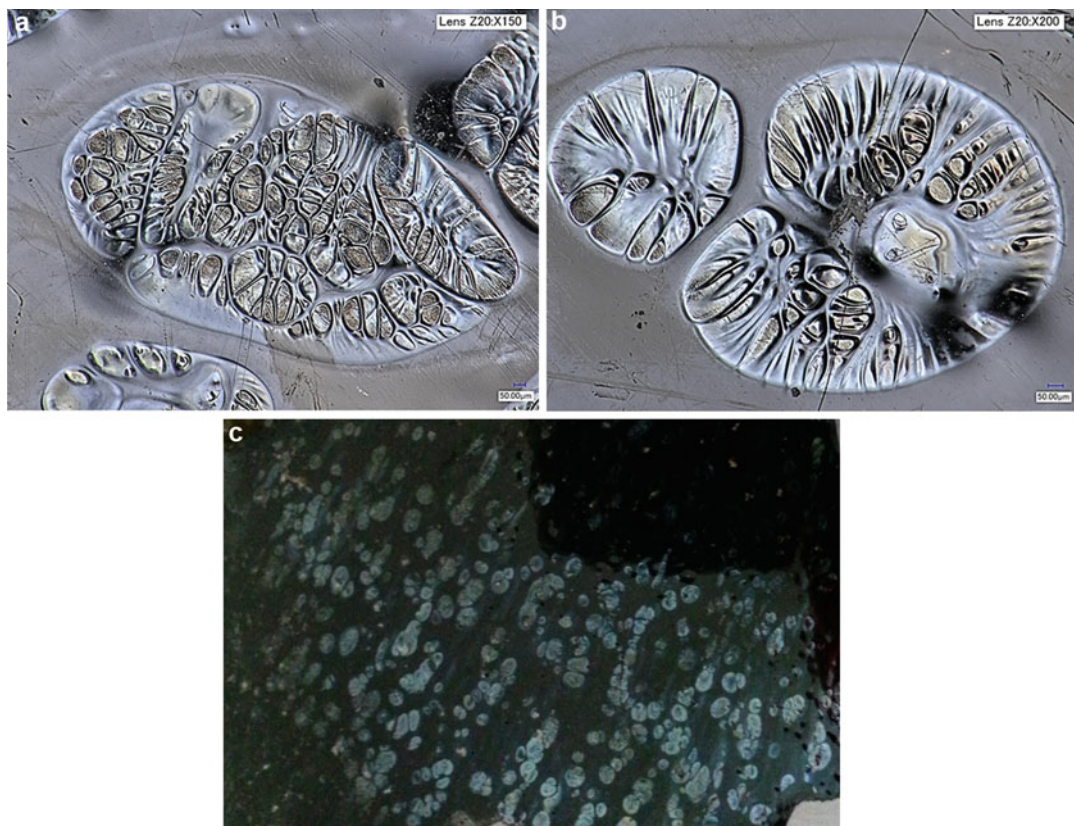
Color and Texture of Ancient Chinese Glaze

A glaze's color and texture are determined by its chemical composition and microstructure. Glaze texture is characterized by its transparency and gloss, which is directly related to the amount, size, and distribution of the scatterers (bubble, crystal, and liquid-liquid immiscible structure) that are existing in the glaze as well as at its surface. Factors affecting the glaze color include the chemical factor (a coloring agent such as iron ion chromophore) and the physical factor (structural coloring); which factor is predominant depends upon specific cases.

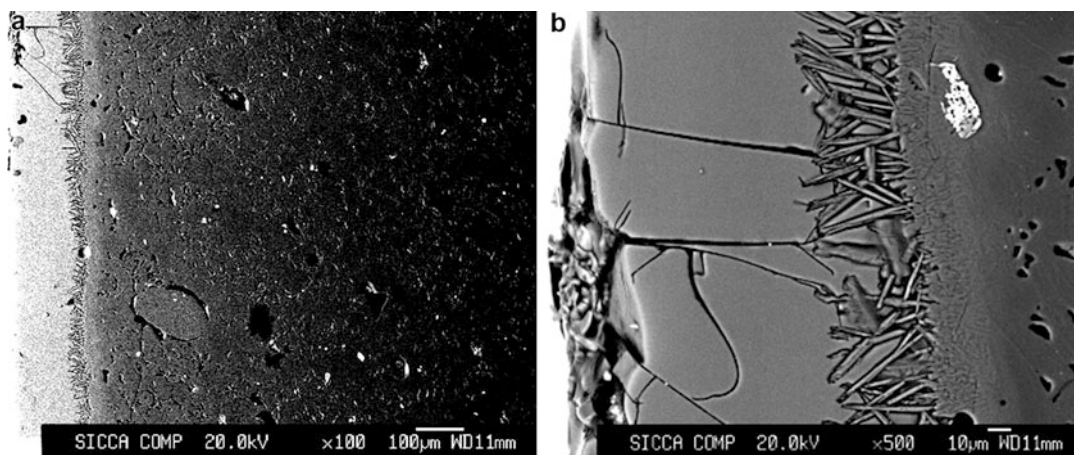
The origin of Chinese porcelain is celadon, which is suitable for the Chinese people's

implicit and humble character as well as guides their special aesthetic taste. The restrained, preferential monochromatic effects imitated or harmonized with the colors of nature, such as the tree, plant, jade, water, and sky. Green glazes in particular have a complicated coloring mechanism and diverse colors.

For the transparent celadon glaze, the transition metal iron ion is the principal coloring constituent. In fact, there is no doubt that the $\text{Fe}^{2+}/\text{Fe}^{3+}$ ions determine the glaze color; furthermore, the body's color beneath the transparent glaze also modifies the visual effect of the glaze color. The light energy absorption mechanism, and thus the production of chemico-compositional coloring, can be explained by an electron displacement or excitation in the absorbing material. Thus, part of the



Glazes in China, Fig. 13 An oil spot glaze from the Jian kiln, Song dynasty. (a, b) OM images of oil spots, showing iron oxide crystals precipitated on *top* of the glaze surface, (b) visual effect of the glaze

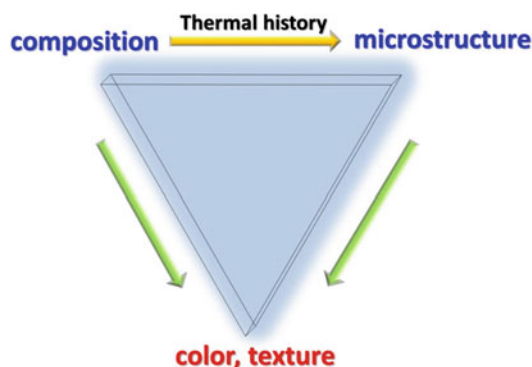


Glazes in China, Fig. 14 SEM image of the cross section of a white porcelain pot from the Gongyi kiln, Tang dynasty. (a) Transparent glaze and an interaction layer at glaze-body interface, (b) close-up of (a)

energy in the incident radiation is utilized in producing excitation, and the light of certain wavelengths falls upon the surface and tends to be reflected selectively. Furthermore, the iron ions' oxidation state or the combination or coordination mode is highly significant. In the glaze, there is a reduction-oxidation equilibrium for Fe^{2+} and Fe^{3+} that is determined by the glaze melt status determined by temperature and kiln atmosphere. Consequently, the ratio of ferrous to ferric iron has an important bearing on the exhibited color, which could be measured using a XANES spectra or Mössbauer spectra.

The coloring mechanism underlying the opaque and translucent glaze is more complicated. Using the Ru glaze as an example, a dual coloring mechanism is in effect by covering the chemico-compositional coloring by the iron ion chromophore and the structural coloring caused by structural inhomogeneities of the nanosized phase-separation structure. As the following scatterers are in the submicron and micron size range, various bubbles, residual quartz grains, undissolved batch material, and anorthite microcrystals create a full-waveband reflection and refraction upon the incident light and are, therefore, responsible for the opacification of the glaze layer. In this case, the size of the scattering particles exceeds the wavelength of visible light, and the Mie scattering theory applies.

Our latest research shows that the mild blue colors of the Ru glaze and Jun glaze primarily occur due to the phase-separation structure in the glazes, which is an amorphous photonic structure with short-range order. Photonic pseudogap results in selective reflection or a scattering of light in the visible range. The physical origin of this mild blue color is the coherent scattering effect resulting from the amorphous photonic structure. Furthermore, the structural blue color is both mild and angle independent. Additionally, computationally simulating the glaze's structure as well as simulating calculations of the optical properties has been conducted in order to establish the corresponding relationship between the structure and reflective spectrum.



Glazes in China, Fig. 15 A triangle representing correlations among the composition, microstructure, color, and texture of ancient Chinese glazes

Although glazes may come from the same kiln site, the glazes' coloring mechanism may still have some variability. This variability may be induced by firing glazes of the same compositions at different temperature schedules or a different kiln atmosphere; doing so may induce different microstructures. Furthermore, the temperature or kiln atmosphere varies in different firing processes or at different positions in the same kiln. Moreover, the Ru glaze colors are determined by both the chemico-compositional coloring and the structural coloring, and they are quite sensitive to the firing conditions. For example, Ru glazes of the same compositions may appear to be different colors, such as azure blue, sky blue, bean green, grayish green, or moon white. Both ion coloring and the phase-separation structure will affect the glaze color, whereas the micron-sized anorthite crystals in the glaze just result in glaze opacification (Fig. 15). The interaction and coordinated effect between the chemico-compositional coloring and structural coloring need to be further investigated.

In general, the chemical composition and firing schedule determine a glaze's microstructure, and likewise, both the composition and microstructure influence the glaze color and texture. Revealing the correlation among the compositions, the microstructures, the colors, and the textures of ancient Chinese glazes is of great importance.

Acknowledgments This work was supported by key project of Natural Science Foundation of China (No. 51232008) and National Basic Research Program of China (973 Program) (No. 2012CB720901). The author would like to thank Fujian Museum, Henan Provincial Institute of Cultural Relics and Archaeology, and Chengdu Municipal Institute of Cultural Relics and Archaeology for providing ancient porcelain samples for scientific research.

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Globes

Emilie Savage-Smith

The celestial globe is the oldest form of celestial mapping, for its origins can be traced to Greece in the sixth century BCE. The stars were perceived as though attached to the inside of a hollow sphere enclosing and rotating about the earth.

The earth, known from early classical antiquity to be spherical, was imagined at the center of the globe, while the stars were placed on its surface. Since this three-dimensional model of the skies presented the stars as seen by an observer outside the sphere of stars, the relative positions of the stars on a celestial globe are the reverse, east to west (or right to left), of their appearance when viewed from the surface of the earth. The sequence of the zodiacal constellations will be counterclockwise when the globe is viewed from above the north pole.

No celestial globes from antiquity have survived, but the basic principles of their design were maintained, with some modifications and elaborations, in the Islamic world, where the earliest preserved celestial globes were made. By the ninth century celestial globes were being made in the Arabic-speaking world. The most important early Islamic center of globe-making was the city of Harran, between the northern reaches of the Euphrates and Tigris rivers. In the ninth and tenth centuries it was an important town at the intersection of major caravan routes and had a prominent Sabian community whose pagan religious interest in the stars and sun was perhaps conducive to the study of astronomy. Many of the early astronomical instrument-makers were members of the Sabian sect at Harran. Several Arabic treatises were composed in the ninth century on the design and use of celestial globes, including one by the famous astronomer of Harran, ► [al-Battānī](#) who was known in the Latin world as Albategni, and others by ► [Ḥabash al-Ḥāsib](#) and ► [Qusṭā ibn Lūqā](#) in Baghdad. In the following centuries, additional treatises on the subject were composed, including one by ‘Abd al-Raḥmān ibn ‘Umar ► [al-Ṣūfī](#) (d. 983) whose treatise on constellations became the model for constellation iconography in the Islamic world.

Over 180 Islamic celestial globes are known to be preserved today. The earliest was made in AD 1080 in Valencia, Spain, and the most recent in Ottoman Turkey in 1882. Regardless of date, the stars represented on Islamic globes are those listed in the medieval star catalogs, and only the 48 constellation outlines recognized in antiquity are indicated. When constellation outlines are drawn

around the stars, the clothing and faces of the human figures, such as Orion or Virgo, reflect the artistic conventions common in the artisan's day. Since the positions of the stars change over time with the precession of the equinoxes, the star positions on a globe, correct when the globe was made, remain valid for only three-quarters of a century.

In addition to the celestial equator and the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), the Tropic of Cancer and the Tropic of Capricorn were also frequently shown on Islamic globes, as well as the north and south equatorial polar circles. On some later globes the ecliptic equivalents of tropic and polar circles were indicated, apparently in an attempt to complete the symmetry. On every Islamic globe preserved today there is also a set of six great circles at right angles to the ecliptic – six ecliptic latitude-measuring circles, reflecting the common use of ecliptic-based coordinates for measuring star positions. To function as an instrument, the sphere needed to be placed in a ring assembly, allowing for adjustment to a particular location. If supplemented by a gnomon or quadrant providing the altitude of the sun, the globe could then be used by an astronomer or astrologer to determine a range of astronomical data, including the length of the unequal day-time hour for a given day and location, or the time elapsed on a certain day, or data for a horoscope. It is questionable, however, whether many of the globes preserved today were of more than didactic or artistic value.

In terms of design, Islamic celestial globes fall into several distinct categories. The first includes the largest and the most elaborate artifacts, all of which display the 48 constellation outlines and approximately 1,022 stars. Those in the second category do not have constellation outlines. Only a selection of the most prominent stars, usually between 20 and 60, are shown.

The third type of design is one in which the globe has neither constellation outlines nor any stars. In general these globes are the smallest. They have on them only the great and lesser circles (ecliptic, equator, tropic, and polar circles), all of which are labeled. This design is not mentioned in any of the written sources, and evidence so far

available suggests it originated in Iran in the late seventeenth or early eighteenth century.

Only a few painted wood or papiermâché Islamic globes have survived, all of them hand drawn or painted. The method that dominated globe making in Europe – namely, laying printed paper gores over a wood or fiber core – seems not to have been practiced in the Islamic world. The vast majority of Islamic globes are hollow metal spheres and were made in two ways: from two hemispheres of cast or raised metal, or cast in one piece by the lost wax process. While globes made of wood or papiermâché or with metal hemispheres are of considerable antiquity, seamless globes, on the basis of evidence so far available, appear to have originated in northwestern India toward the end of the sixteenth century, the earliest confirmed date for one being AD 1589–1590. They became the hallmark of all workshops in the Punjab and Kashmir areas of India through the nineteenth century. The workshop that excelled in this technique was a four-generation family of instrument makers in Lahore (in modern Pakistan). During more than a century, this remarkable workshop produced numerous astronomical instruments, including 21 signed globes (the earliest made in AD 1622). The technique of making seamless globes continued to be practiced in India after this workshop ceased to make them.

Throughout the ten centuries of their production in the Islamic world, celestial globes maintained the medieval tradition of displaying only the classical constellations and stars. On metal globes the stars were usually indicated by inlaid silver points. None of the surviving Islamic celestial globes records the stars and constellations of the southern hemisphere first mapped by Europeans during explorations of the sixteenth century.

While the production of celestial globes was widely and continuously practiced in the Islamic world, there was no comparable tradition of terrestrial globe making. There seems to have been little interest in terrestrial globes until the sixteenth century, when early modern European terrestrial globes became known to Ottoman Turkish astronomers and in the next century to those at the Mughal Indian court.

See Also

- [al-Battānī](#)
- [al-Šūfī](#)
- [Ḥabash al-Ḥāsib](#)
- [Precession of the Equinoxes](#)
- [Quadrant](#)
- [Qusṭā ibn Lūqā](#)

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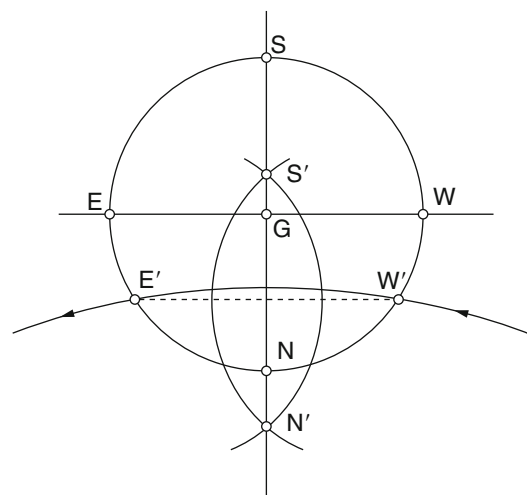
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► [Varāhamihira](#) gave a fairly complete account of its use in India in the *Pañcasiddhāntikā*. This was written in AD 505 and summarized the astronomical information current in India at that time. The *Āryabhaṭīya* of ► [Āryabhaṭa](#) also provides the main results of the theory of the gnomon, and these features appear again in the works of Bhāskara, ► [Brahmagupta](#), and many later astronomers.

The Cardinal Directions

The procedure is illustrated in Fig. 1. G is the foot of the gnomon. The path of the end of the shadow enters and leaves a circle, center G, at W and E. Then the line EW is in the east-west direction. With E, W as centers, circular arcs are drawn intersecting at N, S. Then NS, the perpendicular bisector of EW, is in the north-south direction and intersects the circle at N and S, the north and south points. The ► [east and west](#) points, E and W, can be found by the same procedure since they are on the perpendicular bisector of NS.

This method depends on the symmetry of the shadow path about the north-south line. It does not take into account the small change in the declination of the sun during the day.



Gnomon in India, Fig. 1 Finding the cardinal direction (Neugebauer, 1971)

Gnomon in India

George Abraham

The gnomon is an instrument used widely in early astronomy. The shadow of a vertical rod on a horizontal plane determines the cardinal directions, the latitude of the place of observation, the celestial coordinates of the sun, and the time of the observation.

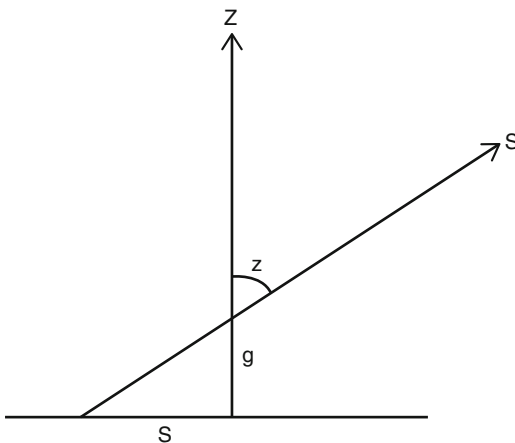
Brahmagupta prescribed a correction for this error in the *Brahmasphuṭa Siddhānta*. This method of finding the cardinal directions, described in the *Pañcasiddhāntikā*, is found in a much earlier treatise, the *Śulbasūtra*, which contains mathematical topics related to the construction of sacrificial altars. The *Pañcasiddhāntikā* also has an approximate method for finding the meridian direction from any three positions of the shadow. This method assumes that the path of the shadow is a circle, whereas in India, it is a hyperbola.

The Noon Shadow

Trigonometric formulas enable us to find the latitude of the observer and the sun's declination from the shadow of the gnomon at noon, when the sun is on the local meridian. In Fig. 2, g is the height of the gnomon, s the length of the shadow, Z the zenith, S the sun, and z the zenith distance of the sun. On any day, the zenith distance at noon is $z = \phi \pm \delta$, where ϕ is the observer's latitude and δ the declination of the sun. The Indian formula is

$$\sin z = \frac{R_s}{\sqrt{s^2 + g^2}},$$

where the sine of an angle is defined as R times the modern sine function, R being a constant



Gnomon in India, Fig. 2 The noon shadow

angle, taken to be 120 min in the *Pañcasiddhāntikā*. When the sun is on the equator, $\delta = 0$, and the formula above gives us the latitude in terms of the length of the noon shadow. On other days, the formula yields the change $\pm\delta$, in the zenith distance, as a function of the noon shadow. On the days of the solstices, the declination has the maximum value, ε , the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course).

When the sun is on the prime vertical (the great circle on the celestial sphere through the east and west points and the zenith), let z_1 be the zenith distance, and $\alpha_1 = 90 - z_1$, the altitude of the sun, and λ , the longitude of the sun. Then the *Pañcasiddhāntikā* formulae are

$$\sin \alpha_1 = \frac{R \sin \delta}{\sin \phi} = \frac{\sin \lambda \sin \varepsilon}{\sin \phi}.$$

With these two formulae, we can find the declination and longitude of the sun from the shadow length, when the sun is on the prime vertical.

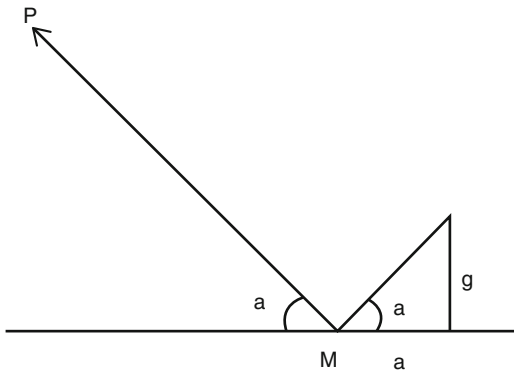
With the gnomon, it was also possible to find the time after sunrise, from the length of the shadow, using formulae which are equivalent to those used in modern spherical astronomy.

The second formula above gives the sun's longitude λ and declination δ , when it is on the prime vertical. λ and δ can be determined at any time, from the length of the gnomon's shadow and the distance of its endpoint from the east-west line. The *Pañcasiddhāntikā* also gives an approximate empirical algebraic formula which would have been useful in very early astronomy:

$$\frac{d}{2t} = \frac{s - s_0}{g} + 1.$$

This gives t , the time after sunrise in the morning or the time before sunset in the afternoon, s_0 is the noon shadow, and d the length of daylight. This formula is derived from the following considerations:

1. There is a linear relation between s and $1/t$
2. At noon $2t = d$
3. $s - s_0 = g$ at $4t = d$



Gnomon in India, Fig. 3 Determining the altitude of the moon or planets

The *Yavanajātaka* of ► [Sphuḥjīdhvaja](#) also has this formula. Chapter 20 of Kauṭilya's *Arthaśāstra* gives the relation between the time after sunrise and the gnomon shadow. The *Arthaśāstra* also gives the rule for the uniform variation of the noon shadow from zero at the summer solstice to g , the gnomon height, at the winter solstice, a reasonable approximation for an observer on or near the Tropic of Cancer, for example at Ujjain. However, the rule for the uniform variation of the length of daylight from 12 to 18 *muhurtas*, also found in the two books above, implies a latitude of about 35° , which suggests a Babylonian origin.

The theory of the gnomon presented above can be applied to the moon and planets also. The altitude of the moon or planet is determined in the following manner, illustrated in Fig. 3.

The moon or planet (P) is seen reflected in a mirror M in the same horizontal plane as the foot G of the gnomon of height g at a distance d from the gnomon. Then the altitude a is given by the formula

$$\sin a = \frac{R_g}{\sqrt{g^2 + d^2}},$$

d is called the *reversed shadow* and takes the place of the shadow length s in the case of the sun.

The eleventh-century Arabic scholar ► [al-Bīrūnī](#) wrote *Kitāb fī ifrād al-maqāl fī umr al-ẓilā* (The Exhaustive Treatise on Shadows),

which contains a comprehensive account of the theory and applications of the gnomon shadow. Al-Bīrūnī refers to many Indian sources, for example:

1. The method described above for finding the cardinal directions. He calls it the method of “the Indian circle.”
2. The algebraic formula.
3. The time from the shadow. Al-Bīrūnī follows the procedure of ► [Brahmagupta](#).
4. Al-Bīrūnī gives the approximate Indian method for determining the meridian from three positions of the shadow. In addition, he describes the procedure, for the same problem, given by Diodorus of Alexandria, a mathematician of the first century BCE. An important result in al-Bīrūnī's book, not mentioned in his Indian sources, is the condition for the shadow path to be a parabola, ellipse, or hyperbola, depending on the latitude of the observer and the declination of the sun.

See Also

- [al-Bīrūnī](#)
- [Āryabhaṭa](#)
- [Astronomical Instruments in India](#)
- [Bhāskara I](#)
- [Brahmagupta](#)
- [Sphuḥjīdhvaja](#)
- [Śulbasūtras](#)
- [Varāhamihira](#)

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Gold in the Andes

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For almost 4,000 years, gold was held in high esteem by many societies that populated the Andes, and indeed, gold continues to be extracted in mines across the region.

Gold has a number of important properties that have made it attractive to cultures all over the world. It is both malleable (can be easily shaped by hammering) and ductile (it can be hammered into very thin forms and is thus highly flexible and not brittle). It can be used to form alloys with other metals such as copper and silver and in so doing add bright color to the finished product, and it resists corrosion and is unaffected by moisture or air. But perhaps most importantly, its golden-red color is attractive to the eye. It reflects sunlight easily, and when polished, it is quite brilliant. Given its relative rarity and the ease with which it can be worked, gold has long served as a

Gold in the Andes, Table 1 Period names, time frames, and archaeological cultures described in the text

Period name	Time frame	Site or archaeological culture
Late Horizon	1476–1534 CE	Inca
Late Intermediate	1000–1476 CE	Chimu
Middle Horizon	600–1000 CE	Wari, Tiwanaku
Early Intermediate	0–600 CE	Moche
Early Horizon	900 BCE–0 CE	Chavin, Kuntur Wasi
Initial Period	1800/1500–900 BCE	Waywaka, Mina Perdida
Archaic	ca. 2000 BCE	Jiskairumoko

desired and sought after commodity no matter what shapes it has taken. Simply put, gold signals prestige, status, wealth, and social power but to varying degrees depending on the culture in which it is found. As Quilter (2011, p. 45) notes, the value of gold is a social construct, and the value it takes depends greatly on that context.

The use of gold is part of an Andean tradition of metallurgy that begins deep in prehistory in the Archaic period (Table 1). As described by Heather Lechtman (2014, p. 369), three metals – gold, silver, and copper – form the basis of this tradition, and through time, larger, more complex artifacts and expanded technologies to fabricate them were developed. Beginning with simple cold hammering, metal-working technologies included annealing (exposing metals to fire to soften them for further work), soldering (the use of a metallic alloy to join metals), sweat welding (a version of soldering), smelting (the heating of ore beyond its melting point to obtain the metal in it), sintering (the fusing of small bits of metal below the melting point), and casting, including the lost wax method (liquid metal is poured into a mold to shape it). A wide range of ancillary techniques were used, including cutting, repoussé (hammering or molding a metal from the reverse side), chasing (refining a surface of an artifact from its front), burnishing, and pickling.





Gold in the Andes, Fig. 1 The gold necklace from Jiskairumoko. The beads have been restrung (Photo credit: Mark Aldenderfer)

Evidence for the earliest use of gold in the Andean world is found at Jiskairumoko, a site located in the Rio Ilave drainage in the south-western Lake Titicaca basin (Aldenderfer et al., 2008). The context in which the gold was found has been dated to 2204–1941 cal BCE, making it not only the oldest gold discovered to date in the Andes but also in the Americas.

Nine gold beads were discovered in a mortuary context of mixed adult and juvenile human remains. The adult was elderly, while the juvenile was from 4 to 6 years of age. The beads were found near the base of the adult cranium in a roughly circular pattern, suggesting they had been once formed into a necklace (Fig. 1). Eleven round, disk-shaped sodalite beads were also recovered in and among the gold beads.

The gold beads were formed by cold hammering and flattening quartz-vein native gold nuggets; the flattened metal was then shaped into a cylinder (Fig. 2). One of the beads was perforated and a small sodalite bead was found in the matrix near this bead, suggesting it was placed in this



Gold in the Andes, Fig. 2 One of gold beads from Jiskairumoko illustrating the folding of the bead and its perforation (Photo credit: Mark Aldenderfer)

hole. There is no evidence of heat treatment or annealing of the metal.

Aside from the early date, what is important about the gold from Jiskairumoko is the kind of society of which it was a part. The inhabitants of the site were mobile hunters and gatherers with an egalitarian social structure on the cusp of a profound social transformation that would eventually lead to greater social and political complexity. Used in a necklace, the gold served to signal the prestige of its wearer, while its interment with the deceased signaled the implied wealth and prestige of its owner and their kin.

Gold artifacts next appear further to the north at two Initial Period sites: Waywaka in the central highlands of Andahuaylas, dated to 1500–1000 BCE (Grossman, 1972), and Mina Perdida in the Lurin Valley, dated to 1400–1100 BCE (Burger & Gordon, 1988). This period is characterized by a significant increase in social complexity and political integration. Sites are larger, residence at them is permanent, and based upon the use of domesticated plants and animals, and in some instances, ceremonial structures are constructed. New technologies of gold fabrication also appear. At both sites, small, very thin fragments of gold foils were recovered. At Waywaka, the gold was hammered into small shapes and placed, like at

Jiskairumoko, in a mortuary context. In contrast, the gold at Mina Perdida was combined with small, thin sheets of copper and was used as a foil to cover it. The metal foils were found atop and near the pyramidal summit of a large mound constructed of soil and faced with stone. The presence of other artifacts reflecting supernatural iconography suggests that these metal fragments were part of a more complex artifact used in these ceremonies atop the mound.

Although forms of gold have changed, the technology to produce the foils continues the earlier tradition of cold hammering. Grossman (1972) found a number of stone bowls and pestles at Waywaka that are thought to have been used to pound native gold nuggets (see also http://www.geospatialarchaeology.com/album-Peru_large21.html for images of these artifacts and the context of their discovery).

In the following Early Horizon, the production of elaborate golden objects can be attributed to the expansion of the Chavin religious cult, with its primary center, the site of Chavin de Huántar in the central Andean highlands (Burger, 1996). The Chavin cult used golden objects as symbols of power, status, and participation in the cult, and artifacts with Chavin iconographic and symbolic elements are found widely distributed at sites in the central and northern Andes. For the first time in the Andes, more elaborate forms of artifacts made of gold are found: crowns, ear spools, nose ornaments, plaques, gorgets or pectorals (a plaque suspended in front of the neck; <http://www.metmuseum.org/collection/the-collection-online/search/318334>), bracelets, beads, and effigy spoons (http://static-content.springer.com/image/chp%3A10.1007%2F978-1-4614-9017-3_15/MediaObjects/185051_1_En_15_Fig5_HTML.jpg). Aspects of technology change as well. Although the hammering of thin sheets of native gold dominates goldsmithing technology in Chavin times, new techniques, such as annealing, soldering, sweat welding, and sintering, appear (Lechtman, 2014, pp. 374–375). Further, there appears to be a good understanding of gold alloy composition and use (Burger, 1996, p. 73).

The Early Intermediate period, especially in the northern and central Andes and associated

with sites of the Moche archaeological culture, is witness to a tremendous florescence of metallurgical technology in which gold is used extensively in the context of elite social, political, and religious activities. Although aspects of the Moche polity continue to be debated, it is clear that it was able to mobilize large numbers of people for massive public works programs, including the construction of ceremonial and religious structures. The polity was dominated by an elite social class, and much of the trade and craft production that is evident in the polity was controlled by them. Religion and leadership were very much interconnected.

Substantial quantities of metals, now including copper, silver, and gold, were used as display and status items by these elites. The forms these artifacts took varied considerably: masks, ear spools, and ear flares, (<http://www.metmuseum.org/toah/works-of-art/66.196.40,.41>) simple (<http://www.metmuseum.org/collection/the-collection-online/search/317801>) and complex (<http://www.metmuseum.org/toah/works-of-art/1979.206.1225>) nose ornaments, crowns, necklaces, beads, vessels, and other decorative objects. Thin gold foils were sewn onto tunics and garments. Gold was used in complex inlays, and it was often paired with silver, which has led many archaeologists to surmise that this represented an aspect of Moche cosmology and gender associations (Lechtman, 2014, p. 377; Schorsh, 1998, p. 129). These items were used by the elites in their royal costumes and were found buried with the dead in elaborate tomb constructions filled with metal, ceramics, feathers, woods, textiles, and other materials.

Moche craft workers employed a wide range of techniques in the creation of these artifacts and extensively used a variety of alloys – copper-gold and copper-silver-gold as well as sophisticated soldering, annealing, casting, and gilding techniques. Copper was used in these alloys to stiffen the gold (or silver) to maintain the shape of the artifact (Lechtman, 2014, p. 379). One of these copper-gold alloys – known by the term *tumbaga* – was often used by these artisans to create a gold color for the artifact without the use of significant quantities of gold. More complex artifacts were constructed through the creative

use of mechanical joining techniques – tabs, slots, wires, and hooks – that were often gilded (Schorsch, 1998, pp. 113–117).

Following the decline of Moche and similar cultures around 800 CE, the major polities of the Middle Horizon – Wari in the central Andes and Tiwanaku in the south central Andes – gold continued to be used in elite contexts although in lesser quantities.

Gold returns to prominence in the activities of the elite in the Late Intermediate period and Late Horizon. In the former, the Chimor of northern Peru accumulated vast quantities of gold artifacts of all kinds, and their metallurgical technologies rivaled those of the Moche in their complexity and variety. One of the motivations for the accumulation of so much gold was due to their political organization. Chimú emperors warehoused their treasures in large *ciudadelas* – walled compounds that enclosed their living quarters, ritual precincts, storehouses, and eventually, mortuary complexes into which they were placed after death. The descendant of the emperor, usually a son, inherited the title, but not the accumulated treasures of his father. In time, he would create his own *ciudadela* and fill it with treasures accumulated through his own military conquests and trade relationships.

The Inca arrive in northern Peru around 1470 CE and conquer the Chimú and almost every other polity in Andean South America from southern Ecuador to northern Chile. With roots in the Cuzco basin of the central Andes, the Inca create a vast empire and in the process collect not only treasures but perhaps, more importantly, the artisans that created them. The Inca looted the Chimú *ciudadelas* of their gold and used it in their own religious and status systems. The Inca emperor was the embodiment of the sun, and gold was seen as the material manifestation of this belief. Gold was used to craft vessels, articles of clothing, decorations, jewelry, and more. The Inca expanded metal production of all kinds for state purposes and accumulated gold and other precious objects through tribute payments by vassals from across the empire.

Perhaps the most ostentatious use of gold by the Inca was in the Qorikancha, or Temple of the

Sun, which was located in central Cuzco. The temple was situated in what the Inca believed was the “pivot of the universe” (Moore, 2014, p. 435) and was composed of a set of four structures surrounding a large plaza. The interior walls of the temple structures were covered in massive sheets of gold (for an imaginative digital reconstruction of the interior of the temple, see <http://commons.wikimedia.org/wiki/Category:Coricancha#mediaviewer/File:Corigold.jpg>). As described by Moore (2014, p. 435):

Using crowbars, the Spaniards pried the gold off the temple walls, removing 700 gold plates, each weighing between 4 and 12 pounds; the gold was hauled away in 178 loads, each carried by four men.

Gold in the form of miniature llamas or deities was also an important element of the Inca ritual of *capacocha*, which involved the sacrifice of children on high Andean peaks (Andrushko et al., 2011).

Although the forms that gold took through Andean prehistory changed significantly, there is one constant that persisted for almost 4,000 years: gold signaled status and some degree of social prestige. Although it was never used as money or coinage, gold signaled the owner's wealth and position within society.

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Gold Mining in Mongolia

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Compared to many other parts of the world, Mongolia is remarkably rich in minerals. More than 6,000 large deposits have been discovered, numbering at least 80 different minerals (Husband & Songwe, 2004, p. 3). The most economically significant of these are gold, copper, molybdenum, and fluorite. The country also has extensive coal reserves, combustible deposits, and gemstone occurrences. Apart from limited hard rock (lode gold) deposits, Mongolia is particularly rich in placer gold (alluvial deposits). These deposits have originated elsewhere and been moved to their more recent locations, often by the force of water or sand. Since placer gold is not geologically integrated with its matrix, it is relatively easy to extract and does not require further crushing, milling, or the addition of chemicals such as mercury or cyanide. Instead companies use various forms of opencast mining and tunneling to extract the placer gold. In areas where water is available, a method known as “hydraulic mining” or “hydraulic sluicing” is used which separates the gold from the gravel. Rockers, trommels [a rotating cylindrical sieve or screen used for washing and sorting pieces of ore or coal], sluice boxes, and other techniques are used in various combinations to recover the

loosened gold. Since many of Mongolia’s placer formations are long, narrow, and relatively shallow, mining companies have rapidly advancing mine faces and, correspondingly, rapidly abandoned mined-out areas. Apart from making the long perimeters harder to police, Mongolia’s “ribbonlike” placer deposits can in some instances be difficult or unprofitable for mining companies to excavate (MBDA, 2003, p. 49). The geological formation of gold thus provides artisanal and small-scale gold miners with lucrative opportunities for both prospecting and mining. Moreover, many mining companies have used technical equipment that was originally developed in the early 1930s in the USSR and therefore not only outdated but also intended for mineralogical conditions dissimilar to those of Mongolia (Farrington, 2000). Given the low gold recovery rates of these companies, they have provided a relatively rich and readily accessible resource for artisanal and small-scale gold miners. When droughts and disastrous weather conditions occurred between 1999 and 2002, causing catastrophic livestock losses among the nomadic pastoralist population, the placer deposits attracted growing numbers of people, and it eventually grew into a nationwide large-scale gold rush.

Placer gold is likely to have been mined as early as the eleventh century in Mongolia (Murray & Grayson, 2003, p. 15). Historical sources describe a long-standing resistance towards mining activities, which were seen to transgress fundamental taboos related to the land (High & Schlesinger, 2010). Amidst local opposition, the first industrial mines were opened in 1899 by the joint-stock mining company Mongolor, which had a recorded production of 771 kg of gold before closing in 1913 due to civil unrest and lack of political support (Atwood, 2004, p. 357). Soviet geological expeditions surveyed the country in 1930–1931, and a systematic mapping of the country’s geology was carried out in 1960, documenting gold deposits in all regions. Only in 1978 did mining become a major branch of the national economy with the opening of a copper and molybdenum mine in Erdenet. When annual gold production figures were made public in 1991, it was recorded

at 722 kg. In 2005 Mongolia's gold production peaked with a recorded annual production of 24,122 kg, making the country the world's top 19th producer of gold.

Mongolia's mineral-rich economy has experienced severe boom and bust cycles in recent years. When global commodity prices and external demand began to plunge in 2008–2009, it shocked the country's economy and exposed its structural volatility. With mineral revenues accounting for one-third of fiscal revenues, 70 % of industrial output, and almost 80 % of exports in 2011, the economy has been at risk of Dutch disease, whereby non-mineral-related sectors of the economy lose their competitiveness from the large mineral sector exports and revenue flows (Reeves, 2011; World Bank, 2012, p. 15). This risk is particularly acute with the 2013 production launch of one of the world's largest copper and gold mines, the Oyu Tolgoi deposit in the South Gobi province (Wacaster, 2012). Measured and indicated mineral resources include more than 650,000 kg of gold and almost 780,000 kg of inferred gold, which is set to make Mongolia one of the fastest growing economies in the world (Ivanhoe Mines Ltd, 2012, p. 13).

In Mongolia mineral resources are the property of the state. In addition to numerous laws and guidelines, the Minerals Law of Mongolia regulates the prospecting, exploration, and mining of minerals. However, the existing legislation only confers licensee rights onto registered mining companies and does not explicitly refer to artisanal and small-scale mining activities (High, 2012). In 2001 and 2002, the government attempted to accommodate informal sector mining by enacting interim regulations, but they proved largely ineffective and were not renewed. In subsequent years, the government drafted an Artisanal Mining Law, which failed to gain parliamentary approval and was abandoned in August 2005. New drafts have since been prepared, but to date, none has been approved. According to a Swiss-funded project that seeks to enable the formalization of artisanal gold mining in Mongolia, there is much reluctance among both government agencies and artisanal miners to

support the formalization efforts. The main challenges have been lack of desire to pay income tax and limited access to viable mining land for miners (Singo Patience, 2011, p. 5). At present, according to the Law, artisanal gold mining is thus still considered an illegal activity.

Artisanal gold miners in Mongolia are locally known as "ninjas." Their use of a green plastic panning bowl, carried strapped to their backs on walks to and from the mines, apparently triggered this colloquial name. Their silhouettes were said to be reminiscent of the television cartoon series called *Teenage Mutant Ninja Turtles*, popular in Mongolia at the time when informal sector mining surged (Grayson, 2006, p. 1). There is a wide range of opinions about the number of artisanal gold miners in Mongolia. This variation stems in part from the large size of the country, the practical difficulties of counting the number of artisanal miners at any given site, and the substantial seasonal fluctuations in their geographical distribution. According to published government figures, there are about 30,000 artisanal gold miners, but independent surveys suggest this to be a significant underestimate, proposing figures of at least 100,000 artisanal gold miners or 20 % of the total rural work force (MBDA, 2003, p. 18; Navch, Bolormaa, Enhtsetseg, & Munhjargal, 2006, p. 17). In addition to these, there are also smaller numbers of artisanal miners involved in the extraction of other minerals and rocks, such as fluor spar and coal (Baatar & Grayson, 2009; Grayson & Baatar, 2009).

Given the scale of formal and informal sector gold mining in Mongolia, the environmental consequences are already severe. Dredges, settling ponds, and panning beds have affected rivers, contaminating them with sediments and other pollutants (Suzuki, 2013). Groundwater resources have been removed at a rapid rate, and dumps of topsoil, waste rock, and tailings have been left without any environmental rehabilitation (World Bank, 2006, p. 16). Since mining typically uses land and water resources more extensively than other industries, conflicts of interest have become increasingly frequent and fierce. Much of the opposition to the impact of mining has been voiced through "river

movements” that draw on and highlight people’s close ties to the locality as an economic, social, and cosmological basis for their livelihood (Upton, 2012). As in the past, gold mining, in its various forms, is also today considered a profitable, yet contentious, activity in Mongolia.

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Gou-Gu Theorem

Joseph W. Dauben

One of the basic theorems of geometry in both the ► **East and West** concerns the relationship between the sides of a right triangle and their squares, known in the West as the “Pythagorean” theorem, but understood in an equivalent form as the *Gou-Gu* theorem in China. The ancient Egyptians, Babylonians, and Chinese probably discovered this remarkable property of right triangles by empirically examining the simplest case of 3-4-5 triangles. Whether in its geometric form or more familiar algebraic expression, $3^2 + 4^2 = 5^2$, the theorem concludes that the sum of the squares on either “side” of the right angle is equal to the square on the hypotenuse (Xian). In China, this was established for right triangles in general, i.e., not just for the 3-4-5 triangle, or for those with sides of integer lengths. The Greek made this discovery as well, but proved it rather differently in the argument presented at the end of the first book of Euclid’s *Elements*, Proposition I-47.

One of the great treasures of Chinese mathematics is the *Jiuzhang Suanshu* (Nine Chapters on the Art of Mathematics). It is the final chapter that is the most famous, in which the *Gou-Gu* theorem is introduced. Even before the *Nine Chapters* was written, results dealing with right triangles had been presented in an earlier astronomical-mathematical work, the ► *Zhoubi Suanjing* (The Arithmetic Classic of the Zhou Gnomon). The *Nine Chapters*, however, goes well beyond the simple applications found in the *Zhou Gnomon* text, which is concerned primarily with applications in astronomy. In fact, Chapter 9 contains 24 problems, each of which deals primarily with right triangles and solutions of quadratic equations. One of these is a variation on one of the oldest of China's mathematical problems (this is Problem 6 in Chapter 9 of the *Nine Chapters*) (see Fig. 1):

In the middle of a pond that is ten “chi” in diameter, a reed grows one “chi” above the surface of the water. When pulled toward the edge of

the pond, the reed just reaches the perimeter. How long is the reed?

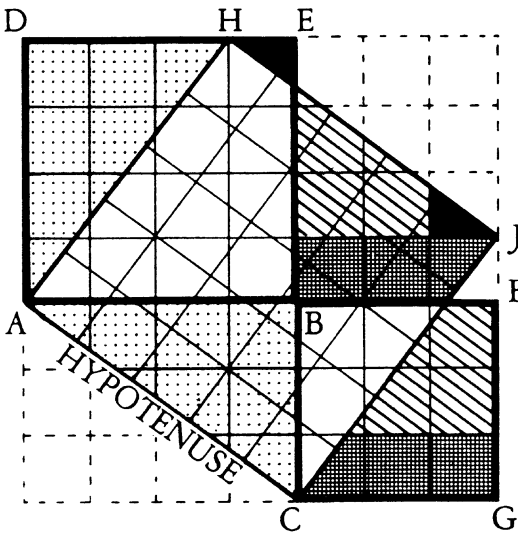
The solution to this problem is a straightforward application of the *Gou-Gu* theorem.

In commenting on a passage from the *Nine Chapters* that reads, “Combining each square of *Gou* and *Gu*, taking the square root will be *Xian* (the hypotenuse),” Liu Hui explains the *Gou-Gu* theorem as follows:

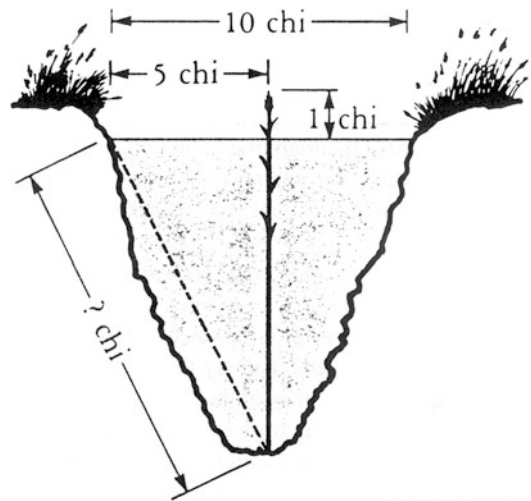
The *Gou*-square is the red square (*Zhu fang*), the *Gu*-square is the blue square (*Qingfang*). Putting pieces inside and outside according to their type will complement each other, then the rest (of the pieces) do not move. Composing the *Xian*-square, taking the square root will be *Xian* (the hypotenuse) (Guo, 1990).

The reference to moving pieces inside and outside is related to a diagram, no longer extant, and makes use of the so-called “Out-In” method which was taken as an axiom by ancient Chinese mathematicians. The power of this axiom can be seen, however, from the following illustration, where the two triangles ABC and ACD are equal (Fig. 2):

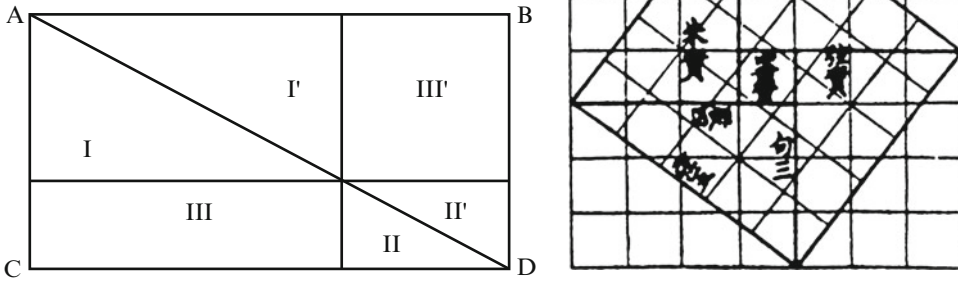
Since the areas I and I', II and II' are equal, then it follows from the “Out-In complementary principle” that III must be equal to III' (Wu, 1983).



Gou-Gu Theorem, Fig. 1 The *Gou-Gu* theorem based upon the $Xian\ Tu = Xian$ diagram, meant to accompany the *Zhoubi Suanjing* (see Fig. 3). Note that the square AHJC on the hypotenuse of the right triangle ABC is comprised of 25 unit squares, equal to the sum of the two squares on each side of the triangle, ADEH (16 unit squares) and CBFG (9 unit squares) (Drawing by the author)



Gou-Gu Theorem, Fig. 2 A problem that can be solved by applying the *Gou-Gu* theorem (see text: How long is the reed?) (Drawing by the author)



Gou-Gu Theorem, Fig. 3 The *Xian* figure

This now helps to explain Liu Hui's commentary on the *Gou-Gu* theorem. First of all, his references to colored squares are similar to colors mentioned in the diagrams illustrating the *Gou-Gu* theorem in the *Zhoubi Suanjing*. There, in the "*Xian* figure," the central square is yellow, while the squares of the *Xian* square are red. Often the *Gou* square is blue (Fig. 3).

Applying the "Out-In" complementary principle to the *Xian* figure, and following Liu Hui's commentary on the *Gou-Gu* theorem, the sum of the squares based on each leg of the right triangle ABC, namely the squares ADEB and BFGC, is equal to the square of the hypotenuse AC, namely the square AHJC (see Fig. 1 above). In accordance with the "Out-In" principle, if we move those parts of the two small squares (ADEB and BFGC) that are on the outside of the large square (AHJC) to its inside, we can see that they fill the inside exactly and that the combined areas of the two small squares equal that of the larger one. Since the areas are analogous to the squared sides of the triangle, the sum of the squared legs equals the squared hypotenuse.

It has been argued that geometry never developed further in China than it did with Liu Hui's commentary because this was sufficient for Chinese needs. After Liu Hui, Chinese geometry does not seem to have made much further progress. Although some authors suggest that this was due primarily to the practical orientation of ancient Chinese mathematics, it may have been

its actual success, its comprehensiveness, that caused the stagnation of any further development. As D. B. Wagner has suggested:

Liu Hui's conceptual framework was adequate, for example, to deal with a much broader range of geometric solids than those which he actually considers in his commentary. Had he felt a need to push his methods to their inherent limits, he would surely have contributed a great deal more to the mathematical tradition. Here we can see the double influence of the enormous prestige of the *Chiu-chang suan-shu*: it provided a challenge and an inspiration; but it was often a strait jacket which confined the interests of mathematicians to certain specific problems.

Like Euclid, Liu Hui summarized his art so successfully that his successors may have felt little need, or room, for improvement.

See Also

- [Jiuzhang Suanshu](#)
- [Zhoubi Suanjing](#)

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Gunpowder

Ho Peng Yoke

Gunpowder was probably discovered in China accidentally. Since the Han period (202 B.C.E.–A.D. 220) Chinese alchemists attempted to make gold or to prepare an elixir of immortality. Sulfur and saltpeter were among the raw materials used for their experiments, and charcoal was among the different types of fuel used in their laboratories. The *Zhenyuan miaodao yaolue* (Classified Essentials of the Mysterious Dao of the True Nature of Things), a book of the late Tang but probably containing material from much earlier dates, carries a note of caution to the alchemists warning them to exercise due care when dealing with sulfur, saltpeter, and charcoal because there were cases where the operators had their hands scorched or their thatched huts set on fire.

In China gunpowder found its early use in amusements, in religious and ceremonial functions, taking the form of fireworks and rockets, and in construction works, such as blasting rocks in the opening of waterways and roads. For

example explosives were used by Gao Ping to open a rocky water route linking Guangdong province and Annam in the ninth century. There are no records that show the use of gunpowder in the battlefield before the tenth century. An early fire weapon that the Chinese used was the “incendiary arrow” (*huojian*) to send a variety of ignited substances to the enemy camp. At first naphtha was one of the combustion agents used. By 919 there appeared the force pump that could throw flaming petrol, or “Greek Fire,” directed toward the enemy. Both naphtha and “Greek Fire” were imports from the West.

The *Songshi* (Official History of the Song Dynasty) mentions that in 970 Feng Jisheng submitted to the emperor a report on the manufacture of “incendiary arrows” and that in 1000 Tang Fu made “incendiary arrows,” “fire balls” (*huoqiu*), and “thorny fire balls” (*huojili*). These were bombs and grenades containing gunpowder for hurling over enemy walls and camps by means of trebuchets. Later on the bombs progressed from those with weak casings to those with stronger ones.

In the middle of the tenth century the “fire-lance” (*huoqiang*) was invented. At first it consisted of a ► [bamboo](#) tube with its septa cleared. Then it was filled with rocket composition and capable of shooting out flames horizontally. According to Needham the “fire-lance” had enormous repercussions in China for some 700 years from the middle of the tenth century, playing prominent roles in many battles. It also marked a transition from the bulky petrol flame-thrower to a much lighter and portable weapon using gunpowder, and heralded the use of the principle of the tube in ► [military technology](#). Bamboo tubes gradually gave way to barrels made of metal. The “fire-lance” took a big step forward in 1259 when the “fire-emitting lance” (*tuhuoqiang*) was developed. This type of “fire-lance” could fire scrap metal and break porcelain, if not also small darts or arrows, on which poison was sometimes applied. The range of the projectiles was short compared to a single bullet from a gun barrel. The Chinese later developed a

similar firearm with a large barrel mounted on a carriage, rather like a field gun but which emitted a large quantity of projectiles instead of a single shell. Again these projectiles could be scrap metal, stone, broken porcelain, arrows, and poisonous or noxious substances.

The earliest document giving the gunpowder formula and describing its applications in various forms of firearms is the Song military compendium, *Wujing zongyao* (Collection of the Most Important Military Techniques), written by Zeng Gongliang in 1044. It describes with illustrations a number of weapons using gunpowder, such as the grenade, the bomb, etc. and gives several gunpowder recipes. The compositions suggest that the earlier Chinese gunpowder was more of the deflagratory type. A much higher ratio of saltpeter for explosives was used later.

Around the year 1000, gunpowder weapons were deployed on the battlefield in China. Large quantities of gunpowder were prepared and stored up during the Northern Song (960–1126). In 1232 the “thunderclap bombs” were brought into action. In the early twelfth century knowledge of gunpowder was acquired by the Jurchen people who eventually occupied northern China and established the Jurchen empire (1115–1234). In 1232 they used the “thunder-crash bomb” and the “flying fire-lance” (*feihuoqiang*) to defend their capital Bianjing against the Mongol invaders. Bianjing fell the next year. Gunpowder and firearm technicians were captured by the Mongols and taken into their service. The Mongols invaded Europe from the year 1236, deploying firearms of the offensive type. For example trebuchets were used on at least two occasions, in July 1237 at the battle of Ryazau, and in July 1241 “incendiary arrows” were used at the battle of Wahlstadt. The Mongols also used their firearms against the Arabs. In 1258 they used “fire-jars” to attack Baghdad, probably a reference to the thunder-crash bombs, which the Mongols also used against the Japanese in a sea battle near Kyushu in 1272. The next important city to fall after Baghdad was Damascus. The

Muslims set up the Mamluk caliphate in Cairo and in 1260 defeated the Mongols in a battle in Syria. From then on, the two sides made little headway against each other for some years, during which the Mamluk caliphate turned its attention to military affairs and weaponry. Some Mongolian soldiers surrendered and some firearms and technicians fell into the hands of the Muslims. The Muslims thus acquired the technique of making firearms. They used them successfully against the Sixth Crusade (1248–1254).

By the latter part of the thirteenth century the narrow cylindrical tube of the fire-lance had already developed into one with much wider bore for the cannon (*huopao*). For example cannons were deployed when the Mongolian fleet went to Java in 1292 and 1293. Many examples of Chinese cannon, both of bronze and iron, are known from 1330 onward. Several types of cannons are described in the fourteenth-century military book, the *Huolongjing* (Fire Dragon Manual).

During the second half of the fourteenth century Chinese firearms were unmatched anywhere in East Asia. They were used by Zhu Yuanzhang, the founder of the Ming dynasty, to overthrow the Mongols and to suppress local rebellions. After his victory he kept his firearms in secret arsenals. There was no need to improve these weapons as they met no challenge, so that he only saw the necessity of guarding both the weapons and the knowledge from falling into undesirable hands. This happened during a period when Europe was undergoing great social change and when European firearms began to come to ascendancy. Traditional Chinese weaponry is now something of the past, but firework displays that we see on auspicious occasions around the world today remind us of the original role played by gunpowder in China.

See Also

► [Military Technology](#)

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Guo Shoujing

Ho Peng Yoke

Guo Shoujing (1231–1316), an astronomer, mathematician, and hydraulic engineer, was born in Xintai (in modern Hebei province). The names of his parents are not known, although records show that his grandfather, Guo Yong, was knowledgeable in the classics, in mathematics, and in water works. As a boy of 14 Guo Shoujing was able to construct an advanced type of clepsydra, or water clock, for his time: the *lianhuailou* (lotus clepsydra), so named because the top of the receiver was in the shape of a lotus flower. In about the year 1251 he restored an old bridge across the Dahuoquan River north of Xinzhou, also in Hebei.

In 1260 Guo accompanied his friend Zhang Wenqian (1217–1283), who was sent by Qubilai Qan to Daming to pacify the local population. There he began to construct astronomical instruments, such as a bronze clepsydra and a ► [bamboo](#) armillary sphere. The same year Zhang Wenqian recommended him to Qubilai for his expertise on irrigation. Guo was soon commissioned to improve irrigation and water communication within the region south of the capital Dadu (modern Beijing) and north of the Yellow River. The mission was successfully accomplished. In the year 1264 Guo again accompanied Zhang to the Circuit of Xixia

(in modern Gansu province) to restore the irrigation canals that had been blocked or damaged during the years of war. He reported on what he saw during his travels and made many recommendations to Qubilai on the improvement of irrigation and water communication systems.

There was an urgent need to reform the existing calendar, the *Damingli*. In 1276 Qubilai captured the Southern Song capital, Linan (modern Hangzhou) and thought that the time was ripe to promulgate a new calendar. Guo and Wang Xun (ca. 1235–1281) were commissioned to lead a special bureau established for the project. Guo Shoujing built 17 new astronomical instruments to obtain more accurate astronomical observations on which the accuracy of the new calendar would depend. Thirteen of the instruments were used in the capital Dadu, and four were used for fieldwork. In 1279 Qubilai established an Astronomical Bureau at the capital. Zhang Wenqian was appointed Director, while Guo and Wang Xun were made the two co-Directors. A new observatory was built at the capital along with new bronze astronomical instruments. Guo organized a large-scale measurement of the length of the shadow of the gnomon cast by the sun in different latitudes, from the capital in the north to Nanhai (modern Guangzhou) in the south, to determine the length of the meridian.

Guo used spherical trigonometry and the method of finite difference involving a cubic equation to do his calculations. The new calendar, the *Shoushili*, was completed in 1280. This was the most accurate calendar ever made in traditional China. It was promulgated the next year. Guo Shoujing was promoted to the Directorship of the Astronomical Bureau.

In 1292 Guo held a joint appointment as head of the water works bureau in the capital. The same year he constructed water locks and canals linking various cities to the capital. The Qan was greatly pleased on completion of the project. While he was in the capital Guo made a clepsydra whose bells and drums would chime and sound

on the hours for his master. After the death of Qubilai, Timur also sought Guo's advice. Guo died in 1316.

See Also

- [Armillary Spheres in China](#)
- [Bamboo](#)
- [Calendars in East Asia](#)
- [Clocks and Watches](#)
- [Time](#)

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H

Ḥabash Al-Ḥāsib

Lawrence Souder

Ḥabash al-Ḥāsib was one of the earliest Muslim astronomers and a major contributor to the development of trigonometry. He was born in Marw, Turkestan (modern Mary, Turkmenistan) and died between AD 864 and 874. Ḥabash lived during the Abbasid empire, when the caliphs became the stewards of civilization. This empire preserved ancient science and philosophy by translating ancient Greek, Syriac, Sanskrit, and Persian texts into Arabic. Ḥabash himself based his work and methods on Ptolemy's *Almagest*. Ḥabash held Ptolemy in high regard, calling him "the wise Ptolemy" and describing his work as having the "utmost in research and precision" (Langermann, 1985). Ḥabash led the way in the Arabic development of astronomy and computational techniques.

As an astronomer Ḥabash worked at calculating more precise celestial distances and at developing more accurate ways of calculating these distances. He calculated such values as the circumference of the earth, the diameter of the moon, and the distance of 1 min along the orbit of the sun. Ḥabash's work in trigonometry consisted of calculating tables of trigonometric values and developing new trigonometric functions. He calculated tables (called *zījes*) of sine values at 1° intervals to

three places, and he is considered to be the first to construct a table of tangent values.

In Ḥabash's time much of Muslim science served the needs of the religion. For example, Islam requires the faithful to face Mecca when they pray. To this end Ḥabash developed an analemma, or graphical, method for finding the azimuth to Mecca, called the *qibla*. Muslim calendars were dependent upon the appearance of the new crescent of the moon. Ḥabash is thought to be the first astronomer to calculate when the new crescent appears. Islam also requires the faithful to make a pilgrimage to Mecca. Ḥabash once calculated what he called the distance "by the straight arrow," or the great-circle distance between Baghdad and Mecca to be 677 miles, while the actual overland distance was known to be about 712 miles. In one of his few surviving works, *Kitāb al-ajrām wa-l-ab 'ad* (The Book of Bodies and Distances), Ḥabash reported that ► [al-Ma'mūn](#), the caliph at the time and Ḥabash's patron, was pleased with the small difference between the two distances considering the uneven terrain between the two cities.

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Calendars in Islam](#)
- [Qibla and Islamic Prayer Times](#)
- [Trigonometry in Islamic Mathematics](#)

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Hair in Egypt

G. J. Tassie

The ancient Egyptian hairstylist was expected to be able to style hair, as well as cure baldness, make hair (of a rival) fall out, get rid of head lice and cover up the signs of aging by dyeing grey hairs. Ancient Egyptian clients would also require more mundane tasks, such as cleansing and scenting the hair.

Tinting

The Egyptians used natural dyes which are known to coat and partially penetrate the hair’s 6–14 layers of cuticles. These natural semi-permanent tints do not leave roots as they wash out of the hair, although a virtually permanent tint may be achieved with frequent application. The main colour the Egyptians would probably have wanted to achieve was black, emulating the dark brown colour of their youthful hair. One recipe was an ointment made of juniper berries and two unidentified plants kneaded into a paste with oil and then heated. The natural blue-purple colouring agent in the plants would rub off on the hair, while the astringent properties of the

juniper would stimulate the scalp (Manniche, 1989, p. 46).

Indigotin (*Isatis tinctoria*) is a blue dye that is found in both indigo and woad, and is an obvious choice for Egyptian hair dye as indigo occurs naturally across much of northeastern Africa. There is considerable epigraphic evidence to suggest that deep blue-black was the colour towards which most Egyptians aspired, and this is the colour that is achieved by putting blue dye on the Egyptians’ natural dark brown hair. This would have been used on both the person’s own natural hair and on hair used to make wigs, as Fletcher (1995) has found traces of indigotin on both. Indigotin also has antiseptic properties and was widely used all over the Middle East on clothing and directly on the skin. As the Egyptians had considerable expertise in so many natural medicines, they are unlikely to have been unaware that trichological (hair science) application of indigotin had a positive side effect as an anti-bacterial agent. On one of the two blonde-haired mummies Petrie found at Gurob was a large black sprang (sprang is closely related to braiding, but it is done on threads which are stretched on a frame, so that the braided fabric builds from both ends towards the middle) headcover that he claimed was worn to cover the person’s own blonde hair, possibly to hide the fact that the individual was foreign (1890, p. 39). However, Fletcher’s examination of the hair and headcovering revealed the fact that the blonde hair had been enhanced with yellow henna, and that the sprang headcover was dyed a dark blue-black using indigotin and a small amount of madder (1995, p. 469).

The later periods of Egyptian Pharaonic history saw the use of tannin to tint hair a dark brown colour, usually in conjunction with iron mordents (Fletcher, 1995, p. 469). A mild form of natural bleach may have been used to enhance or define a style, or to pre-lighten the hair so it could be dyed a brighter colour (Fletcher, 1992, p. 16). Such a substance may have contained natron and lemon juice, a lightening substance that is still used today.

Henna (*Lawsonia inermis* L.; *Lawsonia alba* L.) was also used in the Pharaonic era, but

it would be unwise to use this to support the oft-made assertion that Egyptians commonly used henna to dye their hair, as we know that that black (see above) rather than red was the favoured hair colour in ancient Egypt. However, while red was seen as being a dangerous colour for most of Egypt's history, henna was certainly used as a hair colorant (although probably not widely) by the higher echelons of society at least. This is reinforced by the iconographic record and actual wigs and hair of mummies, which show very little use of henna up to the end of the New Kingdom (1069 BCE). Brunton suggests that the light red-brown hair of an elderly woman from the Badarian (4500 BCE) cemetery at Mostagedda might have been brought about by an application of henna dye (1937, p. 45). Smith believes that the brilliant reddish colour of Henttawy's hair and the dark reddish-brown hair of Thutmose IV were tinted with henna (1912, pp. 19 and 44). However, it should be considered that various types of henna produce different colours, from yellow through to nearly black, and that other ingredients can be added in order to produce different effects. The yellowish hue of Ramesses II's hair is not the result of the mummification process, as once believed, but was the result of henna or one of its derivatives being applied to the King's grey hair (Balout, 1985, p. 256) to resemble the King's natural hair colour in his youth.

The hair of Nesikhons was found to have been "thickly strewn with powdered red resin" (Smith, 1912, p. 109). A similar case of a coloured powder being used in this manner was found on the hair of the mummy of the Priestess Tansertemsutenpa, who was found with a thick coat of yellow ochre over the top of her hair, possibly concealing a small bald patch as well as colouring the remaining hair (Smith, p. 158). While it may be difficult to distinguish intentional dyeing ingredients from naturally occurring materials that inadvertently found their way into the hair, it has been suggested that a small sachet of a fine dark powder, manganese dioxide and quartz – found in the wigmakers workshop at Deir el-Bahari – was sprinkled over the hair for

cosmetic reasons (Laskowska-Kusztal, 1978, pp. 119–120).

Hair Care

The hair of an ancient Egyptian woman was literally her crowning glory as can be attested to by a number of literary and epigraphic sources where men's apparent fascination with long, sweetly smelling dark hair is made abundantly clear. However, if women had a vested interest in keeping their hair in good order for the benefit of men, it is also evident that men also wished to boost their trichological endowments, paying considerable attention to the many medical recipes for the care and restoration of hair. There is a whole section within the Ebers Papyrus that concerns baldness, hair preservation and general welfare of the hair and scalp, including this one to prevent baldness: "castor oil; the fat from a hippopotamus, cat, crocodile, snake and an Ibex and rub this mixture on your head" (Wreszenski, 1913 Spell EB 465). The care of the scalp usually involved various oils such as castor oil or moringa oil (*ben* oil) mixed with other ingredients. Another hair treatment for maintaining the good health of the hair (and scalp) was prepared from "a red mineral; kohl; myrtle berries (?); oil or fat; gazelle dung and hippopotamus fat, mixed to make a paste" (Manniche, 1989, p. 125 Spell EB 471). The most effective ingredient was the oil, which moisturised and nourished the scalp at the same time making the hair feel soft and smooth and look shiny and healthy. The red mineral and kohl may have also added a slight dark reddish hue to the hair.

Head lice (*Pediculus humanus capitis*) were a common parasite in ancient Egypt, and were a major cause of head shaving because washing alone does not kill or remove them from the hair. Head lice are particularly common in children and live just behind the ears and in the nape of their host's head, preferring clean hair to dirty or oily hair. The Egyptian habit of oiling the hair may have had a preventative effect on louse infestation (Dayagi-Mendels, 1989, pp. 76–78), while many other parasites like fleas and flies

were trapped by the glutinous substances (including beeswax and resin) which were used to set the hair. Both the Hearst and Ebers medical papyri contain possible recipes to remedy louse infestation or “*hnsyt*-illness of the head”, such as this one: “fruit of the castor-oil plant; ox fat; moringa oil. Combine and mix into a paste, use as an unguent every day” (Wreszenski, 1913 Spell EB 437; Hearst 24). The term *hnsyt* has been translated as “that which moves about on the head”. The application of the ointment would probably have improved the condition of the ailment; in the case of head lice it would not only remove the adult lice, but loosen the egg cases as well. While we do not know the composition of all the ancient Egyptian oils used, natural insecticides such as quassi, derris, sassafras and stavesacre (Fletcher, 1995, p. 39) may have been used, probably in collaboration with the de-nitting combs mentioned above.

Highly diluted natron (Natron was a salt (sodium carbonate and sodium bicarbonate) that was used in the mummification process to dry out the body of the deceased in order to assist in its preservation) may have been used as a detergent for dissolving greasy deposits when washing the hair (Ghalinoungui, 1983, p. 153), as a fragment of this substance was recovered from the wigmakers’ workshop at Deir el-Bahari, and tests confirmed that it still retained its detergent properties (Laskowska-Kusztal, 1978). The use of these harsh detergents may explain why some women had bald patches.

Ancient Egyptians used beeswax and resin to style their hair, although this appears to have been done every few weeks rather than on a daily basis. Beeswax is commonly found in hair and wigs, and as it seems unsuitable for oiling or perfuming the skin, it is probable that it was used to set the hair (possibly at a ratio of 2/3 wax to 1/3 resin (Fletcher, 1995; Lucas, 1962)). It is unlikely that this mixture of wax and resin comprised the “scent cones” popular in the New Kingdom, as the body/environment would have been unable to reach the melting temperature of wax (60 °C = 140 °F) in order for it to melt naturally and flow over the hair and body. Lucas therefore concludes that the wax and resin mixture must have been

warmed up first and then rubbed into the hair and as it cooled set it in style (Lucas, p. 31).

From Late Neolithic times (4500–3050 BCE) to the Graeco-Roman Era (332 BCE–AD 306), both men and women would scent and oil their hair. The oiling of the hair to keep it supple and pleasant smelling was done on a daily basis as part of the morning toilette ritual. Lucas’ (1962, p. 89) examination of residues found in cosmetic containers found palmitic and stearic acids, which probably represented perfumed ointments made of animal fat mixed with scent. The most frequently cited hair oil was a substance known as *Qemi*, which came from the Red Sea region and found widespread use in the anointing of aristocratic coiffures throughout the New Kingdom. The importance of keeping the hair in good order cannot be overstated, judging from the frequent literary references made to divine hairstyles. For example, in “The Song of the Perfumed Hair”, the fragrant locks of the Goddess Shentayt are alluded to thus: “There is perfume, there is perfume in your hair, O holy Shentayt, perfume in your hair” (Nachtergaeel, 1981, p. 593). In the New Kingdom tomb of Rekhmire the harpist sings: “Put myrrh on the hair (or curls) of Ma’at” (Davies, 1943, pp. 60–61). There is also mention of oils being poured over people’s hair during the Old Kingdom (2613–2181 BCE), such as in the Dynasty V tomb of the Vizier Senedjemib where an inscription states that King Djedkare Isesi “Caused that I be anointed with fat” (Breasted, 1907, p. 122).

Although scented oils could be rubbed into the hair by hand, scent cones are commonly depicted in New Kingdom art (Fig. 1). Scenting or festal cones were first introduced into Egypt during the Middle Kingdom (2040–1650 BCE), where they are depicted on a Dynasty XIII (ca. 1795 BCE) stela relief of Amenysenb from Abydos, where his Asiatic brewer Irsi is seen wearing a smallish lump of unguent on his cropped hair (Fletcher, 1995, p. 446). However, scent cones only start to be depicted in any real number from the reign of Hatshepsut (Dynasty XVIII, from 1473 to 1458 BCE) and become even more popular during the reign of Amenhotep III (1390–1352 BCE).

Hair in Egypt,

Fig. 1 Guests at the banquet with scent-cones on their heads, Tomb of Nakht (TT52) (Author's own photograph)



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Throughout the New Kingdom (1550–1069 BCE) and up to the Ptolemaic Period scent cones were worn (Maraite, 1992). They are most frequently represented on tomb scenes, but can also be found on temples and stelae reliefs (Maraite). A sculpted version can be found on figures of nobility such as the statues of Neferhotep and his wife (Davies, 1932, frontispiece) and Khay and his wife (Muhammed, 1966, pl. 8). Cones are sometimes shown being worn by *ushabtis* (Ushabtis were small figurines made from wood or clay, or occasionally stone or ivory. Often the ushabtis were depicted with tools, or in some act of work. They were buried with Egyptians, so that, if the deceased were called to work in the afterlife, the ushabti would take the deceased's place performing the task), i.e. those of Tuty (Kozloff & Bryan, 1992, p. 259). The ancient Egyptian name for these cones was *bt*. The cones were worn by men, women and children alike, and they were not just limited to the elite classes, but are shown being worn by musicians, dancers and servants as well. Although Fletcher (1995, p. 446) has proposed that they were just symbolic of the scenting and oiling of the hair, some Nubian

peoples (Bisarin) are known to wear similar scented cones (Keimer, 1953, p. 342 ff.). Although in later depictions they become highly stylised and unrealistically tall and thin, it is likely that a small, round tablet of scented animal fat was indeed placed on the hair at banquets and other festive occasions to keep the hair sweet smelling and in good condition. The custom of using scent cones was probably introduced into Egypt from Nubia because of the Egyptian expansion into the region during the Middle Kingdom (2040–1650 BCE).

In ancient Egypt, there was an emphasis on being or looking young, fit, healthy and able. This emphasis is demonstrated by the king having to prove his fitness to rule by running the *heb sed* court on his jubilee. Receding or greying hair is rarely depicted in tomb scenes, particularly on the elite, although the lower orders were sometimes shown in this manner to mark the social distinction between them and the tomb owner (Janssen & Janssen, 1996; Robins, 1996). The various remedies against baldness and concoctions to colour greying hair show that the youthful ideal was not just an artistic principle but a pivotal part of Egyptian socio-economic culture.

The maintenance of the black hair of one's youth was equated with vitality, fertility and potency; receding (completely bald or shaved heads reflected piety and cleanliness) and grey hair were symbolic of disempowerment.

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Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs

G. J. Tassie

The practice of hairstyling in Egypt can be traced back to the Predynastic Period (4000–3050

BCE), and was accompanied by a series of technological changes reflecting this new tradition, especially copper and bronze tools. The oldest tools were bone and wood combs and hairpins, with flint or obsidian blades being used to cut the hair. Although hairstyling was initially mainly utilitarian, Egyptian society's growing complexity led to a proliferation of more extravagant styles. Like most other social status markers, hairstyles helped to maintain and reinforce a person's social position and maintain their privileged access to goods and materials (Trigger, 1993). Hairstyles can therefore be grouped with body decoration, clothing, and jewelry in that they all inform the onlooker as to gender, age, status, class, sexuality, ethnicity, and ritual affinities (Fletcher, 1995; Robins, 1999; Tassie, 2002).

There are five main operations that can be performed on hair:

1. It can be curled or left curly;
2. It can be straightened or left straight;
3. It can be plaited, twisted, or teased;
4. Hair can be added; and
5. Hair can be taken away.

These five operations may be used separately or in any combination. Accessories may also be added, including hairpins, combs, and fillets. (A fillet is a ribbon or narrow band of fabric worn around the head across the forehead, as an ornament or to hold back the hair.) Tinting of the hair may also occur, although this does not come into the above categories of hairstyling. The ancient Egyptians also developed wigs and hairpieces to supplement their own hair, enabling them easily to change their hairstyles to suit the occasion. However, the use of the term "wig" to describe all ancient Egyptian hairstyles is incorrect. Certain statues depict the owner's own hair protruding from beneath a full wig (particularly in the Old and New Kingdom) but other depictions of figures, such as those on the Erotic Papyrus and many of the workers in the fields and other secular tomb scenes are clearly not wearing wigs (Fig. 1). Therefore, unless one is certain that the person is actually wearing a wig, the term



Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs, Fig. 1 Close-up of the head of Nofret showing her real hair exposed beneath her full, bobbed wig. Meidum, Dynasty IV, Old Kingdom (Photograph by author copyright Egyptian Museum of Antiquities, Cairo)

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"hairstyle" should be used. Wig manufacture and wearing are discussed further below.

The types of hairstyles worn by men and women changed throughout time and space. The social significance of hairstyling became codified after the period of unification, allowing only certain status groups to wear particular hairstyles. Constraints were placed upon the choices of hairstyles that individuals were allowed to wear both by society and the technology open to the ancient Egyptian hairstylist. The hairstyles that a person could wear were temporally dependent upon a person's social position and status. A form of sumptuary laws existed in Egypt regulating social etiquette with regards to what forms of hairstyle were permissible by various classes and statuses of individuals at certain occasions. These laws were not written down but were governed by social and courtly modes of behavior. The hairstylists through their creation of hairstyles and wigs helped to perpetuate the hegemonic situation and reinforced the social relations, even when creating new styles.

During the Old Kingdom shaved heads were sported by both men and women of all status groups, as well as cropped hairstyles. Short,



Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs, Fig. 2 Dyad of Meryneith (Meryre) and his wife Iniura, found in his Saqqara tomb by the Dutch Mission. His title is the “Scribe of the Aten Temple in Akhetaten and Memphis.” Her titles are “The favorite and Beloved Wife” and “The Great Lady of the House.” Note the more naturalistic rendering of hair at this period in three-dimensional art; Meryneith has a duplex style and Iniura a gala hairstyle. Amarna Period, Dynasty XVIII, New Kingdom, Saqqara, now in the Cairo Museum (Author’s own photograph? copyright Egyptian Museum of Antiquities, Cairo)

round, curly styles were primarily worn by low to middle class men. The various lengths of bobs were worn by both elite men and women, although with slight variations in the actual dressing. The long tripartite hairstyle was worn by women of any class, but only sacred men (i.e., gods, kings, and the dead). The tripartite hairstyle was symbolic of fertility and rejuvenation. Therefore women as child bearers and sacred men (king – Egypt’s fertility, deities – humanities creation, and fertility and the deceased – rebirth) were allowed to wear the style. During Dynasty XVIII (1550–1295 BCE) the gala hairstyle was introduced for elite women, as was the duplex style for elite men. The Nubian hairstyle became popular just before the Amarna Period of the New Kingdom (1352–1323 BCE), during the reign of Amenhotep III, and remained the standard elite hairstyle of both men and women until the reign of Horemheb (1323–1295 BCE) (Aldred, 1957). The classic children’s hairstyle – the sidelock of youth – remained popular throughout Pharaonic history (Tassie, 2005) (Fig. 2).

The Ancient Egyptian Hairstylist and Barber

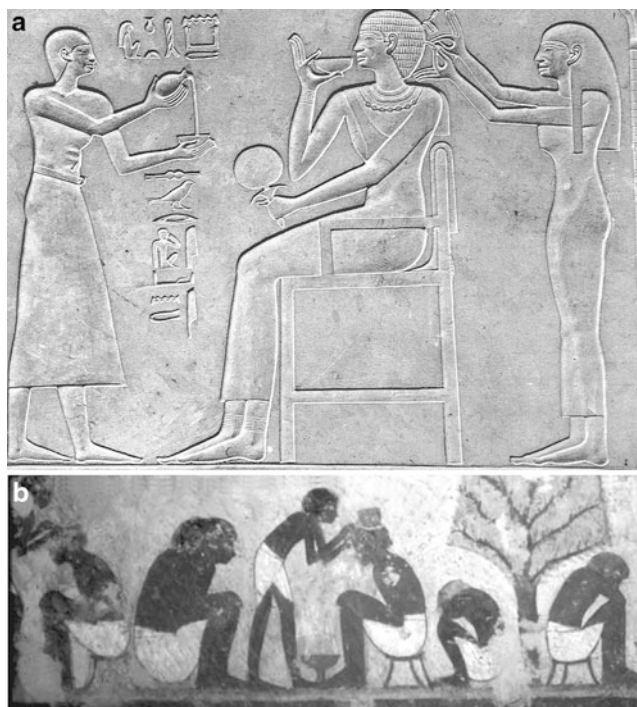
Due to hair’s apparent social importance, many hairstylists and barbers plied their trade throughout ancient Egypt. The elites usually had a hairstylist attached to their staff or arranged for one to visit their homes, whereas poorer people would go to a traveling hairstylist. For everyday care and attention, the elite women would have had a maidservant trained to do the dressing. Poorer people would have to rely upon a relative or friend to style their hair. The work of the barber (*h’ky*) was not thought to be as highly skilled as that of the hairstylist. Barbers would set up beneath the shade of a tree, placing their stools, and cutting the hair of their clients. Tomb scenes and inscriptions from the Old Kingdom (2613–2181 BCE) the Middle Kingdom (2040–1650 BCE) the New Kingdom (1550–1069 BCE) and Late Period (646–332 BCE) bear witness to the fact that certain hairstylists held a high social rank (Gauthier-Laurent 1935–1938). All except two of these inscriptions refers to men. The word used to describe him is *ir-šn(y)*; the rarely found feminine form is *irt-šn(y)* – literally hairmaker, hairdoer, or wigmaker. There is usually a modifying determinative after the word *ir-sheeny*, denoting that the bearer of the title was either a “royal hairstylist” or an “overseer of hairstylists” (Riefstahl, 1952, 1956). Other related words are *nšt*, hairdresser, and *nšy*, which means “to dress hair.” These words are used occasionally from the Middle Kingdom onwards, but usually refer to a casual hairdresser. In ancient Egypt hairstylists were frequently important officials who held important offices in addition to their tonsorial duties (Riefstahl) (Fig. 3).

Wigmaking

Although many publications refer to any Egyptian hairstyles as “wigs,” true wigs were in fact fairly rare, and then almost exclusively the preserve of the elite. That the rulers of the proto-kingdoms were probably using extravagant

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Fig. 3 Hairstylists and Barbers. (a) Queen Kawit having her hair styled by a maidservant while at breakfast. Scene on her limestone sarcophagus, Cairo Museum, originally from her tomb at Deir el-Bahari, Dynasty XI, Middle Kingdom (Author's own photograph ? Copyright Egyptian Museum of Antiquities, Cairo). (b) Army recruits having their hair cut (Note bowl with water between barber and client for keeping the hair moist), Tomb of Userhet (TT56), Dynasty XVIII, New Kingdom (Author's own photograph)



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hairstyles, wigs, and headdresses to signify status is evidenced by the elaborate hairstyle of the elite Naqada II (ca. 3600 BCE) woman in Burial 16 at HK43. This is the earliest palaeoethnobiological evidence for the wearing of false hair so far recovered in Egypt. The hair was shoulder length, tinted with henna, and augmented with a considerable number of false hair swatches. The finished hairstyle was very voluminous with matted tresses (reminiscent of modern dreadlocks) and with a lot of height. Another Naqada II female mummy from Hierakonpolis (Burial 333) had what we now call a Mohican-type hairstyle. (The author has only seen a photograph of this hairstyle and has not examined the mummified remains. Mohican-like was how the director of Hierakonpolis – Dr Renée Friedman – described the hairstyle in a lecture. The modern-day Mohican hairstyle is shaved at the sides with a line of hair sticking up from the center of the skull, like a cockerel's comb, whereas a Mohawk is shorter and normally squared off with the central section of hair starting just above the occipital bone. The photograph of the hairstyle in Grave 333, HK43 did not appear to have shaved sides but was

combed into the medial line of the head giving a Mohican-like appearance to this hairstyle.) Also found at Hierakonpolis HK43, in the double burial 154, is the oldest toupee so far found in Egypt – early Naqada II. This hairpiece was made of either “goat or sheep's wool” and had been secured in place over the bald patch of an elderly man's scalp by weaving strands of the man's own hair into the hairpiece (Friedman, 2001, p. 12). The intricacy of the styling techniques involved in creating these styles indicates that it took many hours of work and was probably performed by a professional hairstylist (Fletcher, 1998). There is also epigraphic evidence of wig wearing. On the famous pair of Dynasty IV (ca. 2613 BCE) statues of Rahotep and Nofret from Meidum, Nofret's own hair can be seen combed flat beneath a full bob wig. Archaeologists found a wig dating from the First Intermediate Period (2181–2040 BCE), in the Dynasty VIII tomb of Hefefi at El-Hagarsa. This wig was shoulder length and black, consisting of long, straight braids made of twisted flax fiber and set with beeswax and resin (Kanawati, 1993, pp. 21, 65). The archaeological record shows an increase in

the number of wigs surviving from the Middle Kingdom; notable examples include the numerous wigs found in their original wig boxes in the Dynasty XII (1985–1795 BCE) tombs at Lisht. These wigs were made of human hair and were styled into long braids (Lansang, 1933). The records show a dramatic increase in the amount of false hair that survives from the New Kingdom, as do subsequent periods. However, there is evidence that the wearing of wigs fell out of favor during the Late Period (Fletcher, 2000a, 2000b).

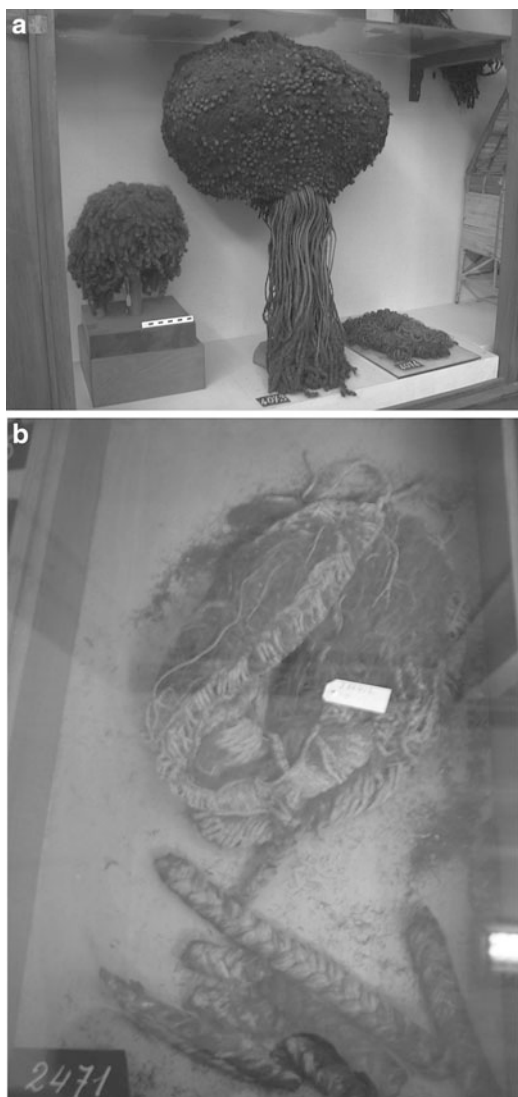
Human hair was the main material used for constructing wigs and hairpieces, sometimes in association with date palm fiber, reeds, and linen (especially during the Graeco-Roman Period – 332 BCE–AD 306; Tassie, 2002). No animal hair was ever used (apart from the HK43 toupee) (Eisa, 1953; Lucas, 1930, 1962), and in every case except that of Maiherpri, cynotrichous (Caucasian) rather than heliotrichous (Negroid) hair was used in wig construction (Fletcher, 2000a, 2000b). There are epigraphic indications that wigs were valuable assets: they were listed alongside gold and incense in the account lists from Kahun (Fletcher, 2000a, 2000b), while a single wig (probably of fiber) constituted two-thirds of a woman's dowry in a marriage contract from 219 BCE (Tassie, 2002). Although false braids could be made from the wig owner's own hair, the vast amount of hair used in wig manufacture was probably shaved from the heads of foreign captives or was sold to the wigmakers by its impoverished prior owners. Hair was traded extensively throughout the Roman Empire, and was sufficiently valuable to cause a specific custom duty to be paid on it (Fletcher, 2000a, 2000b).

Once the hair had been processed, cleansed and detangled, it was ready to be made into wigs and postiches (hairpieces). The processed lengths of hair would then have been styled into plaits, curls, and wefts before being fastened directly onto the head or onto a wig foundation. The wig foundations were usually made of plaited hair (or, more rarely, incorporating leather straps and linen strings) as an open-mesh base or a series of knotted wefts of hair. These mesh bases and wefts were then often sewn on to

a linen cap with a drawstring, so that it could be secured to the head (Tassie, 2002). There was considerable variability across time and space in terms of wig manufacture. For example, Merit's wig consists of wefts of hair knotted together to form a kind of marteaux or diamond mesh around a medial plait with a central parting (Chiotasso, Chiotasso, Pedrini, Rigoni, & Sarnelli, 1992), while the British Museum wig is composed of some 300 locks of hair (each containing about 400 hairs) on a foundation of finely and tightly plaited human hair forming a hair net with rhomboidal apertures (Fig. 4).

The root end of each lock was secured by looping it around part of the mesh, pressing it back against the hair stem and fastening it with substrands of the root section; this was then locked in place with beeswax and resin (Cox, 1977). The greatest collection of ancient Egyptian wigs is in the Egyptian Museum of Antiquities, Cairo where there are 23 full wigs and numerous hairpieces (Tassie, 2002). The Egyptians protected their wigs by keeping them in wig boxes, such as Merit's large rectangular cupboard-like wig box found in her husband Kha's tomb in Thebes with poles to hang the wig from (Chiotasso et al., 1992) or Tutankhamun's square wig box found in his tomb KV62 with a mushroom-like stand in the center for hanging the wig on (Reeves, 1990, p. 193) (Fig. 5).

While our knowledge of wig morphology and structure is considerable, the details of the wig construction process were unclear until the discovery of a wigmaker's workshop dating to between 1800 and 1700 BCE in a crevasse overlooking the Temple of Mentuhotep II at Deir el-Bahari. The workshop contained four alabaster vases in a linen sack with various wigs in different stages of production, tufts of hair, hair wefts (on threads), swatches (tied up with fibers), and a thread net-foundation. A papyrus case found in the workshop held a bronze awl, five bone hairpins, and fragments of two flint knives. In another container were pieces of linen (probably for the skullcap), solid soda "soap," leather straps, bone beads, and other oddments. A unique model head made of wood was also



Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs, Fig. 4 Wigs in the Cairo Museum: (a) left to right: lady Istemkhebs short curly wig – JE26252h, duplex wig – JE26252g, Ahmose-Hentempet short curly wig JE46913; (b) wig of thick triple braids (JE23412) found in side-chamber of Amenhotep II's Tomb (KV35), New Kingdom and Third Intermediate Period (Photographs courtesy Joris van Wetering ? Copyright Egyptian Museum of Antiquities, Cairo)

found and is believed to have been used for laying out the wigs while in production. Black lines had been traced to show the outline of the wig's attachment and its long and short axis (Laskowska-Kusztal, 1978).



Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs, Fig. 5 Large wig box recovered from the tomb of Yuya and Thuya in the Valley of the Kings, Thebes. It is made of papyrus stalks supported by reeds, and measures 107 cm long by 51 cm deep. The box stands on four reed legs, and had an outer lid, and an interior double leaved lid opening from the middle to form a tray. This lid was tied down with linen thread and sealed with black clay seals. The front of the wig box is ventilated by three windows, one at each and the other in the middle of the front panel. The wig box may originally have held Yuya's duplex wig CG51185, which was found in a niche in his tomb KV46, Dynasty XVIII, New Kingdom, Cairo Museum (Photograph courtesy Joris van Wetering ? Copyright Egyptian Museum of Antiquities, Cairo)

Hairstyling was not done for fashionable reasons but was used to convey the class and status of the wearer. However, the hairstyles of the ancient Egyptians were far from static, and evolved to express changes in Egyptian society. This flux gave rise to a large assemblage of tools, unguents and hair products that can be seen in many of the world's museums, along with the mummies whose hair was treated in the ways discussed above. Some museums may hold only a hand-mirror or a razor, whereas others, such as the Metropolitan Museum of Art, New York include whole wigs in their displays of ancient Egyptian hairdressing and beauty paraphernalia.

The art of hairdressing was already well developed by 3000 BCE in Egypt. The social importance of hair was such that ancient Egyptian hairstylists were highly regarded, especially those allowed to work on the hair of the pharaoh.

There was even a goddess of hair and hairstyle (Khonsut) and a god of the royal beard and barbers (Duwar).

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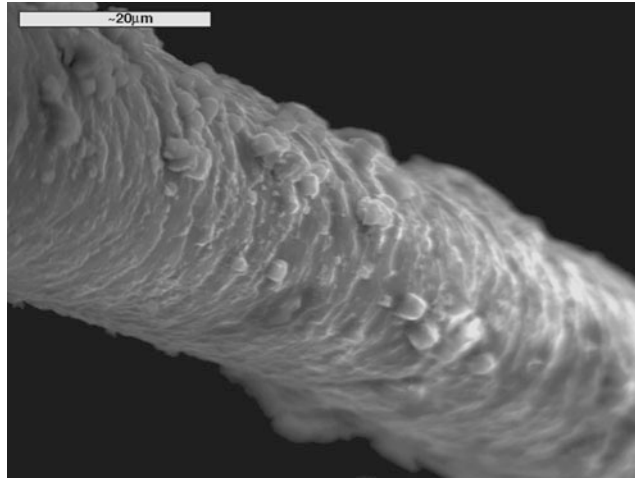
Hairstyling Technology and Techniques Used in Ancient Egypt

G. J. Tassie

Three types of cutting equipment were available to ancient Egyptian hairstylists: the razor, the “composite tool” (a combination of scissors and hair-curler) and the comb. Of these, the razor was the main implement used for cutting the hair. The hairstylist would probably take the bulk of the unwanted hair away using the razor, using a bodkin (hairpin) to separate the hair not being worked on. They would then work on the free section, sculpting with the razor and snipping off any stray hairs with the scissor part of the composite tool before releasing the next section to be cut. The process worked around the hairline first, then up to the crown. The client would view the results in a bronze hand-mirror (Fig. 1).

Microscopic examination of the cut ends of hair on wigs and mummies has revealed the majority to be of the tapered variety and very clean-cut (Fig. 2). This indicates that it was cut with a sharp razor while wet (Fletcher, 1994a), as the razor requires the lubrication of water to make it glide over the hair and give a clean cut. There are modern parallels: many Indian hairstylists and barbers use a razor against a piece of wood, combing the hair flat across the wood, then pulling the razor across it to give a straight line and a smooth-looking finish to the style. However, no depictions of ancient Egyptian hairstylists cutting long hair have been found, so the method employed must remain just supposition at the moment.

After cutting, the next step was plaiting or curling the hair. The former would probably be done wet, whilst the hair would be dried before carrying out the latter. The curling would be done using curling-tongs (composite tool), then dressed and set using beeswax and resin and an assortment of hair accessories such as combs,



Hairstyling Technology and Techniques Used in Ancient Egypt, Fig. 1 Scanning electron microscope (SEM) photographs at 1,100 $\times$ magnification of Romano-Christian hair, ca. third century AD, Egypt. The ends of the hair in this period have been cut using scissors

leaving a blunt end. The cortex (central part of hair) and medulla (middle segment of hair shaft) have virtually disappeared due to calcification, which can clearly be seen on the surface of the cuticles (outside layers) (Photo by author)



Hairstyling Technology and Techniques Used in Ancient Egypt, Fig. 2 Egyptian copper mirrors in the Petrie Museum. Dynasty XII mirror with Hathor column handle (UC13286)

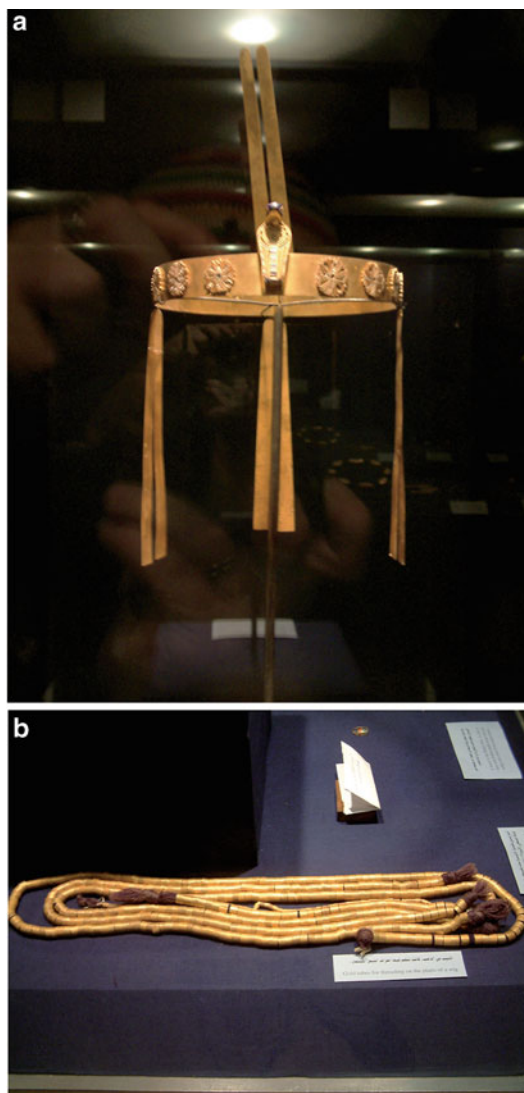
hairpins or more ornamental head dresses (Fig. 3).

Tools Available to the Ancient Egyptian Hairstylist

The Razor: Form and Development

The copper razor (*s3*) had its beginnings in the Protodynastic Period (3350–3050 BCE). It was probably derived from the copper flaying knife (Petrie, 1917) rather than the lithic “razor” which was no more than a side scraper. Originally there were two types of razor: an asymmetrical variant with a single lateral cutting edge and a symmetrical spatula-like tool (Fig. 4a) with parallel sides and a rounded cutting edge (Davies, 1977, p. 110). The asymmetrical type soon fell out of use, and by the end of the Old Kingdom (2613–2181 BCE) had been almost completely replaced by the symmetrical type. This form went through a series of variations; in general terms, the sides proceeded to splay out (Stead, 1986, p. 50) throughout the Old Kingdom.

During the Middle Kingdom (2040–1650 BCE) the cutting edge of the symmetrical razor began to protrude laterally (Fig. 4b). Coming in at



Hairstyling Technology and Techniques Used in Ancient Egypt, Fig. 3 Hair ornaments of Princess Sithathoriunet, a daughter of King Senusret II, Dynasty XII, Middle Kingdom, found with other jewels near her father's pyramid at Lahun now in the Cairo Museum: (a) Gold diadem; (b) Gold tubular hair ornaments that were threaded on the tresses of hair (Photo by author copyright Egyptian Museum of Antiquities, Cairo)

this time (Dynasty XII, 1985–1795 BCE) is the scalpel-like razor or *dg3* type razor (Davies, 1977). This type was made of a thin strip of metal (Fig. 4e), sharpened at one end, which later incorporated a loop (often in the form of an animal, bird or deities' head), in which to rest the

little finger in order to help rotate the razor (Petrie, 1917, p. 50). By Dynasty XVIII (1550–1295 BCE), the *mh'k* razor – one of the most characteristic pieces of toilette equipment of the New Kingdom (1550–1069 BCE) – had evolved into a hatchet-like form, with a wooden handle almost at a right angle to the cutting edge and a spur projecting from the rear of the razor. This is thought to have served as a counterweight, to ensure proper balance and handling (Stead, 1986, p. 50) and also as a little finger rest. Petrie called this type of razor the (horizontal) rotating razor (Fig. 4c). The rotating strip metal razor resembled the later splayed symmetrical razor and proceeded to evolve throughout the New Kingdom, with small varieties becoming more popular. Eventually the symmetrical razor evolved into a vertical rotating form, with its cutting edge splaying out even more to form a half-moon arc (Fig. 4d). By the end of the New Kingdom (ca. 1069 BCE), the rotating razor had superseded the scraping form. From the Middle Kingdom the handles of the scraping form were made in increasingly ornate forms, and by the New Kingdom the handles displayed zoomorphic designs and representations of deities of love and birth such as Bes and Taweret.

The Razor-Usage

The early razors were all of the scraping variety and were used with the hand grasping the handle or the end of the cutting edge (which was either on the inferior or lateral aspect of the tool). The development of the strip and rotating razor saw a technical change: the razor was grasped in the middle of the blade (by the handle or the blade itself) and rotated around the grip in a sawing motion, pushing the cutting edge through the hair. Epigraphic evidence and razor morphology suggest that the stylist would shave off the bulk (or all) of the hair using the large rotating razor and would possibly even style the hair/wig with it as well. The small razor was probably for personal use, and for the precision cutting of the intricate areas of the head and body that the larger razor could not safely reach. The inclusion of both types of razor in the toilette sets of the New Kingdom – such as those of Tutankhamun



Hairstyling Technology and Techniques Used in Ancient Egypt, Fig. 4 Examples of the various types of razors: (a) Spatula razor, symmetrical, parallel sides and ivory handle (UC 40660) – scraping type, Old Kingdom; (b) Protruding or axe-shape razor (UC 40539) – scraping type, Middle Kingdom; (c)

Horizontal rotating razor (UC 38368), New Kingdom; (d) Vertical rotating razor (UC 30134) with the God Bes for the handle, New Kingdom; (e) Looped strip metal rotating razor with goose head as handle (UC 40657), New Kingdom (Photos by author copyright Petrie Museum of Archaeology, University College London)

(Davies, 1977) and Kha and Merit (Schiaparelli, 1927) – seem to support the differing functions of the *mh'k* and *dg3* razors (Davies).

Razors were sharpened on a whetstone made of tapered grained crystalline stone, (i.e. quartzite, diorite, basalt or even hard sandstone) using water and/or oil as a lubricant. To stop the razor becoming blunt too quickly, it could be kept in a wooden razor case inside a leather pouch or case.

The Composite Tool (Curling-Tongs) and Tweezers

Other types of tools were available for the removal of unwanted hair, including tweezers and the

composite tool. Tweezers are known from Dynasty I (ca. 3050 BCE) onwards; they had either pointed or squared ends, and varied in length from 2 to 10 cm, depending on the part of the body they were to be used on. The tweezers are made of a single piece of copper, bronze, iron or – more rarely – gold. The shape of the tweezers varied from triangular with sharp ends to more ornate varieties with paddle-like ends (Petrie, 1917). These tweezers were easily bent out of shape, so were often set around a tapered bone, ivory, stone or wooden block that was shaped to fit the interior of the tweezers and thus prevent them from being misshapen (Fig. 5a). Tweezers would be used to

Hairstyling Technology and Techniques Used in Ancient Egypt,

Fig. 5 Tweezers: (a)

Large pair of tweezers with a wooden block to keep its form (UC 40666), Middle Kingdom; (b) Small pointed tweezers for more delicate work (UC 40655), Early Dynastic Period (Photos by author copyright Petrie Museum of Archaeology, University College London)



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remove any hairs not completely shaved off by the razor and to shape the eyebrows.

The most peculiar tool used by the Egyptian hairstylist was the composite tool or curling tongs, consisting of two metal (bronze) elements pegged together with a pin. One element is a trough-shaped piece of metal pointed at both ends, while the other element has a flat knife-like blade at one end and a cylindrical point at the other (the latter was sometimes omitted and replaced by a zoomorphic figure – Petrie, 1917). The knife-like blade fit neatly into the other section, and could thus be used like scissors, while the other ends acted like tongs (Fig. 6a). As well as curling tongs, these instruments could also be used as a razor or as scissors, for cutting off any stray ends. These composite tools are found from Dynasty IV onwards and vary in size from about 5 to 20 cm in length, with various circumferences for giving different-sized curls. They were not as effective as scissors – which are not found until the Roman Period – because the cutting edges were not sharp enough and do not meet precisely enough for this purpose. As Petrie (1917, p. 49) notes, the knife-like blade was the least important part of the tool, as it is diminished or is entirely absent in some later forms, being replaced by

figures of a running jackal, galloping horse, running leopard, a pelican, or crane (with the hinged opening representing the jaws) or the Goddess Taweret (Fig. 6b). Some rather large knife-like blade types are found in Dynasty XVIII, and were used as curling tongs. The technique involved heating the tool over an open fire or brazier in order to set the curl, but this must have been tempered by a hot plate or boiling water – to avoid burning the hair – as the tongs show no sign of having been exposed to open flames. Some of these tools may have been set in wooden handles, as suggested by a gift list in the Amarna Letters, which states, ‘29 spatulas of silver with handles of boxwood and ebony with which one curls the hair’ (Kozloff & Bryan, 1992, p. 428). Another indication that these tools were indeed used to curl hair is an example in the Manchester Museum which still has a curl of hair attached to it.

Combs and Hairpins

Pins and combs were used to keep the hair in place whilst it was being dressed, cut or styled, and for decorating it afterwards. These implements have their origins in the Predynastic but seem to have become very popular throughout the Pharaonic Period, where numerous combs and

Hairstyling Technology and Techniques Used in Ancient Egypt,

Fig. 6 New Kingdom composite tools from the Petrie Museum of Archaeology: (a) Large, plain composite tool (UC 40664); (b) Panther and lotus blossom decorated medium sized composite tool (UC 30134) (Photographs by author copyright Petrie Museum of Archaeology, University College London)



hairpins have been found in association with other beauty (cosmetic) equipment in houses and tombs throughout the country. The majority of well-provenanced combs are dated to the Ramesside Period (1295–1069 BCE) (Kozloff & Bryan, 1992, p. 360).

The ancient Egyptian word for comb was originally *nšī*, but this changed in the New Kingdom, where the “n” was replaced by a “p” to give *pšī* or “divider” (Janssen, 1975, pp. 178–9). Combs were usually made of wood, ivory or bone. The choice of material and design suggest that they were designed to bend slightly in order to avoid splitting, some incorporating a long handle and a tapering effect from the top of the handle down to the tip of the teeth. Predynastic combs tended to be fairly ornate in design, and were sometimes made in two pieces and with large grip handles (Fig. 7a, b). The handles were often elaborately decorated and could constitute up to $\frac{3}{4}$ of the comb’s total length, while the teeth lengths and widths were also highly variable. One comb with extremely long teeth of Naqada I date (3900–3700 BCE) is now in the Bolton Museum, No. 76.09.5 (Adams, 1988). However,

predynastic combs with very narrow handles and short teeth have also been discovered (Petrie, 1896). Pin-tail combs first appear in the Naqada I Period, and consist of a square comb (usually of wood or ivory) with a long, thin “tail” protruding from the middle of the comb’s body (Fig. 7d). This type of comb could be used as decoration in the hair with the teeth keeping it in place or to style the hair, the tail being used to tuck in the hair tips and arrange the hair, to select sections of hair to be styled or even for scratching the scalp.

Bird designs were by far the most popular motif in the Early Predynastic Period: a particularly fine example of an ivory comb with a double bird emblem is now in the British Museum, EA 18666. Spade and wild animal motifs were also present in the Naqada I Period; two ivory examples can be seen in the British Museum (EA 63075 – spade, and EA 63406, ibex). Anthropomorphic, zoomorphic and animal-headed designs including cow (probably the Goddess Bat or Hathor) headed designs increased in popularity during the Late Predynastic, although all designs were present throughout



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Hairstyling Technology and Techniques Used in Ancient Egypt, Fig. 7 A variety of combs: (a) Predynastic ibex comb (JE29805 and JE52861), Cairo Museum; (b) Predynastic combs in the Ashmolean Museum, Oxford; (c) King Djet's comb (JE47176), Cairo Museum; (d) Predynastic (Naqada II) pintail comb

from Naqada/Ballas, Petrie Museum; (e) Roman denitting comb (UC58604), Petrie Museum (All photos by the author except C, which is courtesy Joris van Wetering, objects D and E copyright Petrie Museum of Archaeology, University College London)

Hairstyling Technology and Techniques Used in Ancient Egypt, Fig. 8 A variety of different hairpins in the Cairo Museum, Predynastic Period (Photo by author copyright Egyptian Museum of Antiquities, Cairo)



the period (Adams, 1988; Garetto, 1955). Early Dynastic combs tend to be shorter with the teeth cut more closely together, some as close as 2 mm (Garetto), although some large ornate examples can still be found. One of the finest examples of such a comb (assigned to King Djef) has a very large handle, a centrally positioned niche palace facade *serekh*, with two *was*-sceptres and an *ankh* on the sides (Fig. 7c). The teeth of the comb are fairly fine and not very long in comparison with the handle (Emery, 1961; Garetto, 1955).

Old and Middle Kingdom combs were simplified, with the handle becoming thinner and the teeth relatively longer, more similar to modern combs except for the highly ornate decoration with semi-precious stones or faience beads (Fletcher, 1995, p. 441; Garetto, 1955). From the New Kingdom onwards, comb designs became increasingly variable, generally becoming more ornate and with more stylistic categories. The comb's teeth start to vary in length, width and spacing, reflecting the fact that they were designed to serve different purposes rather than the all-purpose combs of earlier eras. The combs with short, closely spaced teeth would have been used for denitting and grooming. The combs with long, widely spaced teeth were primarily designed to be worn in the hair (as reflected in their usually high level of

decoration) once it was dressed, or for detangling the hair. The intermediate form (medium length, intermediately-spaced teeth) would have been used to comb the hair into style. A fine wooden example with incised lotus petals on the handle, originally with blue paste filling the spaces, was found at Abusir el-Malek. Measuring 17 cm long by 5 cm high, this comb is dated to Dynasty XVIII, JE 36233 – CG 44316 (Freed, 1987, p. 182). Other examples of these simple combs were found in the tomb of Kha. The two small combs belonging to his wife Merit were 7.5 × 4 cm and were undecorated, except for a slight trace of gilding (Garetto). Rectangular double-sided combs without any handle also appeared in the New Kingdom and were usually designed to be multifunctional with closely spaced teeth on one side and widely-spaced teeth on the other (Fig. 7e). Pintail combs also reoccur in the New Kingdom.

Hairpins or bodkins were usually made from ivory or wood and measured between 10 and 16 cm. They derived their Egyptian name (*3b*) from the term for ivory *3bw*, although they were also made of copper, bronze, bone, or sometimes tipped with gold or other precious metals. Predynastic and Early Dynastic hairpins were often ornately decorated with zoomorphic or anthropomorphic figures and geometric designs (Fig. 8). The Old Kingdom and Middle Kingdom

Hairstyling Technology and Techniques Used in Ancient Egypt, Table 1 Egyptian chronology

Date	Period	Culture/dynasties
7000 BCE	Epi-Palaeolithic (7200–6000 BCE)	Qarunian
6000 BCE		
5000 BCE	Neolithic (5200–4000 BCE)	Merimidian, Faiyumian, Badarian, Omarian
4000 BCE	Predynastic (4000–3050 BCE)	Maadian, Naqada I–III
3000 BCE	Early Dynastic (3050–2613 BCE)	Dynasties I–III
	Old Kingdom (2613–2181 BCE)	Dynasties IV–VI
	First Intermediate (2181–2040 BCE)	Dynasties VII–X
2000 BCE	Middle Kingdom (2040–1650 BCE)	Dynasties XI–XIII
	Second Intermediate (1650–1550 BCE)	Dynasties XIV–XVII
	New Kingdom (1550–1069 BCE)	Dynasties XVIII–XX
1000 BCE	Third Intermediate (1069–664 BCE)	Dynasties XXI–XXV
	Late Period (664–332 BCE)	Dynasties XXVI–XXX
500 BCE	Ptolemaic (332–30 BCE)	Ptolemaic Dynasty
	Roman (30 BCE–AD 306)	Roman Emperors
AD 500	Late Antique (AD 306–AD868)	AD641 Islamic Conquest
	Middle Islamic (AD869–1250)	
	Mameluk (AD1250–1517)	
	Ottoman (AD1517–1798)	

hairpins tend to be less ornate, with a simple engraved top, minimal (or absent) incised decoration and a bulbous or pommel head. While plain pins were used throughout Egyptian history, the range of new designs and decorations in New Kingdom pins is marked. Made from a range of materials including gold (both leaf and solid), elite versions were often decorated with zoomorphic or anthropomorphic designs. Precious metal examples include several gold hairpins that were found in Kha’s tomb (Schiaparelli, 1927), while a fine example of a well-executed zoomorphic design in ivory is that of a hairpin head upon which an ibex turns her head with affection to observe her suckling calf. The recurring image of the ibex (i.e., the comb mentioned above) reflects the importance of Hathor to rituals of beauty and the artefacts related to those rituals. This fine hairpin is 9.5 cm long and is exhibited in the Boston Museum of Fine Arts (Freed, 1981).

The hairpins were used both to dress (keeping locks in place) and to decorate (after dressing) the hair. Depictions of hairpins in use are again rather limited, although more numerous than those depicting combs. One of the finest examples is the Middle Kingdom hairdressing scene where Queen Neferu’s maidservant Henut has pinned

the top section of her mistress’s hair out the way with an ivory bodkin whilst weaving a braid into the hair (Riefstahl, 1956, p. IX).

By the middle of the Old Kingdom, the increasing availability of copper tools meant that ancient Egyptian hairstylists were able to cut, curl, tint, set, and plait the hair in numerous ways. As technology and alchemy progressed and the Egyptian empire expanded in the New Kingdom, hairstylists developed new styles as well as various ways to perfume and dress the hair fostered by emulation and increasing social complexity (Table 1).

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Hardaliye

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Hardaliye, a traditional beverage produced by fermentation using lactic acid bacteria, is manufactured from red grape or grape juice added with crushed mustard seeds and preserved with benzoic acid (Figs. 1 and 2). It is a popular beverage especially in the Thrace region of Turkey. It is produced by red scented grapes such as ripe Hamburg Misketi or Madam Mathies. Production of that drink begins when the grape harvest starts in October or November. After the grapes are washed and pressed, put preferably into wooden (or plastic) barrels with a tap over 10 cm from the bottom, then 0.2 % of crushed raw mustard seeds and 0.1 % of benzoic acid are added. In order to enhance the aroma, crushed cherry leaves can be mixed with black mustard seeds. Since grapes are fermented with their skins, there are transitions of some particles from the skins to the drink during production. There should be some space left in the fermentation barrel considering the swell. The lid of the barrel should be half-open. After fermentation starts, the juice is recirculated twice every other day; then the mix is left to ferment at room temperature for 7–10 days. If the ambient temperature is low, the fermentation process can be



Hardaliye, Fig. 1 Hardaliye produced from red grapes

extended up to 20 days. After fermentation is done, the juice is filtered and bottled. Once fermented, the hardaliye is stored at 4 °C for 3–4 months (Arici & Coskun, 2001; Coskun ve Arici, 2006). The hardaliye is consumed either fresh or aged. If it is aged, hardaliye may contain alcohol.

The mustard seeds' etheric oils affect the yeasts (Akgul, 1993). Due to the contribution of black mustard seeds to both taste and aroma of hardaliye and their superior inhibitory effect, black mustard seeds (*Brassica nigra* (L.) Koch) may be more suitable for the production of hardaliye. White mustard seeds (*Brassica alba* (L.) Boiss) can be also used in this process. The active ingredient of the volatile oil is allyl isothiocyanate. Black mustard essential oil includes ratio of 0.40 :1.80 % allyl isothiocyanate. White mustard seed contains very little volatile oil. Benzoic acid inhibits or decreases alcohol production by affecting the yeast (Jay, 1992, Krämer, 1992).



Hardaliye, Fig. 2 Hardaliye produced from White grapes

The Importance of Hardaliye and Studies on Hardaliye

Fermented foods are important components of daily diets in many parts of the world. Microorganisms (bacteria, molds, and yeasts) play an important role in the fermentation processes. Final products have often undergone considerable changes. These changes are not only because of microbial action but also because of the autolytic process that is brought about by the enzymes which exist in the products. Therefore, fermentation serves the purpose of preparing a fully acceptable, palatable, safe, and mostly very nutritious food at a relatively low cost (Hesseltine, 1979, 1981; Hesseltine & Wang, 1979; van Veen & Steinkraus, 1970; Wang & Hesseltine, 1981). Many fermentation processes are carried out by lactic acid bacteria (LAB) which inhibit

many other microorganisms when they are cultured together. This is the basis of the extended shelf life and improved microbiological safety of lactic-fermented foods (Jay, 1992). In some Middle Eastern countries, lactic acid-fermented fruits and fruit juices such as lactic acid-fermented grape juice, fermented cherry, and medlar are common drinks (Aktan, Kalkan, & Yucel, 1999).

The nutritional value of hardaliye is derived from the grapes and the fermentation process. After fermentation the vitamin content of some fermented foods increases. These types of foods are important in terms of nutrition. Fermented foods formed by the lactic acid bacteria have negative effects on the cholesterol formation mechanism that is one of the biggest causes of heart disease. Lactic acid bacteria have a positive effect on the immune system. Lactic acid bacteria support immunoglobulin A and gamma interferon production. This enhances the antitumor activity of lactic acid bacteria. The lactic acid bacteria taken to the digestive tract together with fermented food reduces the activity of enzymes such as the β -glucuronidase, azotoreduktaz, and nitroreductase in the intestine. Pro-carcinogenic substances are converted to carcinogens with the help of these enzymes (Turantas, 1998). Grapes are rich in phenolic contents. One kilogram of grapes contains 12–15-mg quercetin, less than 2-mg kaempferol, 4.5-mg myricetin, 19-mg catechins, and 1–3-mg coumaric acid (Shahidi & Nacz, 1995). Antioxidant flavonoids such as quercetin reduce the oxidation of low density lipoproteins and cell toxication (Luzia, da Paixão, Marcilio, Trugo, Quinteiro, & de Maria, 1997). Flavonoids are anticancer radicals. They stop the process of cell division. Flavonoids prevent heart attacks by preventing formation causing damage to blood vessels (Anonymous, 1988). Grapes contain resveratrol that has antioxidant properties. In a study, resveratrol reduced skin tumors in mice by 88 % (Geoffrey et al., 1988). Dark red grape juice contains about four times more antioxidants than orange and tomato juices (Carper, 1999).

Studies on hardaliye are under way. The pH of hardaliye is approximately 4.5 at the end of fermentation. *Lactobacillus plantarum* is the dominant species in the microbiota (Arici, Coskun, Celikyurt, Mirik, Gulcu, & Tokatli, 2012). Possible probiotic lactic acid bacteria are used in the production of hardaliye, so it makes the drink a more valuable functional product. Pasteurization might be considered for longer shelf life. For a long shelf life and standard product, studies should be done on starter cultures. Selection of starter culture, pasteurization norms, storage conditions, and time created a new process. In a study, changes in hardaliye samples were examined after storage for 1 year. Decrease in pH, Brix, total phenolic, monomeric anthocyanins, and number of microorganisms and an increase in acidity and levels of invert sugar of samples were observed (Coskun, Arıcı, Celikyurt, & Gülcü, 2012).

Conclusion

Hardaliye is produced in a limited number of provinces and manufactured with nonstandard methods. A standard method should be determined to increase the shelf life of this product that is valuable due to its probiotic properties. There should be more research about this nutritious traditional drink in order to produce it industrially. By using standard culture it is possible to have a standard product. Therefore, hardaliye produced with traditional methods at home, which is very healthy and nutritious and has a relatively short shelf life (3 months), can be industrialized and its shelf life can be extended. The development, increase, and diversity of technological production are possible with the development of traditional methods by the help of scientific research. It is important that the best grape type, the type of the starter culture, and the process parameters should be determined in order to have a desired standard product. If small-scale producers succeed in the production with a starter culture, it might be adapted to large-scale production.

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Haridatta

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Haridatta was an astronomer who introduced the Parahita system that was popular for a long time in astronomy in Kerala and Tamil Nadu. He expounded this system in two of his works, the *Grahacāranibandhana* and the *Mahāmārganibandhana*, of which only the former is extant. There is no positive information about his date or provenance. A late tradition claims that the Parahita system was promulgated in the year 683 CE during the twelve-year *māmāṅkaṁ* (*mahāmāgha*) festival held at Tirunāvāya on the banks of Bhāratappuḷa in Kerala. This is unlikely, as there is no historical evidence for *māmāṅkaṁ* celebrations before the fourteenth century. It may, however, be tentatively accepted that he came from Kerala or Tamil Nadu, as the Parahita system is not known to have existed in any other parts of India. We may also agree with David Pingree that “683 is not an unreasonable date for Haridatta” as he is already cited by Govindasvāmi’s *Prakaṭārthadīpikā* in the ninth century.

Haridatta was trained in the Āryabhaṭa school of astronomy, in which methods of computation were complicated. The Parahita was an attempt to simplify the calculations in the *Āryabhaṭiya* for the benefit (*hita*) of everyone (*para*). The first known use of the *kaṭapayādi* notation is also found in his work. This system, devised to facilitate easier memorization, consists of notations in which numbers are replaced by alphabets in the reverse order. Consider the expression *gorasaṁ rasavārya*. It contains seven syllables, the numbers assigned to them being 3, 2, 7, 2, 7, 4, and 1 respectively. In the reverse order, it produces

the number 1,472,723. Similarly, the four syllables of *girituṅga* yield 3, 2, 6, and 3, which represents the Kali year 3623. It is not unlikely that *kaṭapayādi* was a brainchild of Haridatta's.

Astronomic calculations in India often involved identifying the number of days that have elapsed since the beginning of the Kaliyuga or the Mahāyuga (which is the four yugas put together). This made computation lengthy and cumbersome, as it involved multiplication and division of numbers that were seven to ten digits long. Haridatta overcame this difficulty by introducing a shorter yuga of 576 years (or 210389 days, conveniently remembered by the *kaṭapayādi* notation, *dhījagannūpura*) to substitute for the longer figures. He also made zero corrections in relation to the mean motion of the sun, the moon, and five planets. The choice of 576 seems to have been guided by considerations that are not fully clear to us. The length of the Kaliyuga, Dvāparayuga, Tretāyuga, and Kṛtayuga (or Satyayuga) are 432,000 years, 864,000 years, 1,296,000 years, and 1,728,000 years, respectively, and that of the Mahāyuga, 4,320,000 years. Haridatta's sub yuga is 1/750th, 1/1500th, 1/2250th, 1/3000th, and 1/7500th of these yugas, in that order.

In spite of introducing the sub yuga in which the number of days did not exceed *dhījagannūpura*, the use of lengthier numbers remained an invariable part of computations. One of the computations involved dividing the number of days elapsed in the Kaliyuga by the number of days elapsed in the sub yuga. The quotient indicated the number of sub yugas elapsed, and the remainder, the number of days remaining in the current sub yuga. Haridatta's zero corrections for different planets, when multiplied by the quotient, gave the mean for the respective planets at the beginning of the sub yuga. A further step toward simplifying computations involved the use of units equivalent to six sub yugas where longer time periods were involved.

A major intervention of Haridatta's was the *Śakābdha saṃskāra*, or corrections to the positions, both mean and real, of the planets. He also introduced corrections to the calculation of their

velocities. The zero year for this correction was 523 CE, indicated by the *kaṭapayādi* notation *vāgbhāva* or *vibhava* (deciphered as year 444 in the Śaka Era, and hence the name *Śakābdha saṃskāra*). Haridatta suggested that a correction had to be introduced for every year after the zero year for the mean position of the planets. These corrections yielded figures that were closer to the real values obtained through modern methods, as can be seen from the following table (based on K. Chandra Hari) which shows the mean longitudes at sunrise in Ujjain on Friday, 25 March 931 CE.

Planet	Mean according to Āryabhaṭa's constants	Mean according to Haridatta's corrections	Mean according to modern methods
Sun	00°00 ¹	06°49 ¹	06°42'27 ¹¹
Moon	40°54 ¹	46°58'11 ¹¹	46°54'16 ¹¹
Node of Moon	267°56 ¹	277°31'25 ¹¹	278°07'16 ¹¹
Apogee of Moon	311°35 ¹	335°06'54 ¹¹	335°06'26 ¹¹
Mercury	78°43 ¹	87°44'19 ¹¹	86°27'30 ¹¹
Venus	82°22 ¹	84°44'49 ¹¹	85°09'44 ¹¹
Mars	252°52 ¹	260°59'10 ¹¹	260°56'17 ¹¹
Jupiter	339°16 ¹	344°43'02 ¹¹	344°15'58 ¹¹
Saturn	285°30 ¹	292°54 ¹	294°00'51 ¹¹

Also see Astronomy in India, Āryabhaṭa, Yugas

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Hasdai Crescas

Tony Lévy

Hasdai ben Abraham Crescas (1340–1412) was one of the most influential personalities of Spanish Jewry in the end of the fourteenth century. As chief rabbi of the Aragonian Jewish communities during the persecutions of 1391, he was responsible for their reconstruction. Although his literary work was not very large, it constitutes an important contribution to the history of philosophical and scientific ideas, mainly as a critique of medieval Aristotelianism.

Under the influence of Maimonides' *Guide for the Perplexed* (translated from Arabic into Hebrew in the beginning of the thirteenth century), Aristotelianism had spread in Jewish circles, raising many controversies. Besides those who opposed the study of philosophy only on the ground that it undermined religious beliefs, others invoked scientific and philosophic arguments to give support to their own critique of philosophy. Crescas is certainly the most important of the latter critics.

Apart from a short composition, *Biṭṭul 'Iqqarey ha-Noṣrim* (Refutation of the Principles of Christianity), Crescas' main work is his *Or Adonay* (Light of the Lord) completed in the last years of his life. In the first part of this book the fundamental concepts of Aristotle's physics and metaphysics, as adapted by Jewish philosophers, were analyzed and criticized.

Crescas' main purpose was to establish that the existence of God, His unity and His incorporeality could not be fully proved by demonstrative reasoning, as Maimonides had argued: "it is impossible to arrive at a perfect understanding of these principles except by way of prophecy, . . . , and yet it will be shown that reason agrees with the teachings thus arrived at." In this sense, one could say that Crescas did not criticize philosophy as such, but rather the intellectualization of religion by Aristotelian scholastics. Actually, in many respects,

Crescas opposed to Aristotelian philosophical notions other philosophical notions, more relevant – according to him – to the purposes of philosophy itself.

The main importance of Crescas' contribution lies in his critique of Aristotle's concept of the infinite, and its applications to the notions of space, number and time.

There are three main conclusions of Crescas' analysis which are relevant to history of science. The first is in opposition to Aristotle who had argued that the place of a body (i.e., space) was the inner limit of the enclosing body, Crescas asserted that space was prior to bodies and that the place of a body was equivalent to its extension. Thus the existence of a void was not self-contradictory. Secondly, again in opposition to Aristotle who had argued that the universe was finite, because nothing could be infinite, neither a body nor a substance, Crescas claimed that there was no absolute limit to space. Space was an infinite receptacle, which could contain many other worlds. By analogy, space could be thought of as God's omnipresence. Finally, Aristotle and Aristotelians argued that an infinite quantity was impossible, because it would lead to the absurd conclusion of one infinite quantity being greater than another. Crescas' reply was of importance since it could be viewed as anticipating some modern concepts: the relations "equal to," "greater than," and "smaller than" do not apply to the infinite, in the same manner that they apply to finite quantities. Thus, the notion of an actual infinity is not self-contradictory.

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Hay'a

F. Jamil Ragep

The Arabic term *hay'a* had several distinct significations when used in the medieval astronomical context. Its basic meaning is “structure” or “configuration”; it was used as such to connote the physical structure of the universe as a whole (*hay'at al-'ālam*) or a distinct part of that structure, as in the *hay'a* of the Earth or of Venus. It also referred to those works of theoretical astronomy in which that structure is dealt with in detail. As part of the phrase *'ilm al-hay'a* (the science of *hay'a*), it came to refer, especially after the eleventh century, to astronomy in a general sense. This is an indication of the importance given to physical cosmography in Islamic astronomy. Here the main focus will be on *hay'a* in the sense of the Islamic astronomical genre devoted to cosmography.

Before proceeding, it is important to note two points. Although the term *hay'a* was occasionally used to indicate a religious cosmology, works on *hay'a* are mainly cosmological in the scientific and not the religious sense. Second, this tradition, though departing from it in numerous ways, owes its origins and inspiration to the Hellenistic scientific tradition.

The main ancient sources for the Islamic *hay'a* tradition were the cosmological writings of Aristotle, in particular his *De Caelo* and his attempt in the *Metaphysics* to give a coherent structure to the models of Eudoxus, and the astronomical writings of Ptolemy, especially his *Planetary Hypotheses*. These works provided the fundamental assumption of Islamic theoretical astronomy, namely that the subject matter of astronomy was the simple *physical* bodies, both celestial and sublunar. An astronomer writing in the *hay'a* tradition was charged with transforming mathematical models of celestial motion, usually those of Ptolemy's *Almagest*, into physical bodies that could be nested, along with the sublunar levels of the four elements, into a coherent cosmography (*hay'a*). Despite the obvious connection and dependence on Greek natural philosophy, this “astronomical” (or external) cosmology was often contrasted with both the tradition of Aristotle's *De Caelo* and the astrological corpus, both of which were held to deal with the essential (or internal) aspects of the bodies. Note that because *hay'a* was intended to give a general picture of the universe, it also dealt with the “configuration” of the four sublunar elements. Thus most general treatments of astronomy after the eleventh century came to have a section on the “configuration of the Earth” that included general discussions of geography.

The prevalent *hay'a* was that the universe was a plenum composed of nine contiguous, solid, spherical bodies called orbs, all concentric with an immobile, spherical Earth. The lowest of these, that of the moon, enclosed the four sublunar levels of the four elements: fire, air, water, and earth. Each of the “concentrics” had embedded within it additional, nonconcentric, spherical orbs called eccentrics and epicycles, the former hollowed-out spheres surrounding the Earth, the latter full spheres within the eccentrics. There was one concentric each for the seven “planets” in the following order – moon, Mercury, Venus, sun, Mars, Jupiter, Saturn – another for the fixed stars, and a starless ninth that was the source of the daily motion. Except for the sun, which was embedded within an eccentric, the planets were

situated on the inside surface of their epicycles. Opinions varied as to how motion occurred but generally this was held to result from a combination of the proper motion effected by the orb's own soul and the accidental motion that was a consequence of being contained inside other orbs. All the celestial orbs were composed of a special fifth element called "aether," unlike the four sublunar elements, it could only rotate with uniform motion. Among the most famous and influential works on *hay'a* were the *Hay'at al-ʿālam* (Configuration of the World) by Ibn al-Haytham (d. ca. 1040), the *Tadhkira fī ʿilm al-hay'a* (Memoir on Astronomy) by Naṣīr al-Dīn al-ṭūsī (d. 1274), and *Al-mulakhkhas fī al-hay'a al-basīṭa* (Epitome of Plain *hay'a*) by al-Jaghmnī (thirteenth or fourteenth century).

Although the above cosmography derived for the most part from Ptolemy's *Planetary Hypotheses*, Islamic theoreticians found much to complain about and proposed numerous alternatives that were meant to reform or supersede his models. In his *Doubts About Ptolemy*, Ibn al-Haytham pointed to certain devices that Ptolemy had introduced in the *Almagest*, such as the equant, that violated the principle of uniform circular motion; as such, it was not possible to physicalize such models in any straightforward way. In the thirteenth century, a number of writers, beginning with Naṣīr al-Dīn al-ṭūsī, who was the first director of the Mongol-sponsored Marāgha observatory, proposed alternative models that were meant to reform the Ptolemaic system. These efforts continued for at least three more centuries and included the work of his colleague Mu'ayyad al-Dīn al-ʿUrḍī, his student Quṭb al-Dīn ► [Al-Shīrāzī](#), Ibn al-Shāṭir, the timekeeper of the Umayyad Mosque in Damascus during the fourteenth century who proposed an astronomy without eccentrics, and a number of people associated with the Samarqand observatory in the fifteenth century.

A much more radical attempt to transform the Ptolemaic system occurred in twelfth-century Islamic Spain. A number of Aristotelians, including the famous philosopher Averroes (Ibn

Rushd), sought a radical reform of Ptolemaic astronomy that would rid it of epicycles and eccentrics altogether. The motivation was to return to a purer astronomy in which there was only a single center of celestial motion. The end product of this movement was the work of ► [al-Bīṭrūjī](#). His system, reminiscent of that of Eudoxus, was not very successful from a mathematical point of view, but it was quite influential in the Latin West.

This was not the only case in which Islamic *hay'a* influenced science in other cultures. Byzantine astronomers were certainly aware of this tradition; we also know of several *hay'a* works that were translated into Sanskrit in the eighteenth century. Given that the *Planetary Hypotheses* was unknown during the Latin Middle Ages, it is clear that the main source for the European *theorica* tradition was Islamic *hay'a*; Ibn al-Haytham's *Configuration of the World* was certainly quite influential. In recent years, very strong similarities between the models and motivations of several Renaissance astronomers (including Copernicus) and the late *hay'a* tradition have been discovered, and it now seems quite likely that the former were influenced by Ṭūsī, Ibn al-Shāṭir, and other post twelfth-century writers on *hay'a*. However, because their works seem not to have been translated into Latin, the most likely means of transmission is through Byzantine sources that made their way to Italy (and perhaps Vienna) in the fifteenth century.

See Also

- [Al-ʿUrḍī](#)
- [al-Bīṭrūjī](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Astronomy in the Islamic World](#)
- [Geography in the Islamic World](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn al-Shāṭir](#)
- [Marāgha](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)

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- March 8, 1756. His family were merchants and managed the Shichiya (bank) at Osaka.
- In 1795, the Shogun government planned to make a new calendar using Western astronomy. The former calendar, the Horeki calendar (1754), was a quite traditional Eastern Asian calendar, although Shogun Tokugawa Yoshimune (1684–1751, eighth Shogun, r. 1716–1745) wanted to use Western science. But there were no astronomers who had mastered Western astronomy in the Bakufu Tenmongata (Shogun's Astronomical Observatory). They asked ▶ Asada Goryu (1737–1799) to make a new calendar. However, Asada was already over 60 years old, so he recommended two students, Takahashi Yoshitoki (1764–1804) and Hazama Shigetomi.
- Takahashi was a *Doshin* (police officer) and a Samurai warrior. As Hazama was a merchant, Takahashi did the main work, and Hazama supported him financially. They worked in the Bakufu Tenmongata at Asakusa, Edo. Then Takahashi went to Kyoto to observe in 1796, and Hazama remained at Edo. They wrote the *Rekiho Shinsho* based on Kegler's (Part 2 of) *Li Suan Quan Shu* (1742, China, the same name as Mei's book) in 1797. They began using the Kansei calendar the next year.

Hazama Shigetomi

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Hazama was a Japanese mathematician and astronomer in the Edo era. He was born at Osaka, the sixth son of Toichiya Gorobei, on



Hazama Shigetomi, Fig. 1 Hazama Shigetomi's picture at the Osaka Museum of history

Hazama Shigetomi,**Fig. 2** Hazama

Shigetomi's tomb at the Tokoku-ji temple, Chausuyama, Tennoji, Osaka



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There were two original points in this calendar. (1) They observed the position of the sun from its under edge when they observed the solar eclipse. (2) They defined the twilight, saying that it was two and half *Koku* (1 day was 100 *Koku* at that time) before the sunrise and sunset on the Spring and Autumn Equinox Day in Kyoto.

Hazama also promoted the engineering of astronomical tools.

He died on March 24, 1816 in Osaka (Figs. 1 and 2). (Nihon Gakushiinn (1960, p. 211) describes that he died in 1838, but we obey Nihon Gakushiinn (1954, Vol. 4, p. 141), that is to say, in 1816.)

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Darshan Shankar and Padma Venkat

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The healthcare scenario in urban India and globally is undergoing dramatic transformation, evolving into systems that emphasizes preventive health, customized care, body-mind medicine and the use of natural products. It is in this context that there has been in recent decades a resurgence of interest in the traditional Indian systems of medicine (ISM). The ISMs are based on the use of natural products. They view the human being and other life forms holistically in terms of both body and mind. They assess the uniqueness (*prakṛti*) of each individual and their universal principles can be tailored to the needs of every individual.

The transformation that is taking place in the healthcare scenario is reflected in the marketplace. The global market for herbal products is booming. The *Task Force Report of the Indian Planning Commission on Conservation and Sustainable Use of Medicinal Plants* (2000) estimated it to be about 62 billion per annum and rising at the rate of 15 % per annum. A large percentage of the population in Asia, Africa and South and Central America also depend on traditional knowledge and medicinal plants for their primary health care needs (WHO, 1993). This dependence is likely to continue, as rising costs of conventional healthcare make the traditional plant-based solutions the most viable, safe and affordable option.

Observers of the health sector believe that any societal model of healthcare based on a single system of medicine will soon become obsolete unless it broadens out to combine with complementary systems of medicine. The world's oldest codified and living systems of healthcare are Āyurveda, of Indian origin, and Traditional Chinese Medicine.

It is in the context of this growing consumption of traditional products that questions regarding quality standards have become a matter of concern to policy makers, consumers and to the regulatory authorities. Due to the difference in epistemologies, centuries of clinical evidence and practical methods for quality assurance that are available in the traditional ISM cannot automatically be transferred onto the parameters of western biomedicine, and such translations need to be supported by serious inter-cultural research and epistemologically sensitive methodology. An inter-cultural approach is inevitable because most herbal products originate from non-Western health sciences.

The English word "science" refers to a special kind of knowledge, which is clarified through reason and analysis. We find that our unclarified perceptions of the world are often too narrow, and that our assumptions and beliefs are all too often prejudiced. Accordingly, we use our scientific reason in two ways. On the one hand, we can put our narrow perceptions together, thus building them into broader pictures of the world. The world is thus described objectively,

by relating objects in conceptual pictures. Through systematic reasoning, these pictures grow into coherent fields of knowledge. Each field of knowledge has its own consistency, as a conceptual system, and each one has its place among the other fields.

On the other hand, in order to correct mistakes, our scientific reasoning can function in reverse. Instead of building pictures up, it can reflect back down, in order to investigate assumptions and beliefs. This reflective reason is essentially subjective. Its purpose is to educate, by asking questions that correct the questioner's own understanding. In Sanskrit, this corrective education is described by the word *śāstra*. Literally, "śāstra" means "correction" or "governance", but it is often used as a traditional word for science. It thus conceives of science as a correcting governance that is administered reflectively, through inward-turning reason.

These two ways of using reason have a long history of working together, since the beginnings of ancient science. But in the last few centuries, the objective way has prevailed. Unfortunately, the development has been one-sided. Our modern sciences have a tendency to emphasize the objective and calculating use of reason. So there has been a corresponding neglect of subjective education. It could well be argued that our current environmental crisis comes from this neglect of a more deeply reflective education, which is now needed to make better use of our specialized objective capabilities. The neglect has gone so far that the word "subjective" is routinely assumed to mean just "personal", and a subjective use of reason is thus put outside the essential and proper functioning of science.

Since science is essentially concerned with knowledge, it cannot be just personal. The problem is that our personal faculties are partial. They are partial faculties of body, sense and mind, which show us partial and differing appearances. No such appearance is entirely correct. Each bodily or sensual or mental appearance needs correction, to allow for different points of view. Therefore an impersonal standardization is essential to all sciences. But it can be approached in two ways, which are again objective and

subjective. The objective approach is directed externally, by prescribing standard techniques and instruments in the external world. The subjective approach is turned back in, through a reflective investigation of common principles that different people share, beneath the differing phenomena that nature manifests to them.

In the modern physical sciences that have developed in the last few centuries, the standardization is restrictedly objective. It requires that all theories are tested and applied through standardized instruments and machines, which we fabricate and use in the external world. Subjective reflection is specifically confined to the intuitive creation of ideas and theories. Once the theories are created, they must be tested and applied through their calculation of predicted results, which are measured and observed by a mechanical technology.

In older sciences, which have been developing for some thousands of years, more use is made of subjective reason. Here, reason works through education. Ideas are tested and applied in a living process of learning from experience, through common principles that underlie the variations of personality. The older sciences are based upon that inward investigation, towards a depth of knowing which is both subjective and impersonal. That depth of subjectivity is described by the Sanskrit words *ātma* and *ātmīya*.

The word “*ātma*” means “self”. It describes the self as a knowing subject at the inmost depth of personality, beneath the outward appearances of body, sense and mind. The word “*ātmīya*” means “subjective”. It refers to an inmost subjectivity, which is attained by reflecting back within. Here the word “subjective” is not being used to mean just “personal”. The self-called *ātma* is an inner principle of consciousness or spirit, and the word “*ātmīya*” thus means “spiritual”. It refers to a pure spirit that is found by inward detachment from outgoing personality. (The above discussion on science, vijñāna and on objective and subjective standards has borrowed from the unpublished article on Knowledge Before Printing and After of Ananda Wood, an eminent scholar and philosopher of science.)

Health Sciences in India: Traditional Health Sciences and Their Contemporary Application, Table 1 Two different knowledge systems

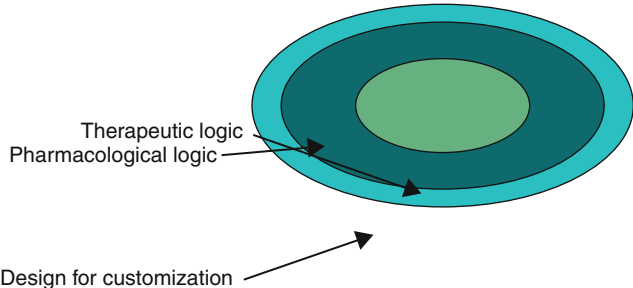
	Āyurveda, Indian health system	Biomedical science
Differing foundation	Based on nine existential entities: Earth (<i>pṛthivī</i>), Water (<i>ap</i>), Fire (<i>agni</i>), Air (<i>vāyu</i>), Space (<i>ākāśa</i>), Mind (<i>manas</i>), Time (<i>kāla</i>), Direction (<i>dik</i>), and the Soul (<i>ātman</i>)	Based on three existential entities: Matter, time and space
Differing worldview	Recognizes physical, biological and spiritual worlds <i>Sāṃkhya</i>	Recognizes physical and biological worlds Logical positivism and later schools
Differing logical system	Nyāya <i>Vaiśeṣika</i>	Aristotelian logic and its evolution
Differing categories	<i>Guṇa</i>	Phyto-chemistry and pharmacology
Differing pathogenesis	Loss of homeostasis	Infection via bacteria, parasite, virus

To place the above discussion in the specific context of healthcare, Table 1 gives a picture of the different epistemological foundations of western biomedicine and Āyurveda. It is important to appreciate these epistemological differences per se and not in terms of which is right or wrong or more superior or less. They represent different ways of knowing and viewing nature.

The traditional Indian systems of healthcare also have their own internal quality standards and logic for drug design and therapeutics. Table 2 illustrates the different logic of drug design and therapeutics used in Āyurveda.

Āyurveda is primarily based on the notion of “homeostasis”. This outlook is different from the theoretical approach of western medicine, which is largely based on disease causation due to infection, structural damages and systemic disorders whose etiology is poorly understood.

Health Sciences in India: Traditional Health Sciences and Their Contemporary Application, Table 2 Logic of Ayurvedic drug design

Logic of Ayurvedic drug design	
	
Therapeutic logic	
To break the chain of pathogenesis of a particular disease	
To alleviate specific symptoms of particular disease	
To block progression of the disease	
To reduce complication or associated diseases	
Pharmacological logic	
To select principal drugs and adjuvants having balanced therapeutic action	
To enhance bioavailability, spread and penetration, through appropriate dosage forms, time of administration, method and route of intake	
To design a combination of ingredients that does not cause unintended side effects	
Design for customization	
Drugs should suit Prakriti (genotype), age, customs, mental poise of the patient	
Drugs should suit local habitat and climate in which the patient resides	
Drugs should suit the digestive capacity (agni) and food habits of the patient	

Source: based on the *Carakasamhitā*

It is Āyurveda’s hypothesis that any disease, whether acute, chronic, degenerative, infectious or functional, occurs only when there is an internal imbalance or loss of equilibrium in the physiological or psychological functions of the body. The Āyurvedic treatments are designed to restore the specific kinds of imbalances caused by a particular disease. They are designed not only to resolve the immediate problem of the patient but also contribute to his/her sustained quality of health (*Āyushyam*). A drug is only one part of treatment. A holistic treatment also includes diet, non-drug therapies (like yoga and pancakarma) and life style changes.

In an emerging era of medical pluralism the project of developing modern inter-cultural standards for quality, safety and efficacy of traditional ISM is not only important for Indians but

also for global consumers. This article outlines the strategy for building upon traditional knowledge to create internationally acceptable modern quality standards.

Do Traditional Quality Standards Really Exist?

Any living, evolving system of traditional medicine which has served society for several millennia – such as we see in Asia, Africa and Latin America – could not have survived without possessing quality standards of its own. In most societies in these regions, health traditions remain undocumented because they are transmitted orally from generation to generation. This oral transmission, despite its remarkable

efficiency, outreach and cost-effectiveness, is poorly understood. There are also codified medical traditions with theory and clinical practice documented in the form of thousands of medical manuscripts in India and China.

In all traditional health cultures, quality standards do exist. They are expressed in the form of descriptions, advice and recommendations for identifying, collecting, processing and therapeutic use of natural products. The criteria for collecting plants, for instance, may include the best season and stage of growth for the plant to be most therapeutically active, and the best regions for gathering them in order to heighten their medicinal potency. There are also standards for storage, post-harvest, processing, and for finished products. Standards also exist for safety and efficacy.

In traditional societies, the health functionaries – the plant collectors, those who store the plants, and the physicians who prepare and administer the medicines – usually belonged to the same community as their customers. In earlier times the knowledge and integrity of the collectors and physicians served as an assurance of high standards. Today, the traditional quality standards can no longer be applied as those involved in preparing the medicines never meet their millions of customers face to face. Moreover, many more people are involved in the production and distribution chain. There is also a problem of soil, water and air pollution that can contaminate the raw materials.

The Inter-cultural Approach to Building Quality Standards

An inter-cultural approach involves the use of the modern scientific tools of physics, chemistry and biology to establish universally verifiable quality standards. The identification of the quality parameters that are to be standardized, however, does necessarily need to be based on the traditional knowledge systems from which the products are originally derived.

The evolution of inter-cultural standards is not an easy task as it assumes cross-cultural understanding and needs to engage experts in traditional knowledge and modern science in a

mutually respectful dialogue. This is not a short-term task; institutions for inter-cultural research need to be created. The starting point for creating quality standards is to establish the identity of the raw materials that go into the making of natural product. To identify the raw material (a plant, for instance), a reliable traditional source – texts as well as traditional knowledge holders – must be consulted. Tradition identifies materials by vernacular names and descriptions. It is necessary to link the vernacular names and descriptions of plants to the appropriate botanical entity. For example *Tulasi* is the vernacular name of a plant which when pointed out to a botanist would be correlated to *Ocimum sanctum*. In the case of certain vernacular names, however one vernacular name may correspond to more than one botanical entity. For example in the case of the plant referred to as *brahmi*, the Āyurvedic texts correlate this name to two distinct botanical entities *Baccoba monneri* (Neer brahmi) and *Centella asiatica* (Mandūkāparni) (Sastri, 1993). Other vernacular names like *pashan bheda* and *śankhapushpī* also have several botanical sources and acceptable regional substitutes, which are different species that possess similar pharmacological activity. There is another kind of complexity connected with vernacular names. This is the problem of synonymy wherein a single traditionally used plant entity may have as many as 70 vernacular synonyms, and one needs the help of traditional scholars to group all the vernacular synonymy that refers to a particular plant. This can be best illustrated by citing the case of a very important Āyurvedic text called the *Carakasamhitā*. In this text there are 12,000 plant names, but after resolving the problem of synonymy, these 12,000 vernacular names refer to only around 620 unique plant entities (Gopal, 2004). These are the kinds of problems that are involved in establishing the botanical identity of a vernacular plant name. It should be clear from the above that in order to establish the correct identity of a plant it is essential for botanists and traditional physicians to work very closely with each other because the inter-cultural correlation between vernacular names and botanical entities needs the intelligent involvement of both.

Since biological materials possess genotypic and phenotypic variability, while establishing standards in the case of a species with either a wide distribution range or even in the case of endemic populations, the sampling size should be adjusted to represent this diversity. For example *Phyllanthus emblica* is distributed right from the coastal plains to sub-tropical habitats and therefore standardizing such a material would require a statistically valid sampling strategy for this purpose.

The next stage in quality assurance of a raw material is to standardize collection procedures based on traditional recommendations regarding season, region and maturity of collection. And how it is processed and stored. Traditional medical texts under the topic *deśa vicara* specify the collection of raw materials at specific times of the plant's life cycle or advise collection from specific habitats. For example, the traditionally recommended mature tubers of the plant *Ipomea mauritiana* are richer in terms of both their bioactivity as well as in phytoconstituents than their immature counterparts (Venkatasubramanian, 2004). Another similar case involves the difference between the bioactivity of fresh and dry brahmi. Another example of collection standards is the case of Turmeric (*Curcuma longa* L.) whose rhizomes for therapeutic purposes are collected at nighttime. Preliminary studies indicate that bioactivity of turmeric collected at night was significantly different from that collected during the day. *Neem* (*Azardicta indica*) manifests its best therapeutic properties when collected from hot, dry and arid habitats (e.g. Rajasthan) than when it is collected from a high rainfall area (e.g. Kerala).

The more complex aspect of quality assurance arises in respect to the standardization of the finished product. Traditional products of different cultures use a wide range of processing techniques and also dosage forms, from simple powders made from a single plant, to extracts made from many plants. The finished products may be aqueous extracts, herbal wines, herbal oils, baked products, plant starches or alkalis. Standardizing all these myriad process and products poses a real

challenge to modern scientists. An interesting example of the relevance of traditional advice regarding processing can be seen in the case of an important pepper (*Piper longum*). This species is very widely used in Āyurveda. The extract of this plant in milk rather than water is better for therapeutic application. Bioassays indicate that the extract of the plant in milk is 27 times more active than the aqueous extract.

The Inter-cultural Gap in Pharmacopoeias

Today's Western-knowledge based pharmacopoeias – official handbooks on medical treatments – of traditional medicine like the US Pharmacopoeia, WHO monographs and even the Āyurvedic Pharmacopoeia of India, largely fail to adopt a comprehensive inter-cultural approach in setting quality standards. The quality standards they lay out for the drugs are limited to the presence of particular ingredients that are assumed to be active rather than the whole range of compounds that may be responsible for the drugs therapeutic actions. Most pharmacopoeias list aspects such as morphology, microscopy, physicochemical characteristics, nature of phytoconstituents and chromatography profiles, but are not as yet much informed by, or sensitive to collection protocols that are critical for the quality standards established by traditional health cultures. They are usually silent on the standards for several traditional dosage forms and online processes involved in their manufacture. This is partly because the information on traditional quality standards is not available in one place as a “ready reckoner” but mainly because an inter-cultural perspective is absent in their design.

International Regulations on Traditional Medicine

The biggest challenge lies in setting modern standards for evaluating a traditional drug's efficacy. This probably calls for a paradigm shift by designing a more holistic approach undertaking clinical trials. Most systems of traditional medicine adopt a multi-pronged approach to treatment. This involves drugs, diet and non-drug therapies. They aim at improving both mental

and physical well-being. Furthermore, the causes of disease and their classification in traditional systems of medicine do not have a one-to-one correlation with Western counterparts. Finally traditional treatments are designed to achieve homoeostasis, rather than to eliminate a single invasive agent.

These differences in the approaches to treatment give rise to two issues. The first is that unconventional evaluation protocols are needed to assess an entire treatment “package”, rather than one specific drug. The second is the need to use appropriate clinical, physiological, psychological or biochemical indices for evaluating outcomes which correlate well with the traditional understanding of cure.

In cases where differential diagnosis and treatment is indicated by TM for patients who from the western biomedicine perspective are suffering from the same disease, the conventional double-blind, placebo-controlled clinical trials might not always be necessary or appropriate. Case studies and observational studies – in which a clinical investigator monitors the effectiveness of treatment – can be valuable (Chaudhury & Chaudhury, 2002). Clinical trials need to be generally designed to evaluate a management regime, rather than a particular drug, although in the case of OTC drugs, the conventional design of drug trials is perhaps relevant.

In recent times regulatory authorities in importing countries such as Germany have restricted the role of traditional medicines to supplements that can be used only for “indications such as invigorating and strengthening” and which cannot be “intended to cure or treat disease” (Blumenthal, 1998). This is because investing in efficacy studies based on inter-culturally sensitive research models has not been recognized as an important enough area. In clinical research, most of the pharmacopoeial standards that are now available have been restricted to single plant extracts or at most extracts of five herbs as fixed combinations. This restrictive approach to the use of traditional medicine is depriving consumers round the world

of many of the benefits of several sophisticated poly-herbal traditional remedies.

With respect to safety, traditional remedies will need to be assessed within the same parameters now used for modern pharmaceutical, nutraceutical and cosmeceutical products. The WHO has accepted that traditional medicines may need less rigorous preclinical toxicological evaluations since their safety of use has been documented historically (Venkatasubramanian, 2004). However in the case of traditional products that are based on the use of metals and minerals, whereas they are known to be therapeutically potent, it is extremely important to ensure that the traditionally prescribed processes are rigorously adhered to else the products can result in toxic side effects. In fact the traditional pharmacy texts themselves underline the need for such rigor. For example in the case of *bhasmas* the particle size of the finished products is expected to be smaller than the intra-cellular space and the products should no longer carry any trace of the metal in its original form. Modern tools like the electron microscope and atomic absorption spectrometer can aid in the evaluation of such products.

The latest EU regulations on traditional medicine state that traditional products must be safe and meet prescribed standards of quality if they have been used for at least 30 years. A catch in this legislation is that 15 years had to be within the European Community itself (Chaudhury & Chaudhury, 2002). This is in principle a progressive rule because it recognizes the value of traditional knowledge. Its practice however needs to be worked out in a way that is fair and makes best use of traditional medical cultures that are located outside the European Union.

Policymakers and medical researchers should understand that the evaluation of traditional systems of medicine and their inherent standards involves inter-cultural research. This is a vital pursuit, as it can enrich the field of medical pluralism – which in its turn seems to be the best route towards the advancement of world medicine.

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Holography

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Appearance and Reality

This entry attempts to show that an ancient period of human creativity as expressed in Egyptian art has an analog in the twentieth-century discovery of holography. Parallels are perceived between both the “frontal-profile stance” and the “canonical tradition” of Egyptian art and the model of the hologram. These analogies appear on both the “empirical” and “conceptual levels” (It is to be noted that an earlier version of this entry appeared in 1986 both in English and in French, in *Aujourd’hui l’Egypte*. Permission to reproduce an updated version was granted to the author by

the editor of *Aujourd’hui l’Egypte*: Mr. Jean Chamas).

Recent breakthroughs in modern physics (Capra, 1980; Jones, 1983; Zuhav, 1980) have drawn attention to the innumerable parallels between the new ways of interpreting modern physics and Eastern mysticism. Capra (1980) in his *Tao of Physics* reflects this trend when he observes:

...The basic elements of the Eastern world view are also those of the world view emerging from modern physics... Eastern thought provides a consistent and relevant philosophical background to the theories of contemporary science...

Similar to modern physics, holograms also lead to a world view which is essentially mystical (Bohm, 1980). The roots of such a view can be found in an earlier period of human creativity, that of Ancient Egypt, where the belief in the mystical reality of art gave impetus to the unparalleled artistic productivity of its people. Through the examination of the frontal-profile stance and the canon, we will demonstrate how the hologram and Ancient Egyptian works of art, which at first glance may seem totally unrelated, share many common features. The entry concludes by suggesting that these two complementary manifestations of the human mind are united in their mystical view of the world.

It is hoped that the ideas expressed in this paper will prove relevant in showing that there is an essential harmony and complementarity between the humanities and science leading to a better understanding of the world around us.

Frontal-Profile Stance in Ancient Egyptian Art

To the Ancient Egyptians an intimate relationship existed between art and the fundamental belief of how to live and die. Where an obsessive horror of death and extinction was reconciled with an absolute faith in immortality, art played an active role.

The Egyptian artist was concerned not with representing a fleeting impression captured transiently, but with what he regarded as an

individual's personal eternity. Principal figures were shown at an undefined age, conforming to preconceived standards of bodily health and vigor. Individual features showed little variation and personal traits were generally avoided. Figures in general were not intended as portraits of the deceased but "...symbolic representations of a perfect man and his family..." (David, 1975) a representation of what was expected to exist for perpetuity.

Each individual object had therefore to be represented in its entirety, as a "whole," with no parts hidden or distorted by shifts of perspective, "because parts omitted were considered missing and bound to mar the eternal image of the objects they represented" (Iversen, 1975).

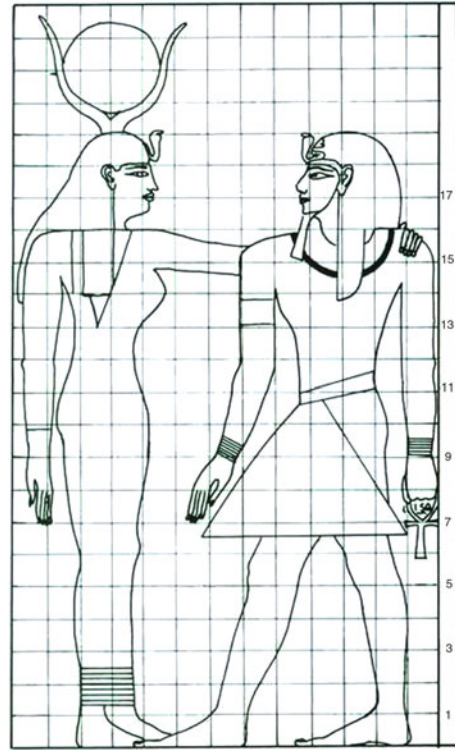
This led to one of the fundamental features of Ancient Egyptian art: the principle of "frontal images" or the "aspective" (Shafer, 1974) as opposed to the "perspective" approach.

Egyptian artists selected in their two-dimensional renderings, only those possibilities which were free from the illusion of perspective, in which characteristic individual parts of an object were set unforeshortened almost as a series of juxtaposed phases.

Applied to human figures, this "frontal-profile" aspect was expressed in an extraordinary treatment of the human body. Apart from rare instances the head and the neck were invariably represented in profile yet the eye was presented full face (Fig. 1). The torso was turned square to the spectator with the nipple seen in profile and the navel "en face." Legs and feet were represented in profile with the left leg foremost (Fig. 1).

Such an impossible physical contortion avoided the perspectival solution to the problem. Through the integration of the front and side views, Ancient Egyptians thus managed to achieve a three-dimensional representation of objects on a plane surface.

It is in this "aspective" expression of Egyptian art, where each element of the representation was scrupulously reproduced, that a first analogy may be perceived with modern holography. To clarify this point and demonstrate the parallels, a few



Holography, Fig. 1 The Ancient Egyptian canon of proportions

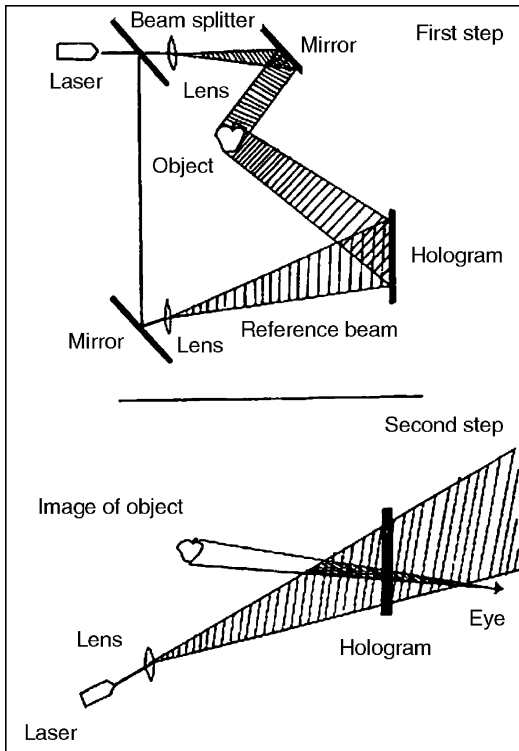
words of explanation about holograms are in order.

Holography is a method of lenseless photography in which the wave field of light scattered by an object is recorded as an interference pattern. When the photographic record called a "hologram" is placed in a light beam, the original pattern is regenerated and the observer sees a three-dimensional picture that is an amazingly realistic image of the original object.

If one moves one's head, one can see a top, bottom, and side view, just as if the object actually existed in space before one's eyes.

To make a hologram, one starts with a single monochromatic and coherent beam of light from a very small source:

...This single beam is then split into two components, one of which is directed towards the object, the other is directed to a suitable recording medium, usually a photographic emulsion. The component beam that is directed to the object is scattered, or diffracted by that object. The wave



Holography, Fig. 2 Creating a hologram

that proceeds directly to the recording beam is termed the “reference beam”. Since the object and reference waves are mutually coherent, they will form a stable interference pattern when they meet at the recording medium. . . the detailed permanent record of this interference pattern on the photographic emulsion, which we call the “hologram” consists of a complex distribution of clear and opaque areas corresponding to the recorded interference fringes. When this in turn is illuminated with a beam of light which is similar to the original reference wave, light will only be transmitted through the clear areas, resulting in a complex transmitted wave. The latter conveniently divides into three separate components, one of which exactly duplicates the original object wave. Thus “holography” is a two-step process by which images can be formed.

In the first step a complex interference pattern is recorded and becomes the hologram. In the second step, the hologram is illuminated in such a way that part of the transmitted light is an exact replica of the original object wave (Smith, 1975) (Fig. 2).

The concept of three-dimensional realism with only two in use is therefore encountered in both Ancient Egyptian art and modern holography.

Such a parallel becomes even more evident by considering De Rachewiltz’s (1960) description of Ancient Egyptian two-dimensional representations:

...on a flat surface (space) an image is drawn which at the same moment (time) evokes a plurality of individual visions. It is almost as if the figure were visualised from several sides, seen simultaneously in profile and from the front in its essential “reality” which is derived from one vision of the various sides synthesized on the flat surface.

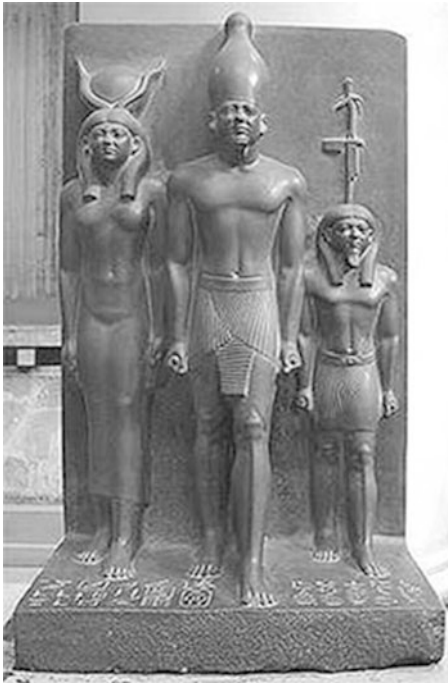
Canons as Holograms

Another striking feature of Egyptian Art, both in the sculpture and in the painting, is the serenity and immutability of the people and the scenes.

A sense of inner life and power imbued with calmness emanates from the various art works. The representation of the human figures suggests that the Egyptian artist’s aim was to establish for all times the laws of harmony and perfection. Such harmony was expressed in idealized human figures free from physical defects and enjoying the blessings of life (Fig. 3).

Technically, such standards of beauty were reached by making use of the well-known “artistic canon.” The latter was encountered in Ancient Egyptian art since the beginning of the dynastic times and represents a system of proportions which was used to indicate the mutual relations of the different parts of the body in its artistic representation. According to Iversen (1975) and Harris (1971), the problem faced by the Egyptians of how to scale the various parts of the body was solved by resorting to an accurate standardization of the natural proportions of the body.

His arguments were based on the premise that within distinct types and ethnic groups, the relations of the various parts of the human body are constant and immutable in all individuals, irrespective of any differences in size and dimensions.



Holography, Fig. 3 Triad of King Menkaure (Picture taken by Dr. John Swanson and reproduced through his permission and that of the director of the Cairo museum Dr. Wafaa al Sadek)

Recent investigations (Robins & Miszellen, 1976) have, however, indicated that Egyptians gave their figures idealized proportions which reflected certain standards of beauty and were not necessarily totally in correspondence with the natural proportions of the body.

Here we are reminded of Plato (1963), according to whom "...Egyptian artists abandoned the truth and gave their figures not the actual proportions but that which they considered beautiful. ..." Whether or not such was the case, there definitely existed a standardized relation between the various parts of the represented figures, and these were based on anthropometric measurements.

For the practical application of such a system, the Egyptians invented the so-called grids, a system of squares in which the width of the grid square was taken as a rough guide for the width of the fist:

On the rectangular blocks intended for sculpture in the round, the squares were drawn or incised on at

least two sides, and on the plane surfaces prepared for two-dimensional representations, they were either ruled with a straight edge or marked by means of strings dipped in red ochre. (Robins & Miszellen, 1984)

A canon of proportions thus evolved as early as the Old Kingdom (3200–2280 BCE), and from the Middle Kingdom (1991–1786 BCE) onwards, it became a normal practice to relate the parts of the body to a grid consisting of 18 squares from the soles to the hairline (Robins & Miszellen, 1983, Fig. 1).

Such a "classical" grid was from the 26th Dynasty (664 BCE), replaced by the "late" grid, known as the "Saite Canon," dividing the height of the male figure into 21 squares from the sole to a new measuring point at the root of the nose.

Without changing the mutual relations of the parts, the dimensions of all proportions of any figure could be altered indefinitely by the simple process of changing the length of the modular square ($1/18$ or $1/21$ of the height depending on what canon was used).

Egyptian artists were therefore able, for more than two millennia, "to find a complete harmonious expression within a single tradition, without once changing its principles and ideas - with the sole exception of the Amarna age" (Harris, 1971).

Robins and Miszellen (1983) recently showed that during the latter period a canon of proportions based on 20 squares from the sole to the hairline was introduced.

It is in this canonical tradition of Ancient Egyptian art that a further analogy may be perceived with modern holography. To appreciate such a similarity, let me point out another crucial property of holograms.

In holography the light scattered from each point of the object spreads out as to cover the entire photographic plate. This means that there is no longer a one-to-one correspondence between a portion of the hologram and a region of the object. The information of any single point is recorded over the "whole" plate.

Because of this only a small portion of the hologram is required to form an image of the whole object (Butters, 1971; Develis & Reynolds, 1967; Smith, 1975). If the hologram were

to be shattered into thousands of splinters of glass, it would still be possible to form, on any small particle of glass, the entire representation.

This key new feature which is apparent in holography that of an unbroken wholeness, where each part contains information about the entire object, is also apparent in the Ancient Egyptian canon of proportions. Any small part of the artistic figure gives, through its dimensions, information of the whole.

The following argument will also show that just as in a hologram, the representation is “everywhere” in the glass plate, shot through it; the communication or message conveyed by the canon is contained everywhere in the work of art (Ross, 1982).

The observation of Egyptian representations as well as a detailed reading of published work (Aldred, 1980; David, 1975; Davies, 1982; De Rachewiltz, 1960; Harris, 1971; Iversen, 1975; Kielland, 1955; Plato, 1963; Robins & Mizzellen, 1976, 1983, 1984; Romano & Bothmer, 1958; Ross, 1982; Shafer, 1974; Smith, 1975; Steindorff, 1949) on Ancient Egyptian art convinces us that through the symbols and metaphors embodied by the canon, a “mystical” message is conveyed that is highly consonant with modern physics (Capra, 1980; Zukhav, 1980). Such a message incorporates the ideas of the interrelatedness of all things, the transcendence of the notion of an individual self-coupled with the firm belief that all observations are but manifestations of the same ultimate reality and finally the idea that space and time are constructs of the mind.

That all things and events perceived by the senses are interrelated and connected is, by virtue of the canon, metaphorically suggested throughout the Ancient Egyptian work of art. The standardized relation between the various parts of the figures such as the relation of thumbs to fingers, fingers to palm, palm to forearm, and forearm to height and breadth symbolically confirms this interdependence. All things are seen as inseparable parts of this cosmic whole.

The canonical tradition, by allowing the tomb owner and his family to be represented as idealized humans with slender bodies and youthful beauty free from physical defects and devoid of

individual and personal traits, expresses a transition from differentiation to sameness. What appears to be different finally is seen to be the same. The canon, throughout the art work, allows the individuality to be dissolved into an undifferentiated oneness where the notion of an individual self is transcended leading to an identification with the same ultimate reality (Figs. 3 and 5).

Iversen (1975), referring to the lack of specification of Ancient Egyptian works of art in the spatiotemporal plane, writes:

In order to prevent any temporal aspect to influence the existence of the individual representations the indications of any particular moment in their corruptible state was studiously avoided. . .

Ancient Egyptian works of art, created out of their spatiotemporal appearances, suggest that space and time are constructs of the mind. Such a message can be shown to be “hologrammed” by the canon.

Indeed a close observation of Ancient Egyptian figures suggests that each single part in the Ancient Egyptian work of art is given a form that is appropriate to its meaning, conveying to the figure as a whole a message valid for eternity.

Starting with the representation of the “feet” (Fig. 1), it is observed that the arch which is generally closed on the outside is shown to appear from the exterior; also “legs” are in most cases depicted as being a pace apart, even when surrounded by seated or kneeling people. Observation of Fig. 1 also suggests that the “hand” hanging open behind the back is mostly so placed that the thumb is turned away from the body. Shafer (1974), commenting on the position of the hands, makes the following conclusions:

. . . This strange positioning of the hands poses great problems as long as the human figure is taken to be the rendering of a single real view. But it does the artist an injustice to consider his work in this way. . .

The intermingling in these representations of the concepts of “back” and “front,” “inner” and “outer,” and those of “rest” and “movement” indeed does suggest an arrest in time and space.



Holography, Fig. 4 Queen Nefertari

In their depiction of “parts” as well as of the “whole” in figures, Egyptian artists were thus inclined not to follow their visual impressions. Instead they sought to convey the significance of a subject by portraying it in an abstract manner, outside space and time (Fig. 4).

It is also noteworthy that in these artistic renderings facial representations were generally devoid of all signs of emotion and of details specifying human feelings and passions (Fig. 5).

The images had a tone of extreme dignity, almost of a higher existence which has been achieved and of which the subject was completely aware. Here, once more, we become aware of artistic expressions taken out of their ephemeral temporal representations.

It becomes clear that the adaptation of the artistic production to a “canon,” considered as an expression of the divine law of harmony, has allowed the full expression of an unbroken



Holography, Fig. 5 Tuthmosis III (Picture taken by the late Dr. Bernard Bothmer) (Reproduced by permission of Mrs. Bothmer and Mrs. Sanaa Ahmed Ali (director of the Luxor museum))

wholeness through which is “hologrammed” a highly mystical message. The artist fashioned an image that expresses in generalized terms the nature of “man” as such.

His prime concern is to create not a likeness but first and foremost “a symbol.”

Conclusion

This entry has attempted to link an ancient period of human creativity, as expressed in Egyptian art, with a modern twentieth-century discovery: holography. Ancient Egyptian works of art and holograms are seen to have striking parallels both on an “empirical” and on a “conceptual” level.

Both techniques, in spite of their different approaches, have succeeded in achieving a mapping of three dimensions onto two. Ancient Egyptian artists did not base their

representations on perspective but were rather concerned to communicate all of the details of the figure by giving every vital part its full definition. If the head were shown frontally, the definition of the nose would be lost for eternity. Similarly the eye and torso had to be exhibited in their most characteristic light and were therefore shown frontally legs and feet which would have been foreshortened if shown frontally were indicated in profile. Such an approach thus gave the “complete” information about the represented figure.

Similarly, holography by reproducing an exact replica of the original object provided an illusion of three-dimensional concreteness from which could be extracted the “whole” information relating to the object.

An additional property, common to both holograms and Ancient Egyptian works of art and also evident on an empirical level, is that just as in a hologram any fragment, which is very small, gives information on the whole object, and in Ancient Egyptian works of art by virtue of the canon, any part of the figure allows the computation of the dimensions of the other parts and of the whole.

From a conceptual point of view, both holograms and Ancient Egyptian works of art similar to modern physics lead to an essentially mystical world view.

Thus, as observed by Bohm (1980):

Holograms provide an immediate perceptual insight into what is meant by undivided wholeness in which the classical idea of the analyzability of the world into separately and independently existing parts is denied.

In an analogous manner Ancient Egyptian art works are “. . . created as a UNITY in which every detail and measurement is determined in relation to the whole. . .” (Kielland, 1955). The interdependence and interconnectedness of all things are again made evident here.

This highly mystical approach is not only conveyed by considering the Ancient Egyptian art work in its entirety but is also seen to be “hologrammed” throughout the individual parts.

As Plato suggests:

The Egyptians managed to penetrate a reality beyond the “merely” seeming presenting this comprehensive intuition in artistic form, as a vision of underlying order in the universe. (Davies, 1982; Plato, 1963)

In the same line of thought, we may reflect on Bohm’s suggestions that the “universe itself may be a hologram,” a realm of frequencies and potentialities underlying an illusion of concreteness, or what he calls the “enfolding” order.

What we actually “see” is the “unfolded” order giving recognizable images of “whole” objects (Bohm, 1980; Milbourn unpublished). Bohm suggests that our reality is of objects rather than waves “because our senses are lens systems” (Fig. 2):

If the universal reality is based on the holographic principle, then what is needed to tune into this reality is a means of bypassing the lens system of the senses and experience the waves of the enfolding order directly. (Milbourn unpublished)

We are reminded here of Steindorff’s (1949) description of Egyptian non-perspectival art as an art “that concerns itself with the object not as it appears to the eye, but as it exists in the imagination of the artist,” representing a mental image that transcends the world of senses.

Thus, both Ancient Egyptian works of art and holograms may be conceived as resulting from an awareness raised to a level above the brain’s sensory input, in which the different aspects of nature, whether recorded as an interference pattern of scattered light or whether resulting from what may be termed the “holographic activity” of the Ancient Egyptian brain, have led to a blurring of the demarcation line between “appearance” and “reality.”

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Honey and Medicine

Rachel Hajar

There is evidence that man has long known that honey is a valuable food source. Early rock paintings on cave walls in Africa and eastern Spain show people gathering honey from trees or rock crevices while bees fly around them (Crane, 1999). A rock painting called the “Man of Bicorp” shown in Fig. 1 was discovered in 1921 in the *Cueva de la Arana* (Spider Cave) in Valencia, Spain. The painting depicts a human figure near a cavity where there is a beehive. Hanging on three lianas, he is picking up honeycombs, while nearby are some stylized bees. The painting is believed to be over 15,000 years old and dates back to the end of the Paleolithic Period. Rock art



Honey and Medicine, Fig. 1 “Man of Bicorp” ca. 15000 B.C.E. Paleolithic rock painting showing honey collection from a wild nest, Cueva de la Arana, Bicorp, Valencia, Spain (Drawing E. Hernandez-Pacheco). <http://www.rupestre.net/tracce/bicorp.html>

from other caves has been found, which shows figures surrounded by bees without being stung.

Prehistoric honey gatherers probably learned by accident that bees are driven away from the honeycomb by smoke as an offshoot of using fire for “warding-off” or driving other animals. Most likely early humans observed the habits of bees and learned that wild bees made their home in the hollow limbs of trees or in hollow places in the trunks of trees. Even now, bee trees often can be found by walking through the woods on bright sunny days and looking into the tops of the trees and watching for the bees coming and going.

The “Man of Bicorp” cave painting is clear proof that early humans actively sought honey as part of their diet. We do not know, however, whether prehistoric man used honey for medicinal purposes.

Honey hunting is an ancient tradition that is still practiced in isolated cultures in Africa, the Indian subcontinent, Southeast Asia, Australia, and South America. Reports of such activities in the popular press describe the practice as heavily permeated with ritual. This is not surprising since the tradition was passed down for generations and has its origins from our distant past.

Honey hunting is a dangerous pursuit since a bee sting could be fatal. Throughout history, there have been alternatives to honey as a sweetener, such as dates and figs. Yet, humans seem to prefer honey and one wonders why humans like honey so much.

Honey in Mythology and Religion

The widespread perception that honey is “good” has its genesis from folklore. Myth has played an important role in folklore. Oral and written records abound with the life-giving qualities of honey.

Quantitative studies of hunter-gatherer diets are scarce. The *Veddas*, or Wild Men, of Sri Lanka esteem honey so highly that they regularly risk their lives to obtain it. The results of a study among some Australian aboriginal tribes reveal that wild honey is regularly consumed although it is difficult and challenging to obtain.

Unfortunately, research into the nutritional role of honey is scanty. However, studies of primitive tribal diets indicate that honey is highly nutritious. For example, among the Guayaki Indians of Paraguay honey is the very basis of their diet and culture (Fallon & Enig, 1999).

Mythology offers rich insights into the perceived life-sustaining qualities of honey. In Greek mythology, Zeus, mightiest of the Greek gods, was hidden from his father who wanted to devour him and was raised on honey and milk by the bee-nymph, Melisseas. Honey made him so strong and tough that when he grew up he seized his father’s throne.

Another myth is that *ambrosia* was the food of the gods and goddesses. Since their gods’ food consisted only of ambrosia, the ancient Greeks attributed the immortality of their gods to ambrosia, which they believed consisted of honey, milk, and nectar. Ambrosia was thought to be a nine-fold extract of honey – a sweet treat enjoyed by mortals throughout the ages. Honey was a divine symbol for the Greeks and honey mixed with blood was the sweetest oblation.

Besides its nutritious benefits, the ancients may have believed that honey had properties to preserve or enhance beauty. It is claimed that many of Cleopatra’s cosmetics were honey-based. Many women in Arabia still believe honey softens their skin and regularly apply it as facial mask.

In Egyptian mythology, “when the God Re wept, his tears fell to the ground and were turned into bees. The bees began to build and were active on all flowers of every kind belonging to the plant kingdom. Thus wax came into being, thus was created honey from the tears of the God Re” (Ancient Egyptian beekeeping).

The ancient Egyptians offered their gods honeycombs overflowing with honey as a valuable gift to show devotion and worship. In the twelfth century B.C.E., Ramses III offered 15 tons of honey to Hapi, the god of the Nile. Jars of honey were buried with the dead as sustenance for the afterlife. Archaeologists have found clay pots filled with honey in a Pharaoh’s tomb in the city of Thebes. The inscription on the clay pot read: *Good Quality Honey*. Large quantities of

honey in jars were also found in the tomb of Tutankhamen (Salim, 1988). Burying the dead (especially nobility) in or with honey was common practice in Egypt, Mesopotamia [Iraq], and other regions. It is rumored that Alexander the Great was buried in honey.

The Pharaohs also used honey in their wedding celebrations. This custom was passed on to Greco-Roman culture and handed down to Medieval Europe. Newlyweds drank honey wine (mead) for a month after the wedding ceremony for good luck and happiness. The ritual gave rise to the word *honeymoon*. Egyptian hieroglyphics dating back at least 3,000 years indicate that honey was used as the principal sweetener in the Egyptian diet and as a base for medicinal unguents. The Egyptians also collected beeswax for use in molding wax images for metal casting and in the “varnishing” of pigments (Shaw & Nicholson, 1995).

The first written record of beekeeping can be traced back to Egypt from about 2400 B.C.E. Figure 2 depicts a relief of hives in ancient Egypt, which are very much similar to the woven wicker baskets covered with clay that are still used in Sudan today.

Temples kept bees in order to satisfy the demand for honey as offerings to the gods as well as for other domestic uses such as mummifying, boat, and ship building, and as a binding agent for paints and in metal casting. However,

the Egyptians valued wild honey more than the homegrown variety. A passage from the Papyrus Harris reads, “I appointed for thee archers and collectors of honey, bearing incense to deliver their yearly impost into thy august treasury” (Breasted, 1906).

Honey is frequently mentioned in the Bible. Moses led his people to the “land of milk and honey.” Solomon in Proverbs 24:13 advised, “My son, eat honey; it is good. And just as honey from the comb is sweet on your tongue, you may be sure that wisdom is good for the soul. Get wisdom and have a bright future.” The Jews believed honey made a person “mentally keen.”

In early Christianity, honey had a deep mysterious meaning and it was given in christening ceremonies as a symbol of renovation and spiritual perfection. When St. John, the Baptist, was in the desert, he lived on honey and locusts. Bees were revered because of their ability to produce wax and therefore provide light, in many cases for religious practices. Before the advent of electricity, candles were important for lighting. In many religions, candles are still used for religious ceremonies. The Roman Catholic Church regarded the bee as an example of godliness and believed beeswax to be “pure” since virgins – i.e., nonmating worker bees – produce it. Monks kept bees to provide beeswax to make candles for the church.

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Honey and Medicine,

Fig. 2 Beekeeping in Ancient Egypt (Tomb of Pabasa). Relief shows cylindrical hives made of clay (© Kenneth J. Stein Illustration from <http://nefertiti.iwebland.com/timelines/topics/beekeeping.htm>)



Honey as Medicine in History

It is possible that prehistoric human's experiences with honey as a valuable food source became encoded in our mythology. In time, the mythic belief that honey was the "food of the gods" passed into ancient writings. Since it was the food of the gods, it must contain the ingredient of immortality, fostering the perception that honey contains the secret to a long and healthy life. It was prescribed as panacea for various ailments and diseases.

Healing for Mankind

"Thy Lord taught the Bee to build its cells in hills, on trees and in man's habitations; Then to eat of all the produce of the earth. . . From within their bodies comes a drink of varying colors, wherein is healing for mankind." (*Qur'ān*, Surah XVI: 68–69). The prophet Muḥammad advised his followers to "Use the two curatives: honey and Qur'ān."

Likewise, the Bible contains many references to honey. "But Jonathan [son of Saul]. . . reached out the end of the staff that was in his hand and dipped it into the honeycomb. He raised his hand to his mouth, and his eyes brightened." (1 Samuel 14:24).

The Hindu Vedas, composed about 1500 B.C.E. and written down about 600 B.C.E.,

speak of "this herb, born of honey, dripping honey, sweet honey, honied, is the remedy for injuries; moreover it crushes insects." In the section on *Hymn To All Magic And Medicinal Plants*, honey is used as a universal remedy: "The plants. . . which remove disease, are full of blossoms, and rich in honey" (Blomfield, 1973).

All the sacred books, including those of China, praise honey as food, beverage, and medicine (Jones, 2001).

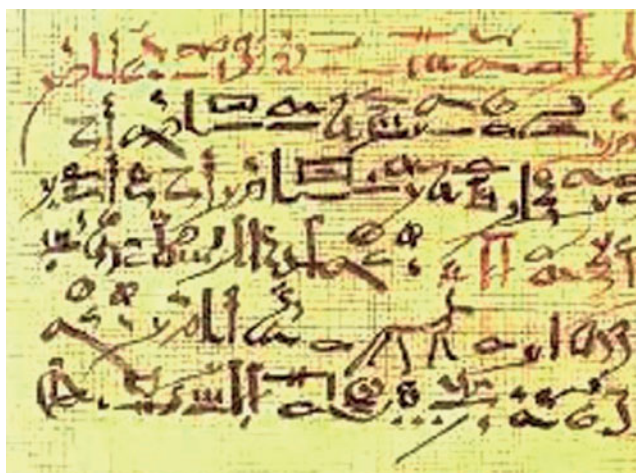
Ancient Writings

There are abundant references to honey as medicine in ancient scrolls, tablets, and books. It was prescribed for a variety of illnesses. Excavated medical tablets from Mesopotamia indicate that honey was a common ingredient in many prescriptions. In ancient Egyptian medicine, honey was the most frequent ingredient in all the drug recipes for both internal and external uses listed in the Ebers and Edwin Smith Papyri (Estes, 1993). Honey was used for treatment of stomach pain, urinary retention, and as an ointment for dry skin. It was used for wounds and burns, skin irritation, and eye diseases.

The author of the Smith Papyrus shown in Fig. 3 directed that honey be applied topically, with few if any other possibly active ingredients, to wounds. An example appears below:

Honey and Medicine,

Fig. 3 Excerpt from the Edwin Smith Papyrus (Illustration taken from Ancient Egypt. The Edwin Smith Surgical Papyrus. <http://nefertiti.iwebland.com/timelines/topics/smithpapyrus.htm>)



Instructions Concerning A Wound In His Head, Penetrating To The Bone:

If thou examinest a man having a gaping wound in his head, penetrating to the bone, thou should'st lay thy hand upon it (and) thou should'st palpate his wound. If thou findest his skull uninjured, not having a perforation in it. . .

Thou shouldst bind fresh meat upon it the first day, thou shouldst apply two strips of linen; and treat afterward with grease, honey, (and) lint every day until he recovers.

In ancient Egypt, honey was the only active ingredient in an ointment described in the Ebers Papyrus for application to the surgical wound of circumcision. Ebers also specifies that an ointment for the ear be made of one-third honey and two-thirds oil. The concentration of honey in seven oral remedies in the Chester Beatty VI Papyrus ranges from 10 % to 50 %, while its proportion in other remedies ranges from 20 % to 84 %. Honey could very well have provided some kind of protection from the kinds of bacteria most likely to infect wounds, at least enough protection to permit wounds to begin healing on their own.

The ancient Egyptians were not the only people who used honey as medicine. The Chinese, Indians, ancient Greeks, Romans, and Arabs used honey in combination with other herbs and on its own, to treat wounds and various other diseases.

Aristotle (384–322 B.C.E.) believed that eating honey prolonged life (Jones, 2001). Dioscorides (A.D. 40–90), a Greek physician who traveled as a surgeon with the armies of the Roman emperor Nero, compiled *De Materia Medica* (shown in Fig. 4) around A.D. 77. *De Materia Medica* was the foremost classical source of modern botanical terminology and the leading European pharmacological text until the fifteenth century.

In addition to excellent descriptions of nearly 600 plants and 1,000 simple drugs, Dioscorides described the medicinal and dietetic value of animal derivatives such as milk and honey. Dioscorides stated that honey could be used as treatment for stomach disease, a wound that has pus, hemorrhoids, and to stop coughing (Salim, 1988).



Honey and Medicine, Fig. 4 (a) Dioscorides, *De Materia Medica*, 15th c. Iviron Monastery, Mount Athos, Greece (18.25 Dioscorides, *De Materia Medica* (Books I-V) 15th c. Iviron Monastery, Cod. 216 Illustration from <http://www.culture.gr/2/21/218/218er/>

[e218er25.html](http://www.culture.gr/2/21/218/218er/). (b) Illustration from *De Materia Medica* of Dioscorides, Baghdad, A.D. 1224. (Arabic Translation of Dioscorides' *De Materia Medica*. Iraq, Abbasid Period, 13th Century ca. 1224)

Honey opens the blood vessels and attracts moisture. If cooked and applied to fresh wounds it seals them. It is good for deep dirty wounds. Honey mixed with salt could be dropped inside a painful ear. It will reduce the pain and swelling of the ear. It will kill lice if infested children's skin is painted with it. It may also improve vision. Gargle with honey to reduce tonsil swelling. For coughing, drink warm honey and mix with rose oil (Dioscorides 65 A.D.).

A tenth century Arab philosopher mentioned uncooked honey for swollen intestines whereas cooked honey was good to induce vomiting when a poisonous drug had been ingested. Al Rāzī (Rhazes, A.D. 864–932), a renowned Muslim physician famous for writing a treatise distinguishing measles from smallpox, claimed that honey ointment made of flour and honey vinegar was good for skin disease and sports nerve injuries, and recommended the use of honey water for bladder wounds (Salim, 1988). His book, *Al Hāwī* (Encyclopedia of Medicine), a comprehensive medical textbook of medicine, which was translated from Arabic to Latin in the thirteenth century and became a standard textbook of medicine up to the 1700s stated:

Honey is the best treatment for the gums. To keep the teeth healthy mix honey with vinegar and use as mouth wash daily. If you rub the teeth with such a preparation it will whiten the teeth. Honey does not spoil and could also be used to preserve cadavers.

► **Ibn Sīnā (Avicenna)**, another famous Muslim physician whose great medical treatise, the *Canon*, was the standard textbook on medicine in the Arab world and Europe until the seventeenth century, wrote:

Honey is good for prolonging life, preserving activity in old age. If you want to keep your youth, take honey. If you are above the age of 45, eat honey regularly, especially mixed with chestnut powder. Honey and flour could be used as dressing for wounds. For lung disease, early stage of tuberculosis, use a combination of honey and shredded rose petals. Honey can be used for insomnia on occasions.

Throughout the ages, honey was prescribed for a variety of uses, frequently mixed with herbs, grains, and other botanicals. Remedies were passed down through the millennia because they seemed to be effective. Many ancient remedies survive today, lumped together by modern medicine under the term “folk medicine” since their effectiveness has not been scientifically proven through clinical trials.

The belief in honey as a remedy for ailments is still pervasive. Honey for coughs and sore throats remains a popular remedy around the world. Honey is frequently mixed with tea and cinnamon as remedy for cold and sore throat. Some antiseptic lozenges contain honey.

In underdeveloped countries, where synthetic medicines are expensive, honey is one of the cornerstones in their pharmacopoeia. For example, lotus honey is used for eye diseases in India. It is used as topical eye ointment in measles to prevent corneal scarring (Molan, 2001). Honey is used to treat infected leg ulcers in Ghana and earaches in Nigeria. Other uses include treatment of gastric ulcers and constipation (Getz, 1991).

Honey in the Twentieth Century Before Antibiotics

In the early part of the twentieth century, the medical literature contained reports on the antimicrobial and healing properties of honey. Russian soldiers during World War I used honey to prevent infections in wounds and to accelerate healing (Bergman, Janai, Weiss et al., 1983). The effectiveness of honey to heal wounds spurred research into its antimicrobial activity, which was attributed to “inhibine.” In 1963, inhibine was identified as hydrogen peroxide (White, Subers, & Schepartz, 1963), a powerful oxidizer that kills bacteria, viruses, and fungi. During the first half of the twentieth century, there were many research papers documenting the wound-healing properties of honey. The

medical profession did acknowledge the value of honey in the treatment of wounds, leg ulcers, and burns. The introduction of antibiotics shifted the focus to synthetic and mass-produced treatment. The medical uses of honey as effective treatment in wounds were forgotten.

Revival of Honey in Medicine

In 1976, an editorial in the *Archives of Internal Medicine* on medical folklore arrogantly dismissed honey as a “worthless but harmless substance” (Soffer, 1976). Over the last two decades, reports from different parts of the world affirmed the effectiveness of honey in treating various wounds, burns, and serious infections. These reports and the emergence of drug resistant infections stimulated a number of scientists to conduct studies on honey, bringing about a resurgence of interest in the medical uses of honey. Recent research on honey has shed light on the mechanisms underlying its antimicrobial effects (Molan, 1992). In summary, the antibacterial effects are due to

that are not hydrogen peroxide but their concentration is reportedly too low to contribute much antibacterial activity.

Honey has been reported to have an inhibitory effect to around 60 species of bacteria including aerobes and anaerobes, gram-positives and gram-negatives (Subrahmanyam, 1991).

There are differences in the antibacterial activity of different honeys. Honey is produced from many different floral sources and its antibacterial activity varies with origin and processing. Long ago, both Aristotle and Dioscorides recommended that honey collected in specific regions and seasons, and presumably from different floral sources, be used for the treatment of particular ailments. Research has since shown that honey has certain organisms sensitive to it while others are resistant, and the sensitivity varies depending on the source of the honey. *Staphylococcus aureus* is one of the species most sensitive to the antibacterial activity of honey (Cooper, Molan, & Harding, 2002).

Other beneficial effects of honey include (Molan, 1992):

- *Osmotic effect*: Honey is a supersaturated sugar solution of fructose and glucose, which comprise 84 %. The interaction of the sugar molecules with water molecules leaves very little water available to support the growth of microorganisms.
- *Acidity*: Honey is acidic, with a pH ranging from 3.2 to 4.5 which is low enough to inhibit the growth of many pathogens.
- *Hydrogen peroxide* is the major antibacterial compound in honey. Bees secrete the enzyme glucose oxidase from nectar. It converts glucose in the presence of water and oxygen to glucuronic acid and hydrogen peroxide. Both the acid and hydrogen peroxide preserve and sterilize the honey during the ripening process.
- *Nonperoxide antibacterial factors*: There have been reports of isolation of various antibacterial chemical substances from honey
- Stimulation of the healing process, especially leg ulcers and diabetic ulcers.
- Speedy clearance of infection when used as dressing on infected wounds. Honey is reportedly extremely effective in the treatment of wounds infected with antibiotic resistant bacteria.
- Cleansing action on wounds: Honey has a debriding effect (removing dead, contaminated tissue) on wounds so that surgical debridement is unnecessary or only a minimum is required.
- Stimulation of tissue regeneration: Honey promotes the formation of clean healthy granulation tissue and growth of epithelia over the wound, thus helping skin regenerate. It has also been reported that dressing wounds with honey gives little or no scarring.

- Comfort honey dressings: Honey is nonirritating and the pain or discomfort associated with changing dressings is minimized.

The current main medical use of honey is in the treatment of infected wounds, chronic leg and skin ulcers, bedsores, especially in settings of drug-resistant infections (Cooper et al., 2002). The effectiveness of honey in wounds and ulcers has been known empirically for thousands of years and has recently been documented in clinical studies.

Honey is reportedly used by ophthalmologists for treating corneal ulcers in India and Russia where it has been used for chemical and thermal burns to the eye, conjunctivitis, and infections of the cornea.

Other traditional folklore medical indications of honey include peptic ulcers and gastroenteritis. At least two studies demonstrated that natural honey, but not commercial honey, was bactericidal against the bacterial isolates obtained and that different types of honey exhibited varying bactericidal concentrations (Haffejee & Moosa, 1985).

Much of the wisdom of folk medicine has its roots in ancient beliefs held by people who understood neither chemistry nor anatomy. Honey is just the latest of the ancient remedies to be “rediscovered.” There are abundant references in ancient writings indicating the beneficial effects of honey and other bee products.

The humble bee makes honey from countless varieties of plant blossoms, and it is logical to assume that by-products from the beehive such as honey contain many substances of medicinal value that modern medicine has yet to discover.

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Hospitals and Medical Schools in the Ottoman Empire

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Medical science is one of the most important professions in our world. In the Ottoman Empire, which was made up of several climate zones with unique health problems, the medical system was enriched by numerous cultural and scientific influences. The Ottoman medical system was based on folkloristic medicine, religious medicine called “prophetic medicine,” and mechanistic humoral medicine inherited from Greek antiquity and the influence of Paracelsus (Shefer-Mossensohn, 2009).

Hospitals in the Ottoman Empire were divided into certain sections, and appropriate treatment protocols were given, if a diagnosis of the disease was possible. In particular, homeless and poor people were not neglected. They had the same stature as in today’s state hospitals; the people who were called *Gureba* enjoyed free cure centers.

Süleymaniye Medical School (Madrassa)

The Süleymaniye Complex, a formal teaching institution in the Ottoman Empire, was built in İstanbul by the Ottoman architect Sinan (1489–1588) for 8 years between 1550 and 1557 (<http://www.muslimheritage.com/article/suleymaniye-medical-madrassa>). This complex sponsored by Kanuni Sultan Süleyman Han is surrounded by various parts of a medical school

called a Madrasa, a large hospital and other social buildings located in the Süleymaniye Mosque.

In the history of the Ottoman Empire, the Süleymaniye Medical Madrasa, which was built adjacent to other buildings in İstanbul, was the first medical school in Islamic civilization (<http://www.muslimheritage.com/article/suleymaniye-medical-madrassa>). It had a special importance in Ottoman medicine in the education of physicians for both public and military needs. Moreover, the medical students at the Madrasa had free meals from the kitchen called *imaret*, and they practiced the theoretical knowledge they learned in school in the hospital called *dar al-shifa* (<http://www.muslimheritage.com/article/suleymaniye-medical-madrassa>).

In the medical Madrasa, there was a staff including one lecturer called *müderris*, eight students called *danişmend*, and three auxiliary staff (<http://www.muslimheritage.com/article/suleymaniye-medical-madrassa>). The students were taught from a total of 66 medical books at the Madrasa by the master-apprentice method (<http://www.muslimheritage.com/article/suleymaniye-medical-madrassa>). The Süleymaniye Medical School was a very important place which provided physicians for all the medical institutions in the Ottoman Empire for about three centuries. Turkish medical lecturers at the Süleymaniye Medical School taught lessons on pathology and surgery for 4 days a week (<http://www.muslimheritage.com/article/suleymaniye-medical-madrassa>). As far as we know, the Süleymaniye Medical Madrasa continued to educate the students until the middle of the nineteenth century. In addition to medical education, lessons regarding logic called *ilm-i mizan* and certain sciences called *fenn-i hikmet* or *ulum-i akliye* were taught at the school (<http://www.muslimheritage.com/article/suleymaniye-medical-madrassa>).

Mechanistic Humoral Medicine

Humoral theory describes the composition of matter and comments on illnesses. According to this theory, everything is composed of

four elements: air, water, fire, and earth (<http://www.muslimheritage.com/article/paracelsian-influence-ottoman-medicine>). Matter has four basic features: warm, cold, moist, and dry (<http://www.muslimheritage.com/article/paracelsian-influence-ottoman-medicine>). The body consists of four humors (fluids): blood (air), phlegm (water), yellow bile (fire), and black bile (earth). And there are four temperaments: sanguine, choleric, phlegmatic, and melancholic (Ullmann, 1978). Illness is a state of imbalance in the body, and the humoralist physician evaluates which of the four humors is in excess or deficiency (Shefer-Mossensohn, 2009).

Paracelsus' Concept of Medicine

After years of following Galen's concept of medicine, Paracelsus (1493–1541) changed medical practice, and this influenced modern Ottoman medicine (<http://www.muslimheritage.com/article/paracelsian-influence-ottoman-medicine>). According to Paracelsus, the elements had two different forms, external and internal. For example, the ego is an example of the internal element which provides for continuation of the species, while physic is related to the external element (Ullmann, 1978). In chemistry, the properties of the four elements are: earth, fire, water, and air (Kasîr al-Naf'. fol.: 4b; Omer b. Sinan: Ibid., No: 7,083, fols: 8a-b). Paracelsus suggested a relationship between the cosmos, the humanity, and the universe. Human beings and every illness should be studied together, as there is no disease and there are patients (Kasîr al-Naf'. fol.: 4a; Omer b. Sinan: Ibid., No: 7,083, fols.: 7b-8a).

The medicine of Paracelsus had a negative effect upon the Ottoman society because of the physicians' dependence on drugs righting the imbalance caused by disease (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). Some Ottoman and European physicians used a new treatment protocol, called *tibb-i jadid*, composed of inorganic drugs which might have caused poisoning (Sarı, Zülfikar, & Yıldırım, 1993; <http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>).

<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). Head physician Gevrekâde Hafız Hasan Efendi (1724–1801) reported some complaints concerning various practices of European scholars in İstanbul (Sarı et al., 1993).

Ottoman Turkish Physicians

Ottoman Turkish physicians investigated the results of various clinical applications based on the traditional rules of humoral theory (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>).

Among the Ottoman physicians, Şerafettin Sabuncuoğlu (1385–1470), the author of a famous treatise on surgery called *Cerrahiyetü'l-Haniyye* (Imperial Surgery), the first illustrated surgical atlas, is a good example of these physicians (Fig. 1) (Turgut, 2007, 2008; <http://www.muslimheritage.com/article/15th-century-turkish-physician-serefeddin-sabuncuoglu-author-cerrahiyetu-%E2%80%98l-haniyye>). He went to İstanbul to present his book, the first example of an illustrated surgical textbook in both Turkish and İslamic medical literature, to the Fatih Sultan Mehmed Han in 1465. Today, there are only three copies of the book in the world (<http://www.muslimheritage.com/article/15th-century-turkish-physician-serefeddin-sabuncuoglu-author-cerrahiyetu-%E2%80%98l-haniyye>). The titles of Sabuncuoğlu's textbooks are *Cerrâhiyetü'l-Hâniyye* (Imperial Surgery), *Mücerrebname* (On Attempting), and *Terceme-i Akraadin* (Translation of Pharmacology).

Mastery in Ottoman Medicine

In the Ottoman Empire, two basic parameters of medical qualification for physicians were experience and mastery according to the trust of deeds, named *wakfiya* (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). Fatih Sultan Mehmed Han was very

Hospitals and Medical Schools in the Ottoman Empire,

Fig. 1 Illustration of spinal traction technique for a patient with vertebra fracture-dislocation for a patient from Sabuncuoğlu (Reprinted with permission of the Atatürk Institute of Culture, Language and History, Institute of Turkish History from Uzel İ (1992))



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interested in medicine (Uzel, 1992). Clinically, Ottoman Turkish physicians evaluated medical principles based on their personal experiences. They noted the special role of good clinical practice in their books. In his book, Emir Çelebi said that it was not acceptable to repeat previous knowledge; physicians should add their own personal experience to the current literature (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). Abbas Vesim Efendi noted that the physician should visit patients in the hospital regularly, since he may encounter formerly unknown interesting diseases. It is very important to examine the patients for their experience, as the physician will observe different diseases (Ural, 1998; <http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>).

Ottoman Turkish medical practitioners did not use unknown drugs or techniques in the treatment of patients. In the fifteenth century, Ibn Sharif suggested that physicians should not prepare drugs from unknown herbs and should try only well-known ones in their patients and those

experienced by oneself (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). Ibn Sīnā's *Canon* was used as a reference both in western and eastern countries for centuries; until the beginning of the eighteenth century, his works were used as textbooks in European universities. Afterwards, they were updated by various medical specialists with their new contributions (Kürkçüoğlu, 1962). Ottoman traveler Evliya Çelebi (1611–1682 AD) reported an account illustrating a surgical procedure for bullet extraction in the seventeenth century (Turgut, 2010a).

In Ottoman medical practice, the *müderri*s in the Süleymaniye Medical Madrasa transferred the medical knowledge of Hippocrates, Galen, and Ibn Sīnā from the ancient Greek, Roman, and Islamic period to his students (Sarı, 1977; <http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). The first principle for all physicians was, “Do not harm the patient” (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). Furthermore, the physician

must not use his/her patients as experimental animals (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). In Ottoman medical practice, it was advised to pay importance to nature's healing power (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>).

Treatment

According to Islamic belief, there is a perfect solution for every disease for which nature provides herbal treatments, called folk medicine. In classical Ottoman medicine, the treatment consists of administering a proper drug to correct an imbalanced temperament. Physicians gave only tested drugs (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>).

Nevertheless, it was possible to do some modifications of the known treatments through experiences by empirical methods, and these were usually kept as a secret and transferred from master to apprentice or from father to son (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). The experiences were valuable information for physicians, although they were not based on scientific methods. The traditional medical philosophy and treatments were based on the knowledge that both health and disease were related to the equilibrium of the four basic elements (Sarı, 2000).

Special written or oral consent, called *hujjat*, was taken from patients or their parents, before medical or surgical treatment, in case there was an action against the physician because of injury or death (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). An agreement (contract) was prepared and signed by witnesses in the presence of the judge called *kadı* (Porter, 1835). As a rule, the judge of the canonical courts, appointed by the Palace, handled different legal problems

regarding relationships between physicians and his patients.

According to Ottoman rule, physicians were not considered responsible for the possible complications of various treatments, in the presence of a written consent, a medical failure, or a surgical technique consistent with well-known medical standards (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). To solve a dispute resolution, an expert surgeon/physician called *ehl-i hibre* was appointed by the judge, and if the practitioner was found to be responsible, he was to compensate for all harm done (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>).

Principles of patients' rights were observed by the Ottomans so that a regulation was published which underlines the behavior of the physicians to their patients. In this regulation, physicians were told to be tender and sincere and to be efficient in their fields. The physicians in Devlet-i Ali Osmaniye followed the examples of medical scientists such as al-Zahrāwī and İbn Sīnā.

Music Therapy for Patients with Mental Disease

Every patient had a special importance, and a proper treatment protocol was given according to the disease. For patients with mental disease, a psychiatry hospital was founded on the borders of the Ottoman Empire. A new era began when Sultan II. Bayezid Han, the son of Fatih Sultan Mehmed Han, constructed the Sultan Bayezid II Külliyesi (Fig. 2). Patients with mental disease were cured not only by medical treatment protocols but also by music therapy in this hospital. There were students studying medical science in the Madrasa inside the complex which is also adjacent to a mosque – called Külliye.

Another center for cure was Devlet-i Ali Osmaniye, Süleymaniye Medical Madrasa, which



Hospitals and Medical Schools in the Ottoman Empire, Fig. 2 Illustration of application of traction method for a patient with back problem in Sultan Bayezid

II Külliyesi which was built by Sultan II. Bayezid Han (r. 1481–1512) in 1488 (Reprinted with written permission of Mr. Veysel Engi from his personal photo archive)

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Kanuni Sultan Süleyman Han ordered to be built by Mimar Sinan. In this Madrasa, the students were studying medical science while having the chance of practical studies in the hospital (Turgut, 2010b). In Darüşşifa, treatments were free and drugs were provided free twice a week to other patients. Other important health centers of the Ottomans were Bayezid Darüşşifa in Bursa and Fatih and Sultan Ahmet Madaris in İstanbul. The health centers were the cornerstones of improvement in medical science (Turgut, 2010b). The foundations developed in the classical period formed the basis of medical science for centuries.

Studies in Ottoman Medicine

Hydrotherapy and Hygiene

European travelers reported the high level of hygiene in the Ottoman world. Water was used not only for hygiene but also as a therapeutic tool. Ottomans bathed in public baths called *hamam*, which were well known and safe in the Muslim community, pools, and rivers (Shefer-Mossensohn, 2009). In the hospital, the hamam was a part of the institution, and bathhouse attendants called *dellak* or *külkhani* maintained the personal hygiene of the patients (Shefer-Mossensohn, 2009).

Effects of Europeans on the Ottomans

Members of the medical Madrasa in İstanbul were not able to communicate with their colleagues in the Europe, because they didn't know European languages (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). However, Ottoman physicians realized that many diseases were contagious. Therefore, diseased people were held in isolated places where healthy people could not go.

Mustafa Behçet Efendi (1774–1834) who was the founder of the Tibhane-i Amire is considered the pioneer of current medical schools in Turkey (<http://www.muslimheritage.com/article/evolution-attitudes-towards-human-experimentation-ottoman-turkish-medicine>). Also, it was considered vital to speak a European language to be a good physician (Efendi, 1259; Ülman, 1995). In the nineteenth century, European medicine had a major effect upon Ottoman medicine, but the classic Islamic works and Hippocratic medicine were also used. According to legal regulations, the Civilian School of Medicine (Mülki Tibbiye) and the Military Medical School, called Mekteb-i Tibbiye-i Şahane, educated students for medical practice in the Ottoman Empire (Sarı, 1977). Most of the physicians educated at the Ottoman medical school went to different European

Hospitals and Medical Schools in the Ottoman Empire,

Fig. 3 Illustration of surgical cauterization technique for a patient by Şerafettin Sabuncuoğlu in the period of Fatih Sultan Mehmed Han (Reprinted with permission of the Atatürk Institute of Culture, Language and History, Institute of Turkish History from Uzel İ (1992))



medical institutions to gain clinical experience in their area.

As a unique sample of medical textbooks in the Ottomans, the *Cerrâhiyetü'l-Hâniyye*, which was dedicated to Fatih Sultan Mehmed Han, was written in Turkish. This book consists of three chapters divided into a total of 193 sections, including abundant colorful, descriptive drawings of surgical instruments and certain operations in the miniature format (Turgut, 2007, 2008; <http://www.muslimheritage.com/article/15th-century-turkish-physician-serefeddin-sabuncuoglu-author-cerrahiyetu-%E2%80%98l-haniyye>). In addition, Sabuncuoğlu added his own experiences based on his practice of surgery. Sabuncuoğlu drew his own color miniatures of surgical procedures (Figs. 3 and 4).

Şerafettin Sabuncuoğlu cites previous pioneers including Hippocrates, Ibn Sīnā, Galen, and al-Zahrāwī. In addition to different surgical instruments described by al-Zahrāwī, he illustrated new surgical interventions. The use of human images in the book marks a very important revolution in Turkish-Islamic medicine. The *Cerrâhiyetü'l-*

Hâniyye clearly demonstrates the high level of Turkish surgery in the Ottoman Empire during the fifteenth century (Turgut, 2007, 2008; Uzel, 1992).

Cerrâhiyetü'l-Hâniyye contains a total of four sections: cauterization techniques, general surgery including pediatric surgery and plastic surgery, orthopedics, and various medical preparations (Fig. 5) (Turgut, 2007, 2008; Uzel, 1992). In addition to many original contributions, Sabuncuoğlu's book is unique for the excellent illustrations that demonstrate the surgical interventions by showing the patients (Turgut, 2007, 2008). Sabuncuoğlu practiced not only as a surgeon but also as a general physician.

Surgical Procedures

In *Cerrâhiyetü'l-Haniyye*, there are a total of 191 sections on different surgical specialties, giving detailed information regarding the diagnosis, classification, and surgical techniques (Turgut, 2007). Şerafettin Sabuncuoğlu describes the management of some neurological diseases

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Fig. 4 Illustration of psychiatric treatment in a patient from Sabuncuoğlu (Reprinted with permission of the Atatürk Institute of Culture, Language and History, Institute of Turkish History from Uzel İ (1992))



Hospitals and Medical Schools in the Ottoman Empire, Fig. 5 Illustration demonstrating surgical treatment of water accumulation (congenital hydrocephalus) in

an infant from Sabuncuoğlu (Reprinted with permission of the Atatürk Institute of Culture, Language and History, Institute of Turkish History from Uzel İ (1992))

including traumatic injury of the spine, peripheral facial palsy, epileptic seizures, headache, stroke, vertebral fracture-dislocation, pediatric skull fractures, and hydrocephalus (Figs. 1, 3, 4, 5,

and 6) (Turgut, 2007, 2008). In particular, he gives useful information on surgical techniques and instruments for pediatric head injury (Turgut, 2007, 2008).



Hospitals and Medical Schools in the Ottoman Empire, Fig. 6 Illustration of removing dead fetus from a pregnant woman from Sabuncuoğlu (Reprinted with

permission of the Atatürk Institute of Culture, Language and History, Institute of Turkish History from Uzel İ (1992))

Start of Radiology in Ottomans

The discovery of X-rays by W. C. Roentgen in 1895 was immediately applied all around the world (Ülman, Livadas, & Yıldırım, 2005). The X-ray was added to Ottoman medicine by Esad Feyzi (Ülman et al., 2005). The first radiographies in Turkey were taken at the Imperial Medical School in 1896 by Esad Feyzi, who was an intern doctor having installed the first roentgen machine in İstanbul (Ülman et al.). One year later, he took X-rays of soldiers wounded at the Turkish-Greek war which might be the earliest example of imaging bullets and shrapnels embedded into the body of the wounded soldiers (Bir Kesf-i Muhim, 1896). More importantly, this might have been the first application of the X-ray method into military surgery all over the world (Ülman et al., 2005).

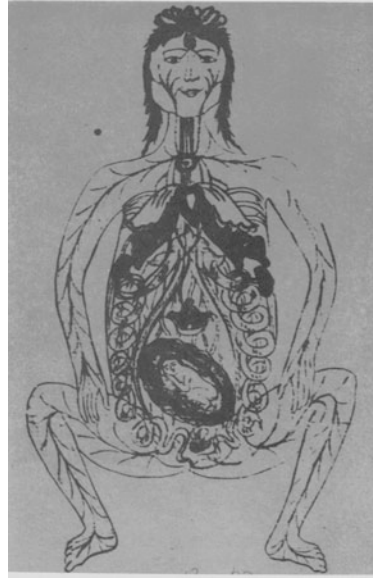
Another significant contribution by Esad Feyzi was his book entitled *Roentgen Rays*,

their Medical and Surgical Applications, published in 1898, which is the first work ever written on X-rays in Turkey (Ülman et al., 2005). Among the various fields covered in this book were proper localization of bullets and shrapnels embedded into the body, identification of foreign bodies aspirated into the esophagus, diagnosis of bone, kidney, and bladder stone diseases, and forensic medicine (Fig. 7) (Feyzi, 1899; Ülman et al., 2005).

Esad Feyzi's article published in *Nevsal-i Afiyet* (Yearbook of Health) was the first scientific article on the clinical use of X-rays in Turkish medical literature (Ülman et al., 2005). He succeeded in incorporating radiological examination as a specific branch of the surgical clinic (Dr. Rifat, 1905). Apart from İstanbul, İzmir (Smyrna) was the first Anatolian city where X-rays were used at the beginning of the twentieth century (Solomonides, 1955).



Hospitals and Medical Schools in the Ottoman Empire, Fig. 7 The hand radiograph of Boyabatlı Mehmed, one of the 1897 Greco-Turkish War veterans, is being taken by Roentgen apparatus integrated by Esad Feyzi and Rifat Osman (Feyzi, 1899)



Hospitals and Medical Schools in the Ottoman Empire, Fig. 8 Illustration of internal organs and fetus in intrauterine localization in a pregnant woman from İtaki (Reprinted from Şemseddin-i İtaki'nin Resimli Anatomi Kitabı with permission of the Atatürk Supreme Council for Culture, Language and History, Atatürk Culture Centre (Kahya, 1996))

Forensic Medicine

In the Ottoman Empire, there were anatomists such as Şemseddin-İtaki providing major contributions to medicine in the seventeenth century (Fig. 8) (Kahya, 1996), but the emergence of forensic medicine was a result of a modernization project through the nineteenth century. The first medical school called Mekteb-i Tibbiye-i Şahane (Royal School of Medicine) was established by Sultan Mahmud II Han for the army's health in 1839 (Gök, 1995; Gök & Özen, 1982). The first autopsy was done in 1841 by Dr. Charles Ambroise Bernard at this school, and the first description of the autopsy was noted in the book *Makalatı-Tıbbiye* written by Hayrullah Efendi (1820–1869) in 1843 (Gök, 1995; Oğuz & Cem, 2009). Afterward, the Department of Medical Jurisprudence in Zabita Tababet-i Adliye was established in İstanbul (Şehsuvaroğlu & Özen, 1974). The first morgue office was established in Sıhhiye-i Umuriye (Gök & Özen, 1982; Şehsuvaroğlu & Özen, 1974).

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Huangdi Jiuding Shendan Jing

Fabrizio Pregadio

The *Huangdi jiuding shendan jing* (Book of the Divine Elixirs of the Nine Tripods of the Yellow Emperor) also known as *Jiudan jing* (Book of the Nine Elixirs) is one of the earliest extant Chinese alchemical texts. Quotations and other references in Ge Hong's *Baopu zi neipian* suggest that the text circulated in a form at least substantially similar to the current one by the end of the third century. The extant version, dating from the latter half of the seventh century, is found in the *Daozang* (Daoist Canon). It is followed by an extended commentary that represents in its own right a compendium of early medieval Chinese alchemy.

Besides its early date, the *Book of the Nine Elixirs* is significant as it provides one of the most complete descriptions of the alchemical practice in China, from the preliminary rituals to the compounding and ingestion of the elixirs. The ritual features include purifications, interdictions, secrecy, retirement, choice of time, delimitation of space, and ceremonies for transmitting the text, for starting the fire, and for ingesting the elixirs.

The compounding begins after the preliminary ritual practices. The first step consists in the preparation of an amalgam of refined lead and mercury, said to contain the essences of Heaven and

Earth, or Yin and *Yang*. This compound is used as a layer in the crucible together with the ingredients of the elixirs. Then one prepares a mud used for sealing the crucible and prevent the loss of *qi* (energy), thus recreating inside the vessel conditions similar to those of primeval chaos.

The methods of the Nine Elixirs proper are based on processes of sublimation (*fei*). The substances most commonly used are mercury, orpiment, realgar, malachite, arsenolite, magnetite, cinnabar, alum, and hematite. The ingredients are first placed in a tightly sealed crucible, and heated on a fire progressively made more intense. After the required number of days, the crucible is left to cool and is opened. The essence is carefully collected from the higher part of the crucible, and mixed with a moistening substance. The elixirs should be ingested at dawn, facing the sun. Their ingestion is said to bestow eternal life, command over gods and spirits, protection from calamities, and sometimes magical powers. Some of the Nine Elixirs can be transmuted into alchemical gold. The text emphasizes that the purpose of this final transmutation is to make sure that the compounds have been correctly prepared.

See Also

- [Alchemy in China](#)
- [Ge Hong](#)
- [Yinyang](#)

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Huangdi Neijing

Richard Bertschinger

The *Huangdi Neijing* (Yellow Emperor's Inner Canon) is the most famous and oldest medical classic of China, being compiled by various unknown authors from the period of the Warring States (475–221 B.C.E.) onward. The book consists of 2 main sections, each of 81 chapters: the *Suwen* (Plain Questions) and *Ling Shu* (Miraculous Pivot), the latter being earlier entitled the *Zhen Jing* (Needling Classic).

These texts are the very earliest to be written on Chinese medical theory. However, Keegan has shown conclusively that none of the *Neijings* now extant are the original. Lu and Needham also summarized the evidence and considered that the corpus was probably already well formed by the first century B.C.E.

The Canon achieved something close to its known form with the recension (ca. A.D. 762) which came about with the editorship of Wang Ping during the Tang dynasty. Another edition, the *Huangdi Neijing Taisu* (Great Simplicity), recently discovered in Japan, may be considered closer to the original text. The insertion of chapters into the text, including those on *wuyun liuqi* (The Theory of the Five Elemental Cycles and Six Climates), undoubtedly took place some time close to the mid-tenth century (Lu & Needham, 1980). Since this date, however, the contents have been fixed.

The book takes on a question and answer form, in which the legendary Yellow Emperor questions his ministers about the need for a medical reformation, in accord with the prevailing tone of Han thought. In the opening paragraphs the Emperor questions his minister-physician Qi Bo:

The Yellow Emperor asked: "I have heard that the men of ancient times lived through a hundred springs and autumns, and remained active and did not reach senility. Now our men only reach half

that age and they are senile. Are we so very different? Or have we missed something?"

Qi Bo replied: "The men of ancient times, they understood the Way, they modelled themselves on Yin and Yang and were at peace with the arts of guiding their destiny. They ate and drank in moderation, they rose and retired at regular hours, neither made wild schemes, nor wearied their bodies at work. . . . The men of the present day are not the same. They drink liquor to excess, they take wild thinking as the norm. When drunk they perform the act of love, seeking to exhaust their energies and waste their lives. They do not know how to be content. They have no time to control the passage of their thoughts, looking only for what cheers – not for the joys of health" (Ch. 1).

This sets the tone for the preventative and rehabilitative character which dominates Chinese medicine. Later in the chapter, the same need for ataraxia (peace of mind) is stressed:

Detach and be at peace, humble and empty – and the true energies will follow. The vital spirit, guard it within! How then can disease arrive?

Among the Canon's other ideas are the well-developed tract system of 12 main channels and numerous collaterals (the *jingluo*); and the science of the 5 elements (*wuxing*): fire, earth, metal, water, and wood. It also introduces the classificatory dialectical tool of *Yin/Yang* (earth/heaven, dark/light, night/day, solid/hollow, etc.). Many chapters also describe the relationship between human beings and their environment, and refer in great detail to circadian, or internal, rhythms within the body. These biological clocks foreshadowed the modern science of chronobiology.

Surgery is also mentioned, and the *bian* stone needle as the forerunner of acupuncture. The Canon accurately identifies gangrene in the feet and says it is more common in the toes, where it advises amputation to save lives. This is just one of the many ideas prevalent in the book which accords with modern medical theory.

See Also

- [Acupuncture](#)
- [Five Phases \(Wuxing\)](#)
- [Yinyang](#)

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Huangfu Mi

Hong Wuli

Huangfu Mi was born in 215 in Anding Chao'na (now Pingliang County, Gansu Province) and died in 282. He was born to a poor family and did not receive any education until he was 20 years of age, after which he devoted all his time to reading, extensively and intensively, all kinds of ancient literature. He eventually became a great master in the art of classics.

During the period 256–260, he suffered *Feng Bi* or apoplexy and became hemiplegic. From then on, he began to study medicine. In view of the overlapping of many texts in several medical classics, he decided to compile a new book on the art of acupuncture and ► [moxibustion](#) under the principle of "sorting out the similarities, excluding the meaningless and useless words and sentences, deleting unnecessary repetition and extracting the essence". He did this by incorporating the relevant portions from the three classics, namely ► [Huangdi Neijing su wen](#) (*Plain Question of Huangdi's Inner Canon*), *Zhenjing* (*Classic of Acupuncture*), and *Ming tang kong xue zhen jiu zhi yao* (*Essentials of Treatment for Acupuncture and Moxibustion with Anatomical Charts and Acupoints*).

A 12-volume *Zhen jiu jia yi jing* (A-B classic of Acupuncture and Moxibustion) was written and divided into two parts. One of them deals with the physiology of the human body, indications for each acupoint, diagnostic measures, way of puncturing, and pathophysiology. The other part is devoted to clinical knowledge, including internal medicine, surgery, pediatrics, and gynecology, with special reference to internal medical science. Emphasis is laid on the unification of channels and acupoints and on exploration of indications and contraindications for acumoxibustion therapy. This work, from which most of the works on acupuncture and moxibustion of later ages were derived, exerted great influence on the development of the art of acupuncture and moxibustion in successive generations. Erudite and learned, Huangfu Mi was very productive in his writings, including works on history and classical literature.

During his time, it was a custom to swallow processed stone remedies for seeking longevity and as an aphrodisiac. Huangfu Mi also practiced this behavior and was brought to the brink of death after a critical illness. After he fortunately recovered, he wrote a book, *Han shi san lun* (On Stone Powder To Be Swallowed Cold) to advise people to avoid such harmful and potentially fatal behavior.

See Also

► [Medical Texts in China](#)

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Ḥunayn Ibn Ishāq

Albert Z. Iskandar

Abū Zayd Ḥunayn Ibn Ishāq al-'Ibādī (Johannitius A.D. 808–873), a physician, philosopher, and translator, was born in al-Ḥīrah (Hira), now southeast of al-Najaf (Iraq). He and his ancestors were Syrians who belonged to the Nestorian church. The family nickname, al-'Ibādī, is derived from “al-'Ibād,” a Christian Arab tribe.

Ḥunayn studied medicine in his youth in Baghdad. The thirteenth-century medical historian, Ibn Abī Uṣaybi'a, author of the book *ʿUyūn al-Anbāʾ fī Ṭabaqāt al-Aṭibbā* (Sources of Information about the Classes of Physicians), gives a lively account of the difficulties that confronted Hunayn as a student of medicine. Yūḥannā ► [Ibn Māsawayh](#) (Mesue d. A.D. 857) was a famous physician and a highly respected teacher of medicine. He conducted classes in a vast room in his large house. Questions from young Hunayn, who was very keen on amassing knowledge, interrupted the serenity of Mesue's lessons. Mesue reprimanded Hunayn several times without effect, then finally ordered him out of the classroom and told him to give up medicine. Mesue advised him to trade in coins instead, which he believed would be financially more rewarding than the practice of medicine. Mesue had in mind the fact that most of the residents of Hira were merchants and money changers. So far as one can tell, Hunayn abandoned Mesue's tutorship and decided on self-education.

Bakhtīshūʿ Ibn Jibrāʾīl, a contemporary of Ḥunayn, held regular meetings at which physicians and philosophers debated questions and problems raised by Caliph al-Mutawakkil (d. A.D. 861). Ḥunayn was invited to attend these meetings at which he showed medical acumen. Al-Mutawakkil is reported to have endowed a school of translation, and appointed Hunayn as its head. Among the members of this school were Ḥunayn's son, Ishāq Ibn Ḥunayn (d. A.D. 910), who translated from Greek into Syriac and

Arabic. He also took charge of revising, against the original Greek, translations by his colleagues. It is worth noting that Ishāq's translations were carefully revised and corrected, whenever necessary, by Ḥunayn himself. Towards the end of his life, Ḥunayn embarked on an Arabic translation of Galen's *De partibus artis medicativae* (*On the Parts of Medicine; Fī Ajzā' al-ṭibb*), of which he had earlier rendered the Greek text into Syriac. Death prevented him from completing his translation. Ishāq attended to Ḥunayn's unfinished work.

Another eminent translator in Ḥunayn's school was his nephew, Ḥubaysh Ibn al-Ḥasan al-A'sam, who was involved in translating Galen's (d. ca. A.D. 200) *De anatomicis administrationibus* (*On Anatomical Procedures; Fī 'Amal al-Tashrīḥ*) into Arabic. This work consists of 15 books. It was translated into Syriac by Ayyūb al-Ruhāwī (Job of Edessa) for Jibrā'īl Ibn Bakhtīshū' (d. A.D. 828–829). A revised Syriac translation was made by Ḥunayn himself for Yūḥannā Ibn Māsawayh. It is generally accepted that Ḥubaysh produced an Arabic version about the end of Ḥunayn's life, and with his active collaboration.

Ḥunayn's school of translation helped to establish a firm foundation upon which medieval Arabic medicine and allied sciences were securely built. Renowned Arabic-speaking physician-philosophers, like ► [al-Rāzī](#) (Rhazes d. A.D. 925) and Ibn Sīnā (Avicenna d. A.D. 1037), and many others, owe Ḥunayn and members of his school a great debt for rendering fundamental Greek texts of antiquity into Arabic, the language of learned men at the time.

Al-Mutawakkil elevated Ḥunayn to the post of Chief Court Physician and dismissed Bakhtīshū' Ibn Jibrā'īl. The latter conspired against Ḥunayn, and, unfortunately, Ḥunayn fell from grace. Al-Mutawakkil ordered the sequestration of Ḥunayn's entire library.

Ḥunayn was 48 when he compiled the first draft of his *Risālat Ḥunayn Ibn Ishāq ilā 'Alī Ibn Yaḥyā fī Dhikr mā Turjima min Kutub Jālīnūs bi-'Ilmih wa-ba'd mā lam Yu-tarjam* (Missive to 'Alī Ibn Yaḥyā on Galen's Books Which, so far as Ḥunayn Knows, Have Been

Translated, and Some of Those Books Which Have Not Been Translated). The fact that Ḥunayn's *Missive*, which presents impressive information about some of his predecessors and contemporaries, was compiled, he says, after the loss of his library, indicates his complete dedication to his work. 'Alī Ibn Yaḥyā, to whom Ḥunayn's *Missive* was dedicated, was a powerful friend and a private confidant of Caliph al-Mutawakkil. Through his intercession, Ḥunayn later recovered his own library.

The following are a few examples to shed light on the depth of Ḥunayn's involvement in translating Galen:

- The *Pinax* (*Index; Fīnaks*) was translated into Syriac for a doctor named Dā'ūd and into Arabic for Muḥammad Ibn Mūsā
- *De ordine librorum suorum* (*On the Order of His Books; Fī Marātib Qirā' at Kutubih*), into Arabic for Aḥmad Ibn Mūsā
- *De sectis ad eos, qui introducuntur* (*On Sects; Fī' al-Firaq*, into Syriac when Ḥunayn was 20 years of age, and another translation for Ḥubaysh when Ḥunayn was 40
- *De febrium differentiis* (*On the Types of Fevers; Fī Aṣnāf al-Ḥummayāt*), the first book to be translated by Ḥunayn, into Syriac, and another translation for his son when he discovered textual gaps which he filled in by collating against other manuscripts, and again into Arabic for Abu'l-Ḥasan Aḥmad Ibn Mūsā
- *De crīsis* (*On Crisis; Fī' al-Buḥrān*). First Ḥunayn corrected a Syriac translation by Sergius of Resaina (d. A.D. 536), then produced an Arabic version for Muḥammad Ibn Mūsā. All these and many more are discussed in detail in Ḥunayn's *Missive*

In spite of his fame as a translator, he was scoffed at by doctors when he wished to practice the art of physic. They admitted that he was an excellent translator, yet he was not a doctor, in the same way that a blacksmith could forge a beautiful sword without himself being a swordsman.

Ḥunayn was also a medical author in his own right. His books are mainly based on Greek sources, such as: *Fī Awjā' al-Ma'idah*

(*On Stomach Ailments*) and *al-Masā'il fi'l-tibb li'l-Muta'allimīn* (*Questions on Medicine for Students*). His book entitled *al-ʿAshar Maqālāt fi'l-ʿAyn* (*The Ten Treatises on the Eye*), covering both the theory and practice of medicine, ranks highly among medieval books of ophthalmology.

Historians of medicine and science are greatly indebted to Hunayn and his school of translation. Without their efforts, many of the works of antiquity would have probably been lost forever. Two examples will suffice. Galen's *On Anatomical Procedures* (*Fī ʿAmāl al-Tashrīḥ*) of which Books IX (in part) and X–XV (inclusive) are lost in the original Greek, is preserved in its entirety in Arabic manuscripts. Again, Galen's book *De optimo medico cognoscendo* (*On Examinations by Which the Best Physicians are Recognized*) is entirely lost in the original Greek. Hunayn's Arabic version has survived in two manuscripts.

See Also

- [al-Rāzī](#)
- [Hunayn Ibn Ishāq](#)
- [Ibn Māsawayh](#)
- [Ibn Sīnā \(Avicenna\)](#)

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Huntian

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Huntian is the Chinese name for a scheme of cosmography, often mentioned as in opposition to the ► [gaitian](#). According to explanations of this scheme, heaven is a sphere surrounding a flat earth whose upper surface lies across its diame-tral plane. Heaven is therefore continuous (*hun hun ran*), unlike the situation described by the *gaitian*, under which heaven has a boundary. The heavenly sphere rotates once daily about an axis inclined at 35° to the horizontal, carrying with it the heavenly bodies, whose risings and settings occur as they move above and below the plane of the earth's surface. The Chinese observer is imagined to be at the center of the earth, and hence at the center of the heavenly sphere. Since the latitude of most ancient Chinese capi-tals was about 35° north, the *huntian* universe

acts as a sort of cosmic planetarium for the official astronomers at those capitals. Observers near the edge of the earth would see a very odd and asymmetrical series of celestial phenomena, but the diameter of the sphere is so large (one version gives a figure equivalent to over 140,000 mile) that the entire inhabited world is effectively at the center of the universe.

The first full account of the *huntian* cosmography is that of ► [Zhang Heng](#), written ca. AD 117. Thereafter it is the usual scheme referred to by those concerned with mathematical astronomy, and a number of texts point out its advantages compared with the *gaitian*. The innovation of the *huntian* was apparently connected with the introduction of the armillary sphere in China at some time after 100 BCE. The nested rings of such an instrument are highly suggestive of the skeleton of the celestial sphere. It would be a mistake, however, to see debates on cosmography as a crucial concern for astronomers in China, since the algebraic/arithmetic character of Chinese mathematical astronomy meant that the detailed geometry of the cosmos was much less of an issue than it was in ancient Greece and Renaissance Europe.

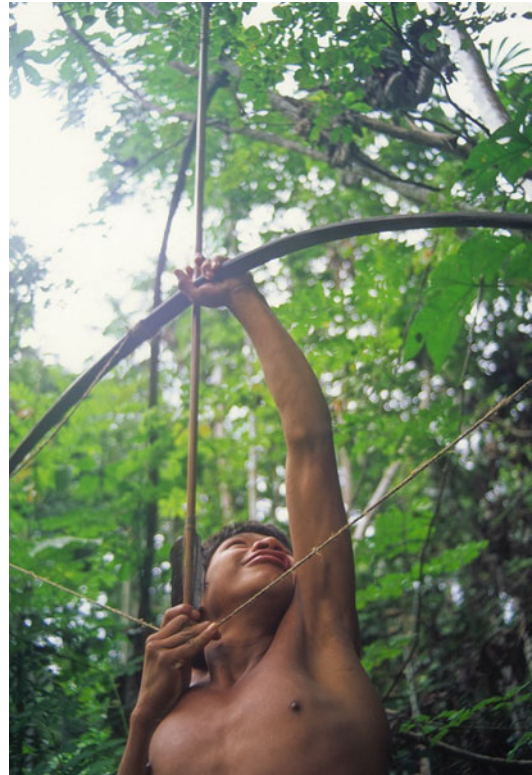
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Hunting in Amazonia

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Hunting is an important food source for Amazon forest dwellers, indigenous and nonindigenous alike. Hunting and predation also represent central concepts in the worldview and social organization of native Amazonian peoples. Both



Hunting in Amazonia, Fig. 1 A Matsigenka bow hunter on the upper Manu River, Peru, 1996

approaches – hunting as a subsistence activity or ecological adaptation and hunting as a social and symbolic practice – are essential for understanding the impact of local livelihoods on Amazonian biodiversity. Unfortunately, the divergent methods and theoretical orientations of these potentially complimentary approaches rarely if ever create a dialog in the scientific literature.

Hunting became a central concern in the 1970s for anthropologists attempting to understand the supposedly low levels of sociocultural complexity of Amazonian indigenous peoples (Fig. 1). Archeologist Betty Meggers (1971) suggested that Amazonia was a “false paradise,” imposing ecological limitations on the growth and social stratification of native societies from ancient times through the present. A whole field of ecologically oriented anthropological studies grew up around the “protein debate,” namely, whether protein capture was a limiting factor on historical and modern Amazonian societies (Gross, 1975).

The debate turned out to be largely spurious, since, as Beckerman (1979) said, protein from aquatic animals, terrestrial game, and even vegetable sources turned out to be more abundant than originally estimated. Moreover, recent archeology has demonstrated far more densely settled and complex societies in prehistoric times than those observed in the ethnographic record (Denevan 1976; Heckenberger et al., 2008). Though the protein debate faded away, quantitative studies on hunting and other subsistence activities by Amazonian communities continued, becoming heavily influenced by microeconomic theory (Alvard & Kaplan 1991; Hames & Vickers, 1982; Hawkes, Hill, & O'Connell, 1982). "Optimal foraging" models predict that hunters' choices will be largely constrained by practical considerations maximizing protein return for time invested, which is to say, "bringing home the biggest bacon" (Jerozolinski & Peres, 2003).

But hunting for indigenous societies of the Amazon is not just a means of obtaining protein. The exchange of meat is important in defining social, political, and even sexual relationships (Siskind 1973). In the Amazonian cosmos-as-ecosystem, hunting is a fundamental metaphor that structures the mutual exchanges, ecological as well as cosmological, between humans, animals, and the spirit world (Reichel-Dolmatoff, 1976; Århem, 1996). Just as humans hunt and kill animals for food, so do certain dangerous animals, demons, and other spirits look upon humans as animals of prey. Widely shared across native Amazonian societies are myths about how primordial humans were transformed into animals and other beings. Despite this transformation in their outward appearance, all such beings retain their fundamental human nature and, indeed, continue to view themselves as humans.

According to the mythology of the Matsigenka people of Peru, for example, the snake is a hunter with poisonous arrows (Shepard, 2002a). The hunter himself is invisible: the snakes that human beings see are his arrows. The snake views himself as a human being, out in the forest, hunting for his family. When he looks at a human person, he sees a tapir, a peccary, or

some other animal of prey, which he shoots and kills to feed his family. Likewise the Matsigenka believe that the spirits of hunted animals can take revenge on a human hunter's family, making small children fall ill or die suddenly, thus reversing the role of predator and prey in a cosmological tit-for-tat (Shepard, 2002b). In the fluid Amazonian worldview, rife with transformations across species boundaries, most beings are both human and animal; their status in any given relationship depends on the point of view, or what is called "cosmological perspective" (Viveiros de Castro, 1996). This prolific area of anthropological study, intellectual heir to the structuralist paradigm of Claude Lévi-Strauss, is thus called "perspectivism." Indigenous rituals and practices associated with hunting are often concerned with re-signifying the killing of the animal to remove its human subjectivity so that the predatory act will not be interpreted as an act of warfare by the offended animal spirit (Fausto, 2007) (Fig. 2).

Both cosmological concepts and practical considerations influence the dietary choices of Amazonian populations, native and otherwise, through restrictions and taboos on their consumption of game animals, fish, and other foods. Indigenous as well as nonindigenous riverine Amazonian peoples may avoid or reject meats and fish with particularly strong or unusual odors, especially during periods of ritual vulnerability like pregnancy, *couvade*,¹ illness, or old age (Murrieta, 2001; Piperata, 2008; Shepard, 2004). Ross (1978) interprets game animal taboos in Amazonia as adaptive responses, aimed at protecting particularly vulnerable species. However Milton's (1991) comparative study documents such a wide variety of dietary taboos among different indigenous societies that any single ecological explanation would be too simplistic; instead, symbolic considerations and notions of group identity appear to be the overriding factor. Yet biologists and ecological

¹The custom in some cultures in which a man takes to his bed and goes through certain rituals when his child is being born, as though he were physically affected by the birth



Hunting in Amazonia, Fig. 2 If possible, Matsigenka hunters avoid touching the animals they have killed, leaving close kinsmen such as a brother-in-law to carry the animal home. In this way, the hunter avoids contaminating himself with the animal's blood and strong odor, which could offend the animal's spirit. The practice also ensures that meat is shared among kin (Manu, Peru, 1996)

anthropologists tend to overlook or ignore altogether the role of food taboos and other cultural factors influencing hunters' choices (see Shepard, 2002b) (Fig. 3).

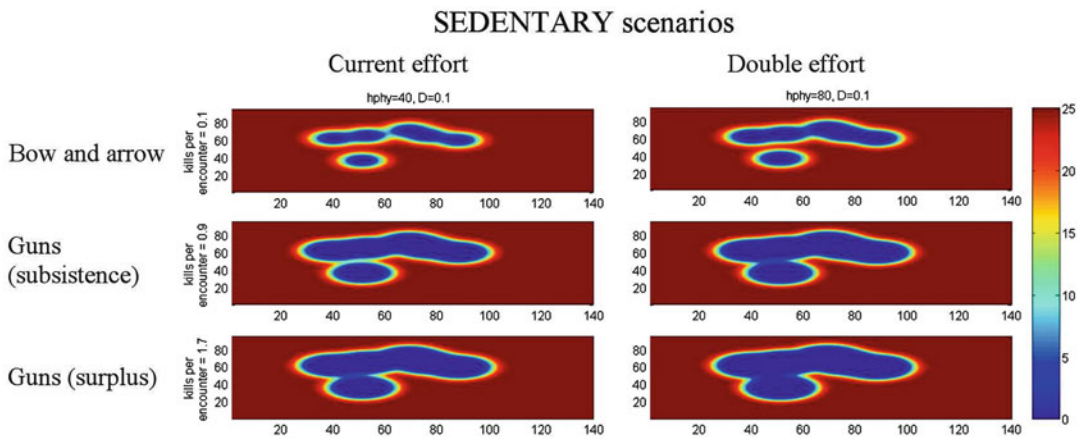
The spatial impacts of hunting pressure are also influenced by variable social systems and cultural norms. Yanomami villages, for example, periodically migrate, creating a "reticular" rather than "central-place" pattern of resource use (Albert & LeTourneau, 2007). Indigenous hunters of the Guyana region appear to avoid sacred places in their hunting excursions, though ecological and geographic factors also strongly affect their choices (Read, Fragoso, & Silvius, 2010). Variable local beliefs and practices related to hunting and food consumption ultimately



Hunting in Amazonia, Fig. 3 White-lipped peccaries are among Amazonian hunters' favorite prey (Manu, Peru, 2007)

influence hunters' behavior and modulate their impact on the local fauna. Developing adequate community-based management systems necessarily requires understanding and leveraging such local concepts (Shepard, 2002b; Vieira, von Muhlen & Shepard, *in press*).

With growing international concern over the erosion of Amazonian biodiversity, ecological anthropologists and tropical biologists have invested much research effort in evaluating the impact of hunting by indigenous and other local populations on vulnerable animal species (Alvard, Robinson, Redford, & Kaplan, 1997; Ohl-Schacherer et al., 2007; Peres, 2000; Robinson & Bodmer, 1999; Sirén, Hamback, & Machoa, 2004; Souza-Mazurek et al., 2000). "Sustainability indices" have been used to calculate the maximum sustainable harvest for different animal species (Robinson & Redford, 1991). Yet such indices depend on detailed quantitative inputs about hunting activity in the study communities, requiring extensive fieldwork. Ongoing empirical research is essential, but it is impractical to conduct hunting surveys in every community to develop case-by-case management strategies. As a way of streamlining conservation planning, computerized modeling techniques have been developed to simulate the intensity and extent of depletion of key species through space and time across different management strategies (Levi, Shepard, Ohl-Schacherer, Peres, & Yu, 2009; Shepard, Levi, Neves, Peres, & Yu, 2012) (Fig. 4).



Hunting in Amazonia, Fig. 4 Spatial modeling described in Levi et al. (2009) and Shepard et al. (2012) allows communities and conservation planners to better

understand the long-term impacts of different management scenarios on the depletion of key game animal species

H

Some conservation biologists question the traditional view of indigenous societies as innate defenders of nature, especially once they adopt Western technology (Redford, 1991). Many conservationists fear that growing, Westernizing indigenous and other local populations will decimate biodiversity (Robinson, 1993; Terborgh, 1999; Peres, 2011). Defenders of indigenous people, however, have contested that indigenous reserves are as efficient as parks at preventing deforestation and fires (Nepstad et al., 2006) and that the “biodiversity cost” exacted by indigenous groups is compensated if they are empowered to deter incursions by more destructive loggers, miners, and ranchers (Yu, Levi, & Shepard, 2010; Zimmerman, Peres, Malcolm, & Turner, 2001). Moreover, indigenous reserves and other human-inhabited protected areas account for more than half of all forest reserves in Amazonia (Peres, 1993), meaning that the conservation of vertebrate biodiversity on a large scale must contemplate the management of hunting by local populations, ideally with their participation (Chapin, 2004; Sheil & Lawrence, 2004) (Fig. 5).

If biodiversity is to be conserved across Amazonia, hunting management strategies must be biologically sound, socially and culturally



Hunting in Amazonia, Fig. 5 As indigenous hunters adopt firearms, their impact on game animal populations increases dramatically (Rondonia, Brazil, 2001)

sensitive, as well as practical and enforceable on the ground (Yu et al., 2010). Hunting is a complex and variable socio-environmental practice, and adequate management requires ongoing dialog across multiple disciplines and collaboration between local people, scientists, and conservation planners.

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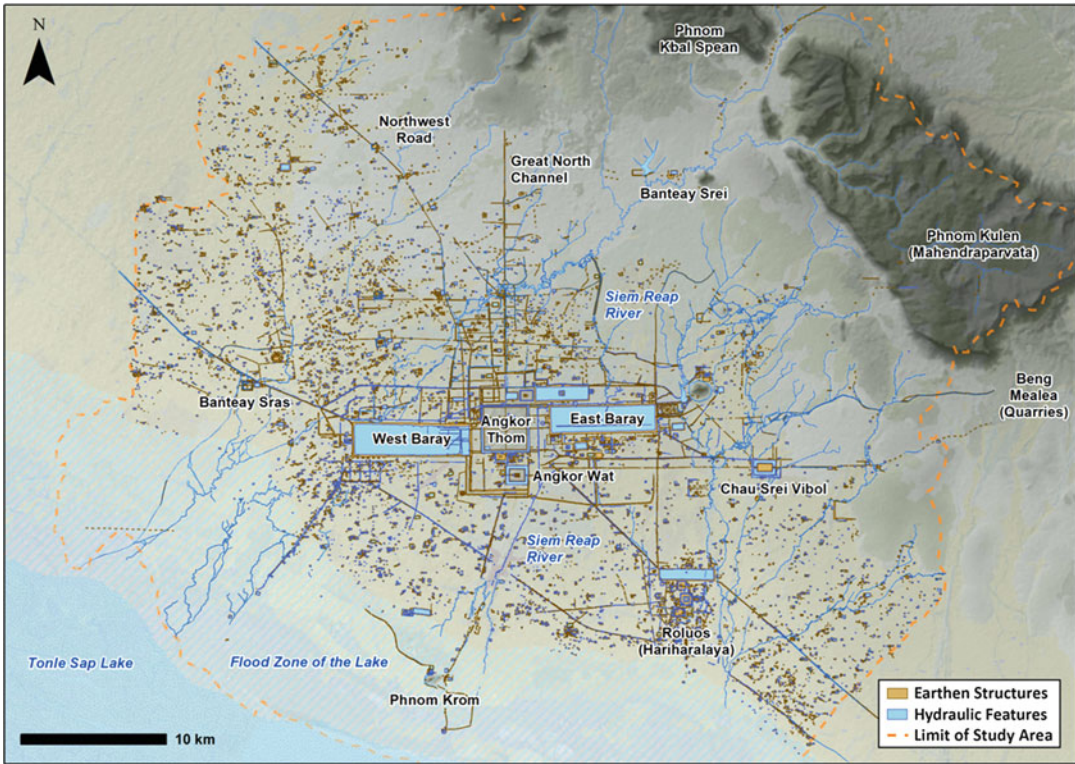
Hydraulic Engineering at Angkor

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The network of water management infrastructure that was developed in the heartland of the Khmer Empire during the classical Angkor Period (approximately ninth to fifteenth centuries AD) is one of the signal engineering achievements of the preindustrial world. Over several centuries, an elaborate and sophisticated water management system was developed over an area of approximately 1,500 km² around the great monuments of Angkor (Fig. 1). The network integrated and sustained a thriving metropolis of several hundred thousand people, located at the heart of an Empire that dominated mainland Southeast Asia for half a millennium. At the same time, it may have created a range of challenges to the long-term viability of that urban complex and to the Angkorian civilization itself (Evans et al. 2007).

The broader network consists of three major components: an upstream system of diversions, canals, and dams designed to alter the natural flow of water across the Angkor plain and channel water toward the central monumental zone; a central system of temple moats and vast reservoirs (known locally as *baray*) designed to store that water (Fig. 2); and a downstream system of canals radiating out from the center designed for the dispersal of stored water (Kummu 2009). With the exception of a handful of masonry spillways and culverts, and perhaps some wooden elements that have long since rotted away, the system is made almost entirely of earth: the channels and reservoirs were dug by hand, with the spoil from those excavations used to form earthen banks. Remnant traces of the system can still clearly be identified from the air (Fig. 3), and studies of archaeological topography have been used to reconstruct the overall structure of the system. However, the system is so complex, and so spatially and temporally extensive, that it is difficult at



Hydraulic Engineering at Angkor, Fig. 1 Archaeological map of Greater Angkor (Christophe Pottier and Damian Evans; background data NASA & JICA)

this stage to arrive at detailed or sophisticated models of its chronological development. However, we can see the broad outlines of major new developments from the beginning of the ninth century (in Phnom Kulen) through to at least the twelfth century (Fletcher et al. 2008).

The greater Angkor area was perhaps the most extensive urban complex of the preindustrial world, and the water management network played a crucial role in functionally integrating the vast inhabited landscape and providing a mechanism of transportation and communication. The stones that were used to build the monuments, for example, were floated down from distant quarries to temples like Angkor Wat by way of canals. In addition to these functional aspects, the waters of Angkor had powerful ritual and symbolic dimensions. They represented the cosmic oceans of Hindu-Buddhist mythology, rendered quite literally into the sacred geography of the earthly realm. Royal programs of

infrastructural renewal and hydraulic engineering reflected a ruler's mastery over the elements and were a key foundation of Angkorian kingship. It is important to note, however, that not all of the system was state-sponsored or controlled and that manipulation of land and water occurred at all scales, right down to the level of individual farmers digging household ponds and building small earthen dams to retain floodwaters.

The question of whether the large-scale system was used for irrigation has been controversial (Pottier 2000). One of the key challenges to the viability of inland agrarian civilizations in monsoon Asia is the sharp seasonality of the rainfall, which can produce an overabundance of water during the wet season followed by severely arid conditions during the remaining half of the year. Furthermore, subsistence-level rice farmers, who depend on the monsoon rains to flood (Fig. 4) their fields and produce a single crop per year, are very vulnerable to annual fluctuations in rainfall.



H

Hydraulic Engineering at Angkor, Fig. 2 Angkor Wat and moat, with the West Baray and medieval canals in the background



Hydraulic Engineering at Angkor, Fig. 3 The temple of Banteay Samre with remnant traces of ponds and canals in the immediate area



Hydraulic Engineering at Angkor, Fig. 4 The patchwork of walled rice fields on the Angkor plain, with the Phnom Kulen ranges in the distance

Since at least the 1940s, archaeologists have proposed that Angkor's engineered landscape was developed, at least in part, as a technical solution to those problems. In this view, by mitigating the risk of water scarcity at the seasonal and annual scale, the hydraulic network afforded a measure of food security – and potentially agricultural surpluses – that contributed substantially to the rise of Angkor. A related argument is that the network was unsustainable and created systemic vulnerabilities to longer-term social and environmental changes and that the failure of the system contributed to Angkor's decline. This “hydraulic city” hypothesis has attracted sustained criticism since the 1970s, and although new findings have in fact lent considerable support to the hypothesis, uncertainty still surrounds various aspects of the theory. For example, although recent studies have shown that Angkor's hydraulic network was technically capable of irrigating rice fields, providing a measure of food and water security, and producing significantly improved agricultural

yields, it still remains unclear to what extent this potential was actually realized.

Exactly when the water management system ceased to function also remains unclear and is the subject of ongoing investigations. For some parts of the system, such as the *baray* and several of the canals, there is evidence for episodic breakdown and rehabilitation throughout the Angkor period, perhaps indicating that the system was problematic from the very beginning and that significant resources had to be devoted to maintenance and repair (Lustig et al. 2008). In any case, it seems clear that the bulk of the system had fallen into disuse by the fourteenth or fifteenth centuries, although European accounts indicate that at least some canals in the central urban area were still functioning into the fifteenth and sixteenth centuries. With the dawn of the colonial period in the nineteenth century, almost all of the system was nonfunctional, although various elements (including two of the four great *baray*) have

been rehabilitated in modern times. Thus, even today, the medieval system still functions in a modified form.

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Hydraulic Engineering in Ancient Peru and Bolivia

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As climate and weather variations played a major role in determining the agricultural strategies of societies in ancient Peru and Bolivia at their major sites (Fig. 1) (Binford, Kolata, & Brenner, 1997; Ortloff & Kolata, 1993), it is of interest to track the adaptive strategies those societies used

to combat uncertainties in agricultural production. Of most interest are those used to counter excessive rainfall and drought and their effect on agricultural field systems over different time periods. Such strategies arise from application of water engineering technology to defend/enhance agricultural production in the face of climactic stress. The defense strategies are specific to different geographic sectors, societies, and cultural periods and represent integrated programs to protect large investments in agricultural fields and water supply systems. Figure 2 shows many types of agricultural systems employed by different societies in different areas of pre-Columbian South America. Figure 2 organizes agricultural systems into categories supplied by surface water sources (rainfall, springs) and subsurface systems (groundwater) on the vertical axis and on the horizontal axis, for artificially created and natural farming surfaces. For each of these major categories, defense strategies to protect from excessive rainfall, floods, and drought exist along with performance and efficiency improvement strategies to increase agricultural yields under predictable weather patterns. Examples of all these strategies put into practice by ancient water engineers are found in the archaeological record and indicate that irrigation farming was truly a science practiced with considerable foresight and oversight to maintain productivity despite the many variations in climate and weather that influenced agricultural output.

While modern systems can use produce from different worldwide climate zones throughout the year, ancient systems had extreme vulnerability to climate- and weather-induced collapse of their systems. On this basis, the defensive measures listed in Table 1 give indication to the concern of ancient societies to protect their agricultural systems to the degree that their technology and innovative resources permitted. The catalog of defensive measures listed in Table 1 gives direct evidence of memory and response of past catastrophic climate and weather events and constitutes further evidence of the importance of such events in shaping the technological responses to protect agricultural fields systems and vital canal

Hydraulic Engineering in Ancient Peru and Bolivia, Fig. 1 Major site locations mentioned in the text



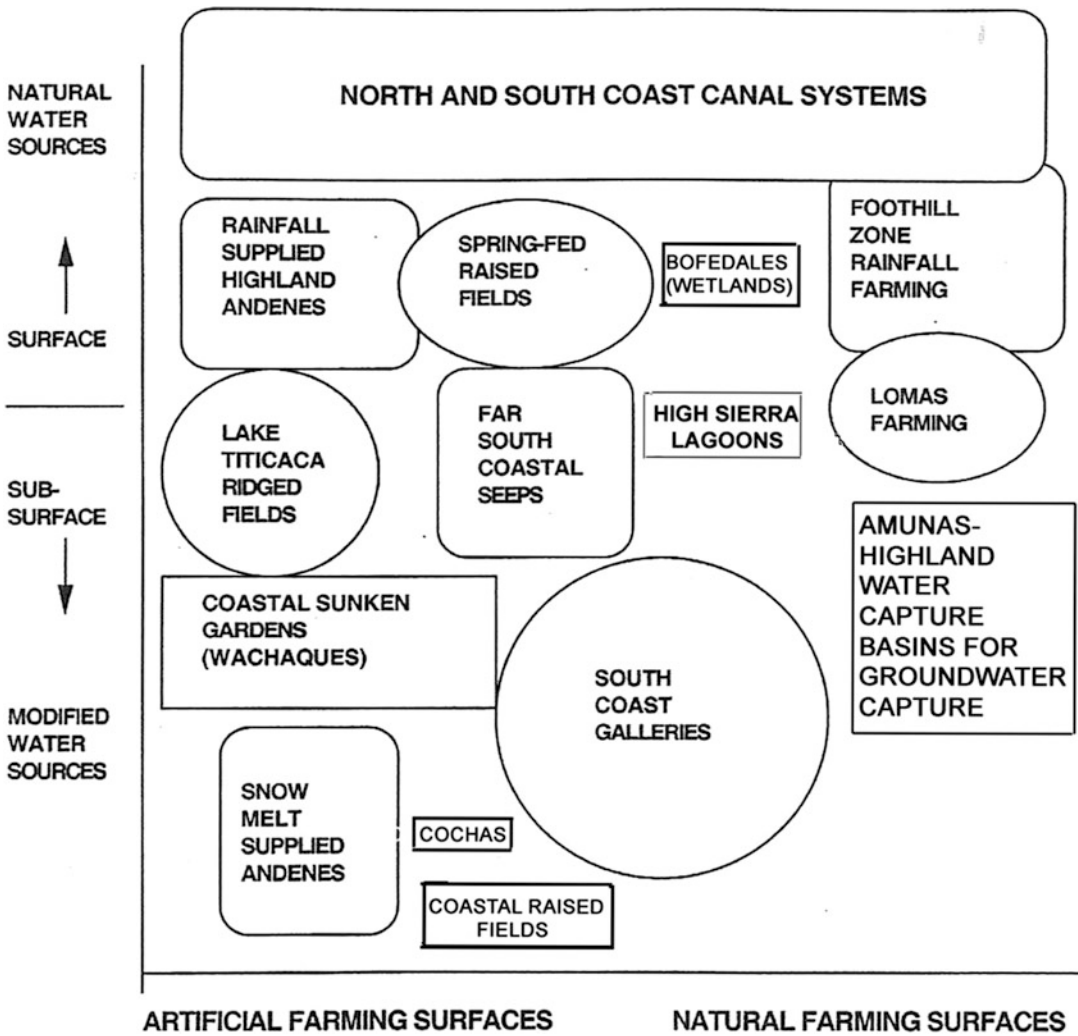
and aqueduct systems against excessive rainfall and drought episodes.

In Table 1, the + Rainfall notation denotes defense strategies exercised in excessive rainfall periods to protect vital agricultural systems; this category also includes efficiency improvements in water supply technology which have been observed in the archaeological record. The – Drought notation represents drought defense strategies and innovations observed in the archaeological record. Table 1 is divided into different spatial divisions of the Peruvian and Bolivian landscape (Fig. 1). These spatial divisions represent the Peruvian north highland sierra (as far north as Wari society occupation areas around Arequipa in Peru), altiplano regions characteristic of Lake Titicaca in highland Bolivia, and the Peruvian north and south coast valleys in different time periods from early

Preceramic/Formative times (2500–1600 BCE) to Late Horizon (LH) times (1400–1532 CE). The numbers in Table 1 refer to the application examples given as numbered listings 2–23 to follow.

Canal Flow Rate Controls and Use of Intravalley and Intervalley Canals for Drought Remediation

Examples of these include adjustable inlet blockages in the form of inserted reed mats and stone barriers at river canal intakes (*tomos*) to regulate flow rates into irrigation canals. Water supply canals frequently contained elevated overflow weirs activated by high water levels in canals when El Niño runoff into canals yielded flow rates in excess of their design capacity. The



Hydraulic Engineering in Ancient Peru and Bolivia, Fig. 2 Agricultural strategies used in the ancient Peru and Bolivia

weirs extracted excessive washed-in runoff water from the canal and conducted it to a lower-level reservoir or drainage ditch to alleviate erosion and overspillage damage to the main canal. In other cases, excessive rainfall runoff into a canal activated chokes (canal width contractions) that limited the flow rate at the contraction location – additional runoff flow elevated the upstream water height causing a side overflow weir to activate to release excess flow from the canal thus reducing erosion damage to the canal from excessive flow rates. Examples of sidewall

overflow weirs are present in the Chicama-Moche Intervalley and in the Jequetepeque Valley and the Farfan-Pacatnamu Canal systems (Ortloff, 2009; sections 1.2 and 1.3). Megacanal systems (e.g., the Chicama-Moche Intervalley Canal, Fig. 3) represent a tenth-century CE drought (Thompson, Mosley-Thompson, & Davis, 1995) remediation measure to redirect water from a valley with a large river (the Chicama River) to an adjacent valley of political importance (the Moche Valley with the Chimu capital city of Chan Chan) to restimulate

Hydraulic Engineering in Ancient Peru and Bolivia, Table 1 Defensive engineering measures

	EH (and Preceramic, Formative)	EIP	MH	LIP	LH
North Sierra					
+ Rainfall	–	–	2,6	–	–
–	–	–	6,13,19	–	–
Drought					
Southern Altiplano					
+ Rainfall	–	–	2,5,6,12,14,23	6,14	6,7
–	–	–	3,4,5,7,8,12,13,14,19, 20, 21,22	4,6,7,8,14	6,7,14
Drought					
North/central coast					
+ Rainfall	2(?),21	2(?),15,16	–	1,5,15,16,17	–
–	3,4,6,9,7,11,12, 17,18,21	4,9,17,18,21(?)	–	1,3,4,7,10,18,21(?), 22	–
Drought					
South Coast Valleys					
+ Rainfall	–	–	3	–	–
–	–	9,10,18	7,9,10,18	7,10,18	10
Drought					

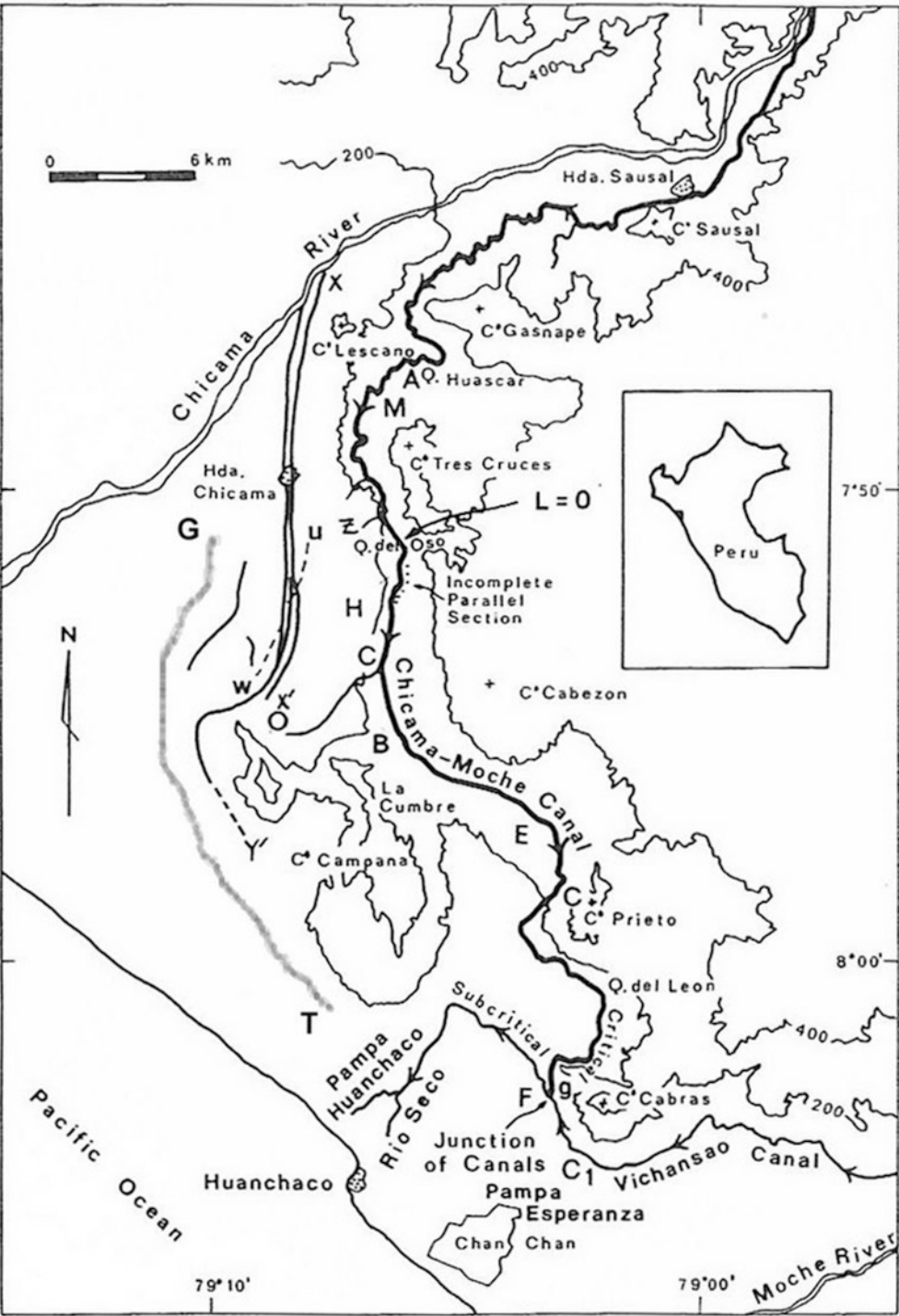
Preceramic Period (2500–1600 BCE); Formative Period (1600–300 BCE); Early Intermediate Period, LIP (300 BCE–700 CE); Middle Horizon, MH (700–1000 CE); Late Intermediate Period (LIP) (1000–1400 CE); Late Horizon (1400–1532 CE)

a defunct northern Moche Valley main canal (the Vinchansao canal, Fig. 3) formerly supplying water to field systems (Ortloff, 1993, 2009; Ortloff, Feldman, & Moseley, 1985; Ortloff, Moseley, & Feldman, 1983;) operational prior to the tenth-century CE drought. Elsewhere, the Lambeyeque-Supe-Leche Intervalley Canal system and the Lima Intervalley Canal complex (Kosok, 1965) provided canalized water diversion from valley rivers and extension of existing segments of intravalley canals to provide irrigation water to additional arable land areas not previously in production. A further subsidiary function of intravalley canals was to redirect water to fields close to valley necks to recharge the lower valley groundwater aquifer; the resulting higher water table limited irrigation canal seepage and evaporation from longer canals serving downvalley field systems and elevated groundwater for city wells. For normal operation of irrigation systems in predictable weather/climate patterns, additional field areas adjacent to and located in between the source and destination

valleys of intervalley canals were supplied by water from intervalley canal offtakes to supplement intravalley agricultural land area and food supplies. Areas along the Chicama-Moche Intervalley Canal exhibit many field areas of this type.

Flood Diversion Channels

Channels of this type are used at the Middle Horizon Tiwanaku Pampa Koani and Lukurmata raised-field farming areas southeast of Lake Titicaca (Fig. 1). They intercept and shunt excessive rainfall runoff from hill slopes directly into Lake Titicaca through large canal systems (Kolata & Ortloff, 1989; Ortloff, 1997; Ortloff and Kolata, 1988). While intercepted rainfall onto fields helped to provide water for the swales adjoining the raised-field mounds, excessive water input increased the swale water height beyond its useful height. Here, swales were excavated about 1 m into the groundwater level.



Hydraulic Engineering in Ancient Peru and Bolivia, Fig. 3 The Chicama-Moche Intervalley Canal and its link to the Moche Valley Vichansao Canal

Tiwanaku drainage canals with elevated outlet weirs set above the bottom of the channel directed channel floodwater above a given height over the weirs into channels draining directly into Lake Titicaca to drain flood water rapidly away to prevent amplification of groundwater and swale water height. In other words, to modulate and control the swale groundwater level with respect to raised-field mound planning surfaces, overflow weirs set a certain height above the drainage channel bottom activated when floodwater height exceeded the bottom height of the weir causing excess water to flow directly into Lake Titicaca through a channel. This arrangement served to regulate field system groundwater height by draining away excess water. Swale water height was important to provide underground water to plant root systems on field mound surfaces. Further regulation of groundwater height was controlled by aquifer seepage water flowing into drainage channels. By having the drainage channel depth intercept the top region of the groundwater aquifer, seepage aquifer water higher than the bottom depth of the drainage channel was collected and drained into Lake Titicaca. The combination of these effects maintained swale height sufficient for crop production during the rainy season. There are applications of rainfall runoff collection channels for Moquegua Valley mountain region terraces (occupied by Wari and Tiwanaku colony presence; Moseley, 2008) to divert excessive rainfall into terrace water supply canals to downhill spillage channels draining into valley-bottom fields.

Groundwater Recharging

North coast Chimu coastal *mahamaes* (sunken gardens) and Chan Chan city wells (Moseley & Deeds, 1982) were activated by irrigation canal water seepage from field plots added to the existing groundwater profile originating from sierra watershed rainfall infiltration and river water seepage as examples of Chimu groundwater recharge technology. Tiwanaku use of spring-fed canals in the Lukurmata area to deliver water to raised-field water troughs provided water with

different biochemical composition (Carney, Binford & Kolata, 1996; Ortloff, 1997, 2009) for specialty crops is a further example of groundwater recharge for a specific purpose.

Sunken Gardens, Wells, Spring Systems, and Reservoirs

Examples of sunken gardens include north coast Chimu and the earlier north and south coast societies' use of excavated pits dug to groundwater phreatic level (*mahamaes*) and pits excavated close to springs (*wacheques*) for agricultural water supply during low river runoff and drought periods (Moseley, 2008; Moseley & Deeds, 1982). Sunken pits intersecting the water table and collecting rainfall (*cochas*) operational in late post-Tiwanaku V times (Ortloff, 1997, 2009) in the Bolivian Pampa Koani area were used to support agriculture and serve as examples of last-resort water systems during drought periods. The use of wells interior to Chan Chan and located close to the coastline where the water table was close to the ground surface and whose depth could be lowered to intercept a declining water table in drought periods served as a Chimu drought defensive measure during the tenth century CE. Reservoirs penetrating groundwater level with lead-off canals to field systems sustained Supe Valley agriculture at Preceramic Caral (2500–1430 BCE) and adjacent valley sites (Ortloff & Moseley, 2012) and provided water year-round to field systems.

Runoff Interception Trenches and Runoff Canal Shunts to Rivers/Lakes/ Pools

An example of these techniques is seen in the collection and channeling of rainfall runoff flows into channels connecting directly to Lake Titicaca to limit runoff interception and seepage into groundwater to regulate local groundwater height in the swales surrounding raised-field mounds. This regulation activity controlled the height of the phreatic layer above the

groundwater layer to serve different crop types with different root system depths having different water needs. Further examples originate from the canals used to drain excess groundwater into channels to regulate moisture available for root systems in raised-field plots (Ortloff, 1997, 2009). The perimeter canal surrounding the ceremonial center of Tiwanaku (Ortloff & Janusek, 2014) served to accelerate ground drying by runoff collection and aquifer seepage to promote improved environmental conditions for city inhabitants. The Chimú used interception trenches uphill from canal systems near Farfán in the Jequetepeque Valley to intercept rainfall runoff originating from mountainous terrain (Ortloff, 1997) to direct flow into *quebradas* (flood erosion gullies) that limited damage to major canals (Ortloff, 2009).

Terrace Agriculture

Terrace (*andenes*) agriculture from post-Tiwanaku V (~1100 CE), MH highland Wari and LH Inka societies used stepped planting surfaces on mountainsides so they could move agricultural zones to higher elevations to intercept higher rainfall amounts during drought periods. The use of high-elevation canals sourced by snowmelt water during the warmer dry season and rainfall runoff water during the rainy season provided additional sources of irrigation water beyond rainy season rainfall. For situations where raised fields were flooded from high Lake Titicaca water levels (a 1.0 m lake level rise can flood upward of 120,000 ha of low-slope land bordering Lake Titicaca), the use of terrace systems provided an alternative to continue agricultural production for the Tiwanaku. The use of multi-terraced hillsides above river bottomland in the upper Supe Valley area together with spring-sourced canals irrigating field systems (Ortloff, 2009; Ortloff & Moseley, 2009) provided a defensive strategy by varying the types of agricultural systems to ensure agricultural continuity through weather/climate changes. The large population at the major Supe Valley site of Caral occupied extensive urban living areas and



Hydraulic Engineering in Ancient Peru and Bolivia,
Fig. 4 The Huaca Major at the site of Caral

multiple monumental architectural complexes (such as the Huaca Major, (Fig. 4). Their livelihood was sustained by spring-supplied canals that irrigated valley-bottom agricultural areas in conjunction with canalized spring water to terrace agricultural systems. These redundant systems maintained agricultural continuity for many centuries of valley occupation.

Specialty Sunken Gardens

These gardens were used by post-Tiwanaku V altiplano societies up to and including Inka occupation to supplement pastoralism-derived food supplies as drought extended past 1100 CE. Excavated basins (*cochas*) located near streams or in areas distant from Lake Titicaca margins where the water table remained high throughout dry periods from incoming groundwater from vast watershed areas provided a limited agricultural base to support populations after the abandonment of the city of Tiwanaku.

The Inka created large, terraced excavated pits for specialty agricultural products at Moray (Wright, McEwan, & Wright, 2006) with temperature and humidity variation to determine best growing conditions for specialty crops. Chimú *mahameas* and *wachaques* provided exploitation of local water resources largely impervious to short-term drought conditions to extend limited agricultural production of specialty crops during

drought conditions. Recent research at Tiwanaku (Ortloff & Janusek, 2014) indicates that *cochas* and variants of raised fields were integral to the urban housing areas of the city during its later phases (600–1100 CE) and had water supplies from spring-sourced canals.

Agricultural Reserve Land and Alternative Field System Following Strategy

The Tiwanaku used raised-field usage area shifts to high groundwater areas as diminishing rainfall interception and drought depressed the subsurface groundwater layer profile toward the edge of receding Lake Titicaca subject to tenth-century-CE drought conditions. Although much effort went into groundwater height control by the Tiwanaku through the use of drainage canals, long-term drought inevitably lowered the height of Lake Titicaca with a corresponding depression of the groundwater profile in areas close to the lake edge. Distant from the lake, the groundwater profile remained high from infiltrated rainfall into vast upland watershed areas in past times gradually percolating as groundwater toward the Lake Titicaca. These distant areas could be farmed in combination with *cochas* to provide limited agricultural produce to supplement livestock sources of food as drought progressed further past 1100 CE. Agricultural field area shifting allowed fallowing of nonused raised-field areas to increase later productivity during regular rainfall, non-drought conditions that prevailed for many centuries of Tiwanaku occupation of the Pampa Koani raised-field area.

Groundwater Collection into Subsurface Transport Channels Supplying Field Systems

Underground galleries penetrating the water table collected seepage water and channeled it to surface fields in the far south coast of Peru. Here, rainfall was scarce and rivers deeply downcut preventing the possibility of river-sourced

irrigation canals. Groundwater-collecting galleries built between late Nazca phases of the EIP, ca. 400–600 CE, are examples of this method (Schreiber & Rojas, 2007).

The use of canalized groundwater pools/reservoirs fed by springs was effective in mitigating short-term drought for the Supe Valley site of Caral (and other valley sites) as the groundwater table showed little variation in height throughout the year due to the large infusion of groundwater originating from mountain watershed areas percolating into the lower valley groundwater table. The Supe Valley is unique in that it maintains a high water table throughout the year and was a natural destination for Preceramic societies' taking advantage of the valley's agricultural potential. Some evidence exists that highland lakes and lagoons transferred water into Supe Valley groundwater through surface and subsurface channels.

Canal and River Water/Groundwater Seepage Utilization

An example comes from the north coast Chimú utilization of irrigation canal water seepage to recharge interior Chan Chan wells (Moseley & Deeds, 1982). This additional conservation use of water added to the existing groundwater base derived from sierra rainfall interception sources and helped maintain numerous wells within the royal compounds of Chimú capital city of Chan Chan. Moquegua Valley Chirabaya coastal groundwater seepage agriculture (Clement & Moseley, 1991) in the Ilo area of southern Peru was based on collection of deep groundwater seepage on cliff face troughs then directed by channels toward adjacent field plots. This mode of irrigation produced flows of a few liters per second and thus could only support limited agriculture. This system provided agricultural continuity through drought periods as the water table had a low subsidence rate and was able to maintain limited agriculture while surface river flow rates diminished to the point where surface irrigation was no longer possible. Some limited opportunistic north coast raised-field agriculture

at Casma, Viru, and Moche Valley coastal areas was observed as a result of amplified water table height after El Niño rains provided moist soils suitable for limited agriculture (Moore, 1988, 2000).

High Sierra Reservoir and Lagoon Water Storage for Canal Delivery to Coastal Valleys

Examples exist from high altitude (>2,000 m) Cordillera Negra mountain lagoons interconnected with canals to deliver water to highland valley and terrace agricultural systems. Water from these sources augmented groundwater levels in coastal valleys by means of water seepage through fault zones and/or percolation through bedrock-limited, shallow soil layers (Avila, 1986). The 50-km-long Hairu Catac Canal (possibly of Inka construction) irrigating the Iambe, Moro, and San Jacinto sierra areas and Nepeña Valley foothill areas are examples of this type of water storage and transfer. The probable water source supplying the Supe Valley high water table comes through geological faults transferring sierra infiltrated and runoff water to the lower coastal valley aquifer to create the high water table prevalent throughout the year that underwrote sustained canal agriculture for Caral and other Supe Valley Preceramic sites (Ortloff & Moseley, 2012).

Canal Water Collection and Diversion of Runoff to Modify Groundwater Profiles

Tiwanaku Pampa Koani used raised-field agricultural systems on the (Bolivian) Taraco Peninsula (Ortloff, 1997) to regulate water table height for different crop types with different root system moisture requirements. Rainfall runoff was collected into swales. Excessive water above the useful design level was conducted by swale connectivity to lower areas draining into Lake Titicaca and, for certain cases, excess water was conducted into adjacent canals that shunted water rapidly to the lake.

Snowmelt Water Collection Channels Directed Toward Mountainside Terraces

Examples are found in upper highland Moquegua Valley drainages in late and post-Tiwanaku V times as well as for high sierra MH Estuquiña and Wari terraces that utilized snowmelt water supplies channeled to agricultural terraces. This technique was used in elevated (or lowered) temperature periods as a water source (or water storage as ice) for terrace agriculture. Inlets to canals supplying water to lower-level terraces were relocated accordingly as the snowmelt boundary varied with precipitation, altitude, and temperature.

Vertical and Lateral Agricultural Zone Shifts

Relocation of raised-field agriculture on the margins of Lake Titicaca by the Tiwanaku to terrace agriculture on nearby hill slopes when Lake Titicaca height excursions from excessive rainfall completely covered the raised fields is an example of an agricultural zone shift. The possible reuse of very early phase MH Tiwanaku terraces during LH Inka occupation times by populations occupying mountainous and hill areas overlapping or outside of the Tiwanaku homeland area represents a strategy shift toward the use of terrace agricultural systems given the ample amount of rainfall in the altiplano environment. The presence of terraces and adjacent raised fields in close proximity to the city of Tiwanaku offered options to shift agricultural areas between Pampa Koani raised fields and highland terrace areas depending on local water table height in raised-field swales as influenced by Lake Titicaca height and groundwater arriving from distant watershed areas downslope to the lake. Lateral shifting and extension of Tiwanaku agricultural raised-field zones toward receding lake edge areas during the dry season or drought periods and expansion of raised-field areas distant from the lake edge during extended rainfall periods added flexibility to continue agriculture

to allow for changes in rainfall intensity as well as dry period duration.

Canal Intervalley and Intravalley Transport/Distribution Canals

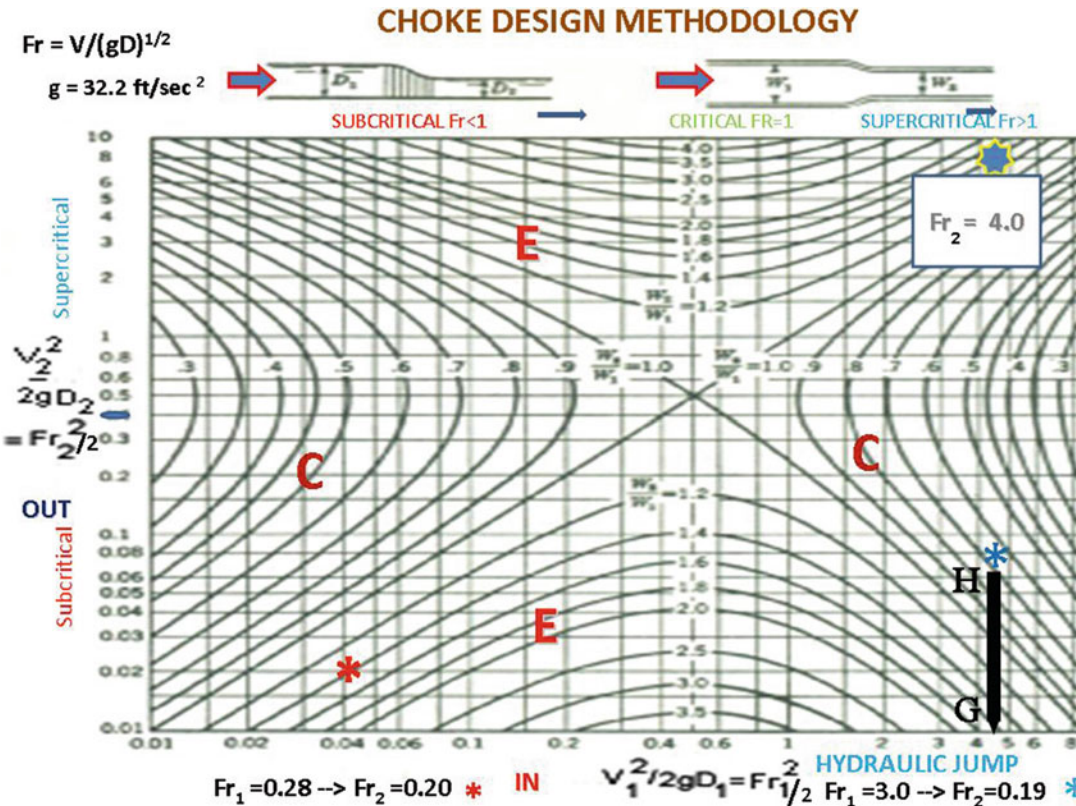
The Chicama-Moche Intervalley Canal, the Lambeyeque-Supe-Leche Canal system, and the Lima Complex (Chillon-Rimac-Lurin Canals) (Kosok, 1965; Ortloff et al., 1985) had been used as a drought remediation measure by distributing river water from large flow rate rivers to reactivate desiccated field systems in adjacent valleys with smaller, intermittent flow rate rivers during extended drought periods. During extended wet periods, water transfer from large rivers to adjacent valley canal systems provided for extension of the growing season (Ortloff, 2009) as well as additional land areas brought into production. Intervalley canal water irrigated field systems located alongside the intervalley canal path and provided an efficient use of water close to the canal water source by limiting seepage and evaporation water losses associated with long canal paths. Long intravalley canals within the Peruvian Lambeyeque Valley (Racurumi, Taymi Canals, Kosok, 1965) served to redistribute water from rivers to field areas only reached by a separate canal dedicated to access difficult-to-reach areas.

Canal Hydraulic Efficiency Improvement Features and Flood Damage Controls

Chimu hydraulic efficiency improvements in the Chicama-Moche Intervalley Canal design came through manipulation of canal wall Manning roughness (n), bed slope (i_b), canal cross-sectional shape (hydraulic radius R_h), and canal width expansion/contraction effects on flows for subcritical and supercritical flows. Analysis of the open-channel flow hydraulic design principles used on a 1.5 km section of the canal near Quebrada de Oso (Ortloff & Moseley, 2009; Ortloff et al., 1983, 1985) indicates a knowledge base of open-channel water control principles to

achieve a canal design for a specific flow rate ($4.3 \text{ m}^3/\text{s}$) while having flow delivered to a destination location in the Froude number (Fr) range, $0.6 < Fr < 1.3$ which is close to modern practice (Morris & Wiggert, 1972). The canal exhibits, over a measured 1.5 km length, variations in n , i_b , R_h , and subcritical and supercritical contraction/expansions of canal geometry to control flow such that $0.6 < Fr < 1.3$ and maintain near-critical slope conditions to yield a flow close to unit Froude number. Thus, the canal design sustains a Froude number close to but either higher or lower than $Fr = 1$. The canal design incorporates hydraulic width contraction elements (Woodward & Posey, 1941) before the (now missing) aqueduct crossing the Quebrada de Oso that converted flow from supercritical to subcritical over the aqueduct (line G-H, Fig. 5). This velocity-reducing effect limited erosion of the fill sidewalls of the aqueduct. Further, hydraulic features of the canal (Ortloff, 2009) indicate an ingenious way to use a bound vortex resident in a concave part of the canal to effectively choke the flow and change its velocity and depth sufficient to regulate the Froude number between $0.6 < Fr < 1.3$. Flow outside of this range from El Niño runoff into the canal was then removed by side weir overflow to limit erosive flood damage. Analysis reveals that changes in i_b , n , R_h , and subcritical and supercritical Froude number effects were effectively utilized to produce a “modern” design (Ortloff, 2009).

The use of half-hexagon cross-section canal shapes for minimum flow resistance using straight-sided canal walls (Henderson, 1966; Morris & Wiggert, 1972) was demonstrated in the Pampa Huanchaco canal system (Ortloff et al., 1982, 1985). The use of stream-wise canal shape changes to regulate water height to activate overflow weirs served to limit El Niño flood damage; examples of this design feature are found in Jequetepeque Valley canals and the Chicama-Moche Intervalley Canal. The use of a choke (contraction section) in a canal to allow a given design-maximum flow rate to pass through the choke (at $Fr = 1$) causes a water height change upstream of the choke for any excess flow rate over the maximum allowable



Hydraulic Engineering in Ancient Peru and Bolivia, Fig. 5 Plot (Woodward & Posey, 1941) of $Fr_1^2/2$ (incoming flow to channel width contraction – vertical axis) versus $Fr_2^2/2$ (outgoing flow from contracted channel). Line G-H represents the path from an incoming flow with $Fr_1 = 3.0$ to an outgoing flow with $Fr_2 = 0.19$ due to a width contraction ratio $W_2/W_1 = 0.65$. The transition

from a supercritical $Fr_1 = 3$ to subcritical $Fr_2 = 0.19$ occurs through a hydraulic jump. Regions labeled C represent channel contraction effects; regions labeled E represent channel expansion effects – note the difference in expansion/contraction effects for different incoming flow subcritical or supercritical Froude numbers

design flow rate. The excess high height flow then activates an elevated side weir eliminating and directing the flow to a lower drainage area.

A further example of flow control derives from changes to existing canal designs related to lowering seepage and evaporation losses for long-length transport canals. A canal lining or letting impervious silt accumulate on canal bottoms sometimes accomplishes this. For the Chicama-Moche Intervalley Canal, a constant slope, contour canal segment entering and making a U-shaped path along the walls of a deep interior valley was seen to be later replaced by a short, straight aqueduct joining the entry and exit points to the deep valley. The shortened

aqueduct canal path lessened the length of the canal by about 1.0 km thus reducing flow resistance, seepage from the canal bed, and evaporation water loss.

Lomas Farming

This type of farming derives from coastal fog condensation water supply to lichen pastures on Peruvian north central coast areas. Winter fog (*garua*) condensation starts lichen growth; this begins the food chain starting with snails using the lichen as a food source which is then followed by predator species feeding on lower life forms in

the chain. This attraction served local residents of the area by providing a food source composed of larger predator species drawn to the area for its diversity of plant and animal life. While the lomas systems were utilized in the early Formative Period to provide agricultural plant products as well as edible protein sources (Lanning, 1967), the degree to which human intervention prevailed to control and amplify its potential as a food production area remains a research topic.

Adoptions Toward a Marine Resource Base

For drought-affected coastal regions with access to marine resources (fish, shellfish, edible aquatic plants), emphasis on exploiting marine resources provided a protein supplement to plant carbohydrate food supplies. Several Peruvian north central coast Preceramic societies organized valley sites with coastal villages providing marine resources and inland sites largely invested in industrial and comestible crop production. Trade between coastal and inland sites formed a cooperative economic model seen in the Supe Valley and to a lesser degree, in adjoining north central coast societies (Ortloff & Moseley, 2009; Sandweiss, Shady-Solís, Moseley, Keefer, & Ortloff, 2009; Shady, 2000, 2009). While this cooperative model served well to provide a balanced carbohydrate and protein diet, later coastal societies resorted more heavily to exploiting marine resources during drought periods when water supplies were insufficient for agriculture.

Adaption Toward Sierra Pastoralism

As a tenth-century CE highland drought response, a shift from agriculture (due to recession of groundwater in raised-field swales) toward herding and pastoralism occurred. This emphasis on alpaca, llama, and vicuña herding was possible due to well-watered highland grassland pasture areas (*puna*) prevalent at high altitude; snowmelt water provided

supplemental water to augment rainfall. This shift to pastoralism provided a protein food source to augment produce from drought-affected raised-field and terrace areas. In many cases (Murra, 1972), major highland societies maintained colonies in different ecological zones that were able to export food varieties back to homeland areas to maintain their viability during both normal rainfall periods and drought. While partially effective in supplying cities with imported food items, this means of support was marginal to support large populations, and as drought intensified, spatially distributed colonies in different ecological zones also suffered from drought and were unable to provide an adequate support base for their homeland cities.

Raised Fields

Examples from the Bolivian altiplano from the MH Tiwanaku society are low-vulnerability agricultural systems largely resistant to short-term drought due to the continuous arrival of groundwater from watershed zones distant from Lake Titicaca combined with slow groundwater subsidence from surface evaporation. These fields originate about 600 CE and excavations to 2 m depth show that experimentation took place to decide the best geometric design of ridges and swales for maximum agricultural productivity and heat storage capability. Earlier versions had short wavelengths between ridges than those observed in later-phase constructions. Raised fields are constructed by excavating swale trenches deeper than groundwater level so that the swales contain groundwater. Excavated soil is mounded between swales to form planting surfaces. Typically raised-field mound widths vary in the 4–10 m range and lengths from 10 to 100 m; mound heights are usually 1 to 2 m above the swale water surface, and swale depths are on the order 1 m. Raised fields are able to store heat from the sun during the day to prevent freezing of root crops during cold altiplano nights (Kolata & Ortloff, 1989, 1996) thus preserving crop spoilage from freezing.

City Environmental Control Through the Use of Drainage “Moats” to Accelerate Ground Drying and Regulate the Deep Groundwater Profiles for Monument Foundation Stability

A depressed, encompassing channel “moat” surrounding the ceremonial center at the city of Tiwanaku collected rainfall runoff and seepage from groundwater layers to promote rapid soil drying throughout rainy and dry seasons thus improving environmental living conditions for city inhabitants. By aquifer seepage into the “moat” during both wet and dry seasons and water supply through a moat-intersecting canal fed by distant springs, deep groundwater levels were stabilized throughout seasonal weather cycles. The year-round stabilization of the deep groundwater level by maintaining the same saturated aquifer water content prevented deep aquifer dry out and collapse which had the beneficial effect of maintaining the bearing strength of foundation soils underlying large monumental structures within the moat boundary thus reducing their settling and deformation (Ortloff & Janusek, 2014).

Hydraulic Jump Control

An example of MH Tiwanaku water engineering utilizing hydraulic jump control comes from the Lukurmata area north of Tiwanaku city. Rainfall runoff collected into a steep, unlined channel flows into Lake Titicaca bypassing a temple to protect it from flood damage. As lake height is high during the rainy season, the intersection of a high-velocity, supercritical channel flow with still lake edge water produces a large, turbulent hydraulic jump eroding the outlet in the upstream direction. To avoid upstream migration of the hydraulic jump and erosion of the fill channel, Tiwanaku hydraulic engineers skillfully vary channel outlet geometry to essentially produce a hydraulic jump of zero height thus canceling the jump (Kolata & Ortloff, 1989; Ortloff, 2009). Open-channel flow engineering in the Chicama-Moche Intervalley Canal and the Jequetepeque

Canal demonstrates that water engineers knew how to create hydraulic jumps to transition flow from supercritical to subcritical flow to avoid canal erosion and to locally elevate water to activate side weirs for the same end (Ortloff, 2009).

The adaptive strategies shown in Table 1 indicate conscious effort by different societies to control water supplies using a variety of engineering technologies specific to different geographic locations and agricultural systems in different time periods. While water engineering improvements and delivery efficiency improvements accompanied long-term favorable climate trends, other engineering responses provided defense measures against El Niño flooding and drought. For changes in weather and climate affecting agricultural productivity, additional responses in the form of modifications to existing systems or in more dire circumstances, design and building of intervalley canal systems to bring additional water supplies to homeland areas proved the only solution. The responses listed in Table 1 required long-term observation and recording of weather and climate patterns and changes in climate that portended future disaster unless large-scale measures were put into place to counteract decreases in water supply. Once recognition of threats to food supply were confirmed by trends over time, perhaps a leadership plan evolved to organize key decision-makers to discuss technical planning to ameliorate crises affecting the well-being of their society. Further logistics to recruit labor and provide material and rations for extended field operations were planned to perform required tasks. The inception and construction of the Chicama-Moche Intervalley Canal as a drought remediation measure fits well into this category.

Table 1 provides a library of agro-engineering responses to long- and short-term climate and weather variations over many time periods and demonstrates that climate and technology development were important factors in design, operation, administrative planning, and construction to ensure sustainability of agricultural fields vital for societal survival. While many of the technology advancements listed came from response to agricultural threats, many listings were technical

improvements used to increase irrigation water flow rates to fields and/or reduce water seepage and evaporation losses by canal redesign and relocation all to improve agricultural yields. In totality, the listings indicate an active and creative engineering mentality in Andean societies to conceptualize an irrigation system design suitable to environmental and water availability conditions, put plans into practice by organizing construction labor, maintaining its operation by experienced farming personnel, and finally, to improve its operational efficiency over time by observance of its performance and instigating appropriate engineering redesigns.

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Hydraulic Engineering in Petra

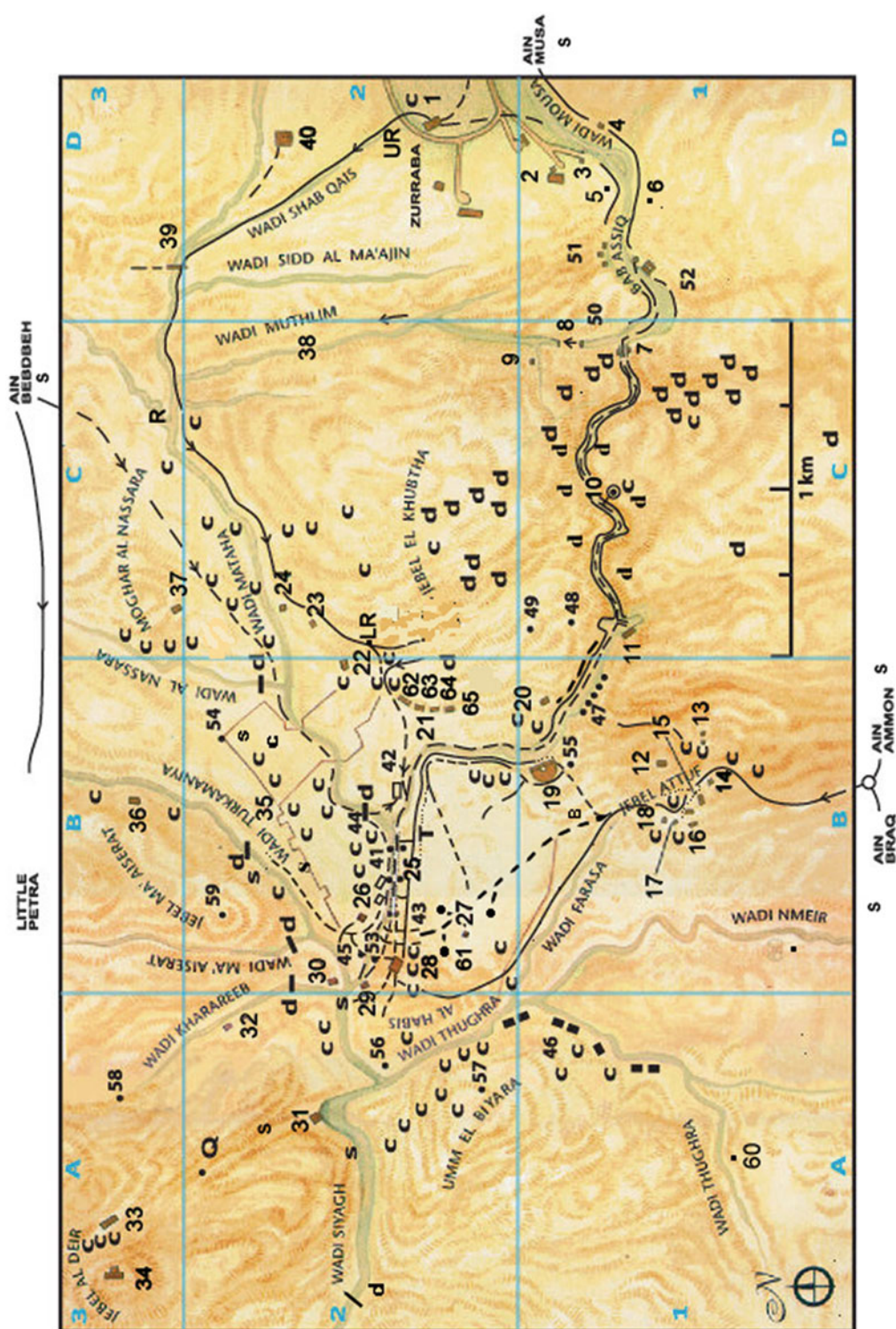
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Water Infrastructure of Petra

To begin the discussion of Nabataean water system development and its progress toward utilizing all possible resources to meet increasing population demands, solid and dashed lines of

Fig. 1 detail the supply and distribution pipeline system leading water into the urban core of Petra. Numbered locations denote the major buildings, temples, and site features listed in the figure legend. Shown are major dams (-d), cisterns (c), water distribution tanks (T), and springs (s). The (-d) dams located across streambeds (*wadis*) are barrier structures built to hold larger quantities of water for redistribution to urban structures or localized agricultural areas. Dams denoted (d) are minor catchment structures that stored water in mountainous areas to prevent its descent to the Petra basin and/or have channels leading water to lower-level cisterns. The superimposed grid system (A, B, C; 1, 2, 3) defines a coordinate system of 1.0 km² grid boxes to enable the location of features listed in the figure legend. Figure 1 represents the present state of discovery of pipelines incorporating logical connections and joining structures extrapolated from existing pipeline segments. Due to degradations from man and nature over 2,000 years, some pipeline sections are now missing from their original holding troughs or obscured by subterranean placements (or yet to be discovered in their entirety) requiring extrapolation between available visible parts to represent the pipeline paths shown in the figure. With further research and excavation, more details will undoubtedly come to light; as such, Fig. 1 represents the current state of research (Bellwald 1995, 2008) and is, at best, a first approximation to the entirety of the total pipeline water system.

Petra's urban core lies in a valley surrounded by rugged mountainous terrain; seasonal rainfall runoff passes into the valley through many streambeds and drains out primarily through the Wadi Siyagh (Fig. 1, A2). The main water flow into the city in ancient times originated from rainfall runoff from Wadi El-Jee to the north, Wadi Al Hudayb to the south, and from the watershed area supplying runoff into the Wadi Mousa streambed; combined surface flows from these sources passed through the Siq (Fig. 1: D1 to C1). By later first century CE construction of a diversion dam and tunnel (8, Fig. 1), water was deflected from the Siq entrance and led to Wadi Mataha (Fig. 1, C-2, 3) that linked up with the



Hydraulic Engineering in Petra, Fig. 1 (continued)

section of the Wadi Mousa streambed within the city center and drained water into the Wadi Siyagh (Fig. 1, A-2). Runoff water from southern sector Wadis Thughra, Nmeir, and Farasa and northern sector Wadis Nharareeb, Kharareeb, Ma'Aiserat, and Turkamanya (Fig. 1) drained runoff into the lower-level Wadi Siyagh away from the city center (Bellwald, al-Huneidi, Salihi, & Naser, 2003). The Siq is a natural divide through the Jebel el Khubtha mountain range whose narrow passageway ranges from 5 to 10 m in width; the north and south walls of the Siq are near vertical and have heights up to 80 m (Fig. 2). Early water supplies to the city in the first and second centuries BCE were through a slab-covered, open channel dug into the floor of the Siq conducting water from the distant Ain Mousa spring into the urban center of the city as far as Hadrian's Gate (43, Fig. 1). Later first- and second-century CE builders abandoned this supply system and replaced it with a long pipeline carrying water from the Ain Mousa spring along the Colonnade Street (Cardo) (23, Fig. 1). Later century construction (Ortloff & Crouch, 2003) revealed an integrated approach to site water system management demonstrated by new and novel features:

1. Surface cisterns to capture rainfall runoff (Fig. 3)
2. Deep underground cisterns (one located in the eastern part of the Great Temple) (28, Fig. 1)

3. Multiple pipeline systems sourced by springs and storage reservoirs
4. Floodwater control through diversion dams and tunnels
5. Pipeline supply system redundancy to ensure water delivery from multiple spring and reservoir sources to high population concentration parts of the city (marketplace and theater) (Fig. 12)
6. Pipeline sand-particle filtration and removal basins (primarily in the Siq)

These later modifications reflected the need to bring high-quality potable water reliably into the city center area and to serve hillside occupation zones above the valley floor. Since the early lowest-level Siq open-channel delivery was located on the Siq floor, its ability to supply water to higher outlying city zones was limited. Here population expansion and the requirement for water to higher elevation parts of the city required higher-level Siq pipeline systems. All these later changes demonstrated the continual evolution of the Petra water system through time and reflect the application of acquired technologies from archaic and/or exterior sources integrated with indigenous hydraulic innovations, to provide for the increasing water needs of the city.

The means to capture and store a fraction of rainfall runoff through dams and cisterns, to build

Hydraulic Engineering in Petra, Fig. 1 Numerical feature designations. (1) Zurraba reservoir (Fig. 3); (2) Petra Rest House (modern); (3) park entrance (modern); (5) Dijn Monument; (6) Obelisk Tomb and Triclinium (Cardo); (7) entrance elevated arch remnants; (8) flood bypass tunnel and dam; 9. Eagle Monument; (10) Siq passageway; (11) Treasury (El Kasneh); (12) High Place of Sacrifice Center; (13) Dual Obelisks; (14) Lion Monument; (15) Garden Tomb; (16) Roman Soldier Tomb; (17) Renaissance Tomb; (18) Broken Pediment Tomb; (19) Roman Theater; (20) Uneishu Tomb; (21) Royal Tombs (62, 63, 64, 65); (22) Sextius Florentinus Tomb; (23) Carmine Façade; (24) House of Dorotheus; (25) Colonnade Street; (26) Winged Lions Temple; (27) Pharaoh's Column; (28) Great Temple; (29) Q'asar al Bint; (30) museum (modern); (31) quarry; (32) Lion Triclinium; (33) El Dier; (34) 468 Monument; (35) North City Wall;

(36) Turkamaniya Tomb; (37) Armor Tomb; (38) Little Siq; (39) aqueduct; (40) Al Wu'aira Crusader Castle; (41) Byzantine Tower; (42) Nymphaeum; (43) Paradeisos, Agora, Hadrian's Gate, (44) Wadi Mataha Dam; (45) Bridge Abutment; (46) Wadi Thughra Tombs; (47) Royal Tombs (-d) denoting major dam; (48) Jebel el Khubtha High Place that denotes a pipeline; (49) El Hubtar Necropolis that denotes buried channel; (50) block tombs (B) that denotes pipeline supplied basin; (51) Royal Tombs; (53) Columbarium; (52) Obelisk Tomb (d) that denotes a minor dam; (54) Conway Tower (c) that denotes a cistern; (55) tomb complex (s) that denotes a spring; (56) convent tomb; (57) tomb complex; (58) Pilgrim Spring; (59) Jebel Ma'Aiserat High Place; (60) Snake Monument; (61) Zhanatur Mansion; (62) Palace Tomb; (63) Corinthian Tomb; (64) Silk Tomb; (65) Urn Tomb

flood control systems and build pipelines and channels to deliver water from distant springs, and to manage these assets to provide a year-round water supply to the city is key to



Hydraulic Engineering in Petra, Fig. 2 View of the narrow Siq entry path into the inner city (10, Figure 1)

understanding Nabataean contributions to hydraulic science and water management practices. While water storage was a partial key to the city's survival, springs internal and external to the city (Fig. 1: Ain Mousa, Ain Umm Sar'ab, Ain Braq, Ain Dibdiba, Ain Ammon, Ain Beidha, and Ain Bebdhehbeh) supplied water channeled and/or piped into the city to provide the main water supply. While the Ain Mousa spring was the main water supply to Siq pipelines, only $40 \text{ m}^3/\text{h}$ was used for this pipeline. Higher spring output levels were used to charge several reservoirs above the city to maintain a backup water supply in case of drought and increased water demands from arriving trade-mission caravans or special ceremonial gatherings that necessitated a sudden increase in water demand. Of all these springs, the Wadi Siyagh spring near the quarry (Fig. 1, 31) is still functional and used by local inhabitants, while all others are currently dry and abandoned. The Ain Mousa spring now provides water for the modern town of Wadi Mousa as well as for religious ceremonies given its historical Biblical and Koranic associations. The upper reaches of Ain Braq water system (Fig. 1) consists of a trough cut into bedrock (Fig. 11) that supported a continuous pipeline at one time. Its continuance to the plateau north of Wadi Farasa (Fig. 1) to supply the Zhantur housing area (Fig. 1, 61) and a cistern (Fig. 8) near the housing area had a pressurized siphon pipeline section to

Hydraulic Engineering in Petra, Fig. 3 Typical water storage cistern found in B-2 sector of Figure 1



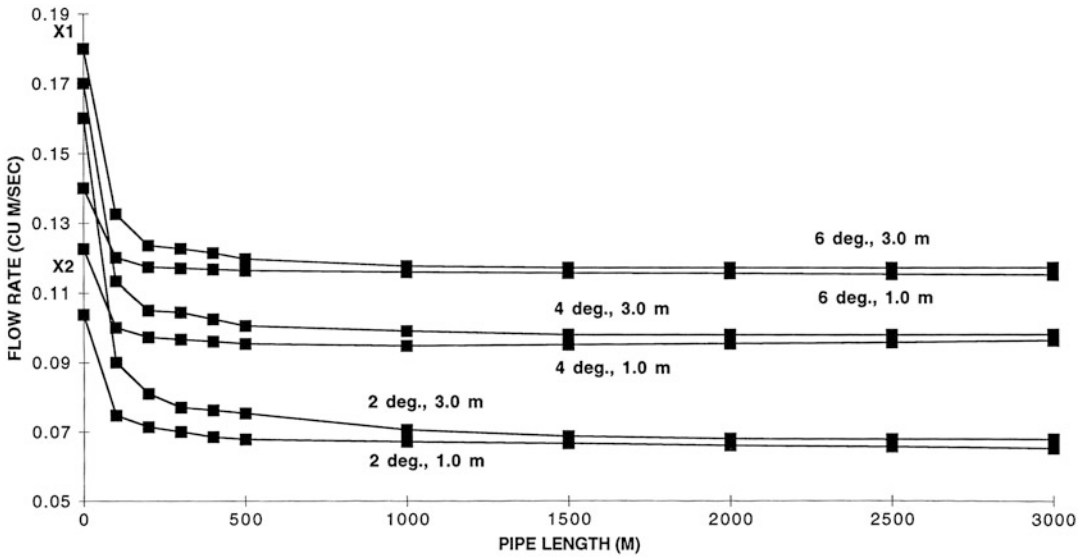
achieve water transit through a depressed valley area (Oleson, 1995, 2007). If earlier versions of the Ain Braq water conveyance system consisted of slab-covered, open trough sections that were sealed to limit evaporation and soil intrusion, then this portion of the conveyance system served as an effective, exterior-sealed “pipeline” subject to similar hydraulic principles governing either full or partial flow in terra-cotta pipelines. Figure 8 illustrates that circular cross-sectional terra-cotta pipelines associated with the Ain Braq system were buried about 1.0 m under the ground surface and led water to a cistern near the pipeline branch to the Zhanthur housing district. Given the preponderance of pipeline sections of this system, it is likely that the entire system contained a continuous pipeline from the spring source. Figures 9 and 10 show (unexcavated) surface traces of water distribution features leading to this area. Notably, a quote from the ancient Greek historian Strabo “. . .and the inside part of the city having springs in abundance, both for domestic purposes and for watering gardens. . .” reaffirms that springs were a vital part of the water resources of the city. Additionally, spring-supplied reservoirs (Fig. 1; Zurraba, 1), many of which are now destroyed by recent town construction, served to supply lower-level fountains and storage facilities to provide water on demand through pipelines.

Water Management of the Siq Pipeline System

The main city water supply originated from the Ain Mousa spring about 7 km east of the town of Wadi Mousa (Fig. 1, D1) and was combined with the waters from the minor Ain Umm Sar’ab spring. Because the flood bypass tunnel at the Siq entrance and infilling and paving of the Siq floor in ancient times reduced flood episodes, parts of the early slab-covered, open channel lie under the pavement surface attributed to Aretas IV and later Roman (and modern) constructions. Recent excavations reveal ~5 m of flood debris coverage over the original paved area in front of the Treasury (Fig. 1, 11) and water basins

connected to the original open-channel water supply system. With increasing water needs for an increasing population in early centuries CE, an elevated 2 km long, north-side “Little Siq” pipeline extension (Fig. 6) completes the totality of the Siq pipeline system (Ortloff, 2005, 2009) to supply potable water to further reaches of the urban core of Petra utilizing a large fraction of the Ain Mousa spring flow. Owing to destructive hydraulic instabilities (water hammer, transient pressure waves, flow intermittency, internal pipeline hydraulic jumps, turbulent drag amplification zones, vapor pockets) that occur in pipelines, a new set of hydraulic and water management problems in design of the system required the development of new technologies to manage stable pipeline flows, match part of the Ain Mousa spring output to the maximum flow rate the pipeline could sustain, and limit pressure within the pipeline to avoid leakage at the many thousand pipe-joint connections along the length of the pipeline. Here for a pipe element length of ~0.35 m and total pipeline length over ~10 km with a total height drop of over ~50 m, high hydrostatic pressure in a full-flow pipeline would increase the likelihood of leakage. The solutions to mitigate all these design and operational problems provide insight to Nabataean water management expertise.

CFD calculation (FLOW-3D 2013) of maximum flow rates (m^3/s) in long 14 cm diameter piping at 2, 4, and 6° slopes for 1.0 and 3.0 m head (height of water in a tank above the entrance to piping) reveals that past 300–400 m, an increase of input head does not substantially increase the flow rate (Fig. 4). This result, noted in antiquity by Archimedes, essentially means that the flow rate due to cumulative water-pipeline internal wall shear resistance limits the flow rate the pipeline allows. In other terms, a pressure gradient is required to produce a given pipeline flow rate; with higher flow rates and longer pipe lengths comes more shear resistance requiring a higher pressure gradient to overcome. Past about 300–400 m, even a 3X head increase is insufficient to increase flow rate. The implication for the Siq pipeline is that only a fraction of the Ain Mousa spring output ($500 \text{ m}^3/\text{day}$ according to



Hydraulic Engineering in Petra, Fig. 4 Allowable flow rate diagram for 18 cm diameter piping for 2, 4 and 6 degree piping declination slopes for 1 and 3 m water

height (head) values. Results indicate that past ~400 m piping lengths, additional head does not significantly increase flow rate

Hydraulic Engineering in Petra, Fig. 5 Typical head reset basin between sequential piping lengths along the Siq pipeline



Oleson 1995, 2007) can be transmitted through the 14 cm diameter pipeline under full-flow conditions due to the pipeline's cumulative flow resistance associated with its ~10 km length. Given this challenge, Nabataean water engineers devised the perfect solution. Along the length of the north-side pipeline, several open basin features (Fig. 5) are found at ~400 m intervals along the pipeline. Each basin permits the accumulation of water serving as a “head tank” for the

downstream ~400 m piping length. Essentially, the head is reset at the origin of each ~400 m piping length so that flow through that segment is sensitive to this supply head value according to Fig. 4 results. The open basins additionally served as drinking basins along the Siq path and provided easy cleaning of any soil particles that accompanied flow from the Ain Mousa spring. The presence of open basins negates the assumption that the piping supported pressurized full

Hydraulic Engineering in Petra, Fig. 6 Remaining pipeline elements in the elevated Little Siq extension past the North Siq pipeline indicated by dashed line (Sector 1, B-C in Figure 1)

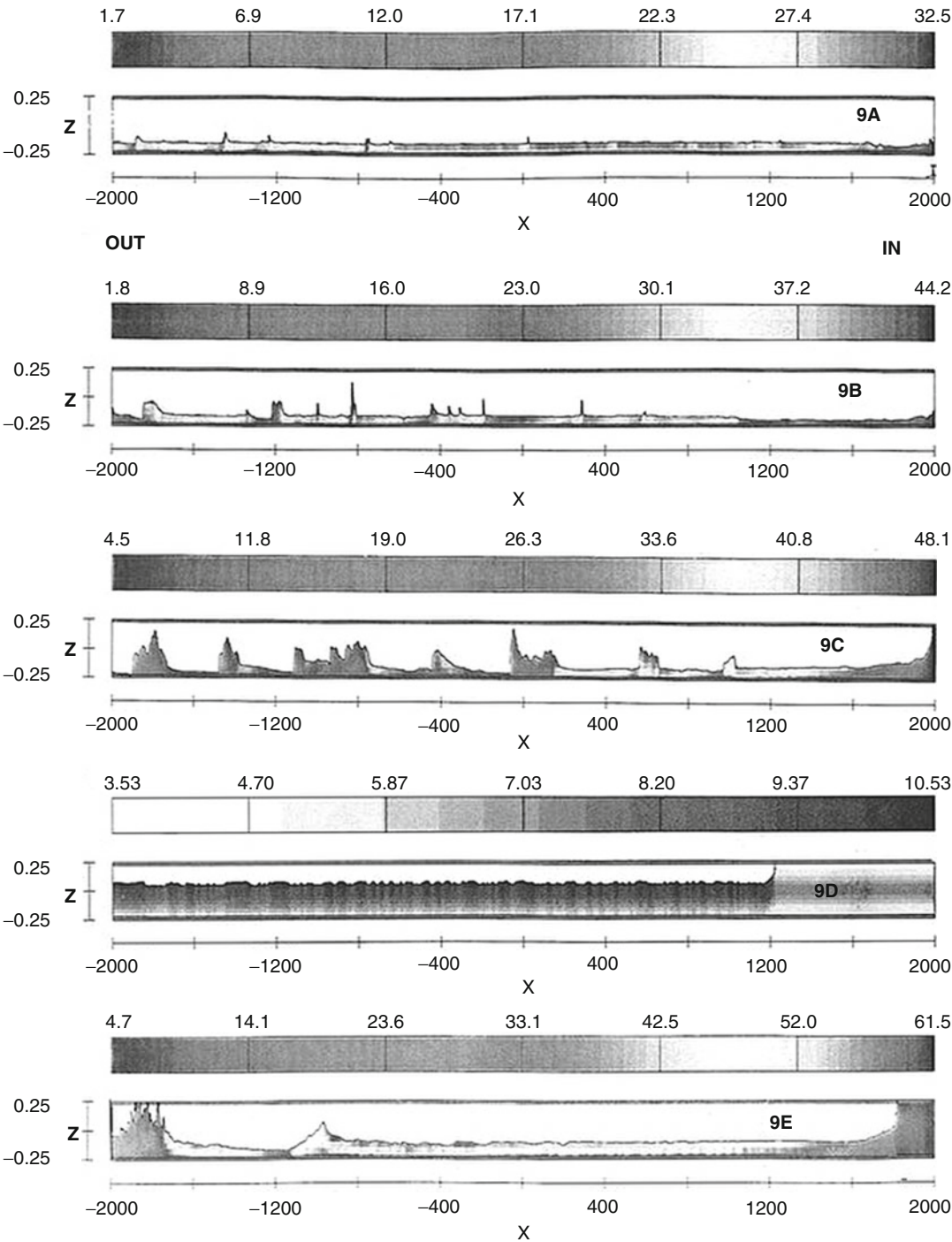


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flow, and because of the open basins, flow in the pipeline is partial flow sustaining an airspace above the water surface at atmospheric pressure, thus eliminating pipe-joint leaking that would occur from pressurized, full-flow conditions. To achieve a piping design based on 14 cm pipe diameter at the floor angle of the Siq when the Siq pipeline was constructed (the piping runs parallel to this angle), ideally partial, critical flow at unit Froude number (Fr) at the critical depth provides the maximum flow rate the piping can convey. As open basins were sequentially lower than their predecessor basins due to the declination slope of the pipeline, water height in a basin supplied the head for its adjoining downstream piping section, and partial flow can be retained throughout the piping sections with a flow height close to the critical depth. In the “Little Siq” area immediately west of the Treasury, a lower-level pipeline appears close to present ground level; this trough would be about 5 m above the original pavement level now obscured by flood debris infilling. Another pipeline appears about 10 m above this pipeline (Fig. 6), and as it runs at a higher elevation, it provides water to further reaches of the city. This higher elevation pipeline section continues the Siq pipeline and is set at a lower angle than the Siq pipeline. Given the (accepted) 40 m³/h Ain Mousa flow rate, a further consideration arises as to the stability of the flow in the piping sections within the Siq as

well as for water arriving to the Nymphaeum (Fig. 1, 42) through the continuation of “Little Siq” pipeline. Here if flow delivery is pulsating into open basins, then spillage and sloshing occurs in the basins amplifying the flow instabilities transmitted along successive piping lengths. Without stable pipeline flow, water transfer in the Siq and continued piping to the Nymphaeum are inoperable due to spillage flow losses and pulsating delivery flow rates; these would all be inconsistent with a competent engineering design expected to be found at a world-class city.

For an examination of flow stability, three-dimensional computer models (FLOW-3D 2013) were made for a 1,220 m long section of the 14.0 cm diameter piping used in the “Little Siq” extension with a declination slope slightly less than that found in the Siq pipeline. This length represents the distance from the exit of the Siq pipeline to the Nymphaeum water destination location. Computer solutions for 0.305 (A), 0.610 (B), 1.54 (C), and 3.05 (E) m/s water velocity were made assuming full-flow entry conditions at the right boundary with wall roughness typical of the interior surface of the piping elements (Fig. 7). Figure 7 (D) results are for a smooth interior pipe element wall at 1.54 m/s velocity to demonstrate the effect of wall roughness on flow patterns at the same water velocity. From the prior result of 40 m³/h accepted into the Siq piping, average pipeline water velocity is on



Hydraulic Engineering in Petra, Fig. 7 Flow stability diagrams indicating internal partial flow, water flow patterns in the Little Siq pipeline for various flow rate conditions

Hydraulic Engineering in Petra, Fig. 8

Recently discovered subterranean pipeline-cistern component of the Ain Braq siphon system (Sectors 1-2, B in Figure 1) delivering water to the Zanthur housing district, Great Temple and Paradeisos (Bedal 2004) districts (2-B in Figure 1).



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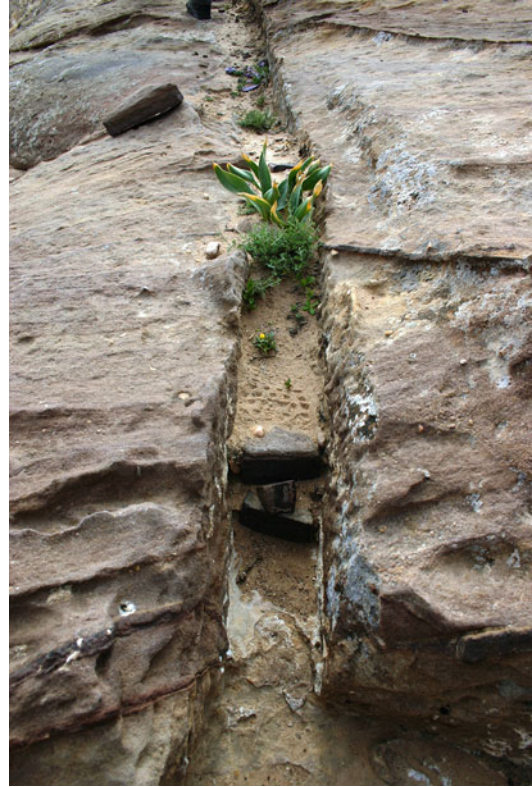
Hydraulic Engineering in Petra, Fig. 9 Surface traces of one of the branches of the subterranean piping channel leading water to the Zanthur housing district (Sector 2-B in Figure 1)

the order of 0.7 m/s. Given that the flow is slightly supercritical ($Fr \approx 1.18$) at this velocity on a hydraulically mild slope, the flow will approach a normal depth (Morris & Wiggert, 1972) for cases (B), (C), and (D) appropriate to each velocity. For flows close to critical, the normal depth is close to the critical depth. Figure 7 shows transition to lower water depths from the initial full-flow boundary condition for all supercritical (B), (C), (E), and (D) cases; for the subcritical case (A), water is at a low level due to the low flow rate and flow velocity. Figure 7 (B) at 0.610 m/s is close to the mean velocity of 0.71 m/s and indicates that only minor, random height excursions occur in the flowing water within the pipeline. This indicates that the water supply system through the Siq to the Nymphaeum is stable. At twice the velocity, Fig. 7 (C) indicates large height fluctuations in the water surface that indicate unstable flow pulsations occur throughout the pipeline system. This indicates that the flow rate selected from the Ain Mousa spring was a deliberate design choice to achieve stable flow in the system. Comparison of Fig. 7 (C) to (D) indicates that internal pipeline wall roughness amplifies large-scale turbulent eddies that contribute to flow unsteadiness; this effect is included in the (B) results. Tracking the end



Hydraulic Engineering in Petra, Fig. 10 Traces of the reservoir tank supplied by the Ain Braq siphon that divided water flow into two discrete piping systems—one directed toward the Zanthur housing district and the other toward the Great Temple (Sector 2-B in Figure 1)

part of the “Little Siq” pipeline reveals it is connected to an open basin indicating a further feature to ensure flow stability for flow into further pipeline branches. While a branch of this pipeline delivers water to the Nymphaeum, another branch likely crossed the Wadi Mousa streambed by a bridge to deliver water into the south marketplace area on the Cardo. This reinforces the observation that redundant water flow paths existed to provide water to key facilities located at, or near to, the marketplace so that water supplies were guaranteed if one of the branches was not serviceable for repairs or cleaning (Ortloff 2005). This redundancy also holds for the Wadi Mataha pipeline as a branch from 22 to 42 (Fig. 1) provides water to the Nymphaeum and marketplace as well as



Hydraulic Engineering in Petra, Fig. 11 Part of the Ain Braq channel (Sector B-1 in Figure 1) that originally supported a pipeline from a distant spring to the siphon that led water through system components shown in Figures 8–10.

supplemental water supplies to the Theater district (Figure 12) by a bridge-pipeline continuation across the Wadi Musa streambed.

Conclusions

Analysis of the Siq water supply system indicates that its design, function, and management had been carefully crafted to eliminate potential water instability effects that promote leakage and open basin spillage while providing $40 \text{ m}^3/\text{h}$ water into the city interior. The pipeline system was crafted to supply this flow rate as the maximum value the pipeline could transport further implying Nabataean knowledge of high levels of hydraulic science only formulated in western



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Hydraulic Engineering in Petra, Fig. 12 The Petra Theater (19, Figure 1). Water supplied to the Theater district originates from a Siq south branch pipeline

extension, a bridge-pipeline extension of the Wadi Mataha pipeline (Sector C–2 in Figure 1) and (possibly) a supplementary branch off from the Ain Braq pipeline.

science years later. Avoidance of flow instability problems by using advanced hydraulic designs found throughout the Siq pipeline system decreases water management problems significantly and decreases maintenance (except for unavoidable accumulation of calcium carbonate “sinter” choking the interior diameter of the pipeline that later required the removal of top parts of the pipeline to restore system functionality at reduced flow rates). Thus water management became routine over long time periods as high levels of technology initially incorporated into the Siq system design eliminated many problems requiring maintenance were a less-efficient design in place. A similar design stratagem underlies modern water delivery systems dependent solely upon gravity for water transport. For Petra, similar design considerations are unique in their foresight of a hydraulic technology only formalized in western hydraulic science some 2,000 years later.

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Hydraulic Systems in the Middle East

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Introduction

Because of its arid climate, much of the Middle East benefits from the development of water management systems: without water to supplement the meager rainfall, agriculture and permanent settlement would be impossible in many places. However, aridity is not the only factor in making the land habitable, and in this entry, we demonstrate that water supply systems have progressively spread from drier areas to eventually develop in wetter parts of the region. This is for reasons other than to combat water deficits. Consequently in this entry, a distinction is made between those water systems that were used to address water deficits (whether for irrigation, drinking water, or for other purposes) and those that were mainly intended to stabilize cropping or intensify yields.

Both domestic water supply and the delivery of water for the irrigation of crops are summarized for the entire Middle East (Fig. 1: location 1). Whereas a number of recent volumes have tackled the history and technology of

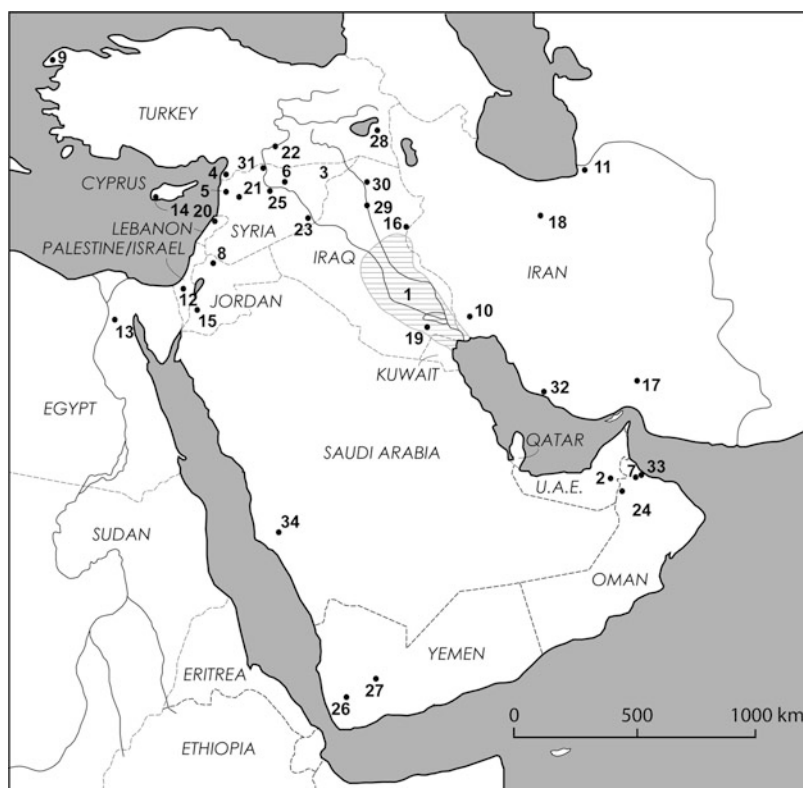
water use (Amit, Patrich, & Hirschfeld, 2002; Biernert & Häser, 2004; Hodge, 1991; Wikander, 2000), this entry will complement these approaches by also focusing on the landscape setting of ancient water systems.

Climate, Environmental Change, and Water Supply

As Fig. 2 indicates (For data see: Schneider, Becker, Meyer-Christoffer, & Ziese, 2011), rainfall averages in the northern Fertile Crescent today are low. Much of Mesopotamia receives below 200 mm per annum, which approximates to the limit of rain-fed agriculture. The core area of southern Mesopotamia is famous for the precocious development of cities in the fourth and third millennium BC, whereas north of this arid riverine desert, agriculture can survive from rainfall alone. In addition, the deserts of Arabia and Iran provide examples of early water management, which have been discovered, in part, because once built, an installation will remain in place because there has been little subsequent activity to remove it. Such “landscapes of survival” have supplied us with some of the earliest evidence of hydraulic management. Additionally throughout the Middle East, smaller rivers, ephemeral wadis or streambeds, surface runoff, and groundwater extraction all have become more significant for water supply.

Numerous studies demonstrate that during the earlier part of the Holocene (roughly 10,000–6,000 years ago), the region was significantly moister than during the last 4,000 years. Although these changes were not necessarily synchronous over the entire Middle East, it is evident that development of irrigation and water supply technology often occurred when the climate was becoming, or had become, significantly drier.

Although water management systems developed during the earlier moister phases of the Holocene there was a significant increase in their use during the last 4,000 years. However, at the same time as the climate was becoming drier, in parts of the Middle East, human



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Fig. 1 Location map showing the main sites or areas discussed in text (locations, including national boundaries are approximate). Numbered locations: (1) Southern Mesopotamia, Iraq; (2) Buraimi, United Arab Emirates; (3) Khabur Basin, Syrian Arab Republic; (4) Amuq, Turkey; (5) Ghab, Syrian Arab Republic; (6) Balikh Valley, Syrian Arab Republic; (7) Wadi Jizzi, Oman; (8) Khirbet ez-Zeraqon, Jordan; (9) Troy, Turkey; (10) Karun River, Islamic Republic of Iran; (11) Gorgan River, Islamic Republic of Iran; (12) Northern Negev desert, Israel; (13) Sadd el-Kafara, Egypt; (14) Kissonerga-Mylouthkia,

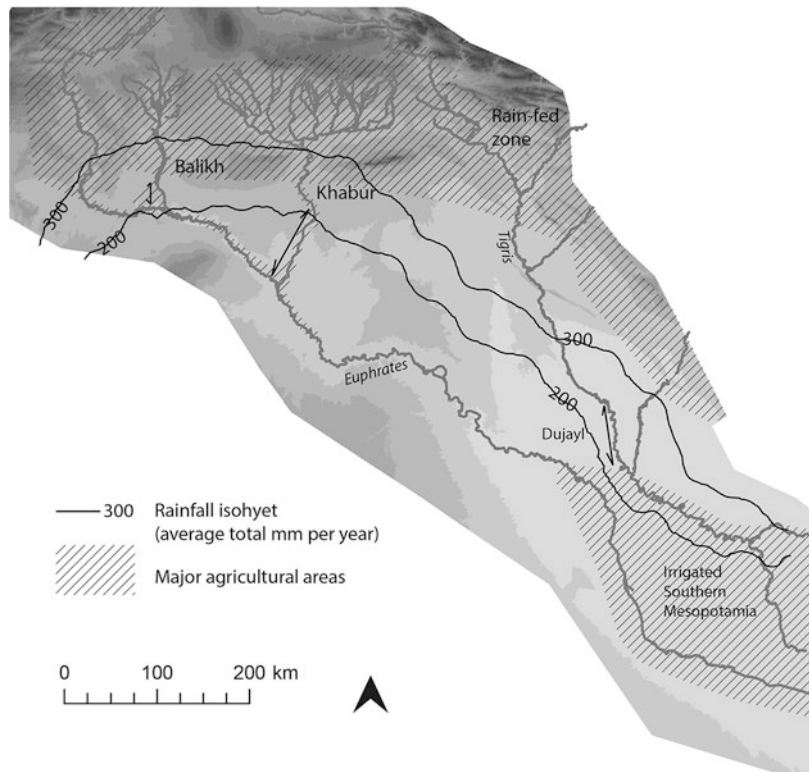
Cyprus; (15) Wadi Abu Tulayha, Jordan; (16) Choga Mami, Iraq; (17) Tepe Yahya, Islamic Republic of Iran; (18) Tepe Pardis, Islamic Republic of Iran; (19) Tell Oueli, Iraq; (20) Byblos, Lebanon; (21) Al-Rawda, Syrian Arab Republic; (22) Kurban Hoyuk, Turkey; (23) Mari, Syrian Arab Republic; (24) Bāt, Oman; (25) Balis, Syrian Arab Republic; (26) Dhamar, Yemen; (27) Marib, Yemen; (28) Urartu, Turkey; (29) Kar Tikulti-Ninurta, Iraq; (30) Nineveh, Iraq; (31) Carchemish: Turkey and Syrian Arab Republic; (32) Siraf, Islamic Republic of Iran; (33) Sohar, Oman; (34) Mecca, Saudi Arabia

populations were increasing, political economies were becoming more complex, and cities were larger. By the first millennium BC, the area was witnessing the growth of massive territorial empires and their associated capitals, which provided the administrative context for creating some of the more sophisticated systems of water supply.

However, the development of such systems also resulted in unanticipated environmental

consequences. For example, excessive irrigation and the accumulation of outflow waters resulted in waterlogging and the development of marshes, such as in the Amuq and Ghab Valleys of Syria and Turkey (Fig. 1: locations 4 and 5), as well as in southern Mesopotamia (Cole, 1994). Elsewhere, the discharge of minor rivers, such as the Balikh, apparently was depleted by the excessive withdrawal of water for irrigation (Fig. 1: location 6).

Hydraulic Systems in the Middle East, Fig. 2 The rain-fed and irrigated zones of the northern Fertile Crescent in relation to modern rainfall



Archaeological Evidence for Ancient Water Systems

Although ancient water supply channels can be long and robust features, their frequent construction within riverine environments that are subject to both erosion and sedimentation can result in canals being eroded away or obscured by sediments.

Field evidence generally consists of visible channels, some of which have upcast banks created during construction and canal cleaning (Wilkinson, 2003). Larger-scale irrigation systems will include intake structures such as a dam and reservoir, abstracting from a perennial water source, as well as a main transport canal. Sequences of offtakes will branch off from this and divert water into the fields. Often, however, only the main canal will be preserved.

Archaeological survey enables irrigation systems to be located and recorded, dating material to be collected and other contextual information to be identified. Excavation is often necessary for

absolute dating and for determining the dimensions of the original, non-eroded/silted canal. These parameters can indicate the amount of water which could flow through the system.

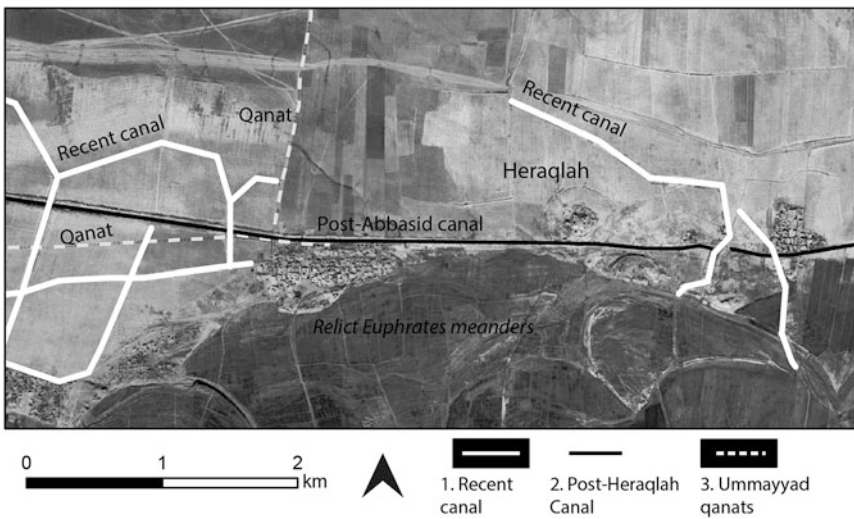
Remote sensing has offered new ways of recording water management features relatively quickly and cheaply and has the advantage of identifying water supply channels over large areas. Data employed includes recent high-resolution imagery such as DigitalGlobe, but declassified CORONA satellite images from the 1960s and 1970s have proved especially useful because they were taken before much destruction of the modern landscape had occurred (Ur, 2005; Fig. 3).

Dating Evidence

Critical to the development of any history of water supply is the date of the features themselves. Dating evidence can be gained through excavation and survey and by the association of canals with dated archaeological sites. Excavated sections in canals can provide material for

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Fig. 3 Satellite image of canal, the Band-e Valī, linking the Gorgan River with the Sasanian (fifth–sixth century AD) Gorgan Wall and ditch in northeastern Iran (CORONA satellite image courtesy of US Geological Survey; from Sauer, Rekavandi, Wilkinson, & Nokandeh, 2013, Fig. 3:61)



Hydraulic Systems in the Middle East, Fig. 4 Post-Abbasid canal cutting the Abbasid site of Heraqlah, near Raqqa, Syria

absolute dating. Archaeological surveys have also facilitated dating through analysis of surface scatters of material alongside canals (Geyer & Monchambert, 2003; Kuhne, 1990). In some cases evidence is provided by written material, such as inscriptions associated with Assyrian canals in Northern Iraq (Bagg, 2000b; Jacobsen & Lloyd, 1935). Perhaps the most significant development in recent years is the use of optically stimulated luminescence dating (OSL), which can provide date estimates for quartz or feldspar grains in canals and their upcast.

In some cases a feature of unknown date can be dated based on an association with features of known date. Irrigation channels around the

Abbasid site of Heraqlah to the east of Raqqa in northern Syria provide an example of the sequence of “layers” which these systems can form in the landscape. The CORONA image (Fig. 4) shows a large canal cutting through the walls of the Abbasid site of Heraqlah, therefore demonstrating that the canal itself postdates the early Abbasid period.

Nevertheless, many irrigation features are multi-period networks. Canals can have lifetimes which involve construction, use, abandonment, and later modification/reuse. For example, the sustainability of many ancient systems in the landscape is demonstrated by ancient (Assyrian–Early Islamic) systems which

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Fig. 5 Travertine-encrusted conduits of Late Antique date at Pamukkale, Turkey



persisted into the early twentieth century AD, as was the case for many canals alongside the Euphrates, Balikh, and Khabur Rivers.

Classification of Water Supply Systems in the Middle East

The recognition of ancient water supply systems by survey or by remote sensing depends upon the existence of diagnostic features that correspond to some of the main classes of those systems. In the Middle East, such diagnostic features also provide evidence of how the technology of water supply developed; they fall into the following broadclasses.

Groundwater Supply

Diagnostic features of wells and water holes include rings of soil and gravel accumulated around the mouth of the well. Wells are usually only capable of supplying sufficient water for a household or small garden but have the advantage of being built and maintained at the household level (Costa & Wilkinson, 1987, pp. 43–53; Hodge, 2000b, p. 33).

Qanats are dug to intercept groundwater (or underground springs) and then lead the water away via a gently sloping tunnel to a settlement and its fields beyond. Following the excavation of the “mother well,” which is the prime

water-gathering point near the water source, the qanat is usually dug from the dry downstream part of the qanat just above the settlement to intersect with the mother well via an underground tunnel (Beaumont, 1989; English, 1998).

Perennial Surface Water Supply Channels

The tapping of water from springs or pools in wadi beds (known as *ghayl* irrigation in much of Arabia) has long been a fundamental form of water supply and in Oman is a technique that extends back to the third millennium BC (Cleuziou & Tosi, 2007). These small, relatively stable flows are usually accommodated within open channels that by the Roman–Parthian period (ca. first/second century BC to third/fourth century AD) could extend up to 40 km in length and were usually lined with hydraulic plaster, although in some locations they have become coated by deposits of natural travertines (Fig. 5). In some cases rock-cut conduits and tunnels were also used to transport water from springs or streams.

In contrast, large open earth-lined channels that diverted water from perennial rivers are characteristic of the Tigris and Euphrates Rivers and their tributaries, as well as other major perennial river systems such as the Orontes, Khabur, Karun, and Gorgan Rivers (Fig. 1, locations 5, 10, and 11 and Fig. 4). Such systems consist

of (1) a water-gathering zone near the source river, (2) a transportation zone that conducted the water, and (3) the settlement and its fields where the water was consumed (Wilkinson, 2003, pp. 47–50).

Episodic Surface Water Supply

Whereas perennial rivers produce an annual flood that can be managed, the utilization of floodwaters incurs higher risk and requires the incorporation of some form of safety net to evacuate excess water. Flood irrigation consists of a suite of technologies based around a continuum of processes. At the largest scale, flood irrigation from rivers is usually termed *sayl* irrigation (see Varisco (1983) for the distinction between Arabic *sayl* and *ghayl*). On the other hand at a small scale, runoff can simply be gathered from the slope above a field and directed to the land to supplement the local rainfall. The fundamental principle underlying the gathering of water from ephemeral flow is the distinction between the contributory runoff area and the recipient or run-on area, usually a field or system of fields (Pacey & Cullis, 1986). In the case of flood irrigation, the contributory area can consist of an entire river basin, whereas local runoff systems may make do with the runoff from a small patch of ground immediately upslope of the recipient field (Wilkinson, 2006). The classic case study of runoff technology was made in the northern Negev Desert where Roman and Byzantine runoff agriculture formed the economic mainstay of farmsteads, villages, and small towns along the desert margins (Fig. 1: location 12; Bruins, 1986; Evenari, Shanan, & Tadmor, 1982).

In addition, water tanks, reservoirs, or basins (*birkehs*) are associated with both episodic flow regimes and perennial flow. These are often connected with dams or bunds, the earliest of which, such as the Sadd el-Kafara in Egypt, date back to the middle of the third millennium BC (Fig. 1: location 13; Fahlbusch, 2004; Hodge, 2000a; Smith, 1971). Basins can be deep (>5 m) and therefore useful for storing water or much more shallow (<2 m) and therefore more suited to

the temporary holding of water at the head of a field system and to act as a flow regulator, where a deep tank would render some of the water unusable (Costa, 1983, p. 286).

Drainage

Unfortunately, as a means of getting rid of excess water, drainage systems have been less thoroughly investigated but are mainly known from Mesopotamian cities (Wilson, 2000a) rather than from the countryside beyond; if drainage canals existed, they are difficult to differentiate from water supply canals.

Earliest Forms of Water Supply

Wells were the earliest known constructed source of water in the Near East (Hodge, 2000b). The oldest examples were already recognizable by the Cypriot Pre-Pottery Neolithic B (Peltenburg et al., 2000) and the Pre-Pottery Neolithic C of the Carmel coast (ca. 7000–6200 BC) (Galili & Sharvit, 1998). The 7–8 m deep wells of Kissonerga-Mylouthkia in Cyprus (Fig. 1: location 14), dated to the period 8400–6400 BC, appear to have tapped small underground watercourses. They were equipped with hand- or foot-holds and were apparently used to supply water for sedentary dwellings (Peltenburg et al., 2000, pp. 846–848). These features appear to represent a fully formed well technology; therefore one can only assume that earlier examples of water holes have not yet been recognized.

Nearly contemporary with the early wells on Cyprus are barrages recorded in the desert south of Amman, Jordan. At Wadi Abu Tulayha (Fig. 1: location 15) and nearby sites (ca. 50 mm of rainfall per annum), several low stone walls have been found constructed across the wadi that are dated by association with a Late Pre-Pottery Neolithic B (late PPNB) agropastoral “outpost” settlement (Fujii, 2007). The barrages are interpreted as having been constructed to hold back water to provide essential moisture for crop cultivation or to supply additional drinking water for the nearby late PPNB community. Such early features are now supplemented by similar

water-gathering structures recorded from the desert margins in central Syria (rainfall 150–200 mm per annum). These PPNB features have again been recorded within “landscapes of survival” where subtle stone-built features are less likely to have been destroyed. The features consist of small water-gathering structures which enhance natural karstic hollows in the limestone but also include small basins (Geyer, Chambrade, & Coqueugniot, 2014). Consisting of small artificial “ponds” bounded by alignments of large stones presumably to gather runoff from the desert surface, the features are associated with abundant scatters of lithics, as well as later artifacts of the Bronze Age and Roman–Islamic date. Although not securely dated, these water-gathering structures and increasing numbers of similar features from the Syrian and Jordanian deserts (Geyer et al., 2014, note 18) together suggest that the development of water systems in the Middle Eastern deserts date back to at least 8000–7000 BC.

In parts of the Levant and Iran, early irrigation appears to have been associated with alluvial fans or minor rivers. Following the initial suggestion of Andrew Sherratt and the recognition of irrigation channels at Choga Mami (Fig. 1: location 16; Oates & Oates, 1976; Sherratt, 1980), early irrigation channels have been identified near Tepe Yahya in southeastern Iran (Fig. 1: location 17; Prickett, 1986) and on the Tehran plain near Tepe Pardis, the latter being dated by radiocarbon to ca. 5000 cal. BC (Fig. 1: location 18; Coningham et al., 2006, p. 51). These narrow, earth-lined channels buried below sites and within landscapes that are prone to burial by later sediments are difficult to find, but such locations provide a sealed stratigraphic context for channels; consequently the dates established (ca. 6000–5000 BC) appear relatively secure.

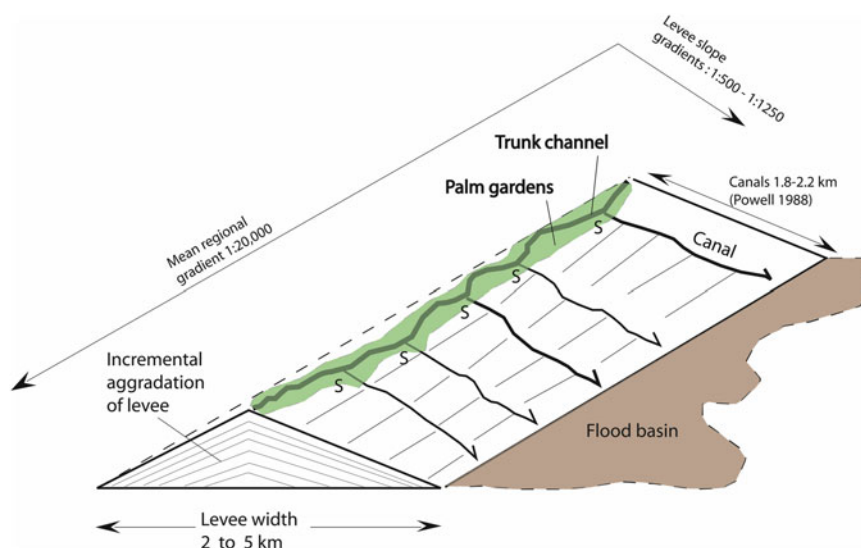
How the above developments relate to the earliest riverine irrigation systems of Mesopotamia is difficult to say, although evidence from excavations at Tell Oueli in southern Iraq suggests that early irrigation was already in place there by 6000–5500 BC (Fig. 1: location 19; Huot, 1996).

Irrigation in Southern Mesopotamia

Southern Mesopotamia, one of the early cradles of civilization and urbanization, was very much dependent upon the manipulation and management of water. The history, development, or practices of Mesopotamian irrigation have been summarized by Adams (1981); Pemberton, Postgate, and Smyth (1988); Postgate (1994, pp. 173–190); Charles (1988); Bagg (2012); Widell, Hritz, Ur, and Wilkinson (2013); and Tamburrino (2010). Evidence for the early history of water distribution in southern Mesopotamia derives from a range of sources: archaeology, paleobotany, ancient cuneiform texts (in Sumerian and Akkadian), as well as geomorphology and history, hence bringing together such a wide range of source materials can result in conclusions that may be difficult to harmonize. Effectively the history of water management in these alluvial lowlands picks up from that at Choga Mami, situated along the eastern fringes of the plain and can be continued at Oueli where a French team has documented the early history of irrigation during the Ubaid period.

During these earlier phases of the Holocene, settlement appears to have been associated with both rivers and marshes (Pournelle, 2007), but by about 4000 BC or slightly later, the distinctive patterns of settlement alignments recognized by Adams (1981) and Jacobsen (1960) started to appear along raised riverine levees.

Because the Mesopotamian plains exhibit very low gradients, the distribution of water laterally is difficult. However, the anastomosing (i.e., branching) river channels of the Tigris and Euphrates Rivers, being frequently raised upon levees some 1–5 m above the flood plain, offer the opportunity to distribute water down the levee slopes, which are significantly steeper than the longitudinal gradient of the plain (Adams, 1981; Fig. 6). This process appears to have resulted in a pattern of longitudinal channels and short (1–5 km) canals which must have contributed to the “herringbone” pattern of canals in many parts of the plain. In addition, longer canals were also constructed. For example, in his royal inscriptions, Ur-Nammu (ca. 2113 BC) claims to have



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Hydraulic Systems in the Middle East, Fig. 6 Block diagram of levee in southern Mesopotamia showing the mode of downslope irrigation

authorized the excavation of major hydraulic works, and large canals, such as the 50 km-long Nina canal, were occasionally recorded (Rost, 2011, pp. 16–17). By the later second millennium BC, Adams (1981) recorded an increased number of longer cross-canals that linked earlier longitudinal channels.

One consequence of the limitations of the low-gradient landscape was that it was frequently difficult to raise water to the required level by gravity alone. Therefore artificial water-raising devices became increasingly necessary from the third millennium BC. Hence, we see evidence of *shadufs* (see below), and by the first millennium BC, a wider range of water-lifting devices were also in use, including the Archimedean screw (Dalley, 2013, pp. 32–34).

Although irrigation provided stable and higher yields, it also came at a cost, namely, salinization. Jacobsen and Adams have made a compelling case for the increased spread of salinization during the third millennium BC throughout southern Mesopotamia, eventually resulting in declining yields, a switch to salt-tolerant barley, and eventual settlement decline (Jacobsen & Adams, 1958). Although details of this salinization model have been disputed (Powell, 1985), salinization is clearly a perennial problem in the

region, and therefore any tendency to either violate fallow by cropping fields every year or extending cereal fields into low-lying flood basins (Altaweel, 2013) must have resulted in salinization and declining yields.

Mesopotamian systems were not, however, restricted to the broad plains south of Baghdad; they also extended further up the Euphrates. At Mari, administrative texts dating predominantly from the early second millennium BC testify to the existence of water-diversion features, canals, and different classes of irrigated and nonirrigated land (Fig. 1: location 23; Durand, 1990; Lafont, 2000, pp. 134–137). This textual evidence is supported by the presence of relict canals in the valley floor alongside the Euphrates which, although not well dated, appear to include major canals from the Bronze Age (Geyer & Monchambert, 2003).

Development of Water Supply During the Bronze Age in the Fertile Crescent and Levant

Outside the main irrigated lowlands, evidence for large-scale systems of water supply is limited, and hydraulic features appear mainly to have

been restricted to wells, pools, tunnels, and a few other examples of water capture.

In the southern Levant, bell- and bottle-shaped cisterns from sites at Mezar and Hazor provide evidence that the technology of storing water in such reservoirs was well advanced by the Chalcolithic and Bronze Age (Tsuk, 1997a, p. 13). For the southern Dead Sea region and the Levant overall, Frumkin (2002, p. 21) suggests that Bronze Age communities lacked sophisticated water supply systems and used water mainly from pools, cisterns, wells, and springs (Patrich & Amit, 2002, p. 9). The combination of springs, pools, reservoirs, and wells within the immediate limits of the settlement not only provided a convenient and accessible water supply for inhabitants, especially during times of siege, but they also may have served for watering flocks of sheep or draft animals. In a similar manner, the Bronze Age tunnels already mentioned at Kherabat al-Zeraqun in Jordan or at Troy in Turkey (Fig. 1: locations 8 and 9; Biernert, 2004; Latacz, 2004) would have ensured that the community inside the city walls was guaranteed access to water, even during times of conflict.

Overall, evidence of Bronze Age irrigation systems outside the Mesopotamian plains is limited. Examples include irrigation channels on the Beersheba plain in the northern Negev (Tsuk, 1997b, p. 130) and at Jawa, in northern Jordan (near Fig. 1: location 8; Helms, 1981). The latter site, dated to the Late Chalcolithic and EBI (late fourth millennium BC) and located in the arid Jordanian desert where rainfall is usually less than 100 mm p.a., was supplied by a sophisticated system of floodwater harvesting coupled with terraced gardens and pools (Müller-Neuhof, 2014). This system, which supplied sufficient water for a settlement of perhaps 5,000 people (Whitehead et al., 2008), is among the earliest known system of water harvesting in the Near East, other examples being known from Yemen (Harrower, 2008; Wilkinson, 1999).

A similar hydraulic landscape has recently been discovered within the zone of marginal rainfall at Al-Rawda in central Syria (Fig. 1: location 21). This system, dating from the third

millennium BC, comprised a series of embankments and transverse walls deployed to capture water into irrigated plots to support the inhabitants of this circular town (Castel & Peltenburg, 2007, pp. 4, 10). Overall, Jawa and Al-Rawda represent a phase of initial sedentary settlement of the arid margins of the rain-fed zone of the Levant at a time when the first cities were developing the northern Fertile Crescent. In southern Syria, water capture within cisterns and by wadi floor bunds and associated water channels supplied fourth and third millennium BC settlements with essential water for fields and domesticated animals (Braemer, Geyer, Castel, & Abdulkarim, 2010, pp. 103–107).

Although new discoveries, such as those around Al-Rawda, urge us to be aware that new data sources can transform our knowledge, it appears that agricultural production was predominantly a result of the following practices:

- (a) The use of rainfall as the dominant means of supplying water in areas where rainfall was greater than ca. 250 mm per annum.
- (b) The development of larger-scale irrigation systems in the alluvial plains of Mesopotamia and Iran.
- (c) The capture of small perennial flows, groundwater, runoff, and floods in the margins between the rain-fed zone and the true desert (Braemer et al., 2010).

The above water systems were all located close to or within the site itself, which implies that the technology of water supply was primarily deployed within a relatively short administrative reach of Bronze Age communities. In other words, the scale of the polities and the territorial boundaries of the settlements constrained the scale of water systems in use, a geographical limitation that was compounded by the needs of the communities to retain access to a reliable water supply during times of conflict or siege. After the Bronze Age, however, this was followed by a very rapid and extensive expansion of settlements and water management systems during the later territorial empires that have controlled the Middle East over the last 3,000 years.

Within Arabia, the development of oasis settlements at sites such as Hilli and Bāt in the United Arab Emirates and northern Oman (Fig. 1: locations 2 and 24) appears to have been associated with a combination of canal and well irrigation (Cleuziou & Tosi, 2007, pp. 154–155). Similarly, Yemen experienced the earliest phases of flood (*sayl*) irrigation within the Marib area (Brunner & Haefner, 1986), while in the Yemen highlands, runoff agriculture and valley floor check dams were in use (Wilkinson, 1999). Again, like their counterparts to the north, these were primarily small-scale hydraulic systems.

Water and Irrigation of the Later Empires

Although aggressive kings had created empires during the Early Bronze Age, only after the Bronze Age did political units increase in size to attain the massive scale and stability of the later territorial empires. At the same time there also appears to have been a shift in the scale of water management so that there was a significant reorganization of the settled landscape. These changes roughly coincided because, as has long been known, there is an apparent relationship between the scale and development of irrigation systems and the scale of the polities that administered them (Wittfogel, 1957). Nevertheless, as Adams has demonstrated, the really large-scale hydraulic systems seem to postdate the rise of centralized control and the early Mesopotamian empires (Adams, 1974; Marcus & Stanish, 2006, p. 4; Scarborough, 2003, pp. 17–19).

The significant changes in water supply and management that occurred during and after the Neo-Assyrian Empire (ca. 1200–612 BC) resulted in the following developments:

- An extension in the area of irrigated settlement, which included more dispersed, small settlements.
- Greater crop production in areas that were already capable of producing crops under normal rainfall (the limit of rain-fed agriculture being defined as 200–250 mm per year).

- The creation of water systems capable of supporting the growth of new and existing towns. This was especially the case for the Romanized Levant.

Many of the largest irrigation systems in the Middle East were constructed in southern Mesopotamia during the Sasanian (224–637 AD) and early Islamic periods (ca. 637–1100 AD) (Adams, 2006). However, major canals were also being built beyond the southern riverine zone, and water management technology spread into formerly more marginal Northern Mesopotamia by the authority of the kings of the larger empires.

To the west, in modern Syria, the Khabur Valley witnessed the construction of a major longitudinal canal system. This was initiated in the Middle Assyrian period around 1200 BC and then continued during the early first millennium BC coincident with the rapid growth of the Neo-Assyrian Empire (Ergenzinger, Frey, Kühne, & Kurschner, 1988; Morandi Bonacossi, 1996). It may also have continued in use into the Early Islamic period which demonstrates the durability of well-designed water supply systems.

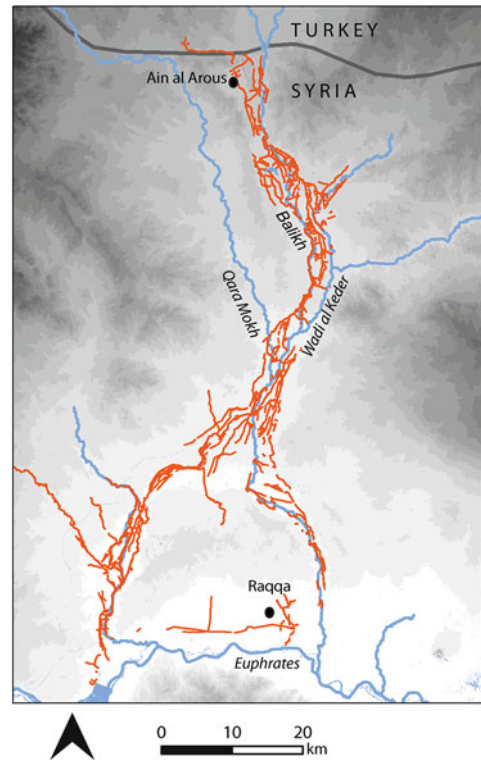
Similarly, in northern Iraq, the Assyrian kings have left behind a remarkable record of canals which both increased agricultural production and also contributed to the pleasure of everyday life (at least for the king and his court) and provided water for religious purposes. Further north within Anatolia, some of the earliest examples of canal construction occurred in the eighth and seventh centuries BC, where Urartian engineers produced sophisticated canal systems to provide supplementary water to their settlements and fields (Fig. 1: location 28; Belli, 1999; Garbrecht, 1980).

Probably the most comprehensive Assyrian hydraulic engineering scheme was that of Sennacherib, who constructed four major canal systems in the hills and valleys to the north of Nineveh (Fig. 1: location 30; Jacobsen & Lloyd, 1935; Oates, 1968; Reade, 1978; Ur, 2005). According to the inscriptions, these were constructed in four stages between approximately 702 and 688 BC and were designed to irrigate

orchards and cereal fields and also served to keep the imperial gardens and parks around the city green (Bagg, 2000a, pp. 318–320; Ur, 2005). Inscriptions state that water was used to irrigate cereal fields, perhaps including sesame and flax fields, or orchards (Bagg, 2000a, pp. 317–318). There can therefore be little doubt that the canals did indeed play a significant role in the increase of agricultural production for the Neo-Assyrian state (Ur, 2005).

In terms of hydraulic technology, these canals were remarkable achievements. They incorporated elaborate offtakes and circumvented obstacles such as tributary valleys by means of sophisticated stone-built aqueducts, the best known being Sennacherib's aqueduct at Jerwan (Jacobsen & Lloyd, 1935). It was also around this time that water-lifting devices such as the *shaduf* became even more sophisticated and visible in the landscape, as illustrated in one of the reliefs in Sennacherib's Southwest Palace at Nineveh (Bagg, 2012, Fig. 14.2). The sophistication of the Assyrian water systems behind Nineveh and the ambiguity of ancient references to the Hanging Gardens of Babylon have led Stephanie Dalley to argue that the famous Hanging Gardens were, in fact, at Nineveh (near modern Mosul) rather than at Babylon in the southern alluvial plains. Overall, Dalley makes the case for the use of sophisticated water-raising devices such as the Archimedes screw in the seventh century BC (Dalley, 2013, pp. 33–34, 56–57, 205–207).

Shortly after the fall of the Assyrian empire, remarkably sophisticated hydraulic installations were constructed around the Achaemenid centers of Pasargadae and Persepolis in Iran. Of particular sophistication is the Achaemenid Dam of Sad-i Didegan and the perhaps linked structure of Sad-i Shahidabad which appear to have controlled and stabilized water from the Rud-i Pulvar River to irrigated agricultural areas downstream (De Schacht, De Dapper, Asadi, Ubelmann, & Boucharlat, 2012; Kleiss, 1988). The five dams recorded, ranging from 150 to 700 m in length, were of ashlar blocks and earthen fill construction, with well-constructed stone-built canals and a remarkable subdivided sluice structure (De Schacht et al., 2012, Fig. 7).

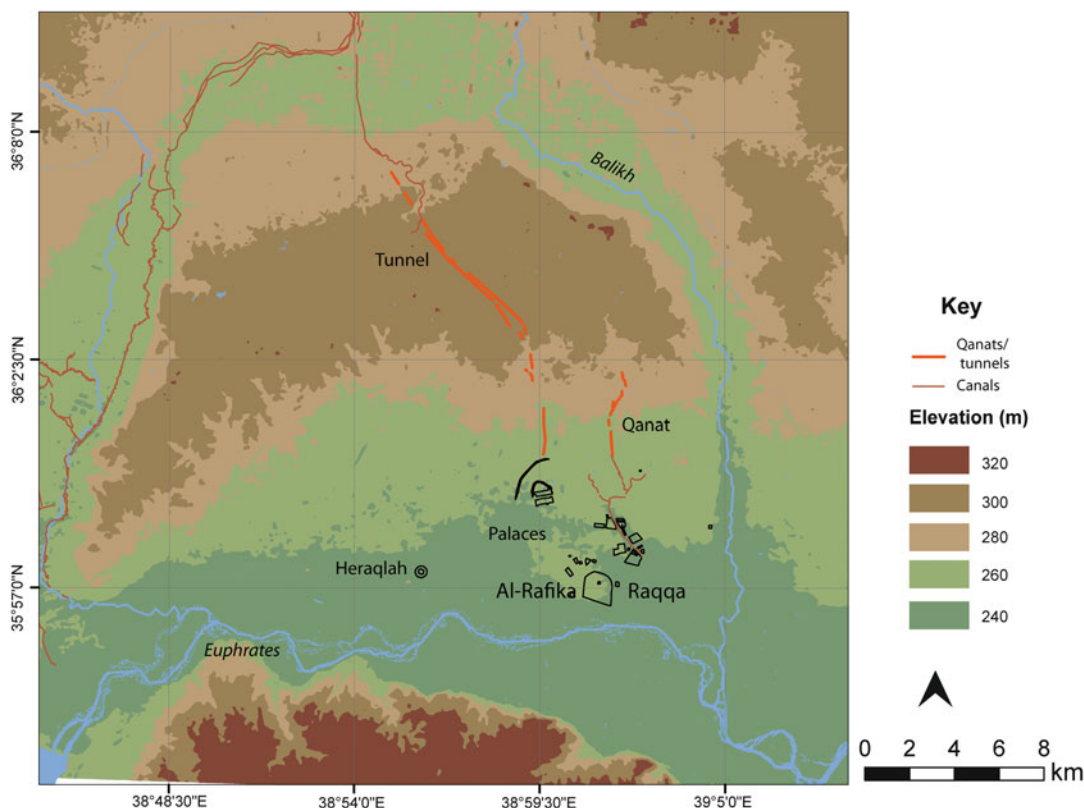


Hydraulic Systems in the Middle East, Fig. 7 The Balikh Valley in Syria showing the dense pattern of canals mapped from CORONA images and in the field. These represent a complex, tangled palimpsest of different cycles of use, reuse, and modification, mainly dating from the Hellenistic period and later (From Rayne, 2014)

Also near Pasargadae, in this case within the Royal Area of the site, Boucharlat (2009) has demonstrated that the Achaemenid gardens were actually much more extensive than the celebrated “Persian garden” described by Stronach (1978).

Like their Assyrian predecessors, the Achaemenid hydraulic works were not only of considerable sophistication, they were also harnessed to supply both functional needs and pleasure. They also demonstrate the sophistication of the engineers of the time, who were sufficiently sensitive to hydraulic challenges that they were capable of stabilizing uneven flows, incorporating sophisticated lifting devices and controlling flows in ways that became much more familiar in the classical world which followed.

Whereas Assyrian and Achaemenid water technologies were of considerable sophistication,



Hydraulic Systems in the Middle East, Fig. 8 Main features of the early Islamic city of Raqqa/Rafiq in northern Syria showing the course of an open channel which flowed through a tunnel to supply the Abbasid palaces

with water. To the east, a *qanat* originates in an area of elevated ground to the north of the civil settlement of Raqqa. Topography derived from ASTER GDEM (From Rayne, 2014)

later water supply systems were often densely distributed throughout the landscape. For example, within the Balikh Valley of Syria (Fig. 7), numerous irrigation systems dating to the Hellenistic and later periods demonstrate how some landscapes became almost dominated by canals and water works (Wilkinson & Rayne, 2010). Textual evidence in the form of letters from the site of Mari provides compelling evidence for water competition between Middle Bronze Age polities during the early second millennium BC. The dispute over water is clearly described in one of the Mari texts where downstream communities in the Balikh Valley complained that upstream users were depriving them of essential irrigation water (Dossin, 1974; Villard, 1987). However, the first archaeological evidence of major canal systems appears somewhat later,

but by the Hellenistic through early Islamic periods, major canals existed along much of the length of the Balikh River Valley (Rayne, 2014). Their dimensions and the size of the areas served by patterns of canals and offtakes suggest that they must have significantly reduced the overall flow of the river (Wilkinson, 1998; Wilkinson & Rayne, 2010). Downstream, additional water management remains are concentrated around Raqqa (Rayne, 2014; Wilkinson & Rayne, 2010). During the Abbasid period, when Raqqa was briefly a capital city under the caliph Hārūn al-Rashīd, the city was supplied with water from a *qanat* which led into several open channels, and there was a separate water supply which served a large palace complex north of Raqqa (Fig. 8). Upstream, the large-scale irrigation systems discussed above generated crops which may

have supported Raqqa with food as well as providing a resource for taxation.

In both the Balikh (around Hisn Maslama) and Euphrates Valley near Balis (Fig. 1: location 25), the field evidence of early Islamic canals can be linked to a specific individual, namely, the Umayyad prince Maslama (a son of Abd al-Malik), who made considerable investments in agricultural activities in the early eighth century AD and who claims to have dug canals in both locations (Ashtor, 1976, p. 62; Le Strange, 1905, p. 105). Extensive canal systems have also been recorded downstream of Deir el-Zor. Dating to the period of the Islamic caliphates, these are inferred to have formed part of the agricultural supply network of the capital cities of Baghdad and Samarra (Berthier et al., 2001; Kennedy, 2011).

Elsewhere, the development of the qanat resulted in a dramatic transformation of the landscape. Qanats (*falajes* or *aflaj* in Oman) utilize areas of enhanced groundwater and flow day and night. They require both sophisticated allocation systems to optimize the use of water and considerable financial investment for their construction and maintenance. Not only did they result in the massive spread of “qanat settlements” across the landscape but at a smaller scale, they have also structured the development of the social landscape.

Qanats are considered to have spread during the early first millennium BC, usually having developed first in Iran or neighboring Anatolia. However, recent excavations of underground channels and associated settlements have convincingly extended this initial area to include southeastern Arabia. It has also been suggested that the qanat logically developed out of the excavation of tunnels for urban water supply, perhaps as early as the Bronze Age tunnels at Kherabat al-Zeraqun in Jordan or at Troy in Turkey (Fig. 1: locations 8 and 9; Biernert, 2004; Latacz, 2004). Alternatively, techniques of tunneling for water may be a by-product of mining technology (English, 1998, p. 188; Forbes, 1964, p. 157).

The most recent evidence now suggests that qanats were supplying water for Iron Age II

settlements in southeastern Arabia as early as 1000 BC (near Fig. 1: location 2; Boucharlat, 2001; Magee, 2005, p. 222; al-Tikriti, 2002). This challenges the earlier notion that qanats were invented in northwestern Iran or northeastern Turkey and then dispersed through Iran and into Arabia, in part under the administrative umbrella of the Achaemenids (Laessøe, 1951; Wilkinson, 1977). By the Roman–Byzantine and Partho–Sasanian periods, they had become common throughout the Near East. For example, Lightfoot asserts that of a sample of 67 “qanat Romani” from throughout Syria, some 90 % were associated with Roman–Byzantine sites, which consisted of small towns, “outpost,” or “guard-house” ruins (Lightfoot, 1996, p. 325). Also in Syria, networks of relict qanats have been recorded using remote sensing south of the Sajur River in Syria near Membij (Dan Lawrence & Niko Galiatsatos pers. comm.), and based on historical sources, these have been interpreted as Hellenistic (Lightfoot, 2003). In this area on the margins of the rain-fed cultivation, although qanats were apparently employed for irrigation, at least some must have fed water to the shrines and temples within the Hellenistic–Roman city of Hierapolis (modern Membij).

The case can therefore be made that the extension of settlement during the first millennium BC and AD was partly the result of the development or introduction of new water supply systems. This extension of irrigated settlement occurred in both the moister area of rain-fed cultivation and in adjoining desert areas, and in the latter region, this entailed the resettlement of the steppe at sites such as Resafa during the Late Antique period (Beckers, Berking, & Schütt, 2012; Geyer, 2001).

The water technologies of the later empires also enabled crop production to be intensified. This took the form of small plastered open channels which can be recognized widely throughout northern Syria as belonging to the Hellenistic to Islamic periods. Near Carchemish, for example, small plastered channels led water from water sources in the hills to small settlements in the nearby Euphrates Valley (Fig. 1: location 31; Wilkinson, Peltenburg, McCarthy, Wilkinson, & Brown, 2007, 236–38).

The combined extensification of settlement and intensification of agriculture during the Roman–Byzantine periods was carefully configured to the prevailing hydrological conditions. Hence, in the semi-arid fringes of the Hauran Mountains in southern Syria, a significant spread of settlement was associated with Roman flood-water farming, canals, and qanats, in some cases employing a technology that resembles the traditional water-gathering technologies of the Nabataeans and other Arabian communities (Braemer et al., 2010).

During the later empires, water use also became diversified so that by the first millennium BC, water systems were being used for far more than irrigation and domestic consumption. By the first millennium AD, water was harnessed for power, in the form of water mills (Fig. 9), to supply new and growing towns, as in the proliferating aqueduct systems of the Levant (Amit et al., 2002), and for novel functions such as industrial-scale brick-making in frontier areas. Also by this time, a range of hydraulic devices were being introduced and adopted to make water supply more efficient and effective (Amit et al., 2002; Hodge, 1991). These included innovations such as the incorporation of siphons into canals and conduits, which enabled water to be led below rivers or valleys to continue flowing at almost the same elevation. By the Roman period, aqueducts were an intrinsic feature of early towns. However, as Brent Shaw has cautioned, aqueducts did not create the conditions for the existence of towns but rather they were the “end product, the result of prolonged economic development within the empire which led to more intense local economic networks, denser nucleated populations, and, above all, wealthy local elites” (Shaw, 1991, p. 68).

Urban aqueducts usually drew their water supply from springs or riverine pools, the flow of which was sometimes held back by bunds or “spring houses” that regulated flow (Patrich & Amit, 2002, pp. 10–11). Channels were usually cemented with hydraulic plaster and were of modest scale because both their discharge and flow variations were less than those of major rivers. Topographic discontinuities were



Hydraulic Systems in the Middle East, Fig. 9 Islamic water mill at Jam, near Siraf, Iran. The penstock is the circular masonry structure in the mid-ground and the milling chamber is below

circumvented by the construction of aqueduct bridges or inverted siphons and occasionally sealed fired clay or stone pipes that made it possible to traverse large valleys (Peleg, 1991). The similarity of open channels throughout the Middle East testifies to a certain common practice, with the Islamic systems building upon Roman and Sasanian predecessors, and these in turn enhanced earlier Assyrian and Urartian systems. In addition, however, innovations were introduced from the classical world (Kamash, 2006, 2012); therefore the water systems of the Hellenistic period and later represent an amalgam of indigenous and classical technologies.

During the later empires, water distribution engineering also became more adventurous (see essays in Wikander [ed.], 2000) and greater use was made of novel or ancient water technologies

to lift water via the simple bucket, the *shaduf*, and a range of water wheels (Oleson, 2000). These developments were not all inventions of the Greeks and Romans, however; the first illustration of the *shaduf* is known from a Mesopotamian seal dated to ca. 2400–2200 BC (Bagg, 2001, pp. 40–41; Drower, 1956; Oleson, 2000, p. 227), whereas the pulley is known from Assyrian reliefs as early as the ninth century BC. Water was also used to generate power using water mills whose penstocks for raising the pressure head became conspicuous features of the landscape (Fig. 9) from the Roman–Parthian period onwards (Wikander, 2000). These were not simply employed for milling cereals from the neighboring fields; they were also used for industrial purposes such as fulling – that is, scouring and thickening cloth, especially wool – and perhaps grinding minerals prior to smelting. By the early years of the first millennium AD, water had become a common feature of industrial processes and was being used for basic sustenance and agriculture (Wilson, 2000b; Wikander, 2000).

Some of the more interesting applications of water technology came during the early centuries of the Islamic period. In addition to using conduit and canal systems to provide towns and fields with a clean and reliable water supply, communities also captured runoff and flood waters to supply the resting places along trans-Arabian pilgrim routes (al-Rashid, 1980). This major engineering enterprise provided cisterns and wells along the entire length of the pilgrim routes from Basra and Najaf (in Iraq), the Levantine cities and Yemen, and across the desert toward Mecca (Fig. 1: location 34; Fig. 7a, b) (Wilkinson, 2003, pp. 165–168).

The Sasanians (224–651 AD) took the construction of large-scale water systems to its peak with, for example, the realization of the spectacular 150 km-long Nahrawan canal in Iraq (Adams, 1965); the canals, water mills, and dams at Shushtar; as well as the water mills of the Deh Luran plain in Iran (Christensen, 1993; Neely, 2011). Similarly, the water systems associated with the Gorgan Wall in NE Iran demonstrate how Sasanian engineers initiated a network of canals along the desert fringes which then

supplied water apparently for the construction of the frontier wall itself, for brick making and supplying the forts along the wall (Sauer et al., 2013).

Water Management, Investment, and Decline

Water was also regarded as a sacred medium, and the conveyance of water endowed status upon the individuals who built or invested in waterworks. The Assyrian kings were quick to acknowledge their debt to the gods for water and the importance of making appropriate offerings to them. A sustained and pure water supply was crucial for many religious buildings right through to the mosques of the Islamic period.

For the Middle East, one can now sketch a continuous history for the development of water systems from the earliest wells of the Neolithic, through PPNB water-gathering systems of the Jordanian and Syrian deserts, to the later Neolithic channels of Iran and the Iraqi borderlands through until the first recognition of irrigation in southern Mesopotamia at the site of Oueili. From that point, we then have a continuous record of irrigation systems, particularly in Mesopotamia, but also in parts of Syria, the Jordanian desert (Jawa), and the Negev. By the fourth millennium BC, early water management systems are also recognized in Yemen (Fig. 10) where they must have formed the foundations of the dramatic irrigation systems at Marib and in the Hadhramout (Brunner & Haefner, 1986; Charbonnier, 2011, pp. 145–146). By around 1200 BC, major water management systems then spread into the rain-fed farming zones of the northern Fertile Crescent, as well as into the Yemen highlands, and in both regions, they contributed to the intensification of farming and the raising of tax revenues.

The range of technological innovations that occurred during the first centuries BC and AD is remarkable and testifies to the propensity for technologies to be transferred under the later empires, either within the empires (by forced transfers of populations from place to place) or between them as in the famous capture of the



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Hydraulic Systems in the Middle East,
Fig. 10 Valley-floor terrace/check dam buried by deep
sequence of sediments accumulated behind the Himyarite

dam of Sedd Ádhra'ah II in Yemen (ca. first century AD).
Soil accumulated behind the check dam yielded a radio-
carbon date of 4960 ± 80 BP (cal. BC 3955–3630)

Roman army in 244 AD by Shapur, in the battle of Carrae /Harran. This resulted in the acquisition, by the Persians, of an abundant supply of captive Roman labor, as well as much expertise in hydraulic technology (Howard-Johnston, 1995, pp. 161, 181). The transfer of skills from one industry to another was also a significant factor in accelerating hydraulic progress.

Just as greater investment resulted in the growth of water supply systems, the lack of investment resulted in decline. Not only were massive resources (both labor and financial) required for the construction of large-scale regional water supply systems, their maintenance depended on a continued high level of commitment and investment. This was especially the case because the large-scale systems often introduced many new problems, such as the need to negotiate rights to preexisting water supply channels and to counteract the effects of salinization.

In both the riverine zone of Mesopotamia and the non-riverine zones, it is thought that hydraulic

developments went into a decline after the tenth century AD and especially so between the thirteenth and fifteenth centuries AD (Christensen, 1998). Decline has been variously ascribed to a range of factors: lack of investment during the ninth and tenth centuries AD by the Abbasid caliphs, destruction by the Mongols (in the thirteenth century AD) or Tamerlane (fourteenth century), salinization (in southern Mesopotamia), vulnerability to flooding (the Nahrawan canal in the Diyala region and the Marib Dam in Yemen), warfare (Christensen, 1998; Lapidus, 1988, p. 136), as well as other causes.

This decline in Iran and Iraq was also evident elsewhere in the Middle East. For example, in the northern Negev Desert, areas that had become agricultural during the Roman/Nabatean and Byzantine periods then went into a precipitous decline in the tenth and eleventh centuries CE (Rosen, 2000).

Nevertheless, despite these declines, in the sixteenth and seventeenth centuries CE, Ottoman

tax records indicate that in the Khabur and Balikh Valleys of Syria, canal irrigation continued to be used (Hütteroth, 1990), and along the Euphrates and in the northern Levant, there are examples of many systems that have survived until modern times.

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Hydraulic Technology in Egypt

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Neolithic hydraulic technology in Egypt developed alongside agriculture, when Egyptians began to alter the river's regularly flooded banks to grow more crops more easily along the Nile (c. 5700–c. 2800 BCE). Since the Nile Valley floods once every year, rising in April and receding in July/August, the flooded areas of the Nile Valley were an excellent place to settle and grow crops. The earliest hydraulic technology was utilized to collect those floodwaters and move them between agricultural plots using diversion technologies. The river also serves as a giant communication and transportation canal, as the current flows north, but the winds blow southwards. The river, therefore, naturally facilitates movement of people, ideas, and goods between the river's delta at the Mediterranean Sea and the first cataract at Aswan and aids political unification (McNeill, 2000, p. 166). Although land-based technologies were popular at various points in Egyptian history, such as roads under the Romans or railways under the British, the Nile has acted simultaneously as highway, irrigation canal, and telegraph network for millennia. The earliest archaeological evidence of hydraulic technologies is Predynastic: by 3100 BCE a system of artificial basin irrigation diverted streams and floodwaters, raised levees to control the floodwater, built small earthen dams, and modified natural overflow channels into drainage canals in order to move the river's floodwaters wherever they were needed.

By the time that Egypt was politically united under the Old Kingdom, some of the hallmarks of Egyptian hydraulic technology had been invented or transferred from nearby civilizations. Nilometers to measure the height of the flood date back to around 3000 BCE. The most famous Nilometer at Rhoda Island was installed in

622 CE. The first large-scale dam was constructed in Lower Egypt near Helwan around 2650 BCE, the Sadd el-Kafara. The largest dam in the world at the time, this structure was intended to control the Nile's floods and would have stored 0.5 million cubic meters. However, it was destroyed by a flood shortly before its completion (Mays, 2008; Fahlbusch, 2009, p. 15). Fahlbusch concludes that the engineering knowledge needed to build the Sadd el-Kafara implies that other smaller-scale dams were constructed in Egypt and the Middle East, but these have been erased from the historical and archaeological record. However, small-scale technologies also flourished. At the level of the individual farm, the *shaduf*, a manual system of raising water from the Nile, was developed around 2000 BCE (Butzer 1976, 47). The *shaduf* is still used in Egypt today and represented one of the major inventions for drawing water onto the fields when the water was low. The *shaduf* is a bucket and rope attached by a pole to a counterweight. The counterweight lowers the bucket into the river and draws the filled bucket back up without the person having to fight against gravity. With the *shaduf*, Egyptians could grow at least two crops per year – one in the immediate recession of the Nile's water after the flood and another in the winter when the river was low.

Other large-scale hydraulic technologies were part of extending irrigation networks. One was the construction of the reservoir called Lake Moeris in the region of the Faiyum. By 2300 BCE an existing canal was transformed into a large-scale construction project connecting the Nile with the Faiyum, a low-lying depression to the west of the river. The reservoir that this canal and its diverted floodwater created was large enough to control high floods, regulate water in the winter, and irrigate the surrounding area. It was utilized as a reservoir from 2300 BCE to 23 BCE when the nearest branch of the river dried up (Chanson, 2004). The first hydraulic project in the Suez region was an irrigation canal constructed around 1850 BCE, extended by the Ptolemies as far as the Bitter Lakes, and

kept open until the Roman era. That canal was filled in for military purposes by the Abbasid caliphs in 775 CE (Encyclopedia Britannica). Four thousand years ago, ancient Egyptians used hydraulic technology to plant and irrigate two crops per year, measure the flood, and successfully control flood levels and attempted flood control in the Nile Valley.

During the Ptolemaic period, the *saqiya* and Archimedes screw were introduced into Egypt. Residents of Alexandria were at the forefront of Hellenistic science, contributing to hydrostatics and invention (Mays, 2010, pp. 15–16). The *saqiya*, probably introduced from Persia, is a waterwheel made of a circle of buckets wherein each bucket draws water up directly from the river or a canal when at the bottom of the circle. It is poured out when the bucket gets to the top; the water then flows into a canal to be drawn onto the fields (Ritner, 1998, p. 2). In order to turn the wheel of buckets, which require a consistent amount of energy, *saqiyas* in Egypt were usually oxen-drawn. Archimedes screws are a screw inside of a hollow pipe, which draws water upwards; Archimedes screws in Egypt were mostly pumped by hand. These devices improved upon but did not entirely displace the *shaduf* for farm-based hydraulic technology. Instead, when paired with irrigation canals to move the water, the *saqiya* and Archimedes screw meant that a system of year-round irrigation could be implemented; farmers could now grow crops perennially because the canals brought the water and these technologies lifted the water onto the fields (Butzer, 1976).

In contrast to other parts of the ancient Middle East and Africa, ancient Egyptians were not highly invested in utilizing groundwater reserves, although there was some use of well water. In the Nile Valley and the Delta, wells, qanats, and groundwater usage was supplementary to rather than substitutive of riparian irrigation because of the regularity of the Nile's rhythms and the potability and abundance of its water (Shahin, 1991, p. 7). However, away from the Nile, wells were sunk as early as the 4th Dynasty (c. 2613–2494

BCE). These ancient wells were sunk up to 100 m deep through soft rock such as sandstone or limestone. In the western desert, oasis wells have been dated to as early as 905 BCE (Shahin, 1991, p. 5). Qanats were introduced to Egypt when the Persians invaded in the fifth century BCE. These underground aquifers collected groundwater. Like the wells, they were used mostly in oases in the western desert; the qanats at El-Kharga Oasis have been extensively studied (Wuttman, Gonon, & Thiers 2000). During the Roman era, underground water-collecting galleries were used along the Mediterranean coast.

In the early Islamic era (641–1171 CE), hydraulic technologies from across Afro-Eurasia became incorporated into Egyptian agriculture as the best methods to cultivate a new series of crops, including sugar, cotton, rice, and sorghum (Bowman & Rogan, 1999, p. 2; Burke, 2009). However, Egypt not only imported hydraulic technologies, it exported them as well. Especially under the political (the Islamic dynasties) and linguistic (the Arabic language) unification, Egyptian technologies, such as the *shaduf* and *saqiya*, were incorporated into a “water management technological package” that was diffused across the Islamic world (Burke, 2009, p. 174). After Egypt came under Ottoman control in 1517, extant Egyptian hydraulic technology was used to make Egypt the Ottoman granary. Special emphasis was placed on perennially irrigating the crops using deep irrigation canals; these canals needed annual clearing (Mikhail, 2011).

In the nineteenth century, large-scale hydraulic technologies took pride of place. Under autonomous Ottoman governor Sa'id Pasha, the French engineer Ferdinand De Lesseps designed and constructed the Suez Canal. This transportation canal, built between 1859 and 1869, was 164 km long and 8 m deep. When completed, it connected the Mediterranean and Red Seas and obviated the need to sail around the Cape of Good Hope. Constructed mostly with French money and Egyptian forced labor, the Suez Canal has since been widened, deepened, and lengthened, but its importance as a sociopolitical, communication,

and transportation hub has continued. Egypt's nationalization of the canal in 1956 caused the Suez Crisis. In addition, the Suez Canal Company completed the Sweet Water Canal in 1863 to send drinking water from the delta to Suez. Other transportation and sanitation canals were constructed during this time, including the Mahmudiyya Canal, which connected the Nile to Alexandria and brought freshwater to the delta (Tignor, 2010, p. 215).

In order to grow better summer crops, especially long-staple cotton, nineteenth-century Ottoman governors instituted a series of hydraulic technologies. They increased the number of deep canals and constructed the Delta Barrage north of Cairo. Originally finished in 1862, the barrage was supposed to raise the summer water level in the Nile delta, but was structurally defective and had to be abandoned. During the 1880s, the delta Barrage was repaired by the British during their occupation of Egypt (1882–1914). The British constructed other large-scale irrigation technologies to increase the amount of water available for summer crops. The most important of these technologies was the original Aswan Dam (1902, heightened in 1912 and 1933). The Aswan Dam created a reservoir in the valley of the Nile, regulated the river's water against high or low floods, expanded perennial irrigation southwards into Middle Egypt, and began large-scale desert reclamation programs. After 1933, the Aswan Dam was also used to generate hydroelectric power. The British also built irrigation canals and a series of barrages along the Egyptian Nile to raise the water levels and carry this higher water to the places where it was needed (Cookson-Hills, 2013).

Egypt lost its vulnerability to, and natural resources from, the Nile floods in 1963, when the Aswan High Dam turned the Egyptian Nile into a vast network of canals. This hydroelectric megaproject stores 162 billion m³ of water and generates 2.1 gigawatts of electricity, and the reservoir, Lake Nasser, stretches 550 km behind the Aswan High Dam into the Sudan. The Egyptian Nile's entire volume is measured,

distributed, and regulated throughout northern Egypt and the delta, and Egypt is no longer dependent on the uncertain flooding of the river, with its potentially high or low floods. Since their connection to the river via a drainage canal in the 1970s, the Faiyum and Lake Moeris are once again used to regulate irrigation projects (El-Shabrawy & Dumont, 2009).

However, the total regulation of the Egyptian Nile has had difficulty providing water to Egypt's burgeoning population, which reached 82.5 million in 2011. Since the construction of the Aswan High Dam, much of the traditionally agricultural land in the Egyptian Delta has been brought under urban development. However, the total amount of agricultural land has increased from six in 1972 to eight million acres in 2003. Large-scale government reclamation projects under Nasser, Sadat, and Mubarak (most recently the New Valley Project which opened in 2005) have been responsible for this increase in acreage while being roundly critiqued (Sowers, 2011). Modern Egyptian hydraulic technology, like that in the Islamic world, has been borrowed from around the globe and shaped global projects, with a tendency towards large-scale government projects – dams, canals, reclamation projects, etc. At the same time, the Nile is being heavily recycled in water treatment plants – each drop was recycled up to three times as of 2009 (Dumont, 2009, p. 18). Egyptian hydraulic technology has been making increasing use of its groundwater resources in an attempt to make up the difference between an expanding population and fully utilized freshwater resources from the Nile (Tahlawi, 2008).

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Hydrologic Engineering of the Tiwanaku

Charles R. Ortloff^{1,2} and John W. Janusek³

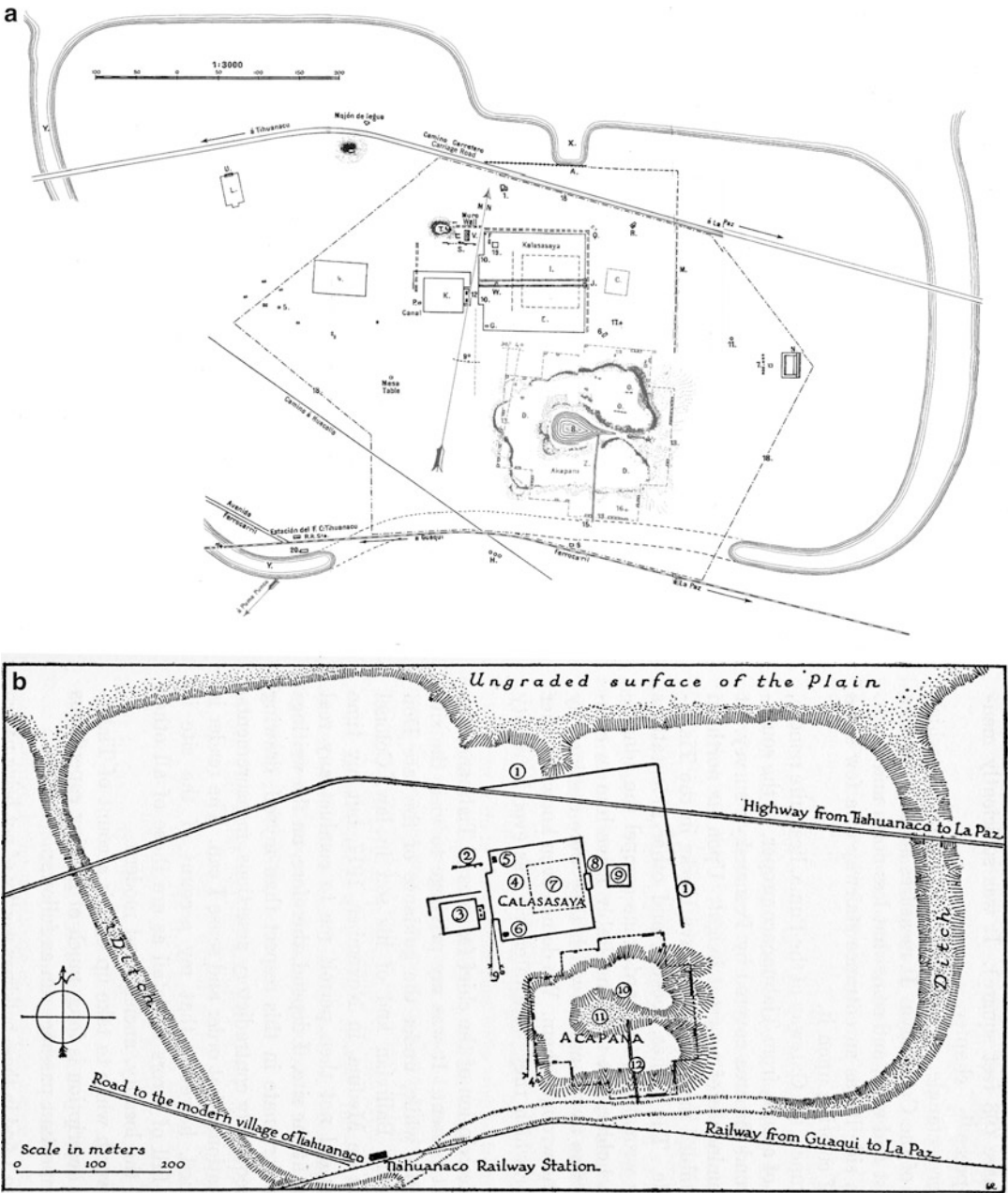
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The city of Tiwanaku, located at the southern edge of the Lake Titicaca Basin at an altitude of 3,800–3,900 m, has been the subject of archaeological research since the late nineteenth century. Excavations revealed extensive monumental complexes and residential districts (Janusek, 2004; Kolata, 2003; Ponce Sanginés, 1961, 1972; Vranich, 2009), indicating the urban core covered an area of 4–6.5 ha. While previous research demonstrated Tiwanaku agricultural hydrological technology (Kolata and Ortloff, 1996; Ortloff, 1996, 2009), aspects of this technology applied to the city’s urban water systems were not investigated.

A massive ditch surrounds Tiwanaku’s northwest monumental complex. Several researchers have characterized this feature as a water-retaining, defensive moat that separated Tiwanaku’s central monumental complexes and elite residences from surrounding urban peripheries (Kolata, 1993; Posnansky, 1945). Drawing on data that incorporates ground survey, newly discovered aerial photographs, and Google Earth imagery, the moat, renamed the “perimeter canal,” served several purposes as a hydrological regulator, controlling aquifer drainage and surface runoff to limit rainy season flooding while promoting rapid soil dry-out after the end of the rainy season. The present reporting of the perimeter canal’s hydrological function demonstrates that water management interwove practical and ritual roles for the city of Tiwanaku.



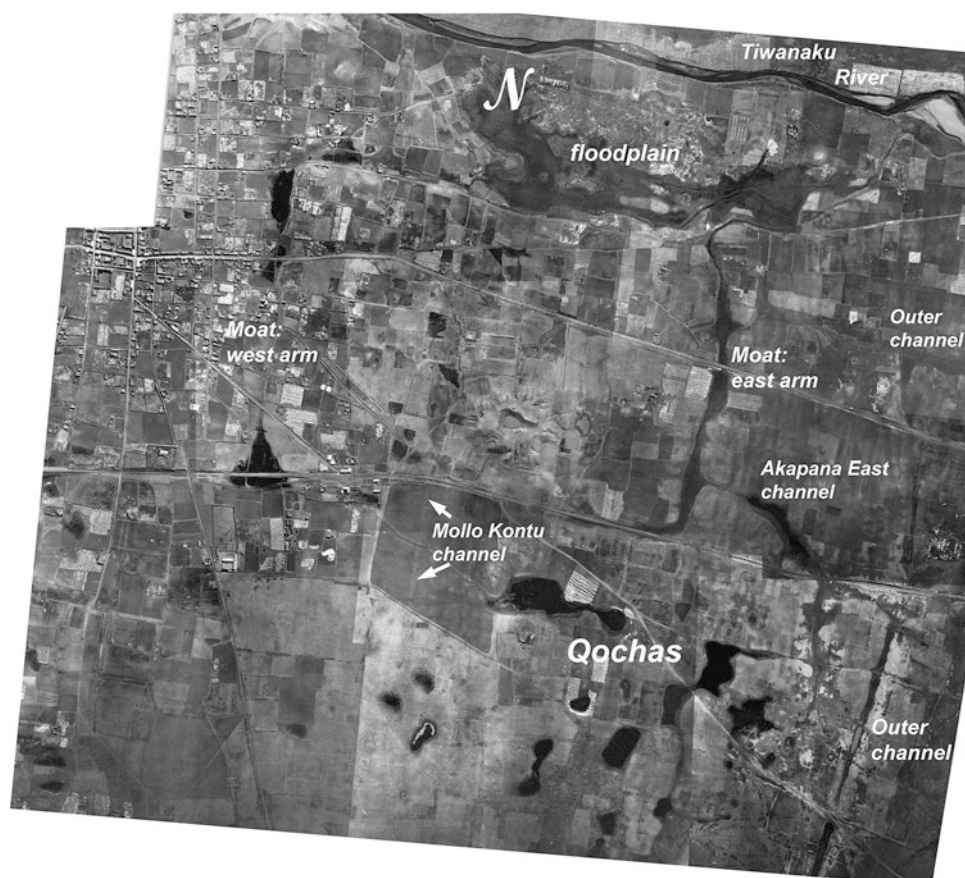
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Fig. 1 Schematic drawings of the “moat”: (a) Posnansky’s final rendering of the “moat” in 1945 (Plate

III); (b) Bennett’s (1931) “simplified” rendering of the “moat” based on Posnansky’s surveys conducted in 1904 and 1912

Perimeter Canal Archaeological Perspectives

Archaeological perspectives on the perimeter canal’s purpose began with Posnansky’s (1945, II,

pp. 121–112) conclusion that a continuous, water-filled moat surrounded Tiwanaku’s urban core (Fig. 1b) with defense as its main purpose. Kolata (1993) stated the moat distinguished the monumental core from urban peripheries, creating a



H

Hydrologic Engineering of the Tiwanaku, Fig. 2 Composite image from the Sawyer aerial photos noting key hydrological features in the northern portion of

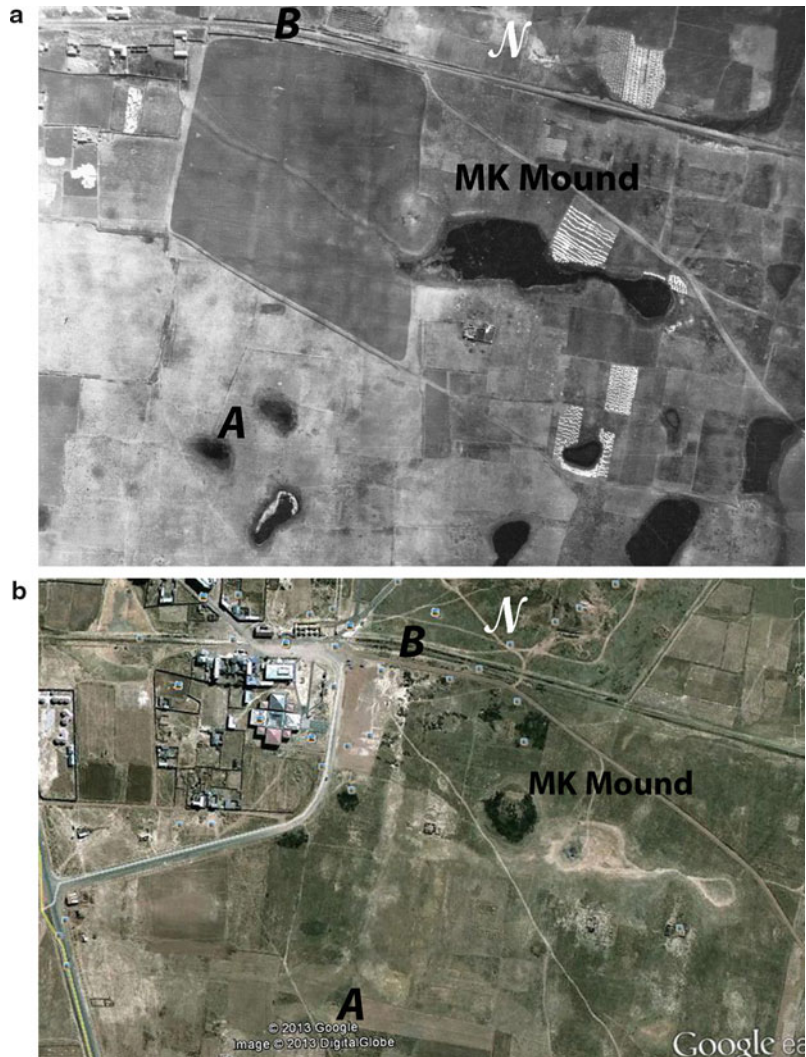
the perimeter canal area showing drainage into the C' floodplain and the C canal leading perimeter canal water to the Tiwanaku River north of the monumental core

“concentric hierarchy” that punctuated the elite status of ceremonial core residents. Several investigators (Denevan, 2001; Browman, 1978, 1997) concurred that a moat-like structure surrounded Tiwanaku’s core while other researchers (Bentley, 2013, p. 122; Isbell, 2013, pp. 178–180) disagreed on its extent. Photographs taken in the late nineteenth century by Uhle and Bandelier together with Bennett’s ground drawings (1931) (Fig. 1a) fail to show evidence for a channel where the canal’s south arm would have passed. To resolve these contentious views, newly discovered aerial photographs indicate that a north–south-oriented canal intersected with the perimeter canal’s south arm, but these features became obscured through runoff-induced, erosion/deposition events over the 1,000-year hiatus since the site was abandoned.

The data assemblages deployed in hydrological analysis include survey, mapping, and excavation (Couture and Sampeck, 2003; Janusek & Earnest, 1990; Kolata, 2003), Google Earth imagery, and the 1930s high-resolution aerial photos over the site of Tiwanaku. The photos (Figs. 2 and 3) reveal the site during the rainy season, providing an aerial view of Tiwanaku’s water-retention features. Later research involved survey and mapping of hydrological features within and immediately surrounding the site, using the aerial photos to verify discovery of remnant portions of the perimeter canal. The canal’s east arm averages 5–6 m deep and ranges 18–28 m in top width; the west arm is not apparent as contemporary structures cover the area. Posnansky suggested that much of the canal had

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Fig. 3 The Mollo Kontu canal (M) as depicted in the (a) Sawyer aerial photos and (b) recent Google Earth satellite imagery

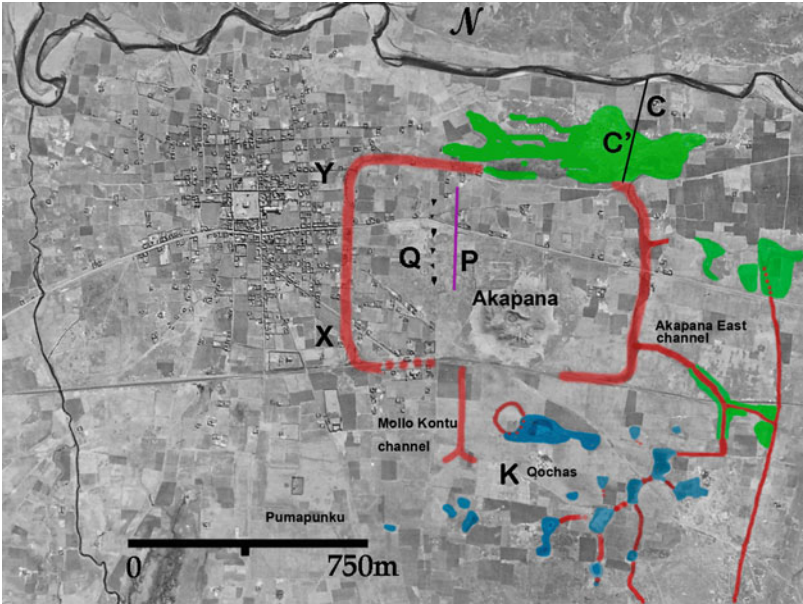


been filled by erosion “detritus” (1945, II, p. 121), yet ground survey, aerial photos, and Google Earth imagery indicate that a north–south canal passed through the Mollo Kontu sector of Tiwanaku and terminated precisely where the south canal arm would have passed (path A–B in Figs. 2, 3, and 6) and was geometrically similar to the east and west perimeter canal arms. Figure 4 shows this canal connection added to the entirety of the perimeter canal (Kolata, 2003, p. 178). Multiple subterranean drainage canals originated in the area of the Mollo Kontu canal intersection with the south canal arm. One such canal was located under the Putuni complex to the north of

the intersection junction (Figs. 5 and 6) and directed water at a 2° grade from the subterranean inlet toward the Tiwanaku River north of the site (Couture and Sampeck, 2003; Janusek, 2004; Kolata, 1993). A fraction of accumulated water in the south canal arm flowed into the subterranean canal inlet to provide flushing water to remove waste material from the Putuni complex; the remainder of the south arm water flowed laterally into the east and west perimeter canal arms then downhill into the north arm where water was conducted to the Tiwanaku River. The north arm of the perimeter canal was interlaced with agropastoral features on the northward

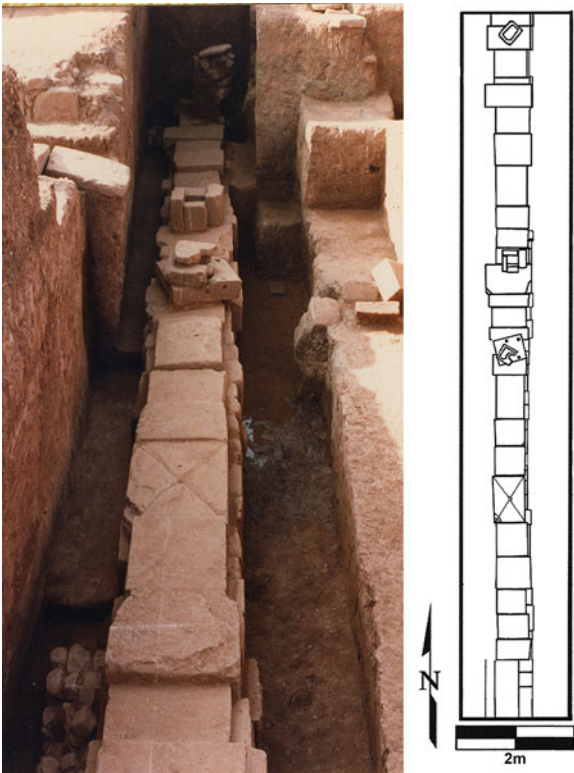
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Fig. 4 Plan view of the Tiwanaku landscape showing location of the ceremonial center’s major structures bounded by the perimeter canal and surrounding hydraulic features – canal geometry inferred from photographic and ground survey sources



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Fig. 5 Detail from the monumental core showing part of the excavated subterranean Putuni Canal (P) under the Putuni platform

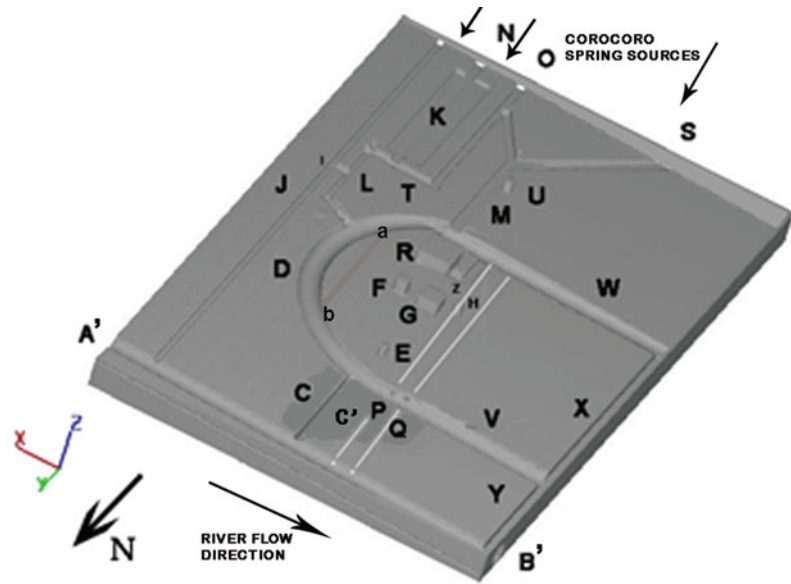


plain that drops sharply downward several meters toward the Tiwanaku River’s marshy floodplain. One portion of the perimeter canal’s east arm turns westward and disappears into the marsh

(Fig. 2) with an imbedded canal that continues northward toward the river. At the west end of the northern arm, one portion of the arm turns sharply to the east and disappears into the marsh north of

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Fig. 6 FLOW-3D CFD model of the hydrological and architectural features of the Tiwanaku urban core identified by letters. Model is a best-estimate representation of the original tenth century CE site layout from the aerial photo source and ground survey



the Kalasasaya while an ancillary canal arm continues northeast toward the river. Thus, the north arm of the perimeter canal originated branch canals that drained east and west perimeter canal arms and marshy floodplain groundwater to the Tiwanaku River. Survey and aerial photography show extensive raised-field systems in the marsh area indicating a productive agricultural area for the expanding urban center.

The Perimeter Canal in Tiwanaku's Urban Hydrological Network

The concentration of water features shown in aerial imagery associated with the ceremonial core region and adjacent urban structures suggests that the perimeter canal served an integral role in an intricate urban hydrological network. Beyond seasonal rainfall, an additional city water resource consisted of a deep groundwater aquifer that originated from the foothills of the mountainous Corocoro formation (Posnansky, 1945, II, pp. 118–119) and drained into Lake Titicaca. This aquifer was supplied by infiltrated rainfall over many centuries from vast watershed areas to the east and south of the city. Several landscape features in the southern portion of Tiwanaku were engineered to utilize this subterranean water

resource. The westernmost was Choquepacha (Bruno, 1999; Janusek, 2008; Kolata, 1993), a natural spring on a bluff southwest of Pumapunku that was fitted with canal stones carved to convey water to surface canals directed toward the city center (Posnansky, 1945, II: Fig. 42). Combined with the adjacent Challa Jawira stream that drained a marshy area of the terreplein and opened up pastoral-grazing lands on the west edge of Tiwanaku (Bruno, 1999), channeled water from this stream and adjacent springs provided water to multiple northward-flowing canals supplying water to multiple *qocha* regions (Fig. 2), canals east of the perimeter canal, and the Mollo Kontu canal. Several prominent water resource features relate to the hydrological function of the perimeter canal. The first is the Mollo Kontu A-B canal that conducted water from the southwest portion of the site near the Pumapunku complex (Figs. 2, 3, 4, and 6) into the south arm of the perimeter canal. A second feature is a cluster of sunken basins (*qochas*) that occupied the southeast portion of the site (Fig. 2). Qochas are pits excavated into the deep groundwater capillary zone to provide moisture for planting surfaces while creating micro-lacustrine environments that attract waterfowl (Craig, Aldenderfer, Rigsby, Baker, and Blanco, 2011; Denevan, 2001). The aerial photos depict a series of canals

dendritically linking individual qochas to each other and ultimately linking into a large northward-flowing channel (Figs. 2 and 4) – the Akapana East channel – that drained into the east arm of the perimeter canal. Here individual qochas were linked by sequential downslope canals so that water exceeding a given height in a qocha is passed on to the next downslope qocha; this limited water height in individual qochas consistent with their agricultural function. While the qocha system functioned well during the rainy season, during the dry season agricultural activity was sustained from channeled Corocoro spring flow to supplement the capillary fringe of the deep groundwater layer in qocha bottommost regions. A further water feature was a long outer channel that bounded the east side of Tiwanaku (Fig. 2).

While the role of this channel is unclear, its southern portion follows an alignment that mirrors that of the Pumapunku complex to the west while its northern portion bounds the east edge of the site with north-direction orientation. The Akapana East canal links through a connector canal to the north arm of the perimeter canal indicating that the outer channel was part of the broader urban hydraulic network. The areas east of this channel contain Tiwanaku's residential sectors and include Ch'iji Jawira, a barrio of ceramic producers that depended on a constant water supply (Janusek, 1999; Rivera Casanovas, 1994, 2004). Immediately east of this sector is a brackish marsh. Fed by rainwater and Corocoro's aquifer, this outer channel provided fresh water for Tiwanaku's easternmost residential sectors. As noted, the northern portion of the perimeter canal branched into a marshy floodplain area (Fig. 2 and 6-C') between the river and the alluvial plain that Tiwanaku occupies and served to drain surface runoff and groundwater north of ceremonial/residential areas into the Tiwanaku River.

Intricate surface and subterranean canal networks provided effective drainage within the area bounded by the perimeter canal. The elaboration of these networks indicate they were built to draw attention to water moving through intricate surface and subsurface constructions that drained the

interior floor of the Sunken Temple and areas outside the Kalasasaya platform (Ponce Sanginés, 1961, 1972). Constructed later, the multi-tiered Akapana pyramid monument incorporated an elaborately constructed, serpentine stone-lined canal network that routed water away from the uppermost down through successively lower platforms to discharge through portals in its basal terrace (Kolata, 1993, 2003). Water then flowed through surface channels at the base of the Akapana into the perimeter canal that carried water into subterranean canals to the east and west of the structure (Bennett, 1934, pp. 378–385). Water was temporarily pooled in sections of ceremonial center sunken courtyards, rendering them iconic “lakes” for ritual events.

Excavations between the Putuni and Kerikala complexes provided a sense of how structures within the ceremonial core articulated with Tiwanaku's subterranean drainage infrastructure (Couture and Sampeck, 2003; Janusek, 2004, p. 146). This area housed high-status groups until at ~800 CE the construction of the Putuni platform repurposed the space to support ceremonies (Couture and Sampeck, 2003; Janusek, 2004; Kolata, 1993, 2003). Reconstruction required new canal networks interlaced into the older system. Each sequential structural ensemble maintained architecturally aligned secondary canals fed by smaller tertiary canals. Most surface canals fed into subterranean canals consisting of sandstone slabs standing approximately one meter high and 0.8–0.9 m across (Fig. 5) that carried water northward on a 2° grade. An early French expedition to Tiwanaku identified one of these primary canals ~3.5 m below the ground surface (Créqui-Montfort, 1906) with later investigators (Couture and Sampeck, 2003; Janusek & Earnest, 1990; Ponce Sanginés, 1961) adding further details on the construction of the canal. An additional reason for the subterranean Putuni canal was to support drainage from a series of upper-level canals located in the monumental core. Only some of the most important secondary canals fed into the subterranean canal, such as the east–west-tending East Palace masonry canal that followed predominant architectural

orientations. The Putuni subterranean canal primarily carried sewage drainage northward and downslope toward the Tiwanaku River. In the 1930s, Bennett located a secondary subterranean canal 1.7–2 m below the surface that carried water directly west from the Akapana and toward a deeper, southward-bound primary “Akapana East” subterranean canal that drained into the “Akapana West” canal. Finally, at least one canal near the Kerikala structure to the northeast flows on a downward gradient to the west, suggesting that it may have fed into yet another primary canal located under that structure.

Encircling Tiwanaku’s monumental complex, the perimeter canal constituted a hydraulic circuit that articulated with all these hydrological features (Figs. 4 and 6). An overview of hydraulic features indicates that water was transferred from multiple Corocoro spring sources into several canals adjacent to and connected into the perimeter canal with an additional canal supplying water to the qocha region. Water from canals supplying water into the perimeter canal was then distributed by further surface/subterranean canals toward the Tiwanaku River.

Models of Water Management at Tiwanaku

To illustrate the hydrological function of the perimeter canal, two cases address seasonal variability in water input. The first case considers effects at the termination of a long-duration (November–March) rainy season on Tiwanaku’s perimeter canal and associated canal network; a second case considers effects of limited spring-water input during the April–October dry season. The analysis to follow utilizes location data based on aerial photographs, Google Earth imagery, and ground contour maps for hydraulic features shown in Figs. 2, 3, 4, and 6 and serves as the basis for a computational model to demonstrate hydrological features of the perimeter canal and its associated canal network. Analysis is provided through Computational Fluid Dynamics (CFD) (Flow Science, 2014) to address seasonal variability in water input. Solutions demonstrate time

history of aquifer seepage from open-face areas of the perimeter canal and water transfer/percolation within saturated/unsaturated portions of an aquifer. A porous soil aquifer model (Fig. 6) is used to demonstrate hydrological responses of the perimeter canal for different seasonal water availability cases. This CFD model shows the labels/positions of key monuments in the ceremonial core and associated canal systems identified from the data assembly. Since only segments of some canal features are available, connections are surmised to furnish a working model of canal systems to illustrate features related to the perimeter canal’s hydrological function. The canal inlets shown (J, N, and O) are sourced by canalized springs located south of the modeled area as well as (S-M) canal water directed from the Mollo Kontu canal from Corocoro spring sources. Figure 6 locates these architectural and hydrological features by letter. These include:

- A’-B’: the Tiwanaku River, flow direction A’ to B’ to Lake Titicaca
- C: canal to A’-B’
- C’: drainage/agricultural area supplied from perimeter canal seepage
- E: La Karaña residential complex
- F: Sunken (Semi-Subterranean) Temple
- G: Kalasasaya ceremonial complex
- H: Putuni Palace
- I: Connecting canal between canals L-K-L and (Akapana West) J
- K: *qocha* region supplied by canal N
- L: Akapana East canal draining *qocha* region K toward perimeter canal segment D
- M: Mollo Kontu canal linking canals O and S to the perimeter canal
- N: Supply canal to *qocha* region K
- O: Connecting canal to canal M
- P and Q: subterranean canal pair with 2° downslope to the
- Tiwanaku River; canal P runs underneath the Putuni (H)
- R: Akapana pyramid
- S: branch canal to Mollo Kontu canal (M)
- T: lateral transverse canal to L; shunt canal I to canal J and/or drain canal to perimeter canal section D

- U: Mollo Kontu monument
- W-D-V-X: perimeter canal circuit around the ceremonial core of Tiwanaku – original perimeter canal depth estimated at ~4–5 m at location D
- Y: drainage canal from V to Tiwanaku River
- Z: canal below the west side of the Akapana (R) draining toward perimeter canal segment D.

Figure 6 is composed of a subsurface porous medium aquifer that represents the soil type through which groundwater percolates. The CFD model incorporates both east-to-west and a south-to-north ground slope declinations and constitutes an approximation to all hydraulic features derived from aerial photograph, Google Earth, and ground survey data.

The perimeter canal seepage surface is the exposed canal bottom and sidewall soil area to the atmosphere. In the CFD model, the deep groundwater layer is composed of saturated soil stabilized throughout the year at ~5–6 m below the ground surface inferred from groundwater water depth measurements provided by probes inserted into drilled shafts. The perimeter canal bottom intersects the upper reaches of the deep groundwater table as evidenced by long-term water retention shown in the aerial photographs. An aquifer phreatic (vadose)-saturated layer lies above the deep groundwater layer whose depth depends on rainfall intensity and duration. For long-duration rainfall periods, this zone extends downward to recharge the deep groundwater layer. The subsurface boundary shapes and extent of these two layers is subject to change depending upon rainfall intensity, duration, as well as runoff transfer/interception during altiplano rainy and dry seasons. For post-rainy season analysis (Case 1), the phreatic zone is saturated, subject to rainfall runoff and intersecting the deep groundwater layer. In the dry season, the phreatic zone decreases in depth from the ground surface due to surface evaporation. For both cases, phreatic zone aquifer seepage occurs from the perimeter canal seepage surface to alter the local water content and shape of these layers; seepage water then accumulates into the perimeter canal

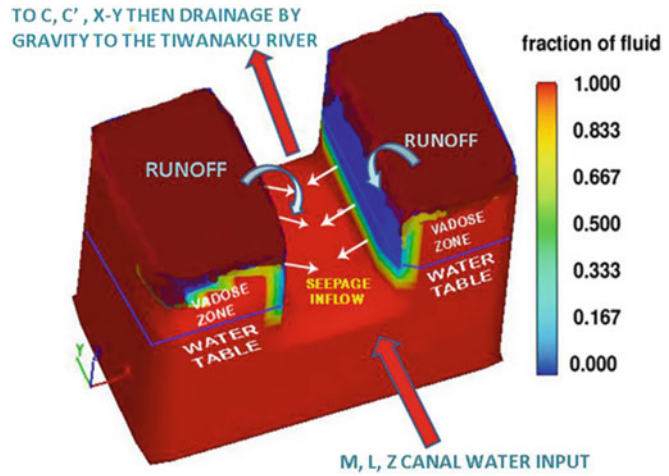
bottom. Water is supplied to the phreatic layer by capillary action from the deep groundwater zone – this effect marginally decreases the deep groundwater layer height as dry season surface evaporation continues to deplete the phreatic layer. In times of extended drought, both the phreatic layer and ultimately the deep groundwater level subside, leading to dry soil conditions to large depths.

Case 1: Post-Rainy Season Conditions

Case 1 examines typical conditions of the end of an altiplano rainy season characterized by the saturated phreatic layer extending to the deep water table upper boundary and continuous water flow through lined canals O, S, N, and J (Fig. 6) not contributing water to deep aquifer recharge. Aquifer seepage from the phreatic and deep groundwater layers arriving into the perimeter canal bottom is transferred to canals D, V, and W to X and then to the Tiwanaku River A'-B' based upon canal downslopes toward the river and accumulated water height exceeding the depth of the saturated bottom of the perimeter canal. Water in the perimeter canal's north branch is conducted to the Tiwanaku River through canal C while supplying groundwater to agropastoral systems in C' with seepage water ultimately discharged into the river. Water arriving into inlet N is conducted by canals K and L into either (or both) canals D and I into J. For downhill-flowing rainfall runoff, as well as phreatic and deep groundwater layer seepage into the perimeter canal bottom, the perimeter canal transfers water exceeding its saturated base depth to the Tiwanaku River. This effect serves as a hydraulic control limiting (or amplifying) surface runoff/groundwater transfer to raised-field systems west of Tiwanaku. A primary function of the perimeter canal was then to intercept and direct rainfall runoff from saturated east/south surface areas as well as from the ceremonial core area given that much of this area was paved and occupied by roofed buildings that limited rainfall interception. Hydrological water input/output associated with Case 1 conditions is summarized in Fig. 7 at a typical perimeter canal section. Solutions of the equations

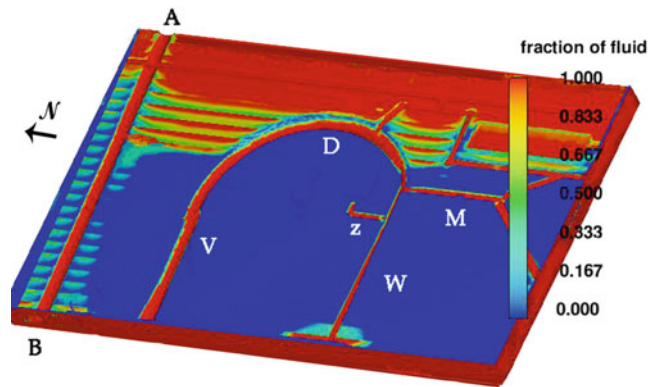
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Fig. 7 Representative summary diagram of water inputs/water outflows in a typical cross-section of the perimeter canal in canal leg D for post-rainy season conditions



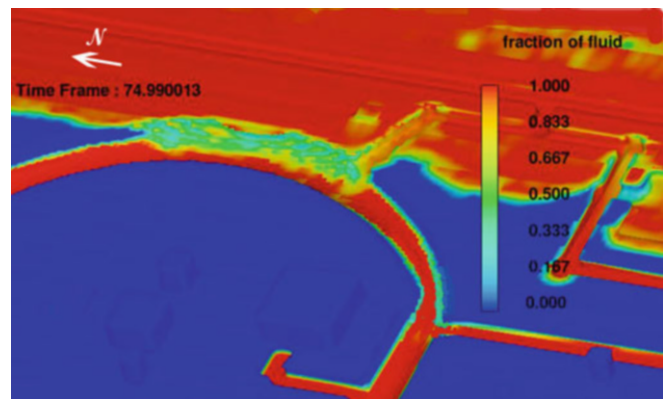
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Fig. 8 Early post-rainy season (Case 1) fluid fraction results indicating water drainage from the eastern perimeter canal seepage surface along the W, D, V canal arms promoting ground drying



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Fig. 9 Close-up fluid fraction detail of the east portion of the perimeter canal showing progressive drying of the ground surface by seepage surface drainage conducting water to the bottom of the perimeter canal for post-rainy season Case 1 conditions at a later time than that shown in Fig. 8

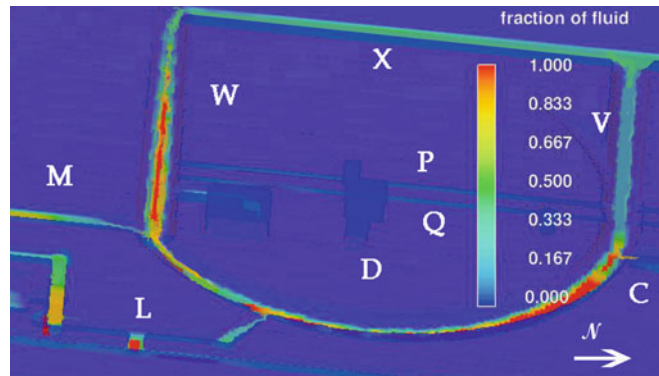


governing porous media flow were made for aquifer percolation/water emission from the perimeter canal seepage surface with results shown in Figs. 8, 9, and 10. For saturated aquifer

conditions, velocity components $q_1 \equiv q_x$, $q_2 \equiv q_y$, and $q_3 \equiv q_z$ are given by $q_i = - (k/\mu) (\partial p / \partial x_i + \rho g \partial z / \partial x_i)$ where k is the (isotropic) specific porous material permeability, p the water pore pressure,

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Fig. 10 Fluid fraction details of the western seepage surface face of the ceremonial core region showing limited seepage due to lower rainfall infiltration on paved, roofed surfaces within the ceremonial core area for post-rainy season conditions at the same time as that shown in Fig. 8

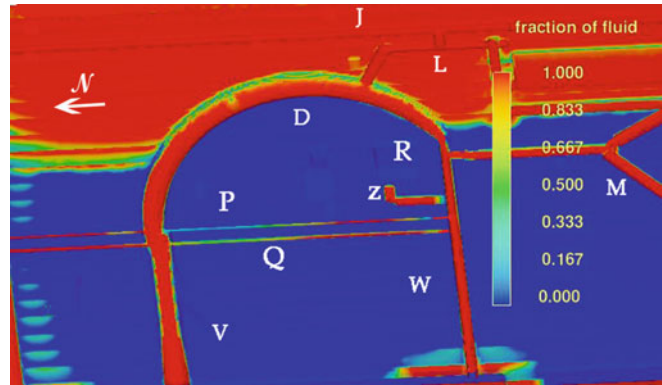


and g the gravitational constant. The rightmost term represents the percolation velocity addition from gravitational forces in the vertical z -direction ($i = 3$). Figure 8 shows the perimeter canal's east-face seepage surface and adjacent ground surface moisture levels at an early, post-rainy season time; Fig. 9 shows the progression of phreatic layer depression/ground drying at a later time indicated by lower values of the fluid fraction (ff) and continued high seepage water outflow from the bottommost part of the perimeter canal seepage surface. To the east, the ground remains saturated as indicated by high fluid fraction values – as time progresses and surface drying continues, the dry area influenced by the perimeter canal's drainage increases. Fluid fraction (ff) is the water volume within porous soil media volume interstices where $ff = 1$ represents saturated soil conditions (total water infilling of open space within a unit porous volume) and $ff = 0$ represents no water present in porous volume interstices. Intermediate $0 < ff < 1$ values indicate lower water content in the porous soil. The product $ff \cdot V_f$ is the total water volume within a porous soil volume element. The vertical (z -direction) pressure gradient at the perimeter canal aquifer–air surface increases with increasing saturated soil depth, thus amplifying the seepage rate. As aquifer seepage water is directed to the bottom of the perimeter canal, top portions of the seepage surface and adjacent ground area exhibit progressive drying in time (lower values of ff) as the phreatic layer profile deflects downward (Figs. 8 and 9). Figure 10

shows the western face of the seepage surface bounding the ceremonial center area, due to lower rainfall interception and high runoff rate from paved, roofed surfaces and less seepage water (but more runoff) deposits into the perimeter canal helping to keep ceremonial core soil areas dry. As the perimeter canal depth intersects the topmost fringe of the deep groundwater layer, regulation of groundwater height was maintained throughout the rainy season by runoff drainage from saturated surface soil, phreatic and deep groundwater layer seepage above the saturated perimeter canal bottom, and water transfer from surface canals M, L, and Z to canals C, X-Y, and C' seepage to the Tiwanaku River (Fig. 7). Thus any water in the perimeter canal exceeding the height of the saturated canal bottom surface was transferred to the river to maintain deep groundwater height constant during the rainy season. This effect maintained soil foundation strength under large monumental structures by keeping the water content of deep aquifer foundation soils constant. If water is withdrawn from porous soil, soil interstices collapse under gravity/exterior loading to form a dense, compacted soil composition – this causes ground settling that affects the foundation strength/stability of massive structures. Thus the perimeter canal's hydrological function includes this structural stability effect during rainy season water input conditions. The perimeter canal path X-Y is subject to uncertainty due to construction disturbance by the modern town but sufficient perimeter canal drainage to the Tiwanaku River existed by canal

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Fig. 11 Subterranean surface fluid fraction results for the subterranean canals P and Q for Case 1 conditions under Case 1, post-rainy season conditions



C (Figs. 4 and 6), subterranean canals P and Q, and the aquifer drainage area C' to establish the perimeter canal's water collection/drainage function.

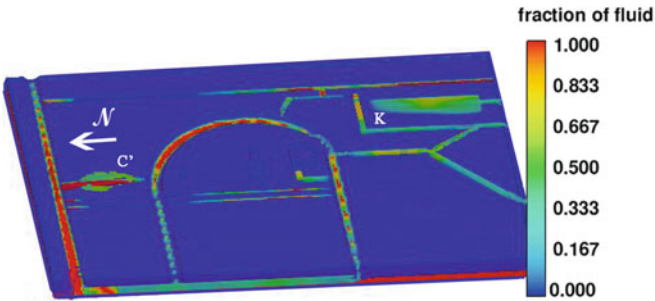
Figure 11 shows the water transport contribution of subterranean canals P and Q. Canal P lies under the floor of the Putuni and canal Q lies ~20 m west of P. Vertical pipes consisting of stacked, perforated stone disks served as water input conduits from higher secondary canals that drained water from the Putuni Courtyard/Palace into P and then toward the V segment of the perimeter canal (Fig. 6). The total extent of the drainage system in/around the Putuni and adjacent monumental areas is not presently known but excavation data indicates that an elaborate network of drainage canals lay underneath the monumental core with surface inlets feeding smaller transverse canals that delivered water to a series of larger, deeper canals. Post-rainy season sources of flushing water for the P and Q canals consisted of seepage water in perimeter canal arm W and water from Mollo Kontu canal M. As the P, Q, M, and C canals and the south–north perimeter canal bottom sloped downhill toward the river, flushing flow kept the subterranean sewer canals clean and directed wastewater toward the Tiwanaku River. Figure 11 indicates that some flow entered P and Q from W seepage and canal M water with remaining groundwater flowing into canal arms D and V which then flowed into the C' floodplain, canal C, and the P and Q subterranean extensions into the Tiwanaku River.

Case 2: Dry Season Initiation

Case 2 considers the perimeter canal under zero rainfall and continuous, but decreased, water supply from Corocoro springs into canals N, O, and M. As the dry season progressed, surface evaporation dries the phreatic zone and creates a moisture gradient between the deep groundwater capillary fringe and the shrinking phreatic layer, increasing capillary water transfer from the deep groundwater aquifer. Water at a low dry season flow rate from canal M maintains saturation of the perimeter canal's base surface, and water deposited over the saturated perimeter canal bottom flows downhill through canals D, C, and C' then to the river. Deep groundwater recession in the dry season is marginal given slow percolation water removal to lower areas, slow capillary water transfer to the phreatic zone, continued seepage accumulation into the perimeter canal's bottom, canal M water supply, and continual groundwater arrival from infiltrated rainfall from higher-elevation watershed areas. The key point is that the perimeter canal depth was intentionally set toward the top of the deep groundwater aquifer layer so that water exceeding this depth was removed to the river by canals C, Y and drainage to C' to maintain the deep groundwater height constant during dry and rainy seasons to promote structural stability of core area monuments. Figure 12 indicates ground surface moisture conditions during the dry season with low canal flow rates and limited water transfer to the phreatic layer from deep groundwater layer capillary flows. The *qocha* region of

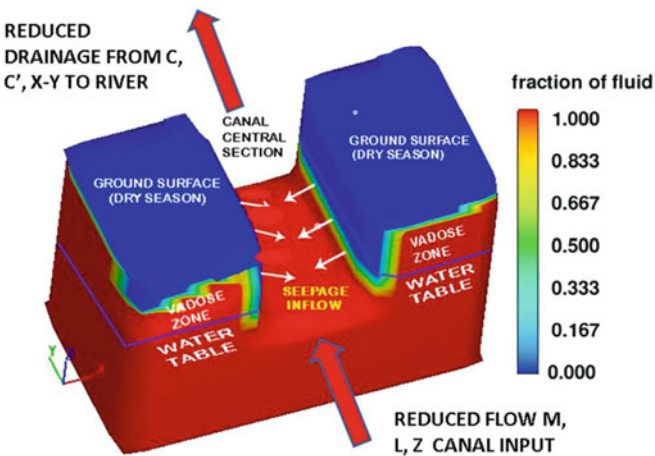
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Fig. 12 Dry season (Case 2) fluid fraction results for the ceremonial core and urban surroundings with limited water supply from spring-supplied canals M, N, and J (Fig. 6) into the perimeter canal



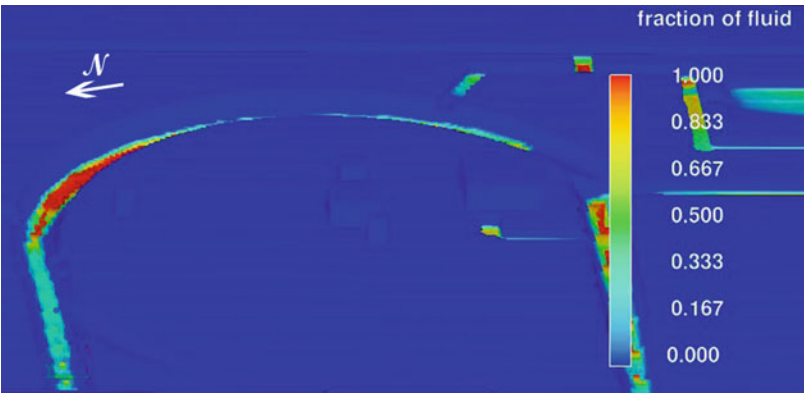
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Fig. 13 Representative summary diagram of water inputs/water outflows in a typical cross-section of the perimeter canal in canal leg D for dry season conditions



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Fig. 14 Case 2 fluid fraction results for the eastern section of the perimeter canal facing the ceremonial core region under dry season conditions – results indicate low seepage due to low rainfall infiltration from the paved, roofed ceremonial core region



Tiwanaku (Figs. 2, 6-K) and floodplain C' maintained dry season agropastural use due to its intersection with the deep groundwater capillary fringe zone augmented by canal M flow and seepage from the north arm of the perimeter canal. Canals P and Q had lower flushing rates from perimeter canal segment W under dry season conditions. Figure 13 summarizes dry season

water input/output flows at a typical perimeter canal cross-section segment. Figure 14 indicates a lower level of seepage into perimeter canal arm D as the dry season progresses; the phreatic layer is nearly absent indicating further ground surface dryness. In total, the dry season deep groundwater water content/height is maintained from continued, but reduced, canal M flow into the

perimeter canal, phreatic zone seepage water outflows, and percolation water transfer from adjacent watershed areas. As the dry season progresses, canals contain diminished spring flow and the phreatic layer continues to lose water from evaporation and drainage. As a result, phreatic layer hydrostatic pressure diminishes, resulting in more of the perimeter canal seepage surface participating in leakage but at a lower seepage rate than that for Case 1 conditions as lower Fig. 14 ff values indicate.

Conclusion

The perimeter canal served to increase drying of Tiwanaku's ceremonial core and nearby urban ground surfaces while providing foundational stability for its monumental structures. Subterranean canals P, Q served the hygienic requirements of the Putuni and Kerikala structures by providing flushing water from accumulated perimeter canal seepage water supplemented by canal M flow directed toward the P inlet. Each major monumental complex maintained an intricate drainage system that simultaneously served practical and ritual purposes. While the Akapana served ritual functions (Kolata, 1993, 1996, 2003), its drainage network limited rainfall infiltration into its internal soil fill to preserve its structural integrity as hydrostatic forces created by internal water seepage would have destabilized its stone-faced construction. Canal M flow, plus seepage water deposited into the perimeter canal bottom, is balanced by outflow canal and seepage paths C, C', X-Y, and P, Q (Figs. 7 and 13). A series of canals O, N located south of the perimeter canal directed water to the *qocha* complex K with excessive water from canal K diverted by canals I → J → L to the river thus protecting agropastoral area K from canal overspillage. Additionally, the perimeter canal regulated the deep groundwater height throughout seasonal water availability change to keep the foundations of Tiwanaku's monumental compounds secure from ground settling. These water management constructions reinforce the conclusion that Tiwanaku engineers envisioned

a drainage network involving the perimeter canal to control site ground soil moisture levels to improve environmental living conditions and maintain the structural stability of the city's monuments. Thus the perimeter canal appears to be the linchpin of an intricate hydrological network that regulated water flow/drainage during seasonal change.

Prior studies focused on Tiwanaku's hinterland demonstrated an understanding of hydraulics/hydrology to develop intensive groundwater-dependent, raised-field farming systems. Present research demonstrates the urban center of Tiwanaku incorporated similar technologies employing the perimeter canal as the central element. The technical innovations applied to advance progress within Tiwanaku society offer perspectives on the societal organization and the idea laboratory behind their engineering creations and demonstrate that knowledge of the three-dimensional manipulation of surface and groundwater by the Tiwanaku provides a further consideration in assessing New World engineering science.

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Ibn ‘Abbād

Zeina Matar

Abū al-Qāsim Ismā‘īl Ibn ‘Abbād Ibn al-‘Abbās Ibn ‘Abbād Ibn Ahmad Ibn Idrīs, also known as Kāfī al-Kufāt, and al-Šāhib, was a famous vizier and man of letters of the Buwayhid period. There is disagreement about his place and date of birth, but he was probably born at Iṣṭakhr on 16 Dhū’l-qa‘da 326/14 September 938. His family included high dignitaries, and his own father had been a *kātib* (clerk) and then vizier, or minister of state, under the Buwayhid Prince Rukn al-Dawla (r. 35/946–366/976).

Ibn ‘Abbād himself became the disciple and secretary of Abū’l-Faḍl Ibn al-‘Amīd (d. 360/970), the father of the Buwayhid vizier Abū’l-Faṭḥ Ibn al-‘Amīd (b. 337/948–9). His close relationship to the Buwayhid *amīrs* (princes) is said to have begun in 347/958, when he accompanied Mu‘ayyid al-Dawla (reigned 366/976–373/983) to Baghdad as a clerk. He was later confirmed in this office when Mu‘ayyid al-Dawla became governor of Isfahan. Ibn ‘Abbād’s career took a more significant turn when he was appointed vizier, replacing Abū’l-Faṭḥ Ibn al-‘Amīd.

Ibn ‘Abbād served two rulers: Mu‘ayyid al-Dawla and Fakhr al-Dawla (reigned 373/983–387/997). The main source for the

study of his vizierate remains the volume of the *Rasā’il* (‘Azzam, 1946), which is a collection of administrative pieces, appointment, and other official letters by Ibn ‘Abbād. According to the sources, the personality of Fakhr al-Dawla was not really compatible with that of Ibn ‘Abbād, although he recognized the latter’s administrative skills and talents. When Ibn ‘Abbād died on 24 Safar 385/30 March 995, Fakhr al-Dawla confiscated his property, and from that time onward, no other member of his family was to be appointed to a high official position.

Ibn ‘Abbād was not only a statesman and a politician, but he was also a talented writer whose works cover a very wide spectrum. In their article in the *Encyclopedia of Islam*, Claude Cahen and Charles Pellat give a classification of his works: dogmatic theology, history, grammar and lexicography, literary criticism, poetry, and belles-lettres.

In Abū Ḥayyān al-Tawḥīdī’s *Mathālib al-Wazīrayn*, a comprehensive list of Ibn ‘Abbād’s works is given. Some of the most important are:

- *Kitāb al-Muḥīt bi-‘l-lughā* (The Comprehensive Treatise About Language) in ten vols
- *Kitāb Dīwān rasā’ilihi* (Collection of Letters) in ten vols
- *Kitāb al-Kāfī. Rasā’il* (The Book of al-Kāfī [that which is sufficient]. Letters [or Correspondence])

- *Kitāb al-Aʿyād wa-faḍāʾil al-Nowrūz* (The Book of Feasts and the Excellent Qualities of New Year's Day)
- *Kitāb al-Wuzarāʾ* (The Book of Viziers)
- *Kitāb Dīwān Shiʿr(ihi)* (Collection of Poetry)

In the *Yatīmat al-dahr* (III, 204), al-Tha ʿālībī commented on a *Risāla* on medicine said to have been written by Ibn ʿAbbād:

I found that it combined beauty of style, elegance of expression, and mastery of the subtleties and particularities of medicine, and it showed that he was thoroughly familiar with this science, and had a penetrating knowledge of its intricacies.

Ibn ʿAbbād often inspired very contradictory opinions and feelings as is shown by Abū Ḥayyān al-Tawḥīdī's hostility on the one hand, and by al-Tha ʿālībī's praise and admiration on the other. However, regardless of personal like or dislike, he certainly was a highly exceptional personality in Muslim history. Maybe one can refer to him as a "patron-vizier", a talented individual who had the ability to mix politics and literature, and a poet whose court once counted as many as 23 poets.

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Ibn Al-ʿArabī

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Muḥyī al-Dīn ibn al-ʿArabī is one of the most influential Muslim thinkers of the past 700 years. Born in Murcia in present-day Spain in 1165, he set out for the western lands of Islam in 1200, traveled in the Arab countries and Turkey, and, in 1223, settled in Damascus, where he lived until his death in 1240. He wrote voluminously and attracted the attention of scholars and kings during his own lifetime. His magnum opus, *al-Futūḥāt al-makkiyya* (The Meccan Openings) – inspired sciences that were “opened” up to his soul during his pilgrimage to Mecca – will fill some 15,000 pages in its new edition. His most widely studied work, *Fuṣūṣ al-ḥikam* (The Bezels of Wisdom), is a short explication of the various modalities of wisdom embodied by 28 of God's prophets, from Adam to Muhammad.

Ibn al-ʿArabī's writings investigate every dimension of Islamic learning, from the *Qurʾān* and the *Ḥadīth* (the sayings of Muḥammad) to grammar, law, philosophy, psychology, and metaphysics. His basic intellectual project was to illustrate the unity of all human endeavors and the underlying, interrelated functions of all human thinking. He cannot be classified as a philosopher, theologian, scientist, or jurist, though his works address most of the basic epistemological issues of these disciplines. He saw himself as an inheritor of the wisdom of the prophets, but one who was given the duty of explaining this wisdom in the subtlest intellectual discourse of the day – at a period that is looked back upon as the high point of Islamic learning. He provides no system, but rather a unified vision that is capable of spinning off innumerable systems, each of them appropriate to a given field of learning or level of understanding. He offers many ways of approaching the basic questions of human existence, such as the nature of reality itself, the role of God, the structure of the cosmos

and the human psyche, the goal of human life, and the relationship of minerals, plants, and animals to other creatures. In short, he provides basic patterns for establishing complex systems of metaphysics, theology, cosmology, psychology, and ethics.

Ibn al-ʿArabī was followed by a number of major thinkers who systematized his “openings” in various ways, depending upon their own orientations and intellectual contexts. The diverse interpretations given to his works are especially obvious in a series of over 100 commentaries that have been written on his *Bezels of Wisdom* from the thirteenth century down to modern times. His stepson Ṣadr al-Dīn Qūnawī (d. 1274) had probably the keenest philosophical mind among Ibn al-ʿArabī’s followers. Qūnawī in turn trained many disciples, several of whom wrote widely influential works. Saʿīd al-Dīn Farghānī (d. 1296) provided systematic expositions of the teachings of both Qūnawī and Ibn al-ʿArabī in Arabic and Persian. Fakhr al-Dīn ʿIrāqī (d. 1289) was a poet who wrote a delightful summary of Qūnawī’s teachings in mixed Persian prose and poetry that helped popularize Ibn al-ʿArabī’s teachings. Muʿayyid al-Dīn Jandī (d. ca. 1300) wrote in Arabic the first detailed commentary on Ibn al-ʿArabī’s *Bezels of Wisdom*. The intellectual tradition established by Ibn al-ʿArabī and Qūnawī gradually merged with various branches of Islamic philosophy, yielding a wide range of intellectual perspectives that dominated the Islamic wisdom tradition down to the coming of Western colonialism.

In order to grasp Ibn al-ʿArabī’s importance for the history of scientific thought in Islam, one needs to understand his basic accomplishment, which was to establish an honored place in the Islamic intellectual tradition for supra-rational knowledge. From their inception in the eighth and ninth centuries, the mainline schools of theology and philosophy in Islam had endeavored to understand the Quranic revelation on the basis of rational modes of investigation taken over from the Greek heritage. Parallel to this, there developed a more practical, existential approach that found the goal of human life in direct experience of the presence of God. This second approach,

which came to be called by the umbrella term “Sufism,” laid stress upon supra-rational modes of knowledge that are collectively known as *kashf* (unveiling), i.e., the lifting of the veils that separate the human soul from God. Unlike some Sufis, Ibn al-ʿArabī was not opposed to acknowledging the authority of reason. However, he maintained that unveiling was a higher form of knowledge, because it grows out of the unmediated perception of God’s actuality. In Ibn al-ʿArabī’s way of looking at things, reason tends innately to divide and discern. It eliminates connections between God and the cosmos and understands God as distant and transcendent. In contrast, unveiling works by seeing sameness and presence; hence, God is perceived as near and immanent. Perfect knowledge of God and of reality as a whole depends upon a happy balance of reason and unveiling. Only through this balance can God be perceived in appropriate modes as both absent and present, near and far, transcendent and immanent, and wrathful and merciful. Ibn al-ʿArabī’s works are devoted largely to explaining the vast range of these appropriate modes.

The long-term effect of the marriage between reason and unveiling effectuated by Ibn al-ʿArabī is symbolized by his meeting when still a boy – of perhaps 15 years – with the philosopher Ibn Rushd (Averroes d. 1198). Ibn al-ʿArabī had already experienced the opening of the unseen worlds, and Ibn Rushd, who was a friend of his father, had asked to meet him. In the brief exchange that took place, Ibn Rushd asked if unveiling and reason achieved the same goals. Ibn al-ʿArabī replied, “Yes and no.” Then, in cryptic language, he affirmed that reason was a valid route to achieve knowledge of the nature of things, but he denied that it exhausted the possibilities of human knowing. In the West, the teachings of Ibn Rushd were employed to help establish nature as an autonomous realm of intellectual endeavor. Under the discerning eye of reason, God was abstracted from perceived reality, eventually becoming a hypothesis that could be dispensed with. The world of nature was now the proper site for rational analysis and dissection, and the result has been the ever-increasing fragmentation of human knowledge, with a total

divorce between science and ethics. In contrast, Ibn Rushd was forgotten in the Islamic world, but Ibn al-‘Arabī and his followers succeeded in establishing a harmony between reason and unveiling. Hence, Muslim intellectuals were never able to conceive of nature as a realm cut off from God. If God is present in all things, then the ethical and moral strictures that he establishes through revelation need to be observed at every level. It becomes impossible to investigate the natural world without at the same time investigating its relationship with God and recognizing the moral and ethical demands that this relationship entails.

Ibn al-‘Arabī’s career and teachings exemplify the dimensions of Islamic learning. The worldview to which he gave detailed expression provided a perspective from within which Muslim intellectuals were able to answer the deepest questions of the human mind. Ibn al-‘Arabī’s achievements contributed to an intellectual equilibrium that refused to subordinate the spiritual demands of human beings to corporeal demands and that gradually established a vast framework within the context of which the intellectual disciplines came to be ever more united and interrelated. This holistic perspective on knowledge in turn prevented the fragmentation of the Islamic worldview and allowed no room for “declarations of independence” by specific schools of science or philosophy. Given that ethics, morality, and spiritual development lay at the heart of this perspective, it was impossible to divorce any branch of science or learning from these concerns.

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Ibn Al-A‘lam

Raymond Mercier

Ibn al-A‘lam, Abū’l-Qasim ‘Alī ibn ‘Isa al-Husain, al-‘Alawī, al-Sharīf was a tenth century astronomer, apparently established in Baghdad. The year of his death is recorded by Ibn al-Qifṭī as 375/985. The ► **Zīj** (astronomical handbook with tables) which he wrote is lost, but substantial information about it may be gleaned from notices in the work of other astronomers. His work was patronized by the Būyid ruler ‘Aḡūd al-Dawla but suffered from lack of support in the disturbed period which followed his death in 372/982.

A near contemporary, the great astronomer Ibn Yūnus of Cairo, reports that Ibn al-A‘lam had fixed the length of the year as 365; 45, 40, 20 days, determined the position of Regulus (α Leonis) in the year 365/975-6 as 15; 6 Leo, and also fixed the rate of precession, 1° in 70 Persian years. He remarks that Ibn al-A‘lam

was known everywhere for the exactitude of his observations and the extent of his geometrical knowledge.

► **Al-Bīrūnī** in his work *Tamhīd al-mustaḡarr li-taḥqīq ma'nā al-mamarr* (On Transits) gives the name of his *Zīj* as *al-ʿAdūdī*, and incidentally provides values for the radius of the epicycles for each of the planets.

In spite of the loss of the *Zīj* full information about its parameters may be obtained from two sources compiled in the fourteenth century, the Persian *Zīj-i Ashrafī*, and an anonymous Arabic collection known as the *Dastūr al-Munajjimīn*. Information is also available from Greek sources, in which Ibn al-Aʿlam is referred to as Alim (ʿΑλημ). The Greek manuscripts are of the fourteenth and fifteenth centuries, but they preserve texts older than the Persian and Arabic compilations. These include *scholia* to the *Almagest* datable to AD 1032 which refer to tables composed for the Greek calendar from the work of Ibn al-Aʿlam, as well as two horoscopes for the years AD 1153 and AD 1162 which have been calculated from such tables, apparently for the Emperor Manuel Comnenus. The tabulation of the equations indicates that the technique of “displacements” was used in order to provide values of the equations which were always positive.

See Also

- **Ibn Yūnus**
- **Zīj**

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Ibn al-Bannā'

Emilia Calvo

Ibn al-Bannā' al-Marrākushī, Abū-i-ʿabbās Aḥmad ibn Muḥammad ibn ʿUthmān al-Azdī was born in Marrakesh, Morocco on 29 December 1256 and died, probably in Marrakesh, in 1321. He studied the Arabic language, grammar, the *Qu'rān*, *Ḥadīth* (commentaries of the prophet), and also mathematics, astronomy, and medicine; but his fame is due to his knowledge of mathematics. His teachers in this field were Muḥammad ibn Yaḥyā al-Sharīf, Abū Bakr al-Qallūsī, and Abū ʿAbd Allah ibn Makhluḥ al-Sijilmāsī. He also studied medicine with al-Mirīkh.

Among his disciples were al-Lajāʿ, teacher of Ibn Qunf ūdh, Muḥammad ibn Ibraḥīm al-Abūlī, Abū-l-Barakāt al-Balāfiqī, and Ibn al-Najjār al-Tilimsānī.

He is credited with having written more than 80 works. Among them are an introduction to Euclid, a treatise on areas, an algebra text, a *Kitāb al-anwāʾ* (about asterisms and stars used in meteorology and navigation), an almanac, two abridgements of treatises by ► **Ibn al-Zarqāllu** on the use of the *Ṣafṭḥas* (astrolabes) *zarqāliyya* and *shakkāziyya* entitled, respectively, *Risālat al-ṣafṭḥa al-mushtaraka ʿalā al-shakkāziyya* (Epistle on the Shakkāziyya Plate), in 23 chapters, and *Taqbīl ʿalā risālat al-ṣafṭḥa al-zarqāliyya* (Epistle on al-Zarqālī's Plate). However, his two most important works are the *Minhāj* and the *Ṭalkhīṣ*.

The *Kitāb minhāj al-tālib li taʿdīl al-kawākib* (The Way of Him Who Seeks the Equation of the Planets) is a very practical book for calculating astronomical ephemerides. This ► **zīj** (astronomical handbook with tables) is based on the one by Ibn Ishāq. The two of them are highly dependent on Ibn al-Zarqāllu's astronomical theories.

The *Talkhīṣ aʿmāl al-ḥisāb* (Summary of Arithmetical Operations) was widely diffused in the Arabic world because of its conciseness, which makes it easy to memorize. ► [Al-Qalaṣādī](#), among others, wrote an important commentary on it. A different version of this work, more extensive and complete, has been edited recently by Saidan (1984) under the title *Al-maqālāt fī ʿilm al-ḥisāb li-Ibn al-Bannāʾ* (The Treatises on the Science of Computation by Ibn al-Bannāʾ). The procedures found in the *Talkhīṣ* are studied here in a more detailed way.

See Also

- [Ibn al-Zarqāllu](#)
- [Ibn Qunfudh](#)

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Ibn al-Bayṭār

Emilia Calvo

Ibn al-Bayṭār al-Mālaqī, Ḍiyāʾ al-Dīn Abū Muḥammad ʿAbdallāh ibn Aḥmad, was a pharmacologist born in Málaga, Spain at the end of the twelfth century (ca. AD 1190–1248). He studied in Seville with Abū-l- ʿAbbās al-Nabātī, ʿAbdallāh ibn Šāliḥ, and Abū-l-Hajjāj. He was interested in the works of al-Ghā fī qī, al-Zahrāwī, ► [al-Idrīsī](#), Dioscorides, and Galen.

Around AD 1220 he migrated to the East and, in 1224, arrived in Cairo where he was named chief herbalist by the Ayyūbid Sultan al-Kāmil. He traveled through Arabia, Palestine, Syria, and Iraq. Ibn Abī Uṣaybiʿa was one of his followers and left a mention of his teacher full of praise in his *ʿUyūn*.

Among Ibn al-Bayṭār's works we can mention *Al-Mughnī fī l-adwiya al-mufrada* (The Complete Book on Simple Drugs), dedicated to al-Kamil's son, Sultan al-Šāliḥ and dealing with the simple medicines, and *Al-Jāmiʾ li-mufradāt al-adwiya wa-l-aghḍhiya* (Compendium of Simple Drugs and Food), which enumerates alphabetically some 1,400 animal, vegetable, and mineral medicines, as well as some 150 authorities including ► [al-Rāzī](#) and Ibn Sīnā.

Ibn al-Bayṭār's main contribution is the systematization of the discoveries made by the Arabs during the Middle Ages in this field. He was also concerned with synonymy, finding the technical equivalents between the Arabic and Persian, Berber, Greek, Latin, and Romance languages. The *Jāmiʾ* had great influence in the Near East, but less in the West. Andrea Alpago used it in his works on Ibn Sīnā.

Other works of Ibn al-Bayṭār, less known than the aforementioned two, are *Mizān al-ṭabīb* (The Measure of the Physician), *Risāla fī l-aghḍhiya wa l-adwiya* (Treatise on Food and Medicines), *Maqāla fī l-laymūn* (Treatise on the Lemon), and *Tafsīr kitāb Diyusqūrdīs* (Explanation of Dioscorides' Book) in which he inventories

550 medicines found in the first four books of Dioscorides.

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Ibn al-Hā’im

Julio Samsó

‘Abd al-ḥaqq al-Ghāfiqī al-Ishbīlī is known as Ibn al-Hā’im. He was an Andalusian astronomer, probably from Seville. He dedicated (ca. 1204) his very important *al-Zīj al-Kāmil fī l-Ta’ālīm* (The Perfect Handbook on Mathematical Astronomy) to the Almohad Caliph Abū ‘Abd Allāh Muḥammad al-Nāṣir (1199–1213). This work, which is extant in a unique and incomplete manuscript in the Bodleian Library at Oxford

University, was influential in the Maghreb and contributed to the development there of a new kind of astronomy in the Andalusian tradition. As a ► *zīj* (astronomical handbook with tables), it is exceptional in Western Islam, because it contains a highly technical and complete exposition of Ptolemaic astronomy with geometrical demonstrations, and not a simple set of instructions for the use of the tables. It also conveys new information on the astronomical works of the Toledan school of the eleventh century, the main representative of which was Ibn al-Zarqāllu/Azarquiel (d. 1100), as well as new planetary parameters. Ibn al-Hā’im appears as a defender of Zarqāllian orthodoxy and harshly criticizes ► *Ibn al-Kammād* (fl. beginning of the twelfth century) for his modifications of Ibn al-Zarqāllu’s doctrines. Ibn al-Hā’im’s *zīj* contained numerical tables (three have been preserved in the *zīj* of Ibn Ishāq, who flourished in Tunis at the beginning of the thirteenth century) but an incomplete copy must have circulated early for ► *Ibn al-Raqqām* (d. 1315) states that Ibn al-Hā’im did not include any tables in his work.

See Also

- *Ibn al-Raqqām*
- *Ibn al-Zarqāllu*

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Ibn Al-Haytham (Alhazen)

Roshdi Rashed

Among the mathematicians of classical Islam, few are as famous as al-ḥasan ibn al-ḥasan ibn al-Haytham (Alhazen in the Latin West).

A physicist and astronomer as well as mathematician, he quickly gained a wide reputation, first in Arabic, in the Islamic East as well as the Islamic West, and then from the translations of his works in optics and astronomy into Latin, Hebrew, and Italian.

But his renown, completely justified by the importance of his contributions and especially of the scientific reforms accomplished in them, contrasts singularly with the paucity of information we have on the man, his teachers, or his scientific milieu. Also, the significance of his works surrounded the man with the aura of a legend. Sources available to us consist of narratives recounted by ancient bibliographers where legend becomes mixed up with the rare historical evidence. These same narratives are precisely what modern bibliographers continue to reproduce partially or totally until today. After a critical reading of these sources, very little information remains: born in Iraq, most likely in Bassorah, sometime in the second half of the tenth century, Ibn al-Haytham arrived in Cairo, under the reign of Faṭimid al-ḥākim. He proposed a hydraulic project to control the waters of the Nile, but it was rejected by the Caliph. He continued to live in Cairo until his death, after 432/1040.

From the thirteenth century until today, biographers have confused al-ḥasan ibn al-Haytham with Muḥammad ibn al-Haytham, a philosopher and theorist of medicine who lived in Baghdād at the same time. This confusion, due undoubtedly to similarity of the two names of these contemporary authors, is serious as it brings into question the authenticity of certain writings attributed to al-ḥasan ibn al-Haytham.

Biobibliographers, notably al-Qifṭī, cite 96 titles of Ibn al-Haytham, not all of which have survived. Half of his writings are in the field of mathematics, 14 on optics, including the authoritative and voluminous *Kitāb al-Manāẓir* (Book of Optics), 23 on astronomy, 2 in philosophy (1 on the *Place* and the other on the *Indivisible Part*), 3 on statics and hydrostatics, 2 on astrology, and 4 on various other topics. This accounting shows clearly that Ibn al-Haytham grappled with all the mathematical sciences of

that time, or at least the most advanced part of this discipline. We will see that he was always at the leading edge of research or at the culmination of one tradition and the beginning of a new period. It is precisely this quality which distinguishes his contributions. Ibn al-Haytham lived at a privileged time, his work following a century of intense research in these fields by eminent scholars such as the ► [Banū Mūsā](#), ► [Thābit ibn Qurra](#) and his grandson ► [Ibrāhīm ibn Sinān](#), al-Qūhī, and ► [Ibn Sahl](#), to name a few. We will now briefly examine the principal aspects of his research.

Mathematics

Ibn al-Haytham's mathematical research was particularly in the field of geometry and not of algebra. Ancient biobibliographers attributed a book on algebra to him, but it has not survived. From the outset, geometers wanted to combine closely the study of the positions of figures and their metric properties: in other words, to combine the geometry of Apollonius with that of Archimedes. This combination is not a static synthesis, but a new organization of geometry which possessed a real heuristic value. Already initiated by al-ḥasan ibn Mūsā and followed by Thābit, this work led to the study of geometric transformations and of projective methods. It was this work which Ibn al-Haytham developed further in his own geometrical studies.

The contributions of Ibn al-Haytham in geometry can be divided into several groups, the most important of which are in infinitesimal mathematics and the theory of conic sections and their applications. He composed 12 treatises on infinitesimal mathematics and then on conic theory. To those can be added a third area in which Ibn al-Haytham takes up several problems relating to the foundations of mathematics and their methods in his treatise *Maqāla fī 'l-taḥlīl wa 'l-tarkīb* (On Analysis and Synthesis), his *Kitāb fī al-ma 'lūmāt* (On the Known Things), his *Sharḥ Uṣūl Uqlīdis fī 'l-handasa wa 'l-'adad wa talkhīṣuhu* (Commentary on the *Elements* of

Euclid), and his *Kitāb fī Ḥall shukūk Kitāb Uqlīdis fī 'l-uṣūl wa-sharḥ ma'ānīh* (Solutions to Doubts) again concerning Euclid. In these books, he deals as much with the constitution of a new discipline, a kind of proto-topology, as with the theory of the demonstration within the difficulties raised by the fifth postulate of Euclid, or with the theory of parallels. Ibn al-Haytham also edited an important paper on number theory, four treatises on arithmetic, and the same number on practical geometry.

Of the 12 papers on infinitesimal mathematics, only 7 have survived. The first three are devoted to the study of lunes and the quadrature of a circle. Note that the calculation of the area of lunes involves the calculation of sums or differences of areas of sectors or of triangles, the comparison of which has recourse to that of the ratio of angles or of the ratio of segments. In the most important of the three papers, Ibn al-Haytham begins by setting up four lemmas, the results of which demonstrate the role of the function f , defined as

$$f(x) = \frac{\sin^2 x}{x}$$

in the study of lunes.

In his study *Tarbī' al-dā'ira* (On the Quadrature of a Circle), he examines the relationship between proving the existence of a magnitude or a property and the question of effectiveness of its construction.

Other treatises on infinitesimal mathematics deal with the volume of a solid curve: *Misāḥat al-mujassam al-mukāfi'* (The Measurement of a Paraboloidal Solid) and *Misāḥat al-kura* (The Measurement of a Sphere). In calculating the volume of a paraboloid, Ibn al-Haytham deals rapidly with the volume of a revolving paraboloid, which had already been studied by ► [Thābit ibn Qurra](#) and al-Qūhī. He then moves on to his own invention: how to calculate the volume of a paraboloid obtained from the rotation of a parabola around its ordinate. He shows that this volume is 8/15 of the volume of the circumscribed cylinder. His calculation is equivalent to that of the integral

$$\pi \int_a^b k^2 (b^2 - 2b^2 y^2 + y^4) dy = \frac{8}{15} \pi k^2 b^5 = \frac{8}{15} V,$$

with V being the volume of the circumscribed cylinder.

Ibn al-Haytham proceeded in this study with the help of the method of integral sums, which he also applied in calculating the volume of a sphere. In order to do this calculation, Ibn al-Haytham generalized the proposition X-1 of Euclid's *Elements*. He devoted the seventh paper in this group to that. This group includes an important treatise devoted to isoperimetric and isepiphane problems. It was the most advanced mathematical work of its time and for several centuries following. In it, to study these *extrema*, he had to undertake the first substantial research on the theory of a solid angle. Moreover he combined both a projective method and an infinitesimal method.

Ibn al-Haytham's second group of mathematical writings dealt with the theory of conic sections. He was well acquainted with the Conics of Apollonius and had copied them in his own hand, so he knew that, in Greek, the eighth and last book was lost. He tried to reconstruct the book according to the indications of Apollonius. In addition to his writings on conics, he applied the theory of the intersection of conics to the resolution of problems which cannot be constructed with a compass or ruler, problems either passed down (for example, the regular heptagon) or posed by him (for example, the solution of a solid arithmetic problem). Ibn al-Haytham was one of the first mathematicians who insisted on demonstrating the existence of the point of intersection of two conics in these last examples.

It is impossible in this space to explicate the mathematical results of Ibn al-Haytham's work. But let us simply note his expression of what is called Wilson's theorem, and the converse of Euclid's theorem for perfect numbers.

Indeed, in the course of solving the problem called the Chinese Remainder, he stated Wilson's theorem, which can be written as:

n is prime

$$(n-1)! - 1 \pmod{n}.$$

As for the converse of Euclid's theorem of perfect numbers, he tried to show that any even perfect number is in Euclidean form, in other words in the form $2^p(2^{p+1} - 1)$ with $(2^{p+1} - 1)$ prime.

Optics

A brief look at the work of Ibn al-Haytham on optics reveals not only its revolutionary nature but also its comprehensiveness, touching all the known branches of optics: optics in its proper sense in his *Book on Optics* and his *Discourse on Light*; catoptrics, notably burning mirrors (parabolic and spherical burning mirrors); dioptrics, in *al-Kura al-muḥriqa* (The Burning Sphere); and meteorological optics in *Daw' al-qamar* (The Light of the Moon), *Aḍwā' al-kawākib* (The Light of the Stars), *Fī Ṣūrat al-kusūf* (On the Shape of the Eclipse) and *al-Hāla wa-qaws quṣaḥ* (The Halo and the Rainbow). With this extension, Ibn al-Haytham modified the meaning of optics. Optics is not any more reduced to a theory of direct vision, a geometry of the gaze with which a theory of vision is associated, but also bears significantly on the theory of light, its propagation, and its effects as a material agent. This leads us to the revolution accomplished by Ibn al-Haytham in optics and more generally in physics.

Ibn al-Haytham sought to bring about a program of reform, which led him to take up a whole range of different problems. The basic aspect of this reform was to clarify the difference between the conditions of the propagation of light and the conditions of the vision of objects. This led, on the one hand, to giving physical support to the rules of propagation – making a firm mathematical analogy between a mechanical model of the movement of a solid ball thrown against an obstacle and that of light – and on the other hand to proceeding geometrically at all times, both by observation and by experimentation. Optics consisted henceforth of two parts: one, a theory of vision and the associated physiology of the eye

and psychology of perception, and the other, the theory of light to which are linked geometric optics and physical optics. The organization of the *Optics* reflects this new situation: there are chapters devoted entirely to propagation, such as the third chapter of the first book and books IV to VII; others deal with vision and related problems. This reform also resulted in the emergence of new problems, such as Alhazen's problem in catoptrics, the examination of the spherical lens and the spherical dioptr, not only as burning instruments but also as optical instruments in dioptrics, and to experimental control, viewed as much as a general practice of investigation as the norm of a proof in optics, and more generally in physics. Let us now take a quick look at how this reform in optics was carried out.

Ibn al-Haytham rejected any doctrine of a ray stemming out from the eye, called a visual ray, in order to defend the intromissionist theory of visible forms. But unlike the intromissionists of antiquity, he did not believe that objects sent off "forms" or totalities which emanated from the visible under the effect of light. He saw them rather as forms reducible to their elements: a ray emanating toward the eye from every point of a visible object. Looked at thus, the eye becomes a simple optical instrument. Ibn al-Haytham then explained how the eye perceives the visible with the help of its rays emitted from all points. In the *Optics* he devotes the first three chapters to the foundations of this theory. In the three following chapters, he deals with catoptrics. The seventh and last chapter is devoted to dioptrics. His theories rest on two qualitative laws of refraction and on several quantitative rules, all controlled experimentally with the help of an instrument which he designed and built himself. The two qualitative laws, known to his predecessors Ptolemy and ► [Ibn Sahl](#), can be stated as follows:

1. The incident ray, the normal at the point of refraction, and the refracted ray are in the same plane; the refracted ray gets closer (respectively, far away) from the normal, if light passes from a milieu less (respectively, more) refringent to a milieu more (respectively, less) refringent
2. The principle of inverse return

Instead of pursuing the path opened up by his predecessor Ibn Sahl, Ibn al-Haytham returned to a study of angles in order to establish the quantitative rules. He devoted a substantial part of the seventh book to a study of the refracted images of an object, notably if the surface of separation of two milieus is either planar or spheric. It was in the course of this study that he fixed his attention on the spherical diopter and the spherical lens. He returned to the spherical lens in his treatise *On the Burning Sphere*, one of the high points of research in classical optics, in order to improve upon certain results that he had already obtained in his *Optics*. This treatise was the first deliberate study on the spherical aberration for parallel rays falling on a glass sphere and giving off two refractions.

Astronomy

By their number, their thematic variety, the power of the analysis they show, and by their results, the works of Ibn al-Haytham in astronomy yield nothing to his works in mathematics or optics. It should be noted only that an elementary treatise of Muḥammad ibn al-Haytham, the *Commentary on the Almagest* is often erroneously attributed to Ibn al-Haytham. The attribution of the book *On the Configuration of the Universe* to him is also doubtful. The authentic works of Ibn al-Haytham have not yet been seriously studied, *a fortiori*, apart from a few rare and particular contributions, such as the *Samt al-ibla bi-al-ḥisāb* (Determination of the Direction of Mecca by Calculation). It remained for subsequent astronomers, notably al-ʿUrdī, one of the founders of the school of Marāgha, to recognize their debt to Ibn al-Haytham's book *al-Shukūk ʿalā Baṭlamyūs* (Doubts on Ptolemy). Before assessing his contribution in astronomy, we must wait until his books have received the editing and study that they deserve.

The impact of the work of Ibn al-Haytham varies according to the field. In mathematics, his influence can be seen in the works of Ibn Hūd, al-Khayyām, ► [Sharaf al-Dīn al-Ṭūsī](#), and

al-Samaw'al, among others. But we do not know anything of successors who might have tried to follow up on his research on lunes, the solid angle, or the measurement of figures and solid curves. In optics, the Latin translation of his *Optics* (under the title *Perspectiva* or *De Aspectibus*, reedited in 1572 under the title *Opticae Thesaurus*) and his treatise *On Parabolic Burning Mirrors* provided a basis of research for centuries of scholars such as Witelo, Roger Bacon, J. Peccham, Frederick of Fribourg, Kepler, and Snell, among many others. In Arabic, there is the commentary of Kamāl al-Dīn al-Fārsī. Finally in astronomy, there is the work of al-ʿUrdī which shows the influence of his work. It is too soon to measure the impact of the writings of Ibn al-Haytham on his successors in this field also, but they appear to be immense.

See Also

- [al-Khayyām](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Geometry](#)
- [Optics in the Islamic World](#)
- [Physics](#)
- [Sharaf al-Dīn al-Ṭūsī](#)

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Ibn al-Kammād

Julio Samsó

Abū Jaʿfar Ahmad ibn Yūsuf ibn al-Kammād was an Andalusian astronomer who flourished in Cordoba toward the end of the eleventh century and the first half of the twelfth. He was probably a direct disciple of Ibn al-Zarqāllu/Azarquiel (d. 1100) as well as the student who helped him in observations made in Cordoba during his last years. He compiled three sets of astronomical tables (*zīj*es) of which only one (*al-Muqtabis*) is extant in a Latin translation made by Johannes of Dampno in Palermo (1262). In it he appears as a follower of the Zarqallian tradition, although he often corrects his master's parameters. Toward 1204, ► [Ibn al-Hā'im](#) makes a strong criticism of one of his other two *zīj*es (*al-Amad' alā' l-abad*, Valid for all Eternity) because of his departures from Zarqallian orthodoxy. Also extant, in Arabic, is a small astrological work in which Ibn al-Kammād studies the problem of the length of human pregnancy and the determination of the exact moment of the conception.

His work was influential in late Maghribean and Egyptian astronomy, for quotations and tabular materials from his *zīj*es appear in the thirteenth century ► [zīj](#) of ► [Ibn Ishāq al-Tūnisī](#) in Abū'l-ḥasan 'Alī al-Marrākushī's treatise on *mīqāt* (Astronomy Applied to Muslim Worship) and in a fourteenth century anonymous Egyptian treatise on the same topic.

See Also

- [Ibn al-Hā'im](#)
- [Zīj](#)

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Ibn al-Majūsī

Sami K. Hamarneh

Abū'l-ḥasan 'Alī ibn al-'Abbās ibn al-Majūsī was considered one of the leading Muslim physicians of his time. He was of Zoroastrian ancestry, and therefore called the Magian, and he is known in Latin as Haly 'Abbās. He was born in the old Persian city of Arrajān, in the southwest of Iran,

at the end of the first quarter of the tenth century. He studied medicine under a leading medical tutor (*shaykh*) named Abū Māhir Mūsā ibn Yūsuf ibn Sayyār, who died ca. AD 983.

When he had developed a reputation for excellence and skill, Ibn al-Majūsī was invited to become a physician-in-ordinary at the palace of King ‘Aḍud al-Dawlah Fannā Khusraw, who reigned from AD 949 to 983 in Shīrāz. He was the Buwayhid Shāh who founded al-‘Aḍudī Bīmāristān, the famous hospital in Baghdad that lasted for almost three centuries. In that period, the Buwayid Dynasty’s power and glory reached their apex.

In recognition of the King’s generosity and patronage to the sciences and the arts, Ibn al-Majūsī dedicated his medical encyclopedia, *Kāmil al-Ṣinā‘ah al-Ṭibbīyah*, known also as *Kitāb al-Malikī* (Latin *Liber regius*, presented to the King’s royal library) in Shīrāz.

The book comprises two parts, the theoretical and the practical, each of which has ten treatises. It brought together original contributions on public health, preventive medicine, dietetics, materia medica, therapy, surgery, clinical observations, and practical medicoethical procedures. *Kitāb al-Malikī* was first rendered into Latin by Constantine Africanus (AD 1020–1087) under the title *Pantegni*, without giving credit to its original author. Al-Majūsī was fully recognized when the book was translated from Arabic into Latin by Stephen of Antioch in 1127. Since then, many editions in Latin and Arabic have appeared, and a facsimile edition was published in 1985 in two volumes.

Among the Arabic compendia on the theme of the healing arts in Islam, Majūsī’s *Kitāb al-Malikī* stands as one of the leading texts in its style, systematization, and precision. It was well read among students and practitioners alike. The judge and historian Ibn al-Qiftī praised Majūsī by saying that he “excelled in the study of medicine, [and] worked hard to comprehend its doctrines and laws from the original sources.”

Ibn al-Majūsī died in Shīrāz in AH 384/AD 994, leaving behind an essential document in the Arabic legacy to the history of the medical sciences in this golden age.

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Ibn al-Nafīs

Albert Z. Iskandar

Ibn al-Nafīs, ‘Alā’ al-Dīn Abu’l-ḥasan ‘Alī Ibn Abī al-ḥazm al-Qurashī, was born in a village near Damascus (Syria). He studied medicine at the Great Nūrī Hospital (*al-Bīmāristān al-Nūrī*) in Damascus, founded by the Turkish ruler Nūr al-Dīn Maḥmūd Ibn Zankī (d. AD 1174). He chose to live, practice, and teach medicine in Egypt, where he eventually became a Chief of Physicians, and was also a personal doctor to the then-ruler al-Zāhir Baybars (r. ca. AD 1260–1277).

In addition to practicing medicine, he was a Shāfi ‘ī jurist, thoroughly educated in Islamic theology and jurisprudence at the Masrūriyya School (*Madrassa*) in Cairo. Hence, he is classed as a “jurist physician,” thus deviating from the

traditional image of the physician-philosopher Galen (d. ca. AD 200), which was so faithfully emulated by many medieval Arabic-speaking doctors, as for example ► [al-Rāzī](#) (Rhazes, d. AD 925) and Ibn Sīnā (Avicenna, d. AD 1037).

Ibn al-Nafis was a prolific author. Among his medical works is *Kitāb al-Shāmīl fī ‘l-ṣinā’ a al-Ṭibbiyya* (Comprehensive Book on the Art of Medicine). He jotted down preparatory notes for this voluminous book in 300 volumes, of which he managed to publish only 80. Its manuscripts, so far unpublished, are to be found in Cambridge University Library (Cambridge, England), the Bodleian Library (Oxford, England), and al-Muthaf al-‘Irāqī (Iraq). In 1960, three autographed manuscripts of this book were discovered in the Lane Medical Library (Stanford University). The first, referred to by Ibn al-Nafis himself as the 33rd *mujallad* (bound volume), is dated AH 641/AD 1243–1244. According to the author, the two other manuscripts are its 42nd and 43rd volumes.

It is of historical significance that Ibn al-Nafis, in *Kitāb al-Shāmīl*, divides the procedure to be followed by doctors in surgical operations into three stages: first, the “stage of presentation for clinical diagnosis”; second, the “operative stage”; and third, the “postoperative period,” during which the patient remains under the doctor’s supervision until full recovery is achieved.

Another important work is *Sharḥ Tashrīḥ Kitāb al-Qānūn fī ‘l-Ṭibb li-Ibn Sīnā* (Commentary on Anatomy in Avicenna’s Canon of Medicine). In it he gives the earliest known account of pulmonary circulation: “. . . This is the right cavity of the two cavities of the heart. When the blood in this cavity has become thin, it must be transferred into the left cavity, where the pneuma is generated. But there is no passage between these two cavities, the substance of the heart there being impermeable. It neither contains a visible passage, as some people have thought, nor does it contain an invisible passage which would permit the entry of blood, as Galen thought. The pores of the heart there are compact and the substance of the heart is thick. It must, therefore, be that when the blood has become thin, it is passed into the arterial vein

(pulmonary artery) to the lung, in order to be dispersed inside the substance of the lung, and to mix with the air. The finest parts of the blood are then strained, passing into the venous artery (pulmonary vein) reaching the left of the two cavities of the heart, after mixing with the air and becoming fit for the generation of pneuma. . .”

Ibn al-Nafīs’ discovery of pulmonary circulation antedates the accounts mentioned by Michael Servetus (AD 1553), Realdo Colombo (AD 1559), and Andrea Cesalpino (d. AD 1603). Andreas Vesalius (d. AD 1564), who does not mention blood circulation, refutes Galen in his statement: “. . . I do not see how even the smallest amount of blood could pass from the right ventricle to the left ventricle, through the interventricular septum. . .” We now say it was William Harvey (d. AD 1657) who, through experimentation which lasted almost 20 years, discovered the entire path of blood circulation.

Ibn al-Nafīs wrote a large textbook, *Al-Muhadhdhab fī ‘l-Kuḥl al-Mujarrab* (The Polished Book on Experimental Ophthalmology), divided into two sections: “On the Theory of Ophthalmology,” followed by detailed accounts of “Simple and Compounded Ophthalmic Drugs.”

A very popular and concise book was Ibn al-Nafīs’ *Mūjiz al-Qānūn fī ‘l-Ṭibb* (Abstract of Ibn Sīnā’s Canon of Medicine). It has been claimed – probably unfairly – that the tedious prolixity of Ibn Sīnā’s *Canon of Medicine*, together with the incomprehensibility of some of its statements, and Ibn al-Nafīs’ *Abstract of Avicenna’s Canon of Medicine*, with its undue brevity and popularity among Arabic-speaking students of medicine, led to the decline of late medieval medical education.

On the philosophy of religion, Ibn al-Nafīs wrote *Al-Risāla al-Kāmilīyya fī ‘l-Sīra al-Nabawīyya* (Missive on the Complete Prophetic Conduct), also known by the title *Fāḍil Ibn Nāṭiq*. It was written along the lines of Ibn Ṭufayl’s (d. AD 1185) *Ḥayy Ibn Yaqẓān*. In it, Ibn al-Nafīs imagines the generation – inside a cave on a deserted island – of a human being. The author guides the reader to the way in which this lone

human being would arrive at the discovery of science and philosophy, then the knowledge of prophecies, and particularly the *Sīra* (conduct) of the Prophet Muḥammad, and the legal doctrines of Islam.

In his old age, Ibn al-Nafīs bequeathed his own house, including an extensive private library, to the Qalāwūn Hospital, founded in AD 1284 by Sultan Qalāwūn (r. AD 1279–1290). Ibn al-Nafīs died in his 80s, a bachelor who devoted all his time to the practice of medicine on which he wrote several books. He died on 17th December 1288 (11th Dhu'l-Qa'dah 687).

See Also

- [al-Rāzī](#)
- [Ibn Sīnā \(Avicenna\)](#)

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Ibn al-Quff (al-Karakī)

Sami K. Hamarneh

Abū'l-Faraj ibn Ya'qūb ibn Ishāq Ibn al-Quff al-Karakī was born on the 22nd of August 1233, in the city of Karak (hence the name al-Karakī) in the district of Transjordan in larger Syria (*Bilād al-Shām*). The first and most intimate biography, by a friend of al-Karakī's family, was by Abū'l-Faraj's first teacher in the healing art – the prominent physician and historian of medicine Ibn Abī Uṣaybi'ah (d. 1270). The meeting between al-Karakī's family and Uṣaybi'ah took place in Ṣarkhad, Syria. As Uṣaybi'ah was the physician-counselor to the governor (*wālī*) of Ṣarkhad and the entire province, al-Karakī's family moved from Karak north to Ṣarkhad. The father was summoned by the governor to serve as a secretary to the Department of Welfare (*dīwān al-birr*). A very close friendship developed between the physician as a leading and resourceful practitioner, and Ya'qūb al-Karakī as an able secretary, adviser, historian, linguist, and man of letters.

At that time, the son Abū'l Faraj was 11 or 12 years of age, a bright fellow who had acquired the basics in education in Karak. The father asked the physician if he would teach his son the healing art, and Uṣaybi'ah willingly accepted the challenge. He soon taught him the basics of the field: the theory and practical aspects of medicine, methods of treatment, and the identification of causes and symptoms of diseases.

The major texts which were studied included some of the writings of Hippocrates (known as the Hippocratic *corpus*, such as the *Aphorisms and Prognoses*) and some of the medically important catechisms, such as *Al-Masā'il* by ► [Hunayn ibn Ishāq](#) (809–873), and the major writings of ► [al-Rāzī](#) (Latin Rhazes, 865–925), particularly the clinical and therapeutic texts.

After the fall of the Ṣarkhad province into the hands of the Ayyūbid King, al-Ṣāliḥ Najm al-Dīn (1245–1249), al-Karakī's family moved to Damascus (the Syrian capital of the Ayyūbids)

where the father was promoted to a higher position. The son continued his study under some of the most illustrious physicians at the time. Damascus had great hospitals, including the hospital located in the Citadel for the Royal family, civil servants, and army personnel. There Ibn al-Quff had his training to become a physician.

This medieval period had witnessed great cultural, political, and technoscientific changes. There was the fall of the prestigious Fātimid (Shī'ite) dynasty in Cairo, and the rise of the Ayyūbid (Sunnite) dynasty in Cairo and Damascus under the leadership of Sultān Ṣalāḥ al-Dīn (Saladin, r. 1171–1193) and his successors. There was also the rise of the *Bahri Mamluks* (slave sultans 1250–1381). However, the true founder of the “Slave” dynasty was Sultān al-Zahir Baybars (d. 1277), who was first purchased to serve in the Ayyūbid army and then became their ruler. During this time, the healing arts reached new heights.

Having had excellent training and having become a worthy practitioner-surgeon, Ibn al-Quff was summoned in about 1262 (at the age of 29) to be the physician-surgeon in 'Ajlūn, his home country in Transjordan. There he served the profession for a decade, at the end of which he published his first medical encyclopedia *Al-Shāfī al-Ṭibb* (The Comprehensive of the Healing Arts), completed in early 1272. It is composed of 12 treatises encompassing the entire medical field. It was a significant contribution to the field at the time and contained many timely observations and innovations.

From 'Ajlūn, al-Karakī was summoned to the Syrian capital, Damascus. There he served at its Citadel and hospital from 1272 until his untimely death in early July 1286 at the age of 52. We know that many medical students came to hear his lectures and listen to his eloquence. He also continued to fulfill his duty in caring for the sick and the wounded and continued his research and publications. Among these are two commentaries: one on the Hippocratic *Aphorisms*, entitled *al-Uṣūl*, edited in Cairo, and the other a commentary on the generalities of the *Qānūn* of Ibn Sīnā (d. 1037). The last *Sharh* was complete about 1274.

His other work is *Jamī' al-Gharāḍ*, on preventive medicine and the preservation of health in 60 chapters, completed about 1275. It is extant in several manuscripts. This is possibly the finest work of its kind in medieval times, and it needs translation into English for wider audiences.

Al-Karakī's best and most renowned manual is *al-'Umdah* on surgery. It was published in Hyderabad, India, in 1356 AH/1937 and ranks second after *al-Taṣrīf* (The Thirtieth Treatise) by al-Zahrāwī (Abulcasis, ca. 939–1013).

Only recently have al-Karakī's literary contributions begun to draw wider recognition. His writings should place him among the greatest physician-surgeons and public health experts during the Arab-Islamic Golden Age.

See Also

► [Ibn al-Majūsī](#)

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Ibn al-Raqqām

Julio Samsó

Muḥammad ibn al-Raqqām al-Andalusī (d. 1315) was an Andalusian astronomer, mathematician, and physician. He was probably born in Murcia and left the city when it was conquered by ► [Alfonso X](#) in 1266. He lived in Bejaia (Algeria), Tunis and, after 1280, accepted the invitation of Muḥammad II (1273–1302) and established himself in Naṣrid Granada where he taught mathematics and astronomy (as well as medicine and law). Among his students in astronomy we find king Naṣr (1309–1314). His son, Ibrāhīm ibn Muḥammad ibn al-Raqqām, was an astrolabe maker: one of his instruments (made in Guadix in 1320) is still preserved in Madrid.

Among his extant works we should mention his *Risāla fī ‘Ilm al-Zilāl* (Treatise on the Science of Shadows) as well as two sets of astronomical tables (*zīj*es), the first of which was probably compiled in Bejaia in 1280–1281, while the second was made in Tunis and later adapted to the coordinates of Granada. His book on *Shadows* is a brilliant treatise on Gnomonics where Ibn al-Raqqām explains how to build all kinds of sundials (among which we find a portable sundial which includes a compass) using projections on a plane which, ultimately, derive from Ptolemy’s *Analemma*. The first of his *zīj*es, entitled *al-Zīj al-Shāmīl fī Tahdhīb al-Kāmil* (A General Set of Astronomical Tables in which [Ibn al-Hā’im’s] Kāmil ► [Zīj](#) is Corrected), follows narrowly the theoretical contents of Ibn al-Hā’im’s *al-Zīj al-Kāmil fī l-Ta’ālīm* to which Ibn al-Raqqām adds

the numerical tables which had been lost in the manuscript of Ibn al-Hā’im’s work. His second *zīj al-Zīj al-Qawīm fī Funūn al-Ta’dīl wa-l-Taqwīm* (The Solid Handbook to Calculate Equations and Planetary Positions) is a summary and adaptation of the first one to the coordinates of Tunis and Granada. Both works bear witness to the diffusion of Ibn al-Zarqāllu’s astronomical ideas in the Maghreb and Andalusia.

See Also

- [Alfonso X](#)
- [Ibn al-Zarqāllu](#)
- [Sundials in China](#)
- [Zīj](#)

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Ibn al-Shāṭir

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Ibn al-Shāṭir, ‘Alā’ al-Dīn ‘Alī ibn Ibrāhīm, was born in Damascus ca. 1305. He was the most distinguished Muslim astronomer of the fourteenth century. Although he was the head *muwaqqit* at the Umayyad mosque in Damascus,

responsible for the regulation of the astronomically defined times of prayer, his works on astronomical timekeeping are considerably less significant than those of his colleague al-Khalīlī. On the other hand, Ibn al-Shāṭir made substantial advances in the design of astronomical instruments. Nevertheless, his most significant contribution to astronomy was his planetary theory.

In his planetary models Ibn al-Shāṭir incorporated various ingenious modifications of those of Ptolemy. Also, with the reservation that they are geocentric, his models are the same as those of Copernicus. Ibn al-Shāṭir's planetary theory was investigated for the first time in the 1950s, and the discovery that his models were mathematically identical to those of Copernicus raised the very interesting question of a possible transmission of his planetary theory to Europe. This question has since been the subject of a number of investigations, but research on the astronomy of Ibn al-Shāṭir and his sources, let alone on the later influence of his planetary theory in the Islamic world or Europe, is still at a preliminary stage.

Ibn al-Shāṭir appears to have begun his work on planetary astronomy by preparing a *zīj*, an astronomical handbook with tables. This work, which was based on strictly Ptolemaic planetary theory, has not survived. In a later treatise entitled *Ta'liq al-arṣād* (Comments on Observations), he described the observations and procedures with which he had constructed his new planetary models and derived new parameters. No copy of this treatise is known to exist in the manuscript sources. Later, in *Nihāyat al-su' l fī taṣḥīḥ al-uṣūl* (A Final Inquiry Concerning the Rectification of Planetary Theory), Ibn al-Shāṭir presented the reasoning behind his new planetary models. This work has survived. Finally, Ibn al-Shāṭir's *al-Zīj al-jadīd* (The New Astronomical Handbook), extant in several manuscript copies, contains a new set of planetary tables based on his new theory and parameters.

Several works by the scholars of the mid-thirteenth century observatory at Maragha are mentioned in Ibn al-Shāṭir's introduction to this treatise, and it is clear that these were the main sources of inspiration for his own non-Ptolemaic planetary models.

The essence of Ibn al-Shāṭir's planetary theory is the apparent removal of the eccentric deferent and equant of the Ptolemaic models, with secondary epicycles used instead. The motivation for this was at first sight aesthetic rather than scientific, but his major work on observations is not available to us, so this is not really verifiable. In any case, the ultimate object was to produce a planetary theory composed of uniform motions in circular orbits rather than to improve the bases of practical astronomy. In the case of the sun, no apparent advantage was gained by the additional epicycle. In the case of the moon, the new configuration to some extent corrected the major defect of the Ptolemaic lunar theory, since it considerably reduced the variation of the lunar distance. In the case of the planets, the relative sizes of the primary and secondary epicycles were chosen so that the models were mathematically equivalent to those of Ptolemy.

Ibn al-Shāṭir also compiled a set of tables displaying the values of certain spherical astronomical functions relating to the times of prayer. The latitude used for these tables was 34° , corresponding to an unspecified locality just north of Damascus. These tables display such functions as the duration of morning and evening twilight and the time of the afternoon prayer, as well as standard spherical astronomical functions.

Ibn al-Shāṭir designed and constructed a magnificent horizontal sundial that was erected on the northern minaret of the Umayyad Mosque in Damascus. The instrument now on the minaret is an exact copy made in the late nineteenth century. Fragments of the original instrument are preserved in the garden of the National Museum, Damascus. Ibn al-Shāṭir's sundial, made of marble and a monumental 2×1 m in size, bore a complex system of curves engraved on the marble which enabled the *muwaqqit* to read the time of day in equinoctial hours since sunrise or before sunset or with respect to either midday or the time of the afternoon prayer, as well as with respect to daybreak and nightfall. The gnomon is aligned towards the celestial pole, a development in gnomonics usually ascribed to European astronomers.

A much smaller sundial forms part of a compendium made by Ibn al-Shāṭir, now preserved in Aleppo. It is contained in a box called *Ṣandūq al-yawāqīt* (jewel box), measuring $12 \times 12 \times 3$ cm. It could be used to find the times (*al-mawāqīt*) of the midday and afternoon prayers, as well as to establish the local meridian and the direction of Mecca.

Ibn al-Shāṭir wrote on the ordinary planispheric astrolabe and designed an astrolabe that he called *al-āla al-jāmiʿa* (the universal instrument). He also wrote on the two most commonly used quadrants, the astrolabic and the trigonometric varieties. Two special quadrants which he designed were modifications of the simpler and ultimately more useful sine quadrant. One astrolabe and one universal instrument actually made by Ibn al-Shāṭir survive.

A contemporary historian reported that he visited Ibn al-Shāṭir in 1343 and inspected an “astrolabe” that the latter had constructed. His account is difficult to understand, but it appears that the instrument was shaped like an arch, measured three-quarters of a cubit in length, and was fixed perpendicular to a wall. Part of the instrument rotated once in 24 h and somehow displayed both the equinoctial and the seasonal hours. The driving mechanism was not visible and probably was built into the wall. Apart from this obscure reference, we have no contemporary record of any continuation of the sophisticated tradition of mechanical devices that flourished in Syria some 200 years before his time.

Ibn al-Shāṭir died in Damascus ca. 1375. Later astronomers in Damascus and Cairo, none of whom appears to have been particularly interested in his non-Ptolemaic models, prepared commentaries on, and new versions of, his *zīj*. In its original form and in various recensions, this work was used in both cities for several centuries. His principal treatises on instruments remained popular for several centuries in Syria, Egypt, and Turkey, the three centers of astronomical time-keeping in the Islamic world. Thus, his influence in later Islamic astronomy was widespread but, as far as we can tell, unfruitful. On the other hand, the reappearance of his planetary models in the writings of Copernicus strongly suggests the

possibility of the transmission of some details of these models beyond the frontiers of Islam.

See Also

- [Astronomical Instruments in the Islamic World](#)
- [al-Jazarī](#)
- [al-Khalīlī](#)
- [Zīj](#)

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Ibn al-Yāsamīn

Ahmed Djebbar

The name of this mathematician is Abū Muḥammad ‘Abdallāh ibn Muḥammad ibn Hajjāj al-Adrīnī, more commonly known as Ibn al-Yāsamīn. As his name indicates, he was originally from a Berber tribe from the Maghreb (North Africa), and, according to Ibn Sa‘īd, he was black like his mother. We know nothing about the exact date of his birth, but can reasonably place it in the second half of the twelfth century. We also know nothing specific about his place of birth, which could have been in the Andalus (Spain) or the Maghreb. But since some historians have given him the surname al-Ishbīlī, he may have been born or grown up in Seville. In any case, Ibn Sa‘īd states that his formative education occurred in Seville.

This education was not restricted to mathematics, since we know he also became famous

in the fields of law and literature, particularly in the Andalusian poetry of the Muwashshahāt. That being said, however, we know nothing of the context in which he received this rich education nor of his teachers. The only information we have is from Ibn al-Yāsamīn himself about one of his professors, Abū ‘Abdallāh Muḥammad ibn Qāsim al-Shalūbīn, who taught him algebra and the science of calculation.

We also do not know exactly when Ibn al-Yāsamīn began to publish his mathematical writings. Ibn al-Abbār tells us only that Ibn al-Yāsamīn’s famous algebraic poem was drafted in Seville and that, in 1190 also in Seville, he was using it in his teaching.

Concomitant with his mathematical activities was Ibn al-Yāsamīn’s dedication to poetry, and according to Ibn Sa‘īd, some of his poems had even been set to music and sung at this time. It may have been his literary success which led to his frequenting the court of the third Almohad caliph Abū Yūsuf Ya‘qūb (1184–1199) and of his successor Muḥammad al-Nāṣir (1199–1213). These frequent court visits and the fame of his literary and mathematical publications probably gained Ibn al-Yāsamīn some enemies. Also some of his contemporaries accused him of leading a dissolute life. But none of these can be seen as the cause of his assassination in 1204 in Marrakesh.

The Mathematical Writings of Ibn al-Yāsamīn

The best-known work of Ibn al-Yāsamīn is a poem of 53 verses in rajaz meter entitled *al-Urjūza al-yāsmīnīyya fī al-jabr wa ‘l-muqābala* (Poem on Algebra and Restoration). In it the author defines the algebra known in his time – number, root, and sequence, then the six canonical equations of ► [al-Khwārizmī](#) with the processes of solving them, and finally, the operations of algebra – the restoration, comparison, multiplication, and division of monomials.

This poem has been widely read throughout the centuries both within the Maghreb and beyond. Thus, there are many commentaries on

it by other famous mathematicians such as ► [Ibn Qunfudh](#) (d. 1407) and ► [al-Qalaṣādī](#) (d. 1486) in the Maghreb, ► [Ibn al-Hā'im](#) (d. 1423) and Sibṭ al-Mārādīnī (d. 1501) in Egypt and elsewhere.

For a long time, the contribution of Ibn al-Yāsamīn to mathematics was known only through his *Urjūza* in algebra. It is quite possible, moreover, that it was the success of this poem which led him to write a second one on irrational quadratic numbers and maybe a third on the method of false position. But the distribution of these last two poems was relatively modest, compared to that of the first one, and aside from the rare copies that exist, we have not yet found any explicit reference to the contents of the two other poems in any works on calculation written after the twelfth century.

The same situation exists for Ibn al-Yāsamīn's fourth written work on mathematics, entitled *Talqīḥ al-afkār bi rushūm Ḥurūf al-ghubār* (Fertilization of Thoughts with the Help of Dust Letters [Hindu Numerals]). This work is much more important than his poems, as much in quantity as in quality. Indeed, it is a book of 200 folios which contains classic chapters on the science of calculation and on geometry. Among the works of the Muslim West which have come down to us, it is the only one which consolidates these two disciplines. Its importance is also due the nature of its materials and its mathematical tools which make it an original book and also one which is totally representative of this period of transition in which three mathematical traditions were juxtaposed – of the East, the Andalus, and the Maghreb – before they became blended in the same mold.

For example, the following elements contribute both to the originality of his work and to its being anchored in the great Arab mathematical tradition of the ninth to eleventh centuries:

In arithmetic, contrary to the Maghrebian tradition which prevailed from the fourteenth century on, Ibn al-Yāsamīn treats multiplication and division first, before addition and subtraction. This approach, which can be found again later in the work of Ibn al-Zakariyā' al-Gharnāfi, seems to be based on Andalusian mathematical practice.

For fractions, the remarks and suggestions of Ibn al-Yāsamīn concerning the reading of certain expressions demonstrate that the symbolism of fractions had not been established definitively in his time. This was not the case, it appears, for the symbolism of equations which had been established relatively early, since there is no difference between the symbols used in the *Talqīḥ al-afkār* of Ibn al-Yāsamīn and those used in the *Bughyat at-tullāb* (The Hope of Students) of Ibn Ghāzī al-Miknāsī (d. 1513).

As for the presence of geometry in a work on the science of calculation, this is not exceptional in regard to the Arab mathematical tradition, viewed in its entirety, in so far as similar chapters (i.e., chapters which deal with problems in metric geometry) had already been inserted in works edited in the East, such as the *Takmila fi l-hisāb* (Complement to Calculus) of 'Abd al-Qāhir al-Baghdādī or the *Kitāb al-Kāfi* (The Sufficient Book) by ► [al-Karajī](#).

In spite of what we have noted about the contents of *Talqīḥ al-afkār*, there has not been any explicit reference to the book in Maghrebian mathematical writing. There could be at least two possible explanations for this. First, a break in the tradition whose cause is to be found outside the scientific milieu of that time. This hypothesis is not implausible if one takes into account the personality of Ibn al-Yāsamīn and his controversial behavior and also his close ties to Almohad power.

The second reason, which is also plausible and which can be added to the first, can be found in mathematical practice after Ibn al-Yāsamīn, a practice which bore the strong imprint of mathematicians from Marrakesh, like Ibn Mun'im (d. 1228), al-Qāḍī al-Sharīf (d. 1282–1283), and ► [Ibn al-Bannā'](#) (d. 1321). We have observed this same phenomenon of the absorption of a mathematical tradition first in the East with the first written Arab arithmetical works from the ninth century and, in particular, with the work of ► [al-Khwārizmī](#), and then in the Andalus with writings of the tenth century, like those of ► [al-Majrīṭī](#) and his pupils.

See Also

- [al-Karajī](#)
- [Al-Majrīfī](#)
- [Ibn al-Bannā](#)

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Ibn Al-Zarqāllu

Emilia Calvo

Ibn al-Zarqāllu, Abū Ishāq Ibrāhīm ibn Yaḥyā al-Naqqāsh, sometimes known as Azarquiel, was born in the first quarter of the eleventh century to a family of artisans. He entered the service of the *qāḍī* (judge) Ṣāʿid of Toledo first as an artisan, and after as the director of a group which carried out astronomical observations. Ibn al-Zarqāllu lived in Toledo until ca. AD 1078, when he moved to Cordoba where he composed his last works under the patronage of the king of Sevilla al-Muʿtamid ► [ibn ʿAbbād](#) and where he died in AD 1100. His work exerted

considerable influence on later authors such as ► [Ibn al-Kammād](#), Abū'l-ḥasan ʿAlī Ibn al-Bannā, Abraham ibn ʿEzra, ► [Ibn al-Hāʾim](#), Ibn Ishāq, and Ibn Bāṣo.

Ibn al-Zarqāllu's works are basically astronomical, although an astrological treatise by him is also extant. Other works of Ibn al-Zarqāllu are described below:

The *Almanac* is a reelaboration by Ibn al-Zarqāllu of the work of an unknown author called Awmātiyūs. It allows the determination of planetary longitudes, without computation, by combining Ptolemaic parameters with the Babylonian doctrine of the goal-years. The goal-years consisted of cycles peculiar to each planet. These cycles included an entire number of solar years which, in turn, comprised an exact number of synodic and zodiacal revolutions. These cycles were known by the Babylonian astronomers, and they are also found in Ptolemy's *Almagest*. The advantage of these cycles for astronomers is that the positions of the planets can be calculated for a complete cycle which will be repeated, so these positions will always be the same for a given date within the cycle.

Treatise on the Motion of the Fixed Stars is preserved in a Hebrew translation. It is probably the most complete medieval text on the trepidation theory. Trepidation consists of a back-and-forth vibration within fixed limits, which is supposed to account for the variation in velocity of the slow eastward motion observed in the fixed stars. The treatise proposed three different geometrical models to demonstrate this theory.

Fīsanat al-šams (On the Solar Year) was probably written between AD 1075 and 1080 and based on 25 years of solar observations. Here Ibn al-Zarqāllu established the proper motion of the solar apogee to be of 1° in 279 Julian years. The text is lost but it can be reconstructed from the works of later astronomers like Ibn al-Kammād, Ibn al-Hāʾim, Ibn Ishāq, ► [Ibn al-Raqqām](#) and ► [Ibn al-Bannā](#).

Risālat al-ṣafīḥa al-zarqāliyya (Treatise on the Zarqāliyya Plate) and *Risālat al-ṣafīḥa al-shakkāziyya* (Treatise on the Shakkāziyya Plate) are two treatises on the use of a universal astrolabe called *Ṣafīḥa* (plate). There is an Alphonsine translation in the *Libros del Saber de Astronomia* of the treatise on the use of the *Ṣafīḥa zarqāliyya*.

This instrument offers the possibility of making calculations for any given latitude by means of only one plate.

Kitāb al-ʿamal bi'l-ṣafīḥa al-zījīyya (Treatise on the Plate for the Seven Planets) describes the equatorium, an instrument consisting of the representation, drawn to scale, of a planetary model, which is used to determine the position of a planet at a given moment. Both his treatise on its construction and his treatise on its use are extant.

He also took an active part in the elaboration of the *Toledan Tables* which seem to have been the result of the work of a group of astronomers directed by the *qāḍī* Ṣāʿid.

Finally, he was probably the author of a treatise on the construction of the armillary sphere, translated or adapted by Ishāq ibn Sīd, which was incorporated into the Alphonsine *Libro de las Armellas*.

See Also

- [Abraham Ibn Ezra](#)
- [Armillary Spheres in India](#)
- [Astrolabe](#)
- [Ibn al-Bannāʾ](#)
- [Ibn al-Hāʾim](#)
- [Ibn al-Kammād](#)

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Ibn Baṭṭūṭa

Bilal Ahmad

Ibn Baṭṭūṭa (1304–1369) was the greatest Muslim traveler of his time. He was born in Tangier to a well-educated Moroccan family that produced many judges. After receiving basic education in his home town, at age 21 he headed toward Mecca both to make a pilgrimage and to study under some notable Muslim scholars in Egypt, Syria, and Hejaz. After reaching Egypt via Tunis and Tripoli, he decided to become a traveler to gain firsthand knowledge about as many parts of the world as possible. Ibn Baṭṭūṭa's fascination for travel took him to Syria, Iraq, southern Iran, and Azerbaijan. He then decided to spend the next 3 years (1327–1330) in the holy towns of Mecca and Medina in Hejaz. Ibn Baṭṭūṭa's next expedition (1330–1332) started from the seaport of Jidda. He sailed across the Red Sea to Yemen, traveled across Yemen by land, and from Aden he sailed along the coast to various trading ports of East Africa. On his way back, he turned his boat to the Persian Gulf area and concluded this trip by another pilgrimage to Mecca.

Ibn Baṭṭūṭa's travels were supported by the contributions of the rulers, governors, and other prominent residents of the places that he visited. After hearing of the benevolence of Muḥammad bin Tughlaq – the ruler of Delhi, India – Ibn Baṭṭūṭa decided to go to India. This time he adopted a very unusual route: by moving northward, he first passed through Egypt and Syria; he

then traveled extensively in Anatolia (Asia Minor) and the territories of the Golden Horde where he was well received by the local sultans and other prominent people. Ibn Baṭṭūṭa's *Riḥlah* (Book of Travels) provides a clear and lucid picture of Constantinople, Saray (the capital of the Khan of the Golden Horde), and other Sultanates. After crossing the Steppes with a caravan, Ibn Baṭṭūṭa passed through the towns of Bukhara, Samarkand, Balkh, and Herat. He then crossed the Hindu Kush Mountains and visited many important towns and cities in the Indus Valley – particularly Sukkur, Multan, and Lahore – before he finally reached Delhi. Sultan Muḥammad bin Tughlaq received him with respect and presents. The Sultan also appointed him the chief justice of Delhi. Ibn Baṭṭūṭa enjoyed the patronage of the Sultan for several years.

In 1342, he appointed Ibn Baṭṭūṭa the ambassador to China. After his ship wrecked near Calicut on the Malabar Coast of India, he decided to go to the Maldives where he married into the royal family. In the following years, Ibn Baṭṭūṭa visited Sri Lanka (Ceylon), supported the Sultan of the Maldives in a war, went again to the Maldives, and visited Bengal, Assam, and Sumatra. The Sultan of Sumatra provided him with a new ship to go to China. He arrived at the Chinese port of Zaytun and reached Beijing via the inland waterways. On his return journey, he eventually reached Mecca via Sumatra, Calicut, the Persian Gulf, Baghdad, Syria, and Egypt. Ibn Baṭṭūṭa's narrative for this entire journey is sketchy and some scholars doubt that he ever reached Beijing.

In April to May of 1349, Ibn Baṭṭūṭa embarked for his home from Alexandria via Tunis, Sardinia, and Algeria. He eventually reached Fez (Morocco), from where he went to the Kingdom of Granada, in Spain. His next destination was western Sudan. After traveling across the Sahara, he visited the Empire of Mali and returned to retire in Fez.

Ibn Baṭṭūṭa was an outstanding adventurer. His education and experience earned him numerous honors and awards, including the position of judge in many parts of the Muslim world. After

his retirement, he again held the office of *qāḍī* (judge) in a Moroccan town and dictated his recollections to Ibn Juzayy – a royal poet. Ibn Baṭṭūṭa's *Riḥlah* is a valuable document for understanding the ways of life in the fourteenth-century Muslim world.

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Ibn Buṭlān

Roger Arnaldez

Abū'l-ḥasan al-Mukhtār ibn 'Abdūn ibn Sa'dūn Ibn Buṭlān was a physician, philosopher, and Christian theologian from Baghdad (eleventh century). He had for a teacher a Nestorian priest, Abū'l-Faraj ibn al-Ṭayyib, a commentator on Aristotle, Hippocrates, and Galen, who was interested in botany and wrote on the humors, wine, and natural qualities. Teaching at the hospital founded in Baghdad by 'Aḍud al-Dawla, he directed his pupil in reading and the use of several medical works. He taught him so well that later, Ibn Buṭlān, in a controversy with the physician ► [Ibn Riḍwān](#), maintained that one could understand the basic precepts of medicine by simply reading books.

On the subject of the *al-Masāʾil fiʾl-Ṭibb fiʾl-Mutaʿāllimīn* (Questions on Medicine for Students) by ► [Ḥunayn ibn Ishāq](#), he believed that Ibn Riḍwān, who had refuted it, had not understood it at all, “because he didn’t study it under the direction of masters in this art.” That is why, in spite of his great knowledge of the works of the Ancients, he refused to conform blindly and to the letter. Also he asked why clear-sighted doctors had lost the habit of caring for certain maladies, as the Ancients had done, with warm medicines, and preferred to use cold ones. It seems also that Ibn Buṭlān was instructed in the practice of medicine by Abūʾl-ḥasan Thābit ibn Ibrāhīm al-ḥarrānī, about whom many praises were said.

Ibn Buṭlān left Baghdad, crossed Syria, and arrived in Egypt, where he undertook several polemics with Ibn Riḍwān. These covered diverse subjects, touching in particular the philosophical questions and ideas of Aristotle concerning place, movement, and the soul on which Ibn Riḍwān had commented before. He returned to Constantinople, where he arrived in 446/1054, at the time of the schism which would eventually separate the Greek from the Latin church. The patriarch Michel Cérulaire asked him to edit a treatise on the Eucharist and the use of bread without leavening. That was also the year when a terrible epidemic of the plague broke out in the capital of the Byzantine Empire. Ibn Buṭlān kept a diary and cited the names of several savants who had succumbed to it. After this he went to Antioch where he directed the establishment of a hospital. Eventually he retired from traveling, and died in 460/1068.

His work is very diverse, covering theology, philosophy, logic, and medicine. His interpretation of the work of the Ancients is original and animated by a critical spirit. He relied on logic and the grammar of languages, and attempted to explain apparent opposition by showing that they had very different points of view. Thus Aristotle studied organic forces relative to their nature, while Galen did so relative to their perceptible action in the organs which were their instruments. Aristotle divided the organs according to their

physical constitution, Galen in relation to the illnesses which affected them. In the same way, with regard to the “egg yolk” color of bile, Ibn Buṭlān tended to agree with Galen who explained it by the predominant action of heat, which rends the bile hotter and lighter. On the other hand, Ḥunayn ibn Ishāq explained it as the result of a mixture of bile and phlegm. These differences can be explained by the ambiguity of the term *muḥḥ*, which signifies at the same time both the egg yolk alone and the entire interior of the egg, both the yellow and the white.

Ibn al-Qifṭī retained for us a list of the problems that Ibn Buṭlān posed. For example, he wondered about the chemical nature of the force of physical attraction between lovers. In the field of physiology, he questioned why it is that when men dream they are urinating, they wake themselves up without urinating in their beds, while when they dream of a sexual encounter, there is an emission of sperm. He wondered why this was so, when you consider how much easier it is to urinate than to ejaculate when one is awake.

Ibn Buṭlān’s most important medical work is the *Taqwīn al-ṣiḥḥa* (Strengthening of Health), a treatise on hygiene dedicated to general questions on the four elements, the humors, and the temperaments. The author studied the nature and value of nutrition, as well as the influence of the environment, water, climate, and housing on health. The originality of the work lies in its form: it is presented in small tableaux. It was translated into Latin and German. Another noteworthy work is *Daʿat al-Aṭibbā* (The Physician’s Banquet), on the subject of medical ethics, which included a satire on charlatans and ignorant physicians. There is also a treatise on the maladies caused by food, with recommended remedies used by monks. Finally, there is a treatise devoted to a discussion of whether a chicken is hotter than a smaller bird.

See Also

- [Ḥunayn ibn Ishāq](#)
- [Ibn Riḍwān](#)

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Ibn Ḥawqal

Emilia Calvo

Ibn Ḥawqal al-Nasibī Abū'l-Qāsim Muḥammad ibn 'Alī was born in Nisibis (now Nusaybin, Turkey) in the second half of the tenth century. He worked as a merchant and traveled, beginning in AD 943, through the Muslim world, visiting the Maghreb and Andalusia between 947 and 951; Egypt, Armenia, and Azerbaijan around AD 955; Iraq, Persia, Transoxiana, and Khwarazm between 961 and 969. In AD 973, he was in Sicily.

Ibn Ḥawqal is the author of a book on geography entitled *Kitāb al-masālik wa'l-mamālik* (Book on the Routes and Kingdoms), also known as *Kitāb Ṣūrat al-'arḍ*, which belongs to the category of the so-called *Atlas of Islam*. It consists of a description of the Islamic countries, although some non-Islamic regions of Sudan, Turkey, Nubia, and Sicily are also described.

Ibn Ḥawqal based his work on al-Iṣṭakhrī's book and incorporated new material from his travels which led to three successive revisions of his *Kitāb al-masālik*: the first one in AD 967, dedicated to Sayf al-Dawla; the second ca. AD 977, and the third ca. 988. The final result was a book whose descriptive part surpassed the works of earlier authors.

From the contents of his work, his sympathy with the Fāṭimid movement can be deduced. He showed a certain interest toward Fāṭimid politics, although he cannot be considered a Fāṭimid *dā'ī* (propagandist). He also gives economic information. His interests are focused not on rare or precious goods but on basic agricultural and artisanal products.

Ibn Ḥawqal's *Kitāb al-masālik* influenced the work of later geographers such as Abū'l-Fidā. He is also the author of a book on Sicily which is not preserved.

See Also

- [Balkhī School of Arab Geographers](#)
- [Geography in China](#)

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Ibn Hubal

E. Ruth Harvey

Muhadhdhib al-Dīn Abū'l-ḥasan 'Alī ibn Aḥmad ibn 'Āli ibn Hubal al-Baghdādī was a famous physician, medical authority, and accomplished poet. Born in Baghdad in 1121 (AH 515), he migrated to Khilat (modern Ahlat, on the shore of Lake Van, Turkey), and became very prosperous in the service of the local ruler. He later moved to Mardin to serve another lord, and died at Mosul (in modern Iraq) in 1213 (AH 610). His chief work, *Kitāb al-Mukhtār fī al-Ṭibb* (The Choice Book of Medicine), was written in about 1165. It resembles the medical encyclopedias of Ibn Sīnā and ► [al-Rāzī](#) in that it is a compendium of Galenic medical knowledge, supplemented by personal clinical practice. *The Choice Book* is divided into three main parts, comprising anatomy and general principles, a pharmacopoeia, and a list of maladies arranged according to the affected organs, running from head to foot. Although this large book does not seem to have been translated into Latin during the Middle Ages, the number, diffusion, and varying ages of the manuscript copies attest to its popularity. No copy appears to survive of Ibn Hubal's *Kitāb al-Ṭibb al-Jamālī* (Book of Medicine for Jamal al-Din al-Wazir). A short work on logic, *al-Ārā' wa'l-mushāwarāt*, in manuscript in Paris (B.N. MS 2348) is ascribed to him.

The manuscripts of *The Choice Book* in Leiden, Paris, Cairo, and India are listed in Brockelmann; there are also several copies in Turkey, and fragmentary ones in Princeton and the British Library in London (the London text starts with the diseases of the brain). The whole Arabic text was edited in Hyderabad 1943–1944, but Albert Dietrich maintains that a proper critical edition is still badly needed. Two chapters of Ibn Hubal's medical encyclopedia were

published from the Leyden manuscript with an accompanying French translation; they describe the causes, symptoms, and treatment of stones in the kidneys and bladder. Ibn Hubal employs the usual medieval medical terminology derived from earlier Greek physicians: four fluids, or humors, within the body (blood, phlegm, choler (yellow bile), and melancholy (black bile)) are held to constitute in their balance and proportions the essential foundations of good health; pain and disease reveal an evil condition or imbalance among the fluids. Most remedies and treatments consist of trying to correct the malfunctioning fluid through diet, bleeding, or alteration of the patient's physical surroundings. In spite of what we might today consider the erroneous basis of his theoretical approach, Ibn Hubal shows an impressive concern for personal observations and clearly relies on extensive clinical practice. In discussing stones, for instance, he attributes the condition to excessive bodily heat which causes phlegm, a "thick fluid," to form deposits in the kidneys and bladder. He prescribes medicines such as horseradish, ginger, and chicken soup to break up the stones or cause them to be passed. He also cites his own personal experience of a more desperate remedy which he witnessed: a surgical operation to remove a bladder stone from a boy. He cites al-Rāzī and Rufus of Ephesus, but conveys the impression of a knowledgeable practical physician, mindful of the agonizing pain caused by the condition he is discussing.

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Ibn Ishāq Al-Tūnisī

Julio Samsó

Abū-l-ʿAbbās Aḥmad ibn ʿAlī ibn Ishāq al-Tamīmī al-Tūnisī was a Tunisian astronomer of the early thirteenth century. He compiled an impressive astronomical handbook with tables (*zīj*) a manuscript of which (copied ca. 1400) was discovered by David A. King. It contains an important set of tables (completed ca. 1218) which mark the starting point of a Maghribian (North Africa) astronomical school. Parts of these tables seem original and are based, according to the famous historian ► [Ibn Khaldūn](#), on observations made by a Sicilian Jew. The rest is a miscellaneous collection of materials which derive from Andalusian sources, many of which seem lost, by ► [Ibn al-Zarqāllu](#) (d. 1100), Ibn Muʿādh al-Jayyānī (d. 1093), ► [Ibn al-Kammād](#) (fl. ca. 1125), ► [Ibn al-Hāʾim](#) (fl. ca. 1204) as well as others. The canons (instructions for the use of the numerical tables) were not written by Ibn Ishāq but by some later author who also used materials derived from the aforementioned Andalusian *zīj*es. Ibn Ishāq's *zīj* is, therefore, a first rate new source for the study of both Andalusian and Maghribian astronomy.

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Ibn Juljul

Emilia Calvo

Ibn Juljul al-Andalusī, Sulaymān ibn Ḥasan, was born in Córdoba in AD 943 and died ca. 994. He studied medicine with a group of Hellenists presided over by Ḥasdāy ibn Shaprūt, a Jewish physician and vizier of the Caliph ʿAbd al-Raḥmān III, and later became the personal physician of Caliph Hishām II (976–1009).

Ibn Juljul is the author of *Ṭabaqāt al-aṭibbāʾ wa ʿl-ḥukamāʾ* (Generations of Physicians and Wise Men), the oldest extant summary in Arabic on the history of medicine (it was finished in AD 987), after Ishāq ibn Ḥunayn's *Taʾrīḥ al-aṭibbāʾ* (History of the Physicians). It contains 57 biographies grouped into nine generations. Thirty-one of them concern Asian authors, and the rest refer to African and Andalusian scholars.

Ibn Juljul used Eastern sources (Hippocrates, Galen, Dioscorides) and Western ones (Orosius, Isidore) and established the chronological limits of the Latin influence on medicine in Andalusia. The work has chronological errors but provides interesting information about the oldest translations into Arabic, in the time of the Caliph ʿUmar II (AD 717–719).

Other works of Ibn Juljul are *Tafsīr asmāʾ al-adwiya al-mufrada min kitāb Diyusqūridūs* (Explanation of the Names of the Simple Drugs from Dioscorides' Book), written in 982, from which only a fragment is preserved, containing the transcription of the Greek names of 317 simple medicines, their translation into Arabic and their identification; *Maqāla fī dhikr al-adwiya al-mufrada lam yadhkurha Diyusqūridūs* (Treatise on the Simples not Mentioned by Dioscorides), which includes 62 simple medicines not mentioned in Dioscorides' *Materia Medica*; *Maqāla*

fī adwiyat al-tiryāq describing the components of the theriac; and *Risālat al-tabyīn fī-mā ghalāṭa fīhi ba'd al-mutaṭabbibīn* (Treatise on the Explanation of the Errors of Some Physicians).

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Ibn Jumay'

Hartmut Fahndrich

A contemporary of the great Jewish doctor and philosopher ► [Moses Maimonides](#), Ibn Jumay', was one of the physicians in the service of Ṣalāh ad-Dīn. He was born of a Jewish family in Fustat (Egypt) and studied with another physician of some renown, 'Ādnān ibn

al-'Aynzarbī (d. 548/1153). The relevant biographical dictionaries mention Ibn Jumay''s talents in medicine as well as his highly developed linguistic consciousness, inducing him always to carry al-Jawharī's *Kitāb aṣ-ṣaḥāḥ* (The Truthful Guide) to class so he could check words of which he was uncertain. Ibn Jumay' died in 594/1198.

In Ibn Abī Uṣaybi'a's dictionary of medical doctors, '*Uyūn al-anbā' fī Ṭabaqāt al-aṭibbā'* (Sources of Information About the Classes of Physicians), Ibn Jumay' is presented as the author of eight works on medical or medicine-related subjects, the most important of them being *Kitāb al-irshād li-maṣāliḥ an-nufūs wa 'l-ajsād* (Guide to the Welfare of Souls and Bodies), a compendium of the different fields of the art of medicine. Others also deal with practical questions of the doctor's craft such as first aid or nutritive advice.

The only one of Ibn Jumay''s works published to date, al-Maqāla aṣ-ṣalāḥīya fī iḥyā 'aṣ-ṣinā 'a aṭ-ṭibbīya (Treatise to Ṣalāh ad-Dīn/Saladin on the Revival of the Art of Medicine), is not mentioned by Ibn Abī Uṣaybi'a. It is a deontological work, i.e., it deals with the doctor's profession on a more theoretical level.

This treatise, as Ibn Jumay' mentions in the introduction, owes its composition to a conversation he had with his sovereign on the deplorable state of medicine in his time, the reasons for this, and ways to ameliorate the situation. Thus, formally the work stands in the literary tradition of the epistle, a genre frequently employed by Ibn Jumay' in other works and by Arabic medical authors in general. Its contents – the complaints about the declining state of the art and considerations about its improvement – were not unknown in his time either. The theme goes back to Galen or even Hippocrates.

The treatise falls into three chapters: Chapter 1 concerns the presentation of medicine, including the qualities of medicine and the need for it, as well as the difficulties of medicine and their consequences; Chapter 2 deals with the reasons for the decline of medicine, including a brief presentation of its history; and Chapter 3 suggests ways to revive the art of medicine.

Whereas compendia of a more technical presentation of medicine in medieval Arabic literature are comparatively numerous, the same cannot be said about this kind of work, with its introductory and deontological character. In that lies the importance of this doctor of the twelfth century AD, Ibn Jumay'.

See Also

- [Medicine in Islam](#)
- [Moses Maimonides](#)

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- and raised in Tunis, he read the *Qurʿān* and studied the religious sciences as well as Arabic and poetry, then was educated in logic, mathematics, natural science, and metaphysics. He also received specialized training in court correspondence and administrative matters, subjects that allowed him to become a court secretary to the Marinid ruler Abū ʿInān in Fez at about the age of 22.
- After some vicissitudes, including almost 2 years of prison, Ibn Khaldūn went to Grenada in 1362 to become an advisor and tutor to Muḥammad V. That position lasted only about 2 years, no longer than his subsequent position as prime minister or *Hājib* to Prince Abū ʿAbd Allāh of Bougie. Following these forays into practical politics, Ibn Khaldūn endured several years of upheaval (1366/1766–1375/1776), settled for about 4 years in Qal ʿat Ibn Salāma near Oran and began work on his history, then moved to Tunis under the patronage of Abū al-ʿAbbās in order to have access to documents and libraries. After a few years there, court intrigues led him to seek tranquility in Egypt.
- During the next quarter of a century he served the Mamlūk Sultān Barqūq as judge (*qāḍī*) and chief judge (*qāḍī al-quḍā*), professor at various universities (including the prestigious al-Azhar), and one time university president. A few years before his death he met with the famous Mongol chieftain Tamerlane. But the period in Egypt was, above all, a time for revising his *Kitāb al-ʿIbar* and working on the Introduction (*Muqaddima*) to it.

Ibn Khaldūn

Charles E. Butterworth

ʿAbd al-Raḥmān ibn Khaldūn (1332/1732–1406/1808) spent the first two-thirds of his life in North Africa and Muslim Spain, fleeing in 1382/1784 to Egypt, where he remained until his death. Though he is best known for the lengthy Introduction (*Muqaddima*) to his massive philosophical history of civilization (*Kitāb al-ʿIbar*), Ibn Khaldūn spent much of his life in political activities. Born

The *Kitāb al-ʿIbar* is a multivolume effort that, in his words, sets forth “the record of the beginning and the suite of the days of the Arabs, Persians, Berbers, and the most powerful of their contemporaries.” Its Introduction consists of six very long chapters that explore the character of human civilization in general and Bedouin civilization in particular, as well as the basic kinds of political associations, and then the characteristics of settled civilization, the arts and crafts by which humans gain their livelihoods, and, finally, the different human sciences. Ibn Khaldūn starts by

explaining the merit of history and how to go about writing it. Properly speaking, the reason to write history or the “inner meaning of history” is, by means of reflection, to get “at the truth, subtle explanation of the causes and origins of existing things, and deep knowledge of the how and why of events.” Though his enterprise is therefore “rooted in philosophy” and to be considered a branch of it, Ibn Khaldūn acknowledges a problem with the way history has come down. Many unqualified people have trammelled with the books of history written by competent Muslim historians; they have introduced tales of gossip imagined by themselves as well as false reports. Moreover, other historians have compiled partial reports of particular dynasties and events without looking to the way things have changed over time, without looking at natural conditions and human customs. Consequently, Ibn Khaldūn considers his task to be that of showing the merit of writing history, investigating the various ways it has been done, and showing the errors of previous historians. What needs to be known, and thus what he sets out to make known, are “the principles of politics, the nature of existent things, and the differences among nations, places and periods with regard to ways of life, character, qualities, customs, sects, schools, and everything else ... plus a comprehensive knowledge of present conditions in all these respects ... complete knowledge of the reasons for every happening and ... [acquaintance] with the origin of every event.” Yet in the end Ibn Khaldūn hints that he has almost digressed in the whole undertaking. What he wanted to do was to explain the nature of civilization and its accompanying accidents, but he fears he has strayed from his basic point.

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Ibn Khurdādhbih

Sayyid Maqbul Ahmad

Abu'l-Qāsim 'Ubayd Allāh ibn Khurdādhbih (also spelled Ibn Khurradādhbih), the first scholar to write on world geography in Arabic, was born in ca. AH 205/AD 820 (or AH 211/AD 825), and died in ca. AH 300/AD 912. Probably born in Khurāsān, he was brought up in Baghdad. His grandfather, Khurdādhbih, was a Zoroastrian, latter converted to Islam, and his father was the governor of Ṭabaristān. When he grew up, he became the director of posts and information in Jibāl (Media) and subsequently became director-general of the same department in Baghdad and later in Sāmarrā (Iraq). He became a companion of the 'Abbāsīd Caliph al-Mu'tamid (AH 256–279/AD 870–892).

Ibn Khurdādhbih was a versatile writer; besides writing on geography, he wrote on history, genealogy, music, wines, and even on the culinary art. Al-Nadīm, in his *al-Fihrist*, lists at least eight works to his credit. The Arab historian Abu'l-ḥasan 'Alī ibn al-ḥusayn al-Mas'ūdī (d. AD 956) considered him an *imām* (leader) in authorship and mentions his voluminous historical work dealing with the ancient kings and peoples of Iran (*Murūj* 1965). Ibn Khurdādhbih also claimed to have translated into Arabic the geographical treatise of Claudius Ptolemy (ca. AD 90–168) from a “foreign language” (probably Syriac or Greek), but the translation is not extant.

However, Ibn Khurdādhbih's major work on geography, entitled *Al-Masālik al-Mamālik* (Roads and Kingdoms), was published by M. J. De Goeje in 1889. In fact, this work is an abridgement (prepared not later than AD 885–886) of his larger work (not extant) written in ca. AD 846–847. Considering the vast amount of information contained in the work and the early date of its compilation, it may be said that Ibn Khurdādhbih was the father of Arab-Islamic geography; no work of such magnitude existed

before him. *Al-Masālik al-Mamālik* deals briefly with mathematical and physical geography, but the major portion of the work is devoted to descriptions of land and sea routes in the four directions emerging from al-Sawād. Then, it deals with marvels of the world, seas and mountains, sources of the rivers, and reports on countries like India and Central Asia.

It is not unlikely that Ibn Khurdādhbih relied heavily for his information on the ancient Sassanian government records which must have become available to him as the person in charge of the department of posts and information in Baghdad and elsewhere. Again, in his methodology and arrangement of the material and in the use of geographical terms and Persian couplets, a distinct Persian influence is discernible. The ancient Persians used to divide the known world into seven circular regions called *kishvars* (kingdoms) with Irānshahr at the center and the remaining six circles drawn around it. Such an arrangement is observable in his descriptions of the various routes emerging from al-Sawād, which, he says, was called *dil-i Irānshahr* (the heart of Iraq).

Ibn Khurdādhbih was not only the first to write on geography in Arabic, but he also set the style for writing on descriptive geography. Several later Arab-Islamic geographers utilized his work as a major source of information.

See Also

► [Geography in the Islamic World](#)

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Ibn Mājid

Sayyid Maqbul Ahmad

Shihāb al-Dīn Aḥmad ibn Mājid ibn Muḥammad ibn Amr ibn Faḍl ibn Duwayk ibn Yūsuf ibn Ḥasan ibn Ḥusayn ibn Abī Ma'laq al-Sa'dī ibn Abu'l-Rakā'ib al-Najdī was the greatest Arab navigator of the fifteenth century AD and one of the greatest of the Middle Ages. We do not know the date of his birth or death, but he must have died at an advanced age sometime in the first decade of the sixteenth century. Born in Julfār (Oman), he belonged to an illustrious family of navigators. Both his father and grandfather were *mu'allims* (masters of navigation) of repute.

Ibn Mājid wrote a number of works, both in prose and poetry, on nautical theory and on describing the seas (mainly the Indian Ocean) which served as guides for the Arab navigators of later periods. Among his important works in prose is the *Kitāb al-fawā'id fī 'uṣūl'ilm al-baḥr wa'l-qawā'id* (The Book of Benefits on the Principles of the Science of Navigation), dated AH 895/AD 1489–1490. This book and many others have been reproduced in the editions mentioned in the bibliography.

Ibn Mājid considered himself the fourth of the great Arab navigators of the Middle Ages; the other three were Muḥammad ibn Shādān, Sahl ibn Abān, and Layṭ ibn Kahlān, who belonged to the Abbāsīd period. He thought his own works were more accurate than theirs, since they were more current and since many of the ports mentioned in the older works no longer existed. Apart from his practical experiences as a navigator, he had studied and improved upon the work of his father (*al-ḥijāzīya*) and had studied a number of

earlier Arabic works on astronomy and geography.

On the practical side of navigation, it is not unlikely that Ibn Mājid was in contact with the Indian navigators of his time, the *Ṣūliyān* (Cholas of Tamil Nadu, India) and with the Gujarati and the Konkani (Maharashtra, India) navigators, whose *qiyāsāt* (readings of the ports and harbors) he seems to have known. He was particularly knowledgeable about Siam and Bengal, and these navigators frequented these regions more than the Arab navigators did.

In his works Ibn Mājid covered a number of subjects relating to navigation, nautical astronomy, oceanography, and geography. In his *Kitāb al-fawā'id*, he pays special attention to subjects of a more general nature, like guidelines to navigators such as the prerequisites for sailing on the sea, and he describes the lunar mansions, the stars corresponding to the 32 divisions (*aqnān*) of the compass card, the winds and seasons of the seas, nautical instruments, and the essentials required by captains of boats. These include knowledge of the rising and corresponding settings of the stars (*al-anwā'*), latitudes and longitudes, landfalls, and tides. He emphasizes that before sailing, captains should see that their instruments are in perfect order, the sailors obedient, and the seasons suitable. They should be patient and soft-spoken, should not deprive merchants of their rights, and they should be courageous, literate, and well behaved. He also presents a systematic description of the sea coasts of the Oikumene (the known world at that time), which no geographer had done before. From his writings, it appears that he did not conceive that a *terra incognita* existed in the southern quarter of the earth, as other geographers of his time believed. He thought that the Indian Ocean was connected with the Atlantic through a sea channel, which he calls *al-madqal* (place of entry).

Ibn Mājid claimed to have made several contributions to navigation and to determining the direction of the *qibla* (Mecca) from different positions of the earth with the help of the compass card. He also claimed to have fixed a magnetized needle on the mariners' compass (probably on a day box). Ibn Mājid had met Vasco da Gama, and

had guided him to Calicut, India. Although the Portuguese sources do not mention him by name in this regard, we know from an Arabic work, *al-Barq al-Yamānī fī'l-faṭḥ al-ʿUṭmānī* (The Yemenite Lightning on the Ottoman Conquest) by al-Nahrawālī that it was he who directed Vasco da Gama from Malindi (East Africa) to India.

See Also

- [Compass](#)
- [Lunar Mansions in Islam](#)
- [Qibla and Islamic Prayer Times](#)

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Ibn Māsawayh

Danielle Jacquart

Abū Zakariyyā' Yūḥannā ibn Māsawayh was born in Baghdad during the caliphate of Hārūn ar-Rashid (786–809), and not in 777 as was stated by ► [Leo the African](#). His father, Māsawayh, was a pharmacist in the service of the physician Jibrāʾīl ibn Baḥtishū', with whom he came from Jundīshāpūr (in Persia) to Baghdad. His mother

was a slave, named Risala, whom Māsawayh bought from the physician Dawūd ibn Sarābiyūn. Thus, Yūḥannā ibn Māsawayh belonged to the milieu of Christian Nestorian physicians, who played an important part during the eighth and ninth centuries. He married the daughter of his colleague Abdallāh at-Tayfūrī and had a son of poor intelligence. He was very famous as a teacher and practitioner; he became the personal physician of four successive caliphs from al-Ma'mūn to al-Mutawakkil. He died in Samarra in 857.

As for many other authors of this period, it is difficult to distinguish legend and history in his biography. It was said that he did translations from Greek into Arabic, but none is extant under his name; most probably, he only commissioned some of them. For instance, it is well attested that ► [Ḥunayn ibn Isḥāq](#) undertook the translation of Galen's *Methodus medendi* (Arabic *Kitāb hīlat al-bur'*; Methods of Healing) at Ibn Māsawayh's request. The relationship between both physicians was nevertheless strained, at least at the beginning: Ibn Māsawayh is supposed to have driven Ḥunayn out of his teaching position, who then went traveling in order to learn Greek and purchase manuscripts. It was also reported by Arabic medieval historians that Ibn Māsawayh had the opportunity of dissecting an ape, which had been given to the caliph by the prince of Nubia in 836 as a present. Following in Galen's footsteps Ibn Māsawayh afterward wrote an anatomical monograph, which can perhaps be identified with his *Kitāb at-tashrīḥ* (Book of Anatomy). Apart from his knowledge of Greek medicine, Ibn Māsawayh had access to some Indian works: he quotes, for instance, ► [Āryabhata](#) in his ophthalmological treatise *Kitāb daḡal al-ʿain* (Book on the Defectiveness of the Eye).

Ibn Abī Uṣaybi'a listed 42 works; some others were quoted by ► [al-Rāzī](#) and ► [al-Bīrūnī](#). But only 31 are extant, as far as we know, and very few have been edited or studied. Those that have been edited – and sometimes translated into English or French – are the *Aphorisms*, the works on barley water, simple drugs, and perfumes, as well as the medical calendar; the

ophthalmological treatises have also been analyzed. It seems that among the works which were translated into Latin during the Middle Ages under the names of "Mesuē" or "Johannes Damascenus," only the *Aphorismi Johannis Damasceni* and some ophthalmological fragments can be attributed to Ibn Māsawayh; the other ones, mainly pharmacological, are probably apocryphal for the most part. The *Aphorismi* – a faithful translation of *Nawādir at-ṭibb* – were largely diffused from the twelfth century; a second translation appeared as the sixth book of Rāzī's *Secrets of Medicine*: it was done during the thirteenth century by the Dominican Giles of Santarem.

Some original features of Ibn Māsawayh's medicine can be drawn from his *Nawādir at-ṭibb*. Dedicated to Ḥunayn ibn Isḥāq and modeled on the Hippocratic *Aphorisms*, this short work was intended to give practical advice. The eight first aphorisms can be considered as a kind of commentary on the first Hippocratic aphorism: "Life is short, art long, opportunity fleeting, experiment dangerous, judgment difficult." They stressed the necessity for physicians to be both learned and skilled. Throughout the remaining 124 aphorisms the following topics are covered: the link between body and soul, the observance of astrological and climatological rules, the attention that physicians have to pay to the healthy nature of their patients, the numerical ratios which rule human temperaments, as well as natural substances used for treatment. It has to be noted that this last idea was deeply developed by Ibn Māsawayh's contemporary, ► [al-Kindī](#). Ibn Māsawayh seems also to have been very much attached to the idea that physicians must mainly reinforce nature by using drugs similar to it; medical treatment with substances contrary to disease had to be prescribed cautiously and their sole goal was to purge. Physicians had to be cautious not to alter nature too much. For example, Ibn Māsawayh stated: "It is important that, against diseases, the strongest contrary is not introduced into the body, since this would be very harmful; it can be compared with a very cold wind which, during the same day, blows after a very hot one" (aph. 60). In the

same manner, treatment by diet was preferred to pharmacopoeia: "If the physician can treat with food, to the exclusion of drugs, he will be very successful" (aph. 108). In addition to several pharmacological treatises, Ibn Māsawayh composed an important work on dietetics.

Ibn Māsawayh's works remain very little known, despite their importance in the history of Arabic medicine. Detailed studies would shed light on the decisive stage constituted by the beginning of the ninth century, before the spread of Ḥunayn's translations.

See Also

- [al-Kindī](#)
- [Leo the African](#)

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Ibn Mu'ādh

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Ibn Mu'ādh al-Jayyānī, Abū 'Abd Allāh Muḥammad (d. ca. 1093) has traditionally been assigned a birth date of 989. However, recent scholarship suggests that Ibn Mu'ādh was born somewhat later, in the early eleventh century. The only secure date we have for him is 1079, the year of a solar eclipse he describes from firsthand observation. The ending "al-Jayyānī" to his name indicates that he was from Jaén in Andalusia, where he evidently served as a *qāḍī* (judge) for much of his life. Among his few surviving astronomical and mathematical works are included the *Tabulae Jahen*, a set of astronomical tables based on those of al-Khwārizmī and probably translated into Latin by Gerard of Cremona; *Maqāla fī sharḥ al nisba* (On Ratio), a commentary on Book 5 of Euclid's *Elements*; and *Kitāb majhūlāt qisiyy al-kura* (Determinations of the Magnitudes of the Arcs on the Surface of a Sphere), a work on trigonometry. Certainly the most original, and perhaps the most historically significant of his extant works, is the brief treatise *On Twilight and the Rising of Clouds*.

While no Arabic exemplar has yet come to light (the original title was probably *Ma'l-fajr wa'l-shafaq*), this work has nonetheless reached us in three other linguistic forms: a fourteenth-century Hebrew translation from the Arabic (represented by 1 manuscript), a late twelfth-century Latin translation from the Arabic, probably by Gerard of Cremona (represented by 25 manuscripts), and a fourteenth-century Italian translation from the Latin (represented by 1 manuscript). The sheer number of Latin manuscripts – plus the Italian translation – indicates the seriousness with which this treatise was received and disseminated in the medieval West. That it was commonly misattributed to Ibn al-Haytham, author of the magisterial *Kitāb al-manāẓir* (*De aspectibus*),

may have had something to do with this. There is also clear, albeit indirect, evidence that *On Twilight* exerted its share of influence in the medieval East as well.

Ibn Mu'adh's purpose in *On Twilight* is to determine the height of the atmosphere under the assumption that the first light of dawn is produced when rays from the rising sun tinge vapors at the very upper edge of the atmosphere. Although he offers no practical justification for this inquiry, he does, in a couple of querulous asides, berate those (religious conservatives?) who would squelch rational inquiry out of mere ignorance. The determination itself depends upon four basic parameters: the depression of the sun below the horizon at first light (18°), the mean distance between the earth and sun (1,110 terrestrial radii), the relative size of the sun and earth (5.5:1 in terrestrial radii), and the circumference of the earth (24,000 mile). On the basis of these parameters and using simple trigonometric functions, Ibn Mu'adh calculates the atmosphere to be around 52 miles high. This figure remained canonical in the Latin West until the end of the sixteenth century, when Tycho Brahe raised the issue of atmospheric refraction to prominence. Within this context, it soon became clear that Ibn Mu'adh's calculation was useless because it failed utterly to take atmospheric refraction into account. Consequently, his figure of 52 miles was drastically reduced by Johan Kepler and succeeding astronomers.

See Also

- [Al-Khwārizmī](#)
- [Astronomy in the Islamic World](#)
- [Ibn Al-Haytham \(Alhazen\)](#)

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Ibn Mun'im

Ahmed Djebbar

The oldest mathematical work from the Maghreb which deals with combinatory problems is the *Fiqh al-ḥisāb* of Ibn Mun'im, a scholar originally from Andalusia, living in Marrakesh in the Almohad era. To our knowledge, his book was the first in the entire history of mathematics to have devoted a whole chapter to these types of problems and to have stated them and solved them according to a common procedure.

Aside from Ibn 'Abd al-Malik, the biographers of the Maghreb do not mention Ibn Mun'im, even though they write at length about mathematicians of lesser significance, and they use the contents of his book. The little information we do have on Ibn Mun'im comes from his own introduction to his mathematical text, cited above, and from the book of Ibn 'Abd al-Malik.

According to the latter source, Ibn Mun'im's full name was Aḥmad ibn Ibrāhīm ibn 'Alī Ibn Mun'im al-'Abdarī. He was originally from the town of Denia on the east coast of Spain, near Valencia, and he lived in Marrakesh where he taught and where he died in 626H/1228. He was

known as one of the best scholars of his era in geometry and number theory. At the age of 30, he began to study medicine which he practiced successfully at the same time as his mathematical activities.

Only three of Ibn Mun'im's numerous mathematical texts and letters are known today: one on magic squares, another on geometry, and the third on the science of calculation. And of these, only the last, *Fiqh al-ḥisāb*, is extant. Ibn Mun'im wrote it under the reign of the fourth Almohad caliph, al-Nāṣir (1199–1213). During his reign celebrated scholars like the grammarian Abū Mūsā al-Jāzūlī, the algebraist ► [Ibn al-Yāsāmīn](#), and the doctors of the Ibn Zuhri family all lived in the Almohad capital, or even within the court itself. This leads one to believe that there was a variety of scientific activity, thanks to a generous and often enlightened patronage.

Combinatory analysis is taken up the 11th section of the first chapter of *Fiqh al-ḥisāb*, entitled “an accounting of words which are such that human beings can express them only by one of them.” This section is not, however, in the eyes of this author, a complete overview of practical calculations. He takes care to explain, in the course of his exposition, that he proposes first to treat the problem in a general manner, even though he is obliged, in order to make his ideas clear, to formulate it in specific terms using the Arabic alphabet. In fact, this study goes beyond the linguistic framework in which it is formulated, as much by the way of posing the problems and linking them to each other, by the methods of reasoning used, as by the established results.

Ibn Mun'im begins by setting out the problem as a mathematician; he defines precisely the framework in which he is stating the chosen hypotheses and the degree of generality researched. Then he establishes, using a set of colors of silk as an abstract model, a rule which enables one to determine all the possible combinations of n colors p times p . In order to do that, he constructs, in accordance with an inductive method, a triangular numeric table, identifies its elements, with the desired combinations, and deduces the relationships:

$$C_n^p = C_{n-1}^{p-1} + C_{n-2}^{p-1} + \cdots + C_{p-1}^{p-1}.$$

Thus, he presents, to our knowledge for the first time, the famous arithmetical triangle which algebraists from the Muslim East like ► [al-Karājī](#) (d. 1029) had already constructed but for other purposes and using another procedure.

Ibn Mun'im's study continues by establishing, using induction, relative formulas with permutation, with or without repetitions, of a group of letters such that they give, by recurrence, the number of possible readings of a word of n letters, taking into account all the signs (vowels and sukūns for Arabic) used by a given language. This is the content of problems 2, 3, and 4. In problem 5, the author concludes the first part by establishing a formula of arrangements, without repetition, of n objects p times p , which take into account the vowels and the sukūn accompanying the letters.

The second part, much longer, seeks to enumerate the combinations with repetitions, adopting a method analogous to the preceding one and which necessitates recourse to the table of numbers. It was moreover this same method that the French scholar Mersenne rediscovered and applied to his work in the seventeenth century.

To set up problem 6, Ibn Mun'im goes back to his model of bunches and proposes to solve a difficult dilemma, apparently removed from the initial problem and stated thus: being given threads of silk in n colors, we want to determine the number of bunches it is possible to make with p threads of k colors, so that $p_1, p_2, \dots, p_k$ threads are, respectively, of the same color.

All these propositions, and even more the techniques, allow the resolution of the problem which Ibn Mun'im formulates as follows: to determine the number of words of one to ten letters which it is possible to make with the letters of the Arabic alphabet, including all possible repetitions of letters in a words, and including vowels and the sukūn which can appear on letters.

The third part of his study includes, along with several applications, a series of tables which

enables the determination, more and more closely, of all the elements (P_n , A_n , C_n , ...) which occur in the counting of words that it is possible to pronounce in a given language.

In addition to the results included in this chapter of *Fiqh al-hisāb*, the way in which Ibn Mun'im established his results is also notable. In fact, he uses two types of reasoning which can be called inductive and combinatorial. While inductive reasoning is a traditional tool of Islamic mathematics with its privileged domains and unique stature, one cannot say the same for combinatorial reasoning which appeared, to our knowledge for the first time, in the *Fiqh al-hisāb*. His systematic use of combinatorial reasoning for establishing general propositions appeared as a clear acknowledgment of its mathematical character.

One can even suppose that if combinatorial reasoning had enjoyed a quantitative development in the field of application, it would have resulted in its explicit recognition as a process of reasoning beside analysis, synthesis, induction, and reasoning *ad absurdum*.

The elaborate nature of his procedures and results which appear in the *Fiqh al-hisāb*, as well as the spirit of the method which emerged from them leads to the theory that the beginning of the mathematization of combinatorial problems within the framework of Arabic science occurred prior to the work of Ibn Mun'im.

While we await the confirmation, or correction, of this conjecture, the *Fiqh al-hisāb* remains the oldest known Arabic work from the Muslim West in which an autonomous chapter on combinatorial analysis appeared. But its importance does not end there: with regard to the linguistic tradition of the Maghreb, the book was a culmination in that it laid out a general solution to a given problem. Also, for mathematics, the work represents an important link, marking the end of one stage in the progress of combinatorics, that of calculation using tables, and the beginning of another stage, that of the extension of formulas and their use in solving problems.

See Also

► [Combinatorics in Islam](#)

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Ibn Qunfudh

Y. Guergour

Abū'l'Abbās Aḥmed Ibn al-ḥasan Ibn 'Alī Ibn al-Khaṭīb was known under the two names of Ibn Qunfudh and Ibn al-Khaṭīb. He was born in 710 AH (AD 1339) in Constantine, Algeria and came from an old family which was cultured and well to do. We know that Ibn Qunfudh began his studies with his father and his maternal grandfather, in order to follow them eventually under the direction of other professors from his same town.

After his elementary education, he returned to Fez, in Morocco, where he remained for 18 years. There he studied with several professors, covering different scientific themes, and teaching and publishing some of his own work. We know that it is in this city that he edited in 771 (1370) his most important mathematical work, the *Ḥaṭṭ an-niqāb' an wujūh' amāl al-hisāb*, which is a commentary on the *Talkhīṣ a'māl al-hisāb* of ► [Ibn al-Bannā'](#), written in 721 (1321). We think that he acquired his advanced education either completely or partially during his stay in Fez.

During the period of famine which raged in all of Maghreb in 776 (1374), Ibn Qunfudh went back to Constantine in order to take up duties as a *khaṭīb* (preacher), *muftī* (jurist), and

qāḍī (judge). At the same time, he devoted himself to the teaching and editing of scholarly work. No information has come down to us on the subject of the contents of this teaching, and we do not even know if he taught the contents of his own mathematical writings at Constantine or in the cities where he was posted, or even if he was content only to edit them, following in that the tradition of several older authors, who wrote on subjects which were very different from each other without having taught them.

What follows is an attempt to give a glimpse of Ibn Qunfudh's contributions to mathematics, of which we know only four titles:

1. *Mabād' as-sālikin fī sharh rajz* ► [Ibn al-Yāsāmīn](#) (Principles for Those who are Concerned with the Commentary on the Poem of Ibn al-Yāsāmīn). Ibn Qunfudh began this poem according to the traditional procedure of commentators of the Middle Ages. What is not traditional is his use of mathematical symbolism to resolve equations and to represent polynomials. This was to become normal practice during this period, since this commentary was adopted by his students. The symbolism was universally used in mathematical works from Maghreb. This hypothesis is reinforced by the presence of this same symbolism in the book *Ḥaṭṭ an-niqāb* and in the book written by Ya'qūb al-Muwāḥidī *Tahṣīl al-munā fī sharh Talkhīṣ Ibn al-Bannā*.
2. *Bughyat al-fāriḍ min al-ḥisāb wa l-farā'id* (The Desire of the Genealogical Specialist to Know Arithmetic and Successional Division). To this day, no copy of this book has been found.
3. *at-Talkhīṣ fī shzarh at-Talkhīṣ* (Abridged Commentary on *Talkhīṣ*). This is a resume of *Ḥaṭṭ an-niqāb*, of which two copies are extant today.
4. *Ḥaṭṭ an-niqāb'an wujūh' amāl al-ḥisāb* (Lifting the Veil on the Operations of Calculation). Five copies of this work are extant.

Since this is Ibn Qunfudh's most important work, it is useful to describe certain aspects of

its contents. Reading it permits us to make several important observations on mathematical writing in this era. The author begins his book with some advice and directions designed to facilitate the reading of any book; then he provides a detailed list of the writings of Ibn al-Bannā'. In the beginning of each chapter, he gives an abstract of its contents, something which one finds nowhere else in the literature of other mathematicians of this time. It is also important to note again the existence of Ibn Qunfudh's mathematical symbolism, particularly in the chapters on roots and on algebraic equations. However, recent research reveals that this symbolism had been used previously at the end of the twelfth or beginning of the thirteenth century, especially in Ibn Yāsāmīn's book *Talqīḥ al-afkār*. Elsewhere, Ibn Qunfudh supplies arithmetic rules which one does not find in Ibn al-Bannā''s work, notably in the chapter on the product. Ibn Qunfudh's terminology also differs significantly from Ibn al-Bannā''s.

Finally, one finds in the work of Ibn Qunfudh an equation of which the second number is zero, an equation which had formerly been studied by Ibn Badr. His originality lies in the symbolic way in which he expressed it:

$$0 \text{ ج } 7 \text{ ي } 8.$$

or, in modern symbols, $8.r - 7 = 0$.

Ibn Qunfudh died in 810 AH (AD 1407).

See Also

► [Ibn al-Bannā'](#)

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Ibn Qutayba

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Ibn Qutayba, Abū Muḥammad 'Abdallāh ibn Muslim, was born in 828 in Kufa or Baghdad, and died in 884 or 889 in Baghdad.

Ibn Qutayba was a scholar of typical Arabic-Islamic education. His studies included all branches of the traditional Arabic and Islamic knowledge of his time: religion, history, biography, philology, lexicography, literature, and some science. He left 20 works of varying lengths covering all the fields mentioned. In his career, for some years he was *qāḍī* (a judge according to Islamic rules) in Dinawar (northern Iran); later he lived and taught in Baghdad, where he also died. Of particular scientific interest is his *Kitāb al-anwā'* (Book on the *anwā'*). *Anwā'* are asterisms and stars used by the Arabs in pre-Islamic and early Islamic times to determine seasons, predict weather-especially rain, and guide them in their nightly desert travels. Many Arabic philologists and lexicographers wrote books of this type, but most of these did not survive. Therefore Ibn Qutayba's *Book on the anwā'*, which was printed in Arabic, in Hyderabad/Deccan (India) in 1956, is of great interest. In it, the author has

assembled information on the popular astronomical and meteorological knowledge of the old Arabs, from the time before their acquaintance with Greek, Persian, and Indian astronomy. Facts, traditions, terminology, and nomenclature are amply described. Much of this material continued to be used later in the most active period of Arabic – Islamic astronomy. And some of it even lived on into our time, as, for example, the star name Aldebaran (for α Tauri).

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Ibn Riḍwān

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Abu'l-ḥasan 'Alī Ibn Riḍwān 'Alī Ibn Ja'far, a self-educated physician philosopher, was born in AD 998 at Gīzah, a suburb south of Cairo (al-Fuṣṭāṭ). He was the son of a poor baker (*farrān*) and had to earn money in his youth by practicing medicine, teaching, and telling people's fortunes from astrological signs. When he was 59, he wrote a book entitled *Fī Sīratihī* (On His Own Conduct). The work is now lost, but its text is partly preserved in Ibn Abī Uṣaybi 'a's *'Uyūn al-Anbā' fī Ṭabaqāt al-Aṭibbā'* (Sources of Information About the Classes of Physicians).

In his youth, he believed in astrology (*'ilm al-nujūm*) and was convinced that the stars at the time of his birth indicated a prosperous medical career. To realize his ambition, he first sought out a popular teacher in Cairo, who instructed Ibn Riḍwān to memorize Ḥunayn Ibn Ishāq's

(d. AD 873) *Kitāb al-Masā'il fi'l-Ṭibb li'l-Muta'allimīn* (Questions on Medicine for Students). Ibn Riḍwān watched him teaching: pupils read the text; the teacher listened but did not utter one word of explanation and did not even bother to correct their errors. Ibn Riḍwān sought to find other teachers and put questions to each of them, based on the writings of Hippocrates and Galen, which they displayed on shelves in their private libraries. He concluded that they merely knew the titles of books but were ignorant of their contents. He pondered over traveling to Iraq for further education, but financial difficulties prevented his going there. He decided on self-education at the tender age of 15. From perusing Galen's *On the Doctrines of Hippocrates and Plato*, he concluded that he should first study geometry and logic. He studied the well-known books on these two subjects, then proceeded to read textbooks on medicine proper. In this way he reached an understanding of the principles of the art of healing.

Ibn Riḍwān worked very hard as a practicing doctor until he reached the age of 32, when he became well known and earned enough money to build his own residential Palace of Candles (*Qaṣr al-Sham'*). At the age of 59 he divided his time between practicing medicine, daily physical exercise (*al-riyāḍah*), and reading books on literature, Islamic law, and medicine. His fame reached the Fātimid Caliph al-Mustaṣhir (r. AD 1036–1094), who appointed him Chief of Physicians (*Ra'īs al-Aṭibbā'*) in Egypt. He was kind-hearted, treated the poor for free, and was always willing to extend a helping hand to the needy.

In old age, Ibn Riḍwān's mind became disturbed (*taghayyar 'aqluhu*) as a result of being robbed of all his cherished possessions. He had adopted an orphan young girl whom he brought up in his own house. She absconded with all the precious items he had accumulated and 20,000 gold dīnārs which he had kept in the house. An extensive search for the girl was abortive. Ibn Riḍwān died in AD 1067.

Among Ibn Riḍwān's extensive bibliography are his treatise *Fī Daf' Maḍārr al-Abdān fī Arḍ Miṣr* (On the Prevention of Bodily Ills in Egypt)

and the *Al-Nāfi' fī Kayfiyyat Ta'līm Ṣinā' at al-Ṭibb* (Useful Book on the Quality of Medical Education).

In *On the Prevention of Bodily Ills*, he describes the Nile and the Muqaṭṭam Hills on both sides of the river. The hills in the east hold back the "hot and humid" winds, which are most favorable for the temperament (*mizāj*) of animals and which do not reach *al-Fuṣṭāṭ*. Ibn Riḍwān gives an account of "the six non-natural causes" (*al-asbāb al-sitta al-ḍarūriyya*) which determine health and sickness: the air surrounding the body, food and drink, movement and rest, sleep and wakefulness, retention and evacuation, and psychic events.

Ibn Riḍwān was discourteous in criticizing members of the medical profession. For example, Chapter 5 of this treatise is entitled "On the Incorrectness of Most of Ibn al-Jazzār's [d. AD 1009] Reasons for the Unhealthy Air in Egypt." Furthermore, disagreements arose with ► [Ibn Buṭlān](#) of Baghdad. These are well documented by Meyerhof and Schacht (1937).

In his *Useful Book*, Ibn Riḍwān preserved for posterity a unique document, the late Alexandrian medical curriculum (sixth to seventh century AD). In it he attributes the decline of medicine in his time to the popularity of poor-quality compendia (*kanānīsh*) and summaries and commentaries of the books of Hippocrates and Galen, compiled by incompetent physicians. The Alexandrian curriculum specifies the titles of textbooks of logic, medicine proper, and mathematics (including astronomy). It consists of preparatory (introductory) courses and main courses. The preparatory courses contain optional subjects, including language and grammar, and compulsory subjects: physics, arithmetic, numerals, measurement, geometry, the compounding of drugs, astrology, and ethics.

The main courses include logic and medicine proper. Sixteen of Galen's books were to be studied in seven grades: Grade 1 included Galen's *On Sects*, *On the Art of Physics*, *On the Pulse*, *To Teuthras*, and *To Glaucōn on Therapy*. In the final and seventh grade, students studied Galen's *On the Method of the Preservation of Health*.

See Also

► [Ibn Buṭlān](#)

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Ibn Rushd (Averroës)

Albert Z. Iskandar

Abu'l-Walīd Muḥammad ibn Aḥmad ibn Muḥammad ibn Rushd (Averroës, AD 1126–1198), a native of Cordoba, Spain, was the namesake of his famous grandfather. Later, to avoid any confusion, he was nicknamed *al-ḥafīd* (grandson). Like his father and grandfather, he was a well-known jurist. By profession, following in the footsteps of his father, he became a *qāḍī* (judge), who specialized in religious matters, and at one time was the Imam of the great mosque of Cordoba. He adhered to the Mālikī sect, one of the four great sects of Islam, and

wrote *Kitāb al-Muqaddimāt al-Mumahhidāt* (A Book of Introductions that Pave the Way), for the followers of the sect.

At his father's insistence, Ibn Rushd studied Islamic law (*Shari'ah*) under the teacher, al-ḥāfiẓ Abū Muḥammad Ibn Rizq. Ibn Rushd also studied the science of Tradition (*Ḥadīth*), but he is known to have been more interested in Islamic law. He memorized the *Muwatta'* of Imam Mālik and was also greatly impressed by the Ash'arite science of Kalām (Theology). Later, he turned against the Ash'arī school of thought and attacked its proponent, the Imam al-Ghazālī (d. AD 1111). Ibn Rushd was also acquainted with the doctrines of the Mu'tazila theology.

His teachers of medicine were Abū Marwān Ibn Jurrayūl, a first-class practitioner, and Abū Ja'far Hārūn al-Tarjālī, a well-known physician philosopher in Seville, who was knowledgeable about Aristotelian philosophy, as well as the medical writings of the Ancients. Al-Tarjālī was employed by the Almohad (*al-Muwahḥid*) ruler Abū Ya'qūb Yūsuf (r. AD 1163–1184). Abū Yūsuf Ya'qūb al-Manṣūr (r. AD 1184–1199), before succeeding his father, attended meetings in Seville, to which notable philosophers, physicians, and poets were invited. Abū Bakr Ibn Ṭufayl (Abubacer), Ibn Zuhr (Avenzoar), and Ibn Rushd were regular attendants at these meetings. Ibn Rushd's education under al-Tarjālī qualified him as a physician-philosopher; his studies in religious law, under al-ḥāfiẓ, entitled him to be considered a jurist (*faqīh*).

In 1153, when he was in Marrakech (Morocco), Ibn Rushd supported the Almohad ruler 'Abd al-Mu'min (d. AD 1163) in furthering education by founding colleges. From his commentary on Aristotle's *De Caelo*, one learns that Ibn Rushd conducted astronomical observations when in Marrakech, and in his commentary on the *Metaphysics*, he mentions his yearning for his early studies in astronomy. Ibn Rushd studied the writings of Arabic-speaking astronomers and expressed his own opinion regarding the three kinds of planetary motions: those that can be detected by the naked eye, those that can be seen by instruments of observation (remarking that some occurred over long periods of time

that exceeded the lifetime of observers), and those planetary movements whose existence can only be surmised by reasoning. Between AD 1169 and 1179, Ibn Rushd visited many places in the Almohad realm. He was actively researching matters pertaining to astronomy when he met ► [Ibn Ṭufayl](#), a philosopher and astronomer in his own right. Ibn Ṭufayl enhanced Ibn Rushd's career by introducing him to Abū Ya'qūb Yūsuf, who appointed Ibn Rushd as *qāḍī* of Seville in AD 1169. Ibn Rushd returned to Cordoba in AD 1171, at which time he was still holding the office of *qāḍī*. In AD 1182, he succeeded Ibn Ṭufayl as a personal doctor to Abū Ya'qūb Yūsuf, and was elevated to the office of grand *qāḍī* of Cordoba.

For 10 years Ibn Rushd enjoyed the patronage of Abū Ya'qūb Yūsuf. Out of jealousy, jurists (*al-fuqahā'*) of the Mālikī sect, whose influence had grown as a result of their religious zeal during the period of the Crusades, successfully conspired against him for his free-minded views. He was summoned to appear in court, and his philosophical writings were deemed contrary to the teachings of Islam. Ibn Rushd fell from grace in AD 1195 and was banished to Lucena, a province of Cordoba.

Very little is known about Ibn Rushd as a teacher of medicine. Nevertheless, the names of two of his students are known: 'Abd Allāh al-Nadrūlī and 'Isā ibn Aḥmad ibn Muḥammad ibn Qādir. The latter transcribed the whole text of Ibn Rushd's book *Al-Kullīyyāt* (Generalities) from the author's own autograph, during his lifetime, and with his approval.

Kitāb al-Kullīyyāt (Latin, *Colliget*) consists of seven books: *Tashrīḥ al-A'ḍā'* (The Anatomy of Organs), *al-Ṣiḥḥa* (Health), *al-Maraḍ* (Disease), *al-'Alāmāt* (Symptoms), *al-Adwiya wa'l-Aghdhiya* (Drugs and Foods), *Hif Ṣ-al-ṣiḥḥa* (Hygiene), and *Shifā' al-Amrāḍ* (Recovery from Disease). The purpose of the book, according to the author, is to provide medical men with an introduction to concise accounts of the different parts of medicine (*ajzā' al-ṭibb*).

Scientific collaboration existed between the eminent practitioner Ibn Zuhr (Avenzoar, d. AD 1162) and Ibn Rushd. Ibn Rushd asked Ibn Zuhr

to write a book on therapy, which he did. It was called *al-Taysīr fī'l-mudāwāt wa'l-tadbīr* (An Aid to Therapy and Regimen). *Al-Taysīr* and the *Kullīyyāt* together were meant to cover the whole science of medicine, possibly instead of Ibn Sīnā's (Avicenna, d. AD 1037) *Kitāb al-Qānūn fī'l-Ṭibb* (Canon of Medicine), which Ibn Zuhr severely criticized.

A merchant from Baghdad presented Ibn Zuhr with a beautifully transcribed and ornamented copy of Ibn Sīnā's *Kitāb al-Qānūn*. After reading it for the first time, Ibn Zuhr condemned the book and kept tearing off the margins of its leaves, which he used for jotting down prescriptions for his patients. It took almost a century before a copy of *Kitāb al-Qānūn*, completed by its author in Hamadan (Persia), actually reached Cordoba, Ibn Rushd's home town.

See Also

- [Ibn Sīnā \(Avicenna\)](#)
- [Ibn Ṭufayl](#)

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Ibn Sahl

Roshdi Rashed

Ibn Sahl, Abū Sa'd al-'Alā', was a first-class mathematician. From his correspondence as well as from diverse information transmitted by

the same crystal. He will not fail to give this same ratio again, nor to reproduce this same figure, each time he discusses refraction in the crystal.

This ratio is nothing but the inverse of the index of refraction in the crystal in relation to air. In fact, let us consider i_1 and i_2 , the angles formed, respectively, by CD and CE with the perpendicular GH. One has

$$\frac{1}{n} = \frac{\sin i_1}{\sin i_2} = \frac{CG}{CH} \frac{CE}{CG} = \frac{CE}{CH}.$$

Ibn Sahl takes on segment CH point I such that CI = CE, and point J at the middle of IH. One has

$$\frac{CI}{CH} = \frac{1}{n}.$$

The division CIJH henceforth characterizes the crystal for all refraction.

Ibn Sahl made innovations not only in optics, but also in mathematics. Among his mathematical inventions, I shall mention only one paper, set down as a follow-up to his contemporary, the mathematician al-Qūhī: his study of the method of projection of the sphere. Al-Qūhī is, in fact, the author of a treatise on *The Art of the Astrolabe by Demonstration*. This treatise is composed of two books, of which the first opens with an introductory chapter on the theory of projections. The propositions which al-Qūhī set forth seemed “difficult to understand” to one of his contemporaries, who turned to Ibn Sahl for clarification of the notions found therein and for the proof by synthesis of what al-Qūhī showed by analysis. We have here a situation of privileged history: we are witness to the elaboration of a new chapter of geometry by two contemporary mathematicians.

In conclusion, I remark upon the emergence of Ibn Sahl, a figure until recently almost unknown, and two chapters: anaclastics and the study of projection of the sphere. Ibn Sahl also made a substantial contribution in infinitesimal mathematics as well as in construction problems – the regular heptagon, for instance.

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Ibn Sarabi (Serapion)

E. Ruth Harvey

There are two different Arab authors known to the medieval Latin west as “Serapion,” and the confusion between them in all of the authorities seems inextricable. The elder of the two authors was a Syrian, Yūḥannā ibn Sarabiyun, who lived in the ninth century. He wrote two books in Syriac, which were translated into Arabic: they are called the *Large Kunnāsh* (it was in 12 parts) and the *Small Kunnāsh* (in 7 parts). Manuscript copies of the Arabic versions exist in European libraries; what sounds like a whole copy of the *Large Kunnāsh* is in Istanbul. Both works deal with medicine and diet, but not surgery; ► [al-Rāzī](#) (Razes), who may have been a younger contemporary, cites Serapion, naming the *Kunnāsh*, and ‘Alī ibn ‘Abbās al-Majūsī (d. 994) criticizes Serapion for ignoring surgery. The *Small Kunnāsh* was translated into Latin by Gerard of Cremona (d. 1187) and entitled *Practica Joannis Serapionis dicta Breviarium*. There are many manuscript copies of this version and some early printed texts. Moses ben Mazliach translated Gerard’s version into Hebrew, and a manuscript of this translation still survives.

The younger Serapion is an even more obscure figure. He was the author of a treatise on drugs called *Kitāb al-adwiya al-mufrada*, which was translated into Latin as *Liber de medicamentis simplicibus* by Simon de Cordo of Genoa and Abraham of Tortosa in about 1290. The younger Serapion cannot have lived earlier than the eleventh century, because he cites among his authorities not only al-Rāzī, but also Ibn al-Wāfid (997–1075). There are many manuscript copies of the Latin translation, and several early prints. Usually the works of both Serapions appear together. In the Latin text, the author explains that he intends to collect and reconcile the views of Dioscorides and Galen on a wide variety of medicinal substances, and then to add in the opinions of others. In his chapter on pearls, for instance, he describes the generally accepted power of pearls to strengthen the heart; he then goes on to cite four Arab authorities on the effects of pearls on the eyesight, the blood, the nerves, melancholia, and as a dentifrice.

See Also

- [al-Rāzī](#)
- [Ibn al-Majūsī](#)

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Ibn Sīnā (Avicenna)

Mehdi Aminrazavi

Abū ‘Alī al-ḥusain ibn ‘Abdallāh ibn Sīnā (980–1037), also known as Avicenna, was born

in the city of Būkhārā in the Eastern part of Persia into an Isma‘ili family. He demonstrated an incredible genius for learning, and having mastered the *Qu’rān* and the sciences of his time, became a physician at age 16. Ibn Sīnā gained favor with the Sāmānid dynasty for having cured Prince Nūḥ ibn Manṣūr and was thus allowed to use the royal library. He mastered other sciences such as psychology, astronomy, chemistry, and pharmacology by age 18, and toward the end of his life said he had learned everything he knew by then.

Ibn Sīnā lived in a tumultuous time when different princes were engaged in a power struggle, resulting in his traveling from city to city. He first went to Gorgān, an area close to the Caspian Sea, crossing the desert on foot, and after a while traveled to Khorāsān, Rayy, and Qazwīn, until he finally settled in Hamadān at the request of prince Shams al-Dawlah. In 1022, following the death of the prince, Ibn Sīnā went to Iṣfahān where he found the peace and serenity that the intellectual life demands. In 1037 while traveling with ‘Alā’ al-Dawlah he became ill and died as the result of colic. He is buried in Hamedan.

Ibn Sīnā gained the title of *Shaykh al-Ra’īs* (Master of the Wise) because he composed numerous treatises, 276 of which have been alluded to by his commentators. It is noteworthy that he wrote a great number of these works on horseback while fleeing from one city to another.

Ibn Sīnā’s most extensive and elaborate work is *Kitāb al-shifā’* (The Book of Healing) which itself consists of four segments: *al-Manṭiq* (Logic), *Tabī‘iyyāt* (Natural Philosophy), *Riyāḍiyyāt* (Mathematics), and *Ilāhāyyāt* (Metaphysics). To this monumental work should be added *Kitāb al-nijāt* (The Book of Deliverance), a synopsis of the *Shifā’*, and his last major work *al-Ishārāt wa’l-tanbīhāt* (The Book of Directives and Treatments). Among his other philosophical works are *‘Uyūn al-ḥikmah* (Fountain of Wisdom), *Kitāb al-hidāyah* (The Book of Guidance), *al-Mabda’ wa’l-ma’ād* (The Book of Origin and End), and the first major work written in Persian for ‘Alā’ al-Dawlah, *Dānishnāmah-yi ‘Alā’ ī* (The Book of Knowledge). Finally, there are a few works

which are mystical and visionary, such as *Ḥayy ibn Yaqẓān* (Son of the Living Awake), and *Risālat al-ṭaīr* (Treatise of the Bird).

Ibn Sīnā was a great synthesizer in that he not only incorporated the ideas of some of his predecessors such as ► [al-Kindī](#) and al-Fārābī, but also made extensive use of Greek philosophy, in particular Neoplatonism, Plato and Aristotle. From Plotinus he adopted the emanation scheme, from Plato his theory of archetypes, and from Aristotle his logic, physics, and psychology. The genius of Ibn Sīnā was in interpreting these different thoughts within the unitary matrix of Islam.

Ibn Sīnā has been called “philosopher of being” for he brought the question of being and the study of ontology to the forefront of philosophical debates and thereby corrected a deficiency that he saw in Greek philosophy, in particular in Aristotle. Ibn Sīnā divided all beings into three categories: necessary, contingent, and impossible. Furthermore, he argued that existent beings were made up of an essence and existence. This distinction became the central theme of medieval ontological discussions as well as of the subsequent debates within the Islamic philosophical tradition.

Ibn Sīnā, who had studied the Ptolemaic and Aristotelian systems, adopted the Islamic astronomical view based on the nine spheres and interpreted them within the scheme of the emanation of intellects. Each order of intellect accordingly corresponds to one of the heavens. For example, the second intellect corresponds to the highest heaven which is located above the fixed stars, and the tenth intellect corresponds to the moon below which the corporeal domain of our world is located.

Medicine

Ibn Sīnā was in the tradition of such grand Muslim physicians as ► [al-Rāzī](#) and al-Majūsī. By the age of 20, he had already become an accomplished physician and gained the respect of the court for having cured several members of the royal family. Eventually he came to be known as

the “prince of physicians”. He is the author of the *Qānūn al-ṭibb* (The Canon of Medicine), which became a standard text both in the Christian West and the Islamic world. In addition to his *magnum opus*, Ibn Sīnā wrote a number of treatises on medicine both in Arabic and Persian some of which deal with particular diseases. He also wrote a book in which principles of medicine are written as poetry in order to facilitate their memorization by medical students.

In medicine, Ibn Sīnā was in many ways a follower of Greek ideas on medicine. However, he made the following revisions:

1. Unified the central principles of Greek medicine and interpreted them within an Islamic framework.
2. Made the theoretical and practical aspects of medicine represent a unified whole.
3. Documented the effects of medications on the body and commented on the necessity of a methodology in the study of pharmacological issues.
4. Introduced a number of medications and treatments for illnesses unknown to Greeks.

Ibn Sīnā believed that the science of medicine was divided into two categories, theoretical and practical. Illnesses were brought about either by internal or external causes. Internal illnesses were caused by an imbalance of temperament in the human body. These causes could also be the result of psychological elements.

Ibn Sīnā is known to have prescribed a variety of treatments for ailments, ranging from psychotherapy and diet to exercising. In the first volume of the *Canon of Medicine*, he states that medicine is the science of knowing the structure of the human body, and he goes on to discuss the fundamental principles necessary to maintain human health. He discusses surgery as an independent branch of medicine and elaborates on the science of anatomy. In the second volume, Ibn Sīnā explains various healing properties of simple and compound drugs and their various applications. In the third and fourth volumes, he presents his diagnosis of a variety of illnesses known to him, ranging from meningitis and cancer to

tuberculosis and gastrointestinal illnesses. In the fifth volume of this work, Ibn Sīnā offers an extensive discussion of pharmacology, providing a detailed description of the effects of medications on body.

Some of his observations are extraordinarily advanced for his time. For example, he attributed the cause of plague to mice, commented on a number of contagious diseases, used single hair lines of horses for stitching after surgery, experimented with various drugs as anesthetics when operating on patients, described surgical processes for many operations such as gall bladder, used spices to stop bleeding after surgery, and understood the relationship between temperature and the spread of diseases. He even experimented on animals using different drugs.

Ibn Sīnā's treatment of the subject of psychology as a science which is both independent and part of the field of medicine is extensive. He first argues for the existence of a soul which is rather similar to the Aristotelian *psyche* and then shows how this incorporeal part of man interacts with his corporeal dimension. Ibn Sīnā then goes on to say that the health of the body to a large extent depends on the health of the soul and he offers much elaboration on that point throughout his works.

Perhaps one of the most important contributions of Ibn Sīnā to the field of medicine is the technical medical terminology which he introduced and which is still used by physicians in the Islamic countries.

Psychology

In *The Book of Healing*, Ibn Sīnā treats the subject of the "three kingdoms" (minerals, plants, and animals). He extends the hierarchy of the incorporeal world to the material world, concluding that whereas each domain has its soul it is only in humans that these souls reach their completeness. Ibn Sīnā's treatment of the human soul, its relationship with the body and the active intellect, is extensive. He introduces

five internal senses and their equivalent five external senses.

The scope of Ibn Sīnā's writings on sciences includes such topics as motion, the process of sedimentation, and classification of minerals in the *Shifā'*, which came to be known in the West as *De mineralibus*. In a famous debate with ► [al-Bīrūnī](#), Ibn Sīnā responded to ten questions on Aristotle's *De Caelo* and eight other questions such as how vision is possible, the relationship between water and light, the nature of a vacuum, heat, cooling, and how it is that ice floats on water.

Ibn Sīnā's philosophy remained the dominant philosophical school in the medieval west where he became known through translations of his works in Islamic Spain by Avendeuth, who was a Jewish philosopher and Gerard of Cremona. The Sicillian school also benefited much from Ibn Sīnā who was translated by Michael Scot. Ibn Sīnā's works continued to be translated through the sixteenth century influencing such western philosophers as the Augustinian Gundisalvo, Albertus Magnus, William of Auvergne, Alexander of Hales, Roger Bacon, and Duns Scotus.

Ibn Sīnā left an indelible mark on the history of science, medicine, and philosophy.

See Also

► [al-Kindī](#)

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Ibn ʿTāwūs

Zeina Matar

Raḍī al-Dīn Abū-l-Qāsim 'Alī ibn Mūsā ibn Ja'far ibn Muḥammad ibn Aḥmad ibn Muḥammad ibn ʿTāwūs was a religious scholar, historian, and astrologer. He was born in al-ḥilla (Iraq) on 15 Muḥarram 589/21 January 1193. He belonged to a distinguished family of scholars, the Banū ʿTāwūs, whose ancestry can be traced back to 'Alī ibn Abī Ṭālib.

Ibn ʿTāwūs grew up in the town of al-ḥilla, which had been established by the famous scholar Abū Ja'far al-Ṭūsī (385–458/995–1066) as a center of learning boasting five *madrasas* (institutions for the study of the Islamic sciences). Ibn ʿTāwūs spent his formative years in his native town, and in Baghdad where he lived for 15 years. He made pilgrimages to the holy Shīʿī shrines of Najaf, Kerbela, and al-Kazimayan. He had a reputation for saintly powers, and concerned himself extensively with popular religious practices.

Ibn ʿTāwūs concentrated mainly on devotional literature, but he also wrote in the fields of history and astrology (see the listing of primary sources in the bibliography). In AH 650/AD 1252, he owned over 1,500 volumes in his private library. Professor E. Kohlberg of the Hebrew University of Jerusalem has contributed a superb reconstruction of this library and a detailed critical analysis of the works it contained.

Ibn ʿTāwūs was one of the most prolific medieval Shīʿī scholars, who aimed at providing the believer with a set of guiding moral and ethical principles. The sources stress his “erudition, knowledge, asceticism, devoutness, trustworthiness, understanding of *fiqh* (science, or knowledge), loftiness and godfearingness [along with his talents as] poet, man of letters, writer, and eloquent speaker” (Āghā Buzurg Tihirānī 1983). A man of deep faith, concerned with religious matters, Ibn ʿTāwūs could also display wisdom

in sensitive political situations, as in this apocryphal story:

When Sultan Hulagu conquered Baghdad in 656/1258, he ordered that the scholars give an opinion on which was preferable: the unbelieving but just sultan, or the Muslim despotic one. The scholars were then gathered in al-Mustaṣiriyya for this purpose. They refrained from answering. Raḡī al-Dīn ‘Alī Ibn Ṭāwūs was present at this Council. When he saw their hesitation, he took the *fatwa* (fatwa, legal opinion), and wrote that the unbelieving but just ruler was preferable to a Muslim despot.

Although Ibn Ṭāwūs declined the office of Naqābat al-Ashrāf under the Caliph al-Mustaṣir (d. 640/1242), he apparently changed his mind during the Mongol Period, and received the title from ► [Naṣīr al-Dīn al-Ṭūsī](#) (d. 672/1273). This important office, which had originated under the Buwayhids (also Buyids, a dynasty in Persia and Iraq, 320–454/932–1062), enabled the Sayyid families to represent their community in political, religious, and scholarly matters.

The date on which Ibn Ṭāwūs died in Baghdad is generally accepted as 5 Dhū-l-qa ‘da 664/9 August 1266, and he was probably buried in Najaf.

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Ibn Tibbon

Emilia Calvo

Ibn Tibbon, Jacob Ben Machir, is known as Profeit in Romance languages and as Prophatius Judaeus in Latin. These names come from the translation of *mehir* (prophet) into the languages of Southern France.

Ibn Tibbon was probably born in Marseille ca. 1236. His family was originally from Granada and, for four generations, had been devoted to the translation of Arabic religious, philosophical, and scientific texts. Through these translations, Arabic learning and therefore Greek scientific traditions were made available to the scholars of medieval Europe. Ibn Tibbon studied medicine at Montpellier and probably lived in Gerona, Spain between AD 1266 and 1267. He spent most of his life in Lunel, where his great-grandfather had established and practiced medicine at the beginning of the twelfth century, and Montpellier where he died in AD 1305.

Ibn Tibbon translated works by Autolycus of Pitane, Euclid, Menelaus of Alexandria, Qusṭā ibn Luqa, Ibn al-Haytham, Ibn al-Ṣaff īr, ► [Ibn al-Zarqāllu](#), al-Ghazālī, ► [Jābir ibn Aflaḥ](#), and Ibn Rushd from Arabic into Hebrew.

He is also the author of some works dealing with astronomy:

Roba ‘Yisrael (Quadrant of Israel), written between AD 1288 and 1293, in which an astronomical instrument, called the *quadrans novus*, is described. It consists of a simplification of the face of the astrolabe. Some examples of this instrument have been preserved.

The *Almanac*, calculated for Montpellier and dated 1 March 1300. It is based on Ibn al-Zarqāllu's reelaboration of Awmātiyūs' almanac, although the author says that he has used the Toledan Tables, which is incorrect.

Ibn Tibbon is also the author of the Prologue to Abraham bar Hiyya's *Sefer Hesbon Mahleket ha-Kokabim* (Calculation of the Courses of the Stars).

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Ibn Ṭufayl

E. Ruth Harvey

Abū Bakr Muḥammad ibn 'Abd al-Malik ibn Muḥammad ibn Muḥammad ibn Ṭufayl al-Qaisi was an Arab physician famous for his encyclopedic learning. He was born at Guadix in Granada (modern Spain) in the first decade of the twelfth century. He served local rulers as physician and diplomat, and eventually became the court physician to Abū Ya'qūb Yūsuf, the Almohad prince who became the most powerful Muslim ruler of his day. Ibn Ṭufayl enjoyed a close friendship with Abū Ya'qūb until the latter's death in 1184; he was esteemed and cherished

by Abū Ya'qūb's successor, Abū Yūsuf Ya'qūb, until his own death in 1185–1186.

Ibn Ṭufayl's importance for history is twofold: the influence of his unique work, *Ḥayy ibn Yaqzān*, and his patronage of one of the most important Muslim philosophers of the Middle Ages, Ibn Rushd (known to the west as Averroes). The medieval Arab historian, 'Abd al-Wāḥid al-Marrākushi, recorded that Ibn Ṭufayl would bring all sorts of learned men to his sovereign's notice. It was in this way that Ibn Rushd was given audience with Abū Ya'qūb Yūsuf, and there was led on by the praise and encouragement of Ibn Ṭufayl to demonstrate his familiarity with Aristotelian philosophical traditions. The Sultan himself joined in the discussion, and Ibn Rushd was commissioned to compose his great commentaries. It was through the mediation of Ibn Rushd's works that Aristotle was reintroduced to the Latin West. The astronomer al-Bītrūjī (known in the West as Alpetragius) was a disciple and friend of Ibn Ṭufayl; he mentions Ibn Ṭufayl's criticisms of the traditional astronomical theories on epicycles and eccentrics.

Ibn Ṭufayl was said to have written poetry as well as works on medicine and astronomy, but nothing seems to survive except *Ḥayy ibn Yaqzān* and (possibly) a poem on medicine recently rediscovered (see Russell, 1986). The highly unusual *Ḥayy ibn Yaqzān* (Life, Son of Awareness) is a philosophical tale in the form of a table: it tells how Ḥayy, cast up as a baby or spontaneously generated on an island, is fostered by a doe and grows to adulthood without any human contact whatsoever. Ibn Ṭufayl's interest lies in positing the natural unfolding of the human reason from the blank of infancy to the highest possible intellectual development; Ḥayy reaches the summit of human possibility in a mystical experience of the godhead. Eventually Ḥayy meets another human being who is so filled with awe at Ḥayy's intellectual and spiritual attainments that he persuades him to make an attempt to convert human society to wisdom. Humanity proves to be unworthy of Ḥayy's teaching, and Ḥayy and his new-found friend retreat back to the island again to spend the rest of their lives in contemplation.

Ḥayy ibn Yaqzān draws on the philosophy of Ibn Sīnā. It was edited as early as 1671 by Edward Pocock, who provided a Latin translation, thus inserting Ibn Ṭufayl's ideas into the mainstream of European culture. The *Philosophus Autodidactus*, as Pocock named it, was sent to Huygens, Locke, and Leibniz; it was possibly an influence on Defoe's *Robinson Crusoe*, and almost certainly one on Rousseau's *Emile*. English translations have been appearing since 1686; there are Dutch, German, French, Catalan, Hebrew, Persian, and Russian versions. It is still stirring up scholarly debate and controversy.

See Also

- [Ibn Rushd \(Averroës\)](#)
- [Ibn Sīnā \(Avicenna\)](#)

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Ibn Wāfid

Emilia Calvo

Ibn Wāfid Abū'l-Muṭarrif 'Abd al-Raḥmān ibn Muḥammad was a pharmacologist and physicist who lived and worked in Toledo during the first half of the eleventh century (ca. 1008–1075). He studied the works of Aristotle, Dioscorides, and Galen in Cordoba but then he moved to Toledo where he planted a botanical garden for the king of this city, al-Ma'mūn.

Ibn Wāfid is the author of a book entitled *Kitāb fī-l-adwīya al-mufrada* (Book on the Simple Medicines) which is a synthesis of Dioscorides and Galen. It is an extensive work to which the author devoted 20 years. It was abridged and translated into Latin by Gerard of Cremona. Translations into Catalan and Hebrew are also extant.

Ibn Wāfid is also the author of a pharmacopeia and manual of therapeutics entitled *Kitāb al-wisād fī 'l-ṭibb* (Book of the Pillow on Medicine) which, according to Juan Vernet, could be a misreading of the Arabic title *Kitāb al-rashshād fī 'l-ṭibb* (Guide to Medicine). This work can be considered complementary to the preceding one because Ibn Wāfid describes compound medicines in it, and it is a practical book: the information given is based on experience. Ibn Abī Uṣaybi 'a attributes to Ibn Wāfid a work entitled *Mujarrabāt fī-l-ṭibb* (Medical Experiences) which could probably be identified with this Book of the Pillow.

Ibn Wāfid is also the author of two works entitled *Tadqīq al-naẓar fī 'ilal Ḥāssat al-baṣar* (Observations on the Treatment of Illness of the Eyes) and *Kitāb al-Mughīth* (Book on Assistance) which are not preserved, and of a treatise

on balneology which is preserved in a Latin version entitled *De balneis sermo* (Venice, 1553).

Ibn al-Abbār attributes to Ibn Wāfid a book entitled *Majmuʿ al-Filāḥa* (Compendium of Agriculture) although his authorship is now being questioned.

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Ibn Yūnus

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Ibn Yūnus, Abu'l-ḥasan 'Alī ibn 'Abd al-Raḥmān ibn Aḥmad ibn Yūnus al-Ṣadafī was one of the greatest astronomers of medieval Islam. Unfortunately, nothing of consequence is known about his early life or education. As a young man, he witnessed the Fatimid conquest of Egypt and the founding of Cairo in 969. In the period up to the reign of Caliph al-Azīz (975–996), he made astronomical observations that were renewed by order of the Caliph al-ḥākim, who succeeded al-Azīz in 996 at the age of eleven and was much interested in astrology. Ibn Yūnus' recorded observations continued until 1003.

Ibn Yūnus' major work was a monumental *zīj* or astronomical handbook with tables. The *Ḥākimī Zīj*, dedicated to the Caliph, is

distinguished from all other extant *zīj*es by beginning with a list of observations made by Ibn Yūnus and others made by some of his predecessors. Despite his critical attitude toward these earlier scholars and his careful recording of their observations and some of his own, he completely neglects to describe the observations that he used in establishing his own planetary parameters – nor does he indicate whether he used any instruments for these observations. Indeed, the *Ḥākimī Zīj* is a poor source of information about the instruments he used. In view of the paucity of this information, it is remarkable that the statement that Ibn Yūnus worked in a “well-equipped observatory” is often found in popular accounts of Islamic astronomy. Sayili has shown how this notion gained acceptance in Western literature.

Ibn Yūnus' *Zīj* was intended to replace the *Mumtaḥan Zīj* of Yaḥyā ibn Abī Mansūr, prepared for the Abbasid Caliph al-Ma'mūn in Baghdad almost 200 years earlier. When reporting his own observations, Ibn Yūnus often compared what he observed with what he had computed using the *Mumtaḥan* tables.

The observations he described are of conjunctions of planets with each other and with Regulus, solar and lunar eclipses, and equinoxes; he also records measurements of the obliquity of the ecliptic (Chap. 11) and of the maximum lunar latitude (Chap. 38).

In spherical astronomy (Chaps. 12–54), Ibn Yūnus reached a very high level of sophistication. Although none of the several hundred formulae that he presents is explained, it seems probable that most of them were derived by means of orthogonal projections and analemma constructions, rather than by the application of the rules of spherical trigonometry that were being developed by Muslim scholars in Iraq and Iran.

The chapters of the *Zīj* dealing with astrological calculations (77–81), although partially extant in the anonymous abridgment of the work, have never been studied. Ibn Yūnus was famous as an astrologer and, according to his biographers, devoted much time to making astrological predictions.

Ibn Yūnus' second major work was part of the corpus of spherical astronomical tables for time-keeping used in Cairo until the nineteenth century. It is difficult to ascertain precisely how many tables in this corpus were actually computed by Ibn Yūnus. Some appear to have been added in the thirteenth and fourteenth centuries. The corpus exists in numerous manuscript sources, each containing different arrangements of the tables or only selected sets of tables. In its entirety, the corpus consists of about 200 pages of tables, most of which contain 180 entries each. The tables are generally rather accurately computed and are all based on Ibn Yūnus' values of $30^{\circ}0'$ for the latitude of Cairo and $23^{\circ}35'$ for the obliquity of the ecliptic. The main tables in the corpus display the time since sunrise, the time remaining to midday, and the solar azimuth as functions of the solar altitude and solar longitude. Entries are tabulated for each degree of both arguments, and each of the three sets contains over 10,000 entries. The remaining tables in the corpus are of spherical astronomical functions, some of which relate to the determination of the five daily prayers of Islam. The impressive developments in astronomical timekeeping in fourteenth-century Syria, particularly the tables of al-Khalīlī for Damascus, also owe their inspiration to the main Cairo corpus.

It is clear from a contemporary biography of Ibn Yūnus that he was an eccentric, careless, and absent-minded man who dressed shabbily and had a comic appearance. One day in the year 1009, when he was in good health, he predicted his own death in 7 days. He attended to his personal business, locked himself in his house, and washed the ink off his manuscripts. He then recited the *Qur'ān* until he died – on the day he had predicted. According to his biographer, Ibn Yūnus' son was so stupid that he sold his father's papers by the pound in the soap market.

See Also

- al-Khalīlī
- Al-Ma'mūn
- Yahyā ibn Abī Manṣūr

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Ibn Ṣuhr

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Abū Marwān 'Abd al-Mālīk ibn Ṣuhr (Latin: Avenzoar; 484–557/1092–1162) belonged to the

Arabian tribe of Iyād, Banū Zuh̄r. His father, Abū al-ʿAlā ibn Zuh̄r (d. 525/1131), was a respected physician in the courts of the Murābiṭ dynasty (482–541/1090–1147). He trained his son in the art and craft of medicine.

Like his father, Ibn Zuh̄r started his career in the service of the Murābiṭ dynasty and earned a good reputation. During the reign of ʿAlī ibn Tashfīn (499–537/1106–1143), he served at the palace in Marrakesh, Morocco, where his life was full of trials and tribulations. In ca. 535/1141, he was stripped of his official position and imprisoned. Although he was pardoned and released, he endured a hard life in prison and the experience left a resentment in his heart against the ruling dynasty.

The beginning of the reign of al-Muwāḥḥidūn proved to be a blessing for Ibn Zuh̄r. He was not only appointed as an official physician but also became a *wazīr* in the court of Abū Muḥammad ʿAbd al-Mūmin (d. 558/1163). During this period, Ibn Zuh̄r transmitted his knowledge and skills to his children with meticulous attention. His son and daughter both became famous physicians. One of Ibn Zuh̄r's treatises, *al-Tadhkirah* (The Remembrance), was dedicated to his son in appreciation of his achievements.

At least nine of Ibn Zuh̄r's works are known, but only a few are extant. He is said to have written two works and dedicated them to ʿAbd al-Mūmin. *Al-Aghdhīyyah* (On Dietetics) is a text on the therapeutic properties of selected foods. *Al-Tiryāq al-Sabʿīnī* is a book of antidotes against poisoning by enemies. This work, perhaps, was Ibn Zuh̄r's way of expressing gratitude to his benevolent patron.

Al-Taysīr fī al-Mudāwāt wa al-Tadbīr (On Preventive Regimen and Treatment), in 30 treatises, is considered to be his monumental work. His friend Ibn Rushd considered it a great source of medical knowledge and therapeutic advice. In its Latin version, *Alteisir scilicet regiminis et medelae*, the treatise remained in wide circulation across Europe for centuries. Both Arabic and Latin copies of this work are extant. True to the medical norms of his days, Ibn Zuh̄r presented in this work a mix of astrology and folklore blended with therapeutics and

pharmacology. *Al-Kulliyāt* (The Collection), a general compilation on medical practice, appears as an appendix.

The great historiographer Ibn Abi ʿUṣaybiʿah, in his encyclopedic work *ʿUyūn al-Anbā fī Ṭabaqāt al-Aʿibbā*, listed only seven of Ibn Zuh̄r's works:

1. *Fī al-Zīnah* (On Beautification)
2. *Al-Tiryāq al-Sabʿīnī* (On Antidotes)
3. *Fī ʿIlāl al-Kilā* (On Diseases of the Kidney)
4. *Fī ʿIllat al-Baraṣ wa al-Bahaq* (On Leprosy and Vitiligo)
5. *Al-Aghdhīyyah* (On Dietetics)
6. *Al-Tadhkirah* (The Remembrance)
7. *Al-Taysīr fī al-Mudāwāt wa al-Tadbīr* (On Preventive Regimen and Treatment)

He does not mention two of his treatises. One of the missing ones is *Al-Iqtisād fī Iṣlāḥ al-Anfūs wa al-Ajsād* (Treatment and Healing of the Soul and Body). Addressed to the general reader, it focuses on problems of hygiene and therapeutics. The second is *Jāmiʿ al-Asrār al-Ṭibb* (Compendium of Medical Wisdom). In addition to a discussion on dietetics, this work describes the physiology of several organs including the spleen, liver, and bladder.

Ibn Zuh̄r was a prolific writer and a highly successful medical practitioner. Some of his work showed the influence of the Hippocratic and Galenic traditions, but his original insights came from a rich family heritage in medical practice. Thus, going against the Greco-Roman medical dictates, Ibn Zuh̄r engaged in experimental work and recorded his observations. His detailed study of the pericardial abscess, pharyngeal paralysis, intestinal and mediastinal tumors, and inflammation of the middle ear were great improvements over the work of his predecessors.

Ibn Zuh̄r was one of the great Muslim clinicians and therapists. Through numerous translations of his works, he remained highly influential in the medical academies of the West. In his later age, he suffered from a malignant tumor that ultimately caused his death. He was buried in Seville, Spain.

See Also

► [Ibn Rushd \(Averroës\)](#)

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Ibrāhīm Ibn Sinān

Roshdi Rashed

Ibrāhīm Ibn ► [Sinān Ibn Thābit](#) Ibn Qurra was born in Baghdad in 296/909 where he died 37 years later in 335/946. Grandson of the famous mathematician Thābit Ibn Qurra, cousin of the

famous literary figure Hilāl al-Ṣābi', son of a great physician and mathematician Sinān Ibn Thābit, he thus belonged to an intellectual aristocracy whose members frequented the corridors of power and the upper levels of the worlds of science and medicine. Ibrāhīm was born into and raised in this world, before being the object of a short-lived persecution to which he makes allusion but explains neither the cause nor the duration. Ibrāhīm Ibn Sinān was not only the "heir" to great tradition, but also a mathematician of genius in his own right who made his own mark on the mathematics of his era.

Ibrāhīm Ibn Sinān was also heir to a historical tradition. He belonged to a privileged generation, the fourth since the ► [Banū Mūsā](#). The translation of the major mathematical texts had been essentially completed and the great traditions of research had already been well established: that of the algebraists, beginning with ► [al-Khwārizmī](#) and extended by ► [Abū Kāmil](#); that of the geometers, ► [al-Jawharī](#), ► [al-Nayrīzī](#), etc., who followed the work of Euclid; and the tradition of the Banū Mūsā which, thanks to mathematicians like Thābit Ibn Qurra, had already gathered considerable results, developed new methods, and elaborated theories. Ibrāhīm Ibn Sinān was clearly a part of this tradition in which Archimedean geometry, a geometry of measurement, and the geometry of Apollonius, which was concerned with the properties of positions, were all combined. Profiting from scholarly works, especially those of his grandfather Thābit Ibn Qurra, Ibrāhīm Ibn Sinān developed the study of geometric transformations and their applications to conic sections, as well as to the measurement of the area of a portion of a parabola. He extended their work on sundials in developing a theory of a whole class of instruments. Finally the questions posed by his predecessors about analysis and synthesis prompted him to write the first treatise worthy of the name on the subject.

Ibrāhīm Ibn Sinān explained the composition of his work in his own autobiography which happily still exists. He published the autobiography after his 25th year, in 934. According to his own account, he began his research at age 15; at 16 or 17 he had written a first version of his book

Fī Alāt al-aẓlāl (On Instruments of Shadows), which he revised at the age of 25. A year later he was discussing and criticizing Ptolemy's views on The Determination of the Anomalies of Saturn, Mars, and Jupiter (*Fī istikhrāj ikhtilāfāt Zuḥal wa al-Mirrīkh wa al-Mushtarī*) in a treatise that he completed 6 years later, at the age of 24. In geometry, Ibn Sinān wrote *Fī al-dawā'ir al-mutamāssa* (The Tangent Circles), *al-Taḥlīl wa'l-Tarkīb* (Analysis and Synthesis), *Fī al-masa'īl al-mukhtāra* (Selected Problems), *Fī misāḥat qif' al-maḥrūt al-mukāfī* (The Measurement of the Parabola), and the *Fī rasm al-quṭū 'althalātha* (Drawing of the Three Conic Sections). All these works had been published and revised before Ibn Sinān was 25.

To illustrate the approach of Ibn Sinān let us look briefly at his *Measurement of the Parabola*, beginning with what he wrote about his own studies:

My grandfather had determined the measurement of this section. But several contemporary geometers led me to understand that a work of ► *al-Māhānī* on the same subject, which they presented to me, was easier than my grandfather's. I was not pleased that al-Māhānī's work was more advanced than my grandfather's without there being one among us who surpassed his work. My grandfather had determined his result in twenty propositions. He proceeded from several arithmetic lemmas included in the twenty propositions. The question of the measurement of the section appeared to him clearly through the method of *reductio ad absurdum*. Al-Māhānī also proceeded from arithmetic lemmas. He then demonstrated his demand by the method of *reductio ad absurdum* in five or six propositions, which involved lengthy discussions. I myself then determined the measurement in three geometric propositions without recourse to any arithmetic lemma. I demonstrated the surface area of this same section using the method of direct proof, and I did not need the method of *reductio ad absurdum*.

In addition to expressing pride in his heritage and the certainty of an exceptional scholar, these remarks also reflect the qualities of Ibn Sinān as a mathematician: brevity, ease, and elegance.

Ibn Sinān's approach is the following: in a first proposition, he demonstrates that the affine transformation conserves the ratios of the areas in the

case of triangles and polygons; he then demonstrates in a second proposition that it is the same for the ratio of the area of a portion of a parabola to that of an associated triangle.

Ibn Sinān again had recourse to geometric transformations in his *Drawing of the Three Conic Sections*. In this treatise, he constructed an ellipse by transforming the circle by an orthogonal affinity – a process already found in the works of the ► *Banū Mūsā*. It was also by means of an affinity that he deduced all the hyperbolas of a particular hyperbola for which the latus rectum is equal to the transverse axis.

The intensity of mathematical activity, the large amount of work done, the new demands of brevity, elegance, and rigor in demonstration, as well as the general interest in geometric transformations, all led Ibn Sinān to take up the theory of analysis and synthesis again. Thus he published the first treatise devoted to this subject. He wrote "I found that the geometers of this time had neglected Apollonius's method of analysis and synthesis, as was the case for the majority of things I brought up, and that they had limited themselves just to analysis, limiting themselves to such a degree that they led analysis to the point of letting people think that this analysis was not the synthesis that they were doing."

In this treatise, Ibn Sinān undertook two tasks at once: one didactic, the other logical. On the one hand, he proposed a method (*Ṭarīq*) for geometry students which allowed them to solve geometry problems; on the other hand, he reflected on geometric analysis itself, proposing a classification of geometry problems according to their numbers and the hypothesis that they are to verify, and explaining for each class of problems the respective parts of analysis and synthesis.

There is not enough space here to take up, even very briefly, the works of Ibn Sinān. But the examples discussed above do show how this eminent geometer left his mark on all the fields in which he worked, including mathematics and philosophy. The import of his work can be discovered in the work of Ibn al-Haytham who followed up on the research of Ibn Sinān in his own treatise on analysis and synthesis and in his writings on sundials.

See Also

- Banū Mūsā
- Sinān Ibn Thābit
- Thābit Ibn Qurra

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Ikhwān al-Ṣafā'

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The 48 treatises composed by the Ikhwān al-Ṣafā' (Brethren of Purity) constitute an encyclopedia of the sciences which has had a long and influential career in Islamic civilization. The collection was prepared by a group of scholars who preferred

anonymity. This anonymity has generated considerable debate among historians over their identity. Current scholarship places the date of composition in the last half of the fourth AH/AD tenth century and the place of composition in Basra. This collection of treatises continues to play an important role in the intellectual milieu of modern Islam, especially among groups influenced by Shī'ite and Ismā'īlī ideas.

The treatises contain a strong gnostic element, an emphasis on esoteric knowledge that exists within the exoteric or phenomenal features of everyday life but is accessible only to the initiated. This interest in esoteric or inner knowledge does not imply that they were uninterested in the physical world. It is necessary to have a thorough understanding of nature in order to penetrate to the inner truth that it expresses. An appreciation of nature, therefore, is one of the first steps toward union with the Divine Knowledge.

Their gnostic orientation can be seen in the classification of knowledge proposed by the Ikhwān. The student begins with introductory or preparatory (*riyāḍiyy*) topics, advances to religious (*shar'īyy*) sciences, and finally reaches the highest or philosophic (*falsafīyy*) sciences. This system is at odds with traditional Islamic discussions of the arrangement of the sciences in that it seems to make religious sciences subordinate to philosophical or intellectual sciences. In the organization of their treatise, the Ikhwān begin with mathematical sciences and advance to physical sciences, human sciences, and finally metaphysical and revealed sciences.

The gnostic tendencies of the authors also appear in the Neo-Platonic and Neo-Pythagorean descriptions of cosmogony and cosmology embedded within these treatises. God created the universe through a series of emanations from himself. First to appear was Intellect, followed by its Archetypes and the World Soul. (Intellect, the Ikhwān tell us, instructs the World Soul through the Archetypes.) The World Soul, through further emanations, produces individual souls or faculties that individuate, or give form to, prime matter. The first of these individuating emanations were the nine celestial spheres (the invisible *primum mobile*, the sphere of the

fixed stars, and the spheres of the seven naked-eye planets: Saturn, Jupiter, Mars, Sun, Venus, Mercury, and the Moon), followed by the four terrestrial elements (fire, air, water, and earth). This represents the farthest separation of soul from God. Drawn by an irresistible desire for union with the unity of God, it commences a return ascent heavenward through a process of purification from the contamination of matter achieved through personal morality and deepening esoteric knowledge of the One.

The treatises contain little mathematical or scientific information that is new. The treatise on geometry (the second treatise of the collection) reports a few simple results from Euclid: the sum of the interior angles of the triangle is two right angles, an exterior angle is equal to the two opposite interior angles, etc. However, there is no discussion of the demonstrations that validate these facts. Rather, the Ikhwān are interested in facts only when related to other facts so as to provide insight into the deeper, esoteric, meanings of mathematical knowledge. Thus, they discuss the relation between sensory and intellectual geometry. This is followed by a discussion of magic squares (numbers placed in geometric arrays) and their almost magical usefulness as talismans. Interspersed with these discussions are meditations on the usefulness of intellectual geometry (because, as abstracted from the sensations, it exercises the soul to move beyond sensory phenomena toward the invisible reality) and on the necessity for human cooperation and brotherhood in the effort.

Astronomy (including astrology) is discussed primarily in epistles 3, 16, and 36. These discussions summarize the basics of Ptolemaic cosmography as a propaedeutic to historical astrology – the idea that historical cycles mirror the cycles of the planets through the heavens. Although the authors include some basic scientific information about the heavens, such as the sizes of the planetary spheres, along with some ideas from Aristotelian physics to describe their motions, it seems their primary interest lies in the hidden meaning of this information or astrology.

Although the treatises provide little insight into the state of intellectual activity in the

sciences, they give an intriguing glimpse of what the educated nonscientist knew about the results of scientific research as they existed in that time. As such, they offer a window into what might be called a subscientific culture, a culture aware of some of the results of science and mathematics but adapting these results for nonscientific (in this case, largely social and religious) purposes.

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Indigo in Bengal

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India was the home of tropical indigo. In the Middle Ages, its international market was catered to from western and northern India through the trading network of the Armenian and Muslim communities in the main, and to a lesser extent, through the Portuguese traders and the Dutch. Its Gangetic belt, including Bengal, cultivated the crop for domestic industrial use – for example, as a dye for cotton textiles that had become universal since the days of antiquity. The global scenario, however, began to change rapidly from the late seventeenth century when the European countries – especially Spain and France, and later on, England – started plantations in their respective American colonies. Indeed, the indigo technology that was developed in America under European initiatives was altogether different from what prevailed in India. The new technology subsequently arrived in Bengal when two West Indian planters, both French by nationality, opened up an indigo factory in 1772 near Chandannagar, which was then under French possession. A series of ventures followed, capable of competing internationally. Within a short span of time, Bengal could again invade the global market using the new technology, and it was able to recover India's glory. Its export evidently rose up from 1,200 maunds (1 maund = 37 kg.) in 1783 to 39,000 maunds in 1800 as against about 12,000 maunds and 14,000 maunds, respectively, from other countries. In 1815–1816, it supplied about

128,000 maunds leaving only a small market for Mexico. In 1831, there were about 830 indigo concerns in Bengal working with 518,000 bighas of land (1 bigha = 1,600 square yards). They generated about 407,000 direct jobs in factories and 518,000 indirect jobs in agriculture.

Though the indigo dye industry developed rapidly in Bengal using foreign technology, the indigenous technology was not altogether lost in the local society. It was widely used for the dying needs of the cotton textile industry. For topical interest, therefore, both technologies are discussed here. We discuss first the plantation aspects of this dye and then deliberate on how it was processed under indigenous and foreign technologies. In view of the latter's importance, it is discussed at length.

Planting of Indigo

There were two types of indigo sowing in lower Bengal: wet (*cheetānee*) sowing and dry (or cultivated) sowing. The former took place in islands (*churs*) and other muddy stretches along the rivers, where alluvia were richly deposited. Sowers scattered their seeds over land in February, usually carrying long bamboo sticks to negotiate the mud – which was often waist or neck deep – and a cane-made basket of seeds (Fig. 1). A head servant of the factory (*āmun*) accompanied them in a small boat (*panchorey* or *dinghy*) to replenish seeds from time to time and to supervise their jobs. Where the mud deposits were deep, the sowers sailed through on a raft of three plantain-tree stems, fastened together, carrying a spirally bound cane basket which could float on the water. When the seeds were thus sown, they sunk 2–3 in. according to their own weights and sprang up in about a week. After the heavy rains during June–July, the plants grew luxuriantly and became fit for harvesting. This cultivation was least expensive, save in weeding, but highly productive insofar as the content of dye was concerned.

The cultivated sowing, i.e., sowing by tillage, took place in October. Thanks to the alluvial soils in lower Bengal, there was neither any need for



Indigo in Bengal, Fig. 1 The *cheetānee* sowing (Source: Reid, The culture and manufacture of indigo)

drilling before the plow, nor for any use of the roller afterward. Every plowing was, however, followed by dragging of a *moi* (made of a large bamboo frame) over it to pulverize the clods. When the soils were thus ready after several plowings, the seeds were broadcast, the *moi* was applied for the last time, and the land was left for the plants to grow. Once they emerged, the field required continuous weeding so that the plants got adequate nutrition. They became ripe and fit for harvesting by about the end of June when flowers began to blossom.

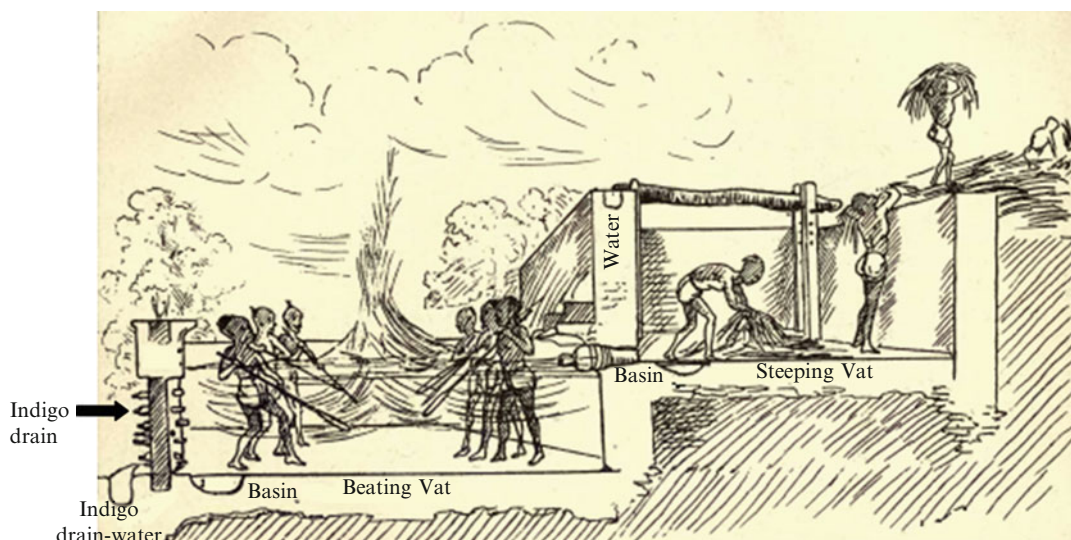
Plants were cut leaving the stalks (i.e., where there were no green or yellow leaves) so that there were further buds and shoots for a second, or even a third, cutting. After harvesting, however, they were carted as soon as possible to the vats since fresh leaves provided a higher productivity.

Processing Under Indigenous Technology

The main raw materials in this process were indigo plants, alkaline ley, and *chākunda* seeds (*Cassia Tora* W.). To prepare the alkaline ley,

a dyer took a given amount (say 20 sers, 1 ser = 0.933105 kg.) of fresh burned roots and stems of the plantain tree. Those were put into a large earthen pot that had a hole in the bottom with a filter of grass over it. Through the filter the dryer slowly poured 60 sers of water, which tuned out as alkaline ley. Another solution was prepared by boiling 1½ sers of *chākunda* seeds in 5 sers of water. Indigo plants were also broken into small pieces so that all the raw materials were readily available when the processing commenced.

There were four stages of processing in the indigenous technology. In the first stage, the dryer took about 60 sers of alkaline ley and five sers of indigo plants together in an earthen tub or vat and stirred them for about 3 h. Those were then equally divided into two pots. In the second stage, half of the *chākunda* solution, prepared earlier, was poured into each of those pots and boiled on a *chulā* (a native furnace) throughout the night. The third stage started the next morning when the decoction was stirred with a stick for about 1½ h. These boiling and stirring processes were repeated for four consecutive nights and mornings. Finally, the solution was filtered by pouring it on another earthen pot where a bunch



Indigo in Bengal, Fig. 2 Indigo manufacturing (Source: Reid, The culture and manufacture of indigo)

of straws were placed as a filter. Five sers of indigo dye provided good color to six sers of cotton thread and $2\frac{1}{2}$ sers of silk.

Processing Under Foreign Technology

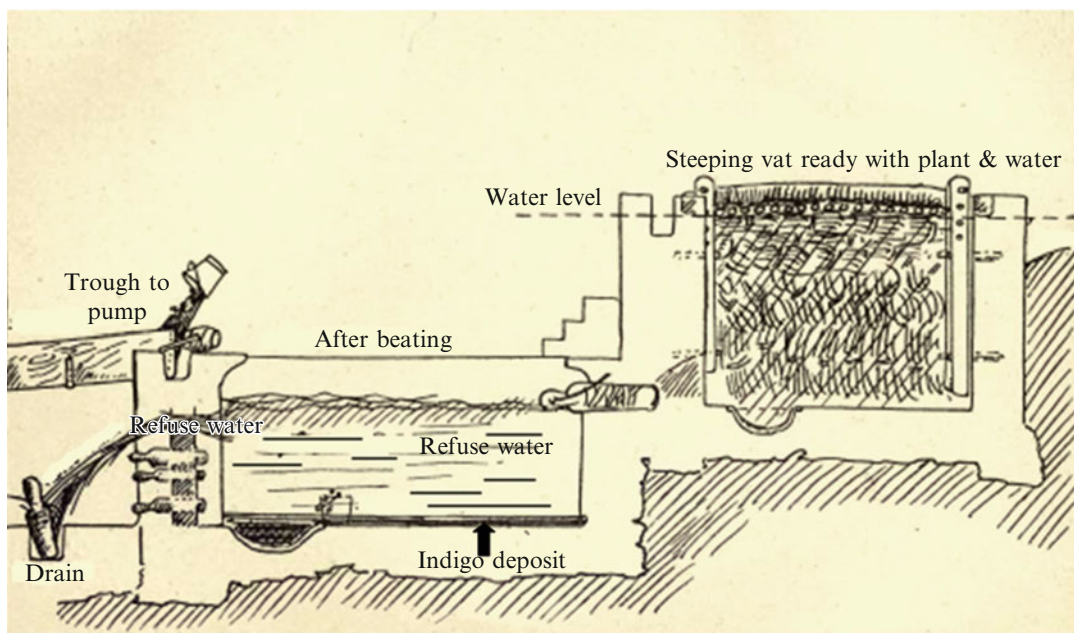
The imported technology had also four distinct stages of processing, though not necessarily bearing any resemblance to those under the indigenous technology. The stages were steeping, beating, boiling, and drying. All these processes were accommodated compactly in contemporary indigo firms.

Steeping: A large amount of water was required for steeping indigo plants. To get its regular supply, indigo works usually depended on wells or canals connected to perennial rivers. Water was first collected from those sources into a reservoir. The reservoir was made of brick walls, about 2–3 ft high, large in size (for exposing maximum water to the sun), and shallow in depth so that impurities might quickly subside. There was a cock in the reservoir enabling the flow of water to the steeping vat. Never was it fixed at the bottom, but a few inches above it, so that heavy impurities were prevented from flowing outward. The steeping vat was also brick built, about 3 ft high, with a diameter of

20 × 30 ft (Fig. 2). Its upper edge ran parallel to the cock of the reservoir for a smooth flow of water, whereby a brick-built channel was laid to connect them.

The main task in the steeping process was to extract the coloring particles from indigo plants that had been brought from the field. To accomplish this, the steepers put those plants in the steeping vat in a square structure so that the impregnated water could run off freely, and covered them with bamboos, weighted by beams across them, to keep them submerged in water. Finally, the reservoir was unpinned allowing water to flow in until the weeds were just covered (Fig. 3). In that state, they were left for 9–18 h for infusion and fermentation. The process was completed when the froth began to break with dull-looking bubbles appearing. The infusion was then drawn out of the weeds through a plug near the bottom of the steeping vat and collected into the beating vat. In the case of a well-fermented vat, the first burst after the opening of the pin should be bright orange. It would be reddish, when over fermented, and yellow otherwise.

Beating: The beating vat resembled the steeping vat in size and shape. Its upper edge was set at the foot of the latter so that the infusion could flow gently thereto (Figs. 2 and 3). The only difference was that its sides were curved



Indigo in Bengal, Fig. 3 Indigo vat (Source: Reid, The culture and manufacture of indigo)

inward at the top to prevent the liquor from splashing out during beating. There were three or more cocks, one above the other, by which clear water was gently drained away from the surface.

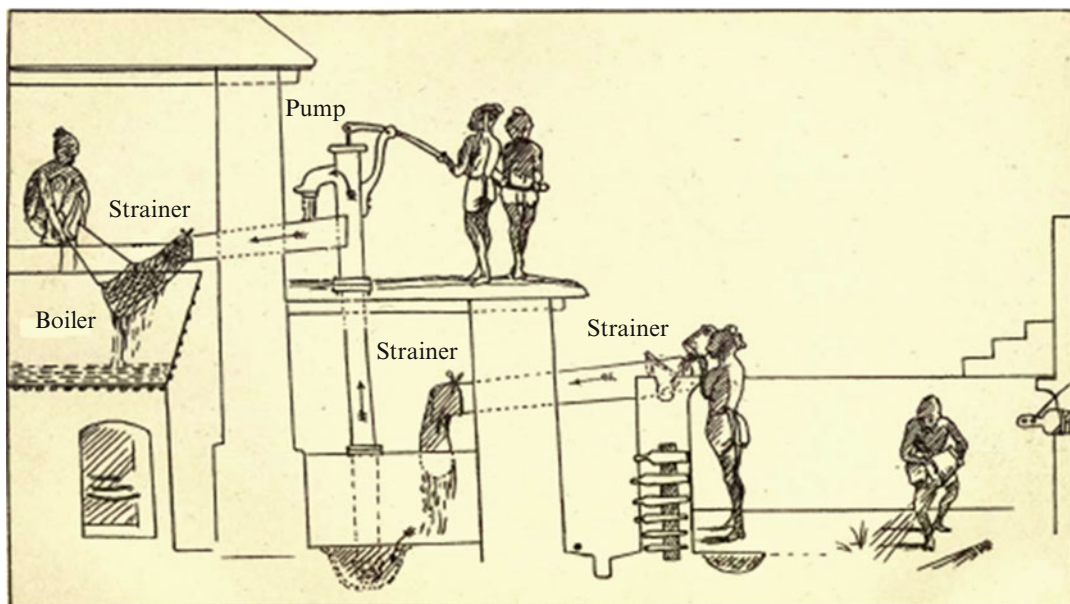
The task in this stage was to generate indigo granules by impregnating coloring particles, which were suspended in the water, with oxygen. To perform this task, 10–12 men were deployed in the beating vat. They stood in two rows of 5–6 each facing each other and beat the infusion as much as possible with wooden paddles or staves to mix air with it. During this operation, the liquor changed in color from bright to dark green, then to purple, and finally to dark purple blue, when the coloring particles were adequately impregnated with oxygen. When impregnation was done, the coloring particles became insoluble in water and united into a solid substance, which was called *facula* (*māl*). The grains were then allowed to settle at the bottom. Often, lime (*chunam*) water was added with it to prevent putrefaction afterward in the indigo. The beaters again came inside the vat and ran around several times to give the liquor a rotatory movement. They then quickly jumped out allowing the *facula*

to settle down again. The entire process took about 2–3 h.

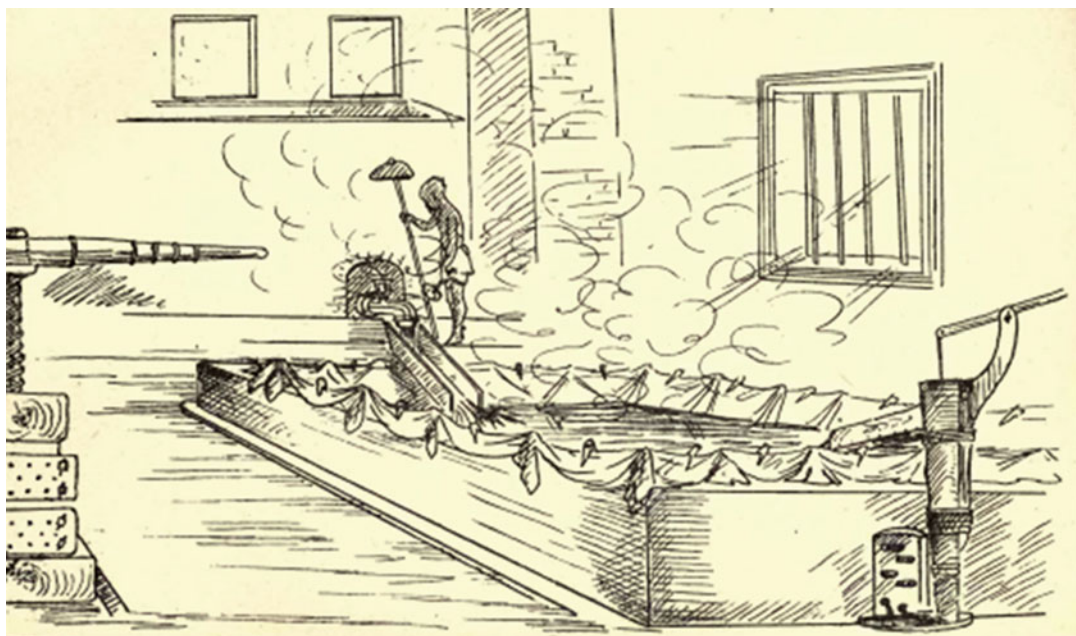
Once the indigo granules settled at the bottom of the vat, the pins were opened up one after another in descending order so that the refuse water was gently run off, and the granules remained at the bottom. Those were then collected in buckets and poured into a reservoir under the boiler pump (Fig. 4).

Boiling: The boiler was a square, brick-built furnace with a large cauldron of iron (or copper) in the center. The *facula* that had already been put into the reservoir was pumped into the cauldron through two strainers, one at the mouth of the pump and the other over the cauldron (Fig. 4). The fire was then lit, and the *facula* was boiled for about 3 h. While boiling, it was stirred occasionally to prevent it from settling and sticking to the bottom. In this process, the *facula* was thickened, giving its particles a strong tendency to cohere.

Drying: After boiling, the moist indigo was poured on a draining table. It was made of transverse bars, surrounded by a ledge (Fig. 5), and covered with a sheet of cloth before beginning this processing. When the boiled indigo was put



Indigo in Bengal, Fig. 4 Pumping up of indigo (Source: Reid, The culture and manufacture of indigo)



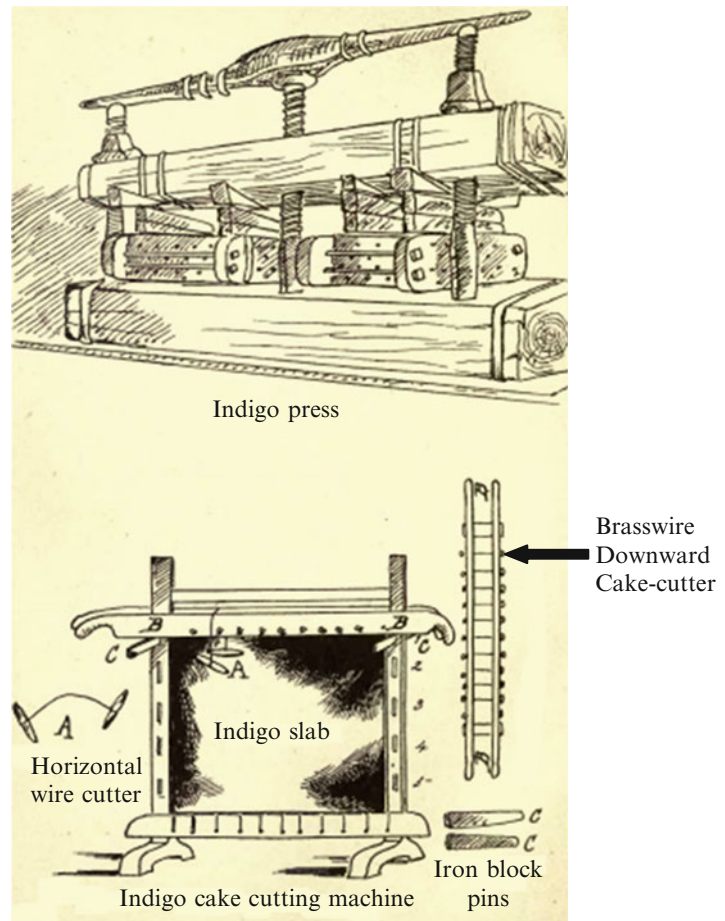
Indigo in Bengal, Fig. 5 Indigo table (Source: Reid, The culture and manufacture of indigo)

on the table sheet, some facula ran out with the water. Those were at once pumped back into the sheet. The process continued until the water ran off perfectly clear.

The facula thus processed still contained some amount of water. To remove it, three more drying methods were followed. First, the table sheet on which the previous processing took place was

Indigo in Bengal,

Fig. 6 Indigo press and cake cutting machine
(Source: Reid, The culture and manufacture of indigo)



folded over the facula, and weights were put on to press it. This removed some amount of water from the matter. Second, the facula was then processed under screw presses. To do this, the dryer took up square boxes, which were perforated with holes on all sides, and lined with pressing cloth. The moist indigo was poured into those boxes and covered with the cloth on all sides so that when pressure was exerted on the matter, its aqueous content came out through the holes after it was filtered by the cloth. The boxes were then put under gentle pressure in the screw press (Fig. 6). The pressure was increased as the indigo hardened and assumed a shape of a bar. When adequately hardened, the bars were removed from the boxes and cut into cubes by a brass wire. Finally, the indigo cubes were brought in

the drying room and placed on the mats that were laid on shelves in tiers. The cubes were sprinkled with wood ashes to prevent flies from laying their eggs on them. When they were perfectly dried, they were cleaned with soft brushes and packed for dispatch.

The indigenous technology thus involved less sophistication than the foreign technology and should be less expensive. This was indeed confirmed in contemporary sources. Each maund of indigo dye evidently cost Rs. 16 under the former technology and Rs. 92 under the latter. Quality wise also, they were highly comparable. Montgomery Martin said, "Whether or not the European dyers have used judgement in rejecting the original and cheap manufacture of India, I cannot say . . . but there is no doubt that the dye produced

by the Indian kind is perfectly good. . . . [T]he Indian drug is . . . equally effectual, and probably easier wrought than the European. . .” (Martin, 1976, p. 986). But the Indian indigo was less productive so that a larger amount was required for a given end. Notwithstanding a lower unit cost, a higher total cost was thus implied. Moreover, it involved higher freight charges also, which was crucial for a distant market. It was, therefore, doubtful whether Bengal’s indigenous technology enjoyed comparative advantages in the European market.

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- Japan was finding the length of a meridian by Japanese measure. Since Sino-Jesuit works had set zero longitude at Beijing, that of Japan had to be accurately measured so that, in predicting a solar eclipse, the Sino-Jesuit method could be employed for the Japanese longitude. After making over 2,000 measurements of latitude, Ino calculated the length of a meridian which agreed (within several tenths of a second of a degree) with the figure given in the Dutch translation of Lalande’s *Astronomie* which had been imported into Japan.

He did not excel in devising new methods or new theories in either astronomy or geodesy. While he was active, knowledge of Western astronomy was available through Dutch translations and Sino-Jesuit works and after, through the works of Lalande. But Ino had no knowledge of Dutch or dynamics and little understanding of astronomical theories. When calculating the length of the meridian, he considered the earth as a perfect sphere rather than a spheroid. Moreover, when observing the position of fixed stars, he did not take into account the effects of refraction, parallax, or nutation.

In his surveying, Ino did not use modern triangulation but relied upon the old traverse method. His mapmaking approach resembled the Sanson-Flamsteed method (it is presumed that his method was developed independently), which is appropriate only for small areas. Ino none the less used the method for an area as large as all of Japan. Despite Ino’s scientific failings, his map of Japan, based upon surveys covering the length and breadth of the land, has an important place in geographical history.

Ino Tadataka

Nakayama Shigeru

Ino Tadataka, 1745–1818, was a Japanese cartographer and an energetic field observer. A major astronomical and geodetic problem of the time in

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- Most of Ino’s works, consisting mainly of maps, observations, records of his surveys, field notes, and diaries are preserved in the Ino Memorial Hall in Sahara City.
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Inoculation

Subhash Kak

The first reliable account of inoculation is found in the eighteenth-century reports by British doctors concerning the Indian treatment of smallpox. In the method, believed to have been discovered sometime before AD 1000 in India (Henderson & Moss, 1999), one deliberately inoculated, either into the skin or by nasal insufflation, scabs, or pustular material from lesions of patients. This resulted in an infection that was usually less severe than an infection acquired naturally. From India, the practice spread to China, western Asia, and Africa and finally, in the early eighteenth century, to Europe and North America.

It appears that the idea of inoculation derived from both *agada-tantra*, one of the eight branches of traditional Āyurveda (Indian medicine) that deals with poisons and toxins in small dosages, and from the application of specific concoctions to punctures in the skin for treatment of certain skin diseases (► *Suśruta Samhitā* in *Cikitsāsthāna* 9.10). The ► *Caraka Samhitā* speaks of how deadly poisons can be converted into excellent medicine and how two toxins can be antagonistic to each other. The *Samhitas* speak of organisms that circulate in the blood, mucus, and phlegm. In particular, the organisms in the blood that cause disease are said to be invisible.

The *Suśruta Samhitā*, Chap. 54 of *Uttaratantra* or *Kāyacikitsātantra* (General Medicine), suggests a treatment regimen that includes avoidance of fatty foods and sweets. In the *Nidānasthāna* (Diagnosis), Chap. 5, it is indicated that physical contact and sharing the same air can cause such diseases to spread. Later, in Chap. 13, there is mention of the eruptive boils of the disease *masūrikā*. It appears that originally it meant chicken pox, but by the twelfth century the term was also being used for smallpox, as in the case of the commentator Dalhana.

The best source concerning the Indian method of treatment of smallpox is a report by Dr. John Z. Holwell in 1767 for the College of Physicians in London. This report is an excellent source for understanding the mind of the Ayurvedic doctor of the eighteenth century.

Holwell says that inoculators are delegated for this service from the different Colleges of Bindoobund [Vrindavan], Eleabas [Allahabad], Banaras, &c. over all the distant provinces; dividing themselves into small parties, of three or four each, they plan their traveling circuits in such wise as to arrive at the places of their respective destination some weeks before the usual return of the disease (Holwell, 1971, pp. 150–151).

One would presume that they were Ayurvedic vaidyas or their assistants.

They inoculate indifferently on any part, but if left to their choice, they prefer the outside of the arm, midway between the wrist and the elbow, for the males; and the same between the elbow and the shoulder for the females. Previous to the operation the Operator takes a piece of cloth in his hand, (which becomes his perquisite if the family is opulent) and with it gives a dry friction upon the part intended for inoculation, for the space of 8 or 10 min, then with a small instrument he wounds, by many slight touches, about the compass of a silver groat, just making the smallest appearance of blood, then opening a linen double rag (which he always keeps in a cloth round his waist) takes from thence a small pledget of cotton charged with the variolous [smallpox] matter, which he moistens with two or three drops of the Ganges water, and applies it on the wound, fixing it on with a slight bandage, and ordering it to remain on for 6 h without being moved, then the bandage to be taken off, and the pledget to remain until it falls off itself. . . . *The cotton which he preserves in a double callico rag, is saturated with matter from the inoculated pustules of the preceding year, for they never inoculate with fresh matter, nor with matter from the disease caught in the natural way, however distinct and mild the species.*

The patient was to abstain from fish, milk, and ghee before and after inoculation for a period of

1 month. Holwell claimed that when the inoculation regime was strictly followed, it is next to a miracle to hear that it “failed in one in a million.” He added that since this practice of the East has been followed without variation, and with uniform success from the remotest known times, it is but justice to conclude, it must have been originally founded on the basis of rational principles and experiment.

This is how Holwell described the explanations offered to him by Ayurvedic vaidyas:

The *immediate* (or instant) cause of the smallpox exists in the mortal part of every human or *animal* form; that the *mediate* (or second) *acting* cause, which stirs up the first, and throws it into a state of fermentation, is multitudes of *imperceptible animalculae* [microorganisms] floating in the atmosphere; that these are the cause of all epidemical diseases, but more particularly of the smallpox; that they return at particular seasons in greater or lesser numbers... That these animalculae touch and adhere to every thing, in greater or lesser proportions, according to the nature of the surfaces they encounter; that they pass and repass in and out of the bodies of all animals in the act of respiration, without injury to themselves... smallpox is more or less epidemical, more mild or malignant, in proportion as the air is charged with the animalculae, and the quantity of them received with the food. (Holwell, 1767, pp. 155–156)

Holwell understood the idea behind inoculation in this manner:

That when once this *peculiar* ferment, which produces the smallpox, is raised in the blood, the *immediate* (*instant*) *cause* of the disease is totally expelled in the eruptions, or by other channels; and hence it is, that the blood is not susceptible of a second fermentation of the same kind.

In other words, he believed that when the disease in its natural form or when introduced in its weak form by the inoculation had run its course, the patient was safe. The difference between these two forms was that in its natural course it is often fatal, whereas when introduced through inoculation, it was only an inconvenience.

It is significant that the spread of disease was taken to be caused by the imperceptible animalculae (microorganisms). This old insight

of the *Āyurvedic Samhitās* was a forerunner to the germ theory of disease that arose in the nineteenth century.

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Iron Pillar at Delhi

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The Delhi iron pillar (Fig. 1) is testimony to the high level of skill achieved by the ancient Indian ironsmiths in the extraction and processing of iron. Hadfield (1912) undertook the first systematic scientific study of the Delhi iron pillar. Results of scientific studies conducted in 1961 were summarized in a special issue of the *NML Technical Journal* (Vol. 5, 1963). A review of its corrosion resistance appeared in 1970 (Wranglen, 1970). While Anantharaman (1997) has reviewed the known scientific facts about the Delhi iron pillar, Balasubramaniam (2002, 2005) has compiled several new insights into the historical, scientific, and technical aspects of the Delhi iron pillar.

The history of the pillar is revealed in the die-struck three-stanza six-line Sanskrit inscription at a level of about 7 ft from the stone platform

(Balasubramaniam, 2000a). King *Chandra*, mentioned in the inscription as the royal donor of this *standard* for Vishnu, is probably identical with Chandragupta II Vikramaditya (AD 375–414), as was also suggested by the use of the name “*Chandra*” on that king’s Archer-Type gold

coins (Balasubramaniam). The original erection site of this pillar was Vishnupadagiri (literally “hill of the footprint of Vishnu”) as mentioned in the inscription. Vishnupadagiri is most probably identified with Udayagiri in central India, in the close vicinity of Besnagar, Vidisha, and Sanchi (Balasubramaniam; Dass, 2001). The astronomical significance of its erection site has been understood (Balasubramaniam & Dass, 2004). The pillar was positioned so that the early morning shadow of the pillar fell in the direction of one of the important bas-reliefs at Udayagiri, i.e., the *Anantaśāyin* Vishnu panel in Cave 13, in the period around the summer solstice. The *chakra* image that originally crowned the iron pillar capital additionally served to highlight its astronomical significance (Balasubramaniam, Dass, & Raven, 2004). The Delhi iron pillar was relocated to its current location in New Delhi in the courtyard of the Quwwat-ul-Islam mosque (near the Qutub Minar) around 1233 AD by Iltutmish (Balasubramaniam 2002; Dass 2001) (Fig. 2).



Iron Pillar at Delhi, Fig. 1 Delhi iron pillar located in the Quwwat-ul-Islam mosque in the Qutub Complex at New Delhi

Iron Pillar at Delhi, Fig. 2 Well-preserved Sanskrit inscription on the iron pillar. This is the oldest inscription on the pillar



Engineering Design

The current burial level of the pillar was not the original burial level of the pillar when it was erected at Udayagiri. Hammer-marked cavities are still visible on the surface of the pillar in the rough region just below the smooth surface-finish region (Fig. 3). The rough portion of the pillar



Iron Pillar at Delhi, Fig. 3 Hammer marked cavities are still visible on the surface of the pillar in the rough region. The rough region was originally buried under the ground when the pillar was located at Udayagiri

was originally buried in the ground and later left exposed outside when the iron pillar was relocated at Delhi around 1333 AD. Beglar, an assistant of Alexander Cunningham, constructed the stone platform around the base of the iron pillar in 1871.

A critical analysis of the dimensions of the main body of the pillar allows an appreciation of the pillar's symmetrical design (Balasubramaniam, 1997a). The rough surface occupies one-fourth (60U) and the smooth surface three-fourths (180U) of the pillar main body length, excluding the decorative top (Fig. 4). The decorative bell capital (Balasubramaniam, 1998a) is again a symmetrical object. A *chakra* (circular discus) image was originally located atop the capital (Balasubramaniam et al., 2004) and this would have been approximately 20U in

length thereby making the total length of the decorative top 60U (Fig. 5). Therefore, the depth of burial below ground level was equal to the height of the decorative capital, indicative of the engineering design of the pillar. The unit U is equal to 1 modern inch.

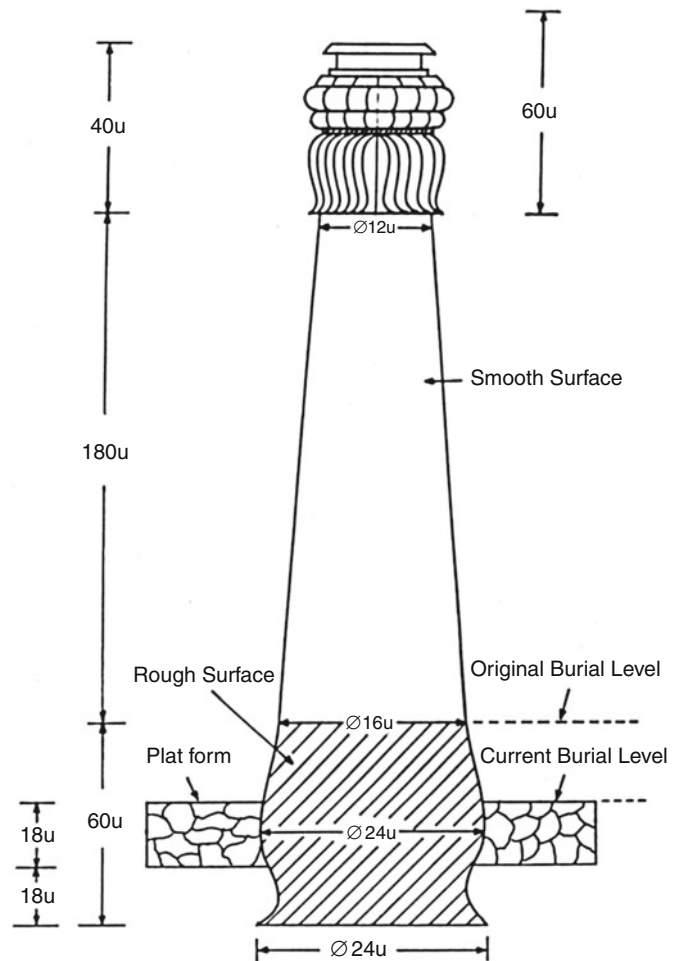
Iron of Delhi Pillar

Several analyses of the Delhi pillar iron's composition are available (Table 1). The variation in the published compositions and the high phosphorus content of the Delhi pillar iron must be noted. Compositional analysis near the surface regions of a sample from the iron pillar revealed that the composition of copper (0.05 %), nickel (0.05 %), manganese (0.07 %), and chromium (Nil) was uniform through several millimetres into the sample from the surface (Bardgett & Stanners, 1963).

The presence of phosphorus is crucial to the atmospheric corrosion resistance of the Delhi iron pillar. The Delhi pillar iron contains a relatively large amount of phosphorus compared to modern-day iron (produced in the blast furnaces). The relatively higher phosphorus content in ancient Indian irons is related to the kind of slag that was created in the extraction process (solid-state reduction). Lime was not added in the ancient Indian furnaces. The absence of calcium oxide in the slags leads to a lower efficiency for removal of phosphorus from the metal, which invariably resulted in higher phosphorus contents in ancient Indian irons. Thermodynamic analysis of phosphorus removal from iron in the absence of calcium oxide in the slag also provides the same answer (Kumar & Balasubramaniam, 2002).

Some aspects of the microstructure of the Delhi pillar iron are also known. All the available published microstructures have been described in Balasubramaniam (2003). It possesses a nonuniform grain structure and slag inclusions are irregularly distributed. Medium to coarse polyhedral grains of ferrite with slip bands were revealed in some grains near the surface. The surface regions were free from pearlite that

Iron Pillar at Delhi,
Fig. 4 Relative dimensions of the Delhi iron pillar. The unit U measures 1 modern inch



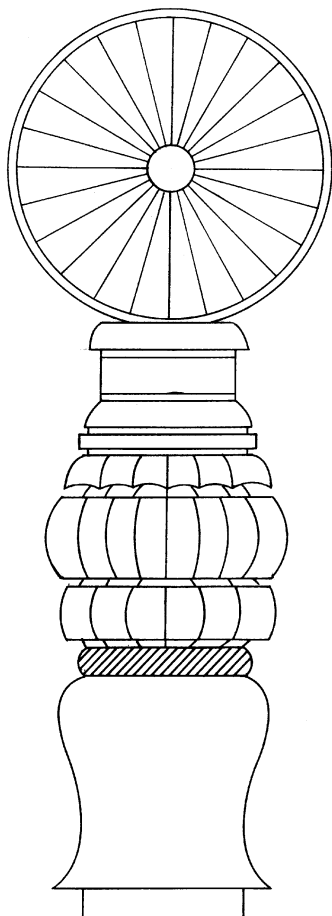
seemed to increase toward the interior. The absence of a uniform distribution of pearlite is indicative of the segregation of phosphorus because, in such areas of phosphorus segregation, carbon diffuses out and the material becomes poorer in carbon content. The interior portions were comparatively rich in carbon. Therefore, the Delhi pillar iron exhibits a wide variation in structure and this is also a characteristic feature of ancient Indian iron.

The pillar is a solid body with moderate mechanical strength (yield strength of 23.5 tons per sq. in., ultimate tensile strength of 23.9 tons per sq. in. and 5 % elongation (Ghosh, 1963)). The similarity of yield strength and ultimate tensile strength are indicative of the composite structure of the pillar iron. In fact, a cannonball fired at

the Delhi iron pillar in the eighteenth century (either by Nadir Shah in 1739 or Ghulam Qadir in 1787) failed to break the pillar.

Manufacturing Methodology

The pillar was manufactured using iron lumps and the method used to fuse the lumps together was forge welding. The individual iron lumps were extracted in bloomery furnaces. The likely manufacturing method has been deduced based on a critical analysis of various aspects concerning the manufacturing methodology like the hammering method, heating method, forging method, use of inserts, use of dies and ease of handling (Balasubramaniam, 1999a). The heated



Iron Pillar at Delhi, Fig. 5 The Delhi iron pillar decorative capital showing the discus image (*chakra*) that was originally located at the top of the capital

iron lumps were placed on the side surface of the pillar and hammered on to the same by the use of hand-held hammers (Fig. 6). The addition of metal would have been sideways with the pillar in the horizontal direction. The pillar’s vertical and horizontal movements would have been aided by handling clamps provided on the surface of the pillar, the protruding portion of which must have been chiseled away during the surface finishing operations. Visual proof for the presence of these clamps has been discussed in detail elsewhere (Balasubramaniam).

The decorative bell capital of the Delhi iron pillar has been described in great detail elsewhere (Balasubramaniam, 1998a). The decorative bell capital consists of seven distinct parts, excluding the circular disc that was originally atop the capital (Fig. 7). There are several evidences at the joints between members to indicate that lead solders were utilized for joining the pieces together (Balasubramaniam, 1998b, 1999b). The bottom-most part is the reeded bell structure, which has been manufactured by utilizing iron rods of uniform diameter. Atop this comes the slanted rod structure. The next three members are rounded structures, with the top one being only half rounded because when the pillar is viewed from the bottom, this part would appear curved when viewed in perspective from the bottom. A round disc comes above this and finally the box pedestal is placed on the top of the capital. The box capital contains holes that are empty at the four corners. The top of the pillar presently

Iron Pillar at Delhi, Table 1 Published composition analyses of Delhi pillar iron

	Hadfield	Ghosh		Lahiri et al.	Lal
	(1912)	(1963) above	(1963) under	(1963)	(1996)
C – carbon	0.08	0.23	0.03	0.26	0.90
Si – silicone	0.046	0.026	0.004	0.056	0.048
S – sulfur	0.006	Trace	0.008	0.003	0.007
P – phosphorus	0.114	0.280	0.436–0.48	0.155	0.174
Mn – manganese	Nil	Nil	Nil	Nil	Nil
N – nitrogen	–	0.0065			
Fe – iron	99.720	Diff			99.67
Others	0.246				0.011
Specific gravity	7.81	7.672–7.747		7.5	

Iron Pillar at Delhi,

Fig. 6 Horizontal forge welding technique for manufacture of the main body of the pillar

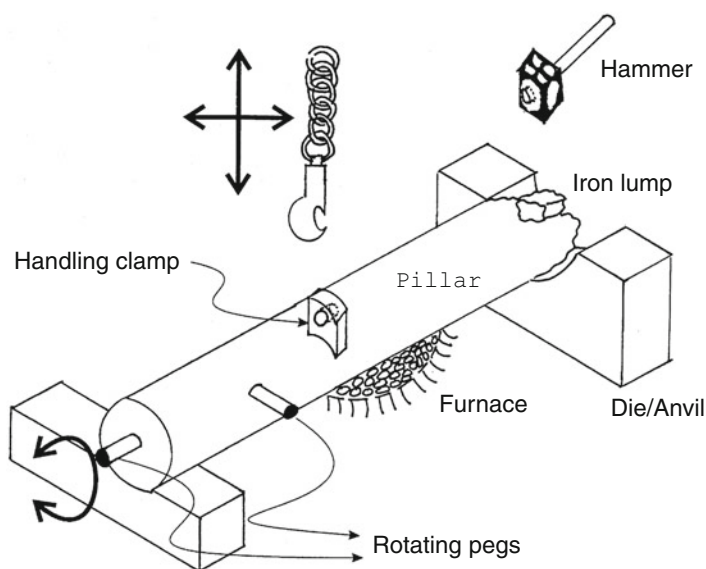
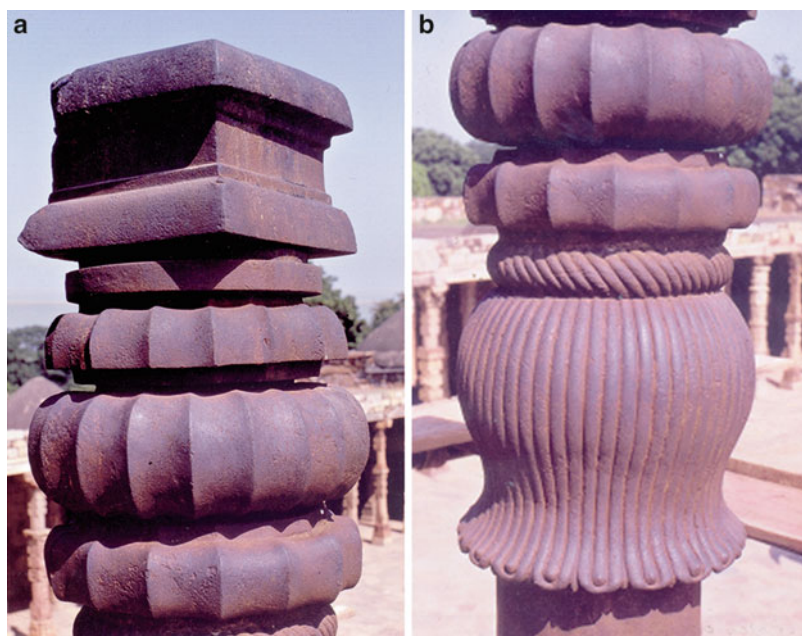
**Iron Pillar at Delhi,**

Fig. 7 The (a) top and (b) bottom portions of the decorative bell capital



contains a hollow slot (Fig. 8), in which a *chakra* image was originally fit (Balasubramaniam et al., 2004). As regards the fitting methodology, the seven components of the capital were shrunk fit around a hollow cylinder, and this was joined to the main body of the pillar by means of a metallic insert (Balasubramaniam, 1998a).

Corrosion Resistance

Several theories that have been proposed to explain the superior corrosion resistance of the pillar can be broadly classified into two categories: the environmental and material theories. These theories have been critically reviewed



Iron Pillar at Delhi, Fig. 8 The top surface of the pillar capital presently contains a hollow slot

elsewhere (Balasubramaniam, 1997b, 2000b; Wranglen, 1970). The proponents of the environment theory state that the mild climate of Delhi is responsible for the corrosion resistance of the Delhi iron pillar, as the relative humidity at Delhi does not exceed 70 % for significant periods of time in the year. It is known that atmospheric rusting of iron is not significant for humidity levels less than 70 %. On the other hand, several investigators have stressed the importance of the material of construction as the primary cause for its corrosion resistance. The ideas proposed in this regard are the relatively pure composition of the iron used, the presence of phosphorus and absence of sulfur/manganese in the iron, its slag enveloped metal grain structure, passivity enhancement in the presence of slag particles and formation of phosphate film. Other theories to explain the corrosion resistance are also to be found in the literature. They include the mass metal effect, initial exposure to an alkaline and ammonical environment, residual stresses resulting from the surface finishing (hammering) operation, freedom from sulfur contamination both in the metal and in the air, presence of layers of cinder in the metal which do not allow corrosion to proceed beyond the layer (cinder theory) and surface coatings provided to the pillar after manufacture (treating the surface with steam and slag coating) and during use (coating with clarified butter).

That the material of construction may be the important factor in determining the corrosion

resistance of ancient Indian iron is attested by the presence of ancient massive iron objects located in areas where the relative humidity is high for significant periods in the year (for example, the iron beams in the Surya temple at Konarak in coastal Orissa (Graves, 1912) and the iron pillar at Kodachadri Hills on the western coast (Anantharaman, 1999). Moreover, a freshly exposed cut surface of the pillar acquires the color of the rest of the pillar in a relatively short period of time (Balasubramaniam, 2001), thereby implying that surface coatings were not intentionally applied.

Sanyal and Preston (1952) proposed that the large mass of the pillar implies a large heat capacity for the iron. In that case, the pillar would heat or cool faster than the surroundings. The role of the Delhi environment on the wetting and drying of the pillar has been mathematically modeled (Halder et al., 2004) and the benign role of the large mass of the pillar was noted.

Rust samples obtained from the region just below the decorative bell capital were characterized by X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, and Mössbauer spectroscopy (Balasubramaniam & Ramesh Kumar, 2000). The XRD analysis proved the existence of crystalline iron hydrogen phosphate hydrate, FTIR and Mössbauer spectroscopy proved the presence of magnetite and several oxyhydroxides in the amorphous form.

The process of protective film formation during alternate wetting and drying cycles of the Delhi iron pillar has been outlined (Balasubramaniam, 2000b) based on rust characterization results. Initially, the corrosion of the matrix is relatively fast due to the presence of second phase particles in the microstructure. The usual corrosion products that are observed in the case of mild steels exposed to atmosphere are generated: α -FeOOH (goethite), γ -FeOOH (lepidocrocite), $\text{Fe}_{3-x}\text{O}_4$ (magnetite) and X-ray amorphous matter. The initial enhanced corrosion of the matrix leads to the enrichment of phosphorus concentration at the metal-scale interface, which results in the formation of a compact layer of amorphous δ -FeOOH layer

next to the metal-scale interface. The formation of this layer confers the initial corrosion resistance to the pillar iron. Conversion of amorphous δ -FeOOH to nanocrystalline goethite is possible on longer exposure times (Yamashita, Miyuki, Matsuda, Nagano, & Misawa, 1994). The enrichment of phosphorus in rust continues with prolonged exposure as observed in P-containing weathering steels (Misawa, Asami, Hashimoto, & Shimodaira, 1974). Enrichment of phosphorus follows the mesoscopic variation of phosphorus in the matrix (Dillmann, Balasubramaniam, & Beranger, 2002). This enrichment should be responsible for the precipitation of the insoluble phosphate, identified by XRD. The formation of this phase at the metal-scale interface provides further corrosion resistance.

A kinetic model for the growth of rust on the Delhi iron pillar has been proposed (Balasubramaniam, 2002), based on the known nature and structure of the rust on the Delhi iron pillar and other corrosion resistant ancient Indian irons. According to this model, the initial fast rate of corrosion is followed by a period where the corrosion rate is reduced drastically. Growth rates have been roughly estimated for these two regions based on available Delhi iron pillar rust thickness measurements (Balasubramaniam).

The Delhi iron pillar is a marvel of ancient Indian metallurgical skills. I have explained the engineering design of the pillar followed by a description of the manufacturing methodology for the main body of the pillar. The characteristics of iron of the pillar and the possible reason for its high phosphorus content have been discussed. The theories of corrosion resistance of the pillar have been reviewed and the importance of the protective passive film mechanism has been highlighted. The nature of this protective passive film has been addressed based on a detailed characterization of its rust. The corrosion resistance of the Delhi iron pillar is due to both Delhi (with the environment providing alternate wetting and drying conditions) and iron (with its high phosphorus content conferring protection by the formation of a protective passive film).

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Irrigation in Egypt

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Irrigation in Egypt is dependent upon the Nile River and has been systematically utilized since the predynastic era. Egypt, surrounded by desert to the east, west, and south, and bordered by the Mediterranean in the north, receives little annual precipitation; the Nile therefore is the primary source of freshwater and the only source of water for agriculture. The annual flood of the Nile is caused by spring rains in Ethiopia washing down from the Ethiopian highlands and traveling north and west along the Blue Nile toward what is now Khartoum, where it joins the White Nile and flows north to the Mediterranean. Under the predynastic kings in the Nile Valley and the river Delta, the river's flooding provided natural inundation for crops. In his eloquent imagery, Alan Richards describes the Nile Valley like "the back of a leaf: the land slopes down gradually from the high land lying along the banks of the river... toward the desert" (Richards, 1982, p. 14). However, before 3100BCE, Egyptians were modifying the flood plain: building dykes and levees to divert the waters, creating intake canals to extend the cropped area, and modifying and making drainage channels.

Inundation, or basin, irrigation utilized the flood's waters. Under basin irrigation, the flood spilled over the river's banks and into shallow basins bounded by low walls, which held the water for approximately 40 days. At that point, the water was allowed to drain off the fields and either back into the Nile or into basins farther removed from the Nile banks. Since the floodwaters were full of Ethiopian silt, when the water

was either drained or allowed to infiltrate the soil, the silt was left behind and provided a layer of nutrient-rich fertilizer.

Around the time of the political unification of Egypt under the Pharaohs (c.3100BCE), basin irrigation was supplemented with the growth of crops year-round, specifically cereal grains (Bowman & Rogan, 1999, p. 5). Although the river floods in summer, it carries a large volume of water the rest of the year, mostly supplied by the White Nile. Egypt's warm and dry climate supports more than one crop each year, so farmers started growing multiple crops. First utilizing buckets and then hand-lifts (*shadufs*) after the Middle Kingdom, Egyptians lifted water from the river to irrigate their crops, gardens, and trees perennially. However, only those farms along the Nile Valley, beside the seven ancient branches in the Delta, or near a deep canal, could draw water year-round.

Ancient Egyptians made significant attempts to promote a large-scale, measureable, and regulated irrigated agriculture designed to improve, expand, and standardize the aforementioned irrigation system, with preeminence placed on controlling and measuring the flood (Butzer, 1976, 47). Nilometers measuring the height of the flood date back to around 3000 BCE. The first large-scale dam, the Sadd el-Kafara, was constructed in Lower Egypt around 2650 BCE. The largest dam in the world at the time, this structure was intended to control the Nile's floods but was destroyed shortly before its completion (Fahlbusch, 2009, p. 15; Mays, 2008, p. 472). From the Old Kingdom until 23BCE, the Fayum, a low-lying depression west of the river, was utilized for canal-irrigated agriculture. By 2300 BCE an existing canal into the Fayum had been transformed into a large-scale construction project connecting the Nile with the low-lying depression called Lake Moeris. The reservoir that this canal controlled high floods, regulated water in the winter, irrigated the surrounding area, and tripled the cropped area through irrigation and reclamation (Butzer, 1976, p. 47; Chanson, 2004).

In contrast to Pharaonic irrigation, which focused on flood control, the Macedonian

Ptolemaic Dynasty (332BCE–30BCE) emphasized canal irrigation (Mays, 2008, p. 473). The *saqiya* (waterwheel) and Archimedes Screw (screw pump) were introduced to Egypt by the second century BCE. These water-lifting devices were animal-powered and meant a drastic increase in the amount of water that could be poured onto the fields during the summer when the volume of water in the Nile was at its lowest ebb; the Ptolemies encouraged their incorporation (Bowman & Rogan, 1999, p. 2). A series of intake canals, dams, levees, and drainage canals were constructed to extend canal irrigation. More effective technology was paired with the large-scale planting of barley, winter wheat, and especially flax. With the newly introduced technology and the new crops, Egypt was able reliably to produce at least two crops per year (Bowman & Rogan, 1999, p. 2).

During the Roman (30BCE–641CE) and early Islamic (641–1171) periods, sugar, cotton, rice, and sorghum were introduced, but the Egyptian system of irrigated agriculture remained fairly consistent, producing up to three crops per year for both local use and export. Canal irrigation was further extended during the Roman and early medieval eras. Since these canals regularly silted up, canal maintenance was one of the key duties of the rulers and local lords under the Ayyubids (1174–1250) and Mamluks (1250–1517). The Ayyubids and Mamluks promoted sugar as the dominant cash crop, and refineries became an important secondary industry (Bowman & Rogan, 1999). However, the Egyptian population, which may have increased to as many as 14 million at the time of the Arab conquest, fell into a long decline, decreasing to approximately 3.25 million by 1798 (McCarthy, 1976). This falling population made canal irrigation difficult to sustain, and the total cropped area fell to 3.2 million acres in 1798.

After the Ottoman conquest of Egypt in 1517, Egypt again became a granary. Egypt grew rice, lentils, beans, wheat, and other agricultural foodstuffs for export to other parts of the Ottoman Empire (Richards, 1982, p. 7). Under the Ottoman regime, control over water usage devolved onto local governments which regulated village

water use instead of either the imperial government or individual water rights (Mikhail, 2011, pp. 21–22). Canal maintenance was part of the local institutional framework, including clearing the canal of silt after the yearly floods. Annual canal clearance was undertaken through the use of forced labor. However, under the Ottoman Empire, the Egyptian irrigation system was a continuation of the mixture of basins and canals extant since the Ptolemaic dynasty.

In 1805, Ottoman governor, Mehmet ‘Ali (r. 1805–1849) started to consolidate power by introducing a number of changes to irrigated agriculture with long-term consequences for Egypt. His government promoted the growth of long-staple cotton, a particularly thirsty summer crop. In order to extend cotton growth, the government built a new series of canals and built a large-scale barrage (the Delta Barrage, completed in 1862) near Cairo to raise the summer water level throughout the Egyptian Delta. Originally, this barrage suffered from structural problems, and as a result mechanical, coal-powered water pumps were introduced to replace the saqiya. In order to deal with the canals’ silting up, the system of forced labor became a “national imposition,” as peasants were compelled to work for months at a time away from their homes; Egyptian governments in the 1870s and early 1880s stopped this exploitative system of agricultural labor (Brown, 1994, pp. 125–126). During the American Civil War, as global demand for long-staple cotton skyrocketed, long-staple cotton became Egypt’s main export crop.

A British military force occupied the Ottoman colony in 1882. After the British occupation in 1882, Egyptian irrigation became increasingly focused on supplying summer water to the Delta to promote cotton growth. Repairing the Delta Barrage in the 1880s allowed agriculturalists to grow three crops per year. The British administrators instituted a number of modifications to the irrigation system which concentrated power in their own hands, and locked Egypt into a specific perennial irrigation system (Cookson-Hills, 2013). The British constructed the original dam at Aswan in 1902, which created a reservoir of 1 billion m³ in the southern Nile Valley.

This reservoir increased the amount of summer water to the cotton crops in the Delta by storing the floodwaters and releasing them later in the spring and summer when they were needed during the low-ebbed summer water. The Egyptian government also used the water to start converting the basins in Middle Egypt into canal-based irrigation. In response to ever-increasing water needs from a growing population (9.7 million people in 1897 and 11.3 million in 1907) and demand for long-staple cotton, Egypt raised the Aswan Dam in 1912 and again in 1933, increasing the size of the reservoir to 5.1 billion m³ (Collins, 1994, p. 69). In order to better regulate the extra water, the government built a series of other barrages: Asyut (1902), Zifta (1902), Esna (1906), Edfina (1951), and Nag Hammadi (1930). Scientific division and regulation of the Nile is a hallmark of twentieth-century Egyptian irrigation systems.

Since 1952, Egyptian nationalist governments have completed the transition from inundation irrigation to perennial irrigation. The Egyptian government finished construction on the Aswan High Dam in 1970. This dam gives Egypt “century-storage” – meaning that its 162 billion cubic meters of reservoir stores more than 1 year’s worth of water behind the dam. The dam itself cuts off the supply of replenishing silt from the Blue Nile and necessitates the heavy use of chemical fertilizers. The Aswan High Dam ended the annual flood; since 1964 the Nile in Egypt has become a series of irrigation canals completing control over the river and ending basin irrigation (Dumont, 2009). Although the Aswan High Dam extended the cropped area to almost 11 million acres, it has also been criticized for causing environmental problems such as desertification and soil salination (Bowman & Rogan, 1999, p. 2).

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Irrigation in India and Sri Lanka

Claude Alvares

Assessments by historians of Asia's irrigation systems and irrigation-related civil engineering techniques have been based on the scantiest of historical or empirical data. Naturally, they have ranged from one extreme to the other. Of these, the one most easily recognized and debated was provided by Karl Wittfogel whose theories led to the idea of “hydraulic civilizations”.

A diametrically opposite assessment has been provided by some Indian historians who have concluded that there was no significant irrigation

technology in use at all. Symbolic of this view is R. Majumdar and H. C. Raychaudhuri's *An Advanced History of India*, in which the authors make a categorical statement on the “comparative absence of artificial irrigation” in eighteenth century India.

However both views – fairly representative of the historiographical terrain – have had to be revised considerably because of the emergence of new historical materials and investigations. These are reflected in new literature specifically devoted to the subject. Illustrative of these materials is the report of Alexander Walker, an English specialist who toured India in the eighteenth century. Walker produced an elaborate treatise on Indian agriculture in which he drew the conclusion that:

the practice of watering and irrigation is not peculiar to the husbandry of India, but it has probably been carried there to a greater extent, and more laborious ingenuity displayed in it than in any other country.

This display of ingenuity, however, is not restricted to eighteenth century India and has indeed found expression in a plethora of irrigation systems in Asia each designed to appropriate its own specific ecosystem potential. There is evidence of large-scale irrigation works in several Asian countries including China and Sri Lanka. The systems studied on the subcontinent include gigantic artificial lakes, large-scale and small-scale embankments, and diversion channels. They include schemes for taking water up a hill against gravity, elaborate canal distribution networks, innovations like the *khazans* on the west coast of India, where unmanned wooden sluice gates control the sway of salt and sweet water in low-lying paddy fields adjoining the coastal or tidal rivers, and storage tanks with a bewildering variety of names.

“The irrigation history of Indian has been studied only in fragments” (Sengupta, 1993). But even this admittedly fragmentary picture that is emerging is far more fascinating than the simplistic or impressionistic scenarios of Wittfogel or later historians like Raychaudhuri and Majumdar. The most fundamental aspect of irrigation technology and civil engineering works

to be noted is that almost all of them are related to monsoon precipitation in one way or another. Over 90 % of the annual runoff in the peninsular rivers and 80 % in the Himalayan rivers occur during the 4 months of the monsoon. Thus, unlike the case of temperate ecosystems, irrigation becomes extremely crucial: in the wet season which stretches approximately 4 months, in several places less, there can be too much precipitation over intense bursts. This is followed by a dry season during which there is no precipitation at all. The result is predictable: periods of excess water followed by drought.

In this context, the basic design of irrigation technology is intimately related to precipitation: how to save it, store it, and divert it, so that spatially it reaches areas where there is no water (diversion techniques) or temporally makes it available during the dry months (storage techniques). Thus, rain-fed rivers are diverted into channels, or river basins are interconnected. Or the rainfall is directly collected in huge storage facilities on the land.

If this is the scenario (and it is as valid today as it was in 3000 BCE), one would normally expect a much richer history of irrigation techniques in Asian conditions – where rice is a basic crop adapted to growing largely in water – than in any other part of the planet, particularly the temperate zones. It would also follow that the irrigation designs evolved for coping with such situations would not readily be available in other ecosystems. For this reason, it has taken some time for engineers and historians trained in other culture areas to appreciate their worth and function.

The irrigation experience of China is documented in Joseph Needham's *magnum opus*, *Science and Civilisation in China*, and will not concern us here. We shall restrict ourselves in this essay to a consideration of the irrigation and civil engineering techniques that arose in the Indian subcontinent including Sri Lanka and which were the result of a close interaction and adaptation between overall environmental situations and human ingenuity.

Irrigation Technologies

In the circumstances related above, it stands to reason that the primary design objective of irrigation engineers would be predominantly in the direction of a water storage system. The following listing is given by Shankari and Shah.

There were storage systems designed purely for drinking water: *nadi*, tanks, *bowari*, *jhalara*, and *pokhar*. Some were reserved only for human beings; others were for human beings and animals. These we shall ignore here.

The second category of storage technologies relates to irrigation, and there is considerable evidence of the spread of such technologies through the length and breadth of the subcontinent. Though the structures here were all designed for irrigation, they also provided other useful functions of soil conservation and ground water percolation and recharge.

Irrigation water stored in such storages was conveyed through two methods: first, under the force of gravity, or gravity irrigation, and second, through extractive or lift techniques or devices of some kind, including for instance the Persian wheel.

There were three main classes of such irrigation-related storage systems. The first comprised tank and pond irrigation systems. These in turn were of two types: *above surface* storage works, where a reservoir was created above the ground through a fairly long embankment. The corresponding structures were called *Keri*, *Eri*, *Cheruvu*, *Kalvai*, and *Kunta* in South India and *Ahar* in Bihar (northern areas). The second category involved *below surface* storage works, which included dug ponds from which water was lifted by some means manual or mechanical: *pokhar*, *talab*, *jhil*, *beel*, and *sagar*.

The second class of irrigation systems comprised land inundation systems: the land was flooded and saturated before cultivation and then drained off prior to planting (another term used is flood irrigation). These were primarily above surface types or referred to (in India) as submergence tanks. Important variations of these

are the *khadin* and the *johad* in Rajasthan and the *bundhies* of Madhya Pradesh.

The *bundhies* were built generally in a series and therefore captured every possible drop of rainwater that fell. If there were a surplus, a waste weir was provided. There was generally a sluice at the deepest part of the storage reservoir. A *stambh* or pillar would indicate the location of the sluice. Sluices could be of different types: pipe sluices or sluices made of masonry for the larger tanks. (Some sluices open, as in the *khazans*, with the pressure of the incoming tides and discharge water automatically when the tide has fallen; these are made from wood.) The crop which was grown in the *bundhies* after the water was drained did not require any irrigation until harvest.

The third class comprised in situ techniques through which storage facilities were created to retain precipitation and ground water infiltration. The difference between classes 2 and 3 was that in the former, cultivation followed drainage; in the latter it occurred simultaneously.

The sizes of these storage tanks varied and the tanks themselves were generally known from the command areas they irrigated: the smallest ones irrigated around 50 acres, the medium ones about 100, and the major ones 500 and above. The large tanks were clearly impressive in scale. The Veeranam Tank in Tamil Nadu has a bund (embankment) 16 km in length. The Gangaikonda Cholapuram tank, also in Tamil Nadu, was constructed by a Chola king from AD 1012 to 1044 and survives even today with a 25 km embankment.

The construction of tanks was a widely dispersed skill. To create a tank reservoir, an earthen embankment, usually curved, was erected in a concave form across the flow of water. The water was retained in the belly of the curve from where it was drawn and directed through channels to irrigate plots at lower levels through gravity irrigation. After the tank was emptied, the tank bed itself could be used temporarily for raising a crop utilizing residual moisture. Many of the tanks in an area were interlinked and functioned as parts of an integrated system. The tank

at the higher level released its surplus water as runoff to tanks at a lower level and the next in turn. These were called *chain tanks*. There were also tanks which were fed by canals from a river. Chain tanks were generally created in the upper reaches of the river basin and river-fed tanks in the lower reaches. Their construction would have required detailed cooperation among several communities in the region.

In Mysore in 1866 Major R. H. Sankey, Chief Engineer, wrote:

Of the 27,269 square miles covered by Mysore, nearly 60 % has, by the patient industry of its inhabitants been brought under the tank system. Unless under exceptional circumstances, none of the drainage of these 16,287 square miles is allowed to escape. To such an extent the principle of storage has been followed, that it would now require some ingenuity to discover a site within this great area suitable for a new tank.

The profusion of such tanks was not a feature of Karnataka alone. Experience was similar in Tamil Nadu, Goa, or Bihar. The area north of the Vindhya mountain range in middle India for instance had more than 8,000 submergence tanks. In one district of Rajasthan alone, there were more than 500 *khadins*.

In Sri Lanka, dry areas were populated with what are known as “tank villages”. “The 1-mile to an inch topographical maps of the island,” writes D. L. O. Mendis:

show nearly 15,000 of these, of which over 8,000 are in working condition today. Tradition has it that some 30,000 of these small tanks had been constructed down the ages and there is a reference in the chronicles to 20,000 in the ancient province alone in the twelfth century.

Water Conveyance

Apart from the storage works, the subcontinent witnessed the emergence of competent and impressive water conveyance systems designed to divert waters of rivers and flowing streams. Some diversions were accomplished without a check or embankment across the river; in such instances, the flood waters of the river were drained through a natural diversion. The *Kuhls*

or *Guls* in the Himalayan areas, the *dongs* of the Northeastern states, and the *pynes* of Bihar all reflect this feature.

The second category involved check dams as a basic feature: the river bed was first raised and the resulting raised water diverted into a channel as was the case with the *band-haras*. Some of these schemes were fairly small, like those in the hilly areas. Others could be extremely large-scale and it is the reports of the latter that probably gave Wittfogel material for his speculations. According to Major T. Greenway, these were works of “truly gigantic magnitude, vast embankments and drainage channels equal to ordinary English rivers in capacity.”

Historical Development of Irrigation Techniques

The interesting question that is now being asked is whether one can talk in terms of an evolution of irrigation technologies and civil engineering techniques from the earliest times to the present? The question is important in view of the fact that many of these storage systems, diversion channels, and embankments are largely intact and still in use. There are still parts of the country where Persian wheels are operated. Tanks and storage vessels are once again being made functional and weirs continue to be constructed.

The answer seems obvious: while more complex technological mechanisms did emerge as time passed, the earlier and the later techniques have continued to coexist. The only major new innovation seems to be the idea of dams; these are new in terms of function, since the generation of hydropower was not intended in earlier times. The idea of large dams, once considered the temples of modern India, has taken a severe beating in recent years. They are now considered unsuited to tropical ecosystems, since the reservoirs invariably lead to displacement of large numbers of people, submergence of forests, and destruction of wildlife, and in places like Sri Lanka, submergence of smaller functioning reservoirs.

This being said, it is possible still to identify certain periods as distinct historical events in a

possible history of irrigation and civil engineering on the subcontinent. There is archeological evidence of artificial irrigation from pre-Harappan and Harappan times (ca. 5500–3500 BCE): this took the form of a large number of wells. One well found had a brick lining going down 12 m. Post-Harappa, the major irrigation find is Inamgaon on the west coast of India where under the influence of the Jorwa culture (ca. 3400–3000 BCE), one finds evidence of a major diversion scheme reflected in a massive embankment 240 m by 2.2 m wide to divert the river into a channel. The channel itself was 200 m long and 4 m wide.

The first storage tanks in their rudimentary form appear around 2500 BCE – also in Sri Lanka – with the invention of iron tools. Hereafter, there are increasing references in literary works of both Sanskrit and Tamil up to the Gupta (AD 350) period. There are tank-related inscriptions which give details of tank construction, maintenance, sources of funds for maintenance, and so on. The word *eri* also comes into circulation by the seventh century as a term for tanks.

The *anicut* (weir) technique is probably older than the *eri* or tank. The most famous of the *anicuts*, the Kaveri Anicut on the river Kaveri, is linked to a Chola king of the second century AD. It involved a dam on the river Kaveri 300 m long and 12–18 m wide and 5 m deep. There is a dispute about the age of the *anicut*, since the *anicut* technique itself bears a strong resemblance to the Sri Lankan technique of massive stone dams and sluices, a technique which developed, according to Sri Lankan historian R. A. L. H. Gunawardene, only in the seventh century AD.

Sir Arthur Cotton paid eloquent testimony to the engineering talent involved in the large-scale irrigation works. He wrote:

There are a multitude of old native works in various parts of India. . . These are noble works, and show both boldness and engineering talent. They have stood for hundreds of years. . . it was from them that we learnt how to secure a foundation in loose sand of unmeasured depth. In fact, what we learnt from them made the difference between financial success and failure, for the Madras river irrigations

executed by our engineers have been from the first the greatest financial successes of any engineering works in the world, solely because we learnt from them. . . With this lesson about foundations, we built bridges, weirs, aqueducts, and every kind of hydraulic work. . . we are thus deeply indebted to the native engineers. . .

Social Arrangements/Religious Sanction

A significant feature of these irrigation works related to their construction and maintenance. Since water availability could be problematic with monsoon failure, those associated with the emergence of these works could gain religious merit for their deed. Though large systems were often sponsored by the state – to include kings, queens, local chieftains, *zamindars* (landowners) – village communities, temples, and even individuals are associated with their construction. Thus a public park in Pondicherry bears an inscription recording a tank built by a *dasi* – a temple dancer/courtesan – while another inscription in Karnataka (AD 1100) records a tank and shrine constructed by a village watchman.

All the major dynasties including the Mauryas (Sudarshan Lake near Kathiawar), the Cholas, the Hoysalas, and the Vijayanagar Kings and Muslim Sultans were associated with irrigation works. Of these, the most impressive schemes are associated with the Cholas. However, these kings depended upon a cadre of skilled hydraulic engineers. Dikshit records the performance of one such engineer in the fourteenth century:

The Kalludi (Gauribidanur taluk) inscription of 1388 AD is well known. According to it, when Vira Harihara Raya's son Sri Pratapa Bukkaraya was in Penugonda city in order that all the subjects might be in happiness – water being the life of the living beings – Bukkaraya in open court gave an order to the master of ten sciences, the hydraulic engineer (Jalasutra) Singayya Bhatta that he must bring the Henne (Pennar) river to Penugonda. Accordingly Singayya Bhatta conducted a channel to the Siruvara tank and gave the channel the name Pratapa Bukka Raya Mandalanda Kaluve.

The day-to-day operation and maintenance of both large and small works were mostly in the hands of local communities and of special

professionals like the *nirkattis* of Tamil Nadu. In many areas, production from certain lands was set aside specifically to meet the maintenance costs of tanks. During the installation of the colonial regime, these revenues were appropriated by the colonial power and consequently the maintenance of such irrigation works fell into bad times leading to declines in efficiency.

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Irrigation in South America

Gray Graffam

Large-scale irrigation systems (canal irrigation) went hand-in-hand with the rise of cities and truly complex societies on the coast of Peru during pre-Hispanic times. Such systems delivered water to hundreds of hectares of potentially fertile land along a dry desert coast. Relatively late in prehistory, from 300 BCE onward, a number of well-known urban cultures (e.g., Moche, Lima)

undertook the construction and expansion of irrigation works, which supported dense populations. This process culminated around AD 1000 in the construction of exceptionally large and sophisticated works by the Chimú, including an intervalley canal of impressive proportions from the Río Chicama. These works made it possible for a population of some 25,000 to reside at the capital city of Chan Chan. Irrigation agriculture played a primary role in sustaining urban communities near the coast, where large irrigable plains of potentially fertile land were brought into production.

Similar irrigation systems in the Andean highlands are also of note. Some researchers, such as Michael Moseley, believe that irrigation agriculture developed here, as an extension of hunter-gatherer practices. Because of the steep slope, short canals would have been sufficient to water desired areas, and over the course of a millennium or more, a sophisticated irrigation technology developed. By AD 600, canal irrigation brought hundreds of hectares of otherwise unusable land into production in the Ayacucho valley of south-central Peru. These networks helped support a population of some 20,000 or more at the urban site of Huari, which is situated at an elevation of some 3,000 m, above any substantial acreage of arable land.

Other agricultural systems are also known for the Andes, and for elsewhere in South America. These include (a) sunken gardens on the desert coast, where plots of land were dug down to the water table and then planted, (b) terraces along the highland slopes, which served to retain moisture and enhance production, and (c) raised or drained fields along lake margins and in the Amazon basin, which served to reclaim inundated wetland. Aspects of irrigation technology theoretically come into play with each. Upland irrigation tends to create a higher water table downslope, which can make sunken fields possible in otherwise very dry areas. Slope irrigation can deliver a supply of water to terraced fields, and such systems are documented for the Inca. During the dry season, spring water can be run into the swales of raised field systems, which can allow for double cropping in some settings,

e.g., Lake Titicaca. Irrigation plays a role in other agricultural systems of the Andes. All of these agricultural systems were geared toward intensive production, as a means for dense human adaptation to the Andean environment.

In general, the construction and maintenance of irrigation systems are portrayed in the archaeological literature as a powerful force leading to the rise of civilization and urban life. This theory is based upon the view expressed by Karl Wittfogel, and subsequently anthropologists such as Julian Steward, that water management plays a key role in crystallizing political authority; it is also referred to as the "Hydraulic Hypothesis." According to this theory, highland peoples came to control a scarce resource of high value – water – which led to a hierarchical system for its management and distribution. Such a scenario is thought to have led inevitably to the formation of stratified society and subsequently state bureaucracy. Political power is seen as a direct outgrowth of the struggle for water, from which centralized authority and state-level government emerge. Not everyone agrees, and some scholars, such as Robert Adams, have argued forcefully that irrigation is the consequence of political power, rather than its cause.

The Peruvian data do not support the "Hydraulic Hypothesis" of civilization's emergence. A strong maritime economy typified subsistence strategy along the coast during preceramic times, and large agglutinated settlements that housed hundreds of people were built along the coast between 2500 and 1800 BCE, e.g., Huaca Prieta, El Paraiso, Río Seco, Playa Culebras, and others. There is an active debate on the role that crops, including maize, had in this developmental process, but it seems quite clear that irrigation agriculture played little part and certainly not to the scale of later times. According to Michael Moseley, the sociopolitical organization that accompanied these settlements was highly evolved, incorporating the management of labor mobilization (a form of taxation) on a regional basis. Irrigation agriculture took hold around 1800–900 BCE in the prehistoric sequence for Peruvian cultures. By this time, authority figures and labor taxation systems had

already emerged. Irrigation technology did not bring them about, but vice versa.

Still, the matter of irrigation's impact on society is a topic of central concern. For the north coast of Peru, it has been argued that irrigation technology went hand-in-hand with hierarchical social organization during late pre-Hispanic times. According to Patricia Netherly, water was a valuable commodity, and groups benefited from a hierarchically organized social structure, capable of resolving conflict when it occurred. Michael Moseley adds the perspective that large-scale irrigation projects were designed and engineered by rulers in these settings. Together both views provide a clear understanding of how irrigation was carried out, on the one hand through kinship organization, and on the other through government intervention in labor-intensive projects. Irrigation may not have given rise to civilization and urban life in the Andes, but it clearly evolved within the power structure of subsequent developments.

Today, systems of native irrigation management are under study, as are the impacts of modern attempts to improve them (Bolin, 1990; Mitchell, 1991). It is noted that highland communities often attempt to maintain their rights to water use and management, although in Peru such rights no longer exist in the legal sense. All water belongs to the Peruvian state, and there are national laws and regulations that govern its use. Highlanders, especially those who regard themselves as "Owners of the Water," fall into conflict with people in the lowland valleys. According to Bolin, there is a great need for agricultural and government agencies to investigate the indigenous patterns of water use, and the competition between and within villages for access to irrigation water. As revealed by Mitchell and Netherly, such patterns of water rights are likely to be deeply embedded within kinship organization and indigenous social structure.

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Irrigation in the Islamic World

Lucie Bolens

From Andalusia to the Far East, from the Sudan to Afghanistan, irrigation in Islamic countries is the basis of all agriculture and the source of all life. After the Roman empire, the classical Islamic empires relied on the great cities like Damascus, Baghdad, Cairo, Cordoba, and Fez. In the countryside, all the small villages, made up of groups of rush huts or houses of stone, wood, or concrete were organized around a water source: a mountain fed by a living spring, a cistern of rain water, or wells bringing water up to the surface from deep beds. The Arabic word for water, *Māʾ*, is also the word for center. The water for religious ablutions at the center of the courtyard facing every mosque is the symbolic echo of a physical fact.

Islamic irrigation recovered pre-Islamic purviews while at the same time developing and expanding them. The historical record describes a vast network of canals from hot climatic zones to cold, rainy ones. The first were developed in the river valleys of semiarid and arid regions. The Nile, the Tigris and Euphrates, and the Guadalquivir have offered rural and urban communities

from earliest times both water and silt, a means of providing refreshment and nourishment.

Where no great rivers existed, human societies dug wells and prospected deep lying aquifer beds, in the south of the Arabian peninsula, in Yemen, and in Hadramawt, as well as in the Sudan. There, where the effects of Indian monsoons are often felt, a tropical agriculture (coffee trees, date palms, banana, and tamarind trees) served as a point of departure for those tropical plant species to Mediterranean regions.

Lastly, on the borders of agricultural zones stretched vast steppes with winter rainfalls varying from 50 to 150 mm per year, seminomadic lands which had been used for thousands of years. Animal husbandry and intensive agriculture at oasis sites have for centuries contributed to the economic base of Yemenites and Maghreb tribes. This association between seminomadic grazing and intensive irrigated agriculture is a distinctive characteristic of Islamic irrigation, a system of a complementary nature between field, pasture, and natural resources in the environment.

For classical Islam, written documentation is inseparable from the latest results of rural archeology; all of the *Kitāb-al-Filāḥat* (Books of Agriculture) – Maghrebian, Andalusian, Egyptian, Iraqi, Persian, or Yemenite – insist meticulously on the deployment of equipment and on the control of water. What are examined are the means of water distribution, following the season and the species being cultivated. A Tribunal of Waters looks at legal cases, and that of the Islamic writer Valence has lasted from the time of the Christian *Reconquista* in 1248 until today. Irrigation was linked to a social time, following necessities of nature but also following the social rank of the users.

In the current state of research, one of the oldest calendars of irrigation was found in the *Filāḥat al-Nabaṭiyyah* (Nabataean Agriculture, by Ibn Waḥshiyyah), which in the 1000s gave information on pre-Islamic Mesopotamia and Abbasidian Iraq. For western Islam, jurisprudence provided historians with precise details of daily life and ecological behavior, and explained the elements relating to the history of that environment, such as torrential rains in the autumn

and the spring, the shifting of waterholes, and complaints from the owners of cultivated estates which had been deprived of water from 1 day to another. The *fiqh* Islamic juris, had to regulate any unexpected events from case to case. The joint purchase of land and water, inherent to the *fiqh*, confronted the fact of the capriciousness of nature: the agrarian weather of microclimates really was the final law. In Islamic law ownership of land is always linked to ownership of waters.

Lastly, financial writings integrate the agrarian dependence on water into the framework of the whole political and social evolution of Islamic history. Irrigation is the crucial element of agriculture in Islamic lands.

The rains follow two dominant climatological patterns: one Mediterranean, the other tropical and subtropical. The Mediterranean basin, along with southern Africa and California, has the only climate which has rain in the winter and maximum heat in the summer. The vegetation there needs a hot, humid season in its tillage phase. In other respects, the torrential spring and autumn rains create a major risk for the thin, mountainous soil which is predominant in the Mediterranean basin. A negative quality can thus indeed have positive effects.

This link between the climate and the soil in Andalusia entailed three inseparable factors: an extremely fragile ecology at risk of erosion, a highly organized and detailed system of irrigation which was adapted to regional conditions, and a stable political and administrative system (except in time of war).

In certain historical cases, like that of Andalusia, in spite of the fluctuating tides of conquest and reconquest, there existed a true ecological pattern which lasted for several centuries and which served as a real ecological laboratory for eastern and western Islamic statutes, based on a high level of natural science, climatology, and botany. The extensive spread of theoretical and technical knowledge made of the Andalusian model a precedent which could be applied to all societies, ethnic, and religious differences aside, which were trying to understand the environment in its historical dimension.

It was water which governed the classification of land types. The rich agronomical and administrative literature of Arabic Islam divided cultivatable land into rainy land and irrigated land. The former were those lands which received enough winter rain to permit the cultivation of olive trees, grape vines, and citrus trees, the Mediterranean trilogy. Irrigated plantings used water stored in deep beds; the surface of the land was hot and irrigated and was worked in squares irrigated by ditches or *acequias*. The device which allowed the flowing of water into the ditches across fields, squares, or gardens was a wheel of variable dimension called a *noria*. More simply, on river banks and along the shore a system of scales and counterweights called *shaduf* was used.

The plan of irrigated water brought about a kind of intensive horticulture comparable to that achieved in the great Asiatic deltas. In the development of the countryside irrigation allowed plant species which became the basis of the popular diet – e.g., rice and legumes rich in protein – to become acclimated to the Muslim west. In Andalusia, sugar cane, rice, and cotton were cultivated.

In plateau regions (Meseta, Morocco, Iran) where aquifer beds were deep, the most profitable procedure was the traditional system of *qanats*. The *qanats* were deep drainage tunnels which directed water to springs or artesian wells. Some were over 16 km long, and their deep tunnel was dug from the outlet up to the mother-well. The gradient incline of the aquifer bed can range from almost zero to very steep. Well sites were marked and were used for ventilation and disposition of debris from land clearing. The science of the *qanats*, traditionally, was based on empirical knowledge and was passed down by gesture or through oral tradition. The earliest descriptions are Iranian. Later they were developed on the Castilian Meseta (Madrid) and in Morocco (in Marrakesh). Today, one can see them in Central America; they are the oil-qanats.

In between the canals of flowing water and the system of *qanats* the Islamic world watered its gardens and fields, its city courtyards and domestic patios, and its mosques, with water from wells

whose volume was increased through a process described by Ibn al-ʿAwwām in the *Kitāb al-Filāḥat* and in *Nabatean Agriculture*. Chapters relevant to finding the underground water level and sinking wells are followed by considerations on ways to increase the volume of water stored, ways to raise water from wells that are too deep, and ways to modify the taste of brackish or salty water.

The detailed observation of the earth or of its vegetation, in order to identify the presence of water, as well as the empirical nature of the investigation to sample the earth, in order to define various qualities of water, such as neutral, salty, or brackish and bitter, systematically mobilized the senses. Empiricism was able to bring about the creation of an irrigated, productive agriculture area. This success was built on the very controlled work of the *fellahs*, a political encouragement of individual appropriation, and on a high level of applied knowledge.

This multisecular, integrated system was the reason behind the development of numerous plant species crucial to the existence of civilization.

See Also

- [Agriculture in the Islamic World](#)
- [Dams and Irrigation in Ancient Arabia](#)
- [Qanat](#)
- [Technology in the Islamic World](#)

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Irrigation Systems in Samarkand

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Dealing with the irrigation systems in the Samarkand oasis with a historical perspective means discussing both the canals watering the territory and the city supply. Commonly considered as the major center in the trade network along the Silk Road, since ancient times, the wealth of Maracanda (Samarkand in Greek sources) is based on a mixed economy, combining the irrigated agriculture in the floodplain with breeding and herding in the uncultivated steppe. However, like many other areas of Central Asia with low rainfall (ca. 350–400 mm/year) and arid environmental conditions, Samarkand and its territory could develop because of a complex irrigation network. The water of the Zeravshan, which is the third longest river of Central Asia, gives rise to the whole system. Springs and wells are less important and usually connected to the water supply in rural mountain areas.

Irrigation in Modern Times

The area of Samarkand is one of the most fertile in Central Asia, and today its cultivated surface covers approximately 3,500 sq. km (Fig. 1). As a result of the USSR's twentieth century policies, the most common crops are cotton, grapes, tobacco, and fruit trees. Crops extend equally on both sides of the floodplain alongside the two major historical canals: the Dargom in the south and the Bulungur in the north. Both branch off in

several minor canals that differ from each other in length, width, and flow rate. The Eski Angar, Yanghiaryk, and Siab-Karasu originate from the Dargom, supply the city and irrigate the southern part of the valley, whereas the Payaryk, Mirzaaryk, and Tuyatartar are the main canals diverted from the Bulungur in the northern half of the plain. 96.8 % of the water supplying the Samarkand region comes from the canals fed by the Zeravshan and the remaining 3.2 % from the piedmont seasonal streams locally known as *sai* (Alimov & Kadyrov, 1979, p. 147).

The Water Intake at Ravatkhodja-Varaghsar

Since the Zeravshan runs below the city of Samarkand and most of its territory, hydraulic control is required to make its water useful for irrigation and urban supply. Approaching Samarkand from the east, during his journey along the Zeravshan Valley in 1869, the Russian explorer A. P. Fedchenko (1870, p. 453) wrote:

Where the conglomerate ceases to prevail, there one finds the first of a system of very large canals, or 'aryks' dug for the irrigation of the southern parts of the valley. The lands here are much more elevated than those of the north ... but for the supply of water to the whole of the southern portion of the valley it has been necessary to divert streams at great elevations.

The whole system has its origin at the *Pervomayskaya plotina* (lit. May 1st Dam) in the village of Ravatkhodja, located on the Uzbek-Tajik border, 40 km to the southeast of Samarkand (Fig. 2). Here, at the outlet from the upper valley, the Zeravshan has high conglomerate banks and its width does not exceed 200 m. In 1921, a flood destroyed the first dam built in 1914–1916. After its reconstruction in 1927–1932 (Fig. 3), several stretches of the ancient Dargom were strengthened and cemented (Fig. 4). Two locks were then constructed at Akmachit and Kishrau to supply the major modern irrigation canals and three hydroelectric plants.



Irrigation Systems in Samarkand, Fig. 1 The Samarkand oasis (*black dot in the box*) from a satellite ArcGIS[®] World Imagery (elaboration: Author)



Irrigation Systems in Samarkand, Fig. 2 The May 1st Dam at Ravatkhodja (from southeast) (photo: Author)



Irrigation Systems in Samarkand, Fig. 3 Construction of the May 1st Dam in a 1930s picture (from southwest)

Irrigation Systems in Samarkand,

Fig. 4 Modern intake of the Dargom canal (photo: Author)



The historian V. V. Bartold was the first to report on the water intake at Ravatkhodja from the description of the Arab geographers of the tenth and eleventh centuries (Barthold, 1928, p. 83, 1965, p. 165; Mukhamedjanov, 1972, 1975). The site is called Varaghsar, translated from the Sogdian as “head of the dam,” and A. R. Mukhamedjanov (1994, p. 272) summarizes its historical importance:

... in the Early Middle Ages the inhabitants of Vargsar were required to keep watch on the Dargom canal dam as a labour duty, in exchange for which they were exempted from land taxes. At that time, about 40,000 people lived in Vargsar ... Whoever held Vargsar could deprive Samarkand of its water supply. In the political history of Samarkand, there are numerous examples of attempts by foreign invaders to destroy the Vargsar dam and so compel Samarkand to surrender.

Irrigation Systems in Samarkand,

Fig. 5 Traditional *sepaya* system in the village of Khodjayuz (photo: Author)



Regarding this toponym, recently P. Lure (2013) suggested that Varaghsar can also refer to the act of “dividing.” It may therefore relate to the traditional system employed in diverting the river water into canals. It consists of a long strip of earth, strengthened by a series of wooden tripods (locally known as *sepaya*) filled with stones and earth, positioned across the Zeravshan’s bed in order to divert the water into the major canals of the Dargom and the Bulungur (Fig. 5). The old pictures available in the local museum at the May 1st Dam, and ethnographic observation from the village of Khodjayuz on the first terrace of the Zeravshan (di Cugno, Mantellini, and Berdimuradov, 2013, pp. 100–101), confirm the use of such traditional solutions before the construction of the modern dam.

Irrigation in Ancient Times

The origin of Samarkand’s irrigation system has been debated at length, but all the scholars agree that it was the result of a long-standing hydraulic engineering project dating back in time. The first interest in the water supply of the ancient city occurred at the very beginning of the twentieth century in connection with the first archaeological investigation by V. L. Vyatkin and V. V. Bartold at Afrasiab. Since then, the attention of scholars has been focused especially on the Dargom (“long course” from old Iranian), the

canal directly connected to the water supply of the city of Samarkand and its southern hinterland. Measuring 100 km, from the May 1st Dam to the junction into the Zeravshan, at the height of the Kumaryk village, the Dargom is the longest canal in the region. Because of its present-day appearance, with an entrenched and meandering channel and very narrow loops, many theories have been advanced on its origin and chronology (Fig. 6).

In the 1930s, while excavating the site of Tali Barzu, G. V. Grigorev (1939, 1940) was the first to notice that the beds of the natural piedmont *sai* were exploited in the construction of the Dargom. Later on, B. Ya. Staviskiy (1969) and many other scholars agreed with this hypothesis. However, M. E. Masson (1972) still considered the Dargom as an old natural branch of the Zeravshan.

In the second half of the 1950s, the Institute of Archaeology of the Uzbek Academy of Sciences began a systematic investigation of Samarkand and its territory. V. D. Jukov (1958) dealt with a first interpretation of the history of the Dargom, proposing three steps in the evolution of the canal. According to this study, the irrigation, in the present-day steppe of Samarkand, had already ended in the fourth to fifth century AD.

Between the 1960s and 1970s, A. R. Mukhamedjanov and Ya. G. Gulyamov dated the main canals of Samarkand to the heyday of the development of large-scale irrigation systems in ancient Central Asia at the time of the

Irrigation Systems in Samarkand, Fig. 6 The Dargom canal today near Kishrau (photo: Author)



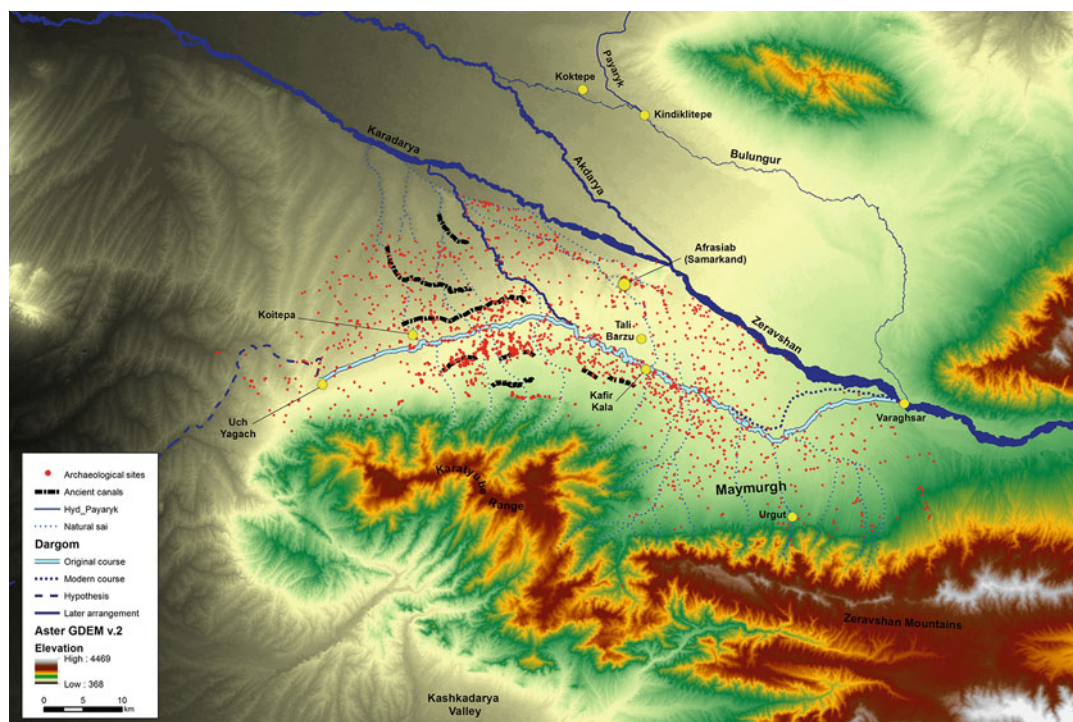
Kushan Empire expansion (first century BC–second century AD) (Gulyamov, 1974; Mukhamedjanov, 1994). Based on the results of the archaeological exploration around Varaghsar and the tunnel carrying the Zeravshan's water into the Dargom, the authors suggested that the Dargom was built in the first century BC (Gulyamov, 1974, p. 120; Mukhamedjanov, 1969, p. 299, 1972, p. 108, 1975, p. 279). Gulyamov and Mukhamedjanov also argued that the Dargom and the ancient Eski Angar formed a unique irrigation system, 300 km in length and designed to irrigate the Karshi oasis in the Kashkadarya valley.

In the 1980s, G. V. Shishkina supported the theory that the Dargom was already functioning during the Achaemenid period (Shishkina, 1987, 1994) because its typical fine gray sediments were found in connection with ceramics of the sixth to fifth century BC at the archaeological excavation of the Lolazor site (modern downtown of Samarkand).

In the mid-1990s, T. Lebedeva (1994, pp. 22–23) and K. K. Askarov (1995) placed the origin of the Dargom at the end of the fifth century AD, in connection with the increase in settlements which occurred in the Samarkand region during the Early Middle Ages. This theory however does not take into account that in his *Geography* of the second century AD, Ptolemy mentioned the Dargomanes as the main water supply of Samarkand.

At the beginning of the twenty-first century, M. Kh. Isamiddinov suggested three different steps in the evolution of the irrigation system of the Samarkand area (Isamiddinov, 2002, p. 30). The first stage concerns the Neolithic and the Bronze Age (from the fourth to the second millennia BC), when the simple strengthening of the natural riverbeds of the piedmont streams could irrigate a maximum of 5,000 ha. The origin of the major canals such as the Dargom and the Bulungur was dated to the Iron Age, possibly to the eighth or seventh century BC. These canals expanded the irrigated surface to 70,000 ha. Finally, the water demand related to the increased settlement, at the beginning of our era, resulted in the extension of the main irrigation systems and the construction of new canals.

Most recently, the Italian-Uzbek Archaeological Project provided a significant advance in the understanding of the evolution of the Dargom. A comprehensive approach combining geoarchaeological fieldwork, remote sensing techniques, and study of historical maps investigated the anthropic landscape of the southern Samarkand floodplain. The survey resulted in the discovery of ca 2,000 archaeological sites showing a continuous occupation from the Hellenistic age (fourth century BC) to the Timurid period (fifteenth century AD) (Mantellini, 2014). The geological stratifications, along the Dargom and subparallel canals uphill and its tributary *sai*,

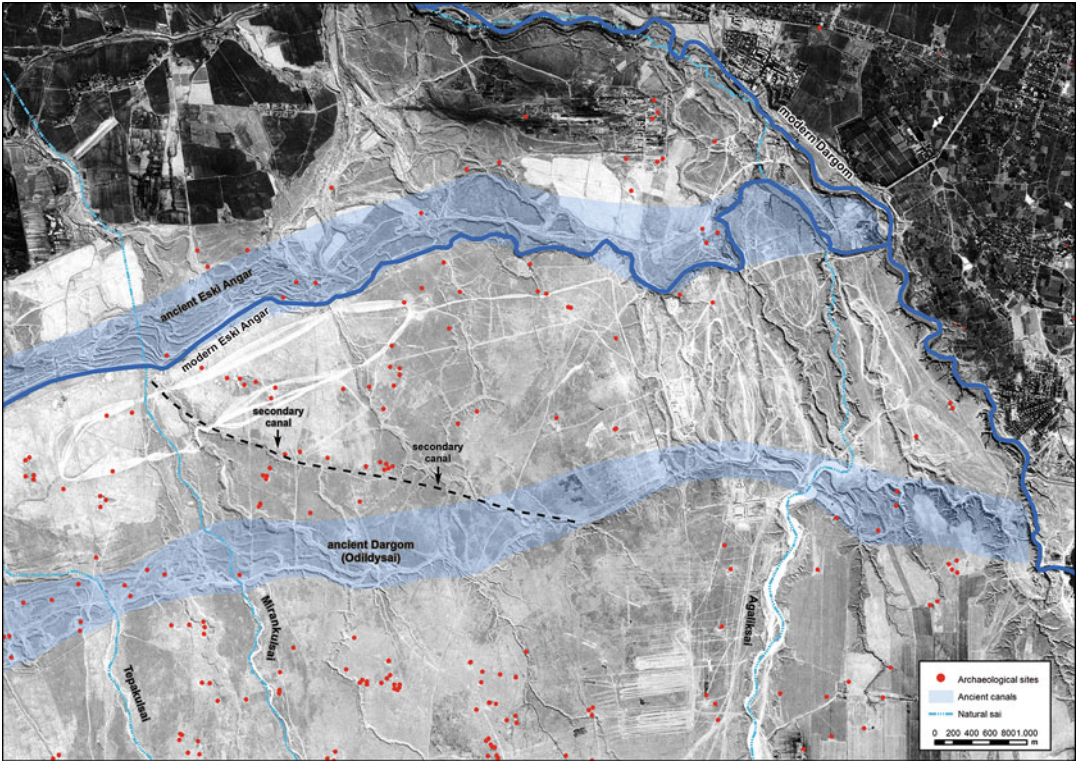


Irrigation Systems in Samarkand, Fig. 7 Archaeological sites and ancient canals in the Samarkand region showing hypothesis of the Dargom canal evolution (elaboration: Author)

confirmed that the canals were dug by cutting the piedmont at a very low angle with respect to the contour. These canals intercepted several *sai* and forced them to flow into the course of the new canals (Fig. 7). The analysis of the microtopography and sediments proved that in the very beginning, the Dargom would have been wider (average 250 m) and shallower (average 3–4 m). The present-day narrow, incised, and meandering course of the Dargom, which resembles a natural river, is in fact the result of rapid erosion, likely due to the diversion of its lower reach into the natural bed of the Agaliksai. ^{14}C samples from the alluvial layers of the Kafir Kala fortress and environs demonstrated that the Dargom certainly existed between AD 80 and 240. During the same period, the Yanghiaryk, now disappeared, irrigated the uphill lands between the Dargom and the Karatyube piedmont. Geochemical analysis of the ancient sediments of the Dargom, the Yanghiaryk, and the canals of Afrasiab

(Malatesta et al., 2012) established that the Dargom was dug in a water landscape dominated by seasonal *sai*. The sediments found in the Achaemenid layers of Afrasiab, in fact, perfectly match those occurring on the Karatyube piedmont *sai* (brown-reddish coarse gravel) and yet are different from the Zeravshan-derived Dargom and Yanghiaryk (fine grey sand) (Malatesta et al., 2012).

The steppe southwest of Samarkand provides more discoveries to posit a better chronology of the Dargom system. There, the lack of modern urbanization and agricultural expansion has preserved a sort of “fossilized archaeological landscape” (Fig. 8). Sediments analysis has demonstrated that the large dry riverbed in the middle of the steppe, identified on topographical maps as Odildysai (Fig. 9) and partially used for the modern Eskì Angar (Fig. 10), was actually part of the Dargom itself. The canal flowed southward before disappearing into the steppe. The presence of the typical Dargom gray sand in the



Irrigation Systems in Samarkand, Fig. 8 Ancient settlements and canals in the steppe “fossilized landscape” southwest of Samarkand (elaboration: Author)

Irrigation Systems in Samarkand,

Fig. 9 Abandoned bed of the ancient Dargom-Odildysai (photo: Author)



large and complex site of Uch Yagach, ca. 50 km southwest of Afrasiab, seems to confirm the hypothesis suggested by Ya. G. Gulyamov and A. R. Mukhamedjanov that the ancient Dargom supplied the Kashkadarya oasis. Traces of other major canals, on both sides and running parallel

to the Dargom, support the theory that in the past, the whole area was watered according to a systematic master plan (Fig. 11). The majority of sites scattered along these canals date to the third to first century BC, thus framing their main origin and function to the late

Irrigation Systems in Samarkand,

Fig. 10 Narrow and incised course of the modern Eski Angar (photo: Author)



Irrigation Systems in Samarkand, Fig. 11 Wide and shallow bed of the ancient Eski Angar (*black arrows* refer to the original levees) (photo: Author)

Hellenistic-early Kangju periods. Somewhat later, the western reaches of the Dargom were no longer supplied with water. This resulted in a progressive abandonment of the area and the consequent massive occupation of the region reported in Chinese sources as Maymurg (modern Taylak and Urgut districts) during the Early Middle Ages (fifth to eighth century AD). It is still unclear whether the present confluence of the Dargom with the Zeravshan at Kumarik (by the course of the Agaliksai) occurred at that time or later. It is however worth noting that the

majority of sites located at that confluence date to Islamic and Medieval times (fourteenth to seventeenth century AD).

Since the Early Middle Ages, when Samarkand was the capital of Soghd, the data are scant. However, it is arguable that the main scheme of the Dargom's irrigation network remained almost unchanged and was always connected to the fate of the city. Certainly the development of the settlements required a significant investment in terms of labor, management, and maintenance of the irrigation network.

Irrigation Systems in Samarkand, Fig. 12 The Bulungur (*left*) and Payaryk (*right*) at Kindikli-tepe in a 1880s picture by the Swiss traveler H. Moser (©Bernisches Historisches Museum, Ethnographical Collection)



In AD 1220, the Mongol army of Genghis Khan conquered Samarkand by interrupting the flow of the urban aqueduct of Djui-arziz (lit. “lead canal”) and causing the abandonment of the Afrasiab plateau. In the following century, the irrigation systems were restored when Timur made Samarkand the capital of his empire. Visiting the city in 1404, the Castilian Ambassador Ruy Gonzalez de Clavijo (1928) reported on many artificial canals supplying the big and lush gardens of Samarkand.

Compared to the Dargom, less attention was devoted to the canals on the opposite side of the valley. The origin of the Bulungur is often connected with the site of Koktepe, where the French excavation revealed an almost uninterrupted occupation from the fourteenth century BC to the Middle Ages. Together with Afrasiab, Koktepe demonstrates the early urbanization process that occurred in the area of Samarkand. On this basis, C. Rapin (pers. comm.) dated the Bulungur within the second third of the first millennium BC, which is the same chronology advanced by M. Kh. Isamiddinov. At present the archaeological evidence is scant and inadequate, even if the main fortress of Kindikli-tepe, at the bifurcation between the Bulungur and the Payaryk, dates to the Early Middle Ages (fifth century AD) (Figs. 12 and 13).

Canals and Urban Water Supply of Afrasiab

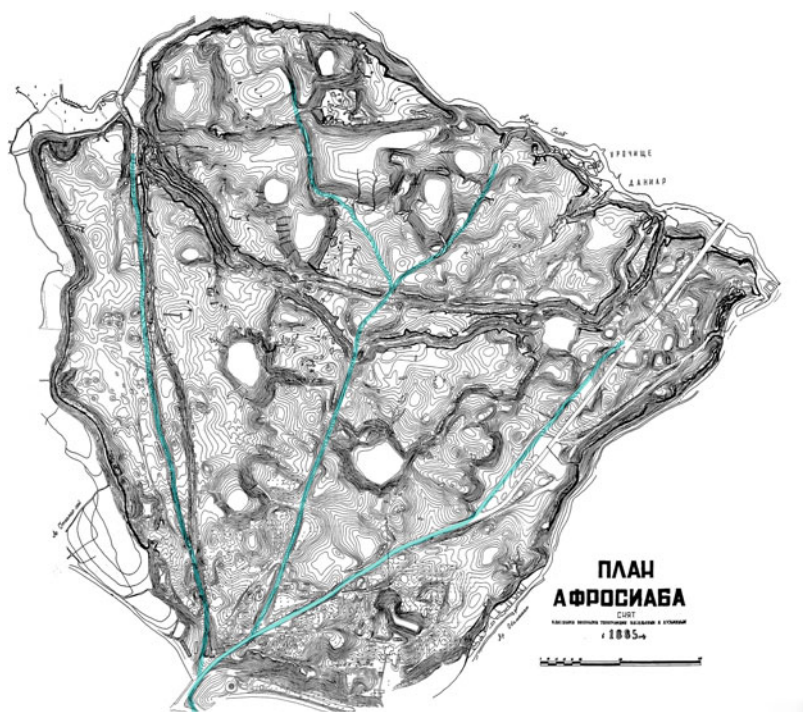
No city can survive and develop without an appropriate water supply, and Afrasiab (the ruined site referring to ancient Samarkand) is not an exception. In the early twentieth century, V. L. Vyatkin (1927) was the first to write about the three-canals system of Afrasiab (Fig. 14). The major, central canal was well preserved and clearly recognizable for a length of 1.5 km. Two canals diverted eastward and westward from it after the southern gate. The later topographical research by V. V. Bartold, and the discoveries which occurred in the market, close to the Bibi Khanum mausoleum, demonstrated that the water supply of the city came from the south.

After the activities carried out in 1959–1965 by G. V. Shishkina, N. B. Nemtsev, and M. H. Fedorov on behalf of the Institute of Archaeology of the Uzbek Academy of Sciences, A. R. Mukhamedjanov and Ya. G. Gulyamov identified three different steps in the water supply of Afrasiab. The early stage, around the middle of the first millennium BC, was based upon the Siab stream and springs. The network with three canals appeared around the third to first century BC, and it was linked to the streams fed by

Irrigation Systems in Samarkand, Fig. 13 The Bulungur (*left*) and Payaryk (*right*) at Kindikli-tepe today (photo: Author)



Irrigation Systems in Samarkand, Fig. 14 The three canals supplying Afrasiab on the 1885 topographical map by Vasilev and Kuzmin (MAFOuz©, graphic elaboration C. Rapin)



natural springs, especially the Novadon and the Obimashat. The connection of these canals to the Dargom occurred only in the Kangju period, due to the expansion of the city and the increased need for water. Then the central canal was more than 6 m wide and 0.7–0.8 m deep.

In 1996 the trench excavated by I. D. Ivanitzkiy and O. N. Inevatkina (French-Uzbek expedition) identified three main periods in the central canal of Afrasiab: (1) mid-first

millennium BC–mid-first millennium AD, (2) end of the fifth to eighth century AD, and (3) ninth–early thirteenth century AD (Ivanitzkiy and Inevatkina 1999). The earliest subphase of the first period dated to the late sixth century BC. The presence of black and fine sand in this layer, apparently from the Zervavshan, was considered as proof that the Dargom supplied Afrasiab since the city foundation (Grenet, 2002). Nevertheless, recent mineralogical

Irrigation Systems in Samarkand,

Fig. 15 Traditional digging operations along the Dargom in the 1920s



analyses proved that the sand has a clear local hillslope signature, thus belonging to a natural *sai*-based system.

Irrigation and Social-Political Implications

One of the most theoretical constructs of Soviet archaeology was to explain the rise of early states in relation to the development of large irrigation systems and the presence of a strong and centralized power, often exploiting slavery to achieve major economic investments. S. P. Tolstov theorized this for Khorezm and suggested that the creation of the great canals, irrigating such an arid and desert environment, was only possible with conditions of oriental despotism conceptualized by K. A. Wittfogel for ancient “hydraulic societies” (Tolstov 1948, p. 45).

This theory was supported through the evaluation of costs required to accomplish the excavation of a canal. According to S. P. Tolstov and B. V. Andrianov in Khorezm and G. N. Lisitsyna (1969) in Turkmenia, in preindustrial Central Asian societies, a worker could dig and remove 2–3 cubic meters of earth daily. For example, in ancient Khorezm, the construction of the 90 km long Kyrk-Kyz canal required the digging of 2.2 million cubic meters of earth, equivalent to

the work of 15,000 men for 30 days. According to these authors, the sole local inhabitants were too few to accomplish such a demanding task, so the participation of additional slave labor was essential.

The construction of a complex irrigation network in Samarkand is also related to a large investment in terms of work, people, and time (Fig. 15). However, some scholars have interpreted this differently.

On one hand, G. V. Shishkina, P. Gentelle, and F. Grenet relate this experience to the early urbanization process recorded at Afrasiab and Koktepe. Such a huge enterprise was possible only thanks to a strong and centralized government, connected in this case to the establishment of the Achaemenid power as early as the fifth century BC or possibly earlier. According to this interpretation, at that time both large canals, the Dargom and the Bulungur, were created within a regional master plan aimed at irrigating the entire valley.

On the other hand, based on the results of an extensive survey, S. Stride, B. Rondelli, and S. Mantellini (2009, p. 80) highlighted that the Achaemenid sites, found in the southern part of the valley, are too few to justify the presence of such a large irrigation project. The construction of the Dargom occurred later on and was not necessarily the result of a strong and centralized power. In this regard, they wrote:

The construction of the Dargom is likely to have been progressive and to have resulted from consensual agreements and alliances between the different local populations which would have benefited from it.

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Isa Tarjaman

Sun Xiaoli

During the Yuan dynasty (1271–1368) the Arabs played a role in Chinese science and technology similar to that of the Indians in the Tang, bringing in stimulating outside influences which were then incorporated and synthesized into Chinese mathematics, astronomy, and medicine. Isa Tarjaman (1227–1308) or Aixue in Chinese, was a remarkable example. Isa Tarjaman, sometimes called Isa the Interpreter or Isa the Mongol, was a Nestorian Arab from Syria. He was skilled as a mathematician and astronomer as well as in medicine and pharmacy. He came to China in about 1247, then worked for the Mongol Khans till his death in 1308. In 1263 Kublai Khan appointed Isa the director of the Muslim Astronomical Bureau and Medical and Pharmaceutical Bureau. During this time he suggested that Kublai prepare a new calendar in the Arabian style which he finished in 1267 in cooperation with a Persian astronomer Zhama Ludin or Jamāl al-Dīn, who was working in China too. This was called the *Wan-nian* (10,000 years) calendar. Meanwhile, they made seven kinds of Arabian astronomical instruments for the Huihui (Muslim) Observatory. All of these exerted some influence on the Chinese astronomer Guo Shoujing (1231–1316) and his work.

From 1283 to 1286, Isa was sent to Il-khan as a member of a delegation. There he visited the famous Maraghā Observatory and worked together with some Arabian and even Chinese astronomers who were working there for a time. Then he brought some of these astronomical and mathematical works back to China. These were

studied by staff members at the Muslim Astronomical Bureau in Beijing.

As the director of the Medical and Pharmaceutical Bureau, Isa Tarjaman established a Capital Hospital to introduce Arabian medicine to China; his wife Sara also worked there. An important Arabian medical work entitled *Huihui Yaofang* (Collection of Muslim Prescriptions) was compiled under his leadership. It is interesting that some of the contents of this work were taken from Ibn Sīnā's *Canon*. Therefore, Isa made a great contribution to the history of the Sino-Arabian scientific exchange, and he thus was praised by the Mongol Khans. After returning from Il-Khan he rose to be a Hanlin Academician, then the minister of State in 1297. After his death the Mongol court made him the Fuolin Prince. He was the only Arab to attain such a high official position in China.

See Also

- [Guo Shoujing](#)
- [Marāgha](#)

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Ishango Bone

Anne Hauzeur

The engraved bone drew international attention as soon as it was described by J. de Heinzelin in 1957. Its uniqueness, as well as its geographical and chronological position, were astonishing.

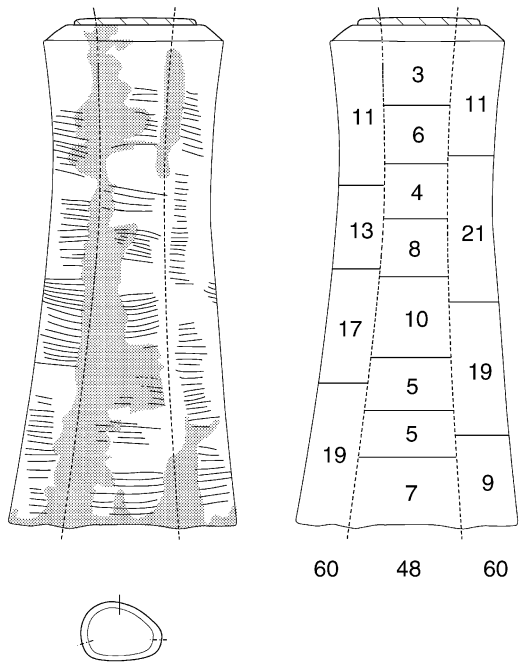
Ishango is located on the top of a fossil terrace of the Semliki River, at the mouth of Lake Edward/Rutanzige, in the Democratic Republic of Congo. There were several prehistoric occupations from 20,000 to 5000 BC, when the volcano Katwe erupted. The different levels of human occupation are characterised either by a great amount of small-sized tools in a translucent white quartz, but most of all by numerous bone harpoons. Those latter evolved from a one-barbed sided to a two-barbed sided type. The settlement of Ishango would illustrate an old step of this harpoon production, whose pattern would have been widespread from the Great Lakes region towards Western Africa and the North in Sudan and Egypt. Rainfall was increasing during this time, so that the way of life was more devoted to fishing. This fishing tradition went on after sedentarisation and the introduction of animal breeding.

The engraved bone has several points of interest. It is the only piece among the whole artefacts assemblage to have a series of notches engraved in a very ordered rhythm (Fig. 1). As with the other tools, it was made on the settlement. A diaphysis [the mid-section of a long bone] from an unidentified animal was prepared and worked. At one end a little piece of white quartz was shafted to be used as a tool. Without any archaeological evidence the function is unknown; perhaps it was used to incise or engrave. The “shaft wears” groups of notches, displayed in three rows on its periphery. When adding all the groups of each row, the sum is 48 or 60, a multiple of 12 (Fig. 2). Each group of notches sums either prime numbers between 10 and 20, or numbers multiplied by 2, or 10 ± 1 . It could illustrate a numerical converter system of base 10/base 12. In such a case, the Ishango bone could be considered as the oldest computing machine, used during the times of the hunter-gatherer nomads. It would be the oldest transcribed testimony of the mathematical intelligence of our ancestors, right in Central Africa, some 20,000 years ago. Originally, the antiquity of the piece was questioned, but new dating has proved its age.

Archaeological facts demonstrate the wide spread of the harpoon tradition, i.e., from Central



Ishango Bone, Fig. 1 The engraved bone from Ishango, with a quartz at the tip (Photo and ©RBINS)



Ishango Bone, Fig. 2 Unrolled sketch of the Ishango bone, and number in each group of notches (After de Heinzelin, 1957)

Africa to the Nile basin. Traditional scholars taught that the first mathematics came from the Ptolemaic period and the Golden Age of Alexandria.

See Also

► [Mathematics in Africa South of the Sahara](#)

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Ishāq Ibn Ḥunayn

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Ishāq ibn Ḥunayn (215–298 AH/AD 830–910) is best known for his role in the translation of Greek texts, both philosophical and mathematical, into Arabic. In addition to his work in the translation institute founded for his father, Ḥunayn ibn Ishāq (193–263 AH/AD 809–877), he served as a physician to the court under caliphs al-Muʿatamid and al-Muʿatadid. Although Ḥunayn was a Nestorian Christian, some sources imply that Ishāq converted to Islam.

As a translator, Ishāq followed the scientific approach applied by his father with such success to the Galenic corpus. Rather than translate mechanically word by word, he attempted to capture the meaning of each Greek thought unit in an appropriate form in the target language. Both Ishāq and his father are said to have preferred to translate first from Greek into their native Syriac,

only later producing an Arabic version based on the Syriac. Assuming such reports to be true, the paucity of Syriac translations among extant manuscripts remains puzzling to historians.

Ishāq's greatest contributions lay in his translations of Greek philosophical texts, especially the works of Aristotle. He produced Syriac versions of a part of the *Prior Analytics* and all of the *Posterior Analytics* and the *Topics*. He also rendered the *Categories*, *On Interpretation*, *Physics*, *On Generation and Corruption*, *On the Soul*, parts of the *Metaphysics*, and the *Nicomachean Ethics* into Arabic. He may also have translated the *Rhetoric* and the *Poetics*. In addition to Aristotle's works, he translated Galen's *Number of the Syllogism* and part of his *On Demonstration*, as well as some logical and philosophical works by Alexander of Aphrodisias, Porphyry, Themistius, and Proclus.

Ishāq was also instrumental in translating several important Greek mathematical treatises into Arabic. These include Euclid's *Elements* (although some manuscripts attribute the translation to his father, Ḥunayn [De Young, 1992]), *Optics*, and *Data*, as well as the *Almagest* of Claudius Ptolemy, *On the Sphere and Cylinder* by Archimedes, the *Spherics* of Menelaus, and minor works by Autolycus and Hypsicles. It is reported that Ishāq's translations of Euclid and Ptolemy were revised by the mathematician Thābit ibn Qurra. Apparently, Thābit compared the Arabic version with additional Greek manuscripts which he had at his disposal and noted differences between the Arabic and Greek versions. Whether any other editing was involved, we do not yet know. All extant Arabic manuscript copies of Euclid seem to reflect some aspects of this editing process, although no manuscript contains the complete set of comments attributed to Thābit [De Young, 1992]. The relationship of Ishāq's version of Euclid to the earlier transmission attributed to al-Ḥajjāj ibn Yūsuf ibn Maṭar is difficult to establish because the earlier version has disappeared, as has the translation of Ishāq, apart from some scattered brief quotations or reports in secondary sources [De Young, 2002–2003]. In the case of the *Almagest*, however, both Arabic versions appear to be extant,

allowing some conjectures to be made concerning the translation principles applied by both men [Kunitzsch 1974; 1985].

Ishāq also produced a number of original works on medicine. Unfortunately, these seem not to have survived. His *Tārīkh al-Aṭṭibāʾ* (*History of Physicians*), an extended version of a Greek book of the same title by John Philoponus, does survive. Ishāq has added the names of philosophers active during the lifetime of each physician mentioned. This work has been helpful to historians of both medicine and philosophy.

See Also

- [Al-Ḥajjāj](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Ḥunayn Ibn Ishāq](#)
- [Thābit ibn Qurra](#)

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Jābir Ibn Aflah

Richard P. Lorch

Almost nothing is known of Jābir's life, but remarks by Maimonides (d. 1204), e.g., that he knew Jābir's son, place Jābir probably in the first half of the twelfth century, and the name "al-Ishbīlī" establishes a connection with Seville. Indeed, legend associates his name (wrongly) with the building of the Torre del Oro and of the tower now belonging to the cathedral in Seville. Jābir's principal work was a commentary (or correction, *iṣlāḥ*) on Ptolemy's *Almagest*, the standard textbook on mathematical astronomy, which he had seen in two translations from the Greek. In this treatise he not only simplified the mathematics and separated theory from calculation (there are no tables in the book), but also indulged in violent criticisms of Ptolemy. The introduction to the commentary contains a list of Ptolemy's "errors", which are considered in detail in the body of the book. His best known astronomical claim of this kind was his assertion, against Ptolemy, that Venus and Mercury must lie above the Sun because of their lack of parallax.

Jābir's lasting contribution was his statement of the requisite theorems in trigonometry. The essence of his plane trigonometry is to be found in the *Almagest* itself, but his clear enunciations of his results for triangles obviated the need for

construction lines that cluttered so many diagrams. Again, his theorems on spherical triangles, which replaced Ptolemy's theorems involving six quantities by proportions involving four, were clearly taken over from a group of scholars, such as Abū 'l-Wafā' and Abū Naṣr ibn 'Irāq, who worked in Baghdad and elsewhere in the eastern provinces of Islam about AD 1000. Curiously, Jābir quotes no Arabic author in his work, not even Ibn Mu'ādh, who had lived and worked in eleventh-century Seville.

The text of the *Iṣlāḥal-majisṭī*, at least in the trigonometrical part, was revised, perhaps by the author. Ibn Rushd (d. 1198) and ► [al-Bīṭrūjī](#) in Spain were both influenced by the work. It was also known in the East, for ► [al-Shīrāzī](#) (d. 1311), one of the Marāghā astronomers, made a compendium of it. There were two translations into Hebrew, by Moses ben Tibbon (1274) and by Jakob ben Makhir (revised by Samuel ben Yehuda of Marseilles, 1335), and Jābir appears to have had considerable influence in Hebrew astronomy. But the most lasting influence of the work was through the translation into Latin by Gerard of Cremona (d. 1187). For the Latins not only was "Geber" a vigorous critic of Ptolemaic astronomy, but his treatise established trigonometry in the West. This can be seen in an anonymous commentary, in an anonymous compilation of the plane trigonometry, *De tribus notis* (On Three Known [quantities]), and in the works of Simon Bredon, Richard of Wallingford (both fourteenth century), and others. Finally,

“Geber” was the source of much of Regiomontanus’ *De triangulis* (On Triangles), perhaps the source for the trigonometrical section of Copernicus’ *De revolutionibus* (On the Revolutions [of the Heavenly Spheres]).

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Jābir Ibn Ḥayyān

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Abū Mūsā/Abū ‘Abd Allāh Jābir ibn Ḥayyān, for a long time the reigning alchemical authority both in Islam and the Latin West, is at the same time among the most important and most enigmatic figures of the history of Islamic science. Doubts already existed in the medieval Arabic tradition as to whether the large corpus of alchemical, philosophical, and religious texts attributed to Jābir were authentic. Scholars of modern times have shared these doubts, and some have gone as far as to conclude that Jābir may never have existed at all, and that contrary to the received view, the Jābirian corpus is not the

work of a disciple of the sixth Shī‘ī Imām Ja‘far al-ṣādiq (d. 765); rather, it was produced piecemeal by several generations of Ismā‘īlī authors, the oldest of whom lived no earlier than the second half of the ninth century.

This essentially is the widely accepted position of Paul Kraus who still remains the greatest Jābirian scholar of modern times. Some historians have disagreed with this position, and others have tended to revise it. At this juncture, then, very little about Jābir can be claimed with certainty. It might be safe to say on the basis of the most recent evidence that Jābir was a historical Muslim figure of the eighth century, that there was a small authentic core of Jābirian writings, and that out of this core developed the largely apocryphal and grand Jābirian corpus as we know it today.

Jābir is generally referred to as an alchemist. But if turning base metals into gold is the essential preoccupation of alchemy, then Jābir is hardly an alchemist, for transmutation of metals was only a minor part of his concerns. He was concerned, rather, with developing an all-embracing metaphysical and natural scientific system based upon immutable universal principles. It is this search for universal principles that led him to the study of language, music, and numbers. The Pythagoreans said that things are numbers; Jābir says that things are the names that designate them. An analysis of the name of a thing is for Jābir an analysis of the thing itself; this daring ontological claim of an equivalence between language and reality sounds more metaphysical than alchemical.

Jābir did write extensively about chemical processes and techniques, and in this field he made some highly original and historic contributions. For example we find in his treatises the theory that all metals are composed of sulfur and mercury existing in various proportions. It was this idea that led to the phlogiston theory of modern chemistry. Another Jābirian contribution is the introduction of sal ammoniac in the repertoire of chemistry. Two varieties of sal ammoniac

were distinguished: natural (ammonium chloride) called *al-Ḥajar*, and derived (ammonium carbonate) called *al-mustanbaṭ*. The latter was obtained by the dry distillation of hair and other animal substances. Again, the use of organic materials, both plant and animal, in addition to the inorganic, is a monumental Jābirian innovation.

Jābir's chemical processes are never carried out in a theoretical vacuum; we find in his writings both a developed theory of matter and a sophisticated cosmology. He believed that matter was ultimately composed of four "natures" – hot, cold, moist, and dry. But unlike the familiar Aristotelian qualities, Jābir's natures were not abstractions; rather, they were real, material, and independently existing entities; hot, cold, moist, and dry were the "first elements" out of which were born the "second elements": air, water, earth, and fire. The former were simple, the latter were compound; the former were primary, the latter were derived; the second elements could be resolved into natures, but natures were immutable. Jābirian natures were, then, the ultimate building blocks of the world.

A striking aspect of Jābir's cosmology is his parallel idea of the "first creation" and the "second creation." The former was an act of God, the latter an act of man. The difference between these two is that God acts in a timeless fashion, whereas man effects his creation in a temporal domain. Thus man can imitate God's work, but he requires time to accomplish it. From this emerges the Jābirian idea of artificial generation. Birds, for example, are found in nature, but these creatures can also be produced over a period of time in a laboratory; so can human babies. Through a manipulation of natures man can generate even such living beings as are not found to exist naturally – monsters, dwarfs, giants, freaks, and so on. Indeed, Jābir's idea of artificial generation sometimes strikes one as thoroughly modern.

If Jābir is the first alchemist of Islam, then he is the pioneer of all that is important and characteristic of Islamic alchemy: the sulfur-mercury

theory, the introduction of sal ammoniac, the use of organic substances, the idea of artificial generation of life, the production (though not recognition) of mineral acids, and the conceptual distinction between heat and temperature. He was widely known in Medieval Europe, and at least three of his treatises were translated into Latin.

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Jade in Southeast Asia

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Jade jewelry was one of the most favored body decorations in prehistoric Southeast Asia. These objects represented outstanding beauty and technical complexity. The word *jade* is used in the broad sense of a hard and shiny stone, and it could refer to either of two types of monomineralic rocks known as *jadeite* and *nephrite*. Both jadeite and nephrite occur in metamorphic rocks, but their chemical compositions are different. Jadeite is composed of jadeite (sodium



Jade in Southeast Asia, Fig. 1 Pinglin prehistoric jade workshop (a) in eastern Taiwan was regarded as the largest in Southeast Asia by Japanese scholar Tadao Kano in

the 1940s. Large amounts of nephrite-working debris and drilled-out cores represent different stages of jade manufacturing (b–d)

clinopyroxene), whereas nephrite is composed of calcium amphibole (tremolite and/or actinolite). Most jade artifacts in Neolithic and Iron Age Southeast Asia are composed of nephrite.

The largest collections of jade artifacts in Southeast Asia are from Taiwan, the Philippines, and Vietnam. Lesser numbers have been reported from Thailand, Cambodia, Burma, Malaysia, and Indonesia. Any single piece can convey an important message for understanding our human past. The oldest known jade artifacts are dated to 3000 BC, reported from sites of the Early Neolithic Dabengkeng (also called Tapenkeng, TKP) culture in Taiwan and the Ha Long culture of northeast coastal Vietnam. Taiwan and Vietnam

witnessed parallel developments of jade manufacturing for more than 3,000 years, which considerably enriched Southeast Asia's prehistory. In the older sites, jade artifacts mostly were stone tools or simple forms of ornaments such as split earrings or bracelets, and they occurred in limited numbers. Later, the abundance and diversity increased greatly, reaching a highlight during the period 1500 BC–AD 1.

Since the 1940s, scholars noted the widespread occurrence of similar forms of jade ornaments throughout Southeast Asia (e.g., Kano, 1946; Loofs-Wissowa, 1982). Generations of archaeologists developed various notions about the dispersal scenario of these beautiful objects,



Jade in Southeast Asia, Fig. 2 Beinan Culture in eastern Taiwan, dated to 1500–300 BC, represents the highlight of jade production in Taiwan. The zoo-anthropomorphic jade ornaments of unique design (about 7 cm in length, 4 cm in width, and 0.5 cm in thickness) (see **a**) were discovered from different regions

in Taiwan but in small numbers. Other jade objects such as bell-shaped beads (as tiny as 5.2 by 4.4 by 3.1 mm) (see **b**) and different forms of split earrings (see **c** and **d**) were very popular during this cultural phase (Courtesy: Shu-ling Yang)

mostly based on classifications of artifact shapes and styles. In the past 10 years, geochemical analysis has been able to trace the natural sources of jade artifacts in Southeast Asia, allowing for new understanding of the complex trading networks of jade products in dated contexts.

Taiwan

Green jade tools and ornaments have been found in several hundreds of sites in Taiwan and on the nearby islands of Penghu, Ludao, and Lanyu dated between 3000 BC and AD 500.



Jade in Southeast Asia, Fig. 3 White nephrite adzes collected by H.O. Beyer in the 1930s, from southern Luzon, the Philippines (Courtesy: National Museum of the Philippines, Manila)

The raw material could be traced back to a quarried source of Fengtian in Hualien of eastern Taiwan. Around Fengtian, several large jade workshops have been found, such as at Pinglin (Fig. 1a) and Chongguang, where archaeologists have discovered square and flat blanks, drilled-out cores, and other debris in remarkable abundance (Fig. 1b–d). During the period 1500–300 BC, jade production reached its peak in Taiwan, best known at the Beinan Site, where slate coffins of a large cemetery sometimes contain hundreds of beautiful jade ornaments (Fig. 2).

Philippines

At least 20 sites have yielded jade ornaments in the Philippines, including those made of a local white nephrite and others made of either local or imported green varieties. H. Otley Beyer (1948) collected thousands of white jade tools, such as adzes and chisels, during the 1930s and 1940s in

Batangas, Rizal, and Laguna provinces (Fig. 3). Robert Fox (1970) excavated green jade artifacts during the 1960s and 1970s from sites on Palawan Island, including many *lingling-o* penannular earrings and other objects (Fig. 4). More findings since the 1990s have verified the oldest known examples of white jade adzes about 1000–800 BC at Uilang Bundok, and the oldest green jade artifacts about 2000–1000 BC in the Cagayan Valley and in the Batanes Islands of northern Philippines.

The specific geological source of white jade (Fig. 5a) has not yet been found, but its composition indicates an origin within the Philippines, likely in southern Luzon. In contrast, most of the green-colored items can be traced back to the Fengtian source in eastern Taiwan (Fig. 5d). Other local green mica, called Mindoro jade (Fig. 5b) from the central Philippines, likely was used as a substitute for green jade to produce similar forms of ornaments. In 2004, the exciting discoveries of several worked pieces and *lingling-o* earrings from Savidug Dune Site on



Jade in Southeast Asia, Fig. 4 Ornaments made of Taiwan nephrite, unearthed from the Tabon Caves in Palawan of the Philippines, including *lingling-o* penannular earring with four circumferential projections (**a**), *lingling-o* penannular earrings with three-pointed circumferential projections (**b top and right**), double animal-headed ear pendant in multiple views (**c**), and beads (**d**).

Similar *lingling-o* penannular earrings made of Taiwan nephrite have been unearthed from Go Ma Voi, Vietnam (**b left**). For scale reference, **a–c** are 3–5 cm width, and **d** is less than 1 cm width (Courtesy: National Museum of the Philippines and Museum of Sa Huynh and Champa Culture in Vietnam)

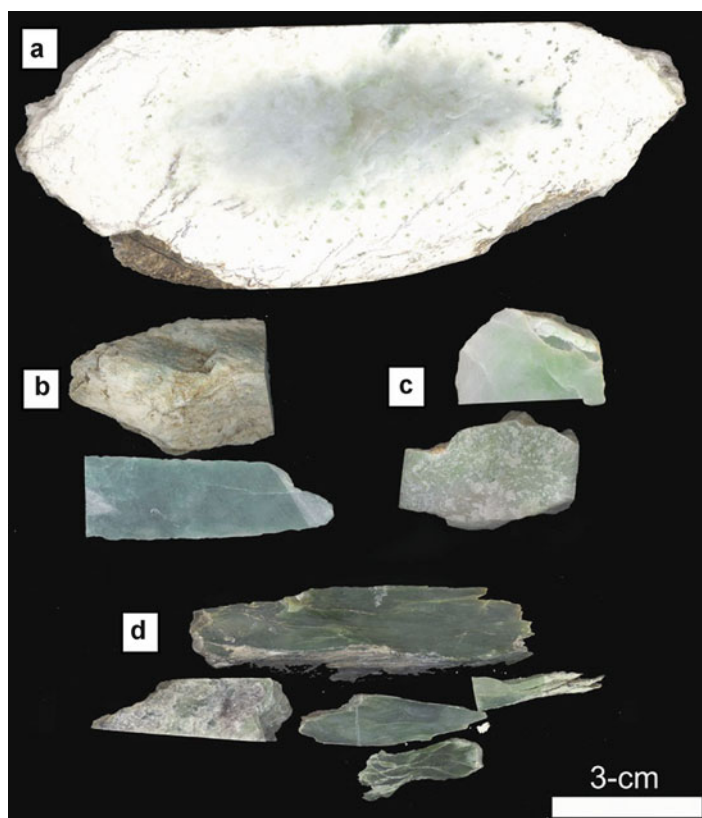
Sabtang Island (Fig. 6a) and the Anaro nephrite workshop on Itbayat Island (Fig. 6b–d) in Batanes confirmed that ancient artists created beautiful jewelry on those remote islands by using imported Fengtian jade.

Vietnam

Vietnam has yielded the richest evidence of jade production in Mainland Southeast Asian prehistory. During the period of 2000–1000 BC, locally

Jade in Southeast Asia,

Fig. 5 Four types of jade or jade-like raw materials. White nephrite block from Beyer's collection, presumably from local sources in southern Luzon (a). Mindoro jade (mica) from Mindoro Island of the central Philippines (b). Zambales jade (anorthite) from the western coast of Luzon (c). Taiwan Fengtian Nephrite (d). The items of a, b, and d were used for making prehistoric stone tools or ornaments in the Philippines



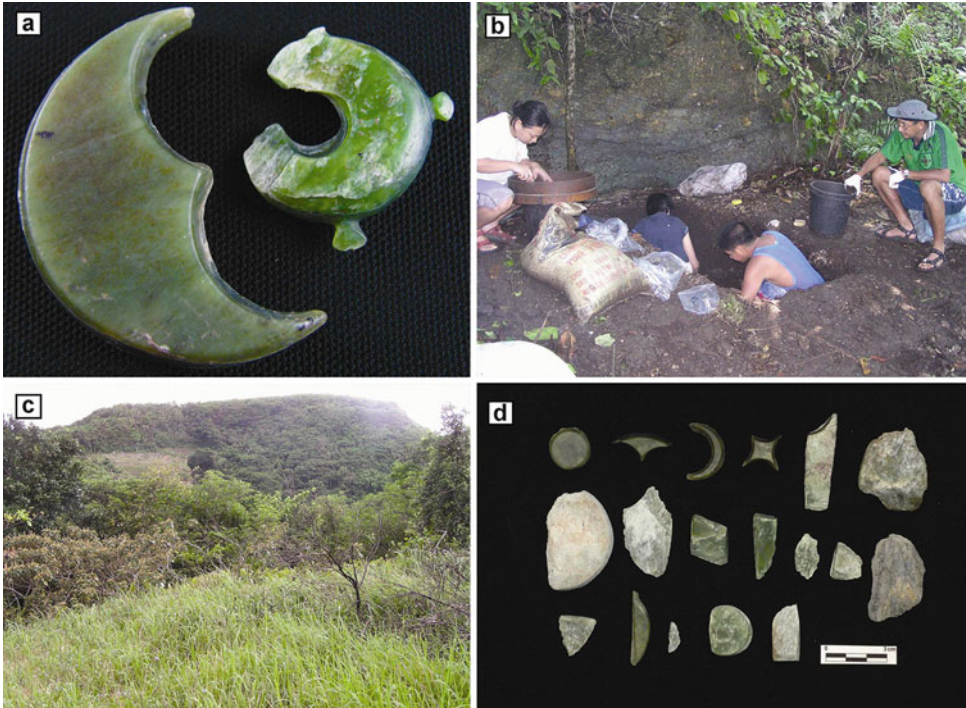
known as the Phung Nguyen Cultural Phase, jade bracelets, spilt earrings, Yazhang blades, and T-sectioned bracelets (Fig. 7) were popular in Northern Vietnam, in many cases exhibiting styles and fashions strongly related with China. At the same time, however, several jade workshops have been discovered in Northern Vietnam, such as Trang Kenh, Bai Tu, Hong Da, and Dau Ram (Nguyen, 1998). Trang Kenh is one of the largest and oldest jade workshops in Northern Vietnam (Fig. 8), dated at least as old as 1500 BC. Most of these Northern Vietnamese jade artifacts are either white or pale orange in color, likely collected from riverbeds in the limestone hills of Northern Vietnam.

Concurrent with the jade production in Northern Vietnam, Southern Vietnam was particularly famous because of two types of jade ornaments during the Iron Age Sa Huynh Period. One type

was the *lingling-o* penannular earring with three-pointed circumferential projections, and the other type was the double animal-headed ear pendant. Many of these ornaments unearthed from Southern Vietnam were made most likely of local nephrite, but some used imported Taiwan Fengtian nephrite. An ancient Chinese record of *Baopuzi* (vol. 11), written by Ge Hong in the Jin Dynasty (ca. AD 265–420), documented that central Vietnam had its own jade mine, although it is unknown today. Jade ornaments made in Vietnam likely were traded into nearby regions, such as Samrong Sen in southern Cambodia.

Sourcing and Distribution

Geochemical studies have clarified the material composition of jade artifacts, traceable to



Jade in Southeast Asia, Fig. 6 Pelta-shaped segment and three-pointed *lingling-o* of Taiwan Fengtian nephrite from Savidug Dune Site, Sabtang Island (a), and the

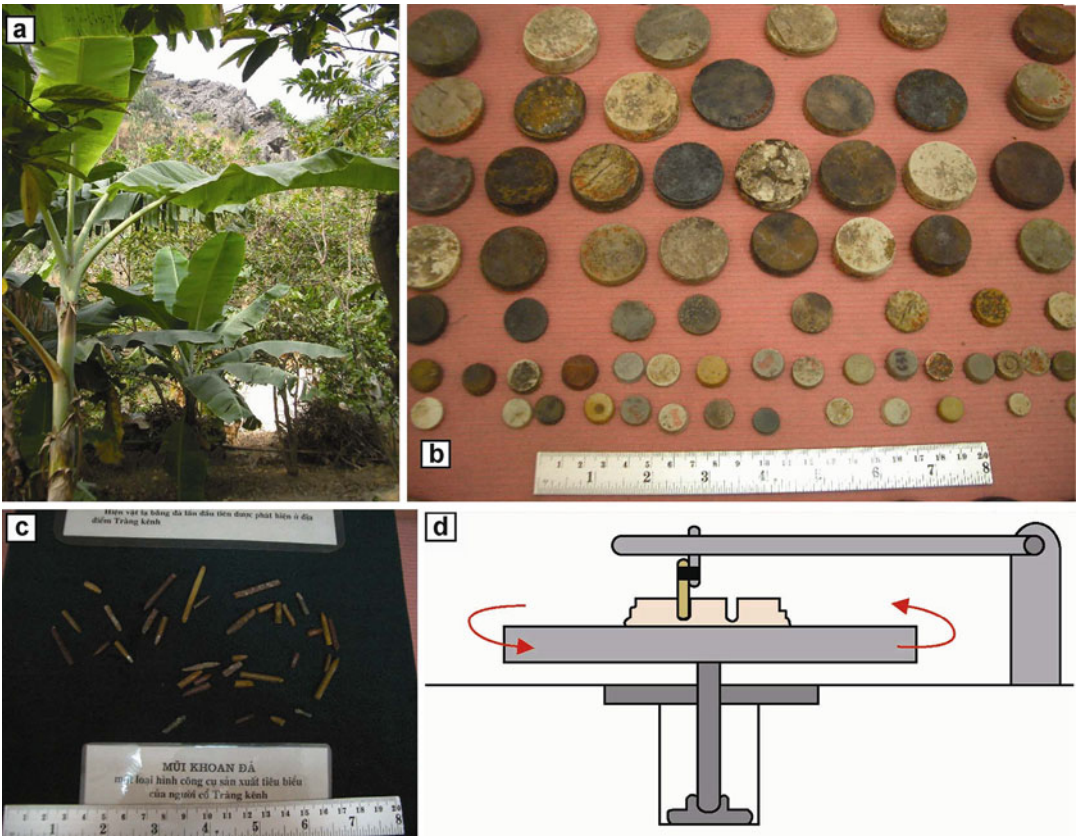
Anaro jade workshop on Itbayat Island with unearthed worked fragments of Taiwan nephrite (b–d)



Jade in Southeast Asia, Fig. 7 T-sectioned jade bracelet from Man Bac in Northern Vietnam (Courtesy: Vietnam Institute of Archaeology in Hanoi). Similar T-sectioned jade bracelets have been unearthed from Thailand, Malaysia, and China

geological sources, and thus we can create maps of the origins and distributions of jade artifacts during separate time periods. Most informative has been the green nephrite from Fengtian in eastern Taiwan, which during the period 500 BC–AD 100 was used for making very specific forms of ear pendants distributed in a 3,000-km-wide halo around the South China Sea, found in sites of Taiwan, the Philippines, East Malaysia, Southern Vietnam, and peninsular Thailand (Hung et al., 2007).

In some cases, the precious Fengtian nephrite was exported as square and flat blanks for final manufacture overseas. Besides Anaro in Batanes as mentioned above, Giong Ca Vo in Southern Vietnam and Khao Sam Kaeo in peninsular Thailand contain workshop debris of Fengtian nephrite, and Khao Sam Kaeo even includes many worked Mindoro jade fragments. Itinerant sea-crossing craftsmen may have been responsible for creating nearly identical signatures and



Jade in Southeast Asia, Fig. 8 Trang Kenh site, one of the largest and oldest jade workshops in Northern Vietnam (a). Many drilled-out cores of nephrite (b) and drills (c) were found from this workshop. Based on the findings

from this workshop, Nguyen Kim Dung reconstructed the model of ancient drilling technology (d) (Courtesy: Nguyen Kim Dung)

specific forms of ear ornaments in these rather small-scale overseas workshops.

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Jagannātha Samrāt

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Paṇḍita Jagannātha (1652–1744), who bore the title “Samrāt”, writer on astronomy and mathematics, and designer of astronomical instruments, was the religious preceptor and collaborator in astronomical pursuits of Jai Singh Sawai (1688–1744), the astronomer-prince of Jaipur in Rajasthan. Born into a Vedic family, the son of Gaṇeśa, Jagannātha was attached to the court of Jai Singh from an early age and assisted his patron in all his social, religious, and scientific activities.

At Jai Singh’s behest, Jagannātha mastered Arabic and Persian, the two foreign languages prevalent in the Mughal court, which he utilized in the study of Islamic astronomy and put to beneficial use translating into Sanskrit texts in those languages for his patron. In this way, Jagannātha produced his *Rekhāgaṇita* and *Siddhāntasārakaustubha*, which are translations of Euclid’s *Elements of Geometry* and Ptolemy’s *Almagest*, respectively, from their Arabic versions by Naṣīr al-Dīn al-ṭūsī. It is interesting that in the case of *Rekhāgaṇita*, Jagannātha himself coined more than a hundred Sanskrit equivalents of technical terms.

In his original work *Siddhānta-samrāt*, composed at the behest of Jai Singh, Jagannātha described the construction and application of a number of astronomical instruments. He also mentioned the reasons that his patron, who was obsessed with metallic instruments like the astrolabe for making celestial observations and reading out the results, later opted for huge outdoor observatories with stone and mortar. The reason was that Jai Singh found that the metallic instruments did not give minute readings, and were also susceptible to wear and tear, and to climatic conditions, which brick observatories were not. His

Yantraprakāra is a more elaborate work on the subject of astronomical instruments, which includes descriptions of some more instruments, computations, a number of tables, and allied data.

Jagannātha’s *Siddhānta-samrāt* and *Yantraprakāra* carry a number of recordings of celestial observations of different types, for periods short or long, which demonstrate how the instruments designed, and observatories constructed, as above, had been put to use for correcting parameters, preparing almanacs and the like. The part played by Jagannātha in these endeavors was considerable and significant.

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Astronomical Instruments in India](#)
- [Elements: Reception of Euclid’s Elements in the Islamic World](#)
- [Jai Singh](#)
- [Naṣīr-al-Dīn al-ṭūsī](#)
- [Observatories in India](#)

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Jai Singh

Virendra Nath Sharma

Jai Singh, or Jai Singh Sawai (Jaya Simha Savāṭī), the eighteenth century statesman-astronomer of India, was born on November 3, 1688 to the royal house of Amber, in the present state of Rajasthan, India. His ancestors were semiautonomous rulers of their princely state under the Mughals and occupied important posts at the Mughal court. Jai Singh lived his life during one of the most troubled, uncertain, and critical periods of Indian history, and he was involved directly or indirectly in just about every political or military conflict of his time. With his diplomacy and political maneuverings, he acquired a great deal of authority and influence throughout the Mughal empire. Making full use of his prestige and power, Jai Singh embarked upon a program of reviving astronomy in his country.

Jai Singh displayed an early inclination toward astronomy and mathematics and soon acquired mastery over these two subjects. He realized that the astronomical predictions based on the Hindu, Islamic, or European books (which were available to him) did not agree with actual observations. He reasoned that the disagreements between predictions and observations were primarily due to the outdated parameters found in the astronomical books, and would not be alleviated until new parameters based on careful observations were made available. Consequently, he decided to obtain new parameters.

With the blessings of the reigning emperor, Muḥammad Shāh, Jai Singh initiated a multifaceted program in astronomy. He designed instruments, built observatories, compiled an excellent library, assembled competent astronomers of different scientific backgrounds, and sent a fact-finding scientific mission to Europe. His scientific career lasted for more than 20 years. He died in 1743, at the age of 54.

Jai Singh started out first with traditional instruments of brass built according to the designs given in the texts of the Islamic school of astronomy. However, the metal instruments did not measure up to his expectations; he discovered with disappointment that the instruments gave inaccurate results once their axes wore down, displacing their centers. The instruments were also unsteady during observing because of their portable nature. He discarded these instruments, therefore, in favor of the instruments of masonry and stone of his own design and tried to achieve the desired precision from their large sizes and steadiness from relatively inflexible structures. His instruments range anywhere from 1 to 25 m in height.

Jai Singh built five observatories in cities of north India, at Delhi, Jaipur, Varanasi, Ujjain, and Mathura, and equipped them with instruments of his own design. His observatory in Delhi was completed in 1724 and the others within a decade. His observatories, all except that of Mathura, are still extant in good to fair states of preservation. His observatory at Jaipur has the largest number of instruments and is in the best preserved state. The observatories of Delhi and Jaipur are big tourist attractions these days and visited by hundreds of thousands of people each year.

An inventory of Jai Singh's major instruments of stone and masonry is presented in Table 1.

The Samrāt, Ṣaṣṭhāms'a, and Dakṣinottara Bhatti are Jai Singh's high precision instruments. With these instruments, he extended precision to the very limit of naked eye observing, i.e., 1' of arc.

Although the telescope had become common with European astronomers and had acquired refinements such as the micrometer and cross-hair, there is no evidence that Jai Singh benefited from it. His instruments do not use a telescopic sight, and with all their ingenuity of concept and design are no more than what may be called "naked eye tools" somewhat in the tradition of the medieval astronomers such as Ulugh Beg of Samarkand. It is reasonable to believe that the invention of the telescopic sight, which had come

Jai Singh, Table 1 Major instruments of masonry and stone of Jai Singh

1	Jaya Prakāśa (hemispherical dial I)	2	Delhi, Jaipur
2	Samrāt yantra (equinoctial sundial)	6	Delhi, Jaipur, Ujjain, Varanasi
3	Rāma yantra (cylindrical dial)	2	Delhi, Jaipur
4	Rāśi valaya (ecliptic dial)	12	Jaipur
5	Ṣaṣṭhāms'a yantra (60° instrument)	5	Delhi, Jaipur
6	Dakṣiṇottara Bhatti (meridian dial)	6	Delhi, Jaipur, Ujjain, Varanasi, Mathura
7	Digaṃs'a yantra (Azimuth circles)	3	Jaipur, Ujjain, Varanasi
8	Nāḍīvalaya (equinoctial dial)	5	Jaipur, Ujjain, Varanasi, Mathura
9	Kapāla A (hemispherical dial II)	1	Jaipur
10	Kapāla B (hemispherical dial III)	1	Jaipur

into vogue with European astronomers only a few decades earlier, did not come to his attention early enough. It should be pointed out, however, that Jai Singh was familiar with the telescope and had observed with it. His personal library inventory lists a telescope bought for him at a cost of 100 rupees.

Jai Singh's early training as an astronomer had been under Hindu *pundits*, and they remained the mainstay of his program until the very end. At one time there were at least 22 astronomers working at the observatory of Jaipur alone. ► [Jagannātha Samrāt](#), Kevalarāma, and Nayanasukhopādhyāya were his principal astronomers. These astronomers constructed instruments, collected data, translated books, and compiled original works in astronomy. The translated works included Ptolemy's *Almagest*, Euclid's *Elements*, and De La Hire's *Tabulae Astronomicae*.

Jai Singh was equally interested in the Islamic and the European traditions of astronomy. He collected astronomical works in Persian and Arabic, and patronized Muslim astronomers of the Persian-Arabic school. The Muslim astronomers included Muḥammad Ābid, Sheikh Asad Ullah, Sheikh Muḥammad Shafī, and Dayānat Khān. These astronomers procured astronomical books for the royal library, constructed instruments, helped with the translations, collected data at the observatories of Delhi and Jaipur, and traveled to distant lands at the command of their patron (Fig. 1).

By 1725, the involvement of the Muslim *nujūmīs* or astronomers in Jai Singh's astronomical program began to taper off and, in its place,



Jai Singh, Fig. 1 Sawai Jai Singh (1688–1743) (Courtesy of the Sawai Man Singh II Museum, Jaipur (used with permission of the author))

the involvement of Europeans, primarily Jesuit priests, increased. The European astronomers included De Bois, Figuerado, Boudier, Gabelsberger, and Strobl. The Europeans played the role of conveyors of European knowledge to the Raja. Accordingly, they led a delegation to Europe, procured texts and instruments, translated De La Hire's tables, and carried out mathematical computations. However, the knowledge these Europeans brought to Jai Singh and his astronomers had already become outdated in

Europe, for it did not include the theories of Galileo, Kepler, or Newton; nor did it include observational techniques such as those employed by Flamsteed in England.

In 1727, Jai Singh dispatched a scientific delegation to Europe after learning that “the business of the observatory was being carried out there.” The delegation, first of its kind from the East, was led by Figuerado, and it reached Portugal in January 1729. The delegation stayed on in Portugal for over a year. It did not travel to Paris or London, however, where the most advanced work in astronomy was being done. In 1730, the delegation returned to Jaipur, the capital of Jai Singh’s state at the time, with some instruments, books on mathematics, and the tables of De La Hire. The delegation did not bring any books elaborating the heliocentric world view, such as proposed by Newton, Kepler, or Copernicus, since these publications were prohibited by the Catholic Church.

After collecting data for nearly a decade, Jai Singh succeeded in obtaining new astronomical parameters. With these parameters, he prepared a set of astronomical tables called a ► [Zīj](#). The *Zīj*, completed sometime between 1731 and 1732, was dedicated to the reigning monarch, Muḥammad Shāh and is, therefore, called *Zīj-i Muḥammad Shāhī*. *Zīj-i Muḥammad Shāhī* is a 400-page long traditional work of astronomy similar to the *Zij-i Sulṭānī* of Ulugh Beg. *Zīj-i Muḥammad Shāhī* may be considered Jai Singh’s most important contribution to the astronomy of India. The *Zīj* remained a valuable resource for traditional astronomers of the country for nearly 150 years.

For the sake of rejuvenating astronomy in his country, Jai Singh expended a great deal of energy as well as his personal fortune, but he failed to initiate the new age of astronomy in India. He himself remained unaware of the Copernican revolution that had swept the intellectual circles of Europe. Lack of good communication systems, and a complex interaction of intellectual stagnation, religious taboos, theological beliefs, national rivalries, and the simple human failings of his associates share the blame

for it. Jai Singh’s scientific accomplishments were medieval in retrospect, but his scientific outlook was quite modern.

See Also

- [Astronomical instruments in India](#)
- [Jagannātha Samrāt](#)
- [Observatories in India](#)
- [Zīj](#)

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Jamu

Christine Tuschinsky

Jamu is the Indonesian and Malay term for indigenous pharmaceuticals made from fresh or dried medicinal herbs. These medicines are popular among the ethnic Malays in the whole Malayan Archipelago (Malaysia, Singapore, Brunei Darussalam, and Indonesia). It is assumed that *jamu* originates from the Javanese principal courts. On the other hand there are different local recipes and ways of preparation with an

old tradition, which contribute to the idea of a common popular knowledge.

Jamu can be an infusion of herbs, a mixture of fresh, dried or dried and powdered medicinal plants, and even an extract of herbs. It can be made of a single plant, but mostly it is a composition of up to 40 different ones. Today *jamu* is sold in the form of powder, tablets, pills, tonics, and capsules for internal use; and in the form of ointments, oils, tonics, or compresses for external use. The powdered *jamu* are packed in individual portions, which are then sold in nearly every small shop across Indonesia. Today these *jamu* as well as pills and capsules are available in Malaysian and Singaporean supermarkets, too.

In the traditional way, *jamu* is produced at home. An experienced family member provides friends and relatives with the homemade version of the product. To supplement family income, female family members sell the surplus to neighbors or villagers. These “*jamu* women” are still a familiar sight in Indonesia, even in the big cities. As a kind of peddler, the *jamu* woman wanders through villages or capital streets, offering the contents of her *jamu gendong* (*jamu* being carried on the back) to a regular clientele.

Indonesia was, and is, the trendsetter in the production, development, and marketing of *jamu*. At the beginning of the twentieth century her *jamu* production reached a turning point. Some innovative entrepreneurs began to produce home-made *jamu* for their sale, thereby founding a flourishing cottage industry. The profits which accrued in this fashion kicked off a process which led to the modern *jamu* industry, in which more than 350 factories are registered in Indonesia. Their product is exported to several countries, the largest consumers being Malaysia and Singapore. The industrialization of *jamu* manufacture had severe consequences. It altered the outer appearance of *jamu*, and demanded more and more modernizing and profitable sale strategies. It was necessary to change the image from an old fashioned herbal remedy to a proudly promoted “ancestral heritage,” which fit better into the Western back-to-nature trend.

Jamu concentrates on aspects and interrelationships which Western medicine does not take as seriously. The *jamu* idea of medication is based on a broad conception of body, health, and sickness; the notion of care and therapy, for example, tend to be kept less separate. *Jamu* is more than a pharmaceutical in the Western sense; it is food supplement, prophylaxis, and specific remedy all at once. Keeping healthy also necessitates staying beautiful and attractive as long as possible. Cosmetics, general tonics, and, above all, aphrodisiacs are very popular, and have considerable stature in *jamu* medicine.

Culturally different world views and concepts of knowledge find their expression in all aspects of culture, including the “hardware” of medicine, the pharmaceuticals. If we characterize the Western world view roughly as individualistic, bound to linear thinking, the ideas of cause and effect and the explanation of isolated phenomena on a microlevel, the Malay world view can be seen as sociocentric, bound to the mutual dependency of microcosmos and macrocosmos, and to the maintenance of balance and harmony on all levels of existence.

Medicines reflect these different aspects. Western pharmaceuticals consist of molecular defined substances or mixtures of substances, which are considered to be active. Any function of inactive substances is denied. The number of ingredients tends to be kept low in order to avoid synergistic effects. In contrast *jamu* are preparations of dozens of entire plants, with all active, inactive, and unknown substances plus the fibrous material. *Jamu* is a whole cosmos of ingredients, in which each part is supposed to play its proper role. *Jamu* has to be taken regularly for some weeks or months, and helps, in a long run, to balance the state of health between the poles of hot and cold.

Jamu cannot be completely analyzed. Pharmacologists are able to screen only some of the active ingredients, not to mention those which are called *inactive*. Synergistic effects are a matter of course and are considered to be of special importance in the efficacy and safety of *jamu*. The discussion of synergism and risk reduction

started in 1976, when the Indonesian scientist Sutrisno formulated his SEES (side effect eliminating/secondary effectiveness enhancing substance) theory which postulates fewer side effects and a well-balanced total efficacy of entire plant extracts. Western science considered the SEES theory not sufficiently proven. Much research has been carried out to prove that some of the active *jamu* ingredients have curative value. This is an attempt to translate a non-Western medical concept into a Western one, which soon reaches methodological limits.

These facts are not perceived as contradictions by the Malay – or, in a melting pot like Singapore also Indian and Chinese – clients. As a vivid element of Malay culture *jamu* is consumed in any form, in tiny villages and big capital cities, and plays a constant role in everyday health care.

See Also

- [Colonialism and Medicine in the Malay Peninsula](#)

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Jayadeva

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Jayadeva was an Indian mathematician who lived before the eleventh century. He was a proponent of the *cakravāla* system involving the process of continuous fraction. We know next to nothing about his life or works. The only source of information about him is the *Sundarī*, a commentary on the *Laghubhaskarīya* of Bhāskara I by the Kerala mathematician Udayadivākara (CE 1073).

In the *Sundarī*, Udayadivākara gives an extract from a lost text of Jayadeva's. It is 20 verses long, and proposes a novel method for the indeterminate equation or the so-called Pell's equation, $x^2 - ay^2 = b$. The discussion and extract are occasioned by an astronomical problem that involves two simultaneous equations, (i) $x^2 - ay^2 = b$ and (ii) $x^2 - ay^2 = 1$. The solution to this problem was dependent on the fact that the value of b in the first equation was always +1, -1, +2, -2, +4 or -4, and involved the method of *varga prakṛti*. According to Jayadeva, *varga prakṛti* is an equation in which the result of the square of an optimal number multiplied by a given number and the product so obtained added or subtracted by another number is in the form of a square. He also described the steps involved in solving the problem, which was a continuous fraction process, cyclical or repetitive in method (*cakravāla*). It consisted of determining the lesser root (*kaniṣṭha mūlam*), greater root (*jyeṣṭha mūlam*), interpolator (*kṣepa*), and two forms of visualization (*bhāvanā*), viz., *samāsa bhāvana* or *tulya bhāvanā* and *viśeṣa bhāvanā* or *atulya bhāvanā*. There were four steps in the *cakravāla* method. It involved the use of the *kuṭṭaka* equation $(\alpha X + \lambda)/\beta = Y$.

This was by no means an easy method, and Jayadeva compares it to an insect trying to fly against the wind. In the oft-quoted words of

Hermann Hankel, the historian of mathematics, “It is above all praise; it is certainly the finest thing which was achieved in the theory of numbers before Lagrange.” Bhāskara II (b. CE 1114) and Nārāyaṇa (CE 1356) later developed the cyclic method. It is also found in Brahmagupta (ca. CE 630). Jayadeva’s method for solving $x^2 - ay^2 = 1$ was the same as Brahmagupta’s, but he differed in his method for solving $x^2 - ay^2 = b$. In the absence of a date for Jayadeva, we have no means to ascertain if it was Brahmagupta or Jayadeva who first introduced the *cakravāla* method.

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Jewelry in the Ottoman Empire

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Jewelry in the Ottoman Empire in the Eighteenth Century

In the domain of jewelry, it is not easy to delineate a specific Ottoman identity since its empire encompassed Europe, Africa, and Asia and its history spread over five centuries. Jewelry, though not recommended by Islamic law, is, however, very much in evidence in travelogues and private and state collections. In this article, I will concentrate on Damascus in the eighteenth century, by drawing upon probate inventories found from one single source. cf Establet C., 2011, Les bijoux dans l’Empire ottoman au

XVIII^{ème} siècle : l’exemple damascène, Turcica, p. 207 à 229 tome 43.

The Source

The probate inventories are the only documents that can help us to determine who possessed what and to judge the share of jewelry in the appraisal of the different kinds of inheritance. 523 male and female inventories from the city of Damascus, *ra’âyâ* and ‘*askar*, have been analyzed. A more detailed study of 121 *râ’yâ* and 77 ‘*askar*, of men and women, focuses on recording the name, value, and number of all the possessions held by the deceased. The detailed descriptions make up a database which is essential for anyone interested in finding out about daily domestic life and jewelry in particular.

Jewelry as Inheritance

The share of jewelry stands at 5 % of the total value of the inheritance. Jewelry constitutes 23.3 % of women’s possessions and 1.3 % of men’s possessions. D’Ohson (1788–1824) observed: “If, among Muslims, men disregard the principles behind the law on the kinds of textile and metals they may wear in dress and ornamentation, one can judge with what freedom women make use of the same, for whom the law is much more lax.”

In the Damascene society, jewelry had a greater share in the ‘*askar* women’s inheritance than in the *ra’âyâ* women’s (34.4 % and 24.2 %, respectively); no doubt the former’s affluence explains this disparity in the importance of jewelry. The share of jewelry in men’s assets is weak whichever the group the deceased belongs to.

From Head to Foot

The cadis and their scribes write the names of jewelry in Arabic or in Turkish; they count them

and appraise them, often giving their weight as well. The following table is based on a sample of only the 198 Damascene men and women whose possessions have been listed in detail:

	Value	Number
Bracelets (<i>siwâr</i> and <i>bilazik</i>)	5,850	117
Necklaces (in gold <i>biqâ'i</i> , <i>tawq</i> , <i>qilâda</i>)	3,095	148
Pearl necklaces (<i>habl</i> and <i>bughma</i>)	1,357	22
Head ornaments (' <i>uqûs</i> , <i>sadjîbâghî</i> , and <i>chayyâlâtlu' lû</i>)	1,553	144
Belts (<i>zunnârkemerqûchâq</i>) and buckles (<i>famm</i>)	620	62
Anklets (<i>khalkhâl</i>)	539	9
Earrings (<i>halqa</i> and <i>kûpe</i>)	474	126
Diadems (<i>istifân</i>)	207	5
Round disks (<i>qars</i>)	195	4
Boots (<i>qabqâb</i>)	88	22
Rings (<i>khâtîm</i> and <i>yûzuk</i>)	76	64
Amulets (<i>hamâ'ilî</i> and <i>khîrz</i>)	6	3
<i>Chahhrûrlu' lû</i> (?)	75	6
<i>Kashtawân</i> (?)	165	11
Total	14,300	743

There are no toe rings, but occasionally you find, somewhere between clothing and jewelry, beautiful *qabqâb* or silver or silver-plated boots, sometimes encrusted with pearls, 4 piastres on average at the rate of 2.5 piastres for a Venetian ducat. We have gold or silver anklets (*khalkhâl*), worn in pairs: their value varies between 6 and 7 piastres when made of silver and between 20 and 40 piastres when made of gold.

Belts are numerous (*zunnâr*, *kemer*, *qûchâq*, *zunnârrakht*, wedding belt) and fall between clothing and jewelry. Their value is very variable, between 2 and 80 piastres. Most of these are in silver and are appraised between 2 and 33 piastres, variation due to the weight of the metal going from 9 to 240 *dirham*. It is sometimes mentioned that only the buckle (*famm*) is in silver. The more expensive belts are decorated with pearls or precious stones: 80 piastres is the value of a silver belt encrusted with unspecified stones (*ahdjâr*) and 60 piastres for a silver belt encrusted with rubies (*yâqût*). One of the belts weighs 770 grams.

Bracelets (*siwâr*, *bilazik*) are the most commonly worn jewels. Always in gold and weighed by the *cadi*, often worn in pairs, rarely encrusted with pearls or precious stones, they are of great value. By themselves, they constitute almost half the worth of the totality of the jewels and their weight varies considerably (8–116 *mithqâl*) as do the prices (20–322 piastres).

The finger rings (*khâtîm* and *yûzuk*), often in gold, sometimes encrusted with stones (*ahdjâr*, *tâchhindî*) of little value, are not weighed and are worth less than 2 piastres on average. There are also numerous necklaces under different names. When they are made only of gold, they are called *biqâ'i*, *tawq*, or *qilâda*, very often weighed, between 11 and 99 *mithqâl*, and thus of very variable value between 5 and 272 piastres. The *tawq* is lighter (18 *mithqâl* on average) and less expensive (46 piastres) than the *biqâ'i* (51 *mithqâl*, 122 piastres). It is often specified that the *biqâ'i* is made up of chains (*habl*); we can deduce from this that the *tawq* must be just a simple choker. In his dictionary, Barthélémy gives to *tawq* the meaning of a “necklace” and gives a second meaning to it calling it “an iron hoop that holds a bale of cloth” or “hoop of a barrel.” We are up against what seems, at least for the moment, an impossible task, that is, to find the exact differences between all these necklaces. The only piece of *qilâda* we have, described though not assessed, is a type of a necklace on which some coins are strung. In this case, they are small coins, *misriyya* (*misriyya* is the fortieth part of a piastre) of not much value.

The *ahbâllu' lû* and *bughmalu' lû* are necklaces of pearl (*lu' lûouinci*) or necklaces where pearls are the principal gem. *Ahbâl* (always in plural) are heavy and expensive weighing between 6 and 25 *mithqâl* and valued at between 3 and 120 piastres (on average one *ahbâllu' lû* weighs 13.8 *mithqâl* and is worth 74 piastres); the lighter and less expensive are *bughma* (11 *mithqâl*, 41 piastres). We can suppose that *ahbâl* were chains in gold with pearls: on the one hand, the *cadi* sometimes counts the *habl*, two or four, and he also mentions twice the number of pearls, six or eight, and their size. One *ahbâl* of six big pearls is worth 56.8 piastres. *Bughma* are simple

“necklaces of pearls in several rows in front and strung by a single thread behind” (Barthélémy, 1969). *Cha’rûrlu’lû* remains a mystery: a pearl jewel, undoubtedly, but is it also a necklace or a head ornament? Their average worth is of 12 and a half piastres, with significant variations of price, from 1.5 to 33 piastres.

We should classify as necklaces or pendants the *qars* owned by just three persons and described as “round objects in the form of a disk” (“metal disk worn by women as ornament,” “a round flat disk” (Redhouse, 2006). This jewel is expensive and is not made of base metal as A. Barthélémy would have us believe. It is strung to the gold chain (*habl*) and pearls. 20 piastres for a simple *qarslu’lû* and 53 for a *qarslu’lû* strung to two gold chains. Among these *qars*, we find a piece that has an abnormally high price: 4.7 *mithqâl*, 122 piastres. Is it an error of misreading? It does not seem so. Or is it an error made by the scribe, which is a rare occurrence? This piece belongs to a man who collects very distinctive pieces, a rich sheikh of the Sa’diyya fraternity.

Travellers have pointed out that head ornaments, specifically meant for domestic intimacy, hold a special place; they are as numerous as bracelets but half as valuable. *Chayyâlât* are “head ornaments in fine pearls (or in golden sequins) that came down each cheek and were pinned behind the head.” Here, they are all composed of pearls (*lu’lû*), all weighed, worth 18 piastres on average. *‘Uqûs* are “objects used in braiding and for attaching long hair with the help of a slide” (a braiding and looping up long hair” (Redhouse, 2006). These could be compared to head jewels reproduced in the *Topkapiin Versailles* catalogue and described thus: “pearls frequently used by the Ottomans to embellish their multiple braids” (*Topkapi à Versailles*, 1999). Here, they are composed of ten chains in pearls, gold, rock crystals, emeralds, and rubies. These ornaments have a silver or gold chain to string pearls and/or gold coins; others are made only of silver; there is one that is made only of silk. The variations in price are also significant: if the average price of this ornament is about 30 piastres, the valuation goes from half a piastre to 133.

Only one woman belonging to the group of State officials owns two *sadjîbâghî* (combs?) in gold, of considerable weight (22 *mithqâl* for one), and valued at 50–80 piastres; a *sadjîbâghî* in amber is valued at 3 piastres only.

Earrings close to the face (*halq, küpe*) are very widespread, of an average worth of 4 piastres, simple gold rings mostly, except in very rare cases: one pair of earring is embellished with rubies (*la’l*), one with pearls, and one more with pearls and rubies.

Diadems, *istifân* (the word comes from the Greek, *stephanos*), are rare, numbering 5 but expensive: from 28 to 62 piastres.

The presence of three amulets, *khîrz* or *hamâ’ilî* (“gold or silver object, a shoulder belt containing relics and which is worn on a chain” Barthélémy (1969)) not of great value, between 1 and 3 piastres, confirms the part played by jewels as lucky charms.

Jewels or ornaments of dress? The strings that tie pantaloons *zamâma* serve as much to embellish as to attach: they are adorned with pearls (*zamâmalu’lû*) or are cords in gold with pearl decorations (*zamâma bi habllu’lû*); one *zamâma* is in gold embellished with pearls and with “little gold or silver buttons that are stitched onto a piece of cloth like sequins, *briqât*” (Barthélémy, 1969). Buttons (*azrâr* or *duyme*) are indispensable objects to close long dresses (the two front parts of *qunbâz*, of *qafân*, of *‘antârî*, and even of *yalik vests*, of sleeve bottoms, sometimes of *sharwâl*, pantaloons bottoms), but these are mentioned only if they are of some value: buttons made of simple cloth embellished with gold or silver thread (*qasab, sarmâ*), or better, pearls, or more frequently with silver. Anyway, on certain pieces of cloth and certain clothes, we find some semiprecious metals stitched on to them: coral (*marjân*) weighed in *dirham* (one-third of piastres is 100 *dirham*), amber (*kârba*), or also glass stones and pearls (*hijâraqazâzwalu’lû*).

As no catalogue has ever shown the variety of Damascene jewels at the end of the eighteenth century, there are still some unanswered questions, as we have seen, about identifying some of the ornaments. And out of honesty, we have

left almost eleven mysterious *kashtawân* or *kastawân* or *gyustuwân* unidentified.

Materials

Gold (*dhahab*, *altûn*) is mentioned most frequently, 202 times, followed by pearl (*lu'lû*, *inci*) 102 times, and at last, silver (*fidda*, *gümüich*, *sîm*) 74 times. Onyx (*balghamî*), coral (*marjân*), and different kinds of amber (*kahrubâ* or *karbâ* and *kahr mân*) are also mentioned, more rarely, precious stones, emerald (*zamrût*) and ruby (*yâqût* or *la'l*), or “stones” without further detail (*tâsh*, *ahdjâr*) and some very rare references, finally, to the very humble iron and copper.

It must not be deduced from the analysis of these attestations of inheritance that this hierarchy revealed through the utilization of materials has any bearing on the actual reality of the Damascene world of jewelry around the 1700s. The inventories are only about the deceased proprietors of a legacy, however small it might have been. In a larger population scale comprising the poorer sections, silver, even copper or iron, must have been utilized more frequently, which explains why the jewels are missing. We will never know anything about them.

The weight of silver is evaluated in *dirham*, 3,207 grams. “The *dirham* is the basic unit used for assessing the different weights in vogue in the Ottoman Empire. Not having changed much in the course of the 14th and 15th century, it is usually fixed at 3,207 grammes” (Panzac, [forthcoming](#)). Gold and pearl are evaluated in *mithqâl*, 4,745 grams. “The scale used for weighing pearls and ambergris is equivalent to 1 1/2 drachmas or 73 English “grains” or 4,745 grammes” (Kelly, 1823).

The rate of silver, from one ornament to the next, is stable: one *dirham* is assessed at 0.1 piastre. It must be the quality of the workmanship that raises in two instances its worth to 0.2 piastres: two belts whose buckles are made of two or three parts (*chaqfa*).

The *mithqâl* standard for gold, on average, is estimated at 2.65 piastres (the calculation has been made from a weight of 108 and the price

fixed by the *cadi*); for most jewels, the gold *mithqâl* is worth 2 or 3 piastres. On the whole, between the two extreme dates of 1680 and 1714, a slight inflation is seen with regard to gold that is linked to the depreciation of the piastre: the inflation is of 1.8 % annually over the entire period although it affects mainly the opening years of the early eighteenth century.

The value of a jewel is certainly not found merely on the weight of the metal but on the quality of the workmanship. The scribe mentions two types of gold only when he describes bracelets: *mabrûm* gold or *jadal* gold. A. Barthélémy translates *jadal* as “braided” and *mabrûm* as “twisted.” These two terms are not synonymous: several persons possess, the scribe points out, both a bracelet in *mabrûm* gold and a bracelet in *jadal* gold. The *mithqâl* of gold says *jadal* is valued at 2.6 piastres, the *mithqâl* of *mabrûm*, twisted more, almost 3 piastres (2.96), regardless of the time. Does this term designate a special technique of working the metal? We do not have the answer. On the basis of our observations of present-day transactions in rural Turkey or in India, we are led to an anachronistic conclusion that when a client invests in the acquisition of a bracelet as a reserve of wealth, he often chooses a simple bracelet, a gold bangle where it is only the weight that gives it value: *jadal* might be a less-worked on metal than *mabrûm*? This is purely hypothetical.

Pearl is precious: 4.2 piastres a *mithqâl* on average. This average value conceals significant fluctuations in rate. Sixty-three ornaments of pearl were weighed and appraised: the rate of pearl varies between 1 and 10 piastres. These fluctuations far outstrip the general rate of inflation and are connected, no doubt, with the quality and with the size of the object (author’s note: In the Topkapi Museum, there is a pearl pendant composed of several pearls of greatly varying size). Thus, the value of an *ahbâl* necklace that is composed of six large pearls (*kabîr*) and weighs 7.3 *mithqâl* is worth 56.8 piastres; the same necklace adorned with eight pearls weighs six *mithqâl* and is valued at 25.5 piastres. In the first instance, the rate of the pearl is thus 7.8 piastres and only 4.3 in the second. The person

who possesses the best pearls whose price varies between 7 and 10 piastres a *mithqâl* is the same sheikh 'Alî al-Sa'dî al-Jibbâwî. These pearls came from the Persian Gulf, no doubt. Evliya Çelebi had observed that a significant pearl market existed on the pilgrim route to Mina. But we cannot rule out another hypothesis: in the trade that unites the Ottoman Empire with India during the Moghul era, the import of Indian pearls is present (Wellington, 2006).

Women, Men, and Jewels

Damascene women possessed more than three-fourths of the jewels inventoried by the judges. Jewels were considered a feminine adornment but not of a "universal 'feminine'." If almost all rich 'askar women possessed them, almost half of the poorest *ra'âyâ* women did not own any. On the other hand, some of the more well-to-do have a whole collection: 11 rings, three pairs of earrings, one bracelet, three belts, three hair ornaments, and four necklaces, besides loose pearls in boxes that were found for just one 'askar woman.

As for men, when they do not quite follow the theologian's precepts, there are, nevertheless, very few who own jewels. On the other hand, they are the only ones to possess rosaries, *masbaha* or *tasbîh-tespih*, common objects not of much value. Scribes do not give them any importance unless they are composed of precious materials like amber or coral; a coral rosary can be evaluated at 1 piastre and three-quarters, an amber rosary (*kahrubâ*) at 3 piastres.

The civil and military officers of the State succumbed more willingly to temptation: 11 'askar out of 55, only 11 *ra'âyâ* out of 277. For very few exceptions, these men do not own the same adornments as the women do, or at least not in the same proportion.

Rings (*khâtîm*) predominate in men's possessions, without however constituting the totality of their possessions in jewelry. They are the only jewels that are "accepted" for men by the theologians. One pilgrim who does not belong to the Damascene population that is presented in these documents but who died in Damascus in 1686

was said to be wearing two rings: one ring incrustated with engraved stones (*bi ahjârmaktûb*) and one silver ring.

Gold is much less present in men's adornments than in women's. Women's rings are almost all in gold; those of men are made in silver. Even iron is used for three necklaces (*biqâ'idemir* or *hadîd*), and there is a pair of copper earrings. Asd'Ohhson said earlier, there was a prohibition of gold but not of silver.

Otherwise, men own unrefined stones, coral, amber, rubies, emeralds, gold nuggets (*habb*), or coins (*sikkadhahab*) not included by the *cadi* in cash. These precious stones seem to constitute the reserves kept for difficult times of need, unless they were meant to be the raw material for making future jewels for women.

However, there are some exceptions, both of them belonging to the *ra'âyâ* group. Thus, a sheikh collects illicit jewels: rings, necklaces of all kinds, bracelets and diadems all in gold, pearl necklaces, and head adornments whose value constitutes almost 60 % of the total value of all the jewels owned by men.

Function of Jewels

Ornaments? Certainly: women adorn themselves and travellers' accounts confirm this.

As reserves or security for unforeseen expenses? In those times when cash was scarce and everyday life beset by unexpected events, jewels were useful as reserves of wealth. Latronc emphasizes that "the Syrian woman among the common people and especially in the rural parts, adorns herself with jewels that constitute her contingency reserve: her bracelets, her torsades or gold and silver rings are her personal savings" (Latronc, 1936, p.45). The frequent use of pieces like pendants makes this easier. One scribe underlines this function of jewels very clearly: a bracelet paid for the funeral expenses of a deceased person. A jewel can also serve as security. Scribes enumerate some cases where goods were deposited in a deceased person's house. Jewels are very much a part of these sets listed and quantified by the *cadi* along with goods

that are much less prestigious, cooking pots, basins, everyday objects made of an expensive metal, or expensive textiles and furs. More significant are the goods that were placed as security in the house of the deceased who even while looking after a business activity did not neglect the lending activity. Such is the case of a merchant selling textile (Inventory number 118 of register 15; thanks to J.-P. Pascual for helping me to decipher this difficult document), whose legacy, at his death, constituted diverse kinds of textiles, debts due, and security. The debtors' names, men and women, are mentioned; under the name of women debtors, we are sometimes given the type of goods placed as security. With the exception of a handkerchief and of some silver-plated knives, only jewels are mentioned: simple jewels not of any value, two pairs of earrings in gold, bracelets not in pairs but single, earrings, a few rings made of silver but in a bad state, and a ring decorated with stones, evaluated at a few *misriyya*. In case of credit given to a woman, jewels play a very important role. The poor quality, the low value of these adornments, placed as security for very small loans, throws light on the general poverty of the Damascene society in the 1700s. The sheen of gold, the colors of emeralds and rubies, and mother of pearl are affordable by a very small part of the female population of Damascus.

Inheritance of Jewels

The attestations of inheritance studied here confirm it; at the death of the deceased man, and especially of the deceased woman, the jewels were passed on to the children, boys and girls, which is a common thing in inheritance. We are not aware if these postmortem arrangements between heirs are respected, favoring female inheritance.

Jewels form also part of the bride's trousseau. We have a document dated 1681 that lists the composition of a future bride's trousseau, the *djihâz*. The contents of the trousseau is varied, linen is mentioned, ten pairs of quilted blankets, cushions, clothes (often embroidered), copper and silver vessels, silver-plated chests, and

jewels, gold earrings with four pearls, two rubies, two emeralds, a gold diadem adorned with pearls and stones, a gold necklace (*biqâ'î*), chains with pearls (*habl*), large gold bracelets, a hair ornament (*uqûs*), and a pair of anklets in gold (25 *misriyya*). The trousseau thus brings into the future family a collection of jewels of which the woman will, no doubt, continue to be the proprietor.

This prolonged perusal of the Oriental and Arab part of the Ottoman Empire around the 1700s has allowed us to establish the history of Ottoman jewels specifically in the region of Damascus in the same period. The ornaments are more than a quarter of the possessions of women and are part of properties easy to deal in. The names, materials, and values are known, but the visual pictures of the ornaments are lost in the annals of bygone time. The jewels belonging to the rich and powerful at the Court, very often without their exact designations of the time, are described at length in the catalogues: we could be allowed to think that the jewels of the most well-to-do among our humble deceased were inspired from the jewels in vogue at the Court.

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Jia Xian

Ang Tian Se

Little is known of Jia Xian's life except that he served as a minor functionary during the reign of Emperor Renzong of Northern Song dynasty in the first half of the eleventh century. He learnt mathematics from Chu Yan, a famous astronomer and mathematician (fl. AD 1022–1054). Jia Xian was said to have written two books, *Huangdi Jiuzhang Suanjing Xicao* (Detailed Workings of the Nine Chapters on Mathematical Art), and *Suanfa Xuegu Ji* (A Collection of Ancient Mathematical Rules). While the latter was irretrievably lost, the former was largely found in Yang Hui's *Xiangjie Jiuzhang Suanfa* (A Detailed Analysis of the Mathematical Rules in the Nine Chapters) of AD 1261 preserved in Ms. form in chapter 16,344 of the *Yonglo Dadian* encyclopedia compiled by Xie Jin in 1407 during the Ming dynasty. In his preface, ► [Yang Hui](#) explicitly stated that his text was an attempt to expound and preserve the works of his predecessors, notably those of Jia Xian.

Jia Xian's main contribution to mathematics lies in his innovative method for the solution of numerical equations of higher degrees. The processes for square and cube root extractions began with ► [Jiuzhang Suanshu](#) (Nine Chapters on the Mathematical Art) at the beginning of the Christian era, and continued to appear in all later mathematical books without many improvements. It was Jia Xian who came out with a method called *Zengchang Kaifang* (Method of Multiplying and Adding for Root Extractions) which could be extended to the solution of numerical higher equations for approximate values of roots. This method is similar to that developed by Ruffini (1765–1822) and Horner (1786–1837) in 1802 and 1819, respectively.

Accompanying the method was an array of binomial coefficients up to the sixth power tabulated in the form of a triangle similar to that by Blaise Pascal (1623–1662) in 1665, now

commonly known as the Pascal Triangle. This triangle of binomial coefficients was subsequently copied and expanded by Zhu Shijie in the thirteenth century. Thus, Jia Xian's mathematical knowledge to some extent laid the foundation for the rapid development of mathematics during the twelfth and thirteenth centuries.

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Jiuzhang Suanshu

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The Nine Chapters on Mathematical Procedures (*Jiuzhang Suanshu* 九章算術, hereafter abbreviated to *The Nine Chapters*) is the oldest Chinese book devoted to mathematics that has been handed down through a written tradition. Mainly composed of problems, answers to them, and algorithms solving them, the book was probably compiled in the first century after the Common Era. The earliest piece of evidence bearing witness to its existence is the mention of its title in the inscriptions borne by a standard measuring vessel enacted by the Chamberlain for the National Treasury (*Dasinong* 大司農) in 179.

The main reason why *The Nine Chapters* survived may well be that, soon after its completion, it became a “Canon” (*jing* 經). This is the term which the first commentator whose comments on it came down to us, Liu Hui 劉徽, uses for it. Consequently, several commentaries were composed on it, two of which were selected by the tradition to be handed down with the Canon: Liu Hui’s commentary, completed in 263, and the commentary composed by a group under the supervision of Li Chunfeng 李淳風 and presented to the throne in 656. In fact, there is no surviving edition of *The Nine Chapters* that does not contain these commentaries. Liu Hui’s and Li Chunfeng’s commentaries mention the works of other scholars, Zhang Heng 張衡 (78–142), Zu Chongzhi 祖沖之 (429–500), and his son Zu Geng (or Zu Gengzhi), attesting to a tradition of research on the topics dealt with in *The Nine Chapters* that historical evidence confirms. The Song dynasty testified to a keen interest in *The Nine Chapters*. The Department of the Imperial Library printed it in 1084, the reprint of this edition by Bao Huanzhi 鮑澣之 in 1213 being today the earliest extant edition. Moreover, new commentaries were composed, such as Jia Xian 賈憲’s *Detailed Procedures of Huangdi’s Canon of The Nine Chapters on Mathematics* (*Huangdi Jiuzhang Suanjing Xicao* 黃帝九章算法細草), in the first half of the eleventh century, and Yang Hui 楊輝’s *Detailed Explanations of The Nine Chapters on Mathematical Methods* (*Xiangjie Jiuzhang Suanfa* 詳解九章算法) in 1261.

During the Song dynasty, the status of *The Nine Chapters* as a “Canon” was regularly and forcefully emphasized. Hence, in one of his prefaces, Yang Hui, quoting the preface composed by Rong Qi when he had Jia Xian’s commentary printed in 1148, states:

“When the government instituted the examinations in mathematics to select officials, they chose *The Nine Chapters* to be the most important of the mathematical Canons, since, indeed, it is like the six Canons of the Confucians, the (*Canon of*) *Difficulties* and the (*Grand*) *Simplicity* of the medical schools, the *Book of Master Sun* of military art!”

The matching of the book with the Confucian Canons expresses the immense value bestowed on it, echoing with the fact that it was then believed to have been written by some mythical emperor or some sage of antiquity. In any case, all the practitioners of mathematics of the Song-Yuan period whose writings came down to us, Qin Jiushao, Li Ye (or Li Zhi), Yang Hui, and Zhu Shijie, drew inspiration from it, taking this Canon as a key reference work. This testifies to the significance of the book for the mathematical traditions that developed in China from the beginning of the Common Era up until the golden age of the Song-Yuan period and beyond.

The nine chapters of the Canon embody a traditional organization of mathematical knowledge in ancient China in “nine parts of mathematics (*jiushu* 九數).” According to the *Rites of Zhou* (*Zhouli* 周禮), the education of the children of the high dignitaries included the teaching of six arts, the last of which consisted in “the nine parts of mathematics” or “the nine procedures.” Quoting on this point the Chamberlain for the National Treasury (*Dasinong* 大司農) Zheng Zhong 鄭眾 (?–83), the scholar and commentator Zheng Xuan 鄭玄 (127–200) interpreted these as branches of mathematics that, for the main part, gave their names and, hence, corresponded to the various sections of *The Nine Chapters*. Probably, the process of “recovery” of the damaged Canon included the identification of what the *Rites of Zhou* meant by the “nine parts of mathematics” or the “nine procedures.” Let us review briefly how *The Nine Chapters* provides an interpretation of this organization of mathematics.

Chapter 1: “Rectangular Field” (*Fangtian* 方田)

This chapter describes algorithms to carry out the basic computations on fractions, on the basis of numerators and denominators. It also contains algorithms to compute the areas of the fundamental figures or “fields”: the rectangle, the triangle, the circle, the annulus, the spherical sector, etc.

Chapter 2: “Millet and Husked Grains” (*Sumi* 粟米)

This chapter is devoted to the rule of three and some of its applications. There, the rule is mainly used for computing equivalence between grains, according to official rates enacted by the National Treasury and relating to the payment of taxes in kind.

Chapter 3: “Parts Weighted According to Degree” (*Cuifen* 衰分)

The algorithm for dividing a given whole into unequal parts defined by given coefficients constitutes the main topic of this section. The main field of reference for the algorithm consists in sharing gratification between officials having different status in the bureaucracy.

Chapter 4: “Reducing the Width” (*Shaoguang* 少廣)

The chapter gathers together various sorts of “divisions,” divisions with fractionary numbers and root extractions, which were conceived of as divisions: square root and cube root extractions, as well as “circular” and “spherical” root extractions. In it, irrational numbers of the type “square root of 2” are introduced as exact results for square root extractions.

Chapter 5: “Discussing Works” (*Shanggong* 商功)

Mainly devoted to the organization of civil works, this chapter describes algorithms to compute the volume of fundamental solids: the parallelepiped and the cylinder, the trapezoidal prism, the pyramid and the truncated pyramid with square basis, the tetrahedron, the cone and the truncated cone, etc.

Chapter 6: “Paying Taxes in a Fair Way According to Transportation” (*Junshu* 均輸)

The title of the chapter refers to the topic of the first problems, devoted to a fair distribution of taxes or corvée (labor exacted by a local authority for little or no pay or instead of taxes) among various administrative units. The various problems gathered usually require combining rules of three or unequal sharing.

Chapter 7: “Excess and Deficit” (*Ying Buzu* 盈不足)

The chapter is devoted to the rules that in the Latin West were to be called of false double position.

Chapter 8: “Measures in Square” (*Fangcheng* 方程)

An algorithm for solving the systems of n linear equations with n unknowns is described and progressively extended throughout the chapter. It is equivalent to what is today called the “Gauss elimination method.” In order to carry out this algorithm in all cases or to use it with full generality, positive, negative, and zero coefficients are introduced.

Chapter 9: “Base and Height” (*Gougu* 勾股)

These are the two technical terms for designating the sides of a right-angled triangle, the treatment of which is the topic of this section. An algorithm corresponding to the so-called Pythagorean theorem opens the chapter. The following problems lead to solving some of the fundamental problems linked to the right-angled theorem. In this chapter, one of the problems is solved by using a quadratic equation.

The Nine Chapters displays mathematical knowledge in the form of algorithms. The book

attests to specific ways of carrying out research on algorithms and manifests some of the theoretical trends guiding this research. In particular, the algorithms contained in *The Nine Chapters* are general. This feature relates to the fact that generality was one of the main theoretical values prized by the practitioners of mathematics in ancient China. This key fact accounts for the properties that algorithms contained in *The Nine Chapters* regularly exhibit. They make use of assignment of variables, conditionals, and iterations. Furthermore, with the help of these techniques, the algorithms of the Canon can cover distinct cases that a given problem may present. They can also integrate distinct procedures and hence allow solving various types of problems. All these features contribute to shaping algorithms that are as general as possible. Such is the Canon that, in mathematics like in any other field of inquiry, commentators set out to expound.

Two kinds of evidence shed light on the historical process that led to its composition. As a canon, *The Nine Chapters* is not ascribed to any "author." Liu Hui's preface to his commentary mentions two scholars who contributed to its "edition." According to him, the Canon took shape in high antiquity and was damaged by the process of transmission. Later on, Zhang Cang 張蒼 (ca. 250–152 BCE) and Geng Shouchang 耿壽昌 (fl. 50 BCE) successively strove to restore the book, as it had been composed in antiquity. This indicates that, early enough, the process that produced *The Nine Chapters* was understood to have extended over centuries, and probably, Liu Hui thought he was carrying it out further. In addition, a mathematical book was recently unearthed from a tomb sealed around 186 BCE: the *Book of Mathematical Procedures* (*Suanshushu* 算數書). This piece of evidence is extremely important for two reasons. On the one hand, it provides us with the first known mathematical writing preceding the compilation of *The Nine Chapters*. On the other hand, it is a book that was not handed down by the written tradition, but arrives to us in exactly the shape it had at the beginning of the second century before the Common Era. It shares many algorithms with *The Nine Chapters*,

which indicates that the Canon had much in common with documents of that type. Furthermore, by comparison, it appears that the Canon contains algorithms obtained from other algorithms attested to in the *Book of Mathematical Procedures* by abstraction. What is even more interesting is that when Liu Hui comments on the abstract algorithms of the Canon, he interprets them concretely along the lines of algorithms found in the *Book of Mathematical Procedures*. This piece of evidence thus also casts light on the process of composition of the commentaries.

The earliest exegete whose commentary was handed down, Liu Hui, appears today as being the most important of them all. However, almost nothing is known concerning his biography, except that he composed a commentary on *The Nine Chapters* as well as a small treatise, originally conceived as restoring a missing part of the Canon and devoted to geometrical methods of surveying: the *Mathematical Canon of the Sea Island* (*Haidao Suanjing* 海島算經).

The significance of Liu Hui's commentary for the history of mathematics cannot be underestimated.

First, in contrast to *The Nine Chapters*, which consists mainly of problems and algorithms solving them, the exegetes systematically established that the algorithms provided by the Canon were correct. This implies that, in contrast to Euclid's *Elements*, the proofs of which establish that theorems are true, the commentaries' goal is to prove the correctness of algorithms. Moreover, to do so, they seem to follow stable patterns of reasoning, which indicates that proofs were conducted according to procedures that were normalized. Liu Hui's commentary hence bears witness to the earliest known practice of mathematical proof in China. How should this branch of the history of mathematical proof be integrated in a world history of proof? As far as I know, this question has not yet been addressed.

Furthermore, Liu Hui's commentary provides evidence showing how he read *The Nine Chapters*. On the one hand, his testimony sheds light on actual mathematical practices in ancient China. On the other hand, it discloses his

expectations with respect to, and his approach of, a book of the kind of a Canon. In both respects, the evidence he provides is essential for recovering the details of mathematical activity and intellectual pursuit in ancient China.

Last, but not least, Liu Hui quotes several philosophical texts, thereby pointing to a relationship between mathematics and philosophy in ancient China. In addition, he stresses, and comments on, the theoretical aspects of the mathematics he is dealing with. He thereby gives essential clues regarding the theoretical dimensions of mathematical activity as it developed in China.

See Also

- [Gou-Gu Theorem](#)
- [Mathematics in China](#)
- [Qin Jiushao](#)
- [Yang Hui](#)
- [Zhu Shijie](#) 朱世傑

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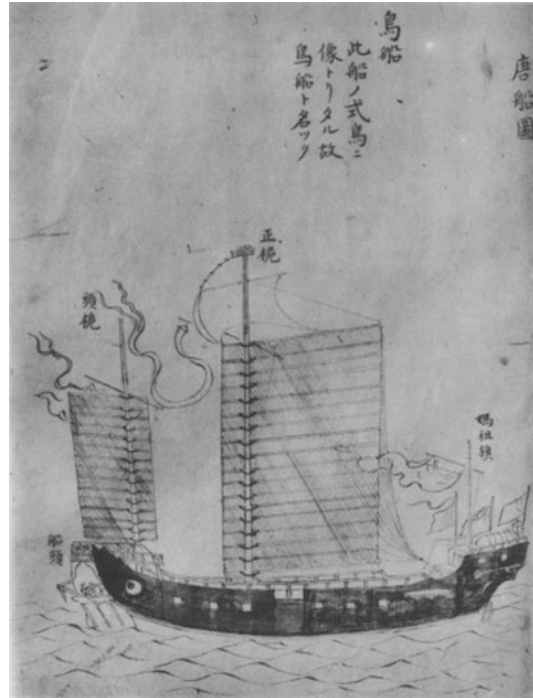
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Junks

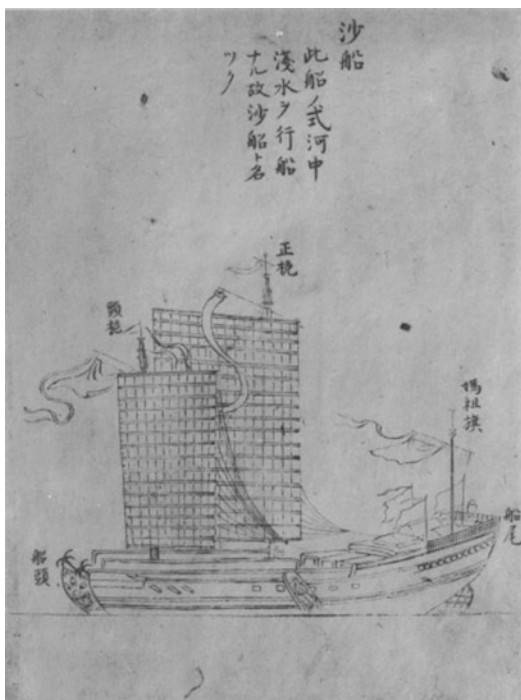
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Junk is a term that foreigners use to refer to large Chinese sailing ships. The origin of this term is probably “Zumcum,” a transliteration that Odoric of Pordenone (1265?–1331), a missionary from the Order of Friars Minor in Italy, used in his writing about his voyage to China via the Indian Ocean during the Yuan dynasty. In his book, *Rihla*, Ibn Baṭṭūṭa (1304–1377), a Muslim traveler, referred to ships seen in the Indian Ocean and along the Chinese coasts as “Gonku” or “Chunko.” Later on, they were employed mainly to refer to large Chinese sailing ships.



Junks, Fig. 2 *niaochuan* (Bird junk). “Nagasaki-shi,”-Nagasaki-Bunko-kankoukai, 1928, p.354a,b



Junks, Fig. 1 *shachuan* (Sand junk). “Nagasaki-shi,”-Nagasaki-Bunko-kankoukai, 1928, p.354a, b



Junks, Fig. 3 Nagasaki Hanga, ‘Tosen nyuushinn no Zu’ 19c

Junks, Fig. 4 A Foreign Trader, John Barrow, “Travels in China,” 1804, p. 36



These ships appear in Chinese sources as *fengchuan* (ship with a balloon sail), *minchuan* (public ship), or *fanchuan* (sail ship). They were sometimes named after their places of construction. Four major types of Chinese ships were used during the Qing dynasty: *shachuan* (sand junk), *niaochuan* (bird junk), *fuchuan* (Fuzhou junk), and *guangchuan* (Guangzhou junk). A sand junk had a flat bottom. It would leave the mouth of the Yangtze River and sail in the shallow waters along the Chinese coasts. Bird junk, Fuzhou junk, and Guangzhou junk, in contrast, all had a V-shaped crossed sections at the front and a keel along the bottom. The first two were built in Fujian province, and the third one in Guangdong province.

When Chinese merchant ships visited the port of Nagasaki in the Edo period, the locals usually called them *Tōsen* (Chinese ships), instead of mentioning them by their Chinese names. However, Matsura Tōkei (1752–1820), a mid-Edo period writer, recorded “sand junk” and “bird junk” in Chap. 13 of his work *Nagasaki kokon shūran*: “Only two sand junks came to trade during the An’ei period (1772–1781), but they ended up being destroyed.” “The recently arrived bird junks were larger than those (that had visited Nagasaki) previously.” These records show that sand junks or smaller bird junks were present in Japan at the beginning of the Edo period and that from the middle to the end of the period in question, larger bird junks were called on the port of Nagasaki (Figs. 1, 2, 3, and 4).

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Jute in Bengal

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Around the mid-1830s, modern jute technology was launched at Dundee in Scotland and

subsequently spread across the world – prominently in Bengal – to revolutionize the global packaging industry. Behind this success story of a modern industry hid a vibrant cottage industry in Bengal, which dates back to the pre-Common era. Bengal's jute goods, manufactured on indigenous technology, are referred to in Kauṭilya's *Arthaśāstra* in the ancient period, Abu'l Faẓl's *Āīn-e Akbarī* in the Middle Ages, and in several public documents on the eve of the modern era. Premodern industrial uses of jute are not, however, in evidence for the rest of the world, though its edible consumption was common. *Melochia* – which the historians believe an edible variety of jute, botanically called *C. olerious* – was said to be a favorite vegetable of Jesus Christ and was cultivated along the Euphrates river. That was an indigenous crop of Bengal, where another variety, called *C. capsularis*, was cultivated for industrial purposes under the broad generic name of flax. From about the mid-eighteenth century, it was traded as jute. The industry, however, worked on three product lines: (a) gunny bags and cloths, (b) rope and twine, and (c) paper. There is evidence that Bengal's jute products, especially gunny bags, were exported to the places like the UK and North America from 1828, and the value of such exports stood at Rs. 2.16 million in 1850–1851.

Similar to its modern counterpart, traditional jute technology involved three distinct processing stages: (1) retting and stripping, (2) spinning, and (3) weaving.

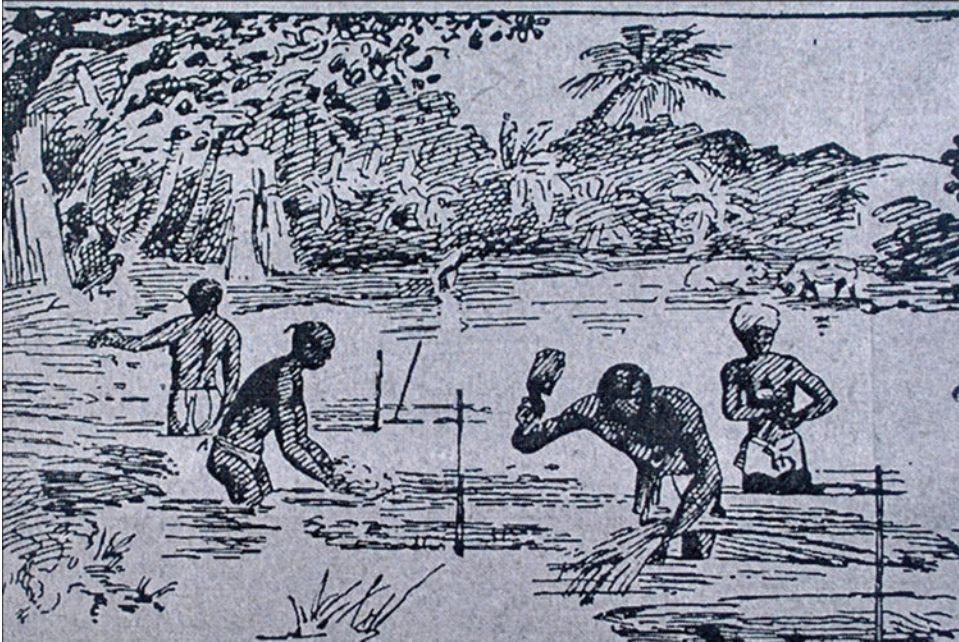
Retting and Stripping of Jute

The jute plant is characterized by fiber-vascular bundles, each containing 6–20 fibers firmly coherent with the wall. These fibers, usually 1½–3 mm long, are of the fusiform type, appearing in section as thick walled and polygonal. Chemically, jute contains two substances, cellulose and non-cellulose, and it is therefore called lignified cellulose. Because of this chemical property, it is highly susceptible to heat and moisture or even feeble chemical agents.

The cultivators in Bengal (called *ryots*) initially processed jute using a very simple technology. The central task in this case was to remove, by the application of water, the natural gum that sticks to fibers on the stem. To this end, the *ryot* used to submerge on average 10–15 bundles of jute plants, each containing 50–100 plants, into roadside ponds where water was stagnant. They avoided running water as it delayed the fermentation process and also damaged the quality of fiber. To keep them properly sunk, a raft-like wooden structure, filled up with turf and clods of earth, was put on them so that the plants were not directly exposed to the sun. Otherwise, they became specky. Sods were always avoided to keep up the color of fibers. The disintegration of fiber, however, involved a bacterial action, whereby gas came out of decomposing plants causing bubbles in the water. The frequency of those bubbles indicated the status of retting, which matured by 8–20 days depending upon the quality of plants as well as the water. Under-retting, indeed, caused inconveniences to stripping, while over-retting damaged the strength and color of fibers.

Once barks were loosened and their fibers became soft, stripping was carried out in four stages within a couple of days (see Fig. 1). In knee-deep water, a dresser took up 5–6 stalks together in the left hand and, using a mallet in his right hand, beat them flat at the bottom. After every beating, the bundle was turned skillfully. In the second stage, he/she broke the stalks by about 2 ft at the bottom so that the fiber ends could be held tightly by hand. In the third stage, the stems were jerked in water to and fro, stripping off the fibers. Finally, impurities were removed in the pond, and the fibers were rinsed and dried in the sun. For marketing purposes, however, those fibers were again bundled in parcels of 1–2 maunds each. About 70 lb. of dry fiber could be obtained in 10 h.

An alternative method of stripping involved the following process: The dresser held the bottom of the plants in his right hand in such a way that when the fibers were pulled off by the left hand, the fibers passed through the fore and middle fingers on the right hand. A skilled stripper



Jute in Bengal, Fig. 1 Jute retting and stripping in the nineteenth century (Source: Carter, H.R. *Jute and its Manufacture*, p. 10)

could strip three plants at a time by creating three different spaces through four fingers in the right hand. The yield rate in this process was, however, low – about 50 lbs on average in 10 h.

A simple technology was thus followed in the retting and stripping of jute. Despite several institutional supports for mechanization, it still survives. Low family income of the peasantry partly explains the apathy toward mechanization. But no less important is the question of quality, where the traditional technology dominates over its mechanical alternative. In this context, the expert testimonies underscore that compared to the latter, the former yields softer fibers and ensures better color, luster, and strength.

Spinning of Jute

Spinning of jute used to support rural livelihood extensively in Bengal, engaging the whole family in labor. It was customary for artisans to keep hanging bundles of jute fibers together from their thatched roofs so that every family member could spin at his/her leisure hours. However, for the

sake of yarn variety, three alternative implements were used – *D'hera*, *T'akku*, and *Ghurghuria* – involving different technological processes.

The first process involving *D'hera* span yarns for coarser cloths like gunnies and sail cloths (called *gun*). The instrument was of cylindrical design with a number of bamboo (or wooden) spokes on the body and an iron handle on the right-hand side. The process involved four stages. In the first stage, the spinner drew a given number of strands from the hanging bundles, noted above, tied their upper ends to a post (or to one of the bamboos in the thatched roof of his cottage), and dressed the other ends to tie up with the instrument. In the second stage, he/she held the instrument on his left hand and twisted those strands using its handle in his right hand. In the third stage, when sufficiently twisted, the thread was wound up on the body of the *D'hera*, and the first stage was reverted to. In the final stage, threads were taken off from the *D'hera* and arranged in a ball, which was locally called *loti*.

The second process involving *T'akku* was used to spin finer yarns for sack cloths (locally



Jute in Bengal, Fig. 2 Ghurghuria

called *tat*) that poor people wore as apparel and used as sleeping mats. *T'akku* was a conical wooden implement, 12–15 in. long and 1½ in. diameter at the base tapering to ½ in. at the top. Three stages were involved in this process. In the first stage, spinners squatted on the floor and pulled out several strands from the hanging bundles to group them into a thin tissue or ribbon (somewhat similar to rove without any twist). One end of the ribbon was held in the left hand, and the other end was attached to the spindle of *T'akku*. In the second stage, the instrument was stroked against the thigh (or the sole of the feet), causing it to rotate and thereby imparting twists to the fiber. The degree of twists depended on the distance the *T'akku* had to traverse in spinning the yarn round it. Generally, 15–18 in. of yarn could be spun in one operation. In the third stage, yarns were collected in the roller of the *T'akku* (locally called *Fetia*). When a sufficient amount of thread was spun, it was separated from the *Fetia*.

The third process involving *Ghurghuria* was meant for spinning rope-making yarn. It was a very rudimentary device, made up of two pieces of wood (about 20 in. in length, 5–6 in. in breadth, and 2–3 in. in thickness), fixed crosswise at the center by an elongated nail (see Fig. 2). The top of the nail served as a hinge where the lower ends of 10–20 jute strands were tied. With the upper ends hinged on a post, the spinner rotated the instrument with a full blow so that it continued rotating

for some time, imparting twist to the strands. A spinner could operate with 3–4 *Ghurghurias* at a time drawing jute from the attached bundle on the post. When the fibers were adequately twisted in a particular instrument, they were wound up in its body, and their upper ends were joined by manually twisting them with another set of strands. The spinning process was then repeated. When about 200 m of yarn were thus spun, they were brought to an open field, where bamboos were dug in two rows about 200 m apart. The yarns were tied to the bamboos. When an adequate number of yarns were thus arranged, two spinners took up two yarns at their respective ends and twisted them manually together. When adequately twisted, they took up another yarn to twist it with the previous one to add thickness and strength. The process continued until requisite thickness was obtained.

Weaving of Jute

Weaving was traditionally done on a contraption that consisted of five bamboos (or wooden spars), 36–40 in. in length. One of them was hung from a post, another was horizontally secured to two posts at their top, and three others were placed between them one after another in such a way that two of them could be used for warping and one for weft. Warping was done by two central bamboos, which acted as lease rods on the one hand and as cams on the other, to provide necessary shedding motions during weaving. It should be mentioned that warp yarns, which spinners provided in the form of ball, were not treated with any dressing or stiffing materials at the weaving stage. The central-most bamboo was, however, used for weft. Weft was arranged on a split bamboo, measuring 18–22 in. in length and 1½ in. in breadth. It performed the task similar to a shuttle in the power loom.

Despite the fact that this traditional contraption was very tedious, causing interruptions and delay in the production process, jute weavers in Bengal could ensure a high standard of quality for their end products. Even compared to the late nineteenth-century mill products, their quality

dominated in two important aspects – evenness and purities. Expert opinions are on record that traditional technology ensured even spacing both in warp and weft and also that its end products contained few sticks, gaws, or snarls, which often characterized the mill products.

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Kamalākara was one of the most erudite and forward-looking Indian astronomers who flourished in Varanasi during the seventeenth century. Belonging to a Maharashtrian stock, and born in about 1610, Kamalākara came from a long unbroken line of astronomers, originally settled at the village of Godā on the northern banks of the river Godāvarī. Towards AD 1500, the family migrated to Varanasi and came to be regarded as reputed astronomers and astrologers. Kamalākara studied traditional Hindu astronomy under his elder brother Divākara, but extended the range of his studies to Islamic astronomy, particularly to the school of Ulugh Beg of Samarkand. He also studied Greek astronomy in Arabic and Persian translations, particularly with reference to the elements of physics from Aristotle, geometry from Euclid, and astronomy from Ptolemy. He wrote both original treatises and commentaries on his own works and those of others.

Kamalākara's most important work is the *Siddhānta-Tattvaviveka*, written in AD 1658. The work, which is divided into 15 chapters and

contains over 3,000 verses, faithfully follows the *Sūryasiddhānta* in the matter of parameters, general theories, and astronomical computation. However, in certain matters Kamalākara made original contributions and offered new ideas. Though he accepted the planetary parameters of *Sūryasiddhānta*, he agreed with Ptolemaic notions in the matter of the planetary system. He presented geometrical optics and was perhaps the only traditional author to do so. He described the quadrant and its application. He proposed a new Prime Meridian, which is the longitude passing through an imaginary city called Khalādātta, and provided a table of latitudes and longitudes for 20 important cities, in and outside India, on this basis. Kamalākara was an ardent advocate of the precession of the equinoxes and argued that the pole star also does not remain fixed, on account of precession. Kamalākara wrote two other works related to the *Siddhānta-Tattvaviveka*, one a regular commentary on the work, called *Tattvavivekodāharaṇa*, and the other a supplement to that work, called *Śeṣāvasanā*, in which he supplied elucidations and new material for a proper understanding of his main work. He held the *Sūryasiddhānta* in great esteem and also wrote a commentary on that work.

Kamalākara was a critic of Bhāskara and his *Siddhāntaśiromaṇi*, and an archrival of Munīśvara, a close follower of Bhāskara. This rivalry erupted into bitter critiques on the astronomical front. Thus Ranganātha, younger brother

K. V. Sarma: deceased

of Kamalākara, wrote, at the insistence of the latter, a critique on Munīśvara's *Bhaṅgī* method (winding method) of true planets, entitled *Bhaṅgī-vibhaṅgī* (Defacement of the *Bhaṅgi*), to which Munīśvara replied with a *Khaṇḍana* (Counter). Munīśvara attacked the theory of precession advocated by Kamalākara, and Ranganātha refuted the criticisms of his brother in his *Loha-gola-khaṇḍana* (Counter to the Iron Sphere). That in turn was refuted by Munīśvara's cousin Gadādhara in his *Loha-gola-samarthana* (Justification of the Iron Sphere). These kinds of astronomical and intellectual battles were typical of the philosophical and religious disputes which were common in ancient India.

See Also

- ▶ [Astronomy in Medieval India](#)
- ▶ [Astronomy in the Islamic World](#)
- ▶ [Bhāskara I](#)
- ▶ [Munīśvara](#)
- ▶ [Precession of the Equinoxes](#)
- ▶ [Sūryasiddhānta](#)
- ▶ [Ulugh Bēg](#)

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Kauṭilya and Strategy

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Kauṭilya was an Indian political thinker who is credited with helping Chandragupta Maurya lay the foundations of the Mauryan Empire (c. 321–185 BCE) which at its zenith was rivaled only by the Mughal and later, the British Empire of India. Chandragupta's early career is shrouded in mist, and some believe he was in touch with Alexander the Great who invaded northwest India in 327 BCE. Others claim he started his military career fighting against the Greek outposts that Alexander had established along the River Indus. After subjugating them, he shifted his attention to the kingdom of Nandas in eastern India and in 321 BCE defeated the Nanda King Dhana Nanda and occupied the throne of Magadha (located in the present-day Indian state of Bihar). Whatever may be Chandragupta's past, it is certain that he was the architect of a truly great Indian empire, and in this quest he was advised and aided by a brilliant strategist variously called Kauṭilya or Chanakya whose magnum opus, *Arthaśāstra*, stands out as a classic text of statecraft.

While the role of Kauṭilya in establishing and consolidating the Mauryan Empire is generally acknowledged, doubts nonetheless have been voiced about both Kauṭilya and *Arthaśāstra*. Ever since the latter text was discovered by Dr. R. Shamasastri of Mysore in 1904 (the English translation came out in 1915), concerns have been expressed about both the man and his work. Among the allegations, the most serious is that *Arthaśāstra* was not written by Kauṭilya but is a compilation of various old texts and ideas, all brought together by scores of individuals. The debate has been an ongoing one, but it is widely accepted that Kauṭilya is the main author of the text and that he lived around 300 BCE. However, it is also true that some sections of the text are

later additions and revisions, some of which may have been made as late as CE 300.

Kauṭilya's treatise is entitled *Arthaśāstra*. The name is made up of two smaller words: *artha* and *śāstra*. The word *artha* has a variety of meanings but it may simply be translated as "wealth." *Śāstra* means science. A simple translation of *Arthaśāstra* would therefore be *Science of Wealth*. The purpose of this science is to lay bare the study of politics, wealth and practical expediency, and the attainment and protection of power. Thus the subjects covered by Kauṭilya include: administration, law, order, and justice; revenue and expenditure; foreign policy; and defense and war. The aim of gaining knowledge on all these topics was to realize three interrelated objectives: promotion of the welfare of the king's subjects, which leads to acquisition of wealth, and this, in turn, made it possible to enlarge one's territory by conquest. Kauṭilya is, therefore, writing about strategy which may be defined as a bridge that relates military power to political purpose. It is not military power per se nor political purpose but concerns the deployment and use of military might to attain a given political objective. This objective is the consolidation and subsequent expansion of one's domain. Such a strategic goal entails mastery over diverse fields. The concept of "grand strategy," now popular among strategists, academics, and statesmen, calls for the study of industrial, financial, demographic, and societal aspects of war, and Kauṭilya in *Arthaśāstra* focuses on these issues. The moral quality of the king, the welfare of the people, justice and legitimacy of the regime, as well as military prowess are also necessary for a state to be strategically successful. Kauṭilya's field is grand strategy, not military strategy or tactics, and this is what makes him different from other classic writers on strategy like Sun Tzu and Carl von Clausewitz.

Given Kauṭilya's focus on grand strategy it is natural that *Arthaśāstra* consists of three distinct parts: administration, law and justice, and foreign policy. Kauṭilya takes for granted that the context in which states act is a lawless one, or

matsyanyaya – the law of the fish where big fish eat up small ones. How to survive in such a chaotic condition and transform the *vijigishu* (the king desirous of fresh conquests) to a *chakravartin* (universal king the wheels of whose chariot rolls everywhere without obstruction) is the objective of *Arthaśāstra*.

The state is made up of seven constituent elements or *prakritis*: (a) *swamin*, the ruler; (b) *amātya*, the minister; (c) *janapada*, the people; (d) *durga*, the fortress; (e) *kosa*, the treasury; (f) *danda*, executive power; and (g) *mitra*, allied state. All the elements are entwined with each other and deficiency in any one element has a deleterious effect on the others. Kauṭilya believed that the state's security cannot be ensured if its economic base is weak. Hence, he emphasizes increasing economic productivity for payment of taxes when people are prosperous. While happiness and welfare of the subjects are of concern to the king, Kauṭilya is of the opinion that deception, lies, betrayal, intrusive surveillance, and extrajudicial killing should also be available to the king to ensure his control over the state. Ethical dilemmas should not prevent the state from doing what it deems to be right. A state thus internally secured can embark on its desired foreign policy quest.

For the state to survive in the *matsyanyaya* system and ultimately become a *chakravartin*, it is imperative that it understand its position in the *mandala* system of states. The *mandala* literally means a circle with a center, which in this case is the *vijigishu*. The *mandala* is based on the geopolitical assumption that the *vijigishu* is at the center of system and his immediate neighbor state is most likely an *ari* or enemy (real or potential). The state next to the immediate neighbor is most probably the *vijigishu's mitra* or friend. After the *mitra* state appears an unfriendly state (*ari-mitra* or ally of the enemy state) and next to that a friendly state (*mitra-mitra* or ally of the friendly state) and so on. The *vijigishu's* rear neighbor is called the *parshnigraha* which may create trouble for the *vijigishu* from behind. This is really an *ari*, but such a state waits until the *vijigishu* has started offensive against the *ari* or

frontal neighbor and then pounces from the rear. Behind the *parshnigraha* is a rather friendly state, identified as *akranda*, which helps the *vijigishu* when a call for assistance is made. Immediately after the *akranda* is a friend of the *parshnigraha*. This is called the *parshnigrahasara*, which is also an enemy state. Adjacent to this is *akrandasara*, a friendly state. There are also two other actors who might have an adverse impact upon the king's ambition. These are *madhyama* (the middle kingdom) and *udasina* (the neutral kingdom). The *madhyama* state is situated on the borders of both the *vijigishu* and the *ari* and is capable of helping either. The *udasina*, a very powerful state, is located beyond the territory of the *vijigishu*, the *ari*, and the *madhyama* and is capable of helping them together or individually or of resisting any of them individually.

It should be pointed out that Kautilya's idea of *mandala* is not meant to be one of fixed geographic relationships. Rather, the system applies to relationships of power, influence, and interest. All the states in the *mandala* face the same predicament: they are surrounded by a ring of allies, enemies, and middle states and powerful yet remote neutral powers. Thus, the *mandala* system is a fluid one where relationships are being constantly interpreted and reinterpreted, thereby introducing opportunities for some states and exposing some to danger. To deal with such a constantly evolving situation requires acumen and skill, and Kautilya suggests that the *vijigishu* can obtain success under such conditions by following the *shadgunya* (sixfold) policy. The policy comprises six foreign policy methods which the *vijigishu* uses to obtain his objectives. Kautilya explained *shadgunya* as follows:

- (i) *Sandhi* (peace): Whoever is inferior to another shall make peace (with him).
- (ii) *Vigraha* (war): Whoever is superior in power shall make war.
- (iii) *Asana* (neutrality): Whoever thinks "No enemy can hurt me, or am I strong enough to destroy my enemy" shall observe neutrality.
- (iv) *Yana* (march): Whoever is possessed of necessary means shall march against his enemy.

- (v) *Samshraya* (seeking alliance or shelter): Whoever is devoid of necessary strength to defend himself shall seek the protection of another.
- (vi) *Dvaidhibhava* (double policy): Whoever thinks that help is necessary to work out an end shall make peace with one and wage war with another.

Kautilya also realizes that success will only be achieved if the *shadgunya* policies are implemented through various means or *upaya* (techniques). The various *upayas* are:

- (a) *Sama* (conciliation): When chances of success are slim, the ruler must attempt conciliation.
- (b) *Dana* (gift): Inferior kings and discontented people are to be given gifts and won over without any resort to violence.
- (c) *Bheda* (dissension): If gifts fail to yield result, then dissension is to be followed. Dissension's avowed purpose is to create confusion and chaos among the enemy and neutralize them.
- (d) *Maya-Indrajala* (deceit and pretense): The enemy can be lulled into passivity by nonaggression treaties, postures of moral probity, or religious righteousness.
- (e) *Danda* (open attack or war): When all else fails, then war is to be initiated. However, Kautilya deems war to be a serious matter and should be undertaken only after a proper consideration of the enemy's war-waging capability.

Kautilya looks at the issue of war as an important subject, and *Arthaśāstra* describes various types of wars which are to be used by the *vijigishu* to attain his objective. Three types of wars are discussed: *prakashayudda* (open war), *kutayudda* (concealed war), and *tusniyudda* (silent war). Open war is obvious and concealed war is what is usually identified as guerrilla war. The silent war is a type of war in which the *vijigishu* and his officials and subjects purport to be at peace with another kingdom, but all the while the *vijigishu's* secret agents and spies are carrying out a campaign of assassination against important leaders in the other kingdom, creating fissures among key officials and groups

and spreading false information. While countless treatises on wars have been written, one finds it difficult to identify anything like silent war being discussed so candidly in any texts.

Is there any relevance of *Arthaśāstra*, a book written nearly 2,500 years ago? Any serious student of strategic studies, foreign policy, political science, and business studies will undoubtedly benefit from a thorough study. However, one should also keep in mind that *Arthaśāstra* is a complex and subtle work and as such is particularly prone to selective reading and interpretation. Also Kauṭilya's writing makes clear that Indian leaders could expect little loyalty from their subjects. In spite of this, *Arthaśāstra* offers no advice on how such a drawback can be improved through collective effort. Whereas Machiavelli emphasizes the need for creating "civic consciousness" and thereby allows an astute ruler to make better use of his human resources, Kauṭilya lacks such an approach. Unlike Plato, who started his political writings as attempts to think his way forward following the fate of Athens in the Peloponnesian War, Kauṭilya did not propose any break with the past or strive to suggest something new. His world is an unchanging social landscape where traditional norms must be upheld. Still, the work is considered by scholars as the most important ancient Indian text on strategy from which many lessons can be derived for modern military and strategic thought. As for its relevance in the twenty-first century, R. P. Kangle, whose translation of *Arthaśāstra* is considered classic, best answers this question when he points out that given the prevailing nature of world politics, Kauṭilya's teachings are knowingly or unknowingly followed by all, even those who openly decry him.

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Kerala School of Astronomy and Mathematics

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After ► [Bhāskara II](#) (b. A.D. 1114), the most significant contributions to mathematics and astronomy in India came from Kerala, in the

southwestern part of India. Kerala has had a continuous tradition of astronomy and mathematics from much earlier times. Sarma has listed nearly 750 independent works on astronomy, astrology and mathematics including minor works by 110 authors in the Kerala tradition.

Vararuci (date unconfirmed), who is credited with the authorship of 248 *Candravākya*s (sentences for computation of the moon's longitude) by the manuscript tradition, is considered to be the father figure in the astronomical tradition of Kerala. *Āryabhaṭīya* (ca. A.D. 499) of ► *Āryabhaṭa* which set the tone for all further work on mathematical astronomy in India, appears to have become popular in Kerala soon after its composition. In fact, out of the 20 or so available commentaries on *Āryabhaṭīya*, as many as 12 are from Kerala. The astronomical parameters in *Āryabhaṭīya* were revised by a group of astronomers who had gathered in the religio-educational centre of Tirunavay in northern Kerala in A.D. 683–684. Haridatta in his *Grahacāranibandhana* enunciated the revised system called *Parahita-gaṇita*. Many later works refer to the *Parahita* system.

Laghubhāskarīya and *Mahābhāskarīya* of ► *Bhāskara I*, which expounded the *Āryabhaṭa* school in detail, were also popular in Kerala. Govindasvāmin (A.D. 800–850) wrote an elaborate commentary on *Mahābhāskarīya* and his student Śāṅkaranārāyaṇa (A.D. 825–900) wrote one on *Laghubhāskarīya*. Udayadivākara (eleventh century), who wrote a detailed commentary titled *Sundarī* on *Laghubhāskarīya*, also probably hailed from Kerala. This work contains a method for solving quadratic indeterminate equations or *Varga – prakṛti* and ascribes it to Jayadeva. It is in fact the same as the famous *Cakravāla* algorithm, expounded in detail later by Bhāskara II in his *Bījagaṇita*. Suryadeva Yajvan (A.D. 1191–1250) wrote detailed commentaries on both *Āryabhaṭīya* and *Laghubhāskarīya* of Manjulācārya.

The Kerala tradition entered a new phase with ► *Mādhava* of *Sanḡamagrāma* (A.D. 1340–1425). His *Venvāroha* and *Sphuṭacandrāpti* both contain an efficient computational procedure to calculate the true

longitude of the Moon every 36 min. Those books and *Aganītagrahacāra* are conceptually not major works. However all the later astronomer-mathematicians from Kerala attribute the path-breaking results in the infinite series for the inverse-tangent, sine and cosine functions and many innovations in astronomical calculations to him. He is also hailed as *Golavid* (master of Spherics). Parameśvara of Vatasserī (A.D. 1360–1455), a student of Mādhava, was a prolific writer, authoring about 30 works. Emphasising the need for revising the planetary parameters through observations, he thoroughly revised the *Parahita* system and introduced the *Dṛggaṇita* system. Apart from *Dṛggaṇita*, the other important works of Parameśvara are *Goladīpikā* in three parts, *Bhaṭadīpikā*, a commentary on *Āryabhaṭīya*, *Mahābhāskarīyabhāṣya* and *Siddhāntadīpikā*, a super-commentary on Govindasvāmin's *Mahābhāskarīyabhāṣya*, and *Grahaṇamaṇḍana* on eclipses. He was one of the astronomers to discuss in detail the geometrical model of planetary motion implied in the conventional calculational procedures in Indian astronomy in his *Siddhāntadīpikā* and *Goladīpikā*.

No full-fledged work of Dāmodara, son and disciple of Parameśvara is known, but he is quoted at several places by his famous pupil, Nīlakaṇṭha Somayāji or Somasutvan (A.D. 1445–1545) of Trkkaṇṭiyur. Nīlakaṇṭha's *Tantrasaṅgraha* ranks along with *Āryabhaṭīya* of Āryabhaṭa and *Siddhāntaśiromaṇi* of Bhākaracārya as one of the major works which significantly influenced all further work on astronomy in India. In *Tantrasaṅgraha*, Nīlakaṇṭha introduced a major revision of the traditional Indian planetary model. There are also important innovations in mathematical techniques especially related to the series expansion of the trigonometric functions and systematic and exact treatment of spherical astronomy problems.

In addition to *Tantrasaṅgraha*, Nīlakaṇṭha composed many other works. *Āryabhaṭīyabhāṣya*, composed late in his life, is perhaps the most elaborate commentary on *Āryabhaṭīya*. He himself calls it a *Mahābhāṣya* (from *mahā*, great and *bhāṣya*, commentary), which is amply justified considering the wealth

of information in it. Apart from the detailed explanation of mathematical results and procedures, it discusses the geometrical model of planetary motion, eclipses, and even some “physical” concepts like the planets’ being illuminated by the Sun. Some of his other major works are *Golasāra* on spherical astronomy, *Siddhāntadarpaṇa*, in which he presents the planetary parameters as verified through his own observations, *Candracchāyā-gaṇita* on ‘shadow’ problems, and *Grahaṇanirṇaya* on lunar and solar eclipses. *Jyotīrmīmāṃsā* of Nīlakaṇṭha has a unique place in the history of Indian astronomy, as it is the only work which focuses on epistemological issues concerning the science of astronomy and mathematics. It falsifies the claim of many scholars that Indian astronomy, in contrast to the Greek tradition, did not have a scientific methodology worth the name. It strongly emphasises the role of observations and experimentation in revising astronomical parameters. Sundararāja, a contemporary of Nīlakaṇṭha hailing from Tamilnadu, sought clarifications on many topics in astronomy from Nīlakaṇṭha, the answers to which formed the work *Sundararāja-praśnottara*, as stated by Sundararāja himself in his *Vākyakaraṇa*. Clearly, it is a work different in nature from texts and commentaries. The manuscripts pertaining to this work have yet to be traced.

Jyeṣṭhadeva (ca. A.D. 1500–1610) of the *Parakroda* or *Paroṇṇottu* family, was also initially a pupil of Dāmodara and received instructions from Nīlakaṇṭha Somayāji later. In his *Gaṇita-Yuktibhāṣā* (Rationale of Mathematics and Astronomy), popularly known as *Yuktibhāṣā* composed around A.D. 1530, we see an elaborate and systematic exposition of the rationale of mathematics in Part I and of astronomy in Part II. Though it claims to explain the contents of *Tantrasaṅgraha* and provide the rationale for the calculational procedures in it, it is really an independent work (especially part I). It is a unique work in Indian astronomy/mathematics for two reasons (1) it is exclusively devoted to proofs and demonstrations, including the infinite series for π and trigonometric functions, and explanations for all astronomical calculational procedures current at that time and (2) it is written in Malayalam, the

local language of Kerala. Perhaps this is one of the reasons for the title of the book, *Yuktibhāṣā* (the language which is spoken is called *Bhāṣā*). A Sanskrit version of the text is also available, but it is clearly a rough translation into Sanskrit of the Malayalam original. Śaṅkara Vārier of Trikkutaveli (A.D. 1500–1560) was a disciple of Nīlakaṇṭha Somayāji, and as he himself stated, was also deeply influenced by Jyeṣṭhadeva. He is the author of two commentaries on *Tantrasaṅgraha*, namely *Laghuvivṛitti* (in prose), and a far more elaborate *Yuktidīpikā* (in verse). He is also the author of a major portion of the commentary on Līlāvati called *Kriyākramakarī* which was completed by Mahisamangalam Nārāyaṇa. *Yuktidīpikā* and *Kriyākramakarī* are also devoted to proofs and demonstrations, and there are similarities between the treatment of various topics in them and in *Yuktibhāṣā*.

Citrabhānu (A.D. 1475–1550), the author of *Karaṇāmṛta* was also a disciple of Nīlakaṇṭha, whereas Acyuta Piśaraṭi (A.D. 1550–1621) of Trkkaṇṭiyūr was a student of Jyeṣṭhadeva. It was Acyuta who discussed the “Reduction to ecliptic” in detail in his *Sphutanirṇayatantra* and *Rāśigolasphutāniti*. Putumana Somayāji’s (A.D. 1660–1740) *Karaṇapaddhati* provides rationale for astronomical algorithms. *Sadratanmālā* of Prince Śaṅkara Varman (A.D. 1800–1838) is a compendium of the Kerala school of mathematics and astronomy. The tradition continued up to modern times with works incorporating some of the results of modern positional astronomy.

Apart from these major works, there are several short texts which interpret and discuss specific formulae and procedures associated with specific topics. These texts have the words *Yukti* or *nyāya* (rationale) attached to their titles. Examples are *Grahaṇa-nyāya-dīpikā* on the computation of eclipses by Parameśvara and *Gaṇita-yuktayaḥ* by an anonymous author. There are also a large number of works devoted to astrology. Many of them are in the Kerala tradition but by non-Keralite authors.

There is great emphasis on observation in the Kerala school. In his *Siddhāntadīpikā*,

Parameśvara refers to the numerous eclipses observed by him over a long period. In his *Āryabhaṭīyabhāṣya*, Nīlakaṇṭha observes that Parameśvara revised the planetary parameters in his *Dr̥ggaṇita* after observing eclipses and planetary occultations for 55 years. In his *Jyotirmīmāṃsā* he argues:

One has to realise that the five *siddhāntas* had been correct at a particular time. Therefore, one should search for a *siddhānta* that does not show discord with actual observations (at the present time). Such accordance with observation has to be ascertained by (astronomical) observers during times of eclipses etc. When *siddhāntas* show discord, that is, when an earlier *siddhānta* is in discord, observations should be made of revolutions etc. (which would give results in accord with actual observations) and a new *siddhānta* enunciated.

Major Contributions

Astronomy

In his *Tantrasaṅgraha*, Nīlakaṇṭha introduced a major revision of the traditional Indian planetary model. He arrived at a unified theory of planetary latitudes and a better formulation of the equation of centre for interior planets (Mercury and Venus) than was available, either in the earlier Indian works, or in the Islamic or European traditions of astronomy until the work of Kepler. In his other works *Golasāra*, *Siddhāntadarpaṇa* and *Āryabhaṭīya bhāṣya*, Nīlakaṇṭha outlined the

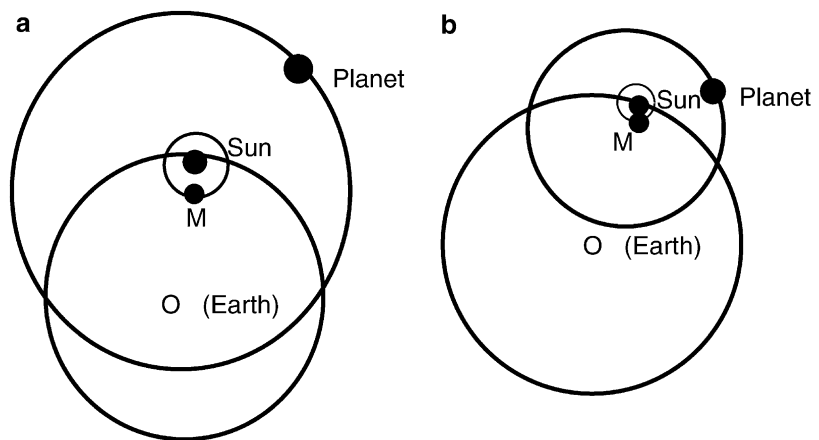
geometrical picture of planetary motion that follows from his model. According to this picture, the five planets Mercury, Venus, Mars, Jupiter and Saturn move in eccentric orbits inclined to the ecliptic around the mean Sun, which in turn goes around the earth. This is similar to the model of Tycho Brahe (A.D. 1583). Nīlakaṇṭha's "heliocentric" planetary model is depicted in the accompanying figure (Fig. 1).

The discussion on physical distances of planets in the last chapter of *Tantrasaṅgraha* indicates that Nīlakaṇṭha meant it to be a physical model. Parameśvara anticipated many of the ideas of Nīlakaṇṭha regarding the geometrical picture of planetary motion in some of his works. The model is discussed in detail in *Yuktibhāṣā* also.

In *Tantrasaṅgraha*, we have a discussion of the instantaneous velocities of planets, including the correct expression for the derivative of the inverse – sine function. There is a systematic treatment of spherical astronomy problems with exact spherical trigonometry formulae and with applications to the determination of time from the shadow, *Lagna* (orient ecliptic point), eclipses, exact angular separation between the centres of the solar and lunar disks, and elevation of lunar cusps. There is emphasis on methods rather than mere computational algorithms, in contrast with the other *Tantra* texts in Indian astronomy. All the spherical astronomy results are proved in detail in *Yuktibhāṣā*.

Kerala School of Astronomy and Mathematics,

Fig. 1 Nīlakaṇṭha's geometrical model of planetary motion for (a) an exterior planet, and (b) an interior planet. In each case, *M*, which is in the direction of the aphelion (the point in the orbit of a planet, comet or other celestial body that is farthest from the Sun), is the centre of the eccentric orbit



The Moon moves in an orbit inclined to the ecliptic, and as noted earlier, Acyuta Piśaraṭi provided the expression for the correction to the orbital longitude of the Moon to reduce it to the ecliptic. Interestingly, Tycho Brahe (A.D. 1546–1601) who discussed the “reduction to the ecliptic” for the first time in the European tradition, was a contemporary of Acyuta.

Mathematics

The crowning achievements of the Kerala school in mathematics are the infinite series expansion of the inverse-tangent function (*Yuktibhāṣā*, *Yuktidīpikā* and *Knīyākramakarī*), and the sine and cosine functions (*Yuktibhāṣā*, *Yuktidīpikā*). In modern terminology:

$$\begin{aligned}\tan^{-1}x &= x - \frac{x^3}{3} + \frac{x^5}{5} - \cdots, \\ \sin \theta &= \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \cdots, \\ \cos \theta &= 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \cdots.\end{aligned}$$

As noted earlier, these are all ascribed to Mādhava. Geometrical proofs for the above are to be found in *Yuktibhāṣā*. When $x = 1$, the inverse tangent series reduces to

$$\frac{C}{4D} = \frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \cdots,$$

where C and D are the circumference and diameter of a circle.

Earlier, Nīlakaṇṭha had noted the irrational character of π in his *Āryabhaṭīya bhāṣya*.

The above series for π is slowly convergent. A systematic procedure to calculate π with a finite number of terms and a suitable “remainder” or “correction” term is discussed in *Yuktibhāṣā* with the final result:

$$\begin{aligned}\frac{\pi}{4} &= 1 - \frac{1}{3} + \cdots + (-1)^{n-1} \frac{1}{2n-1} \\ &+ (-1)^n \frac{n^2 + 1}{(4n^3 + 5n)}.\end{aligned}$$

When $n = 50$, this leads to a value of π correct to 11 decimal places. In *Sadratnamālā* (A.D. 1823) of Śaṅkara Varma, the value of π is given as 3.14159265358979324, which is correct to 17 decimal places. This value was probably obtained using the same procedure, with the correction term evaluated to a higher degree of accuracy.

It is possible to obtain a fast convergent series for π by incorporating the correction terms from the beginning itself. Two of the fast convergent series for π mentioned in *Yuktibhāṣā* in this context are

$$\begin{aligned}\frac{\pi}{16} &= \frac{1}{1^5 + 4.1} - \frac{1}{3^5 + 4.3} + \frac{1}{5^5 + 4.5} - \frac{1}{7^5 + 4.7} + \cdots, \\ \frac{\pi}{4} &= \frac{3}{4} + \frac{1}{3^3 - 3} - \frac{1}{5^3 - 5} + \frac{1}{7^3 - 7} - \cdots.\end{aligned}$$

Use of the sine-series to compute the sine of an arbitrary angle to a high degree of accuracy with the aid of simple mnemonics is found in *Yuktidīpikā*.

The differential of the sine (cosine) function is proportional to the cosine (sine) function. These differentials are used with confidence in various applications to problems in astronomy in *Tantrasaṅgraha* and *Yuktibhāṣā*. The correct expression for the differential of the ratio of two functions involving sine/cosine functions is given in Acyuta’s *Sphutanirṇayatantra*. Integration procedures to calculate the area and volume of a sphere are also given in *Yuktibhāṣā*. The area and circumradius of a cyclic quadrilateral in terms of the sides are some of the other topics discussed in *Yuktibhāṣā*.

Another characteristic feature of Kerala mathematics is the geometrical demonstration of many algebraic and arithmetical results. Multiplication, division, squaring, etc. are all illustrated geometrically in *Yuktibhāṣā*. An advanced example is the geometrical proof of

$$1^3 + 2^3 + \cdots + n^3 = \frac{n^2(n+1)^2}{4}$$

in Nīlakaṇṭha’s *Āryabhaṭīyabhāṣya*.

See Also

► Nyāya

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Kitora Burial Mound

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Inside the Kitora burial mound at Asuka, a village in the northern half of Nara prefecture in Japan, is a tomb that dates approximately to CE 700 and has a celestial map and murals of cosmological significance. Both the map and the murals bear evidence of scientific and artistic diffusion from China to Japan via the Korean peninsula, with the direct cultural link being to the northern Korean kingdom of Goguryeo (37 BCE to CE 668). Most notable, however, is the fact that the map is the oldest extant celestial map that is currently known to be scientific in spirit and, more or less, complete.

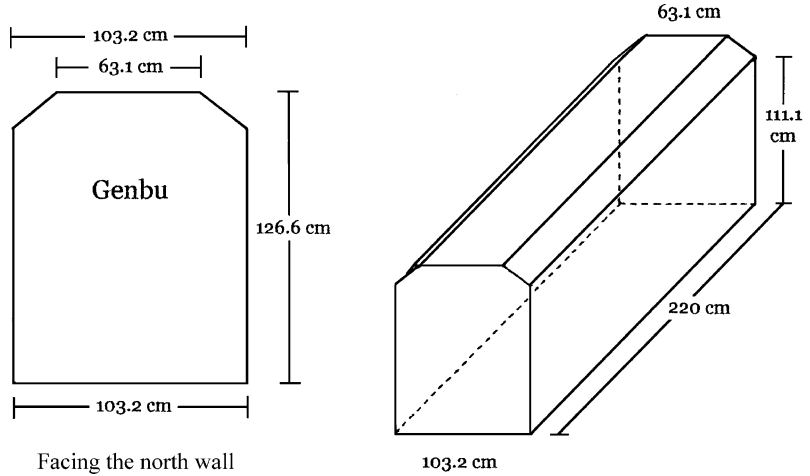
The Mound and the Tomb

Kitora dates to ca. CE 700 and is thereby a rather late burial mound since most of those in Japan were constructed in the fourth, fifth, and sixth centuries CE. Although it had been replaced by nearby Fujiwara in 694 (until 710), Asuka had served as the capital city of the Yamato state throughout the seventh century, and Kitora seems to have been built in the aftermath of a period of significant Korean influence on higher learning and its applications in Japanese society. It is not known who was buried inside Kitora, but it is reasonable to think that it was probably a person of high status within the community of seventh-century migrants from the Korean peninsula.

The conical burial mound stands 3 m high, has a diameter of 14 m at its base, and archeologically is classified as a circular mound. Today, it is partially obscured by a building which has been put up to try to protect its contents from further damage that occurred while research was being done from the late 1990s into the first decade of the present century. Inside the burial mound is an essentially rectangular stone tomb that measures about $220 \times 103.2 \times 126.6$ cm, with the ceiling disrupting the geometry by having a centered flat part of 63.1 cm width that is flanked on either side by small slopes that make the walls along the length of the tomb stand at 111.1 cm high (Fig. 1). Other than the celestial map and murals, which are discussed subsequently, the chamber had only a few small artifacts by the time that it was opened up for research, apparently having been raided centuries ago.

The Celestial Map

Volume 2, Book 2 of *The History of Cartography* series (Harley & Woodward, 1994) provides substantial information about the rich heritage of celestial cartography in East Asia, and its foundations were laid in ancient China many centuries before the Kitora burial mound was constructed. Chinese astronomy involved observing celestial phenomena, compiling catalogs of stars, and making diagrams of the night sky, all of which

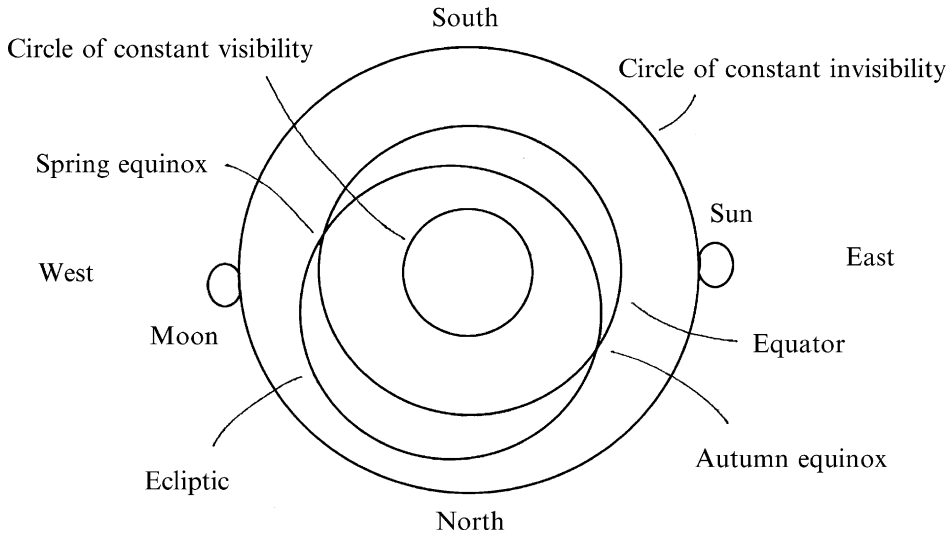
Kitora Burial Mound,**Fig. 1** The dimensions of the chamber containing the star map and murals inside the Kitora Burial Mound

contributed to improvements in scientific knowledge that was applied in such fields as calendar making, government, and prognostication. Important cartographic features included the celestial equator, the plane of the ecliptic, the line of constant visibility (within which were the circumpolar stars, i.e., those which could always be seen), the line of constant invisibility (beyond which no stars could ever be seen), the 28 lunar lodges which marked the path of the moon through its monthly cycle, and other constellations which were not directly associated with the moon. Although the earliest celestial maps cannot be tracked down, it is known that Chinese astronomy and other sciences such as medicine spread to the Korean peninsula and, from there during a period of peninsular instability from the mid-sixth century CE, to the western part of the Japanese archipelago. The route of diffusion was southward from the northern kingdom of Goguryeo to Baekje, the weakest of the three independent Korean kingdoms which transmitted knowledge to Japan through specialists and books in a time of political trouble that extended into the 660s when the third Korean kingdom, Silla, conquered the other two.

The celestial map inside the Kitora burial mound includes the four circles just mentioned (equator, ecliptic, constant visibility, and constant invisibility) as well as constellations which may be traced to China (photographs may be found at Nara Bunkazai Kenkyūjo, Asuka

Shiryōkan Kurabu (1995), Renshaw and Ihara (2002), and Tokai University Research and Information Center (2002), as well as in Bunka-chō, Tōkyō Kokuritsu Hakubutsukan, Nara Bunkazai Kenkyūjo, and Asahi Shinbunsha (2014)). Both the circles and the stars were formed by chiseling into the stone, with the grooves of the circles and the stars having been filled with cinnabar and the holes for the stars evidently with gold leaf, and the dispositions of the circles and stars suggest that the projection for the map was azimuthal or zenithal equidistant. The diameters of the three concentric circles are 16.8 cm (constant visibility), 40.3 cm (equator), and 60.6 cm (constant invisibility), while the offset ecliptic is about 40.5 cm. Outside the western and eastern edges of the circle of constant invisibility, and just touching it, are small circles for the moon and the sun, respectively (Fig. 2).

Two of the circles have significant errors, both of which might be explained by the circumstances faced by the craftsmen. One is that the circle of constant invisibility is smaller than it ought to be based on the radii of the circle of constant visibility and the equator, and this probably was due to an attempt to fit all of the map within the flat part of the ceiling after work was in progress or to emphasize the constellations inside the celestial equator. The ecliptic has two errors, one being that it is circular rather than oblate and slightly larger than the equator as it should be on the zenithal equidistant projection (and therefore



Kitora Burial Mound, Fig. 2 The main circles of the Kitora star map

does not display the equinoxes correctly) and the other being that it is offset toward the northwest rather than toward the northeast. Whereas the first error can be attributed to the use of a circle-making compass, the second probably resulted from confusing west for east when the ecliptic was transferred from the model diagram to the ceiling of the tomb.

If the circle of constant invisibility had been drawn in the correct proportion to the other concentric circles, it would be possible to derive a reasonably accurate estimate for the terrestrial latitude which corresponds to the sky shown in the Kitora map. Despite this and other problems regarding the placement of the stars, early estimates based on photographs of the radii of the circle of constant visibility and the equator came to about $38^{\circ}24'$ (Miyajima, 1999b) and $38^{\circ}09'$ (Renshaw & Ihara, 2002) north latitude, while a more recent calculation based on the same radii as given in Bunka-chō et al. (2014), after researchers could make direct measurements, yields $37^{\circ}31'$ (Potter, n.d.); because of its significance, to these ought to be added the latitude of $39^{\circ}04'$ which was derived by assuming that the circles of constant visibility and constant invisibility are correct (Potter, n.d.). These latitudes are well north of Asuka ($34^{\circ}30'$ in the Nara Basin) and fall within central Tōhoku, which, at the time

that the Kitora map was made, was a frontier region of Japanese rural settlement. Because the estimated latitude of the Kitora map was approximately 450 km north of the Japanese cultural hearth in the Nara Basin and in an area which hardly interested the Japanese at the time, it would seem that the Kitora map was based on observations made elsewhere and, therefore, on an imported star map that served as its model. The ancient major Chinese centers of Cháng'ān (now at Xī'ān) and Luòyáng lie between 34° and 35° north, the same as the Nara Basin, and Dūnhuáng and Āsītǎnā, which have Táng dynasty (CE 618–907) celestial diagrams or maps inside archeological sites, are, respectively, at about 40° and 43° north, while a capital city prior to CE 510, Píngchéng at present-day Dátòng, was also at approximately 40° north. On the Korean peninsula, there were two major cultural centers at latitudes that might have been the basis for the Kitora map, Pyongyang (39° north, the capital city of Goguryeo from CE 427 until the kingdom was conquered by Silla in 668) and Wiryeseong ($37^{\circ}32'$, the capital of Baekje from 18 BCE to CE 475, in present-day Seoul); the recent calculations of $39^{\circ}04'$ and $37^{\circ}31'$ are therefore very close fits for these respective sites.

Judging from the work done by Miyajima (1999b), it is not clear when the data about the

stars in the Kitōra map were compiled, hence coming up with a reasonable date for its model has been problematic. One of two estimates made places the date of observation of the sky to the latter half of the fifth century CE, when Pyōngyang was a capital city, yet there is little confidence in this mainly because the celestial north pole does not coincide with the center of the concentric circles. The other estimate was derived by considering the positions of the stars according to their right ascensions, suggests ca. 65 BCE as a possibility, but is not reliable because of insufficient data, differing values according to which stars are used, and errors that can be attributed to the workmanship. Despite their roughness, Miyajima (1999b) had proposed that these estimates could be pointing at a synthetic map in which a graticule for the Pyōngyang area was superimposed on a distribution of stars according to a Chinese catalog or survey from the first century BCE.

Such a synthetic, incorrectly layered map could conceivably have been put together when Pyōngyang served as the capital of Goguryeo, and the best evidence to support this idea is a verbal reference on a late fourteenth-century circular star map to its own model, an engraving on a stone stele which was sunk in the Daedong River around the time that Goguryeo fell to Silla in the late seventh century CE. At least one rubbing of the map had been made before the stele was sunk because the inscription on the *Cheonsang Yeolcha Bunya ji Do* (Map of the Sphere with Images in the Heavens and the Line of Lodges), another stele made in CE 1395–1396 and reengraved approximately 300 years later, relates this history. Other documentary evidence supports this as well as the idea that celestial diagrams in general had existed in Goguryeo, and calculations from the engravings of the *Cheonsang Yeolcha Bunya ji Do* indicate that it could have been based on an original with stars that were surveyed approximately 2,000 years ago, which is to say around the same time as the suspected model for the Kitōra map. The biggest problem in linking the Kitōra map with the *Cheonsang Yeolcha Bunya ji Do*, however, is that a detailed comparison reveals that they differ

considerably from each other, perhaps to the point that they used different models.

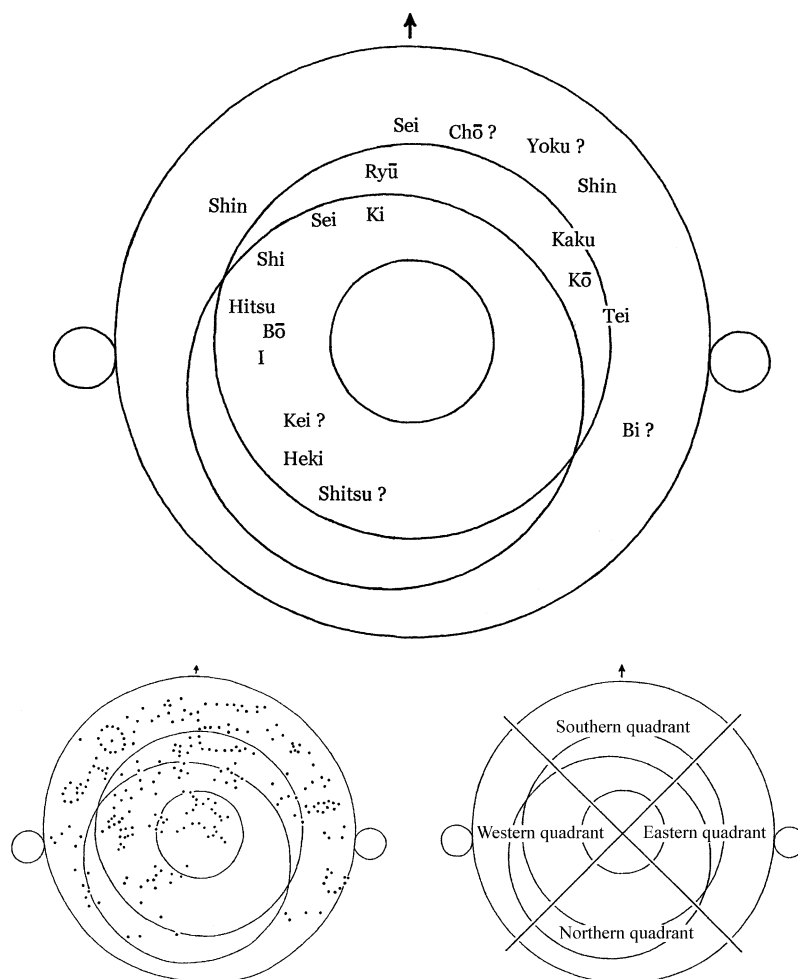
Detailed star maps such as the *Cheonsang Yeolcha Bunya ji Do* and a Chinese circular map at Sūzhōu that was engraved in stone in CE 1247 were useful for identifying the lunar lodges and other constellations in the Kitōra map, many of which are given away by the red lines that connect stars. Although a complete picture cannot be put together because of the damage to the ceiling in the tomb, the reasonably good assessment of the southern half of the map which has been made argues that the map was engraved with an appreciation for scientific detail and an intention to get the important stellar information reasonably correct. Notable is the distribution of the identified and possibly identified lunar lodges, which demonstrates that they were positioned within their proper directional quadrants, seven to each, with all seven of the south having been identified despite the possibility of two of them having been switched (Fig. 3). Other constellations such as *Gunshi* (Army Town), *Bunshō* (Written Prosperity), *Taibien* (Big Faint Fence), and *Hokutoshichisei* (Seven Stars of the Northern Ladle) were also identified by the patterns created by the lines that connect their stars, and their placement is correct in a relative context. Analysis of the lunar lodges and other constellations also revealed that they and, vis-à-vis the geometry of the constellations, their stars are larger than usual, while the errors made in positioning them were greater than those on the *Cheonsang Yeolcha Bunya ji Do* and other celestial maps that were used for comparison.

The Murals

Two sets of illustrations, both from Chinese cosmology, adorned the walls inside the Kitōra tomb (Bunka-chō et al., 2014 has good photographs). The set which was found in better condition are the upper pictures, which show the four spirit beasts (*shinjū*) or spirits (*shijin*) that are usually described as tutelary or protective deities of the north, east, south, and west. Their Japanese names are, respectively, Genbu (Black Warrior(s),

Kitora Burial Mound,

Fig. 3 The distribution of the extant stars in the Kitora star map (*left*), the identified or possibly identified lunar lodges (*above*), and the sky divided into quadrants, within each of which are supposed to be seven lunar lodges (*right*)



K

a turtle-like creature and a snake together), Seiryū or Seiryō (Blue [Green] Dragon), Suzaku or Shujaku (Red Bird), and Byakko (White Tiger), and each was found on the wall corresponding with its direction. The discovery by the research team of Suzaku on the southern wall generated a fair amount of excitement because it was the first time that the complete set of spirit beasts had been found inside a Japanese tomb. Previous work on the nearby Takamatsuzuka burial mound had revealed the other three on the walls in the tomb there and led to the assumption that Suzaku must have been painted on the southern wall, which had been destroyed sometime in the past by grave robbers.

Below the spirit beasts were paintings of other creatures, but this set is no longer complete

because of damage to the walls. From examining what has remained of them, however, it is clear that each wall had three creatures with different heads standing up and dressed in period attire as if they were human beings. The first has a catlike head, which led to the assumption that the painting was of the tiger in the 12-animal Chinese zodiac; later research revealed a rather clear painting of a creature with a horse's head in the middle of the southern wall, which corresponds with the correct location of the horse in the same zodiac. What makes this set of illustrations special is that this is the only known case of their having been painted on tomb walls in any country.

The 12 animals of the Chinese zodiac popularly get linked to a cycle of 12 years, but they

also have directional and temporal equivalents which are more important for cosmology. Along the northern wall of the tomb would have been the boar or pig (north-north-west), mouse (north), and ox or cow (north-north-east); along the eastern would have been the tiger (east-north-east), rabbit (east), and dragon (east-south-east); along the southern would have been the snake (south-south-east), horse (south), and goat or sheep (south-south-west); and along the western would have been the monkey (west-south-west), cockerel or bird (west), and dog (west-north-west). Each of these animals, in the same sequence, corresponds with a 2-h block of time, which makes sense in a geographical context so that, for example, the mouse straddles midnight at 11 p.m. to 1 a.m., the hours for the rabbit are 5–7 a.m. when the sun comes up in the eastern sky, the horse overlaps noon from 11 a.m. to 1 p.m. when the sun is due south and at its highest, and the cockerel or bird symbolizes sunset in the west between 5 and 7 p.m.

Korean Provenance

Both the science and the art with scientific implications inside the Kitora tomb may be traced ultimately to ancient China, yet the evidence argues not only for one or more countries on the Korean peninsula as the immediate agent of cultural transmission but also for the strong probability that migrants from the peninsula and/or their descendants were directly involved in the Kitora project. The estimated terrestrial latitudes based on the concentric circles of the celestial map, mentioned previously, contribute to this line of thinking and to surmising that the star map might be related to the one which is noted in the inscription for the *Cheonsang Yeolcha Bunya ji Do* as having been sunk in the Daedong River during an intra-Korean conflict. Examination of the murals, however, has provided more depth to argue for Korean provenance, as the following briefly notes.

An important lead in the early investigations was the fact that both a celestial diagram and murals of the four spirit beasts were found inside

the tomb, something that was far more common in Goguryeo than in the other Korean states and China. Although there is no known celestial map with the scientific spirit of that inside Kitora that either predates or is contemporaneous with it (that on the ceiling of the Takamatsuzuka tomb is a square diagram without any of the astronomical circles), archeological evidence from contemporary and later tombs suggests that there was no specific model for such celestial diagrams. In the case of the murals and the four spirit beasts, though, there are similar drawings inside earlier tombs in Goguryeo as well as inside Takamatsuzuka at Asuka to use for artistic comparison. When those and other murals inside Takamatsuzuka were discovered in 1972—11 years before Genbu, 26 before Byakko and Seiryū, and 29 before Suzaku were discovered inside Kitora—experts from the two republics in the northern and southern halves of Korea were invited to examine them. The reasonable probability of Korean influence on them cannot be discounted, which may also be true for the spirit beasts inside Kitora because of the similarities between the three that are found in both tombs at Asuka. Further evidence to suggest a Korean provenance for the murals inside Kitora is the fact that influential artists of seventh-century Japan were settlers from the Korean peninsula, who most likely brought models which could have been used for the murals, and their descendants; speculation has notably focused on the Kibumi painters, a school which was established in CE 604.

See Also

- [Time in China](#)
- [Time in Korea](#)

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Knowledge Systems in China

Yang Di-Sheng

The science and technology developed in China often led the world before the fifteenth century. Statistics of significant discoveries in the world from the sixth century BCE to the nineteenth century AD show that before the year 1500, discoveries made in China comprised more than half of the total (Guo Jianrong & Guo Guangyin, 1987). Then, the percentage dropped rapidly, and in the nineteenth century it became less than 1 %.

The mode of development of ► **science in China** is, roughly speaking, a slowly progressed “mode of accumulation.” It is not full of ups and downs like the Western saddle-shaped “mode of revolution”.

In contrast to the West, Chinese scientific and technological achievements mainly belonged to the technical and empirical type. The Chinese were less inclined to use theoretical and experimental methods. The four best known inventions – compass, ► **gunpowder**, paper, and printing – when they came to Europe, exerted a great influence on the West.

The most developed sciences in ancient China were astronomy, mathematics, medicine,

agronomy, and other related branches. This was determined by the needs of the agricultural Chinese society.

The characteristics of the development of science and technology in China were formed by factors that existed before the Christian era. At that time Chinese culture was already very different from Greek culture. There were both a different value orientation and a different way of thinking, which had long-term influences over the directions of the development of Chinese society and Chinese science and technology.

In regard to value orientation, the highest goal for Chinese ancient thinkers was in searching for the harmony and balance in one’s mind, and in the relationship between Man and Man, Man and Society, and Man and Nature. The core of the Confucian thought is *ren* (loving people). Therefore, the only important criterion for learning is usefulness for humanity’s purpose; other factors do not matter at all. In this regard, it is very different from ancient Greece, where study was for knowledge’s sake only and without any practical intention.

Huishi was the only exception among Chinese ancient thinkers. But thinkers from all the other schools such as Confucians, Daoists, Mohists, and Legalists uniformly criticized him, and they suppressed him. This contributed to the fact that the ancient Chinese were strong in technological achievements and relatively weak in theoretical ones. Even though the Mohists discussed almost all the problems contained in classical logic, they never made a single step toward formalization or axiomization. Therefore, they never came up with their own axiomatic system. The main reason for this was that logic, at that time, did not seem to have any practical use.

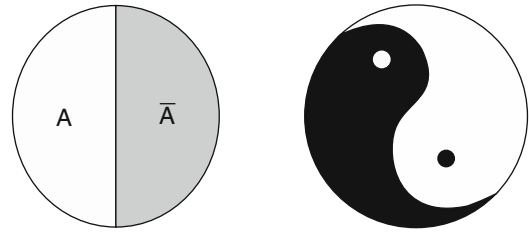
The Chinese also developed mathematics to a very high level. For example, in the ► **Shushu Jiuzhang** (Mathematical Treatise in Nine Sections) compiled by ► **Qin Jiushao** in 1247, there was a method of solving high degree equations. However, the Chinese never developed axiomatic systems similar to Euclidean geometry. Therefore, despite the fact that China had the most complete, most systematic astronomical records in the world at that time, and that she

was rich in cosmological constructions, such as the ► **gaitian** (hemispherical dome), the ► **huntingian** (celestial sphere), and the *xuan ye* (infinite empty space) hypotheses, she never produced any geometric cosmological models similar to Ptolemy's or Copernicus'. Chinese mathematics characteristically took practical use as its aim and centered around calculation. Its earliest representative work is ► **Jiuzhang Suanshu** (Nine Chapters on the Mathematical Arts) written in the Western Han dynasty. Ancient Western mathematics was mainly geometry; ancient Chinese mathematics was mainly algebra. Today, when computing technique once again is the primary concern of so many mathematicians, the practical value of ancient Chinese mathematical inclination becomes more and more obvious.

The development of modern science and technology makes people realize that it is a double-edged sword; it can bring benefits as well as destruction. Therefore, its development must be controlled ethically and politically, under strict management and control. In this respect, Chinese value orientation is a very significant model.

In regard to ways of thinking, Chinese traditional philosophy has always inclined to an organismic view of nature. Chinese philosophers regarded heaven, earth, and man as a united whole. This was fundamentally different from other ways of thinking, as there was no distinction between Object and Self. French thinker L. Levi-Bruhl (1857–1939) misunderstood when he considered the Chinese way of thinking primitive. The Chinese idea of the unification of heaven and man mainly emphasizes that humans are only a part of heaven (nature); the Way of Heaven and the Way of Man are one and the same. Humans should be in a harmonious existence with nature, and these two should not be opposed to each other.

Chinese philosophy also claims that heaven, earth, and everything else are constituted by a pair of contradictions. Chinese philosophers use two symbols, *yin* and *yang*, to represent this pair of contradictions. ► **Yinyang** is a unity of contradictions. There is an antagonistic as well as a complementary and containing relationship between them. There is *yang* in *yin* and there is



Knowledge Systems in China, Fig. 1 Two-valued logic and the *yinyang* fish *taiji* pattern

yin in *yang*. They can convert to each other under certain conditions. Therefore, in order to achieve harmony in nature, the stability of a society, and a long rule with eternal peace, as well as the health of individuals, “the doctrine of the mean” has to be applied to keep a dynamic balance between *yin* and *yang*. The philosophy advocates that nothing should be overdone, and all actions should be done appropriately. This way of thinking is different from the dichotomy in two-valued logic (A or $\bar{A}$), in which every proposition is either true or false. Its symbolic representation is the *yinyang* fish *taiji* pattern (Fig. 1).

A mechanistic mode of thought has never been dominant throughout Chinese history. This organismic way of thinking affected the development of Chinese science to a very large degree. It can be found in ancient Chinese cosmology, astronomy, medicine, agronomy, and social theories. It contributed tremendously to keeping peace and stability during the Middle Ages. However, at the same time it restrained the growth of capitalism, and served as one of the most important reasons that prevented China from having a scientific revolution.

According to the Chinese traditional view, the origin of the universe is the result of the changes of *yin* and *yang*. Imbalances of *yinyang* caused natural disasters like earthquakes, as well as social disturbance. The *yinyang* theory is also the theoretical foundation of Chinese medicine. It considers the human body as a whole. If a body loses its balance of *yin* and *yang*, the person becomes sick. The task of a medical doctor is to use every method to help the patient to resume this organismic dynamic balance. However, Chinese medicine is not a two-value system; it is a

multiple-value system, totally different from the Western medical system. But these two can go hand in hand and complement each other, thereby enriching the treasury of our medical knowledge.

The Chinese traditional way of thinking is an organismic one which emphasizes integrity and perceivability, and allows fuzziness. It is, relatively speaking, weak at analytical thinking and it does not value axiomatic systems. Generally it is not good for macrocosmic descriptions in the area of physics, especially mechanics. However, it is closer to the microcosmic world of modern science, such as the area of quantum mechanics, or to descriptions of cosmological, artificial intelligence, and social systems. The return from accuracy back to fuzziness is one of the main indications of contemporary science. Nowadays many scientists realize that this Chinese way of thinking could indeed bring helpful inspirations to the progress of modern science.

See Also

- [Acupuncture](#)
- [Algebra in China](#)
- [Computation: Chinese Counting Rods](#)
- [Environment and Nature: China](#)
- [Jiuzhang Suanshu](#)
- [Mathematics in China](#)
- [Medicine in China](#)
- [Qin Jiushao](#)
- [Yinyang](#)

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Knowledge Systems in India

A. V. Balasubramanian

Traditionally all knowledge in India has been traced to the Vedas. The Vedas are considered to be divine revelation. They were organized into four major branches: *R̥gveda*, *Yajurveda*, *Sāmaveda*, and the *Atharvaveda*. Various other branches of knowledge grew up as auxiliaries that were to be developed in order to interpret and put to practical use the material of the Vedas.

There were a total of 14 *Śāstras* or branches of knowledge: the 4 Vedas, the 4 Upavedas (auxiliary Vedas), and the 6 Vedāṅgas (parts of the Vedas). The four Upavedas were (1) *Āyurveda*, literally “The Science of Life,” which constituted the medical system; (2) *Arthaśāstra*, which constituted state craft and political theory; (3) *Dhanurveda*, literally, archery, but practically constituting the art of warfare in its varied aspects, and (4) *Gāndharvaveda*, constituting music, drama, and the fine arts.

Similarly, the knowledge systems required for understanding, interpreting, and applying the Vedas were organized into six branches called *Vedāṅgas*, literally “the limbs of the Vedas,” with the Vedas personified in a human form. The six *Vedāṅgas* are *Vyākaraṇa* (Grammar), *Chandas* (Metrics), *Śikṣā* (Phonetics), *Nirukṭa* (Etymology), *Kalpa* (Ritual), and *Jyotiṣa* (Astronomy and Mathematics).

These *Vedāṅgas* were essential, since the Vedas had to be understood correctly (needing

etymology and grammar), pronounced and chanted accurately (needing metrics and phonetics), and used properly in various contexts (needing ritual), and the times for these performances had to be computed correctly, requiring the knowledge of computation of the flow of time and of planetary movements (needing astronomy and mathematics). Even though the *Śāstras* originally evolved in the context of the Vedas, they also developed an independent identity and their own corpus of literature and applications that extended well outside the originally formulated requirements of the Vedic context.

In later periods the list of *Śāstras* became much larger and the area covered was much wider. For example, in his famous text *Kāmasūtra*, the author Vātsyāyana provides a list of 64 arts with which any scholar should be familiar.

Since the various branches of Indian knowledge systems are extremely diverse, we will focus upon a few that can best illustrate some characteristic different features. These are (1) the fact that linguistics occupied a seminal place even for exact sciences (unlike Western knowledge systems); (2) the nature of theorization and theory building in Indian tradition; (3) the algorithmic nature of Indian computation, and (4) the sociology of organization of knowledge -the “classical” and the “folk” streams and their interrelation.

In any scientific discourse it is essential to achieve precision and rigor. In the Western tradition, the geometry of Euclid is considered the paradigm of an ideal theory, and various other branches of knowledge tried to emulate Euclid by setting out their knowledge on the basis of a formal axiomatic system. In contrast, in Indian tradition, an attempt was made to use natural language and to refine and sharpen its potential by technical operations so that precise discourse was possible even in natural language. This is so, particularly in Sanskrit, where we find that even the most abstract and metaphysical discussions regarding grammar, mathematics, or logic are still written in natural language. In Indian knowledge systems, it is the science of linguistics that occupied the central place which, in the West, was occupied by mathematics.

Linguistics

Linguistics is the earliest of Indian sciences to have been rigorously systematized. This set an example for all the other Indian sciences. Linguistics is systematized in *Aṣṭādhyāyī* – the text of Sanskrit grammar by ► [Pāṇini](#). The date of this text is yet to be settled with any certainty. However, it is not later than 500 B.C.E. (The dates mentioned here are those based on Western scholarship. An indigenous Indian dating and chronology in this matter have yet to be established.) In the *Aṣṭādhyāyī*, Pāṇini achieves a complete characterization of the Sanskrit language as spoken at his time, and also manages to specify the way it deviated from the Sanskrit of the Vedas. Given a list of the root words of the Sanskrit language (*dhātupatha*) and using the aphorisms of Pāṇini, it is possible to generate all the possible correct utterances in Sanskrit. This is the main thrust of the generative grammars of today that seek to achieve a purely grammatical description of language through a formalized set of derivational strings. It is understandable that until such attempts were made in the West in the recent past, to the Western scholars the Paninian aphorisms (*sūtras*) looked like nothing but some artificial and abstruse formulations with little content.

Science in India seems to start with the assumption that truth resides in the real world with all of its diversity and complexity. Thus for the linguist what is ultimately true is the language as spoken by the people. As Patañjali, a famous grammarian who wrote a commentary on Pāṇini’s *Grammar* emphasizes, valid utterances are not manufactured by the linguist, but are already established by practice in the world. Nobody goes to a linguist asking for valid utterances, the way one goes to a potter asking for pots. Linguists do make generalizations about language as spoken in the world, but these are not the truth behind or above the reality. They are not the idealization according to which reality is tailored. On the other hand, what is ideal is real, and some part of the real always escapes our idealization of it. It is the business of the scientist to formulate these generalizations, but also at the same time to be attuned to the reality, to be

conscious of the exceptional nature of each specific instance. This attitude seems to permeate all Indian science and makes it an exercise quite different from the scientific enterprise of the West.

Astronomy and Mathematics

Indian mathematics finds its beginning in the *Śulbasūtras* of the Vedic times. Purportedly written to facilitate the accurate construction of various types of sacrificial altars of the Vedic ritual, these *sūtras* lay down the basic geometrical properties of plane figures like the triangle, the rectangle, the rhombus, and the circle. Basic categories of the Indian astronomical tradition were also established in the various *Vedāṅga Jyotiṣa* texts.

Rigorous systemization of Indian astronomy begins with ► [Āryabhaṭa](#) (b. A.D. 476). His work *Āryabhaṭīya* is a concise text of 121 aphoristic verses containing separate sections on basic astronomical definitions and parameters; basic mathematical procedures in arithmetic, geometry, algebra, and trigonometry; methods of determining the mean and true positions of the planets at any given time; and descriptions of the motions of the sun, moon, and planets along with computation of the solar and lunar eclipses. After Āryabhaṭa there followed a long series of illustrious astronomers with their equally illustrious texts, many of which gave rise to a host of commentaries and refinements by later astronomers and became the cornerstones for flourishing schools of astronomy and mathematics. Some of the well-known names belonging to the Indian tradition are ► [Varāhamihira](#) (d. A.D. 578), ► [Brahmagupta](#) (b. A.D. 598), ► [Bhāskara I](#) (b. A.D. 629), Lalla (eighth century A.D.), Muñjāla (A.D. 932), ► [Śrīpati](#) (A.D. 1039), ► [Bhāskara II](#) (b. A.D. 1115), Mādhava (fourteenth century A.D.), Parameśvara (ca. A.D. 1380), Nīlakaṇṭha (ca. A.D. 1444), Jyeṣṭhadeva (sixteenth century A.D.), Gaṇeśa, and Daivajña (sixteenth century A.D.). The tradition continued right up to the late eighteenth century, and in regions like Kerala, original work continued to appear until much later.

The most striking feature of this tradition is the efficacy with which the Indians handled and solved rather complicated problems. Thus the *Śulbasūtras* contain all the basic theorems of plane geometry. Around this time Indians also developed a sophisticated theory of numbers including the concepts of zero and negative numbers. They also arrived at simple algorithms for basic arithmetical operations by using the place-value notation. The reason for the success of the Indian mathematician lies perhaps in the explicitly algorithmic and computational nature of Indian mathematics. The objective of the Indian mathematician was not to find “ultimate axiomatic truths” in mathematics, but to find methods of solving specific problems that might arise in astronomical or other contexts. The Indian mathematicians were prepared to set up algorithms that might give only approximate solutions to the problems at hand, and to evolve theories of error and recursive procedures so that the approximations might be kept in check. This algorithmic methodology persisted in the Indian mathematical consciousness until recently, so that ► [Ramanujan](#) in the twentieth century might have made his impressive mathematical discoveries through its use.

Āyurveda: The Science of Life

The third major science of the classical tradition is Āyurveda, the science of life. Like linguistics and astronomy this finds its early expression in the Vedas, especially the *Atharvaveda*, in which a large amount of early medicinal lore is collected. Systemization of *Āyurveda* takes place during the period from the fifth century B.C.E. to the fifth century A.D. in the ► [Caraka Saṃhitā](#), ► [Suśruta Saṃhitā](#) and the *Aṣṭāṅga Saṅgraha*, the so-called *Bṛhat-trayee* texts which are still popular today. This is followed by a long period of intense activity during which attempts are made to refine the theory and practice of medicine. This process of accretion of information and refinement of practice continued right up to the beginning of the nineteenth century.

Folk and Classical Traditions

There exists a vast amount of knowledge which represents the wisdom of thousands of years of observation and experience. While in any given area (such as medicine) there may be a body of experts or learned professionals, knowledge also prevails in more diffuse or scattered forms. In Indian tradition, it seems to be a general principle running through all types of learning that knowledge can and does prevail in various forms and also gets communicated in many ways.

The general picture that emerges seems to be that the “classical texts” in any area of learning may set out broad general principles as well as their application in a given context, say a particular region of the country. But in various different contexts or regions, knowledge gets expressed based on the given situation, and the generalities get adopted, modified, or even overridden sometimes based on the specificity. This can perhaps best be illustrated in the case of medicine, where classical medical texts themselves deal with this issue. A classical text of *Āyurveda* such as *Caraka Samhitā* expounds general principles of drug action on the six factors: *Dravya*, *guṇa*, *Rasa*, *Vīrya*, *Vipāka*, and *Prabhava*. It also discusses remedies for several diseases and lists specific drugs. These may get modified to suit local conditions. In any recipe for a drug, one can substitute a nonprincipal component with an equivalent, which may be listed in the text or selected on the basis of the principle of *Rasa*, *Vīrya*, etc. From time to time traditional physicians produce texts and manuals which set out prescriptions for drugs in any given area based on what is available and suitable to the requirements of that area. For example, the text *Rājamṛgaṅka* lists 129 recipes, and in his foreword the editor states that it is a compilation that must have been made by a *vaidya* (physician) from Tamil Nadu, since it contains recipes based on herbs readily available in Tamil Nadu. Such recipes are not only easier to formulate, but they are also more suited to the area, in accordance with Caraka’s dictum, “For a person who belongs to a particular country or a region, herbs from the same region are most wholesome.”

The fact that it is the particularity of the context that is the overriding consideration and that Sastric (i.e., scientific) principles are to be considered as precepts and guidelines and not applied in a mechanical or legalistic manner is clearly stated in many classical texts. “A Vaidya who comprehends the principles of *Rasa*, etc. would discard treatment if not wholesome to the patient in a given situation, even if it is prescribed in the texts; on the contrary he would adopt treatments that are helpful to the patient, even if they do not find a mention in the texts.”

It is also interesting to note what the texts of *Āyurveda* say about folk knowledge. The ► *Caraka Samhitā* states that “the goatherds, shepherds, cowherds and other forest dwellers know the drugs by name and form. “Similarly, the ► *Suśruta Samhitā* states” one can know about the drugs from the cowherds, tapasvis, hunters, those who live in the forest and those who live by eating roots and tubers.”

This is an overview of Indian knowledge systems and does not go into the details of achievement in a variety of areas, particularly those pertaining to material sciences. Our attempt is to highlight basic characteristics of these knowledge systems, particularly in those respects where they differ from their modern counterparts.

See Also

- [Astronomy: Indian Astronomy in China](#)
- [Mathematics in India](#)

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Knowledge Systems of Aboriginal Australians: Questions and Answers Arising in a Databasing Project

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Why Use a Databasing Project to Tell About an 'Other' Knowledge Tradition Like That of Aboriginal Australians?

There are many reasons for being interested in 'other' peoples and their knowledge. A general or removed interest about 'others' often arises out of curiosity. Satisfying that curiosity can put into perspective our selves, our times and places, our cultures and accepted ways of going on. There are many different ways of knowing. Recognising some differences and similarities between knowledge traditions helps to see the strengths and limitations of our own ways.

Sometimes there are more specific reasons for learning and puzzling about other knowledge traditions. In this article I consider knowledge traditions of Aboriginal Australians comparatively, by referring to a particular contemporary way of 'doing knowledge'. The aim of the project I write out of is to devise some specific forms of databasing that might be useful for Aboriginal people. You can find out more about this project at <http://www.cdu.edu.au/centres/ik/>. This contribution takes the form of questions and answers that are frequently asked about Aboriginal Australian knowledge traditions in the context of such projects.

The databasing project involves the intersection of two quite different knowledge traditions. The intersection 'reveals' both technoscientific knowledge traditions and Aboriginal Australian knowledge traditions. Engagements of various sorts must occur in an Aboriginal digital databasing project, and studying that process is helpful from the point of view of comparatively learning about Aboriginal Australian knowledge traditions.

How Can Asking About Knowledge in the Context of a Databasing Project Help in Understanding Aboriginal Australian Knowledge Traditions in General?

Many Aboriginal communities in northern Australia are interested in using digitising technologies – computers, video and still cameras, audio recorders, and written texts – to generate digital items that can contribute to the various forms of collective memory in Aboriginal communities. Just as in the sciences, collective memory in its various guises is important in using and making knowledge in Aboriginal knowledge traditions.

When it comes to actually doing the work of assembling a collection of digital objects that might be useful to an Aboriginal community however, several aspects of how to do it immediately become problematic. For example, what sorts of things digital objects *are* in an Aboriginal context of knowing turns out to be surprisingly puzzling and difficult to predict. How a database might be organised so that it could be useful to Aboriginal people as they do their knowledge in their own ways, using their own forms and structures, is likewise not at all clear in the beginning. Needing to think through those questions helps to understand knowledge traditions generally, and Aboriginal Australian and technoscientific knowledge traditions in particular.

Why Use the Term 'Knowledge Traditions' Rather than 'Knowledge Systems' When Discussing Databasing of Aboriginal Knowledge?

Both 'systems' and 'traditions' are metaphors, working images of how we understand knowledge using and knowledge making. 'Tradition' comes from the Latin word *tradere*, 'to give'. Traditions emphasises human communities 'doing' their knowledge, giving across generations and to other knowledge communities. 'Systems' come from the ancient Greek term *systema* meaning 'set'. Systems imply a concern with

boundaries and focus on framings and separations. It emphasises the structures of knowledge.

In using traditions I am not denying the importance of structure in knowledge. The practical difficulties that can arise in working disparate knowledge traditions together are often caused by differences in the ways things are framed and structured. In using 'knowledge traditions' I mean to draw attention to the fact that all human communities have complex and varied ways of dealing with such issues in their practices of knowledge using and making. The ways that framings and re-framings are managed when knowledge traditions work together is part of what is at stake in a project like Aboriginal databasing. When we want to compare and contrast knowledge traditions we need to think about and discuss the various sorts of re-framings we need to do so that we can usefully juxtapose knowledge traditions.

What Are the Terms We Can Use in Discussing the Various Sorts of Re-framing We Need to Do So That We Might Compare and Contrast Knowledge Traditions?

In using and making knowledge there are some framings that people are very aware of. There are others that are deeply hidden. For example all knowledge traditions have experts in various fields and disciplines. Access to expert knowledge must be managed. There is 'outer', 'inner' and 'secret' knowledge, and institutional ways of managing access to those levels. The institutional arrangements involved in using and making knowledge express theories about what knowledge is in that knowledge tradition. The social arrangements involved in working a knowledge tradition embody the ways that knowledge is justified as true. 'Epistemic' is the general term we use to name this aspect of knowledge. Discussing and considering the management of these institutionalised structurings and re-framings is epistemology. These terms come from the Greek word for knowledge, *epistēmē*. The *-ology* bit of the term means 'to study'.

There are also divisions and definitions that knowledge users and makers are far less aware of. Becoming sensitive to this level of difference can be crucial in successful working together of disparate knowledge traditions. These structural differences are embedded in language use and in the ordinary generalising we do when we use numbers. Here people are working at the level of assumption; things are usually just taken for granted as people go on together. In working disparate knowledge traditions together people must bring these assumptions and what they take for granted out into the open. Often, especially in the beginning, that is not comfortable. Philosophers name this profound level of framing the ontic (referring to the existing reality) level. Ontology is the study of what there is. 'Ontic' and 'ontology' come from the ancient Greek term *onto-* a form of the verb form *eimi* or 'am' in English, part of the verb 'to be'.

How Do Epistemic Differences Arise When People Try to Work Technosciences and Aboriginal Knowledge Traditions Together?

One of the many reasons for researching Aboriginal databasing is the need to manage epistemic differences that emerge when environmental scientists and Aboriginal land owners try to work together to conserve biodiversity. In northern Australia perhaps the most valuable tool for ecological management is firing the bush. By maintaining a sophisticated regime of firings, a complex mosaic of dynamic ecological successions is achieved. Aborigines have been doing this in Australia for millennia. Science, which has been working with Australian nature for only a little over 200 years, seems to be much less successful at achieving complex dynamic mosaics. And besides, much of the land in northern Australia is owned by Aboriginal Australians who have a right to work their lands according to the standards of their own knowledge traditions.

A firing is judged as a valid and efficacious instance of the knowledge tradition of Aboriginal Australians in several ways. These are epistemic

concerns. Theories of knowledge determine the forms of witnessing and evaluating any instance of applying and engaging knowledge. In Aboriginal knowledge traditions it is most important that particular knowledge authorities participate in specific roles in the planning and execution of the firing. Expressions of knowledge are not valid unless this condition is met.

Firing of any particular place must always begin in a specific spot and proceed in certain ways, through a series of contiguous particular named spots in the landscape. The names of a series of contiguous spots in the landscape must be publicly and collectively recited before a firing begins. The knowledge authorities are those who know which spots are where, and the directions in which the various sequences of names move across the land. In addition it is important that particular items of food are gathered in the process of firing and distributed to appropriate persons in the correct relative amounts. This distribution of various foods collected from the multiple micro-ecological zones that constitute the area fired expands the number of people who can attest a firing episode as legitimate. A particular firing will imply that people are moving through places where it is recognised that particular foods are found. Being able to present the appropriate food items to others is a form of proof that the firing was valid. These institutionalised forms of proof and witness go along with epistemology which sees that true knowledge can only be performed and enacted in place.

These forms of Aboriginal witnessing and evaluating an episode of firing are very different from the ways epistemic concerns are institutionalised in environmental science. There, scientists plan their firings with maps that allow areas to be delineated. They collect observations on the fire and its effects on vegetation and assemble the results in scientific papers that are published, reports that other environmental scientists might read. These reports attest and witness the efficacy of the firing. These forms express an epistemology which understands knowledge as representing an 'out-there' reality.

Nowadays when it comes to managing Australia's northern savannas to promote a robust

biodiversity through firing, there are two incommensurable standards. There are no possibilities for an Aboriginal way of judging a firing to be a valid expression of knowledge to have salience in science. In the same way it is literally inconceivable that scientific validation could legitimate in Aboriginal traditions. The epistemic differences are unresolvable as such.

Yet perhaps digitising technologies can help us get around this problem. It is possible to imagine assembling digital objects during planning, execution and evaluation of firing. Audio files can capture what is said, and still images, movies, and spoken commentaries might also be gathered, along with the foodstuffs, and/or the measurements, as Aborigines and scientists go about their tasks of planning, execution, and witnessing firing episodes.

Imagine storing these digital items in a structure free digital matrix. In databasing terms this implies that there is no distinction between data and metadata. If we want to go further we could imagine two quite differently configured interfaces by which the set of digitised objects might be interrogated. One interface can express the epistemic concerns of science, the other can be configured in a way that embeds the epistemic concerns of Aboriginal Australian knowledge traditions. To do this of course the two sets of epistemic standards must be translated into digital interfaces. In each case, in becoming database interfaces, the epistemic standards take up new forms of institutionalisation. In actuality of course, those sorts of translations require a lot of work and resources.

How Do Ontic Differences Arise When People Try to Work Technosciences and Aboriginal Knowledge Traditions Together?

Different knowledge traditions make very different assumptions about what there is. One set of clues we can get about this level of difference lies in the grammars of different languages. Grammars are deeply embedded in and express the ontic. Another set of clues can be winnowed out

by considering the everyday forms of generalising we find working in a knowledge tradition. We can look at what is involved in using numbers for example. In the case of Aboriginal Australian communities we need to consider the generalising that makes up their very different form of mathematics. You can read about this in my other entry in this encyclopaedia 'The Mathematics of Aboriginal Australia'. Yet another set of clues can be found in the stories that peoples tell about the origins of the worlds they know and the things that comprise it. This is generally called the metaphysics of a knowledge tradition. That is the subject of my next question.

Imagine a scientist watching an old Aboriginal man demonstrating the process of making fire by rubbing two sticks together. The old man has chosen sticks from bushes that look very different. He uses one as a base and cuts a notch in the middle. He uses the other stick like a drill bit. Seating it in the notch he twirls it very fast between his palms. Gradually a pile of hot sawdust accumulates and when it is smoking he tips this smouldering pellet into a nest of shredded bark which when blown on breaks into flame.

Enthusiastic and interested, the scientist asks the names of the two bushes from which the fire making sticks were plucked. It is quite clear to him that the plants are very different – they belong to different biological families. He is genuinely shocked when the old man insists that they are *really* the same. While the old man accepts that the plants might look different, he insists that what is important is that *logically* they are 'the same one'. The old man and the scientist have been confronted with an ontic difference.

Is this ontic difference resolvable? Yes, but only by opportunistically assuming the existence of a third translating domain. This move involves an ontology that is both and neither Aboriginal and scientific. But this is not a meta-ontology. It is not an ontic domain which supervenes and contains the other two. On the contrary, it is an infra-ontology, an inside connection. It takes enough of what matters ontologically to Aborigines when they are dealing with firings, and enough of what matters to scientists when they

are engaged in doing their prescribed burns. Learning how to do this in on-the-ground situations is not easy because it involves working with contradictions in disciplined ways. Particularly for scientists it is difficult, because contradiction is usually outlawed in science.

'Same and different' are constituted through different framings in science and Aboriginal knowledge traditions. It often shocks people when they experience this form of difference. Another similar sort of experience is often associated with differences around 'whole and part'. Recognition of this sort of difference can also emerge when Aborigines and scientists try to learn each others' firing regimes.

Scientists assume that a thing like a habitat is an entity found in nature. While there may be many attributes and characteristics which could be the subject of quite different scientific disciplines – pedology, botany, hydrology – the habitat itself is just a single given object. Many different representations of this given, whole thing might be made, and they tell of the various parts of a single whole thing. The differences between the experiences of the separate groups of scientists are downplayed and backgrounded. This being so, when scientists report their burning of an area, they tell their activities in accordance with the assumption that they are about a single entity. They go to great pains in the introduction and conclusion of their reports to show that all the separate experiences of the scientists really relate to one thing – the habitat under observation.

But when Aborigines report their episodes of burning, they completely fail to attend to the place as a whole. They emphasise and recognise only the diverse involvements of the groups who have variable interests at stake in a collective episode like a firing. The singularity achieved in different kin groups working together in a single purposeful episode is taken for granted background in any reporting. Aborigines do not assume that places exist in the here-and-now as single whole things. Places might achieve a form of ephemeral singularity when a firing or some other such collective activity occurs – if all the correct people are present and things are done in a

correct manner. Those ephemeral unities of actual existence are achieved re-enactments of an originary act of creation by spiritual ancestors.

As scientists see things, reports of firings given by Aborigines fail to attend to the place as a whole. In contrast Aborigines feel that scientists fail to credit properly the multiplicities that inhere in place. This is another instance of ontic difference. It too, with care and caution, can be worked around well enough for Aborigines and scientists to feel confident in going on together.

How Are Aboriginal Accounts of the Origins of Knowledge Different to Technoscientific Understandings of Origins of Knowledge?

As well as issues of epistemology, such as theories of knowledge and truth, and issues of ontology, commitments to particular sorts of things being in the world and issues of metaphysics, such as originary stories, are involved in working disparate knowledge traditions together. The metaphysics of Aboriginal Australian knowledge traditions is very different to that of the technosciences. They have very different accounts of the origins of knowledge.

In Aboriginal Australian traditions knowledge is taken as already always in the land. However, knowledge needs the correct circumstances for true expression. In Aboriginal Australian knowing, there is no given or a priori separation of places and persons who belong to that place. Knowledge is in the land and in people by virtue of their belonging to the land.

The origin of knowledge/place/persons is often named in English as 'The Dreaming'. This is a transcendental time parallel to the secular time of the ordinary here-and-now. From The Dreaming the creative impulse for the world arose and continues to arise. This creative impulse of The Dreaming emerges from the complex collective lives of a multiplicity of beings, both human-like and non-human in form. Entities that can be known in Aboriginal Australian knowledge are framed primarily as here-now expressions of The Dreaming. Knowledge and

the spiritual life of religion are not separate in Aboriginal traditions, so all things have an intrinsic spiritual dimension.

As well as an ultimate division between the eternal Dreaming and the secular here-and-now world of everyday individual experience, there is a subsidiary division between the world's two sides. There is exhaustive division of both the secular domain and The Dreaming, into formal opposites. Amongst the Yolngu Aboriginal clans in northeast Arnhem Land for example, these two sides or moieties are named *Yirritja* and *Dhuwa*. Everything is either *Dhuwa* or *Yirritja*.

Knowledge in the ordinary world of the secular is the outcome of *Dhuwa* Dreaming knowledge and *Yirritja* Dreaming knowledge working together to generate true expressions of The Dreaming. Knowledge in the here-and-now is justified as a true expression of The Dreaming if relevant knowledge authorities of the opposed moieties with interests in the particular set of issues at hand, witness and attest a particular expression of The Dreaming as valid.

In the technosciences, while many practitioners might profess religious belief, Islamic, Buddhist, or Christian for example, these spiritual commitments are not embedded in the forms of technoscientific knowledge. The entities of technoscience do not possess an intrinsic transcendental element. Knowledge of the world is taken as distinct from the world itself. Knowledge is a representation. Knowledge is about the world and the origin of knowledge is the human mind which knows the world. There is some disagreement over whether the ultimate structure of knowledge reflects the structure of the human mind, or the structure of the world. Most philosophers agree that it is some form of combination of both.

In the sciences there is a fundamental division of people as knowers and things (including places) as known about. Things known are matter that extends in space and time and is situated in an empty space-time frame. In a secondary or derived way abstract things like numbers are understood by analogy to primary material things. True knowledge about those material and abstract things is taken as accumulating

through the application of proper scientific method. Knowledge is justified as true if it can be shown to have been produced in valid ways.

Aboriginal Knowledge Is Taken as in the Land Itself. How Can Knowledge Be Stored in the Land and in Databases Too?

How can we understand Aboriginal people when they say 'knowledge is in the land?' How can science learn how to take that claim seriously? The land is a set of sites with meaning embedded, with information there in place. But those meanings, necessarily organised in some way, are accessible only to those who have been sensitised and trained in the right traditions.

One way to think about databasing in an Aboriginal context is to understand a computer as a simplistic and 'outside' version of one of those meaning full sites in land. 'Doing databasing' can contribute to the remembering/forgetting that is inherent in community life, as can 'doing ceremony' which mobilises information embedded in the land.

Databasing can be understood as a way of doing outside collective memory with digitised materials. Images made with digital cameras – video and still, audio files, and written texts typed up on a computer can record something that might be re-presented later in another forum in such a way as to help those involved in some endeavour to remember in a helpful way. Seeing things this way reminds us of the importance of developing some protocols around generation of digital objects.

What Are the Knowledge-Making Sites in Aboriginal Australian Knowledge Traditions? How Are They Similar to or Different from Knowledge-Making Sites in the Technosciences?

Aboriginal knowledge-making centres around ceremonies, some of which might involve firing episodes. In much the same way technoscientific

knowledge-making pivots around the workings of laboratories and field sites. Just as there are many and varied types of laboratories, so too there are many different sorts of ceremonies in Aboriginal life. These are religious ceremonies, but they are not repeated rituals. No two ceremonies are identical in Aboriginal life. Each is concerned with spiritual practice and knowledge making with respect to particular times and places and groups of people.

We can describe scientific knowledge making in laboratories and field sites through elaborating the specific sorts of social institutions involved, the material routines that are crucial in knowledge making, and the literary texts and literacies involved. But to give a complete picture we need also to include the paradigms, theories, or imaginaries in which these processes make sense. These same headings can be used to describe the workings of Aboriginal ceremony and the knowledge making that occurs in them. Just as the entities that emerge from laboratories and field sites remake their worlds, so do the entities that emerge from the ceremonies of Aboriginal Australian life.

Ritual and Ceremony Are Parts of Aboriginal Knowledge. How Can You Recognise the Role of Ritual and Ceremony When Knowledge Is Stored in Databases?

In ritual and ceremony Aboriginal knowledge authorities use many diverse sources of information. In ceremony, dance, painting, song and story need to be performed correctly and under the right auspices to become knowledge making.

Often people see databases as 'archives'. But in this project we are *not* seeing them as tiny digitised museums. We are asking if databasing can become a useful additional experience. Can digitised information feed into, complement and extend the already well-developed ways that information is handled and managed in Aboriginal communities to support Aboriginal people in doing their knowledge? Under what conditions might databasing become a useful form of

managing information? These are empirical questions and Aboriginal people are the ones who must drive the process to come up with answers.

Aborigines Have Local Knowledge but Databases Are Universal. How Is Local Knowledge Consistent with Having Databases?

The notion of databases as somehow universal knowledge assumes two things. First it takes for granted the existence of ‘facts’ – little pieces of knowledge referring to a single reality. And second it assumes that if you could only get enough of them together in one place, facts would eventually link up into one complete system of knowledge. In many traditions of Indigenous knowledge (and in many sciences) both assumptions are seen as wrong.

Anyone who thinks about the notion of universality for very long will see that facts are always generated and ‘made solid’ in specific places and times by particular groups of people. Knowledge is always done in specific ways. It is a commonplace that it is actually very difficult to get things to link up. It is sometimes very difficult actually to link working databases – for example those that have been assembled in doing biodiversity. Data are just as diverse as biological organisms are.

We found this when we started searching for databases in northern Australia that included ‘indigenous knowledge’. A database *is* a form of local knowledge. It is a collection in digitised form of data items that have been generated using very specific local methods.

Of course Aborigines have local knowledge. All knowledge is local. It remains true that sometimes with prodigious collective effort some, or even many, local knowledges can be linked. Sciences often are good at linking up their local knowledges, although sometimes it is very difficult to get different sciences to work together. Sometimes and in some places scientific knowledge and Aboriginal knowledge can be usefully linked.

How Could Elements of Traditional Culture Be Strengthened by Encouraging Aboriginal People to Use Digitising Technologies?

A problem arises if we think of traditional Aboriginal knowledge as ‘anti-modern’, the opposite of modern culture. Then we will begin to think of traditional cultures as stuck in the past and want to put them in a museum and close the exhibit case. Understanding ‘traditional’ in that way, we think of it as somehow inconsistent, perhaps even incompatible, with computers.

Traditional cultures are contemporary forms of life just as modern cultures are. They are rich in modes of innovation as well as having ways for preservation of cultural forms. We can understand traditional cultures as involving non-modern forms of identity. They have ontologies that make modern assumptions about knowledge and knowing look strange. Digitised information arranged in ways that make sense and are useable by those working within non-modern cultures can surely be devised. As long as we do not make assumptions based on modern ways of using digital objects, if we proceed in open ways, empirically researching how indigenous people actually use digitising technologies, there is the possibility of strengthening traditional forms of cultural innovation with computers.

Traditional forms of passing knowledge from an older generation to a younger one often involves young and old being in the same place at the same time doing things together, talking about it. It involves a process of re-imagining it together, finding new forms in which to express the understandings in sharing them.

We often find that indigenous communities want to assemble collections of digitised items for specific reasons. They want to be able to intervene in a specific context in a particular way. Assembling digitised items in these projects becomes a site, a time and place where young and old, with their varying competencies work together. Databasing can become an impetus for young and old to work together in ways that can empower and educate the young while

recognising older people as knowledge authorities.

What About Protecting Intellectual Property? Can Databases Not Easily Lead to Indigenous Peoples Losing Control Over the Natural and Cultural Resources Their Groups Own?

Protecting collective intellectual property is important in all 'closed' knowledge economies. Aboriginal societies are no different from American corporations in this. The issue is one of controlling who knows and how much they know. Strategic revealing and hiding is involved.

Modern companies protect their intellectual property with patent laws, by various technical means, and by selectively authorising and commissioning various knowers. Aboriginal clans have equally effective means of managing the strategic revealing and hiding of intellectual resources.

There are two rather separate elements that need to be considered in thinking about intellectual property and indigenous knowledge with respect to collections of digitised items that point to natural and cultural resources.

The first relates to forms of management for these collections that express indigenous ways of doing intellectual property. Workable ways of respecting different clan ownership of various elements, and recognising differential individual access need to be found. Our stance at this point is to restrict our research to secular contexts. We avoid engaging with knowledge that is sacred and religious. Second, maintaining collections of digitised material in ways that protect the collections appropriately to avoid piracy from outside interests is important.

Can We Articulate Some General Principles for Thinking About Engaging Disparate Knowledge Traditions?

Genuine recognition of difference can be painful. It involves beginning to doubt our own

knowledge traditions as sources of absolute certainty and see them as having limits. Accepting that every knowledge tradition is inherently and systematically partial is challenging. It is sometimes difficult to accept the profound significance of difference and at the same time persevere in learning about 'the other' and in considering how our familiar ways of knowing might engage with other ways of knowing. Very often we approach other knowledge traditions thinking that they are just an odd or unusual version of the ways we know. That is a form of inauthenticity.

The odd aspect of seriously engaging with the other is that in order to recognise difference in knowledge traditions we need to 'make strange' our own. In part that is what I have tried to do in these questions and answers, telling of some of the issues that arise when Aborigines and scientists work together. Beginning to explore how digitising technologies might contribute, I engaged in a process of 'strangification'. I 'made strange' the epistemological assumptions of science, revealing them by setting them alongside another way of 'witnessing' valid expressions of knowledge associated with an alternative account of truth. To make strange our own knowledge traditions we must begin to open up questions of metaphysics.

Eventually we must find ways to do a form of 'experimental metaphysics'. This way we make both sides strange with respect to each other. An experimental metaphysics is a framing of issues of difference that takes elements of both metaphysical systems to develop what we might call an ad hoc hybrid translation borderland. This can help us begin to accept the limits of our own ways of being certain about what we know – our own types of epistemic standards. It can also provide a way to imagine how we might connect in partial, strategic, and opportunistic ways. Some entities that might be usefully linked in partial ways – like Aboriginal firings and the prescribed burns of science can be identified. The on-the-ground activities that enable strategic linking can be identified. Each firing can begin to make some sense in the other knowledge tradition through the use of a metaphysically explicit translating zone.

See Also

- [Environment and Nature: Australian Aboriginal People](#)

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Knowledge Systems of Indigenous America

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First Words

Knowledge is inherent in all things. (Luther Standing Bear, 1933)

Luther Standing Bear's observation that knowledge inheres in all things openly expresses what

many indigenous knowledge systems presuppose and what, by being presupposed, shapes several of their distinctive features. The inherency of knowledge and the inclusiveness of its scope are reflected in what is taken to be primary or fundamental – in what knowledge is held to be knowledge of. They are also reflected in a web of prescriptions and proscriptions that guide the process of knowing. In both respects, indigenous knowledge systems stand in contrast to their counterparts originating within the West (a location more ideological than geographic).

We can only begin with our own assumptions, with what is taken for granted in what follows. And that is that knowledge systems are diverse and their value is contextual. Oppressive relations of power, however, have shaped their histories and continue to inflict the present in ways that obscure or override this diversity. As a result, the existence and value of indigenous knowledge systems, in the Americas and elsewhere, has been systematically denied. In the origin stories of the dominant culture, indigenous peoples have superstitions, myths, or belief systems based on ignorance. They do not have knowledge systems.

These stories no longer have the force they once did. There are two reasons for this. The first is that the dominant knowledge system has begun to falter in ways that are obvious even within the West. While some have seen this as a matter of inadequacy or incompleteness, others believe the problem lies deeper. The second is that indigenous peoples across the planet are presently engaged in various and vigorous projects of recovery: of language and land, of law and sovereignty, and of knowledge and value systems. We will touch only lightly on the first two of these but linger on the third. Indigenous peoples, in the Americas and elsewhere, are intent on restoring and protecting their knowledge systems. And they are using many different approaches and every means available to do this. This story of resistance and recovery is essential to understanding not only the politics of indigenous knowledge systems but also their substance and their vital role in the world.

It is a story we attempt to relate here by drawing on as many different voices as possible, mindful that

writing things up gives authority to a particular view and a particular writer. . . writers are insulated from the discipline imposed on purveyors of knowledge in an oral culture – from the collective analysis and judgment of a community, each of whose members share equal authority to interpret reality. (Castellano, 2000)

Relatedness and the Inherency of Knowledge

In each place they lived, they learned the subtle, but all important, language of relationship. (Cajete, 2000)

If knowledge inheres in all things, it can only properly be educed or drawn forth. So coming to know another entity or process is best approached as an educative process that turns on establishing certain relations with it. Coming to know it well involves strengthening and sustaining those relations. So knowledge within indigenous knowledge systems is always knowledge of relations; it is not individual entities or processes which are primary or basic but the relations that hold between and among them. Indigenous knowledge, Battiste und Henderson (2000) note, is “the expression of the vibrant relationships between the people, their ecosystems, and the other living beings and spirits that share their lands.” Relatedness, or affiliation, is best understood in its primary – genealogical – context. One of its clearest and simplest expressions is in the Lakota invocation *mitakuye oyasin* (“I am related to all that is”). It is reflected as well in the Andean concept of an *ayllu* – a group of related persons, human, and nonhuman who live in a particular place: “*Ayllu* refers not only to relationships between human beings but to the relationship between all members of the *Pacha*. . . they are all relatives and are at once children, parents, and siblings” (Rivera, 1995).

Those seeking knowledge must first elicit, or solicit, then sustain relations with whatever it is they hope to know. As Deloria (1992) states, the “principle of relatedness always remained the

critical interpretive method of understanding phenomena.” Because knowledge is a matter of establishing connections with other entities, or of recognizing bonds that already exist, the process of knowing is dynamic and interactive. Both parties are actively engaged in knowing as well as in being known. Since most things are held to be animate rather than inanimate, they are fully capable of engaging in relationships, of entering into relations with human beings. Knowledge of them is not, as the dominant knowledge system would tend to have it, a unilateral process, the result of an active knowing subject working upon a passive object that is known. Within indigenous knowledge systems, coming to know other entities is always a bilateral and most often a multi-lateral process. This involves and encourages an awareness of interdependency.

Only through interdependence could the human beings survive. Families belonged to clans, and it was by clan that the human being joined with the animal and plant world. Life on the high, arid plateau became viable when the human beings were able to imagine themselves as sisters and brothers to the badger, antelope, clay, yucca, and sun. Not until they could find a viable relationship to the terrain – the physical landscape they found themselves in – could they *emerge*. (Silko, 1996)

Another implication of Standing Bear’s comment that knowledge inheres in all things is that knowledge is not an exclusively human project. Other-than-human entities are capable of knowing, of making, and of maintaining relations; if they were not, we would not be able to know them. Moreover, if alternative ways of knowing the world were not possible for us, the scope of human knowledge would be severely constrained. Indigenous knowledge systems place considerable value and significance on gaining access to the perspective of the other than human. By expanding “our understanding of the sense of being relatives,” Deloria (1992) observes, “We discover that plants, birds, and animals often gave specific information to people.”

Indigenous accounts of knowledge as a process of relating and of acknowledging relatedness, of making connections and sustaining bonds with other entities, allow great latitude in

what can be known and how one comes to know. They embrace “the relational potentiality of all peoples and all creation” (Williams, 1997). Their commitments to epistemological pluralism and nonanthropocentrism, to coming to know the world through perspectives that are diverse and not restricted to that of the human, run counter to those of the dominant knowledge system. They are at odds too with the idea that knowledge requires separating the knower from the known in order to capture the one way the world really is, independently of the human beings who know it. As Momaday (1976) comments, nature is not something apart from the human but the element in which the human exists.

If human beings are in fact inextricably bound up in relations – to one another and to the entities and processes in the natural world – what is vital is understanding those relations, knowing how our behavior threatens them, and how we can best sustain them. Indigenous knowledge systems do not purport to offer knowledge in the sense of universal truth or of accurate accounts of the one way the world really is independent of us. Their virtue is that they enable survival by helping us realize the relatedness, the role, and the contribution which all entities make and how those roles may best be preserved and continued.

Sovereignty, Responsibility, and Respect

Yet within the Aboriginal community, a paradox seemingly exists. In no other place did the individual have more integrity or receive more honor than in the Aboriginal community. The individual’s ability as a unique entity in the group to become what she or he is ultimately meant to be was explicitly recognized. There was explicit recognition of the individual’s right in the collective to experience his or her own life. No one could dictate the path that must be followed (Ermine, 1995).

Indigenous construing of knowledge as relatedness, as a matter of appreciating how we are bound to other entities and processes, makes integration with them possible, desirable, and necessary for survival. Our fates and futures are understood to be conjoined with theirs. Knowing

them commits us to cohering and cohabiting with them. Indigenous knowledge systems enable such coherence, such holding, and such living together. To acknowledge affiliational ties with other entities in the natural and social worlds is to acknowledge that and how our lives are linked together with theirs. Connection or affiliation with them makes survival possible, and because we are so connected our survival can only be mutual. We are allied and responsible for one another.

This leads to an understanding of sovereignty that diverges markedly from those that have prevailed within the West. Sovereignty is held to be relational, rather than absolute; it is conditioned by responsibility and respect. It is also applicable to all entities, human or not. Relations of domination and assimilation have no place within such a concept of sovereignty; self-determination is held to be compatible with, and constrained by, mutual interdependence. The *Gus-Wen-Tah*, the Two Row Wampum Treaty Belt that the Iroquois presented to the United Nations, visually expresses this view of relational sovereignty. According to it, different peoples may be allied and interdependent, yet retain their full distinctiveness and ability to live according to their own laws, customs, and ways: “We shall each travel the river together, side by side, but in our own boat. Neither of us will steer the other’s vessel” (Penner, 1983). The same vision of a relational sovereignty in which power and agency are constrained by responsibility and respect was expressed by a delegate to the United Nations Working Group on Indigenous Populations:

We need to begin to think of self-determination in terms of peoples existing in relationship with each other. . . . [T]he right of a people to self-determination is not a right for peoples to determine their status without consideration of the rights of other peoples with whom they are presently connected and with whom they will continue to be connected in the future. For we must realize that peoples, no less than individuals, exist and thrive only in dialogue with each other. Self-determination necessarily involves engagement with and responsibility to others. . . . (Scott, 1996)

Sovereignty, so construed, is accountable. It enables and endorses collective survival but is inconsistent with domination and assimilation.

Human power and agency are thus limited in fundamental ways by the relationships that bind us to other entities, as Coffey and Tsosie (2001) suggest. Knowledge of other beings involves acknowledgement of them, that is, respect for their role in and responsibilities to the alliances that bind us together. In other words, to know is to value. The processes of knowing and valuing are integrated in indigenous knowledge systems; they mutually inform, and are informed by, one another. This is evident in the fact that one of the primary virtues within indigenous value systems, respect, is as much a cognitive virtue as an ethical one. Knowledge that is not conditioned by respect cannot be had, nor can there be respect in the absence of understanding. Among the Iroquois, respect, or the “wish-to-be-appreciated,” is the “fundamental shared perception – the first principle – of existence. As long as everything is appreciated for what it does and what it shares to sustain the cycles of Creation, the world will be in balance and life will continue” (Barriero, 1992). The Anishinabe concept of *minobimaatisiwin* (the good life) expresses a similar notion. “Implicit in *minobimaatisiwin*,” La Duke (1999) notes, “is a continuous habitation of place, an intimate understanding of the relationship between humans and the ecosystem and of the need to maintain this balance.” It describes “how you live your life according to natural law, how you behave as an individual in relationship with other individuals and in relationship with the land and all the things which are animate on the land” (La Duke, 1997). In this manner, indigenous knowledge systems offer accounts of knowledge “intended to incite humans to act in such ways as to ensure the protection and reproduction of all creatures in the universe” (Holmes, 2000).

Story: Experience and Imagination in Indigenous Knowledge Systems

There is a story connected with every place, every object in the landscape. (Silko, 1996)

Since knowing other entities involves sustaining relations with them that acknowledge mutual

responsibilities and respect, knowledge is so intimately tied to experience and imagination as to be inconceivable without them. Stories are acts of the imagination that enable us to enact and re-enact experience. They do so, typically, by focusing on characters who establish relations with one another and respond to one another in various ways. One source of their richness as pedagogical vehicles is their facility in demonstrating how knowing and valuing implicate, and are implicated in, one another. Another is that they permit us some access to the perspectives of other beings, often those very different from ourselves. We come to know them by relating ourselves to them, by imaging what it is like to be them, and to experience the world – including ourselves – through them.

Stories have long figured as indispensable aspects of indigenous legal and political knowledge practice. As Williams (1997) observes,

Indian diplomats recognized that making connections with others was a most difficult process. Successful treaty-making required the use of great acts of the imagination so that the two sides could come to see themselves as related in their needs and sufferings as fellow human beings. . . this is why a treaty was told as a special kind of story, a way of imagining a world of human solidarity where we regard others as relatives.

The integrative power of stories, the way they help us initiate and maintain relations with others who may appear different from us, is especially needed to guide human interaction with the other-than-human world. Stories are related to convey the behavioral constraints that should guide us if we are to act responsibly and if we are to understand and respect the role of other entities and their unique contribution to the natural world we share. Many different peoples have many different stories about what happens when someone, human or otherwise, violates these constraints.

The significance of stories within indigenous knowledge systems lies as much in the telling as in what is told. The intergenerational transmission of knowledge from elders is both a responsibility and a gift. Stories are only told in the context of particular relationships and are a

means of maintaining and nurturing those relationships. Part of the responsibility of telling stories lies in determining when and to whom they should be told.

Elders often decline to have their words printed or to be videotaped because they insist that what they have to say must be communicated in person. Aboriginal people know that knowledge is power and that power can be used for good or evil. In passing on knowledge, the teacher has an obligation to consider whether the learner is ready to use knowledge responsibly. Teachers who allow these things relinquish the possibility of adjusting their teaching to the maturity of the learner and thereby influencing the ethical use of knowledge (Castellano, 2000).

As vehicles of experience, stories relate empirical knowledge about the relations that connect us to the world and to one another and about how those relations can be well or adversely affected. Such knowledge is the product of careful observations, of spanning generations, of how entities in particular places are interrelated, and of the complex dynamics of their relationships. While it is temporally “deep” or historically replete, it is also spatially located or endemic knowledge – intimately bound to the land, to specific places, and to the entities located there. It is, thus, presentational rather than representational knowledge; its continuation, its transmission, and its possibility turn vitally upon the presence of the natural world and on the kind of experiences that the world offers.

The need to walk on the land in order to know it is a different approach to knowledge than the one-dimensional, literate approach to knowing. Persons schooled in a literate culture are accustomed to having all the context they need to understand a communication embedded in the text before them. Persons taught to use all their senses – to absorb every clue to interpreting a complex dynamic reality – may well smile at the illusion that words alone, stripped of complementary sound and color and texture, can convey meaning adequately (Castellano, 2000).

It is in this sense that knowledge inheres in the world; it is caught up in experience and cannot be extracted from its context. The value of knowledge, so construed, the ultimate test of its validity, “is whether it enhances the capacity of the people to live well” (Castellano, 2000).

The Politics of Knowledge: Resistance and Recovery

If we do not resist, we will not survive. Our resistance will guarantee our children a future. (La Duke, 1997)

Knowledge has not become politicized; it always has been so. Indigenous knowledge systems explicitly recognize this by their responsiveness to the normative aspects of knowledge, to how human power and agency must be constrained if relations of affiliation with other entities are to be acknowledged and maintained – relations that enable our mutual, and multigenerational, survival. Yet the ideology of Western science, wedded as it is to the thesis of value neutrality, insists that issues of power do not enter into knowledge making or shape the dynamics of knowledge systems. The relations of domination and assimilation that characterize imperialism – whether in its historical or contemporary variants – are thus neither acknowledged nor acknowledgeable.

And so the endangered status of indigenous knowledge systems is recognized, but responsibility for it, complicity in it, is denied.

Critical analysis of *why* indigenous knowledge is threatened rarely moves beyond simplistic assertions that “Elders are dying” or the assumption that IK systems are more vulnerable because they are oral. The answers to how and why our knowledge has become threatened lie embedded in the crux of the colonial infrastructure (Simpson, 2004).

With the aid of such depoliticization, and often under the guise of humanitarian concern, powerful Western institutions – corporate, academic, and legal – have joined together to “save” indigenous knowledges by documenting them before they disappear. The disappearance of indigenous peoples, their cultures, and languages, by contrast, is assumed to be inevitable. Thus are the rich contexts that constitute living indigenous knowledges reduced to texts. “Documenting and digitizing Indigenous Knowledge is a seemingly benign way of appearing to recover Traditional Indigenous Knowledge while at the same increasing access to the knowledge and vastly

increasing the potential for its exploitation” (Simpson, 2004).

It is a process that is both extractive and assimilative. What is held to be of value is removed and processed, made over in the image of knowledge as formulated within the dominant knowledge system, by methods which “seek to remove knowledge from the person, its proper place (location), and the process from which it is embedded... its context” (McGregor, 2004). Indigenous agricultural and medicinal knowledge, along with traditional medicines, plant genetic resources, and the cell lines of the peoples themselves, are “discovered,” processed in laboratories, legally transformed into private intellectual property, rendered as commodities, and placed for sale. A pattern that began with indigenous land and tangible resources continues now with indigenous knowledge. The response to these developments from indigenous communities, elders, activists, and scholars has been twofold: (1) a fierce resistance to and critique of such ongoing imperialism coupled with (2) a wide-ranging effort to recover and preserve indigenous knowledge systems and all that they inhere in – language, land, and culture.

The resistance begins with an insistence that this contemporary phase of colonization be recognized for what it is. Since the way in which knowledge is conceived has ethical and political implications, knowledge systems must be assessed in those terms. The tendency to abstract, isolate, and immunize the various “extractive” projects of the dominant knowledge system has been subjected to vigorous critique. Indigenists have insisted on contextualizing recent research initiatives like the Human Genome Diversity Project and the Genographic Project, both historically in terms of the impact of earlier comparable research and currently in terms of how such research is situated within powerful social alignments that perpetuate inequities. They have mounted strong advocacy internationally, within both political and legal fora, for the inclusion of broader human rights standards in scientific research. Individual tribes and tribal members have initiated lawsuits to

protect genetic materials and resources. Throughout these struggles, extraordinarily effective use has been made of modern communication technologies to exchange information, to generate solidarity, and to ensure publicity and exposure. Organizations like the Indigenous Peoples Council on Biocolonialism (IPCB) are representative of these efforts by indigenous peoples across the globe. The IPCB provides educational and technical support “to assist indigenous peoples in the protection of their genetic resources, indigenous knowledge, cultural and human rights from the negative effects of biotechnology” (www.ipcb.org).

Resistance has spawned numerous projects of recovery. In article after article, indigenous scholars and activists speak of “an indigenous renaissance” of how native peoples are “taking control of their destiny,” and of the “revitalization of aboriginal societies.” Evidence for this is plentiful and promising. Consider, for example, the articulation of diverse indigenous research methodologies. Critiques of Western research methodologies, the role of colonialism in shaping these methodologies, and their impact on indigenous peoples have long been a part of the decolonization project of indigenous studies. Since at least the turn of the new millennium, such critiques have been complimented by the development of research methodologies which place indigenous knowledge and value systems at the center of the creation of new knowledge. This work begins with the recognition that “methodology necessarily influences outcomes” and that we have arrived “at a point where it is not only Indigenous knowledges themselves that require attention, but the processes by which Indigenous knowledges are generated. Thus Indigenous methodologies are the next step” (Kovach, 2009).

Evidence of indigenous revitalization also includes a range of initiatives to take control of education through curricular development and the creation of tribally controlled programs and schools. These consist of various measures to restore indigenous languages, such as language immersion programs and Internet classes.

The connection between language preservation and knowledge preservation is often underscored.

Our native language embodies a value system about how we ought to live and relate to each other. It gives a name to relations among kin, to roles and responsibilities among family members, and to ties with the broader clan group. There are no English words for these relationships; if you destroy our languages, you not only break down these relationships, but you also destroy other aspects of our Indian way of life and culture, especially those that describe man's connection with nature, the Great Spirit and the order of things" (Taylor, 1992).

Efforts are also underway to revive spiritual ceremonies and protect the land and ecosystems that sustain indigenous peoples themselves. "The ecologies in which we live are more to us than settings or places; they...do not surround Indigenous peoples; we are an integral part of them and we inherently belong to them" (Battiste & Henderson, 2000).

What is at stake in all of this is more than continued physical existence. "Survival for Indigenous peoples...is an issue of preserving Indigenous knowledge systems in the face of cognitive imperialism. It is a global issue of maintaining Indigenous worldviews, languages and environments...a matter of sustaining spiritual links with the land" (Battiste & Henderson, 2000). Determined to replace the politics of disappearance with the politics of debate and dialogue, indigenous people and communities worldwide are pursuing these and other strategies of resistance and recovery (Shiva, 1993). "Disappeared" knowledge systems are political acts, ones of omission as much as commission, and assumptions that the disappearance of indigenous knowledge systems, languages, and peoples are somehow inevitable often lie behind both. The indigenous response has been that nothing in this is foreordained. It is in our power to prevent further loss.

It was not inevitable that Western knowledge would conquer Indigenous knowledge, or that our ways of life had to end. At any point in history we could have worked jointly toward conditions that would facilitate the return of Indigenous ways of being while appreciating the knowledge that supported those ways. Even now this is not an impossible task. (Wilson, 2004)

Extra 1: Indigenous American Knowledge Transmission

The Varieties of Knowledge Experience

The ability to transmit knowledge from one generation to the next, and from one community to another, might be said to constitute the principal foundation of civilization. Without this capacity none of the many advances achieved by tribal communities over the millennia could have been sustained. Native American tribes, stretching over the last 5,000 years, have numbered in the thousands. This essay constitutes an attempt to summarize a few of the more useful generalizations that have been formulated in relation to the varieties of knowledge experience and transmission in the indigenous Americas.

Native American societies have utilized various forms and technologies of representation and achievement in order to create, execute, preserve, and transmit knowledges of many kinds across time and space. Knowledge-bearing objects, from the near and distant past, are still found embedded in the landscapes of the Americas. Knowledge as embodied in objects, monuments, texts, images, and practices may also be found in great abundance in museum collections of material culture and in the modern lives of Native American peoples, sometimes openly shared with the world and sometimes confined to the kiva or other sacred tribal spaces.

Recent Scholarship

Beginning toward the end of the twentieth century, both native and nonnative scholars in many disciplines provided significant advances in the scholarship and understanding of indigenous knowledge transmission in the pre-Columbian era. These contributions are too numerous to detail in this essay, but three specific examples give a clear indication of how thinking on these questions has changed.

Written Knowledge

Perhaps the most noteworthy contribution to our understanding of indigenous writing in the Americas is found in work arising from a 1991 Dumbarton Oaks conference entitled "Art and

Writing: Recording Knowledge in Pre-Columbian America” (Boone & Mignolo, 1994). By focusing on the structure and technology of writing itself, Elizabeth Hill Boone’s seminal essay (1994) draws us to her remarkable conclusion that “art and writing...are largely the same thing.” To establish her case, Boone focuses on the received idea of a necessary nexus between writing and speech. She shows how this widely accepted connection stems originally from Eurocentric notions of the definition of “true” writing. Even more important is her exposure of the limited and damaging views previously held by large numbers of respected linguists, anthropologists, and epigraphers in relation to indigenous thought and knowledge and “what constitutes the expression of these thoughts and this knowledge.”

What is most alarming about these statements and views is that they are based on harmfully narrow views, and they summarily dismiss the indigenous Western Hemisphere. It is time that we realize that such views are part of a European/Mediterranean bias that has shaped countless conceptions – such as “civilization,” “art,” and the “city” – that were defined according to Old World standards and therefore excluded the non-Western and non-Asian cultures. An expanded epistemological worldview would and should allow all notational systems to be encompassed. If the indigenous American phenomena are to be considered objectively, a broader view is required (Boone, 1994).

The central importance of broadening our understanding of what we mean by “writing” comes from the realization that there exists in the world knowledge that is not readily expressible in long strings of words.

The notion that spoken language is the only system that allows humans to convey any and all thought fails to consider the full range of human experience. Certainly speech may be the most efficient manner of communicating many things, but it is noticeably deficient in conveying ideas of a musical, mathematical, or visual nature, for example (Boone, 1994).

Boone goes on to consider many modes of thought and experience that cannot be fully

comprehended or even effectively expressed by the use of linear languages: choreography, musical and mathematical notation, all of the sciences, maps, charts, diagrams, road signs, and semasiographic systems, both conventional and iconic – and other scholars would include any knowledge in which relationship (especially to land or to other life forms), kinship, implicit values, and nonlinear connectedness loom large. A careful reading of the main entry above (or any other authoritative treatment of indigenous knowledge) will show the many ways indigenous knowledge (of the past, present, and future) depends on nonlinear transmission in place of, or in addition to, the spoken word. This recognition has led to calls for a new “ethnography of writing” (Basso, 1974) to be “extended to put systems grossly different from alphabetic ‘writing’ onto an even heuristic footing with more familiar ones” (Salomon, 2004).

An explicit example of the need to make our ideas of writing more inclusive relates to the pervasive indigenous process of thinking about relatedness and kinship. A recent and indeed highly fruitful turn in anthropological scholarship takes a new look at what indigenous people say about being human in a world in which all life forms, and even the land itself, are intimately interrelated. In such a world, “glaciers listen” (Cruikshank, 2005), “forests think” (Kohn, 2013), and “stones speak” (Tinker, 2004). In a closely related vein, Hall (2011) in a work principally of Western philosophy puts forward the view that “nature is a communion of subjective collaborative beings that organize and experience their own lives.” The meanings these scholars find in the indigenous knowledge under examination are more than metaphorical, but the authors strive to avoid reductionist solutions. New tools are needed to express these timeless meanings.

Finally, based on the writings of M. T. Clanchy, André Leroi-Gourhan, and Jacques Derrida, Boone, in a remarkably prescient passage for 1994, considers the possibility that writing in the sense of a linear inscription of the spoken word is already an outdated concept, likely to disappear rapidly. Directly or indirectly,

this is a reference to the advent of hypertext or hypermedia. By combining Boone's "inclusive" 1994 definition of writing with the various meanings that have been assigned to the notion of hypertext, one can formulate a definition that will apply equally to, say, Maya hieroglyphic writing and to the latest indigenous blog on the Internet. Hypertext is the communication of relatively specific ideas, knowledge, and data in connected associations that a user can make by means of pictures, signs, patterns (as in weaving), alphabetic writing, maps, song, dance, mathematical and scientific notation, and value judgments, always in relation to their interconnections and larger context.

This approach argues against the so-called "evolution of writing systems" notion (Taylor, 1899, Gelb, 1963, DeFrancis, 1989) that posits a hierarchy ranging from pictographs to hieroglyphs to alphabetic writing. Such notions are not only mistaken historically but also perpetuate the damaging idea that indigenous American writing is nothing more than a primitive precursor to European developments. As Walter Mignolo (1989, p. 62) put it, "The history of writing is not an evolutionary process driving toward the alphabet, but rather a series of coevolutionary processes in which different writing systems followed their own transformations." Hypertext, in its honoring of the indigenous focus on relationship and interconnection, is in some respects closer to pre-Columbian indigenous writing than it is to linear alphabetic writing. Whereas the associations of modern hypertext are made possible by the computer, indigenous writing systems brought together pictures, glyphs, dances, songs, and healing rituals through the medium of elders, spiritual leaders, weavers, storytellers, and scribes.

Mayan Hieroglyphic Writing

During the last decade of the twentieth century, great progress was made in our understanding of Native American writing. Michael Coe's and Linda Schele's contributions to deciphering Maya hieroglyphic writings are perhaps the most highly celebrated of these (Coe, 1992; Schele, 1990**). The Mayan writing system

was developed over 2,000 years ago and today is known primarily by four books (or codices), with inscriptions also found on many thousands of objects of material culture, especially stone monuments and stelae found scattered in Mayan cities across Mesoamerica. The story of the decipherment of the hieroglyphs is particularly interesting – as much for what it tells us about European attitudes to native culture as for what it tells directly about the great achievements of Mayan civilization. The first important name we encounter in this regard is Bishop Diego de Landa, infamous as one of the cruelest and most brutal participants in the Spanish Inquisition as it was realized in New Spain (now Mexico). De Landa singlehandedly undertook the destruction of the great majority of existing Mayan books, thus ensuring the loss of much Mayan history, literature, and cultural tradition. The cultural arrogance and lack of appreciation of native culture by de Landa were echoed by European actions across the Americas accounting for the destruction of untold numbers of knowledge-bearing objects and of their associated knowledge.

For several hundred years, the primary question in relation to hieroglyphic inscriptions was whether they were simple pictures or whether they represented a full writing system, enabling speakers to write anything that could be spoken. In the 1930s, the anthropologist Benjamin Lee Whorf argued for the latter interpretation, suggesting that the Maya script was indeed phonetic. These ideas were confirmed by the Soviet anthropologist Yuri Knorozov, working in the fifties and sixties, although most Western anthropologists simply ignored his contributions due to Cold War considerations of the times. Another misconception that was resolved in the middle of the twentieth century had to do with the subject matter of the Mayan inscriptions which most scholars believed to be largely limited to mathematics, astronomy, calendrical arithmetics, and religious beliefs. Because of the early translation of mathematical glyphs, the remarkable accuracy and sophistication of Mayan astronomy and mathematics had been known for some time. But after the publications of Tatiana

Proskouriakoff (1960), many scholars began to suggest that the inscriptions would likely contain social and historical data as well (Chambers, 1965).

Beginning the comprehensive translation of the several Mesoamerican writing systems has proved beyond doubt the breadth of knowledge conveyed by sources upon which this writing is found: not only the stone monuments and four preserved codices and intact ceramics but also smaller fragments of ceramic, shell, bone, textiles, wood, and stone.

Khipu (Quipu) Knowledge Transmission

[Ed. note: See the article on the Quipu in this volume.] The khipu, a knotted-string device “for recording both statistical and narrative information” (Urton, 2003), is best known for its extensive use as an administrative tool in the vast Inka Empire. Long thought to have originated about a thousand years before the rise of the Inka, it now seems likely, based on recent archeological finds in Caral, that its first use may have occurred closer to 5,000 years ago. Furthermore, a growing body of scholarship has shown that the complexity and sophistication of this technological system is far greater than previously assumed. Just as alphabetic systems use a few dozen letters and integers to communicate the entirety of world literature, so might a khipu system (consisting of primary and subsidiary cords, in many colors and patterns of color, with variable types of knots and cords which have been spaced, grouped, and ordered into sets of data) convey far more complex information than the simple numerations which were first assumed by scholars. Indeed, it has been argued that many khipu convey not mathematical information but may actually represent human language (presumably Quechua). If you doubt such a possibility, remember the simplicity of the binary code used by computers for knowledge transmission.

Whatever may be ultimately discovered as to whether this Andean device actually records the spoken word, there can be no question that a significant percentage of the knowledge conveyed was of qualitative rather than quantitative

nature. Not only is this widely accepted among current researchers in the field, but it was also the opinion of the sixteenth-century Spanish chroniclers who were present at a time when khipus were still in active use (Cummins, 1994; Zárate, 1555; Calancha, 1638). Finally, the interpretation of the khipu must be seen in the broader context of Andean weaving and painting traditions, the structures of which also served as a major mode of knowledge transmission and the expression of ideas. Cummins (1994) points out that khipus, weaving, and paintings were all nonlinear representations, “equally abstract, dependent upon form and color as signifying agents.”

The Indians of Peru, before the Spaniards came, had no sort of writing like those of China or Mexico; but in spite of this, they conserved no less the memory of ancient lore, nor did they have any less account of all their affairs of peace, war, and government (Acosta, 1590, translated by Maureen Dyokas in Mignolo, 1994).

To understand the full power of the khipu, it must be considered as a complete and elaborate technological system rather than a single, simple device. The khipu knowledge system consisted of component parts, skills, tasks, processes, objects, structures, and semiotic interactions as well as subsystems to achieve these functionalities. In particular, scribes, accountants, philosophers, teachers, interpreters, archives and archivists, runners (i.e., messengers who must be trained, housed, and fed on the road), and thousands of kilometers of roads and trails: these functionalities have all been described in the literature.

The Spanish never understood that if the Amerindian lacked letters, they (the Spanish) by the same token lacked *khipu* and *amoxltli*. And while the Spanish had men of letters, the Incas had *quipucamayoc* and *amauta* and the Mexica had *tlatlaquilo* and *tlatmatini* (Mignolo, 1994).

Conclusion

Some workers in indigenous studies have followed the lead of other disciplines (such as cultural studies), broadening the theoretical notion of the “text” to include any object of study which has a semiotic or tacit component.

This is perhaps close to Derrida's idea of the "text" (1988, p. 148) as referring to "all structures called real...in short, all possible referents...there is nothing outside the text." An indigenous interpretation of this passage might affirm that all discussion of any knowledge bearing text must include consideration of its relations, its broader context. In this sense, indigenous knowledge may be found in any cultural or natural artifact capable of interpretation. Knowledge and culture are thus transmitted through language, image, implicit relationship, structure, procedure, or performance, or more particularly through story, dance, calendars, maps, architecture, textiles, hunting and farming practice, rock art, trails, spaces, stone placement, and numerous other forms in which knowledge may be fixed, discerned, or performed.

Rosaleen Howard's study (2002) considers the relation of verbal discourse and the ritual *ceque* lines in the Inka landscape especially in relation to the reading of the khipu. "Visible, tactile and emotive, they each embody knowledge, produce history, and harness the memory." In this context, Howard notes that, "Western theory of memory has limited application to the operation and cultural function of memory in Andean practice."

It has been frequently suggested that knowledge transmission devices like, say, storytelling or dance have mnemonic value, reminding the audiences of larger meanings. While this is certainly true, the Western notion of "memory aid" may in some cases trivialize the significance of what might be called "holistic mnemonics" which incorporate many meanings in relation to the past and the present. The multiplicity and complexity of such meanings, whether culturally inscribed or inherent, require that we reconsider not only what is meant by the concept of text, but also what is meant by the concept of literacy (both reading and writing) (Boone & Mignolo, 1994).

One dimension of this approach is the important suggestion that indigenous knowledge traditions cannot be subsumed in particular linear language texts, whether written or spoken, or in single objects, such as a maps, monuments, and

khipu, or in environments, altered and constructed, or in performance, such as agricultural practice or dance.

Knowledge is only fully apprehended by exploring connection, relationship, kinship, and reciprocity. In indigenous America, all knowledge is ecological – a broad range of narratives, local practices, artifacts, and ontologies taken together with their interactions, physical and cultural. This perspective makes clear that the Europeans who invaded the Americas in the fifteenth and sixteenth centuries were functionally illiterate within the cultures they encountered. Precisely speaking, they were blind to the meanings of the texts that surrounded them. On the other hand, the alphabetic literacies of the Europeans were to become a primary instrument of colonial domination, often displacing or completely effacing alternative ways of knowing.

In an important sense, what we call colonialism constitutes an ongoing battle among alternative literacies, not so much between delineated opposites like oral vs. written or pictorial vs. alphabetic or Native Science vs. Western Science. Indigenous knowledges, especially in the modern era, rely on the full panoply of literacies. Their fight now is specifically against the positivism and reductionism of Western Science with its attempt to exclude and devalue indigenous ways of knowing and transmitting authoritative knowledge.

The major issues now to be decided are what do we mean by knowledge, how are knowledges to be established, how can disparate knowledge systems exist together, and how can the varieties of knowledge be authoritatively transmitted?

Extra 2: International Resolutions and Declarations

Over the last quarter century, there has been no shortage of documents, issued by a range of international organizations and conferences, which recognize the intellectual stature and continuing social validity of indigenous modes of thought. These reports, resolutions, and declarations usually emphasize the integrity and value of

traditional knowledge while also attempting to bring indigenous knowledge and modern science into a more productive and, at the same time, more socially equitable, working relationship.

Efforts to achieve such a reconciliation are manifest across a broad spectrum of social practices, such as agriculture, health care, and environmental and resource management, raising important and difficult issues in relation to sustainable development, equity in resource governance, knowledge access and control, intellectual property rights, and the maintenance of biological and cultural diversity.

Such matters have remained a major concern of UNESCO, which has commissioned, over a period of time, a number of reports on knowledge, culture, and development, all of which have taken strong positions opposing past policies of cultural assimilation, policies which have been viewed, almost universally by indigenous peoples, as culturally destructive and even genocidal. The rhetoric and content of these reports can be seen in the brief extracts given below from two major UNESCO documents appearing in 1981 and 1995.

More recent UNESCO declarations have explored forging new links between indigenous knowledge systems and Western technoscientific knowledge. In a 1999 Declaration adopted by the World Conference on Science in Budapest (jointly sponsored by UNESCO and the International Council for Science (ICSU)), this position was developed in some detail. (See extract below).

Such initiatives as that taken at the Budapest conference, while widely welcomed, have generated serious tensions on both sides of the knowledge divide. For example, when the ICSU General Assembly was asked to ratify the above declaration, major doubts were voiced, suggesting that unqualified approbation of indigenous knowledge was likely to encourage the advocates of pseudosciences, like astrology and intelligent design. The GA resolutions then “reaffirmed its support for the values and methods of verifiable science” while recognizing that the “relation between traditional knowledge and modern science is both important and a highly complex political and sociological

question that cannot be addressed in a few lines of a wide ranging document.”

These developments led the ICSU to set up a study group to prepare a report giving the question a more thorough examination. The study group report was issued in 2002 in two different formats both of which strongly reassert the original thrust of the Budapest Declaration, while providing guidelines for distinguishing between indigenous knowledge and the pseudosciences. The study group report also gives limited recognition to the importance of reversing the trend for the “gradual weakening and disappearance of traditional knowledge.” (See below for links to both of these documents).

Finally, it must be noted that these resolutions and declarations have brought few significant benefits to indigenous cultures around the world. Indeed, some scholars have taken the position that such documents, however well-intentioned, have simply expedited the exploitation of these peoples.

UNESCO: Report on Endogenous Development and the Transfer of Knowledge Extracts from: *Domination or Sharing?* (1981)

What sort of transfer of knowledge would it be that had as its purpose or consequence the stifling of the culture of such groups or peoples, that sought to impose uniformity upon them by forcing them to adopt a model or systems devised and developed by an elite or a dominant nation?

This was the failing of colonialism. The danger is the same today... we introduce them to ways of life, techniques and economic imperatives which have the effect of destroying their traditions, imprisoning them in a new state of dependence, preventing them from making their own distinctive contribution.

Thought should be given to the desirability for each country to determine the models, the systems of representations and values and the technical knowledge that have been supplanted by those imposed from abroad. Some ancient practices... are proving essential to further progress. Evidence of this is to be found in such different fields as agriculture, physical education, medicine, art and philosophy... Everywhere the

curtain is being lifted on civilizations which, only yesterday, were still despised by the West. . . . The objective is not merely to preserve the national heritage but . . . the rehabilitation of traditional forms of knowledge and, above all, of the potentialities which have been stifled by the pressure of the dominant countries or groups.

What is the possible starting point for this innovative effort? . . . On the one hand, traditional education transmits knowledge and systems of representations and values that are peculiar to a society or group but does not prepare the ground satisfactorily for the receipt of knowledge from abroad. On the other hand, models of education imported from dominant countries detract, deliberately or otherwise, from everything that has its origin in the basic culture, while encouraging those dominated to seek the particular type of education which, in their eyes, is the only avenue to advancement in the new society. If the transfer of knowledge is to offer any opportunity for endogenous creative activity, it must be fed with resources from within.

UNESCO: World Commission on Culture and Development Extracts from: *Our Creative Diversity* (1995)

Cultural ethnocide is the process whereby a culturally distinct people loses its identity. . . . as the use of its language and social and political institutions, as well as its traditions, art forms, religious practices and cultural values, is restricted. . . . The challenge today for nations committed to cultural pluralism and political democracy, is to develop a setting that ensures that development is integrative. . . . and inclusive. This means respect for value systems, for the traditional knowledge that indigenous people have of their society and environment, and for their institutions in which culture is grounded.

If the communities of the world are to improve their human development options they must first be empowered to define their futures in terms of who they have been, what they are today and what they ultimately want to be. Every community has its roots, its physical and spiritual affiliations reaching back symbolically to the dawn of time, and it must be in a position to honor them.



Knowledge Systems of Indigenous America, Fig. 1 Geometric figures, Tsankawi Cave Dwellings, Bandelier National Monument, New Mexico (Photo by Wade Chambers)



Knowledge Systems of Indigenous America, Fig. 2 Human and elk at Chevelon Canyon, Arizona, USA (Photo by Christopher Angeloni)

It is crucial that a people's understanding of its values, beliefs, and other cultural patterns be developed – in the first place by the people directly concerned.

Through centuries of living close to nature, indigenous peoples throughout the world have acquired detailed knowledge of their environment and its natural resources. . . . Equally, ecological concerns are embedded in their very struggles for survival, identity, autonomy, and in many cases democratic rights and governance. Who decides the fate of tribal culture and nature?

Knowledge Systems of Indigenous America,

Fig. 3 Cosmological panel petroglyph on sandstone, Central Utah, USA (Photo by Christopher Angeloni)



UNESCO: World Conference on Science – Budapest Extracts from: *The Declaration on Science and the Use of Scientific Knowledge*

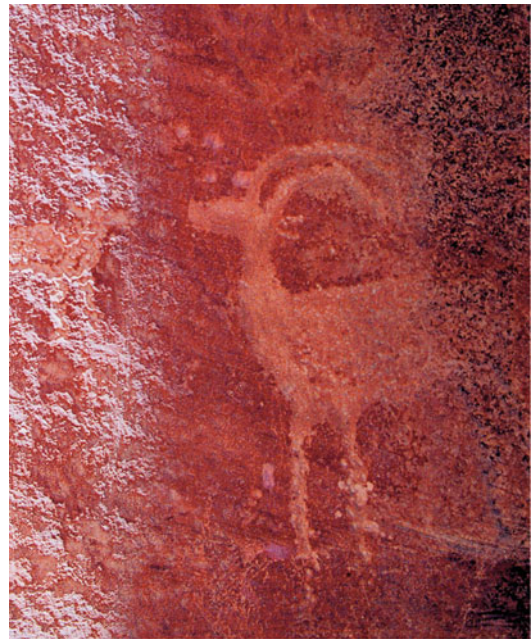
Version adopted by the Conference (1 July 1999)

26. That traditional and local knowledge systems as dynamic expressions of perceiving and understanding the world, can make and historically have made, a valuable contribution to science and technology, and that there is a need to preserve, protect, research, and promote this cultural heritage and empirical knowledge.
38. There is also a need to further develop appropriate national legal frameworks to accommodate the specific requirements of developing countries and traditional knowledge, sources, and products, to ensure their recognition and adequate protection on the basis of the informed consent of the customary or traditional owners of this knowledge.

Extracts from *Science Agenda-Framework for Action*

Version adopted by the Conference (1 July 1999)

- 2.2 Science, environment and sustainable development.



Knowledge Systems of Indigenous America, Fig. 4 Bighorn at Capitol Reef National Monument, Utah, USA (Photo by Christopher Angeloni)

32. Modern scientific knowledge and traditional knowledge should be brought closer together in interdisciplinary projects dealing with the links between culture, environment and development in such areas as the conservation of

Knowledge Systems of Indigenous America,

Fig. 5 Hunting panel on sandstone at Nine Mile Canyon, Utah, USA (Photo by Christopher Angeloni)



biological diversity, management of natural resources, understanding of natural hazards and mitigation of their impact. Local communities and other relevant players should be involved in these projects.

33. Governments, in co-operation with universities and higher education institutions, and with the help of relevant United Nations organizations, should extend and improve education, training and facilities for human resources development in environment-related sciences, utilizing also traditional and local knowledge. Special efforts in this respect are required in developing countries with the co-operation of the international community.

3.4 Modern science and other systems of knowledge

83. Governments are called upon to formulate national policies that allow a wider use of the applications of traditional forms of learning and knowledge, while at the same time ensuring that its commercialization is properly rewarded.
84. Enhanced support for activities at the national and international levels on traditional and local knowledge systems should be considered.
85. Countries should promote better understanding and use of traditional knowledge systems, instead of focusing only on extracting

elements for their perceived utility to the S&T system. Knowledge should flow simultaneously to and from rural communities.

86. Governmental and nongovernmental organizations should sustain traditional knowledge systems through active support to the societies that are keepers and developers of this knowledge, their ways of life, their languages, their social organization and the environments in which they live, and fully recognize the contribution of women as repositories of a large part of traditional knowledge.
87. Governments should support cooperation between holders of traditional knowledge and scientists to explore the relationships between different knowledge systems and to foster interlinkages of mutual benefit.

Local and Indigenous Knowledge Systems (UNESCO LINKS Programme)

Version from Website (May 2014) <http://www.unesco.org/new/en/natural-sciences/priority-areas/links/infocus-links/>

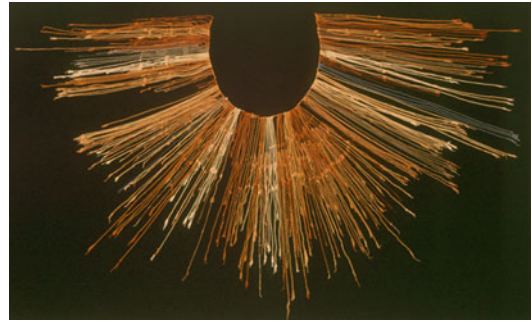
Sophisticated knowledge of the natural world is not confined to science. Societies from all parts of the world possess rich sets of experience, understanding and explanation. Local and indigenous knowledge refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their



Knowledge Systems of Indigenous America, Fig. 6 Sketch of a Quipucamayoc from *El primer nueva corónica y buen gobierno* (*The First New Chronicle and Good Government*), a chronicle of Inca history by the indigenous Inca historian Felipe Guaman Poma de Ayala (ca. 1535–1616). Shown on the lower left side is a yupana

natural surroundings. For rural and indigenous peoples, local knowledge informs decision-making about fundamental aspects of day-to-day life.

This knowledge is integral to a cultural complex that also encompasses language, systems of classification, resource use practices, social interactions, ritual and spirituality. These unique ways of knowing are important facets of the world's cultural diversity, and provide a foundation for locally-appropriate sustainable development. The Local and Indigenous Knowledge Systems (LINKS) program is a UNESCO interdisciplinary initiative that brings together expertise from the Natural Sciences, Social and Human Sciences, Culture, Communication & Information and Education.



Knowledge Systems of Indigenous America, Fig. 7 Inka khipu



Knowledge Systems of Indigenous America, Fig. 8 Inka weaving. From *El primer nueva corónica y buen gobierno* (*The First New Chronicle and Good Government*), a chronicle of Inca history by the indigenous Inca historian Felipe Guaman Poma de Ayala (ca. 1535–1616)

Knowledge Transmission

Education programs provide important tools for human development, but they may also compromise the transmission of indigenous knowledge. With formal education, children spend much time

learning passively in classroom settings, rather than engaged in hands-on learning on the land. Teachers replace parents and elders as the holders of knowledge and authority. National languages become the medium of instruction, while vernacular languages are sidelined. Formal education may therefore contribute to an erosion of cultural diversity, a loss of social cohesion and the alienation and disorientation of indigenous youth. There is an urgent need to enhance the intergenerational transmission of indigenous knowledge, as a complement to mainstream education. Efforts are now being made to bring indigenous language and knowledge into school curricula, and to move learning back into the community, thus reaffirming the status of elders as knowledge holders.

Climate Change

Many small island, rural and indigenous peoples' communities are on the frontlines of climate change. Arctic, high altitude, desert margin and small island communities are observing and experiencing early impacts due to the particular vulnerability of their territories and their reliance upon resource-based livelihoods. Understanding indigenous knowledge of weather, long-term observations of environmental change and community-based strategies for resilience are essential in the face of a changing and increasingly unpredictable climate. They illustrate how indigenous and/or local knowledge contributes to a broader understanding of the changes occurring, as well as the responses required for effective adaptation. Promoting the inclusion of diverse knowledge systems within climate change processes, UNESCO provides decision-makers with an understanding of how indigenous knowledge contributes to assessing climate change, its impacts and the range of options for community adaptation.

Biodiversity

The recognition that local and indigenous people have their own ecological understandings, conservation practices and resource management goals has important implications. It transforms the relationship between biodiversity managers



Knowledge Systems of Indigenous America,
Fig. 9 Maya stone inscription at Tikal

and local communities. While previously they were perceived simply as resource users, indigenous people are now recognized as essential partners in environmental management. However, differences between scientific and indigenous worldviews continue to create barriers to meaningful collaboration, as does the widespread assumption that science is superior to other knowledge systems (Figs. 1, 2, 3, 4, 5, 6, 7, 8, and 9).

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Links to Relevant Websites

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- Alaska Native Knowledge Network: <http://www.ankn.uaf.edu/http://www.ankn.uaf.edu/publications/handbook/integrating.html>
- American Indian IKS Internet Resource Index: <http://www.hanksville.org/NAresources/indices/NAknowledge.html>
- Columbia University CIESIN Agriculture IKS: <http://www.ciesin.org/TG/AG/iksys.html>
- Development Gateway: <http://topics.developmentgateway.org/indigenous?goo=1744>
- Indigenous Environmental Network: <http://www.ienearth.org/>
- Indigenous Knowledge Listserv: http://www.africa.upenn.edu/Listserv/Indigenous_Knowledge_13238.html
- Indigenous Knowledge Management Software: <http://www.archimuse.com/mw2003/papers/hunter/hunter.html>
- Indigenous Knowledge Resources: Americas: http://www.ik-pages.net/browsetree.asp?item_id=002.004.%26allarticles=true
- Indigenous People's Biodiversity Network: Declaration on Biodiversity: <http://www.ecouncil.ac.cr/rio/focus/report/english/ipbn.htm>
- Indigenous Peoples Council on Biocolonialism: http://www.ipcb.org/http://www.ipcb.org/publications/other_art/bsinabs.html
- Indigenous Peoples' Restoration Network: <http://www.ser.org/iprn/default.asp>
- Infography: Indigenous Peoples' Knowledge Systems: <http://www.infography.com/content/620138698080.html>
- Joint ICSU & UNESCO version of Study Group Report: http://www.icsu.org/Gestion/img/ICSU_DOC_DOWNLOAD/65_DD_FILE_Vol4.pdf
- Khipu Database Project: <http://khipukamayug.fas.harvard.edu/Researchers.html>
- Native Eyes Indigenous Studies: <http://www.iaia.edu/nep2/index.php>
- Native Tech Internet Resource: <http://www.nativetech.org/>
- Original ICSU Study Group Report: http://www.icsu.org/2_resourcecentre/RESOURCE_list_base.php4?rub=7

Science and Development Network – Indigenous Knowledge: <http://www.scidev.net/dossiers/index.cfm?fuseaction=dossierfulltext%26Dossier=7>
 Science and Development Network – Intellectual Property: <http://www.scidev.net/dossiers/index.cfm?fuseaction=dossierItem%26Dossier=8>
 Seventh Generation Fund: <http://www.7genfund.org/index.html>
 UNESCO: 1999 Budapest Declaration: http://www.unesco.org/science/wcs/eng/declaration_e.htm
 UNESCO: Indigenous Knowledge: Best Practice: <http://www.unesco.org/most/bpikpub.htm#ik>
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 UNESCO: Science-Agenda Framework for Action: <http://www.unesco.org/science/wcs/eng/framework.htm>

Knowledge Systems of the Incas

R. Tom Zuidema

On the 14th of November, 1533, Francisco Pizarro and a small Spanish army entered the town of Cajamarca. On the next day they took Atahualpa, the last Inca king, prisoner after he had come to their encounter with a large army. It was the first and the last time that the Spaniards received a glimpse of the independent Inca state which had conquered an empire into southern Colombia and northern Argentina and Chile. Perhaps the empire had already been weakened by the civil war that Atahualpa had won over his brother Huascar, the crowned king. While in prison, Atahualpa had Huascar killed, and after some months in Cajamarca the Spaniards executed Atahualpa. But more than these events, it was the possession of superior arms, including horses, and the help of native troops choosing their side, that allowed the Spanish army to cross the country almost without resistance and to enter the capital of Cuzco a year later. Here they set up Manco Inca as a puppet king. Less than 2 years later Manco Inca fled Cuzco and withdrew to the eastern slopes of the Andean mountains where heavy forest made it difficult to defeat him and his successors. In 1572,

36 years later, the last Inca king, Tupac Amaru, was captured and executed in Cuzco. It was the end of Inca resistance, and the viceroy Francisco de Toledo could consolidate a colonial government that ruled until the early nineteenth century when the Andean countries of Colombia, Ecuador, Peru, Bolivia, Argentina, and Chile declared their independence.

Some of the first Spaniards that described their participation in the conquest of the Inca empire included in their accounts valuable information about its people. But only after some 20 years did the first chronicles appear, by Juan de Betanzos [1551] (Square brackets after the name of an old author indicate the date of writing or of first publication), one of the first Spaniards to learn the Inca language of Quechua well, and Pedro Cieza de Leon [1551]. These give an integrated view of Inca culture, referring to aspects of history, social and political organization, agriculture and husbandry, and religion. Although much of this information derived from the memory of Inca nobles in Cuzco, it was not based on direct observation of a thriving culture with all its rituals and feasts. Moreover, Andean civilization never developed a system of writing, recognized by the chroniclers as such, through which we would be able to hear the independent voices of its peoples on what they thought about their cosmos, their gods and goddesses, and their myths and rituals, without being directed by the questions of representatives (administrators, lawyers, priests) of Spanish domination. Almost all the documentation needed for Inca administration was recorded on knotted cords with numerical information organized in bundles, called *quipus*. Hundreds of these *quipus* have been found in graves on the desert coast of Peru. Most are from Inca times but some are from the earlier Wari culture, demonstrating a different system of knots and chords. We can study the sophistication of Inca mathematics, analyze some of the information, mostly on bureaucratic and economic but also on ritual matters, as released by *quipu* specialists through Spanish prodding, and be aware of additional information on the Inca past and culture memorized by the specialists. But most of this research is still in its infancy (Ascher, 1981).

Other promising sources of information on Inca culture are the many textiles that survived in coastal graves, were conserved in heirlooms from colonial times, and were represented in colonial art. The Incas inherited sophisticated techniques of weaving from earlier cultures, but the style of their art was very much their own. Certain types of male tunics show highly standardized geometric patterns. Others include a wide variety of square designs, *tucapus* that in their distribution as possible signs with meaning are reminiscent of a writing system, although only for a few *tucapus* are there clues to their interpretation. None the less, a careful comparison with written sources on the use and iconography of Inca textiles can help us to establish this art as an independent, pre-Hispanic source of documents on aspects of Inca culture.

The colonial chroniclers provide us with the only written knowledge of Andean culture at the time of the Spanish conquest. Beginning with Betanzos and Cieza, they organize their material in a historical framework. Thus they tell how Manco Capac, the first Inca king, came out of a cave some 50 km south of Cuzco with three brothers and four sisters and founded the future capital. At the time of his writing, the conquered people in the valley of Cuzco still remembered their pre-Inca past. From here the Incas first conquered surrounding valleys and gave their kingdom an administrative structure recognizing the old local lords as lower-ranked members of their own nobility. This nobility consisted of different ranks defined according to criteria of kinship to the reigning king and queen; thus the local lords were defined by the chroniclers as "Incas by privilege". Like the Inca nobility, they themselves were exempt from contributing labor to Cuzco but their subjects were not. Moreover, they and their subjects participated in the ritual organization of the town. From this base the empire was conquered.

When the Spaniards were still in Cajamarca, they had some inkling about the enormous extent of the Inca empire but no idea how it was obtained and who had been the successive conquerors. On their arrival in Cuzco, they reconstructed the last two royal successions

before the Spanish conquest. Twenty years later a certain consensus was arrived at of the earlier dynasty. But as this list of kings was not based on historical records, its reconstruction conformed more to a pattern of western than of indigenous ideas about royalty, succession, conquest, and history. One of the most arduous tasks of research deals therefore with the questions of evaluating how the Spaniards reconstructed the conquest of the Inca empire, how their Inca informants presented this conquest to them, and how the conquered peoples, especially those outside the original kingdom, understood how this Inca domination had occurred.

Betanzos, Cieza, and others after them, especially Pedro Sarmiento de Gamboa [1572], placed as the central person in the epic of Inca conquests the ninth king, called Pachacuti Inca. Cuzco had been attacked by the kingdom of the Chancas during the reign of his father, Viracocha Inca. As the latter fled from town, Pachacuti Inca defeated the enemies and was crowned king even though he had not been designated as crown prince. He rebuilt the city, reorganized the people who lived in its valley, elevating in rank those who had helped him in the defense and lowering others, and he established different institutions of government. Thus he divided the valley into districts based on the system of agricultural irrigation; he organized a system of worship of those ancestral mummies that he decided to recognize as such; he assigned administrative posts to relatives and other nobles; and he established the calendar of state celebrations.

The story of Pachacuti Inca has all the characteristics of a foundation myth and with its help we can get an understanding of how the histories of the Incas before and after this king were constructed in colonial times. Memories of earlier times were organized according to the ancestral system, wherein a ranking order of mummies was used to establish a dynastic order. But the dynastic sequence after Pachacuti Inca cannot be taken without critical examination either. The many conquests of the Inca empire toward Colombia and Chile and Argentina were said to be accomplished mostly by Pachacuti Inca's son, Tupa Yupanqui, and grandson, Huayna Capac.

(The latter died some 7 years before the Spaniards arrived). But the Inca informants to Spanish questioning recognized that some rulers after Pachacuti Inca had been suppressed from the official list of kings. Thus it is very possible that the history of Inca conquest was not as short as suggested. Here the memories of the conquered peoples can help us to arrive at a more realistic picture of Andean history.

Intensive documentary research beginning some 50 years ago on various local kingdoms integrated into the Inca empire allows us to get some idea of their cultural and institutional differences and their ties to earlier peoples whose art and archaeology we study. Perhaps the most important kingdoms that the Incas conquered were those of the Chimú on the north coast of Peru and around Lake Titicaca. All had had a prestigious history of their own. The Chimú had built a kingdom along the coast from about the valley of Lima to near the present-day border of Peru with Ecuador. Their capital of Chanchán had been the largest city in South America. They were the descendants of the Mochica people (ca. AD 0-700) whose pottery with realistic painted scenes established one of the high points of Andean arts. The Chimú are the only kingdom on which we have some dynastic information from before the Spanish and even Incaic conquests. Recently, much work has been accomplished reconstructing their culture and political organization (Moseley & Cordy-Collins, 1990).

Around Lake Titicaca the cultures of Pucara (ca. 200 BCE-AD 400), north of the lake, and Tiahuanaco (ca. AD 200-900) south of it once flourished. The impressive stone ruins of their ceremonial centers played an important role in Inca mythology. Chroniclers constructed the myth of a creator god coming from Lake Titicaca or Tiahuanaco, called Tunupa, around the lake and Viracocha in Cuzco. In the sixteenth century three different languages were spoken: Aymara that extended to the west of Cuzco and near Lima, Puquina, and Uru. Puquina was probably the most important language at the time of Tiahuanaco, and Uru may have been there and in the high plains of Bolivia even earlier. But since colonial times Uru was retained mostly by people

with a fishing and hunting economy, and Puquina died out. Today, Aymara is mostly spoken by people living south and east of Lake Titicaca.

Most of our historical information on Aymara culture derives from colonial administrative documents. Among these are, however, two of the most important ones for research on local government and economic organization in the Andes at the time of Spanish conquest. The first, from 1567, describes the former kingdom of the Lupaca south of Lake Titicaca. Its economy was based not only on highland crops grown there but also on crops from distant valleys down on the Pacific coast. Instead of obtaining these lowland crops through trade it had sent its own people to grow them. The second document, from 1568 to 1570, concerns a former kingdom north of the lake; here cultivation of coca in the lower valleys east of the Andes had been important.

In conquering Chimú and Lake Titicaca, the Incas had concentrated their rule near former centers of power. In other cases they established new provincial capitals away from such centers. The most important and best researched example of this kind is the city of Huanucopampa in central Peru near the eastern slopes of the Andes. It formed part of a chain of provincial capitals going north from Cuzco, including Vilcas Huaman, Bombon, Huanucopampa, Cajamarca, Tumibamba (present day Cuenca in Ecuador) and Quito. Huanucopampa was perhaps the largest of all. It is also best preserved, as its location on a high plateau did not attract later Spanish settlement. Huanucopampa expresses in an admirable way the basic ideas of Inca town planning. Around a huge rectangular plaza the four quarters of town were organized, each with its own pattern of social activities. In the center of the plaza stood the Ushnu. Chroniclers describe the Ushnu in the plaza of Inca towns as a platform or pyramid near a small round structure of stone where offerings of corn beer were pledged to the Sun god, the ancestors, and the forces of the underworld. Cuzco had such a ritual complex but the platform was probably a temporary structure used only during special feasts. But in Huanucopampa the large platform was built of stone and could have served also during military parades. On the east

side of the plaza and aligned with the Ushnu stood the palace of the Inca governor. The king probably resided here when passing through town. It contained three courtyards, as one chronicler also describes for a royal palace in Cuzco. Thus we can assume that Inca and non-Inca subjects could enter the first and largest courtyard, that only nobility entered the second courtyard, and that the family of the governor or the king had exclusive access to the third and smallest courtyard to which were attached their living quarters. There was a straight road leading from the plaza to the inner court and the various gates through which visitors had to pass still stand, each crowned by two stone lions facing one another like on the lion gate of Mycenae. Above the town, on its outskirts, can still be seen the hundreds of storehouses for the tribute brought by the people of the province of Huanucopampa. Two extensive documents from 1562 describe in detail the demographic composition of this province and the contributions that its villages had to make to the state. Huanucopampa and its province have provided us with the best opportunity for research on the organization of an Inca province and its economy.

Many documents now being studied allow us to reconstruct the local sociopolitical situations in Inca times. Regular forms of organization, like those consisting of moieties and of three or four local groups, reveal patterns of regional variation which have survived in many places. Although the social functions of these organizations may have changed after almost half a millennium, they retain their ritual importance. A form of state organization that could be combined with the ones already mentioned consisted of bringing together families in numbers of 10, 50, 100, 500, 1,000, 5,000, 10,000, and finally 40,000, the latter number expressing an ideal way of organizing an Inca province. In a similar way, the population of Cuzco itself consisted of ten *panacas* and ten *ayllus*, the first referring to the relatives of the king who administered these groups. *Panacas* and *ayllus* played a crucial role in the calendrical rituals of the capital.

With the Inca conquests of the empire, the administrative model of Cuzco was replicated in

the organization of the whole empire. For instance, the four quarters of town, the *suyus*, were extended into the four provinces of the empire. Inca nobles and lords of the Incas-by-privilege became imperial administrators (*tucricuc*) supervising local lords (*curacas*) who themselves governed their territories like the king in Cuzco. But *curacas*, or their representatives or sons, also had to visit Cuzco. Periods of 4 months' or a year's residence in town are mentioned, but we do not know how regularly they were repeated. A specially important time for such visits was after harvest, when lords came with their tribute and presents for the Inca king. He consulted with them about their governments and discovered who did not want to comply with his obligations. Presents that the king received from one province were awarded by him to the lords of another.

Of particular interest is the imperial (re-) organization of the *acllas*, the "chosen ones." Girls were selected in local organizations according to set criteria of beauty and assigned tasks, like weaving and making corn beer, in houses built for that purpose. From there they could be reselected and sent to provincial capitals and even to Cuzco. Their organization touched on almost all aspects of Inca culture. Ranking was expressed in an idiom of age-classes, and these applied also to men from their time of initiation and marriage to the time that they turned over their social obligations to their sons. Some *acllas* were married off by their *curaca*, an Inca governor or the king, either as a principal or as a secondary wife, or were dedicated to a role in Inca religion. When, with the Spanish conquest this organization fell apart, one way *acllas* were dealt with was by converting them to nuns. But their roles were not really comparable to those of nuns, because this female organization with the queen at its head in most respects paralleled the male hierarchy. The concept of *aclla* also played a central role in the imperial organization of sacrifice, the *capac hucha*, as this practice had grown out of the calendrical organization of local rituals in Cuzco. Children were selected as *acllas* and dedicated to various but always specifically recorded purposes. Thus they were sacrificed,

including couples of a boy and a girl. In their own locality, sacrifice might be for the purpose for obtaining good pottery clay. In far-away places sacrifices commemorated important events, such as winning a battle. In Cuzco it was part of a great state ritual, either for the time of planting, of the December solstice or of the harvest. *Accha* sacrifice was the culminating act in an organization of rituals that crystallized the cosmological values of Inca government.

Inca religion forms an integral part of Andean religion in general as observed in various parts of the empire. Because of the importance of Cuzco as imperial capital and the intellectual interest of the Spanish in its history, we are also well-informed about Inca religion. However, for reasons of colonial history we also have extensive accounts of myths, rituals, and religion in the mountain provinces of Huarochiri and Cajatambo, central Peru, where in the early seventeenth century the Spaniards believed they observed a resurgence of indigenous beliefs that they tried to eradicate. While the original belief systems in Cuzco and the two other provinces may not have been that wide apart, the circumstances of their recording were very different. Chroniclers in Cuzco, among whom there were well-educated people, came to the Inca past through their own curiosity and were informed by Inca nobles. Initially, both parties may have looked for a common intellectual basis. However, the religious expressions in Huarochiri and Cajatambo were seen as a rebellious return to pagan beliefs in villages after more than 80 years of teaching that Christianity was the only true religion. I will deal here with the problem of studying Inca religion, although many myths and rituals may have been recorded in Huarochiri and Cajatambo in a form closer to pre-Hispanic reality.

Unlike the situation of extensive pantheons in Aztec and Maya religions and of illustrations of gods, goddesses, and priests dressed as such in pre-Hispanic and early colonial codices and chronicles, the Spaniards described only a few gods and goddesses for the Incas, and even those were not visualized in any way in Inca art. Nevertheless, documents and chronicles are

replete with names of sacred places in the form of mountains and rocks, lakes and springs, and all other kinds of natural and man-made objects with ritual significance. Foremost were three male gods, the Sun, the Thunder, and Viracocha and one female god, Pachamama, the “mother earth.” The ruling king was considered to be the son of the Sun, but from Cuzco we have no mythical description of the latter’s actions. The Thunder god was seen in various parts of the country as an active mountain god, but in Cuzco only indirect references to his deeds occur. The god Viracocha seems to have corresponded to a type of mythical figure, known elsewhere in the Andes under various names. The myth of the god Coniraya in Huarochiri, there compared to Viracocha, has perhaps best preserved this pre-Hispanic image. He pursues a woman along a river down to the Pacific Ocean. Here she escapes as he cannot follow her any further. Along the way and through various acts that present him as a trickster, he defines the interests of people in their land for cultivation, water for irrigation, and wild animals for use in rituals. An original way of representing Viracocha in Cuzco, although found in a late chronicle, is as a force of nature, a giant, who during a month of heavy rain comes down the Villcanota river near Cuzco, flowing from the southeast to the northwest, threatening to destroy it. But Betanzos and Cieza describe Viracocha as a god who brought forth from the island of Titicaca (the rock of the cat), in the lake of the same name southeast of Cuzco, the sun, the moon and the ancestors of different peoples. Viracocha sends these underground to their local places of origin, from where they reemerge to establish local government. Viracocha himself also travels northwest, following the Villcanota river near Cuzco, but continues until he arrives at the sea in Ecuador. There he disappears, not into the sea but over it toward the horizon. This version of the myth was well adapted to the imperial interests of the Incas and may have also received a colonial reinterpretation because of the Spanish interests of including Peru in a universal empire. Soon the exploits of Viracocha were also phrased in terms of those of two early apostles, Saint Bartholomew or Saint Thomas, who had been

said to have traveled through the country bringing Christianity long before the Spaniards did. According to this colonial reinterpretation, Viracocha was the creator god of the Incas. But his mythology became embedded also, in fragmentary form like that of other gods, in the legendary history of kings. Stories were told of the eighth king, Viracocha Inca, that were more fitting for his namesake the god Viracocha, and in a similar vein his son Pachacuti Inca was associated with the Thunder god. In fact, one chronicler recognizes these relationships as such when he says that each king took as his name of nobility that of his god. Pachamama was the great goddess of the earth, but again no stories of her exploits are told. The myths of some Inca queens are more interesting, considered in their roles as ancestral deities. Probably, the attention to Pachamama was mostly developed in early colonial times.

Of more immediate interest for the study of Andean religion are the numerous sacred places, the huacas, mentioned in various local documents. Sometimes myths are told about them as actors like humans. Two indigenous chroniclers from the early seventeenth century give us extensive hierarchies of huacas of more than local importance, although our sources tell us little about their possible organization. In about 1560, however, the Spaniards had become aware that in Cuzco the cult of the huacas was organized according to a highly sophisticated scheme of directions as seen from the temple of the Sun in the town. Families each took care of the cult of a particular huaca and larger social groups were associated with the huacas along one direction, the ceque, or with groups of ceques. The organization of the ceques served various social purposes. For instance, the topographical description of the valley was of interest for land distribution in agriculture, irrigation, husbandry, and mining, especially in terms of quarries of stone used for building purposes. Through the ceque system a formal description can be given of Cuzco's political organization including its calendrical organization of state rituals as defined in terms of its system of astronomical observation. Polo de Ondegardo, the chronicler who discovered the

ceque system in Cuzco, mentions that other villages, towns, and provinces of southern Peru and Bolivia also had their ceque systems. Some interregional ceques are described, of use in the imperial system of capac hucha sacrifice that suggests a hierarchy and network of ceque systems. Ceque systems were recorded on quipus. They supported an Andean way of reflecting in an abstract way on cultural values.

Andean civilization did not direct its interests toward the use of writing like Mesoamerican civilization did. Thus the intellectual aspects of Inca culture are difficult to grasp. But so much can still be studied of early Andean practices through those of their descendants, as in techniques of agriculture and weaving that it will become possible to define the originality of Andean civilization.

See Also

- [Calendars in South America](#)
- [City Planning: Inca City Planning](#)
- [Irrigation in South America](#)
- [Mummies in South America](#)
- [Quipu](#)
- [Stonemasonry of the Incas](#)
- [Textiles in South America](#)
- [Time](#)

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Knowledge Systems of the Olmec, Fig. 1 Olmec “Jade” mask from Arroyo Pesquero, University of Veracruz Museum of Anthropology (Author photo)

Knowledge Systems of the Olmec

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People in Formative Period Mesoamerica (2000–250 BCE) developed an array of empirical knowledge and technological adaptations that became the foundation for the later great civilizations. These included domesticated plants, skilled ceramic production, lithic technologies, and long-distance travel and trade.

This essay will focus on the little-studied topic of Olmec knowledge of the human body. It uses as evidence the hundreds of Olmec three-dimensional sculptures of the human figure in stone and clay (Fig. 1). Apparently the Olmec recorded their empirical observations about the process of human gestation and about the innate energies of the adult human body in many kinds of sculptures (Fig. 2). The practice of encoding knowledge and lore in sculpture characterizes all Mesoamerican cultures. It is documented for the



Knowledge Systems of the Olmec, Fig. 2 Fetus figurine found in a bowl containing cinnabar. Alabaster. Private Collection, drawing by Corey Escoto

sixteenth-century Yucatec Maya, whose word “its” refers to art not as a category of objects made to be admired, but the related knowledges of science, art, philosophy, and wisdom.

Between 1000 and 400 BCE, Mesoamericans made small stone figurines that could be transported across linguistic zones to convey the new knowledge. By 900 BCE, the subjects of these sculptures and of the incised symbol system were quite consistent in cultures across southern Mesoamerica. Most of the sculptures portrayed human beings, and some of these showed humans in specific stages and states of being. Many sculptures illustrated Olmec knowledge of human gestation, bodily organs, and mental disciplines of the body. Because the sculptures and the knowledge they encoded were linked to ritual practice, we might consider the sculptures as illustrations of spiritual technologies. However, Olmec knowledge of gestation and the disciplines of the human body also informed agriculture, and calendrics, and was part of a long-distance trade technology.

The name “Olmec” was given in the early twentieth century to the inhabitants of ancient Mexican Gulf Coast civic centers such as La Venta and Tres Zapotes. At that time, little evidence of the Formative Period existed, and many scholars assumed that most early culture traits originated in the Gulf Coast region. Since then archaeologists have shown that nascent civilizations in Central Mexico, Highland Oaxaca, the Pacific Coast, Guerrero, and the Gulf Coast all contributed to an ideological system that coalesced by the Middle Formative. This article follows the (debatable) convention of referring to all the groups who participated to some extent in this ideological system as “Olmec.”

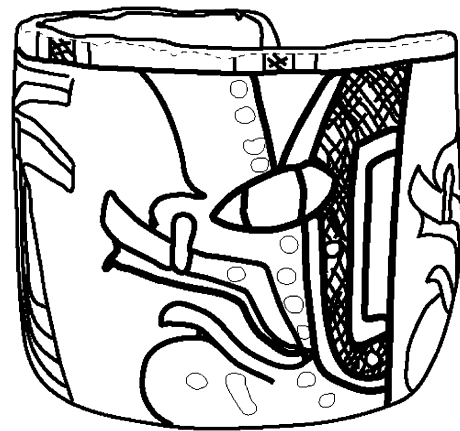
By no means did ALL Olmec sculptures portray these scientific subjects. Many sculptures showed humans as a part of creation stories or engaged in political events (Fig. 3). However, a significant number of monumental and small sculptures displayed Olmec knowledge of life processes, beginning with gestation.

The Human Embryo

Recent research strongly suggests that a human embryo image formed part of the earliest



Knowledge Systems of the Olmec, Fig. 3 Monument 1 of San Martin Pajapan. Portrays a ruler in part of creation narrative, in the act of “raising the world tree” (Reilly, 1994). On the headdress is an embryo plaque (Drawing by corey Escoto)



Knowledge Systems of the Olmec, Fig. 4 An early form of the stylized embryo image on a ceramic vessel from Tlapacoya, a village in the Basin of Mexico. About 1200 BCE (Drawing by Corey Escoto)

symbol system of Mesoamerica. A figurine from Oaxaca (made in the Tierras Largas Phase, about 1400 BCE, at the cusp of the appearance of “Olmec” traits in Mesoamerica)

portrayed a human female with a fetus enclosed in a cavity in the abdomen (Marcus, 1998). In the Basin of Mexico around 1200 BCE, villagers created a stylized image of the human embryo at about 48–56 days of gestation (Fig. 4). Within the next 300 years, many groups throughout Mesoamerica forged, shared, and adapted an ideological system, or a set of interconnected concepts and metaphors.



Knowledge Systems of the Olmec, Fig. 5 A greenstone headdress ornament of the embryo face adorned with a headband (Private collection, drawing by Corey Escoto)

To show alliance to these concepts and the supernatural and meta-environmental powers they indexed, men wore images of the human embryo in greenstone (Fig. 5). This kind of exotic, elite regalia evoked powers of creation, vital energy, and the dawn of life. The “embryo” symbol was one of the most widespread characteristics of the “Olmec” civilization. Earlier in the twentieth century, scholars referred to the symbol as “were-jaguar,” “were-snake,” or “were-crocodile.” The interpretation of it as “embryo” remains controversial (see Extra).

The Human Fetus

The argument that the Olmec focused on the human embryo as a major symbol of vital spirit is strengthened by the fact that they also made sculptures of the human fetus (Fig. 6). About 50 such sculptures are known, many from the Gulf Coast. One small fetus figurine was excavated, along with an embryo figurine and two of children, from La Venta, which demonstrates that the fetus was a legitimate subject of sculpture (not the invention of modern forgers). Also, three colossal fetus sculptures were found at La Venta in the 1940s and recently installed at the site museum. Fetus sculptures have the disproportionately large head and flexed limbs of a human fetus. They must have been modeled on fetuses that aborted, yet all are portrayed alive. Their meaning is less clear, but

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Knowledge Systems of the Olmec, Fig. 6 Olmec sculptures of the human fetus (Author drawing)





Knowledge Systems of the Olmec, Fig. 7 Hollow sculptures of human infants, in the National Museum of Anthropology, Mexico (Author photo)

I suspect that they were considered to be intermediaries between the world of humans and that of the supernatural life forces.

The Human Infant

Olmec exploration of the human gestation process continued with representations of infants (Fig. 7). These most often appear in the form of large, sometimes life-sized, hollow ceramic figurines. The proportions and faces of some of these figures seem older than infants, so the significance of the hollow figures seems to vary. Nevertheless, they seem to have celebrated the rapid growth and vitality of infants as well as an acknowledgment of the precariousness of human life in its early years. Just as many communities today carry statues of specific saints into the agricultural fields to bless and promote the fertility of the crops, these hollow babies may have brought their vital energy to ancient crops (Fig. 8).



Knowledge Systems of the Olmec, Fig. 8 This embryo sculpture and canoe of “matching” jadeite were found together at Cerro de las Mesas. The excavator, Drucker (1955), noticed that the figurine “fit” into the canoe. On each end of the canoe is an incised embryo symbol (Drawing by Corey Escoto)

Human Gestation and the 260-Day Calendar

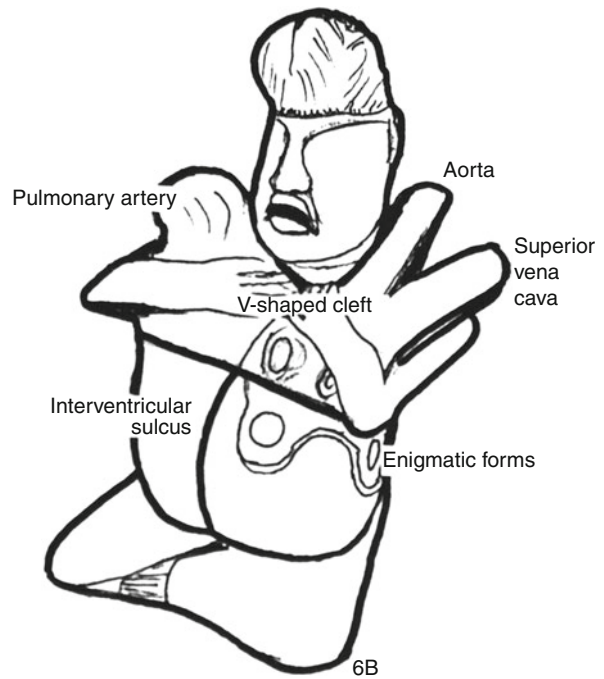
The ancient focus on human gestation explains the priority of the 260-day calendar in Mesoamerican ideology, and ties ancient knowledge of lunar cycles ($9 \times 29 = 261$) to menstruation and gestation. The 260-day calendar seems to have been established in Oaxaca (where the earliest known figurine of a woman with a fetus in an abdominal cavity occurred), well before the existence of the ► [Long Count](#). It continued to serve as a divinatory calendar, primarily consulted by female clients, into the sixteenth century and even later. Many Mesoamerican groups considered the life cycle of maize to be 260 days, like the gestation of humans, despite the fact that from the Western point of view, it is shorter. Rituals conducted before the planting of maize and after its harvest extended the life of maize to parallel the period of human gestation. The Maya believed that humans were made of maize. “Humans are maize” was a major operative metaphor of many Mesoamerican cultures.

Olmec Art as Medical Illustration

Not only did the Olmec illustrate the processes of embryogenesis and human infancy, they also

Knowledge Systems of the Olmec, Fig. 9

A drawing of a small ceramic vessel representing a seated human with an outsized, but fairly accurate, human heart, (Drawing by Gordon Bendersky)



explored and illustrated certain organs and congenital anomalies.

One small hollow ceramic vessel illustrates a seated human figure with an exposed heart of exaggerated size (Fig. 9). Gordon Bendersky, MD, a cardiologist, has discussed the relative accuracy of the portrayal, concluding that the image must have been made from direct observation of a heart but that certain features were changed “to display the organ more symmetrically and to facilitate the placement of the head directly on the sulcus” (Bendersky, 1997). As with Olmec representations of the human embryo, the representation of the subject in sculpture was modified (or in artistic terms, “stylized”) – the actual thing was transformed into a symbol.

Dr. Bendersky (2000) has also made a case that a number of figurines with a normal number of facial features served to illustrate an incidence of congenital defects in the small farming community of Tlatilco, on the shore of Lake Texcoco in highland Mexico. A number of figurines from the site exhibit two heads, or sometimes, double-facedness, with two noses and mouths and three or four eyes (Fig. 10). While these figurines have

traditionally been interpreted as mythological beings, Bendersky found a 1:1 correspondence between documented cases of a congenital anomaly called diprosopus and the range of features shown in the Tlatilco figurines.

The case is compelling that Formative Period Mesoamericans were fascinated with the processes of human gestation and physical development. Another class of objects, stone figurines of humans, suggests that they were also interested in the potential of the disciplined body, in what we might call mind-body communication.

Exploring the Spiritual Potential of the Adult Body

Small-scale stone images of the human figure occur across Mesoamerica (except in the Maya area) in the later Formative Period (900–400 BCE). From Guerrero to the Gulf Coast to the Pacific Slope, “Olmec” people made stone figurines in only a few variations: standing figures, seated figures, kneeling or half-kneeling, and lying on the belly with the legs bent backward so the feet touch the head.

Knowledge Systems of the Olmec, Fig. 10

Left: Tlatilco figurines, from about 1100 BCE, exhibit multiple features or heads (Drawing by Gordon Bendersky, used with kind permission. *Right:* Photo of an individual exhibiting a form of diprosopus, courtesy Gordon Bendersky)



Knowledge Systems of the Olmec,

Fig. 11 Standing figures from La Venta Offering 4 (Photo by John Verano)



Over 100 “standing figures” with an exceptionally consistent posture have been published. The best known of these are the 16 that constitute a group known as La Venta Offering 4. Each figure is made of a different stone, probably by a different sculptor, yet the poses are nearly identical. The figures neither wear costumes nor hold regalia, so the focus of the piece is on the pose itself (Fig. 11). The figures stand with their weight distributed symmetrically. The knees are flexed and the pelvis is tilted to straighten the spine (Fig. 12). The limbs are loose and muscles are not articulated, providing a sense of focused

relaxation. In sum, the figures exhibit a perfectly straight spine with relaxed limbs and a focused gaze. This pose looks comfortable, but it is deceptively difficult to maintain. Flexing the knees demands effort from the quadriceps, the largest muscle in the body. After a minute of standing this way, the heart begins to pound. This posture is common to several physical-spiritual disciplines. In Hatha Yoga, this position is called Tadasana, the Mountain Pose. It is said to teach endurance, steadiness, contentment, and enable a person to experience the flow of energy spiraling up from the feet to the top of the head.



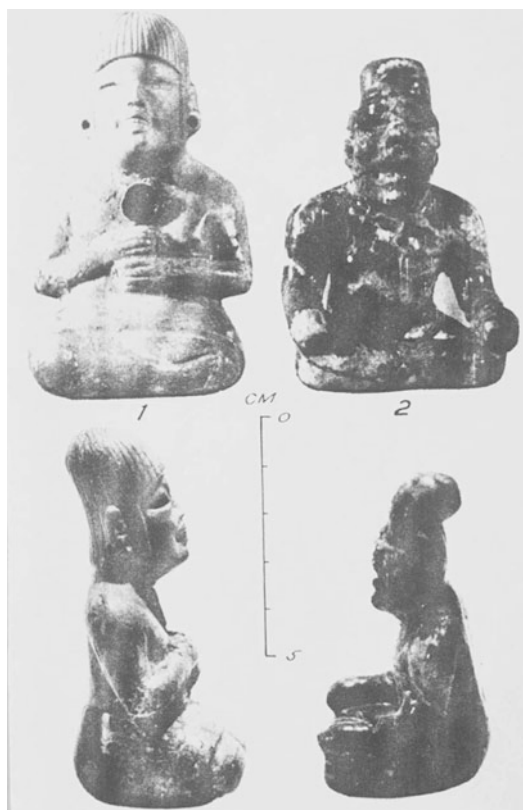
Knowledge Systems of the Olmec, Fig. 12 A standing figure from La Venta Offering 4. The profile shows the straight spine and flexed knees (Photo courtesy John Verano)

In T'ai Chi, the pose is called Hun-Yuan Kung or Beginning Posture. In this position, it is said that the earth is invoked by the rootedness of the feet, the sky by the verticality of the spine, and humanity by the sinking of energy to the Dan T'ien, an energy center below the navel. In both traditions, the pose is used to focus the mind or meditate. However, although both Asian traditions are at least as old as 1000 BCE, no known portrayals of this pose survive from Asia from this era.

Not all Olmec standing figures portray nude figures in this pose. A few wear clothing and hold weapons or ritual items. Their meaning is distinct from that of the standing meditators.

Seated stone figurines are more rare in the Olmec corpus, but the few that exist (about eight, half of which are from archaeological contexts) also seem to exhibit a disciplined posture (Fig. 13). Each sits cross-legged with a straight spine. In a few, the hands are resting on bent knees. At least two sit in a half-lotus position, with one foot resting on the other knee.

Quite a few Olmec sculptures portray a human in a pose clearly based on a very difficult



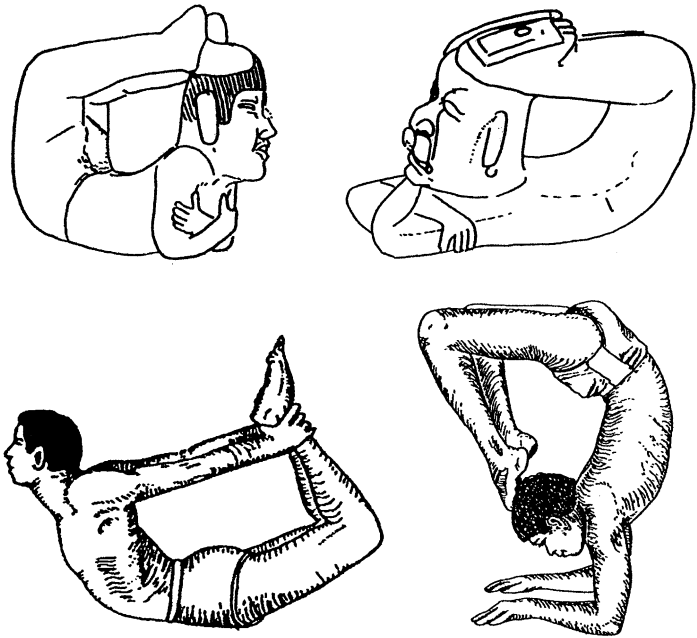
Knowledge Systems of the Olmec, Fig. 13 Seated figures from La Venta Tomb A (From Drucker, 1952: Plater 46. Public domain)

disciplined posture. The figure reclines on the stomach and bends backward to form a wheel (Fig. 14). The elbows support the elevated chest and head. The back and legs arch so that the feet touch the top of the head. Hatha Yoga includes several such postures. Within the many systems of yoga, these postures are ascetic disciplines whose practice and attainment involves controlling the body and mind, sometimes with the goal of realizing oneness with the divine consciousness. In the past, these backward arching figures have been called “acrobats” and considered to be “court jesters.”

Another subject of Olmec stone figurines shows a person kneeling or half-kneeling with hands on the knees. In many of these, an animal skin partially covers the human figure. The skin has split and is peeling away, like that of a snake

Knowledge Systems of the Olmec, Fig. 14

Top: Figurines in the backward arching pose. Private collection. *Bottom:* Portrayal of an expert Yogi, Swami Vishnudevananda, in similar disciplined poses (Author drawings)



or lizard that sheds its skin. Kent Reilly (1989) has interpreted such figures as humans transforming into an animal alter ego. In light of the focus on the human embryo in Olmec sculpture, symbolic of the rapid transformation of the human “seed” into various animal-like forms and finally into a human form, the fetus, this adult transformation makes sense as a part of larger ideological structures.

In summation, While Formative Period people were domesticating food plants, building early public architecture, engaging in long-distance travel and trade, getting to know their environment, and establishing the ideology that would permeate later Mesoamerican cultures, they were also exploring the human body itself. One major focus was on the mysteries of human development from the stage of the embryo, which appears as much like a tailed animal, bird, or fish as a human, to the fetus, which is clearly human, to infancy. No later Mesoamerican civilization focused to this extent on the early stages of life, the “seed” stages, as did the people in these seminal societies. It is also clear that a guiding metaphor of Mesoamerican civilization, “humans are maize,” so clearly expressed in the Maya

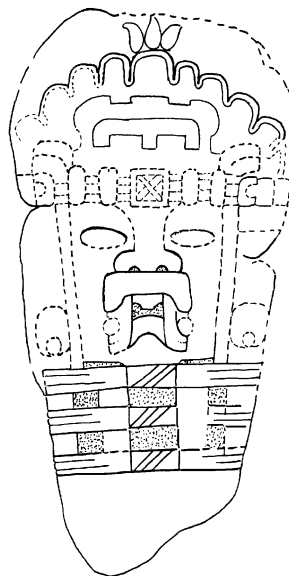
Popol Vuh, originated in the Formative Period. Another major focus of their research, which they expressed in sculpture, was that of the physical-spiritual disciplines of the body. Although later cultures, notably the large central Mexican city of Teotihuacan, made similar standing and seated stone figures, the postures are less specifically “disciplined” and the meaning of these figures seems to have changed in the Classic Period.

Extra: Human Embryo or Were-Jaguar in Olmec Sculpture?

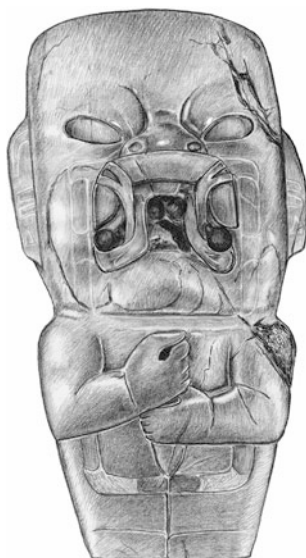
One of the characteristic features in Olmec art is a symbol that is widely known as a were-jaguar. The symbol appeared as a disembodied head on headdress ornaments, as a whole body in the form of figurines (Fig. 15) and large ritual axes, and on monumental stelae (Figs. 16 and 17). First advanced in 1946, the interpretation of this symbol as a were-jaguar has survived many attempts to replace it with alternatives. All of these have pointed out that the symbol lacks the pointed ears, fangs, claws, whiskers, tail, spots, and body of a jaguar. The only vaguely jaguar-like features are



Knowledge Systems of the Olmec, Fig. 15 Figurine representing an Embryo with a pronounced crest on its head. Private collection (Drawing by Corey Escoto)



Knowledge Systems of the Olmec, Fig. 17 La Venta monument 25/26 represents a human embryo with a head-band, bundled at the bottom, and with a head in the shape of a mountain. Here the embryo symbolizes the vital energy inherent in seeds (Author drawing)



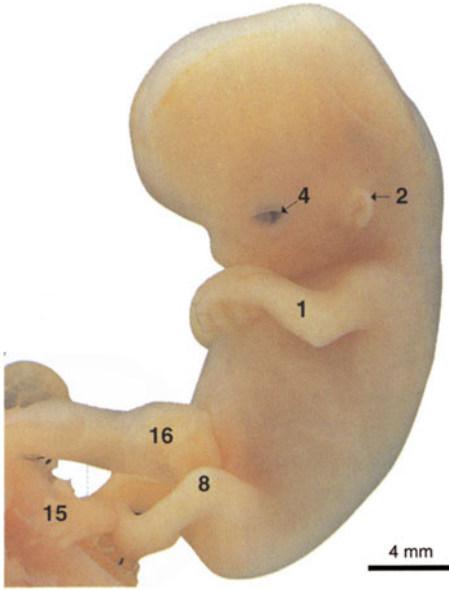
Knowledge Systems of the Olmec, Fig. 16 The Kunz Axe, jadeite, American Museum of Natural History. Represents an embryo or “human seed,” (Drawing by Corey Escoto)

a puffy upper lip, a flat nose, and an open mouth, usually toothless. Newer interpretations contend that the symbol was based on another animal: a crocodile, snake, or a fantastic creature or represents a deity. It was considered a hallmark of Olmec art that the Olmec portrayed “biologically impossible creatures.” Very recent research strongly suggests that the symbol IS biologically based and that it represents the human embryo of about 56 days (Fig. 18).

To explore the proposal that this image represents the human embryo, this discussion compares the features of a human embryo of 56 days to those of two Olmec pieces, a figurine and an “axe” (Fig. 19):

- *Overall proportions:* in each case, the head is very large in proportion to the body. The human embryo’s torso from the base of the head to the rump head is about 1.25 times the size of the head. The same is true of the Olmec figurine. On the axe, the head is even larger than the rest of the stylized body.

- *Head*: the embryo's forebrain, midbrain, and hindbrain form bulges that create the shape of the head. Soft bony portions are separated by large sutures called fontanel. The anterior fontanel is diamond-shaped. The Olmec figurine's head shows these typical swelling masses. The stylized forms on the axe give

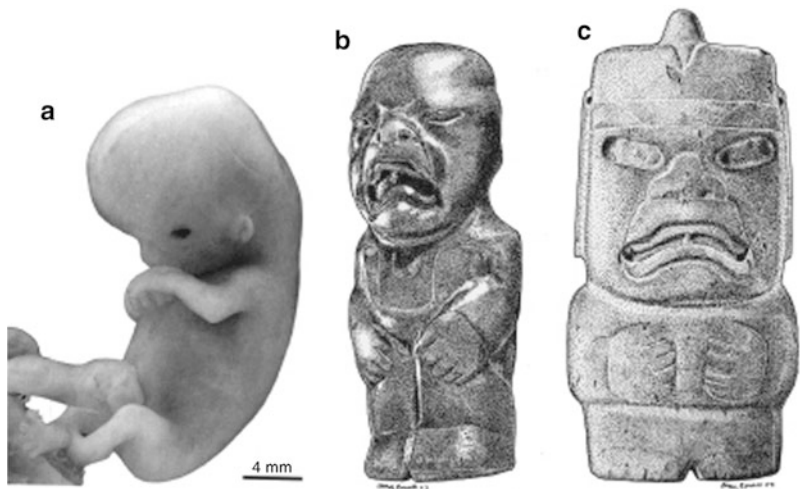


Knowledge Systems of the Olmec, Fig. 18 Photograph of a human embryo of 56 days (From England, 1996. Used with kind permission)

the head a slightly curved, tapering rectangular shape. Both the figurine and the axe show the anterior fontanel. In the figurine it is subtle but present; in the axe it takes the stylized “cleft-head” form. In other examples it is diamond-shaped.

- *Eyes*: lidless oval eyes sit on the sides of the head in the human embryo (Fig. 20). The eyes are still open but eyelids begin to form between days 52 and 57. On the figurine and axe, the eyes are widely spaced and lidless although on the figurine, which seems to show an embryo of about 57–58 days, lids are beginning to close over the eyeball (Fig. 21).
- *Nose and mouth*: at 4 weeks, the embryo exhibits a single, arching slit where the nose and mouth will soon develop. In the fifth to sixth week, buds at the corners of the slit, called maxillary prominences, grow rapidly toward each other to form an upper lip that separates the nostrils from the mouth. The maxillary prominences are just that – prominent or puffy. At this stage, the nose barely projects above a swollen upper lip. This facial development occurs rapidly and at the stage during which the embryo is frequently lost from the womb (this will be explained below). Anyone who had seen several embryos would have noticed the swollen

Knowledge Systems of the Olmec, Fig. 19 A comparison of a human embryo at 56 days, an Olmec figurine, and an Olmec axe. The figurine is somewhat naturalistic, and the axe is a more stylized representation of the human embryo (Drawings by Corey Escoto)





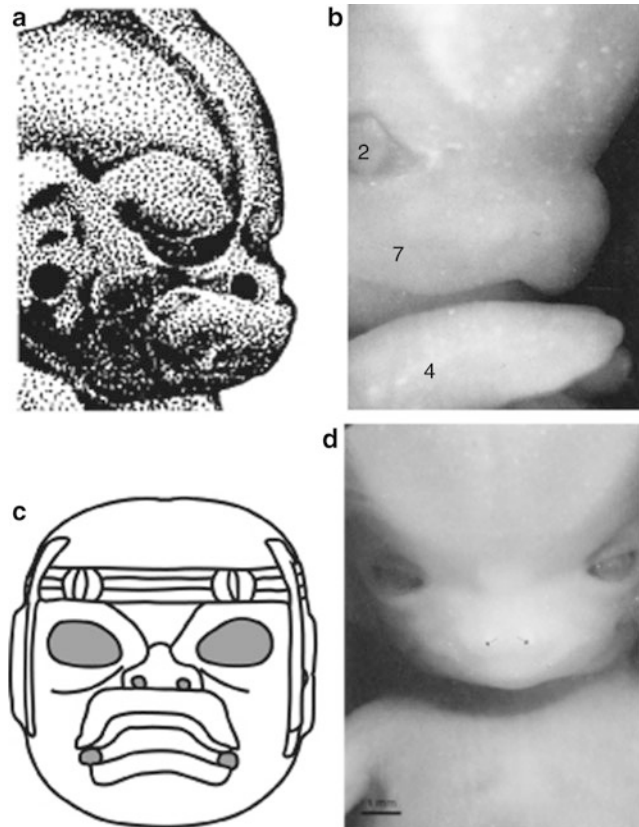
Knowledge Systems of the Olmec, Fig. 20 The Face of human embryo (Photos courtesy England, 1996)

upper lip and shallow nasal pits. The principal feature of the Olmec symbol is its “puffy upper lip” and arching mouth, usually toothless. Above the upper lip are the flat nostrils of a human embryo. Sometimes Formative Period people added the dentition of various animals to the basic image to confer certain mythical associations or animal-like qualities on the symbol (see Fig. 22).

- *Ears*: on an embryo the ears first appear as small arches on the sides of the neck. They do not move up onto the head until Week 10. Similarly, on the figurine, ears are not shown. On this axe, the maker included the cultural symbols of the headband and long earflaps but no ears.
- *Limbs*: in the developing embryo, the arms appear in Week 4, slightly before the legs. Hand plates appear in Week 6 but toe rays only in Week 7. Most of the Olmec images

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Knowledge Systems of the Olmec, Fig. 21 A comparison of the faces of actual human embryos with those of Olmec embryo figurines (Photos courtesy England, 1996. Drawings by Corey Escoto)





Knowledge Systems of the Olmec, Fig. 22 An Olmec “axe” based on the form of the human embryo, with feline teeth added (Drawing by Corey Escoto)

show short arms with poorly differentiated fingers. Both the figurine and axe show arms that are better developed than legs. Apparently the Olmec took care to show the developing stages of the limbs in both naturalistic and conventionalized images.

The degree of correspondence between the Olmec symbol and the human embryo is so high that there is little question that the symbol indeed is a stylized representation of an embryo. The use of the embryo as a symbol points to knowledge of the human gestation process. Could this be possible? Access to embryos in the Formative Period was at least as high as it is today. Since about 20 % of recognized pregnancies in the modern industrialized societies terminate between 42 and 56 days, (Weeks 6–8) it is also likely that miscarriage was at least that common in the past. The embryo measures from 20 to 30 mm at that stage, and so is quite visible. Human embryos were described in texts from other cultures, such as in the *Garbha Upanishad* (1400 BCE, India), so clearly ancient people did observe them.

Although there are no written texts from the Formative Period to corroborate the notion that the symbol represents an embryo, there are

many references by modern indigenous people to embryos, placentas, conception, and gestation. Two modern stories illustrate the survival of this cultural focus. These stories illuminate what the embryo might have meant to the Olmec.

The first story comes from Nahuatl (Aztec) speakers. In a village in Veracruz, people place a cedar box in the shrine of the earth mother, Tonantsij. Her domain includes ruling over her children, known as the seed spirits, who are “. . .the life force or potential for fertility of each crop” (Sandstrom, 1991, p. 244). These “seed spirits” seem to be a modern version of the ancient embryo symbol. From woman-made paper, villagers form elaborately dressed figures of the seed spirits and place them in the box. These are cleaned, renewed, and redressed annually. Throughout the year they are given offerings of food, so they will not want to return to their mountain-cave home. The most important seed spirits, those of maize, are called 7-Flower and 5-Flower, and are considered to be divine human twin children. Also, the Amatan people make bundles out of bandanas. They call these “elote child” and say they represent spirit and flower of maize. Three ears of corn are tied together, one for its backbone and two for its face. Marigolds, (representing the fiery energy of conception) emerge from the opening at the top and a candle, representative of the phallus, is inserted into this womb-like bundle to bring male energy in the form of fire.

Similarly, the twentieth-century Maya of Santiago Atitlán keep a box representing the womb of one of the three Marias in a shrine. In the box is a bundle called “Heart of the Placenta.” It is wrapped in a woven, beribboned cloth decorated with three faces called the corn girls, which a shaman places on the belly of a pregnant woman to give her fetus its face. Hanging from the ribbons, which represent umbilical cords, are two small bags filled with dry corn paste. The Atitecos call these bags “divine twins” – one male, one female – and consider them to be the original placentas that wrap the original seeds of the human race: the “root of children” (Tarn & Prechtel, 1986, pp. 175–176).

The ultimate spiritual technology in Olmec ideology seems to have been the evocation of the embryo (seed) spirit as the vital force that animates crops and human life.

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Knowledge Systems: Indigenous Knowledge of Trees and Forests

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The knowledge of indigenous peoples about the use and maintenance of natural resources and their environment has accumulated over many generations and comprises local practices for biodiversity conservation. Such practices are generally rooted in a combination of local ecological knowledge and belief systems that have developed over a long period of time. Indigenous knowledge basically refers to a system of local perceptions, practices, technologies, and skills that are unique to a specific culture and region.

The interrelationship between cultural and spiritual values of plants and other natural resources that are part of local people's cosmology has since long been studied in conjunction with their practices, supporting that indigenous beliefs have a significant influence on people's local use and management behavior (Elisabetsky & Posey, 1994). As Posey (1999) notes, anthropologists have now a major task to further document and study the local context of these cultural and spiritual values and beliefs underlying indigenous knowledge and practices that – as a result of lack of understanding – so far have largely contributed to the gap between scientific and indigenous knowledge systems. According to Brodt and Arorara (2012), indigenous knowledge implies any knowledge produced by and/or is distinctive to a particular culture group or any loosely defined group of resource users in a given area. In this context, forests represent a treasure house of local knowledge accumulated by forest-dwelling communities through ages of their interaction with and understanding them.

Evolutionary Myth of Trees and Forests

Forest-dwelling tribal communities in Odisha, India, take reference of their cosmogonic myths to describe their identity, life and livelihoods, and interactions and interrelations with their immediate environment. Their myths not only describe the origin or coming into being of the community but also deal with the justification of origin of many animate and inanimate subjects and objects imminent for the survival of the community. The plants and trees in the forest world have ever been considered as the life-sustaining system for most of the tribal communities in Odisha and almost everywhere in India. Hence, trees, forests, and forested landscapes represent a virtual world for those communities who define their identity and culture with reference to their myths of origin.

The Dongaria Kondh myth of origin states that they took birth from their supreme mother under the earth. They needed a strong support to climb up to reach on the surface of the earth. The supreme mother thought of the problem and provided help by the creation of bamboo. Tall bamboo species could help the people climb up and settle on earth. Once on the earth, the Dongaria community got dispersed in the open. There was no shelter. To protect her creation, the supreme mother created big trees. The Dongaria lived under the trees. The people felt hungry, and to provide them food, herbs, and tubers, fruit-bearing trees were created by the supreme mother. The sum of all the plants and trees finally made up the forests.

The Dongaria Kondh myth of origin describes the origin of many forest species from the dead remains of a demon (*Asur*) who was killed by a supreme god called Dharam Devta. After the demon was killed, the followers of Dharam Devta used the limb bones of the demon as poles to build a small hut covered by the demon's hide called *Asur kudi* (demon hut) for their lord to relax in the hut and conduct meetings. The god did not like the hut made of the body parts of the demon and hence dismantled the hut and threw away the demon's bones. From the leg bones of the demon grew the Sargi mara (*Shorea robusta*),

from bones of his hand grew the Sahaj mara (*Terminalia tomentosa*), from its rib bones grew Japi mara (*Michelia champaca*), from one set of rib bones grew bamboo, and from other bones grew Daman mara (*Grewia tiliaefolia*) and Bada mara (*Ficus benghalensis*). The herbs, grasses, and creepers grew from different body hairs of the demon.

The myth provides an understanding of utilitarian and cognitive aspects of plants, trees, and forests in the life and livelihoods of the community. Apart from the uses of the trees and forests as a shelter or habitation space and food source, the myth provides that the Dongaria Kondh perceive their world as a world of trees and forests. An ecological understanding is embedded within that myth that the forest is conceived as a collection of plants and trees in proportion to the units akin to the constitution of the demon's body from which the plants and trees grew.

Forest is also the basis of the Kuttia Kondh tribal culture in Odisha. They perceive trees and other plants as creatures akin to animals and human beings, the former contributing significantly to the belief system of their material and religious culture. The relationship between the Kuttia Kondh and the plant world can be traced back to many myths and beliefs (Kui Gaani and Kapka Gaani). The Kuttia Kondh myth of origin, Kui Gaani, describes the evolution of plants and trees (Jena et al., 2006, pp. 309–472). According to the myth, vegetation evolved from two different sources. The first occurred when plants and trees were born from the body of a Sambar deer (*Cervus unicolor*), and the second, when the first crop planted by Kuttia Kondh grew from the seeds they carried with them on emerging from the mythical Sapangada hole. The plants that evolved from a Sambar's body include timber species, shrubs, herbs, creepers, and grasses. One exception specified in the myth is bamboo, which is claimed to have developed from coarse turmeric powder and the hair of Nerandali, the supreme earth goddess. From their early history, the Kuttia Kondh have categorized plant groups by distinguishing between domesticated plants and wild plants (Jena et al., 2006, pp. 193–94).

The life of a plant, its pattern of growth, germination, and association with other plants inspire the Kuttia Kondh to believe that the plants socialize with one another and communicate and interact with other plant species. This is the most likely explanation why the Kuttia Kondh attribute gender characteristics to plants, implying that plants and in particular trees reproduce through sexual union. The attribution of sex to plants and trees is a common phenomenon among tribal societies (Parkin, 1997; cf. Jena et al., 2006). The Kuttia Kondh not only believe in gender of plants and in the concept of tree birth but also that the two different plant species acting as the parent generation may generate a completely new species which does not resemble either of the parents. From the evolutionary point of view, however, the interspecific and intraspecific hybridization process in the natural vegetation is responsible for the diversity of plants (Jena et al., 2006, pp. 189–90). The Kuttia Kondh oral lore also depicts familial relations between plants and trees where tree marriages are ultimately resulting in diversity. While explaining the tree marriage, the Kuttia Kondh attribute that in the case of a tree couple, the robust and stronger one is the male and the other one is the female. In their myth, *Shorea robusta* and *Terminalia tomentosa* are the first pair from which other tree species evolved. Thus, the two trees are religiously significant to them.

The Lanjia Saora, another tribal community of Odisha, and their myth of origin, the Kureitung Kata, mention the origin of plants and particularly trees for human needs and the beautification of Nature. According to this myth, the Supreme Being Kitung gave birth to plants and trees and created birds out of dry leaves to eat the fruits and help in the dispersal of their seeds. When there were plenty of fruits, nuts, and tubers available in the forest, the god created different animals to feed on the plant products. Rather indirectly the Lanjia Saora myth of origin talked about the food chains in a forest and the relationship of the community with the trees and forests. The Lanjia Saora myth of origin put the evolutionary succession in an order: first, there was water and then the plants, and they were followed by animals and finally human beings.

Different forest-dwelling cultures, as referred to above, see the origin of trees and forests through their oral lore. There are symbols and metaphors in each myth which are knowledge encoded by the communities in their own respective context through their cultural practices and environmental perceptions. The trees and forests that are mentioned in their myth have been generally been considered as religiously important. Further, close observation of the myths and their interpretation by the respective tribes indicate that the climax community in the plant succession and associate species are mostly referred to as important for religious grounds which indirectly enable the preservation and conservation of those species which are relevant to them.

Ecological Classification of Forest and Forested Landscapes

Classification of Forests by the Dongaria Kondh

The Dongaria Kondh distinguish between various types of forests on the basis of their ecological situation, composition of vegetation, canopy, climax vegetation, moisture regime, and above all relating them to their livelihood and their nutrition value. The forests are classified accordingly with a specific denomination. The Dongaria Kondh classify the forests into eight types. These are Horu (forest located on a hill), Kaman (primary forest with canopy and climax vegetation), Jada (small forest generally with underwood with about or less than 40 % canopy density), Hada (scrub jungle), Patra (forest located on a plateau), Trunjeli muanri (sacred forests and shrines), Mahane Dangu (a part or whole patch of forest used as cremation ground), and Nellu and Neta (swiddens). These categories may be further classified on the basis of the forest structure. While Kaman, Trunjeli muanri, and Mahane Dangu are mostly primary forests with a closed canopy, Jada and Hada are depleted primary forests or secondary or coppice forests. Nellu and Neta are spaces where once a primary forest existed that was used or cleared for swiddening, and these are the spaces where

scrub vegetation and coppice forest appear after a fallow period. Vegetation density, diversity, and the moisture regime in the primary forests are much better compared to other types. The hill forests may be primary forests or secondary forests depending upon the level of biotic interference. Nellu and Neta are usually located on hills. However, the entire hill forest is not slashed for swiddening. The forest existing on top of the hill is spared from slashing. Hence, a hill forest with swiddens, in most cases, bears both primary and secondary forests during the fallow period and primary forests with crops in the phase of swiddening. Jena et al. (2002, pp. 223–334) have provided a detailed account of how the Dongaria Kondh have classified their plant groups, forests, and their environment in general.

In the Dongaria understanding, in a Kaman, the predominant vegetation are trees and under-wood species forming a canopy. It is usually well stocked and biologically diverse and comprises a four-tier vegetation structure. It remains cool and shady, arrests the surface runoff during the heavy monsoon rains, and thus maintains a good moisture regime providing favorable conditions for the growth of vegetation on its relatively fine and soft soil. The location of Kaman may be on hill slopes or foothill plains, but the density of the climax vegetation and canopy makes it easily recognizable.

Jada is a forest of underwood, shrubs, and tall climbers mostly located close to a settlement. Jada forests are also used as horticultural plantations. It has relatively open canopy, and hence, the forest floor is drier compared to Kaman. Human horticultural activities in a Jada forest are frequent owing to its mixed vegetation and proximity to the settlement. It can be located on hillocks, in the valleys between two hills, but also in the plains and on river banks, and those on a long-fallowed swidden area are also called Jada. The lower middle part of hill slope is perceived to be the area favorable for a Jada forest. Hada forests are characteristically composed of bushes and shrubs and located on foothills, wastelands, and near settlements. There may be some trees, and in particular coppicing trees, but climbers, thorny plants, and invasive species

dominate the composition of the vegetation. In this type of forest, free grazing is allowed, and it is not perceived as a habitat of wild animals, although smaller animals such as hare, pea fowl, jungle fowl, and snakes are to be found there. The Dongaria households mainly collect their fuel wood from this type of forest.

Trunjeli muanri are forests partly revered as abodes of gods and goddesses, and hence, there is the least human interference with them. Every Dongaria village identifies one or more forest patches as Trunjeli muanri, i.e., sacred forests. Because of their religious sanctity attached to the space, people refrain from felling trees there or clearing the forest for any common or individual purpose which adds to its biodiversity. In their cultural life, the Dongaria observe many occasional and seasonal rituals in these forest patches to seek the benevolence of the gods and goddesses for their common welfare and well-being. This also applies to the forests where cremations take place. There are traditional taboos attached to such forests that except for the purpose of obtaining fuel wood for the cremation, no tree felling is done and medicinal plants are rarely exploited from there. The use restrictions attached to these forests indirectly help the gene pool conservation.

Classification of Forests by the Lanjia Saora

The Lanjia Saora tribe of Odisha classifies the forests in their environment into four categories. These are Gada or Tulab, which are used synonymously, Barooh, Sala, and Kitungsing. As per the Lanjia Saora myth, the supreme god wanted to classify the forests to make easily understood which resource is available and where and what rituals are to be made in which type of forest.

Gada and Tulab comprise grasses, herbs, shrubs, and trees. The Gada-type forest expanding over a larger landscape is called Mada Gada, meaning a big forest with tall trees. In contrast to that, the primary forests in the fringe areas and in between slopes are called Sana Gada. The Lanjia Saora distinguish Mada

Gada and Sana Gada by the height of the trees. In their perception, the tall trees almost at the center of a forest landscape form a Kuitab (umbrella), i.e., a canopy, and gradually the canopy opens up as one moves to its fringe areas. The mythical name of Gada is Tulab. In general usage, Tulab is understood as a denser and more diverse forest as compared to Gada. A monoculture plantation may be called Gada, but it can never be a Tulab. Usually, these forests are spared from swiddening, and there is also less human activity in it. The Tulab thus is richer in biodiversity and is believed to be the dwelling space of ancestral spirits; people abstain from entering into this forest at night. Gada comprises the climax vegetation and its biological associates and hence is home to all types of wildlife.

Barooh literally means hill and hill forest. Unlike in Gada or Tulab, swiddening is done on Barooh. Barooh is devoid of climax vegetation if swiddening is ongoing. The vegetation is thus less diverse and sporadically distributed. A long time ago, the Gada type of forest was seen on Barooh till it was cleared for swiddening as the Lanjia Saora cleared the central part of Gada forest on hills and spared the tall trees in its fringe. Thus, the climax vegetation was lost in course of time. The fringe area was not cleared as it acted as a sort of a barrier for the cattle and thereby prevented the standing crops from being browsed. The tall trees on the fringe also functioned as shelter-bearing trees for a watch hut to safeguard the crops from wildlife. However, over the years of human interference, the endemic forest vegetation has been replaced by economic plantations such as mango and cashew. The slopes on a Barooh that had been depleted of endemic species were converted into terraces for settled cultivation. In the patches where it was very dry due to massive soil loss, the *Ficus* species are taking over the other natural vegetation. In a Barooh, certain species like Lua (*Ficus glomerata*), Anjer (*Ficus benghalensis*), Kurgad (*Syzygium cumini*), Uda (*Mangifera indica*), Titin (*Tamarindus indica*), and Uring (various species of bamboo) are spared from felling to prevent soil loss, and if so, the thinning is done in a way that no shadow may fall on crops. However, most of

the Lanjia Saora ritual practices are conducted on the Barooh (plural of Barooh).

Sala is the term used to describe a small forest. The vegetation comprises a few tree species and mostly scrubs with a degraded fringe area. Usually, Sala comes up in an abandoned or long-fallowed swidden located near villages. Open grazing is done in Sala, and the village community members collect a major part of their fuel wood from there. The Sala forest has a subcategory, Saladabur, which is a small forest on the bank of a perennial stream that is different in terms of its mixed green vegetation. These forests are habitats of snakes and monitors.

Kitungsing means Kitung's (supreme god) abode. It is like a sacred grove amidst a dense forest patch where gods like Kitungsum and Lobosum are worshipped. Usually, the Kitungsing is a patch of Sal (*Shorea robusta*) trees with associate species, and the patch is considered to be very significant from the religious point of view. Nobody does any harm to the vegetation there in order to be spared from the wrath and anger of the gods. Larger patches of forests are also reserved as the abode of a number of gods and goddesses, especially for Gadasum, the forest god. These are the patches rich in plant and tree diversity. The larger patch of forests protected and conserved in the name of Gadasum are called Gadasum asalo, meaning forest clusters of Gadasum.

The Forest-Related Knowledge Systems and Their Relevance in the Present Context of Odisha

Sooner or later, tribal communities tend to respond to outside or social mainstream developments in either a conservationist, an adaptationist, or way of fundamentalist isolation or rejection of being modernized. Then the question arises whether indigenous knowledge is to be equated with ecologically sound knowledge. Is there, for instance, an overall notion of cosmos in any tribal society that encompasses all physical, social, and spiritual aspects of life in a form of animism or natural symbolism and ritualism? The understanding of the environment as understood and

internalized by some of the forest-dwelling tribal communities in Odisha has been, by and large, taken from their myths, oral lore, of legends and tales. "There is always a fundamental basis of inherited knowledge in every community, a representative of the society in its typical geographical and climatic surroundings that is individually interpreted, modified and passed on for generations. The experience and knowledge of a people's ancestors are generally passed down orally to the younger generations, but increasingly often this transmission is limited by cultural change" (Seeland & Jena, 2008). These experiences, perceptions, and their reflection in their work culture provide important hints to understand their conceptualization of a living environment in a socio-ecological complex. These orally transmitted knowledge systems, although in local dialects, are important links for researchers to deduce their knowledge on ecology and understanding of ecological factors influencing the tribal communities' livelihood and culture, which shapes their adaptive responses to changing ecological situations. While some forms of knowledge are common among all community members, there are also specialized and discrete knowledge systems known to specialists only acquired from their occupations. Systematic documentation of indigenous knowledge in the context of trees, forests, and more comprehensively of the environment would not only pave the way for strategizing efforts for biodiversity conservation but, at the same time, would be very useful in promoting actions towards streamlining conservation and sustainable use of biological resources in the broader context of conservation and livelihoods.

Shackeroff and Campbell (2007) citing references from many authors on importance of local peoples' knowledge of ecology highlight that conservation researchers are approaching traditional ecological knowledge with increased alacrity (Drew, 2005; Drew & Henne, 2006; Fraser et al., 2006) recognizing its potential contributions to both understanding biological phenomena and the practice of protecting species and ecosystems. For example, fishery biologists and ecologists have recognized the need to engage

with local knowledge holders, particularly when they are indigenous and/or have long ties to ecosystems, in order to fill in the gaps in our understanding of marine ecosystems (Pauly, 1995; Pitcher & Pauly, 1998) and to explore alternative approaches to management (Berkes, 2003; Mac Goodwin, 2001; Pitcher & Pauly, 1998). Engaging with traditional ecological knowledge may indeed be a means for conservation researchers to link their efforts to the local, environmental, and cultural contexts (Berkes, Colding, & Folke, 2004). It may also provide a much needed tool to help the rethinking of environmental management practices (Acheson, 2005; McLeod & Leslie, 2009). Thus, in response to a growing interest in accessing traditional ecological knowledge (TEK) for conservation purposes, complexities involved in doing TEK research which assume relevance.

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Knowledge Systems: Local Knowledge

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The concept of local knowledge has recently come to the fore in the field of the sociology of scientific knowledge, where it is a common

empirical finding that knowledge production is an essentially local process. Knowledge claims are not adjudicated by absolute standards; rather their authority is established through the workings of *local* negotiations and judgments in particular contexts. This focus on the localness of knowledge production provides the condition for the possibility for a fully fledged comparison between the ways in which understandings of the natural world have been produced by different cultures and at different times. Such crosscultural comparisons of knowledge production systems have hitherto been largely absent from the sociology of science. A necessary condition for fully equitable comparisons is that Western contemporary technosciences, rather than being taken as definitional of knowledge, rationality, or objectivity, should be treated as varieties of such knowledge systems. Though knowledge systems may differ in their epistemologies, methodologies, logics, cognitive structures, or in their socio-economic contexts, a characteristic that they all share is their localness. Hence, in so far as they are collective bodies of knowledge, many of their small but significant differences lie in the work involved in creating assemblages from the “motley” of differing practices, instrumentation, theories, and people (Hacking, 1992). Much of that work can be seen as strategies and techniques for creating the equivalences and connections whereby otherwise heterogeneous and isolated knowledges are enabled to move in space and time from the local site and moment of their production and application to other places and times.

In this view, all knowledge systems from whatever culture or time, including the contemporary technosciences, are based on local knowledge. However within the master narrative of modernism, local knowledge is an oxymoron. Exploring this contradiction and the manifold meanings of local requires a brief excursion into postmodernism as well as some of the arguments underpinning the sociology of scientific knowledge.

Though postmodernism eludes definition and is more likely a stage of modernism than a marked epistemological break, there has been a

recent coalescence of strands of thought in a wide variety of areas that have questioned the assumptions underlying modernism. Postmodernism is most frequently equated with the collapse of the concepts of rationality and progress held to accompany the emergence of the postindustrial society and is consequently concerned with the rejection of universal explanations and totalizing theories. But perhaps the strand that is most truly pervasive in the constellation of reformulated approaches to understanding the human condition is the emphasis on the local.

In physics, ecology, history, feminist theory, literary theory, anthropology, geography, economics, politics, and sociology of science, the focus of attention has become the specific, the contingent, the particular. This is the case whether it is a text, a reading, a culture, a population, a site, a region, an electron, or a laboratory. Within this diversity of uses of local there seem to be two broad and rather different senses being used. On the one hand there is the notion of a voice or a reading. The voice may be purely individual and subjective or may be a collection of voices belonging to a group, class, gender, or culture, but in all cases the notion captures one of the basic characteristic elements of postmodernism, courtesy of deconstruction, that all texts or cultures are multivocal and polysemous. That is they have a multiplicity of meanings, readings and voices and are hence subject to "interpretive flexibility" (Collins, 1985). On the other hand, local is used both in the more explicitly geopolitical sense of place and in the experiential sense of contextual, embodied, partial, or individual. A range of disciplines from meteorology to medicine now recognize the necessity of focusing on the particular conditions at specific sites and times rather than losing that specificity in unlocalized generalizations.

The sociology of scientific knowledge is one of the most classically post of all modernisms and is therefore an area in which the local is also a thematic presence which is only now coming into focus. Some philosophers of science have come to re-evaluate the role of theory and argue that scientists practicing in the real world do not deduce their explanations from universal laws

but rather make do with rules of thumb derived from the way the phenomena present themselves in the operation of instruments and devices. Similarly philosophers and sociologists of science alike have recognized for some time the lack of absolute standards and the role of tacit knowledge in technoscientific practice, and have sought to display the context in which the practice of science is manifested as craft skills and collective work. However the recognition of the social and material embodiment of skills and work in the cultural practice of individuals and groups has only recently coalesced into the general claim that all knowledge is local. Knowledge, from this constructivist perspective can be local in a range of different senses. "It is knowledge produced and reproduced in *mutual interaction* that relies on the *presence* of other human beings on a direct, face-to-face basis" (Thrift, 1985). It is knowledge that is produced in contingent, site, discipline, or culture specific circumstances (Rouse, 1987). It is the product of open systems with heterogeneous and asynchronous inputs "that stand in no necessary relationship to one another" (Pickering, 1992). In sum scientific knowledge is "situated knowledge" (Haraway, 1991).

Perhaps the most important consequence of the recognition of the localness of scientific knowledge is that it permits a parity in the comparison of the production of contemporary technoscientific knowledge with knowledge production in other cultures. Previously the possibility of a truly equitable comparison was negated by the assumption that indigenous knowledge systems were merely local and were to be evaluated for the extent to which they had scientific characteristics. Localness essentially subsumes many of the supposed limitations of other knowledge systems compared with western science. So-called traditional knowledge systems have frequently been portrayed as closed, pragmatic, utilitarian, value laden, indexical, context dependent, and so on. All of which was held to imply that they cannot have the same authority and credibility as science because their localness restricts them to the social and cultural circumstances of their production. Science by contrast

was held to be universal, nonindexical, value free, and as a consequence floating, in some mysterious way, above culture. Treating science as local simultaneously puts all knowledge systems on a par and renders vacuous discussion of their degree of fit with transcendental criteria of scientificity, rationality, and logicity. Now the multidisciplinary approaches to understanding the technosciences which together constitute the sociology of scientific knowledge can be made more fully anthropological by the addition of a new subdiscipline called comparative technoscientific traditions.

Emphasizing the local in this way necessitates a re-evaluation of the role of theory which is typically held by philosophers and physicists to provide the main dynamic and rationale of science as well as being the source of its universality. Karl Popper claims that all science is cosmology and Gerald Holton sees physics as “a quest for the Holy Grail,” which is no less than the “mastery of the whole world of experience, by subsuming it under one unified theoretical structure” (Allport, 1991). It is this claim to be able to produce universal theory that Western culture has used simultaneously to promote and reinforce its own stability and to justify the dispossession of other peoples. It constitutes part of the ideological justification of scientific objectivity, the “god-trick” as Donna Haraway calls it; the illusion that there can be a positionless vision of everything. The allegiance to mimesis has been severely undermined by analysts like Richard Rorty, but theory has also been found wanting at the level of practice, where analytical and empirical studies have shown it cannot provide the sole guide to experimental research and on occasion has little or no role at all. The conception of grand unified theories guiding research is also incompatible with a key finding in the sociology of science: “consensus is not necessary for cooperation nor for the successful conduct of work.” This sociological perspective is succinctly captured in Leigh Star’s description:

Scientific theory building is deeply heterogeneous: different viewpoints are constantly being adduced and reconciled... Each actor, site, or node of a scientific community has a viewpoint, a partial

truth consisting of local beliefs, local practices, local constants, and resources, none of which are fully verifiable across all sites. The aggregation of all viewpoints is the source of the robustness of science. (Star, 1989, p. 46)

Theories from this perspective have the characteristics of what Star calls “boundary objects”; that is they are “objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites.” Thus theorizing is itself an assemblage of heterogeneous local practices.

If knowledge is local we are faced with a problem: how are the universality and connectedness that typify technoscientific knowledges achieved? Given all these discrete knowledge/practices, imbued with their concrete specificities, how can they be assembled into fields or knowledge systems; or in Star’s terms “how is the robustness of findings and decision making achieved?” Ophir and Shapin ask, “How is it, if knowledge is indeed local, that certain forms of it appear global in domain of application?” The answers, considered here, lie in a variety of social strategies and technical devices that provide for treating instances of knowledge/practice as similar or equivalent and for making connections, that is in enabling local knowledge/practices to move and to be assembled.

Research fields or bodies of technoscientific knowledge/practice are assemblages whose otherwise disparate elements are rendered equivalent, general, and cohesive through processes that have been called “heterogeneous engineering” (Law, 1987). Among the many social strategies that enable the possibility of equivalence are processes of standardization and collective work to produce agreements about what counts as an appropriate form of ordering, what counts as evidence, etc. Technical devices that provide for connections and mobility are also essential. Such devices may be material or conceptual and may include maps, calendars, theories, books, lists, and systems of recursion, but their common function is to enable otherwise incommensurable and isolated knowledges to move in space and time from the local site and moment of their production to other places and times.

Some of these devices have been revealed relatively unproblematically through direct observation. Others are less susceptible to investigation and analysis, being embodied in our forms of life. One way to catch a glimpse of these hidden presuppositions and taken for granted ways of thinking, seeing, and acting, is to misperceive, to be jolted out of our habitual modes of understanding through allowing a process of interrogation between our knowledge system and others. Such an interrogative process of mutual intertranslation can enable us to catch sight of the cultural glasses we wear instead of looking through them as if they were transparent.

This challenging of the totalizing discourses of science by other knowledge systems is what Foucault had in mind when he claimed that we are “witnessing an insurrection of subjugated knowledges” and corresponds to an emphasis on the local that has emerged in anthropology at least since Clifford Geertz’s *Interpretation of Cultures*. In his critique of global theories and in his emphasis on “thick description” Geertz pointed out that cultural meanings cannot be understood at the general level because they result from complex organizations of signs in a particular local context and that the way to reveal the structures of power attached to the global discourse is to set the local knowledge in contrast with it.

Equally there is the pervasive recognition characterized as postcolonialism that the West has structured the intellectual agenda and has hidden its own presuppositions from view through the construction of the other. Nowhere is this more acute than in the assumption of science as a foil against which all other knowledge should be contrasted. In the view of Marcus and Fischer we are at an experimental moment where totalizing styles of knowledge have been suspended “in favour of a close consideration of such issues as contextuality, the meaning of social life to those who enact it and the explanation of exceptions and indeterminants.” In this emphasis on the local we are postparadigm.

However we should not be too easily seduced by the apparently liberating effects of celebrating the local since it is all too easy to allow the local

to become a “new kind of globalizing imperative” (Hayles, 1990). In order for all knowledge systems to have a voice and in order to allow for the possibility of intercultural comparison and critique, we have to be able to maintain the local and the global in dialectical opposition to one another. This dilemma is the most profound difficulty facing liberal democracies now that they have lost the convenient foil of communism and the world has Balkanized into special interest groups by genders, race, nationality, or whatever. By moving into a comparatist mode there is a grave danger of the subsumption of the other into the hegemony of western rationality, but conversely unbridled cultural relativism can only lead to the proliferation of ghettos and dogmatic nationalisms. We cannot abandon the strength of generalizations and theories, particularly their capacity for making connections and for providing the possibility of criticism. At the same time we need to recognize reflexively that theory and practice are not distinct. Theorizing is also a local practice. If we do not recognize this joint dialectic of theory and practice, the local and the global, we will not be able to understand and establish the conditions for the possibility of directing the circulation and structure of power in knowledge systems. It is in the light of this recognition that I want to consider the ways in which the movement of local knowledge is accomplished in different knowledge systems and their consequent effects on the ways in which people and objects are constituted and linked together; that is their effects on power. The essential strength of the sociology of scientific knowledge is its claim to show that what we accept as science and technology could be other than it is. The great weakness of the sociology of scientific knowledge is the general failure to grasp the political nature of the enterprise and to work toward change. With some exceptions it has had a quietist tendency to adopt the neutral analyst’s stance that it devotes so much time to criticizing in scientists. One way of capitalizing on the sociology of science’s strength and avoiding the reflexive dilemma is to devise ways in which alternative knowledge systems can be made to interrogate each other.

Considerable advances in understanding the movement of local knowledge have been made possible through Bruno Latour's insightful analysis. For Latour the most successful devices in the agonistic struggle are those which are mobile and also "immutable, presentable, readable, and combinable with one another." These immutable mobiles are the kinds of texts and images that the printing press and distant point perspective have made possible. These small and unexpected differences in the technology of representation are on his account the causes of the large and powerful effects of science. That which was previously completely indexical, having meaning only in the context of the site of production, and having no means of moving beyond that site, is standardized and made commensurable and representable within the common framework provided by distant point perspective. Hence that which has been observed, created, or recorded at one site can be moved without distortion to another site. At centers of calculation such mobile representations can be accumulated, analyzed, and iterated in a cascade of subsequent calculations and analyses.

Latour's account has been augmented by the work of Steven Shapin and Simon Schaffer in the *Leviathan and The Air Pump* (1985). They have shown that experimental practice in science is sustained by a range of social, literary, and technical devices and spaces that we take for granted but which had to be created deliberately to overcome the fundamentally local and hence defeasible character of experimentally derived knowledge claims. In the seventeenth century, the problem for Robert Boyle, one of the earliest experimentalists, was to counter the arguments of his opponent Thomas Hobbes about the grounding of true and certain knowledge which they both agreed was essential in a country riven by dissent and conflicting opinion. Reliable knowledge of the world, for Hobbes, was to be derived from self-evident first principles, and anything that was produced experimentally was inevitably doomed to reflect its artifactual nature and the contingencies of its production; its localness would deny it the status of fact or law. Boyle recognized the cogency of these arguments and set out to create the forms of life within which the

knowledge created at one site could be relayed to and replicated at other sites. In order for an empirical fact to be accepted as such it had to be witnessable by all, but the very nature of an experimental laboratory restricted the audience of witnesses to a very few. Boyle, therefore, had to create the technology of what Shapin calls virtual witnessing. For this to be possible three general sorts of devices or technologies had to be developed. Socially groups of reliable witnesses had to be formed. Naturally in the seventeenth century they were gentlemen. These gentlemen witnesses had to be able to communicate their observations to other groups of gentlemen so that they too might witness the phenomena. This required the establishment of journals using clear and unadorned prose that could carry the immutable mobiles, experimental accounts, and diagrams. The apparatus had to be made technically reliable and reproducible, but perhaps most importantly the physical space for such empirical knowledge had to be created.

Hobbes, of course, was right: experimental knowledge is artifactual. It is the product of human labor, of craft and skill, and necessarily reflects the contingencies of the circumstances. It is because craft or tacit knowledge is such a fundamental component of knowledge production that accounts of its generation, transmission, acceptance, and application cannot be given solely in terms of texts and inscriptions. A vital component of local knowledge is moved by people in their heads and hands. Harry Collins, a sociologist of science, has argued that this ineradicable craft component in science is ultimately what makes science a social practice. Because knowledge claims about the world are based on the skilled performance of experiments their acceptance is a judgment of competence not of truth. An example of the centrality of craft skill is the TEA laser, invented in Canada by Bob Harrison in the late 1960s, which British scientists attempted to replicate in the early 1970s. "No scientist succeeded in building a laser using only information found in published or other written sources" and furthermore the people who did succeed in building one were only able to do so after extended personal contact with

somebody who had himself built one. Now TEA lasers are blackboxed and their production is routine and algorithmic. But in order to become routinized, Harrison's local knowledge had to be moved literally by hand.

Joseph Rouse (1987, p. 72) in considering the contemporary production process of scientific knowledge has summarized the implications of this understanding of science:

Science is first and foremost knowing one's way about in the laboratory (or clinic, field site etc.). Such knowledge is of course transferable outside the laboratory site into a variety of other situations. But the transfer is not to be understood in terms of the instantiation of universally applied knowledge claims in different particular settings by applying bridge principles and plugging in particular local values for theoretical variables. It must be understood in terms of the adaptation of one local knowledge to create another. We go from one local knowledge to another rather than from universal theories to their particular instantiations.

According to the historian of science Thomas Kuhn the way a scientist learns to solve problems is not by applying theory deductively but by learning to apply theory through recognizing situations as similar. Hence theories are models or tools whose application results from situations being conceived as or actually being made equivalent. This point is implicit in the recognition that knowledge produced in a laboratory does not simply reflect nature because nature as such is seldom available in a form that can be considered directly in the lab. Specially simplified and purified artifacts are the typical subject of instrumental analysis in scientific laboratories. For the results of such an artificial process to have any efficacy in the world beyond the lab, the world itself has to be modified to conform with the rigors of science. A wide variety of institutional structures have to be put in place to achieve the equivalences needed between the microworld created inside the lab and the macroworld outside in order for the knowledge to be transmittable. The largest and most expensive example of this is the Bureau of Standards, a massive bureaucracy costing six times the R&D budget. Without such social institutions the results of scientific research are mere artifacts. They gain their truth, efficacy,

and accuracy not through a passive mirroring of reality but through an active social process that brings our understandings and reality into conformity with each other.

The result of the work of Latour, Collins, Shapin, Star, Hacking, Rouse, and others has been to show that the kind of knowledge system we call Western science depends on a variety of social, technical, and literary devices and strategies for moving and applying local knowledge. It is having the capacity for movement that enables local knowledge to constitute part of a knowledge system. This mobility requires devices and strategies that enable connectivity and equivalence, that is the linking of disparate or new knowledge and the rendering of knowledge and context sufficiently similar as to make the knowledge applicable. Connectivity and equivalence are prerequisites of a knowledge system but they are not characteristics of knowledge itself. They are produced by collective work and are facilitated by technical devices and social strategies. Differing devices and strategies produce differing assemblages and are the source of the differences in power between knowledge systems.

In conclusion, it has been argued that Western science, like all knowledge in all societies, is inherently local, and furthermore other non-Western societies have developed a variety of social and technical devices for coping with that localness and enabling it to move. Some of them are technical devices of representation like the mason's templates, and the Incan *ceques* and *quipus*. Some of them are abstract cognitive constructs, like the Anasazi and Incan calendars, and the Micronesian navigation system. All of them also require social organization, rituals, and ceremonies. All of them have proved capable of producing complex bodies of knowledge and in many cases have been accompanied by substantial transformations of the environment. The major difference between Western science and other knowledge systems lies in the question of power. Western science has succeeded in transforming the world and our lives in ways that no other system has. The source of the power of science on this account lies not in the nature of scientific knowledge but in its greater ability to move and apply the knowledge it produces beyond

the site of its production. However at the end of the twentieth century we can now perceive that there is a high cost to pay for science's hegemony. Much of that cost in terms of environmental degradation and ethnocide is due not so much to the totalizing nature of scientific theories but to the social strategies and technical devices science has developed in eliminating the local.

The task of resisting and criticizing science may now be addressed by reconsidering the causes of its dominating effects. Without the kinds of connections and patterns that theories make possible we will never be able to perceive the interconnectedness of all things. Without the awareness of local differences we will lose the diversity and particularity of the things themselves. Thus, rather than rejecting universalizing explanations what is needed is a new understanding of the dialectical tension between the local and the global. We need to focus on the ways in which science creates and solves problems through its treatment of the local. Science gains its truthlike character through suppressing or denying the circumstances of its production and through the social mechanisms for the transmission and authorization of the knowledge by the scientific community. Both of these devices have the effect of rendering scientific knowledge autonomous, above culture, and hence beyond criticism. Equally problematic is the establishment of the standardization and equivalences required in order that the knowledge produced in the lab works in the world. The joint processes of making the world fit the knowledge instead of the other way round and immunizing scientific knowledge from criticism are best resisted by developing forms of understanding in which the local, the particular, the specific, and the individual are not homogenized but are enabled to talk back.

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Knowledge: Indigenous Knowledge in Africa

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Introduction

The term “indigenous knowledge” describes the different beliefs and practices of societies and

communities all over the world that are older in time and in their uses than any other beliefs and practices that are recognizable as acquired through contacts with foreign cultures, especially those brought to them through Western colonial influence. In this sense, the term often appears to court the idea of the exotic and unreal representation of some people as if they have been frozen in time. But this worry is largely false. Rather, these systems of belief and practice change frequently as people who live by them adapt to new ways of effectively exploiting the natural resources of their environments and associating with each other by acknowledging and applying acceptable rational and normative principles to regulate their daily lives. These changes may come from within, or through contacts and interactions with neighboring societies and communities, including influences from far away like Europe or some other distant cultural tradition. New customs and traditions may be adopted selectively and so may bring about new forms of behavior without interrupting the core values of the local people.

The concept of indigenous knowledge systems is both new and old. It is old because the people who live by such knowledge have possessed it for a long time; it is their reality, their "world" as describable in (reducible to) statements or, in philosophers' language, sensible propositions. Whether it is empirical or purely theoretical, this knowledge is the result of long-term testing through life by trial and error experimentations in which human rationality prevails in adopting only that which makes sense or that which produces wanted results. The adage "If it works, don't fix it" is an old and time-tested saying of practical reason. Its novelty, on the other hand, is relatively recent as a deliberate statement of their recognition and identification as autonomous systems of belief and other forms of cognitive principles, as well as the practices they support, that communities across the world possess and use, or the practices they perform in the management of their daily lives away from, and often also alongside the corpus and regime of the knowledge acquired formally through more recent systems of institutional instruction. Dualistic in its nature,

this focus recognizes the informal dichotomy in many non-Western societies: one part of society that organizes life largely on the basis of traditional beliefs, and the other part whose lifestyle is, relative to the former, largely organized around the dictates of the principles of the broader market economy. Because those who live in the latter group are more likely to go to a supermarket to buy their milk, or go to a health clinic when they have a headache, and go for a leisurely walk as a kind of entertainment, they are said to be participants in a modern kind of lifestyle, regardless of whether they live in urban or rural settings. It is how they define their behavior based on the kind of knowledge they have and value about the world around them and their place within it. Their counterparts, on the other hand, live mixed lifestyles. Although they may have breakfast made from ingredients bought at the local market, this is neither the sole nor the dominant source of their procurements. A disproportionately large volume of their daily needs is prepared at home from scratch from family-grown primary goods. It is more likely for a woman in this setting to fetch her family water supply for the day from the river, or from a community source at the village well, and even more likely to not pay for its consumption nor pay a landlord or landlady for her family abode. Overall, it is more likely that the woman in the latter setting lives a more rural lifestyle where most of her neighbors are likely to also be her relatives, and her daily life routine is based on close social relations and personal knowledge between all those who make up her village community. In the pre-mobile phone era, it was more likely for the woman in the village to walk over to her neighbor in the next home to seek advice or to ask for a little scoop of salt if she found out late in the day that she had run out or if she just did not have anywhere else to turn for some temporary need. Her urban counterpart is more isolated, which is why she depends on institutional services far more obviously than the rural relative. Contacts and mutual dependency between urban and rural populations continue to exist, however, and a strong claim of differences between the people and their lifestyles can be grossly

misleading. Historically, many urban populations of African descent are either themselves recent migrants from rural regions into urban settlements in search of employment or are descended from earlier generations of such local migrants. To some extent, rural lifestyles are known to a great number of urbanized Africans, thus establishing a continuity of knowledge and practice instead of an apparent break in location.

Rural–urban mobilities keep traditions alive between rural and urban spaces just as much as they keep the economic flow sustained in both directions. The dynamics of exchange between rural and urban spheres are not mute exchanges of goods between people of different locations whose meetings are dictated solely by the coincidental reality of mutual needs between producer and consumer. All these sociological structures are universal even if different societies experienced them and then moved on in different directions. At the same time, they are not. Rural–urban separations do not mean the same thing in Kentucky, USA, as they do in central China, or in central Brazil, or in Zimbabwe. It would be accidental that a farmer in central Kentucky is surrounded within ten square miles by people with whom he shares descent, but it is more likely than not to be the case in rural Zambia. The significance of these differences lies in culturally defined forms of social organization – how social relations are defined and valued – which, in turn, define what and how people produce and exchange their goods. Relations between people, and, together, between them and the ecological system of their lives and work, define their goals which are conceived on the basis of what cultural norms dictate. For example, a Luo man preparing for a visit by his in-laws does not buy cabbage and eggs from the supermarket for their meal, nor is he likely to get to the kitchen and cook the meal himself. Instead, understanding well the cultural significance of his relations with his in-laws gets him informed not only about what he ought to present for their meal but also how he ought to conduct himself during their presence. In other words, life is not lived randomly, and people do not act just because they have to do something. Organized behavior is

about purpose and selection, principles that lie at the center of cultural differences.

Indigenous Knowledge and Its Critics

The claim that there are indigenous knowledge systems has strong opposition. The opposition is often based on the mythical assumption that knowledge is universal and that the negation of this obvious truth embraces relativism. In philosophy, this myth is founded on the idea that all knowledge is empirical or, put differently, that only empirically derived statements can qualify as knowledge. The argument is then developed that if that is the case, as they believe it is, then there can only be universally true statements, leaving no room for knowing the same reality or object a different way, especially if that different way makes a claim that may appear to be the contrary of the true one. In such a case, critics claim, science is bound to prevail, as no statement can be both true and false at the same time. This argument is based on a gross misunderstanding of what exactly is meant by “indigenous knowledge.” The false view that “indigenous” means that which is both private and unscientific is widespread. The term “indigenous” has never been used in existing literature to imply beliefs that are so local they can only be understood by those who practice the specific cultures to which the claimed knowledge belongs, or that “indigenous” implies inviolable faith in one’s cultural beliefs they would be unwilling to give them up even when proven false. Such beliefs, critics claim, cannot count as knowledge which, according to the principles of Karl Popper, the historian of science, ought to be refutable by better evidence or arguments. It aims at shooting down the idea of the existence of “indigenous knowledge” which, in their misunderstanding, is conceived as a separate and parallel system of knowledge held by ordinary folk that is different from the knowledge acquired in institutions through organized and systematic research methods. Here is the irony: that critics of the idea of “indigenous knowledge,” regularly Western scholars, or scholars with agendas to protect the clout of Western attempts to control how the rest of

the world should define the world or live in it, never realize that there may be many readings of the world besides the readings through Western eyes.

Philosophy and the Concept of Indigenous Knowledge

The idea that knowledge is universal and should not allow room for relativism is especially strong among philosophers, and there are good grounds for this position. The argument for this is based on the idea of the universality of reason and rationality. In the active sense of the mind, reason is opposed here to mere perception, sensation, or another type of passive way of engaging with or experiencing an object. Reason is also defined as the employment of mental principles with which we make connections between statements or, as philosophers prefer, between propositions and draw other propositions based on the rules, logical rules, that govern the propriety of such associations and inferences. We apply such rules to assess evidence and congruency of inferences in arguments or claims as expressions of different types of belief about the world. We proclaim someone to be either rational when they correctly apply those principles in clarifying or defending their beliefs, or that they are reasonable in believing as they do based upon the type and nature of the evidence they have to support their belief. We also call a person reasonable when he or she habitually takes time to consider the manner of his or her utterances with careful application of such principles of reason. There are other principles that are regarded to be natural to how all minds of people with physically healthy brains ought to operate. They are called the natural laws of the mind, and they include the ability to abstract or make generalizations about things based on the experience of a number of them that are believed to belong to the same class or category. For example, we believe that the term "table" is applicable to an endless number of objects that satisfy a basic criterion that all objects, any object, will have in order to be a "table." This criterion or defining principle must

be somewhere in the mind since all real and individual tables will have vast physical differences between them.

The ability to have that "idea that makes an object to be a table" is called abstraction, and there is a belief that it comes naturally to the mind. Also natural to the mind is the principle that one cannot believe, for example, that an object **p** can be both itself and also not itself at the same time. That would be a contradiction, and healthy minds do not operate in a contradictory manner as speaking to other people or making sense to oneself would not be possible. This is called the law of noncontradiction. Other natural operative endowments of the mind are the ability to identify people or objects and the ability to make deductive and inductive inferences. For example, even a child who goes out to eat at a restaurant with his parents for the first time knows what a fork is because he or she is able to identify it based on what he or she has seen and had been using at home. These principles work closely with the principle of abstraction. Despite these natural and universal endowments, humans are susceptible to mistakes in the course of handling their thoughts, and the problem is not that they suddenly lose control of their mental powers. The world is both vast and complex, and aligning perceptions with beliefs is a far more complex activity than we often realize, and philosophical arguments often stem from the fact that our assumptions and beliefs about what the world really is are so different that making universally identical inferences from them is an impossibility. Philosophical dialogues are built on and aim at endeavors to understand each other's beliefs and assumptions that drive our differences.

Obsessed with the universality of the operative principles of the mind, philosophical opponents of the idea of "indigenous knowledge" claim that belief in different forms of knowledge as is implied in the concept of "indigenous knowledge" courts relativism, and, to them, this would lead to contradictory beliefs about the world. Of course, relativism is not always a good thing, especially when it may lead to irreconcilable rifts regarding positions with possible practical consequences. Sometimes, however,

relativism is evoked as a scarecrow where the real issue is the lack of understanding of what an alternative claim really is. Here is an example: in Western epistemology where the individual is believed to be the central agent for determining epistemological truth and moral right judgment, correspondence theory of truth and the theory of moral right judgment as ingrained as law in the collaborative venture between the will and pure reason respectively rule. Some African philosophers have argued that these two positions are wrong because individuals can only perceive the world from their own point of view, whatever that may be; hence, their perceptions can only be opinions, and so truth in the sense of what the world is independently of everyone's individual opinion cannot be derived from any one of them. African philosophers argue that the operative principles of the mind as we identified above do not warrant the inference that individual minds are therefore capable of apprehending the world as it truly and objectively is. The implication here is that the only things we can know directly are our own sense data or other phenomena in our own minds. The pursuit of truth, then, starts honestly only when everyone involved in any dispute about a perception should report honestly what their own point of view is – that is, what exactly it is that they have perceived or are perceiving. In their view, knowledge is always an intersubject enterprise. Similarly, they argue, what should be a morally right action cannot be a function of the perception of an individual but an intersubject enterprise. In this specific example, note is taken of what is known to philosophers as the Kantian categorical imperative. It says, basically, that “one should always act in such a manner that the principle of their action should become a universal law.” While this principle sounds true as a description of a common feeling in moral psychology of all well-thinking people, it falls short of guiding how exactly one ought to act in every specific moral case. It is the view of some African philosophers that the categorical imperative functions only as the beginning point for moral discourse in a manner pretty similar to the epistemic dialogue in pursuit of truth. Where they hold positions that differ from those held by

people from other traditions of thought, African philosophers deem their positions are better, not just because they are their own, but because the conceptual or theoretical schemes make better sense, and they would indeed rather see everyone adopt them. In the examples shown here, they argue, the differences from similar ones in the Western tradition are due to the Western myth that the individual is an autonomous agent of epistemic and moral knowledge. African thinkers, by contrast, believe that the individual is a relational being and in inextricably allied to others around her or him. Her or his well-being, not just physical and mental, but also in regard to the development to full and active operational level of the mental principles we discussed above, is dependent on others through communication. Humans are fundamentally relational by virtue of being *homo communicationis* (see Wiredu, 1980, 1996; also Appiah, 1992, and Gyekye, 1995, 1997). The idea of *homo socialis* is a function of the foundational role of communication in the making of personhood. In other words, communication is the foundation of personhood. Many African societies have stories, some of them in allegorical forms or other types of metaphors, that support these philosophical positions. Since the arrival of Christian missionaries and the eventual decision to use existing indigenous systems of thought to teach the Christian message, many of these speculative traditions have been distorted into religious beliefs, thus leading to the invention of the so-called African traditional religions. Placide Tempels, the Belgian missionary who became famous for his book entitled *Filosofie bantoue* (1944) in the Flemish original, with French translation, *La philosophie bantoue* (1945), and English translation, *Bantu Philosophy* (1959), started his project with descriptive analyses of possible points of encounter between African modes of thought and Christian beliefs. One of these, *Notre rencontre* (Léopoldville: Centre d'Etudes Pastorales, 1962) had appeared earlier in a series of journal essays. Although the libretto clarifies this point, the idea and many publications establishing something called “African traditional religions” were already in place earlier. In *African Religions*

in *Western Scholarship* (Nairobi: East African Literature Bureau, 1970), Okot p'Bitek narrates how Italian Comboni missionaries arriving in Uganda in the years just before WWII had tried in 1938, unsuccessfully at first, to convert the Luo there by trying to convince the natives to admit that there was a "creator God" who was responsible for their existence; that they, like all humans and everything that exists, had been created by this Spirit. Unfortunately, the Luo had no such idea of creation of anything, let alone of humans being created by some Spirit. This, they thought, must therefore be an evil power, albeit invisible. So they rejected the missionaries' advances until much later when, after some coaching at missionary schools, their own children would narrate the myths to them. The missionaries had to find names from neighboring communities to introduce into the Luo language for this new metaphysical concept and entity called God.

Indigenous Knowledge and the Ecosystem

The idea of "indigenous knowledge" is not about a system or body of claims about the world that is either contrary or parallel to the claims of science. As I have said above, the populations we refer to as "ordinary folk" may be people who live on the margins of those spheres that run on the dictates and practices of the grand institutional narratives, but their knowledge of facts is no hazier than anyone else's, nor are they less keen observers of the world around them than the scientists who work with specimens in the laboratory. In a recent book on indigenous technologies, Clapperton Chakanetsa Mavhunga (2014) argues rightly that if local rural communities find it easy to adapt new, mass-produced forms of technology, it is only because these new technologies are more efficient in application than the traditional ones. Thus, he explains, for example, that local communities have sometimes engaged in poaching activities not because they suddenly learned that guns kill, but because, in contrast as opposed to the poisoned arrow, guns can fell an

elephant more efficiently – that is, instantly, thus saving the killer(s) the time that would be spent trailing the animal a relatively long distance before the poison overpowers it. Local communities in Southwestern Kenya learned how to protect themselves and their domestic animals from hoards of hyaenas by trapping them with meat smeared with raw tobacco, and that it took just one hyaena to eat this for its whole family to be wiped out. To continue the trail of knowledge of dangerous materials, the Turkana in northern Kenya have throughout their history known the poison potency of the crocodile bile which they have used successfully to wipe out marauding prides of lions or scavenging leopards and other carnivores that pose threat to them and their cattle. Alongside these, local communities all over the continent and the world not only have the knowledge of other inhabitants of their natural environment, or of the flora and fauna that make part of the ecosystems that they share, they also produce materials with which to tame these systems, or they design ways to use other inhabitants as tools for their own human ends. As example of the latter, narrated by Mavhunga, hunting communities in some parts of Africa have learned to trail prides of lions along well-known buffalo passages and waited strategically for a pride's kill of the big prey before they chase the pride away to get hold of their share of the kill. Generally, hunting depended on thorough knowledge of the forest, of which animals were available for hunting – not all animals were huntable – within it and of their behavior by species. This kind of knowledge was required for planning hunts and for increasing the probability of success and the safety of participants. Knowledge of the footprints of different animals, and being able to tell their probable age and gender by reading footprints, was part of this knowledge. Equally important was the knowledge of other hunting communities; their identities, language, and customs and traditions of signaling peaceful encounters were important for preventing violence from territorial rivalry or overkills. In other words, even an activity as widespread and as everyday as hunting was not random. Experts in hunting were individuals with admirable knowledge of

the ecosystem of their region and adjoining ones. They are also often well versed in multiple major languages and dialects of their regions as well as in the customs of neighboring communities. They are indigenous anthropologists, only not formally recognized as such. Instead, and ironically, recognition is almost unexceptionally awarded to foreign scholars and sometimes their local academic heirs who depend on precisely these local experts for the data they collect and disseminate abroad. At the same time, local knowledge systems have been revealed through them. Examples include, but are not limited to, such household names like E. E. Evans-Pritchard (1937) with his widely debated account of the Azande oracular method of managing their justice system and Jan Vansina with his grounding work that formally recognized for the first time oral traditions as credible sources of history, including through regionally drawn and time-based analysis of indigenous lexicon of ecological vocabulary. The lesson here is that people know who they are and whom they are different from. They know the changes they have encountered and how those changes have affected both their identities and their understanding of the world around them. They have migrated for either political or ecologically related reasons, and they have accounts of these matters. Above all, they have their ways of archiving and transmitting such knowledge. Bethwell Allan Ogot, the eminent historian of the Luo-speaking peoples of eastern Africa, has compiled an immense historical account (see Ogot, 2009) of this large and widely dispersed population of linguistically related clusters of clans by means of a careful analysis of their language and dialectical variations and other changes such as in names of people, clans, and places to know how they moved from place to place and who they met along the way in the long march from central southern Sudan to north-eastern Democratic Republic of the Congo, to Uganda, Kenya, and eventually into northern Tanzania by c.1850. In his view (2005), history is not just destiny; it is knowledge.

The rationale used by UNESCO to establish the Indigenous Language Revitalization and Preservation Project in 1976 was that many native

languages were endangered and would likely disappear within a short time due to a variety of social pressures on minority groups around the world. Preserving or revitalizing these languages was commensurate with preserving human history as well as recognizing the contribution of all groups to the creation of human heritage. As evidenced by the works of Vansina (1961) and Ogot (1966, 1968, and 1970), much more than just knowledge of history is lost when a vernacular disappears from existence or use. A whole library of the world's ever-and-fast-changing ecosystem would disappear with the loss of any language. In the view of the UNESCO experts, native languages are a dependable source for reconstructing the history of social and scientific knowledge. Researchers who work in the areas of ethnobotany and, by extension, ethnoagriculture have documented indigenous knowledge and various practices that stretch from management of sustainability of soils and their productivity by use of organic matter to exchanges of seeds between families to vary and augment crop resistance to local crop pathologies and to vary tastes of staples. I grew up in Western Kenya where villagers cultivated different varieties of sweet potatoes and cassava, some of which were "imported" from as far away as Uganda. In the case of cassava, for example, the breed was popularly known as *Nya-Uganda* (the Uganda breed). Natural cross-pollination by bees eventually led to new breeds (Bedigian, 2006). In addition, or in the course of studying these practices and the knowledge that drives them, researchers have come to realize indigenous classification of crops and plants into edibles, medicinals, and, as we mentioned already, poisons, and that besides these broad categories, indigenous people know, cultivate, and protect those plants that belong to multiple categories, for example, plants that serve both as food and as medicines (Bedigian, 2008).

Indigenous Knowledge and Social Organization

Indigenous knowledge systems are not limited to the tabulation of flora and fauna and their

physical makeup or their genetic histories by region or to other aspects of the respective ecosystems of plants and crops. Methods of managing everyday activities and major production practices are equally important. Long before the formal currency of the term “cooperatives” in its relation to the formation of unified groups for purposes of protecting economic interests of members, villagers knew how to organize themselves into groups for more efficient cultivation and crop management. In these organizations, village women, typically the controllers of local economies, formed themselves into groups that worked together on each member’s farm on a rotational basis. This enabled all members to get their farms cultivated in time for the arrival of the rains, or that their crops were weeded and later harvested with similar efficiency of group effort, making true the adage that many hands make work lighter. Today’s so-called and fast-growing practice of “table banking” as a self-managed financial cooperative by rural women is a recent extension of the older arrangement whose goal was labor efficiency. These arrangements protect individual members and their families from shortfalls in goals of the number of farms to be cultivated or of the needed but otherwise unaffordable small-scale investments. By and large, by these measures, local communities beat the gender biases that continue to define the practices of formal financial institutions. Despite their roles in rural economies in the developing world, women are still less likely than men to own land or livestock, to attend school, let alone college or professional training, especially in areas related to food production, or to open a bank account and secure loans. Through small organizations, women everywhere are paving alternative paths to empower themselves and to feed their families. Ironically, the beneficiaries include men who are the favored gender where women are marginalized through open discrimination. In West Africa, women’s market cooperatives are many, strong, and vociferous. By their nature, these organizations are not limited to running marketplaces in the form of product delivery and pricing. They literally also control the infrastructural networks and the traffic that moves the merchandise from

ports to markets. They also, therefore, control the lives of many individuals and groups involved in this traffic and merchandise handling.

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Kūshyār ibn Labbān

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In his book *al-Madkhal fī Ṣināʾat aḥkām al-nujūm* (Introduction to the Art of Astrology), the author calls himself Kūshyār ibn Labbān ibn Bāshahrī al-Jīlī. This name indicates that Kūshyār was a son of Labbān who was a son of Bāshahrī and that he hailed from Jīlān (or Gīlān), a region of modern Iran south of the Caspian Sea. The date of the book is sometime around AD 992, the year for which positions of the fixed stars are given. In the same book he refers to his two earlier books on astronomical tables (*zīj*es), *al-Zīj al-jāmiʾ* (Comprehensive) and *al-Zīj al-bāligh* (Far-reaching). In some manuscripts “Abū al-ḥasan” (the father of al-ḥasan) is added at the top of his name. No further information is available about his family and life.

One of the most famous of his books is the *Kitāb fī uṣūl ḥisāb al-hind* (Book on the Principles of Hindu Reckoning) which is known as the oldest surviving Arabic book on arithmetic using Hindu numerals. The Arabic text is divided into two parts. In the first section of the first part, Indian numerals and the decimal system of notation are introduced. The following sections are (2) addition, (3) subtraction, (4) multiplication, (5) results of multiplication, (6) division, (7) results of division, (8) square root, and (9) arithmetic checks. The second part comprising sixteen sections is devoted to sexagesimal computations using sexagesimal tables.

According to Kennedy's (1956) classification of the subject matter of Islamic *zīj*es, Kūshyār's *Comprehensive Astronomical Table* covers the following subjects: chronology, trigonometric functions, spherical astronomical functions, equations of time, mean motions, planetary equations, planetary latitudes, stations and retrogradations, parallax, eclipse theory, visibility conditions, geographical locations, star tables, and astrological tables.

Kūshyār's book on astrology seems to have been one of the most popular handbooks on this subject, especially in the eastern half of the Muslim world, as is witnessed by the abundance of surviving Arabic manuscripts and translations into Persian, Turkish, and Chinese. The book consists of four books, following the model of Ptolemy's *Tetrabiblos*. Almost all the chapters in the first book have corresponding ones in the *Tetrabiblos*. The second book deals with so-called judicial astrology where Kūshyār shows his knowledge of topics of Persian and Indian origin. Most of the subjects in the third and fourth books are found in Books III and IV of the *Tetrabiblos*. The last two chapters of the third book are devoted to a subject which was not unknown to Ptolemy but which found a significant development in Persian astrology, namely, the rules for computing the so-called *tasyīr* arc for determining the length of an individual's life.

In the introduction of this book, he clearly distinguishes between two branches of the science of stars: astronomy and astrology in modern terms. The former, dealing with spheres of planets, their motion, and the computation of their positions, is more fundamental and is grasped by instruments and observation and is to be proved by geometry. The latter branch concerns the knowledge of human deeds which is derived from the planets, their power, and their influence upon whatever is below the sphere of the moon. This is grasped by experience and analogy (*qiyās*).

See Also

► [Sexagesimal System](#)

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La Taptana

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The *taptana* is a contemporary version of a historical abacus device known as the “Cañari Counter” (“contador Cañari”) from Ecuador. Numerous finds of this kind in the region of Cañar suggest that many years ago rocks with inscriptions used for counting purposes were commonplace; thus, the historical Ecuadorian abacus carries the name of the region in which it was found. Evidence of such carved rocks is found in museums throughout Ecuador (Fig. 1), although it is difficult to acquire images of such ancient artifacts. Two such devices were referenced by Carlos Radicati di Primeglio (1990) (Fig. 2), noting that these particular rock counters found in Ecuador are different from the *yupanas* of Peru because the counting compartments are created by incisions on the surface of the rock instead of carved hollows. These devices also differ from the *yupanas* because their composition is more indicative of a circular counting motion as noted by Montaluisa (Fig. 3).

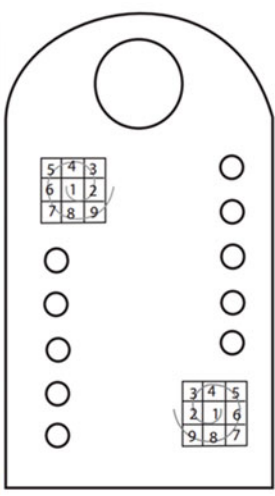
The historical abacus, the contador Cañari, is a tablet composed of two three-by-three tables

located diagonally across from one another, with additional spaces carved alongside (Fig. 3). The tables are used to move stones in a circular motion to either add or subtract values, and the five spaces on either side of these tables could have represented the first five multiples of 10: 10, 20, 30, 40, and 50. The presence of five holes on either side of both of the table incisions does not appear to be coincidental as many Ecuadorian languages favor multiples of 5 in their linguistic understanding and labeling of numeric values (Fig. 4). This interpretation would only work for adding and subtracting values whose result did not supersede 59; it is probable that alternative methods were used for representing and manipulating larger values.

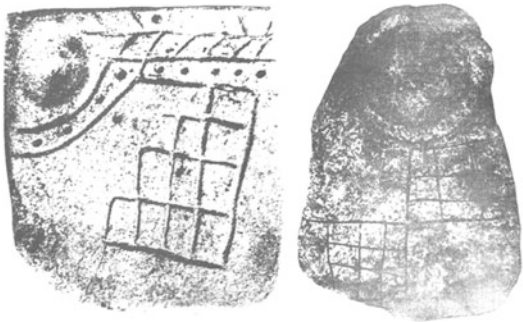
Using the circular motion and tabular values proposed by Montaluisa (Fig. 3), we propose a method of addition and subtraction whose simultaneous circular motions act as a dual system of checks and balances, typical of Andean math systems and records, as noted by Gary Urton in regard to the *quipu* (2009). The summands are placed on the top and bottom tables, and the bottom summand is added to the top summand by moving the top summand in an increasing direction and the bottom summand in a decreasing direction, until the bottom summand reaches 0 and the addition is concluded. As the top summand moves from 9 to 1, a step is taken to increase the tens counter, and as the bottom summand moves from 1 to 9, a step is taken to decrease the tens counter. For example, let us



La Taptana, Fig. 1 Ancestral Cañari Taptana. Courtesy of the reserve of the Museum of the Central Bank of Ecuador (Photo by David Montaluisa Álvarez y María Belén Montaluisa Álvarez)



La Taptana, Fig. 3 The Cañari Counters (Contadores Cañari). On the right side we see the values that each square held and a direction used for counting as proposed by Montaluisa (From Montaluisa, 36–37)



La Taptana, Fig. 2 Historical taptanas (After Radicati di Primeglio, 225)

add $27 + 14$ by placing 27 on the upper table and 14 on the lower table (Fig. 5:A). We will eventually move the stone in the top table 11 times, passing through the values representing 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, and 41 while the bottom counter is reduced to 0 (Fig. 5:B–O). The final summation, 41, is represented on the final taptana (Fig. 5:O). Additional tokens used in the calculation could be placed in the carved hollow above the tables, which has been eliminated from this sketch for the sake of simplicity.

The ingenuity of these historical instruments inspired Luis Montaluisa to create a contemporary

version of the abacus for use in education. Montaluisa is a linguist who has dedicated a part of his life to uncovering and promoting Quichua language and cultural production in Ecuador through curriculum development and the creation of local linguistic and numeric models. Montaluisa stresses that the Quichua language actually better represents and structures numeric words than many romance languages. While English requires learners to memorize the number lexemes 1 through 19 as these are unique denominators that do not show repetitions in the creation of subsequent values, a Quichua speaker simply needs to memorize the lexemes for 1 through 10 (*shuk, ishkey, kimsa, chuska, pichka, sukta, kanchis, pusak, iskun, chunka*) as every subsequent number is a direct composition of these 10. In addition, English requires the rote memorization of the distinct powers of 10 while in Quichua these powers of ten can be derived from the base number lexemes (ex., $20 = 2 \times 10$ or *ishkay chunka*). This is illustrated below (Fig. 6) in a table similar to the one constructed by Montaluisa (2011), but differentiates between those numbers that can be derived from unit number words and those whose particularities simply require them to be stored in memory. Given the capacity of the Quichua language to represent and understand number patterns

No.	Cha'pala (Chafiki)	Waotededo	Siapedee	Paikoka/Baikoka
1	mallu	adoke	aba	te 'o / te 'e
2	pallu	mea	omé	kayayë
3	pema	mea go adoke (2+1)	ompé	toasofñë
4	Taapallu (2+2), (2x2)	mea go mea (2+2)	khimari	kajese 'ë
5	manda	emenpoke (right hand)	joisomá	te 'ejënte
6	manchis mallu (5+1)	emenpoke go adoke (5+1)	joisomá aba (5+1)	te 'ejënte te 'o (5+1)
7	manchis pallu (5+2)	emenpoke go mea (5+2)	joisomá omé (5+2)	te 'ejënte kayayë (5+2)
8	manchis pema (5+3)	emenpoke mea go adoke [5+(2+1)]	joisomá ompé (5+3)	te 'ejënte toasofñë (5+3)
9	manchis taapallu [5+(2+2)]	emenpoke mea go mea [5+(2+2)]	joisomá khimari (5+4)	te 'ejënte kajese 'ë (5+4)
10	paytya (2x5)	tipenpoke (left hand)	omé joisomá (2x5)	si 'ajëna

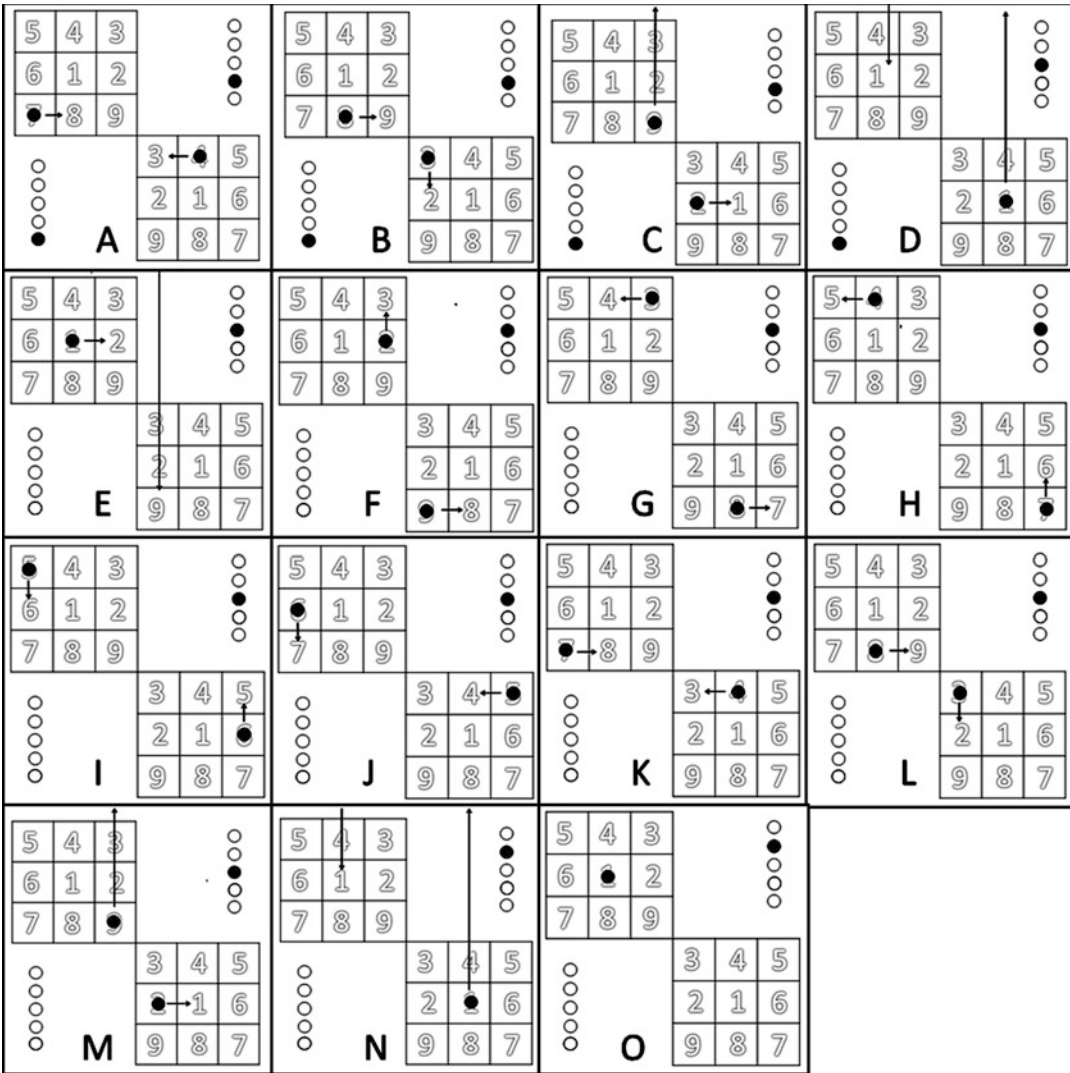
La Taptana, Fig. 4 Numbers 1–10 in various indigenous languages of Ecuador (Image by Molly Tun after Montaluisa, 14–16)

in base 10, the taptana actually operates most perfectly when using this language.

The taptana created by Montaluisa, known as the Taptana Montaluisa, highlights this relation by illustrating each power of 10 in a separate column, starting with the ones column on the far right (Fig. 7). Each column is composed of nine holes, indicative of the nine memorized numbers in Quichua (numbers 1–9), and each subsequent column presents a different multiplier of 10 (*chunka*). This abacus not only shares a close relationship with the Quichua language but also with the representation of numbers using Arabic numerals, common to most mathematics classrooms. In a fashion similar to that of adding with pen and paper, the taptana can be used to add, subtract, multiply (repeated addition), and divide (repeated subtraction), by combining the tokens in the units column first and working from

right to left. Only two rules regulate taptana calculations: (1) groups of 10 tokens are bundled together in a single token, and (2) bundled tokens are placed in the adjoining column on the left.

This calculating device is also known as the Taptana Nikichik which is identical except for the implementation of distinct colors in each column; the taptana ultimately designed by Montaluisa has been copied and reproduced by other individuals and organizations claiming it as their own. Those parties benefitting from taptana designs along with the attention this calculating device has received in contemporary society and its widespread use have led Montaluisa to patent his design, although he does wish for greater diffusion of the taptana to aid in mathematics education efforts throughout Ecuador (Fig. 8). Montaluisa named this counting device the “taptana” because this was the denomination



La Taptana, Fig. 5 Possible method of addition on the Cañari Counter, showing $27 + 14 = 41$ (Image by Molly Tun)

given to the “chess” or “playing boards” in Domingo de Santo Tomás’s Quechua dictionary *Lexicon, o vocabulario de la lengua general de Peru* (1560). Montaluisa also notes that Nikichik is misleading as this term in Quechua refers to ordinal numbers as opposed to cardinal numbers. He writes: “I must inform that some people, without consent of the author, have started denominating the Taptana Montaluisa as Taptana Nikichik and place different colors in the columns. This is a mathematical error, since *nikina* in Quechua, is to order a sequence in relation to a

referent. *Nikina*, from which come the words *niki*, *nikichina*, *nikichik*, serve to designate the ordinal numbers, not to represent the cardinal numbers. Nor does it explain a system of positional enumeration. The *niki* is used for example in *Shukniki* (first, this appears to come from *shuk mikpi*), *ishkayniki* (second), *kimsaniki* (third), etc. *Nikichina* means to order. This doesn’t have anything to do with the fundamental objective of the Taptana Montaluisa, the latter being positional. Therefore, in the Taptana Montaluisa distinct colors are not placed in the columns.

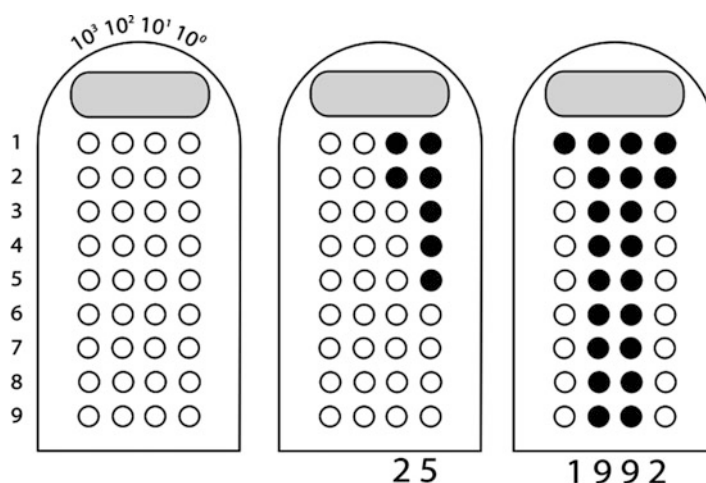
No.	Quichua	English	Spanish
1	Shuk	One	Uno
2	Ishkay	Two	Dos
3	Kimsa	Three	Tres
4	Chusku	Four	Cuatro
5	Pichka	Five	Cinco
6	Sukta	Six	Seis
7	Kanchis	Seven	Siete
8	Pusak	Eight	Ocho
9	Iskun	Nine	Nueve
10	Chunka	Ten	Diez
11	Chunka Shuk (10+1)	Eleven	Once
12	Chunka Ishkay (10+2)	Twelve	Doce
13	Chunka Kimsa (10+3)	Thirteen	Trece
14	Chunka Chusku (10+4)	Fourteen (4+10?)	Catorce
15	Chunka Pichka (10+5)	Fifteen	Quince
16	Chunka Sukta (10+6)	Sixteen (6+10?)	Dieciseis (10+6)
17	Chunka Kanchis (10+7)	Seventeen (7+10?)	Diecisiete (10+7)
18	Chunka Pusac (10+8)	Eighteen (8+10?)	Dieciocho (10+8)
19	Chunka Iskun (10+9)	Nineteen (9+10?)	Diecinueve (10+9)
20	Ishkay Chunka (2x10)	Twenty	Veinte
30	Kimsa Chunka (3x10)	Thirty	Treinta
40	Chuska Chunka (4x10)	Forty	Cuarenta
50	Pichka Chunka (5x10)	Fifty	Cincuenta
60	Sukta Chunka (6x10)	Sixty (6x10?)	Sesenta
70	Kanchis Chunka (7x10)	Seventy (7x10?)	Setenta
80	Pusak Chunka (8x10)	Eighty (8x10?)	Ochenta
90	Iskun Chunka (9x10)	Ninety (9x10?)	Noventa
99	Iskun Chunka Iskun (9x10+9)	Ninety nine (9x10?+9)	Noventa y nueve (90+9)

La Taptana, Fig. 6 Table of number lexemes in Quichua, English, and Spanish. Numeration in Quichua requires far less memorization of number lexemes than in other languages in order to derive the full range of values (Image by Molly Tun after Montaluisa, 12)

Different colors in the columns of the taptana are distractors that can cause difficulty in understanding the concept of the positional value of numeric symbols, and of the semiotic process of the

formation of abstract thinking and mathematic thought” (2011). Other variations of the taptana have also been identified in historical and contemporary

La Taptana, Fig. 7 The Taptana Montaluisa. The columns represent distinct powers of ten, with the ones, tens, hundreds, thousands, etc. moving from left to right. The counters can either be placed closest to the top or bottom of the tablet (Image by Montaluisa, 21)



La Taptana, Fig. 8 Children from Cañar calculating with the Taptana Montaluisa and the Taptana Cañari, 2014 (Photo by Magdalena Guamán)

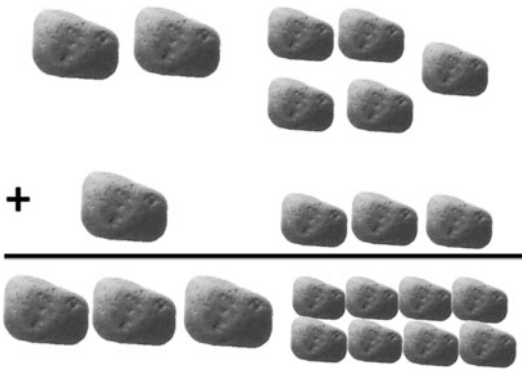
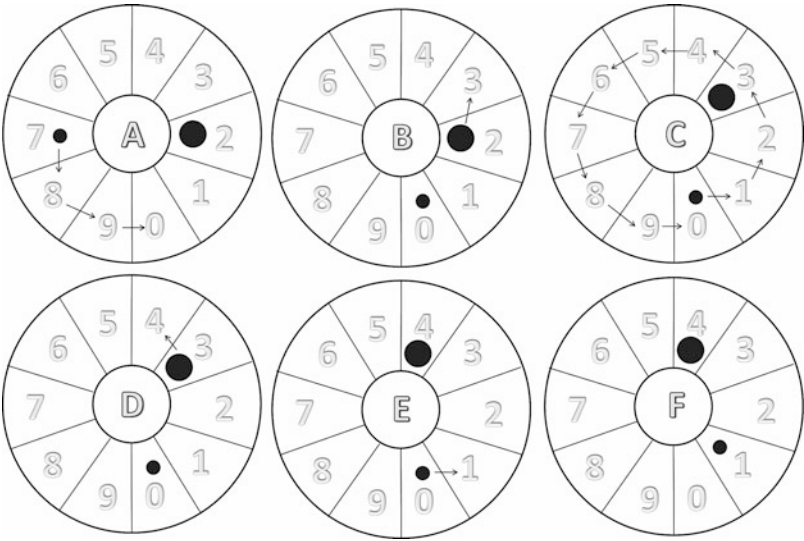
contexts. As the multitude of indigenous Andean languages have different ways of representing numeric values (see Fig. 4) and rely on different bases, the Taptana Montaluisa could easily be modified to match a numeric system of any base. Just as the base-10 taptana (Fig. 7) has nine spaces in each column, a base 8 system would contain seven spaces, a base 5 system would contain four spaces, etc. Other circular counting tablets (Fig. 9) have been designed such as that used by Yonit Bousany in a bilingual Quechua-Spanish school outside of Cusco (2008). With this method a summand is placed on the table and another summand may be added by moving the units token in a counter-clockwise motion the desired number of additional spaces.

The only rule to this taptana is that whenever a token crosses 0, the next larger place value token must be increased one space. This variation of the taptana uses stones of various sizes (or colors) to represent the ones, tens, and hundreds. This method reflects the various Andean traditions of using stones (or knots) of multiple sizes as indicators of place value in order to calculate (Párraga Chirveches 1992; Figs. 10–11).

The studies working to promote knowledge and use of both the contemporary taptana and the historical Cañari Counter contribute to an ethnomathematical discussion of alternative conceptions of numeracy and quantification in an attempt to recover indigenous ways of knowing. The circular counting techniques of Ecuador and

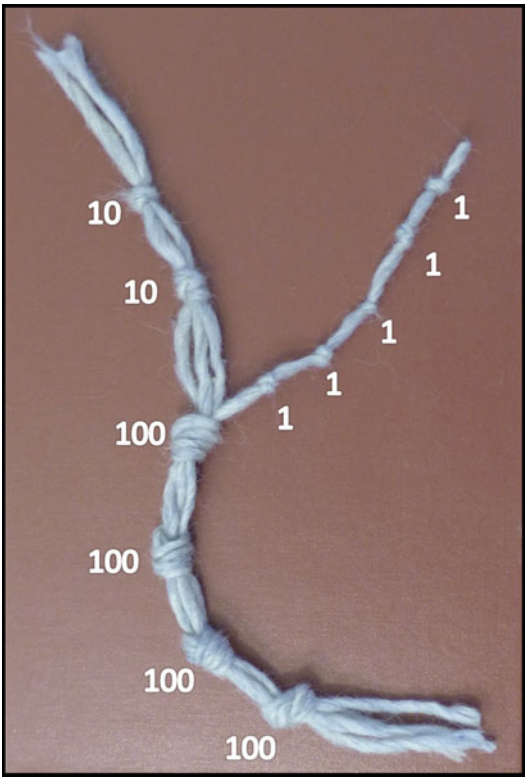
La Taptana,

Fig. 9 Adding on a circular version of the taptana, showing $27 + 14 = 41$ (Image by Molly Tun)



La Taptana, Fig. 10 This image shows the calculation of oxen prices (Bs 2.500 + Bs 1.300 = Bs 3.800) as practiced in the Bolivian provinces of Camacho, Loayza, and Ingavil (Image by Jennifer Leonard)

other Andean communities deeply contrast with the linear, chronological number line as conceived of in Western culture and provide definite advantages to the numeration and manipulation of values. Taptana is oftentimes associated with indigenous board games (Arriaga, Verneau, and Rivet) and has been equated to the game shown in Guaman Poma de Ayala's illustration (Holm 1958; Fig. 12). Regardless, the knowledge of these game boards and counting tablets was lost with the extermination of indigenous culture, in



La Taptana, Fig. 11 In the Bolivian province of Omasuyos different sizes of knots are used to represent different place values of ten as seen in the knotted value of 425 above (Photo by Molly Tun)



La Taptana, Fig. 12 Atahualpa and a Spanish soldier gathered around a taptana or alquerque game board before Atahualpa's execution

this case symbolically represented through the execution of Atahualpa (Fig. 12). Although many of the exact details regarding the historic counting techniques of the Andes are unknown, engaging in the tradition of the taptana seeks to recover the indigenous perspective that has been obscured through processes of colonization and globalization.

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Lalla

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Lalla was an eighth-century Indian astronomer, astrologer, and mathematician from Dasapura in the Mālava region of western India. He was the son of Tāladhvaja and grandson of Trivikrama, also known as Sāmbha. He is known for his *Śiṣyadhīvrddhida*, a text to “improve the student’s intellect.” This work was perhaps meant to be a textbook for scholars of astronomy. Lalla also wrote the *Jyotiśaratnakośa*, a treatise on astrology that survives in the form of several incomplete manuscripts.

Lalla was an Āryabhaṭan by persuasion. He wrote the *Śiṣyadhīvrddhida* in order to expound Āryabhaṭa’s tenets of astronomy. Nevertheless, he was also critical of the master and at times adopted principles promulgated by the rival school

pioneered by Brahmagupta. For instance, he refuted Āryabhaṭa's theory that the earth was in a state of rotation. If this view were to be accepted, Lalla held, how would it be possible to explain how birds flying in the sky returned to their nests to roost? Lalla also suggested that the principles for astronomical calculation proposed by Āryabhaṭa be accepted but advocated corrections to be carried out every 250 years, beginning with the base year, 498 CE. The first such corrections were due for 748 CE, which is generally considered the date of Lalla. In his calculations, Lalla used 62832/20000 as the value of π .

The *Śiṣyadhīvrddhida* was considered a work of great significance for many centuries. It invited commentary from no less a figure than Bhāskara II in the twelfth century. It is divided into two sections, the *Grahādhyāya* on celestial calculations and the *Golādhyāya* on spherics. The *Grahādhyāya* consists of 13 chapters dealing with the mean and true longitudes of planets, the three problems concerning diurnal rotation, eclipses, syzygies, etc., and includes discussions on planetary and astral conjunctions and the moon's cusps. The *Golādhyāya* has nine chapters, which handle among other things the graphical representation of planetary motion, principles of mean motion, the celestial and terrestrial spheres, geography, a critique of superstitions about astronomy, and astronomical instruments. Lalla's is one of the few Indian texts that tell us how to construct an armillary sphere. The model it proposes consists of an inner sidereal sphere and an outer sphere representing the firmaments, the *bhagola* and the *khagola*, respectively. It carries a pin that roughly corresponds to the equator and the ecliptic. The sidereal sphere is rotated so as to allow the pin's shadow pass through the center of the sphere. Lalla uses this to determine the time of the orient ecliptic point (*lagna*). The arc of the equator intervened by the pin, and the horizon shows the time elapsed since sunrise, and the one on the ecliptic indicates the degrees risen since sunrise.

There is very limited information about Lalla's life. He is said to have written a commentary on Brahmagupta's *Khaṇḍakādhya*, which has not

yet come to light. Lalla was also a mathematician, whose propositions were extensively quoted by writers who followed him. His work on mathematics has also not been found so far. That he was a master of the three sciences (astronomy, astrology, and mathematics) seems to have earned him the title *Triskandavidyākuśalaikamalla*. His work influenced many later-day astronomers in India, like Vaṭeśvara, Śrīpati, and Bhāskara II.

See Also

- [Armillary Spheres in India](#)
- [Āryabhaṭa](#)
- [Astronomy in Medieval India](#)

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Land, Labor, Water, and Technology in Pre-Columbian South America

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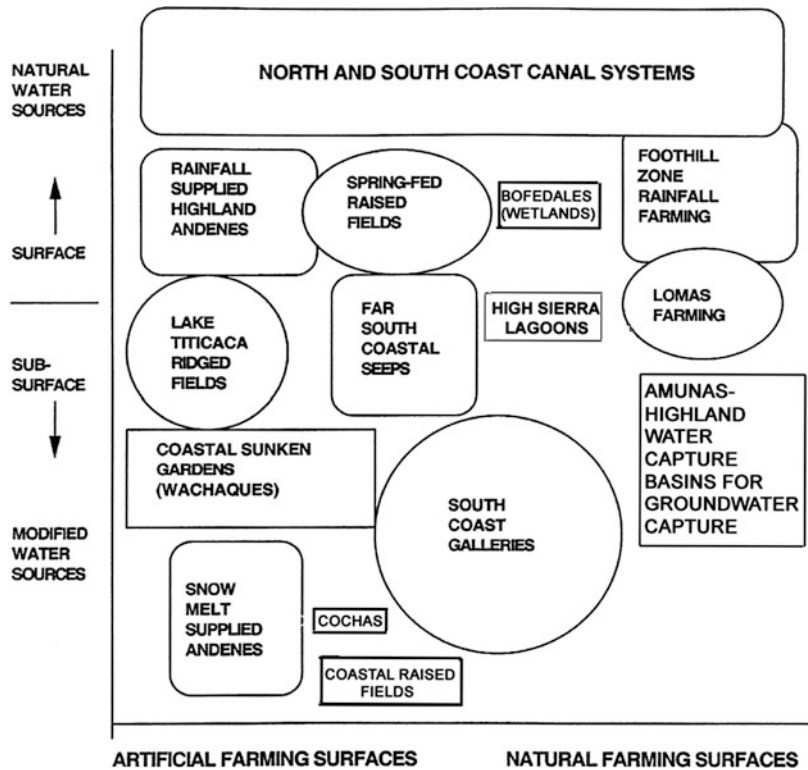
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Measuring Engineering Creativity

Archaeology examines the cultural remains of a society. Through anthropologic models, it attempts to interpret the thinking and societal/political/economic structure underlying the

Land, Labor, Water, and Technology in Pre-Columbian South America,

Fig. 1 Agricultural techniques used in different Andean ecological zones



creation of ceremonial and secular architectural remains, iconographic and material objects, and historical reports from ancient sources. These tell how a society used resources to support its institutions and how it was organized and achieved sustainability. Further insight derives from examination of the use of land, labor, water, and technology to optimize agricultural production to maintain societal continuity through weather, climate, and geophysical landscape variations. The development of technologies vital for agricultural yield increase follows from observation of what works best to increase agricultural production. These heuristic principles were refined over time by in-field agricultural experiments (and chance discoveries) to improve field system designs and irrigation strategies. While the archaeological record demonstrates the progression of engineering skill applied to agricultural systems as they evolved over time, the science underlying changes in agricultural system evolution remains

elusive as the archaeological record shows evolutionary changes but not the development and codification of the science underlying these changes.

To investigate the science underlying evolutionary changes in agricultural systems, one strategy is to determine the theoretical optimum use of land, water, labor, and technology given a society's resource base and then to determine, from the archaeological record, how close to this optimum was achieved. Given the wide variety of agricultural methods applied by Andean civilizations adapted to different environmental conditions (Fig. 1) and archaeological knowledge of societies that occupied Pre-Columbian Peru and Bolivia, examples illustrating their agricultural strategy changes due to climate and geophysical landscape change provide illustrative cases on how these societies modified land, labor, water, and technology to maintain productivity. Given that different productivity optimums exist for different environmental resource conditions in different areas occupied by

different Andean societies, different optimum conditions exist. A basic equation that incorporates land, water, labor, and technology parameters as independent variables and the rate of food production as the dependent variable is required to evaluate agricultural strategy evolution. When coincidence exists between equation predictions and archaeological record observations of agricultural field evolution in terms of use of land, water, labor, and technology to achieve optimum food production, then insight into the thinking used by ancient Andean societies follows.

The derivation of an equation that relates optimum use of land, water, labor, and technology variables to the rate of food production is achieved by use of Buckingham Pi-Theorem (Buckingham, 1914; Murphy, 1950) similitude methods. The first step is to express the units of key variables in terms of length (**L**), mass (**M**), and time (**t**) as follows.

Variable	Description	Units
F	Food supply mass over a time interval	M
dF/dt	Rate of food production over a time interval (time derivative)	M/t
r	Average consumed food mass/person over a time interval ($r = \text{constant}$)	M/r = total population P (number of persons)
L_c	Total canal lengths to supply land area A	L
A	Area under cultivation	L²
V	Volume of terrain removed/alterd to produce terraces or canals; this parameter relates to the labor force size and soil volume transfer capacity; in terms of units, $k_1 \mathbf{M}$ = labor force and $k_2 \mathbf{L}^3$ = total soil volume removed and/or altered on a project by the $k_1 \mathbf{M}$ labor force	L³

(continued)

Variable	Description	Units
Q	Water volumetric supply rate	L³/t
t	Time	t
Φ/Φ*	Technology level (low angle surveying)	
	(Low) $0 < \Phi/\Phi^* < 1$ (High)	Nondimensional

The equation for optimum use of land, water, labor, and technological resources is expressed in general functional form as:

$$dP/dt = f(L_c, A, V, Q, t, \Phi/\Phi^*)$$

or, after applying the Pi-Theorem,

$$\left(A^{3/2}/QP \right) (dP/dt) = f\left(L_c/A^{1/2}, V/A^{3/2}, Q t/A^{3/2}; \Phi/\Phi^* \right)$$

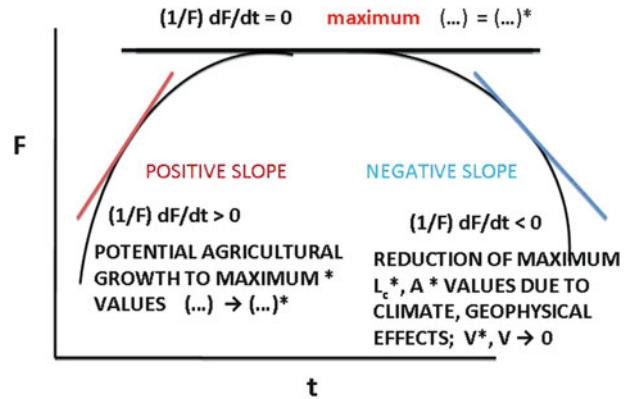
Rearranging and selecting a functional form with k_1 , k_2 constant and population **P** related to food supply **F** and the food mass consumption per person **r** (in a time interval) by

$$P = F/r, \text{ then}$$

$$\begin{aligned} (1/F)(dF/dt) = K \left\{ \left[(L_c^* - L_c)/(A^* - A - \Delta A^*)^2 \right. \right. \\ \left. \left. + (V^* - V)/|A^* - A - \Delta A^*|^3 \right] \right. \\ \left. \cdot \left[(Q^* - Q)|Q - Q^*|t(\Phi/\Phi^*)/ \right. \right. \\ \left. \left. |A^* - A - \Delta A^*|^3 \right] \right\} \end{aligned}$$

where $K = \text{constant}$ and $\Delta A^* = \text{fraction of maximum land area } A^* \text{ unusable for cultivation due to nonaccessibility by an irrigation canal or landscape contours. The } * \text{ notation denotes the maximum value of a variable. The basic equation incorporates a constraint condition guaranteeing maximum food production when all land, water,}$

Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 2 Food supply (F) as a function of time (t)



labor, and technology resources are maximally (*) exploited. While different functional arrangements are possible, the selection given reproduces known economic laws and provides interpretation of archaeological data related to agricultural field systems and irrigation networks. When L_c , V , A , and Q equal their * counterparts, $dF/dt = 0$ given that $0 < \Delta A^* < A^*$. The zero derivative denotes a maximum value of food production in an F versus t plot (Fig. 2); the zero derivative coincides with zero slope at the maximum of the F versus t curve. A positive slope of the F versus t curve, $dF/dt > 0$, indicates potential growth of a society's food supply due to large available exploitable resources of land, water, labor, and technology ($L_c < L_c^*$, $V < V^*$, and $Q < Q^*$). For negative slope, $dF/dt < 0$, and land, water, labor, and technology resources are diminishing caused by flood deposition/erosion events, farming land area contraction due to drought and/or geophysical land wasting effects, water supply decline, and/or labor decline due to plagues/migrations. Here L_c^* decreases rapidly below L_c , indicating rapid contraction of the irrigation canal network due to drought or geophysical land wasting effects, and $V > V^*$ as a larger than necessary labor force works less available land. No options remain to sustain food production as A^* contracts and Q can exceed Q^* indicative of available, but non-usable water, due to contraction of arable land and the canals necessary to support them.

To illustrate the application of the basic equation, two scenarios are examined. The first considers too large a labor force ($V > V^*$) exploiting a small farming area ($A < A^*$) with low water resources ($Q < Q^*$) using a low level of technology in the form of short irrigation canals (L_c^* small) emanating from a river source. Here

$$(1/F)(dF/dt) \approx K \left\{ \left[(L_c^*) / (A^* - \Delta A^*)^5 \right. \right. \\ \left. \left. + (V^* - V) / (A^* - \Delta A^*)^6 \right] (Q^*)^2 t (\Phi / \Phi^*) \right\} < 0$$

where the dominant ($V^* - V$) term is negative and $A^* - \Delta A^* > 0$ leading to $(dF/dt) < 0$. The above expression is a version of the *economic law of diminishing returns* in that excess labor ($V > V^*$) added to balanced resource assets (V , L_c , A , Q) does not increase food output without a corresponding increase in the resource assets that utilize additional labor resources. This condition is typical of the leftmost branch of the Fig. 2 F versus t curve. A second example involves a small labor force exploiting large farming areas with large water resources using a high level of technology. Here $V < V^*$, $A < A^*$, $Q < Q^*$, and $\Delta A^* < A^*$. The basic equation becomes

$$(1/F)(dF/dt) = K \left\{ \left[(L_c^* - L_c) / (\Delta A^*)^5 \right. \right. \\ \left. \left. + V^* / (\Delta A^*)^6 \right] Q^{*2} t (\Phi / \Phi^*) \right\} > 0$$

where $(1/F)(dF/dt) > 0$ indicating potential to increase food production. This result is typical

of the rightmost branch of the Fig. 2 F versus t curve. A further result originates from extreme drought conditions imposed upon a canal irrigation system; here $Q \rightarrow 0$ with Q^* small with remaining variables fixed at their pre-drought values; the basic equation reduces to

$$\partial F / \partial Q \sim \exp \left\{ -c(Q^*t)^2 \right\}$$

where c is a constant; as food supply F is balanced with and supports population through $P = K_1 F$,

$$\partial P / \partial Q \sim K_1 \exp \left\{ -c(Q^*t)^2 \right\}$$

where K_1 is a constant equal to $1/r$. This indicates that population P diminishes as negative (time)² under severe and sudden drought conditions in a closed system where food resources are available from land, water, and labor within a closed geographical boundary with no outside resources available.

From the basic equation, a new form of civilization extinction can be derived and compared to

Malthusian predictions (Malthus 1798). Figure 3 shows Malthusian theory where population increases geometrically with time while food resources increase linearly with time. In the past when food supply and population curves cross, civilization extinction prevails as food supply F is inadequate to support population P . Using the basic equation, again with population increasing geometrically with time, the food production curve under extended drought conditions lasting from $\int_{t_0}^{t_1}$ is

$$F = k_3 \int_{t_0}^{t_1} (\partial Q / \partial t) \exp \{ -k_4 t^2 \} dt$$

where k_3 and k_4 are positive constants and F depends on the water decline rate $(\partial Q / \partial t)$ between time limits t_1 and t_0 . If the decrease in water supply due to drought $(\partial Q / \partial t)$ is exponential in time in the form $k_5 \exp \{ -k_6 t \}$, $k_5 < 0$, $k_6 > 0$, then the food decline with time is

$$F = F_0 - |k_3| (k_5/2) (\pi/k_4)^{1/2} \exp \{ k_6^2/4 k_4 \} \operatorname{erf} (k_4^{1/2} t + k_6/2 k_4^{1/2}) \Big|_{t_0}^{t_1}$$

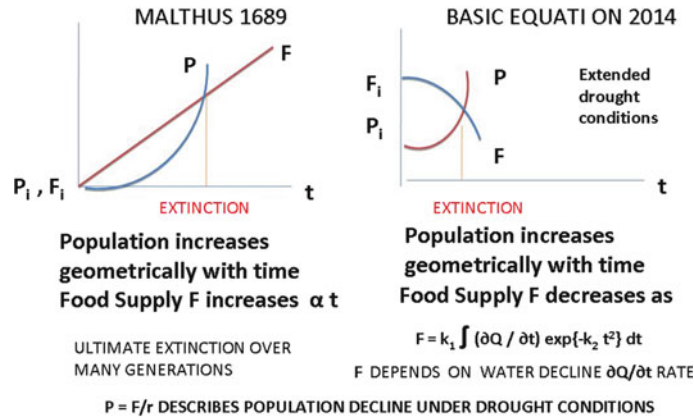
where $\operatorname{erf} (\dots)$ is the error function (Abramowitz & Stegun, 1964) and F_0 is the food mass at t_0 , k_3 and k_4 have dimensions of (time)⁻², k_6 has dimensions of (time)⁻¹, and k_5 has dimensions of (mass)⁻¹. From Fig. 3, when the P (population) and F (food mass) curves cross, insufficient water is available to support food supplies necessary for a geometrically growing population under extended drought conditions causing civilization extinction to occur.

Figure 4 shows the sustainability of major ancient South American civilizations (Ortloff & Moseley, 2009) occupying coastal and mountainous highland areas within present-day Peru and Bolivia. Major seventh- and tenth-century CE drought (Thompson, Davis, & Mosley-Thompson, 1994) caused cultural decline and

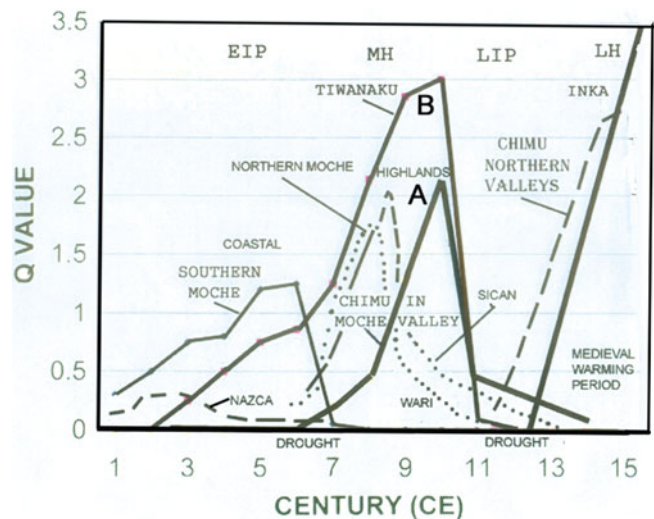
societal transformation of several major Andean societies in their homelands while other societies were able to cope with changes in irrigation water supplies through modification of their canal systems and/or massive construction projects transferring water from distant sources. An example from the Chimu society of north coast Peru involved construction of the 75 km long Inter Valley Canal in the tenth century CE that transferred water from the Chicama River to reactivate distant Moche Valley desiccated fields (Ortloff, Moseley, & Feldman, 1982; Ortloff, 1993, 2009). In other cases, migration to ecological zones with larger water and land resources occurred (seventh-century CE Moche migration to the Lambayeque Valley, Dillehay, 2001), while other examples exist where conquest of

Land, Labor, Water, and Technology in Pre-Columbian South America,

Fig. 3 Extinction theories: Malthus (1689) and the basic equation (2014)



Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 4 Time spans of major Andean societies



weaker states and population transfer occurred (thirteenth–fourteenth-century Inka conquests, D’Altroy, 2003). Examples of other societies disappearing from the archaeological record unable to cope with ecological disasters, geophysical landscape change, drought, and El Niño flood events altering field system’s productivity are indicated from archaeological records (Fig. 4). Figure 5 provides a list of these events, and Figs. 6, 7, and 8 illustrate landscape changes that marginalized former agricultural areas evident from satellite imagery and archaeological excavations (Ortloff, 2009; Ortloff and Moseley, 2012). Figure 9 illustrates results from archaeological excavations of canal profiles taken from the Huanchaco canal (N1, N2, and N3 profiles,

Fig. 13) that provided agriculture for the Chimú capital of Chan Chan. Successive contractions of canal profiles mirror the decline in available water supply from the Moche River through canal systems during the tenth-century CE drought (Ortloff, 2009; Ortloff et al., 1982, 1985; Ortloff and Moseley, 2009).

Advances in Technology

The benefit of higher agricultural technology levels is next considered. More coastal field area can be used when lower canal slopes are achievable as canals placed higher on sloping hillsides include more downslope farming area. Assuming

- 6-7TH CENTURY CE LAMBEYEQUE SICAN COLLAPSE INFLUENCED BY DROUGHT
- 6-7TH CE CENTURY DROUGHT, SAND ENCROACHMENT INTO THE MOCHE VALLEY- COLLAPSE OF SOUTHERN MOCHE V
- SUPE VALLEY LATE FORMATIVE PERIOD 1800 BCE LOSS OF COASTAL AGRICULTURAL LANDS DUE TO FLOOD EROSION, BEACH RIDGE FORMATION, BAY INFILLING AND AEOLIAN SAND TRANSFER COMPROMISING THE AGRICULTURAL AND MARINE RESOURCE BASE
- 10-11TH CENTURY CE COLLAPSE OF CHIMU MOCHE VALLEY AGRICULTURAL LANDS FROM DROUGHT, TECTONIC RIVER DOWNCUTTING LAND LOSS
- 10-11TH CENTURY CE COLLAPSE OF TIWANAKU, WARI SITES DUE TO DROUGHT
- 10-11TH CENTURY CHIMU JEQUETEPEQUE VALLEY SITES INFLUENCED BY DEFLATION, DROUGHT EPISODES
- EARLY COASTAL SOCIETIES IN FAR SOUTHERN PERU- ILO, MOQUEGUA AREAS

Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 5 Examples of A* agricultural land loss from climate and geophysical effects for major Andean societies

Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 6 Marsh infilled coastal bay from flood debris transfer blocked by a beach ridge; bay located on the Peruvian north central coast area resulting in A* loss of arable land and loss of the marine resource base. Event occurred in the Late Archaic/Preceramic Period 3000–1600 BCE



additional farming land available for canal placement, then from surveying accuracies sufficient to measure small canal declination slopes, A/A^* is proportional to the technology ratio Φ/Φ^* . Here Φ^* represents the maximum angular refinement possible given the accuracy achievable by Chimu surveying instruments (Ortloff, 2009). Substituting $A/A^* \propto \Phi/\Phi^*$ into the basic equation and integrating over time,

$$F = \exp\left\{K A^*{}^{-1} \left[(L_c^* - L_c) / \Omega^2 + (V^* - V) / A^* \Omega^3 \right] \right. \\ \left. (Q^* - Q) |Q - Q^*|^2 / 2 A^*{}^2 \Omega^3 \right\}$$

where $\Omega = (\Phi/\Phi^*) - 1$. As $\Phi/\Phi^* \rightarrow 1$, $\Omega \rightarrow 0$ and F increases. For a fixed water resource $Q < Q^*$, canal lengths $L_c < L_c^*$, and labor resources $V < V^*$ and A^* , as Ω decreases toward zero, F increases exponentially due to Ω^2 and Ω^3 terms. Figure 10 shows surveying accuracies (in degrees) for several major Andean societies in different time periods. Figure 11 plots these values and illustrates that from early surveying accuracies available at 2500 BCE, technical transfer (or invention) occurred over time to refine surveying accuracies producing an A^*

Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 7

Infilled bay behind a beach ridge in the Peruvian Supe-Huanchaco Valley coastal zone that gradually destroyed the bay marine resource base of preceramic coastal societies over time.



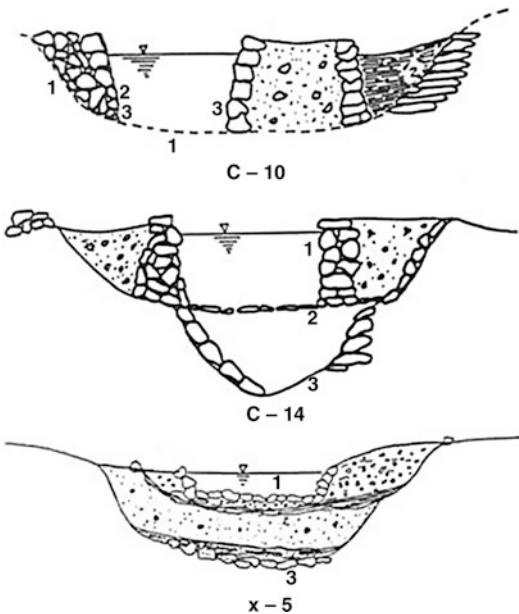
Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 8

Aeolian sand infiltration – Supe Valley agriculture moves from wide, down-valley to narrow, upvalley field areas in the Late Archaic/Preceramic Period



increase from larger populations requiring higher productivity from increased land resources. From Fig. 11, technology advanced by technical transfer/information diffusion exchange between societies or from invention within a society with little contact with more advanced societies. For any of these paths, direct evidence is absent from the archaeological record, but guidance as to how Andean technology developed can be obtained from the basic equation.

If the rate of technology growth ($\partial\Phi/\partial t$) originates from an existing, highly developed body of knowledge ($\Phi \sim \Phi^*$), the rate of technical advancement derives from the present technology level. In mathematical terms, $\partial\Phi/\partial t = k\Phi$ or $\Phi = C e^{kt}$ where k and C are constants. Substituting into the basic equation, integrating, and examining time dependence, $F \sim (e^{kt}) (k t - 1)$ results from which $\partial F/\partial t \sim k^2 t e^{kt}$ governs the increased rate in food production with time. This



Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 9 Contraction of Chimu Pampa Huanchaco canal cross-sections due to ninth–tenth-century CE Drought. Original canal profile (1) contracts to (2) and finally (3) under sustained drought that progressively decreases canal flow rate

indicates that high levels of technology growth proceed from a base of advanced technology similar to that observed by present societies where knowledge and invention multiply rapidly over short time periods. A more likely path for technology improvement over time involves technology advancing by a power law $\Phi = K t^n$. The time exponent is very small (<0.2 , Fig. 11) indicating minimal intersocietal technology exchange limiting cooperative progress in surveying accuracy improvement. This follows from Andean societies being geographically widely dispersed over different ecological zones with widely varying water supply conditions developing agro-technologies only useful for their ecological niche. A further impediment to technical transfer originates from societal collapse episodes (Fig. 4) which interrupt intersocietal technical transfer, but would stimulate intra-societal innovational development. An example (Bandy, 2013) of innovative technology

• TYPICAL SURVEYING ANGLE ACCURACIES (degrees) from field measurements	
▪ Zaña (~ 5000 BCE)	~0.05
• Caral (2800- 1600 BCE)	~0.16- 0.18
• Tiwanaku (~300 BCE- 1100 CE)	~0.0014
• Taraco (north Lake Titicaca)	~0.0006
• Chimu (800 -1480 CE)	≤0.001
• Wari (Moquegua area)	~0.005
• Moche (100 BCE- 700 CE)	~0.008

Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 10 Φ/Φ^* technology advances: surveying angle accuracy capability of major Andean societies from 3000 BCE to 1500 CE

based on specific ecological conditions (groundwater raised field irrigation) underwrote rapid Tiwanaku development and underscores the $\Omega^2, \Omega^3 \ll 1$ dependencies in the above equation. For stable climate periods between major seventh- and tenth-century drought events, a high rate of internally developed agrotechnology existed driven by population increase demands (or conversely, technical development allowed for population increase).

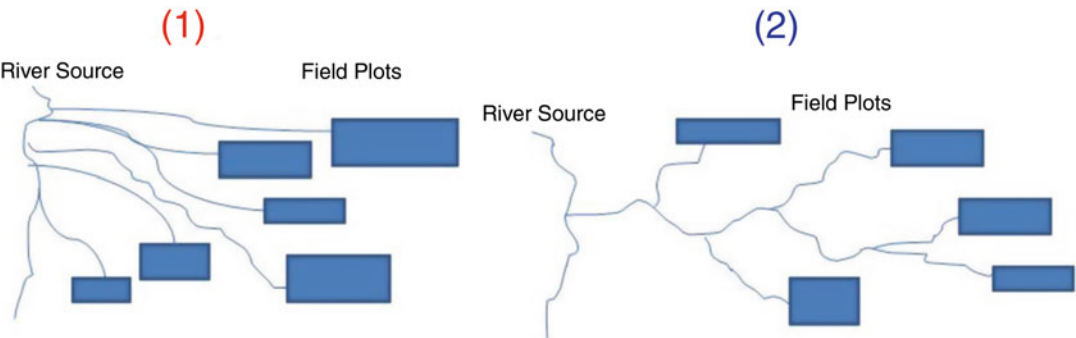
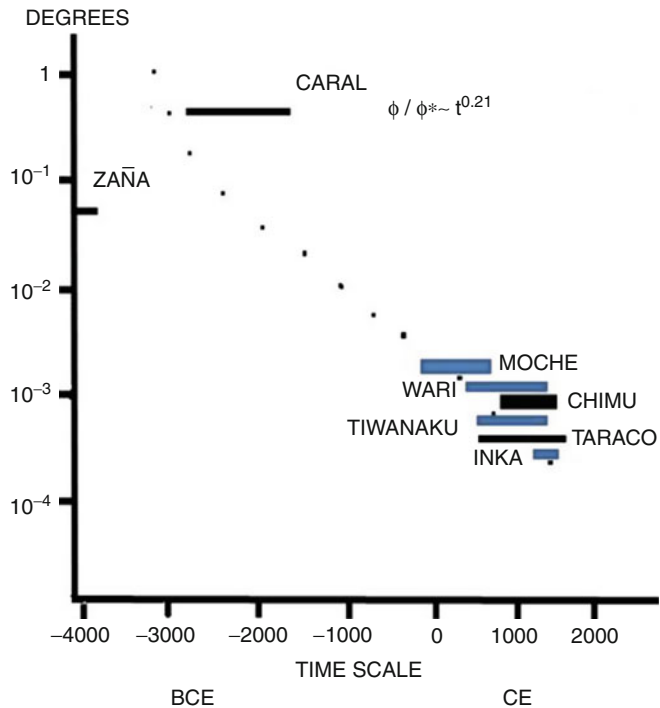
Optimal Agricultural Strategies

Questions arise as to what agricultural strategy is optimum given land, water, labor, and technology resources to exploit the land’s agricultural potential. As initial field and irrigation system designs improve as new strategies and technologies are implemented from field trials that contribute to increased productivity, agrosystems evolve toward an optimum design. Initially individual field plots (Fig. 12, Strategy 1) have individual water sourcing and represent lands farmed by established kin groups. Groups migrating into the area wanting to establish individual farms have less access to river sourced, short canal systems than previously established groups and must use longer canal paths to distant fields (Fig. 12, Strategy 2) requiring increased labor demands. If realization that cooperation rather than competition between resource-competing

L

Land, Labor, Water, and Technology in Pre-Columbian South America,

Fig. 11 Surveying accuracy (canal slope) as a power law function for major Ancient Peruvian societies



Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 12 Evolution of bottom-up to top-down agricultural strategy – Strategies 1 and 2

groups yields higher productive use of land/water resources through canal path redesign under a management consensus structure (Strategy 2), then societal integration proceeds to the first step. To illustrate that cooperation leads to higher productivity for all, the basic equation is invoked:

$$\begin{aligned} (1/F)(dF/dt) = & K \left\{ \left[(L_c^* - L_c) / (A^* - A - \Delta A^*)^5 + (V^* - V) / (A^* - A - \Delta A^*)^6 \right] \right. \\ & \left. \cdot (Q^* - Q) | Q - Q^* | t(\Phi / \Phi^*) \right\} \end{aligned}$$

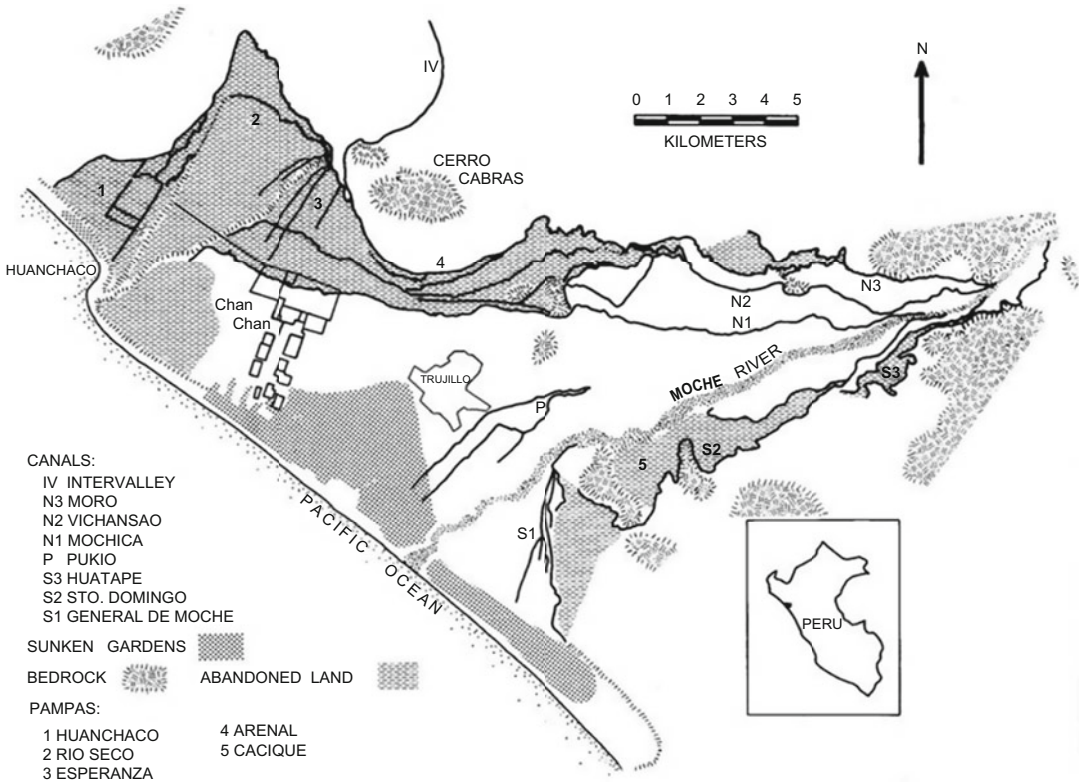
Noncooperative Strategy 1 requires $L_c > L_c^*$ and $V > V^*$ so $dF/dt < 0$ meaning that Strategy 1 is inefficient compared to Strategy 2 for which $L_c \leq L_c^*$ and $V \leq V^*$. For Strategy 1 to be sustained for new, incoming groups, long canals to outlying land areas require increased labor to manage leading to $(1/F)(dF/dt) < 0$. Here a chaotic bottom-up Strategy 1 can evolve into a cooperatively managed top-down Strategy 2 provided concession to an oversight management body provides tangible productivity benefits to all through increased field system yield. This process involves individual groups exploiting agricultural resources collectively and sharing common societal objectives; this societal structure characterizes Andean societies' past (and present) as higher productivity is achieved through shared labor. While some kin groups will concede independence to an umbrella group to govern projects, other groups will maintain self-rule identity and limit evolution from a bottom-up to a top-down structure. An example of kin group control of productive areas using this advantage to rise to political power characterizes Tiwanaku elite political structure (Bandy, 2013). As locally controlled management is often better than elite, corporate-level management, bottom-up structure prevails as management realizes not to disturb a process that functions efficiently without their intervention. A further alternative relies on elite groups exercising control and mandating organization of individual farming groups into a collective. In his case, top-down management ceases to be a cooperative, evolutionary end but rather an element of elite group control. While many societal structure paths exist, lack of knowledge of Andean society structure limits determination of whether bottom-up or top-down structures evolve by collective action or by edict. Cases exist for which Andean societies were characterized by dispersed villages emphasizing their independence from central authority or, alternatively, opportunistically adapting to a changing resource base to maintain survivability. An example of the former lies in the Moche occupation of the Jequetepeque Valley characterized

by little central authority (Dillehay, 2001); a latter example resides in late post-Tiwanaku V society abandoning the central city for local sites near water resources to support farming (Kolata, 1991).

A further question asks how ideas are generated to improve agricultural system design. This posits a science that governs decision making, perhaps codified from observations deriving from agricultural experiments that produced either positive or negative results related to field system productivity. Given that an optimum configuration exists for an agricultural system for an area's ecological conditions, the basic equation is instructive to determine the optimum design. The closer to optimum field system/irrigation network designs that ancient farmers initially chose (or evolved to) provide insight into their science. Key questions are the following: What is the optimum way to irrigate a field system by subdivided water path networks? How close to the optimum methodology was practiced by Peruvian coastal and Bolivian highland societies from early to late times? To address these questions by use of the basic equation, first divide resources as follows: A/n , where n is the number of field plot subdivisions with their required amount of water supply Q/n and supply canals L_c/n . Here sufficient labor resources are assumed distributed as required to service n land plots or, equivalently, $V = V^*$. Substituting into the basic equation,

$$[(1/F)dF/dt]_{\text{divided}} \sim n^2 [(1/F)dF/dt]_{\text{undivided}}$$

The best way to section an area into divided subplots with individual water access involves a high number (n) of smaller plots, each with a proportionate amount of water and labor to optimize production. For typical irrigation systems (Fig. 13) of north coast Peru (Ortloff, 1993, 2009; Ortloff et al., 1982), the optimum field system configuration consists of many daughter branches from a main canal, each serving an accessible field plot; for Tiwanaku raised field systems, agricultural mounds surrounded by swale groundwater represent the optimum



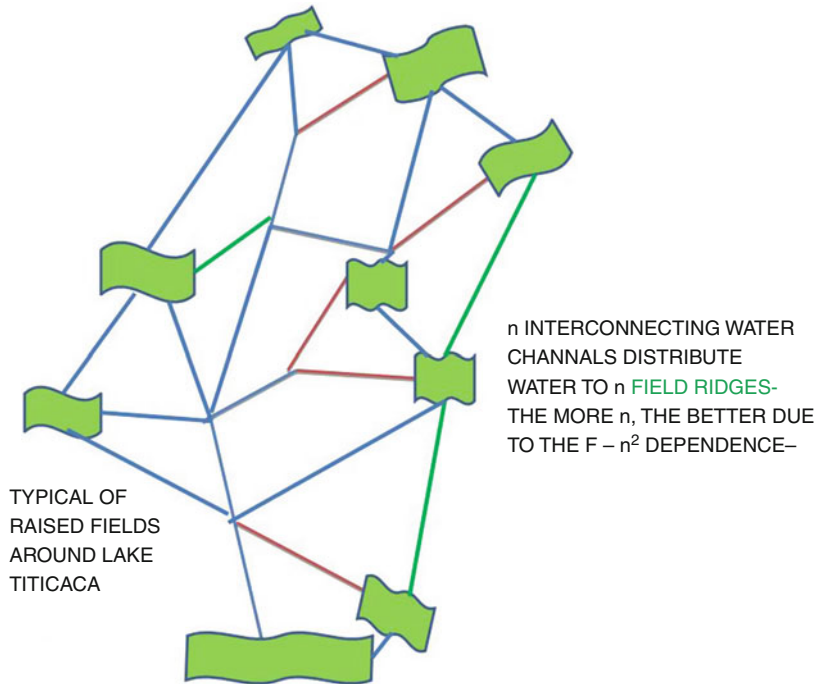
Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 13 Moche Valley north-side Chimú canal systems (900–1450 CE)

configuration. While more subdivided raised fields surrounded by swale water increases food production, there is a minimum raised field width sufficient to capillary transfer water to root systems and preserve mound heat storage capability (Kolata & Ortloff, 1989). Figure 14 shows a field system design where n interconnecting water channels distribute water to n raised field ridges; the higher n is, and the more subdivision ridges exist served by encompassing swales, the higher productivity results. As an example of raised field division strategy, the raised fields at Taraco on the northwest boundary of Lake Titicaca shown in Fig. 15 (Henderson, 2012) conform to a near optimum design, reinforcing that Tiwanaku science had insight into best designs for productivity optimization.

For field system/irrigation network designs typical of north coast Peru in the ninth to fourteenth centuries CE (Figs. 13 and 16), a different field system design philosophy existed due to the presence of gradually sloping farming land within alluvial river delta valleys using a river source to provide irrigation water through canal networks (Ortloff, 2009; Ortloff et al., 1982). Figure 16 indicates that multiple branch, daughter canals emanating from a main canal provide best land area coverage. The more field plots with individual canal water supply, the closer to optimal production exists given that a land area fraction (ΔA^*) is inaccessible due to topographic features that prevent access by canal branches. Again, a multi-branched canal pattern emerges as the optimal way to increase productivity.

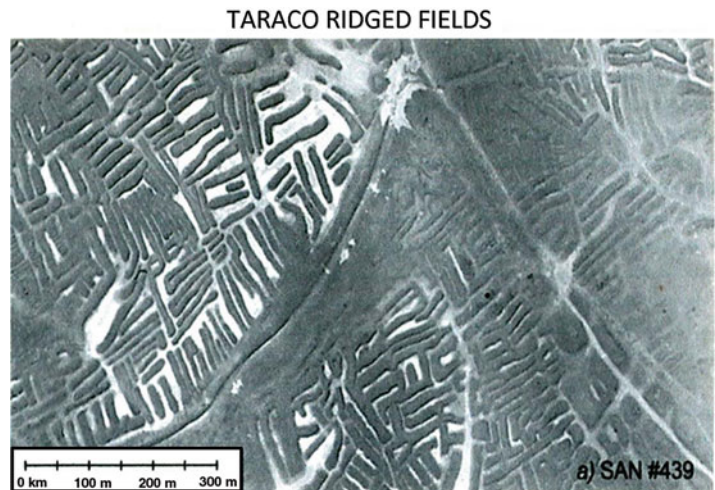
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Pre-Columbian South America, Fig. 14 Basic equation optimal configuration for open systems typical of raised-field systems built by the Tiwanaku (300 BCE–1100 CE)



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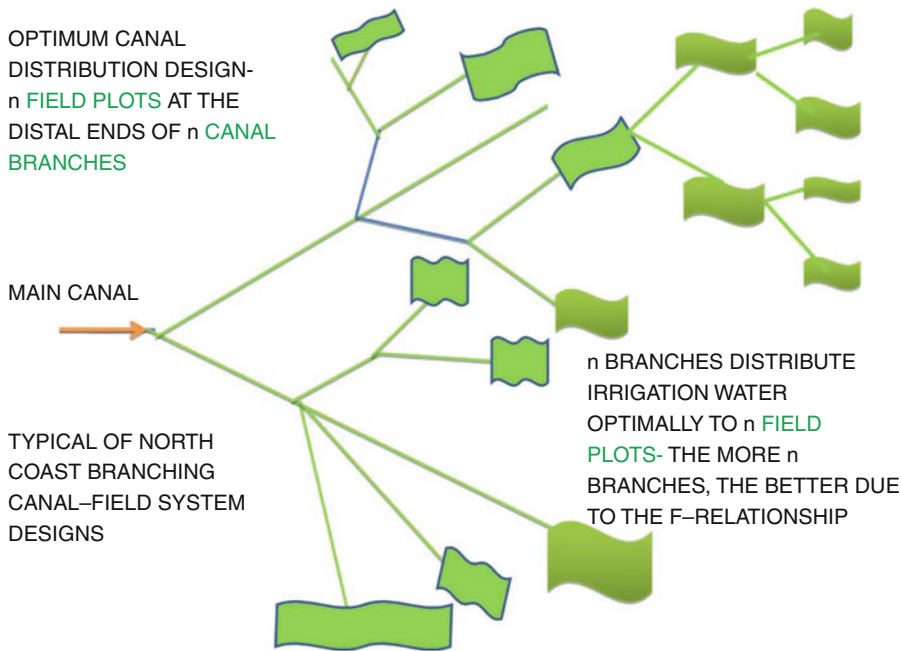
Pre-Columbian South America, Fig. 15 Taraco raised field designs in the northeast Lake Titicaca area of Bolivia



Inka Strategies

As climate change in the fourteenth century CE resulted in increased rainfall, Inka administrators developed lowland agriculture to redistribute restive populations of conquered territories to

farmlands distant from their homeland (D'Altroy, 2003; Murra, 1982). This reorganization was an integral part of Inka top-down management of resources. Some change from terraces to more productive bottomland agriculture occurred due to well-understood canal



Land, Labor, Water, and Technology in Pre-Columbian South America, Fig. 16 Basic equation optimum configuration for open systems

irrigation practices, predictable and longer duration river water supplies than rainfall fed terraces, more fertile soils, higher productivity per unit labor input, more available land area, and wider crop varieties less subject to temperature

extremes. A change in food production going from terrace to lowland agriculture involves, for the same labor input, farming area and water supply; the following result from the basic equation:

$$F_{\text{bottomland agriculture}} - F_{\text{terrace agriculture}} = \exp \left\{ K \left[(L_c^* - L_c) (Q - Q^*)^2 (\Phi / \Phi^*) / 2 (A^* - A + \Delta A^*)^5 \right] \right\} > 0$$

The difference is largest when L_c is smaller (the case when supply canals originate from a nearby river), Φ / Φ^* is large (canal water distribution technologies are more advanced, controllable, and have longer water supply duration than terrace intermittent rainfall systems), and $A \rightarrow A^*$ (easier agrosystem construction and maintenance on flat terrain with better bottomland soil fertility than on mountainside terraces to increase productivity of different crop types in a more temperate climate). From the above equation, the RHS is a positive underlying Inka management decision for best use of labor to increase

the productivity of lands under their control. While not all labor was channeled in this manner owing to lack of large bottomland areas close to highland Inka administrative centers, much terrace agriculture continued as it was well adapted to the mountainous terrain that prevailed over the highland Inka domain.

Conclusions

Andean agriculturalists improved field system designs with land, water, labor, and technology

strategies that optimized food production. The origin of science governing these designs derives from field trials conducted over time to codify advances in technology that improved agricultural productivity. As agricultural improvements follow basic equation optimal prediction trends, an argument may be made for Andean societies developing a science underlying their agricultural system designs.

For Chimu canal irrigation systems constructed during the Late Intermediate Period (800–1480 CE), extended drought together with tectonic/seismic geophysical landscape change/river downcutting required continual modification of canal systems (Ortloff, 1993, 2009). The history of canal development within the Moche Valley Chimu heartland reveals abandonment of early intravalley canals having inlets placed far up-river at the Moche River entry location into the Moche Valley later replaced by canals with down-river inlets (Ortloff, 2009; Moseley and Deeds, 1982; Moseley, 2001). The sequential down-river canal inlet placement was a consequence of tectonically induced river downcutting that successively stranded canal inlets with concomitant loss of arable land and left little Moche Valley land available for agriculture. Such A* reducing agricultural landscape changes (Fig. 5) originating from geophysical tectonic/seismic forces and climate change effects inducing inflation/deflation landscape effects support the conclusion that the Peruvian agricultural environment was subject to instabilities that required continual modifications to balance food supplies to population growth. Examination of the initial configuration of Chimu and Tiwanaku agrosystems demonstrates most are designed close to an optimum configuration to produce high productivity while possessing sustainability features (Tiwanaku raised fields invulnerable to short-term drought and Chimu ability to bring in exterior valley water resources) indicative of application of their science. Where geophysical/climate change altered agrosystems, different strategies to manage these systems evolved. As Fig. 4 indicates, no defense under long-term drought was possible for coastal societies dependent upon highland runoff

into rivers supplying their irrigation systems or for societies relying on constant groundwater levels (Ortloff, 2009; Ortloff & Kolata, 1993; Ortloff et al., 1985). As complex issues related to agricultural productivity existed in ancient societies, much intellectual effort was devoted to promote its success and sustainability. Recent research (Ortloff, 2014) indicates that the hydrological engineering knowledge behind the success of Tiwanaku raised field agriculture (Kolata, 1991) was applied in a different manner in Tiwanaku's urban center by means of an encircling moat around the city's ceremonial center that promoted rapid, post-rainy season soil drying to improve environmental livability and health standards for the city's population. The moat, through water supply and drainage channels, additionally served to regulate the deep groundwater level to promote constant foundation soil bearing strength that limited subsidence of monumental structures. Thus the examples presented of groundwater engineering and water supply optimization used by Tiwanaku, Chimu and other Andean societies reveal an underlying engineering base that supported and sustained their agricultural continuity through millennia.

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Landscape and Temples in Ayutthaya

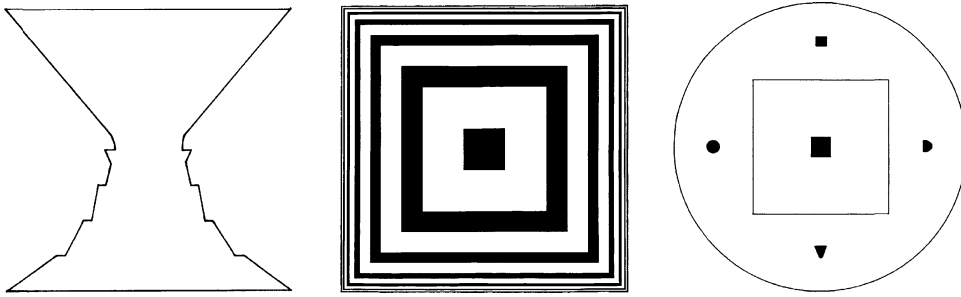
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From 1351 to 1767, the Thai city of Ayutthaya served as the capital of an eponymous kingdom, which has also been known as Siam. During this time, the city became the commercial center of southeast Asia, while the kingdom flourished as an absolute monarchy from regional agriculture and taxes which were levied on the foreign trade. The official religion of Ayutthaya was Theravada Buddhism, from which the “Mount Sumeru World” was used as a model for arranging impressive, brick-based temples and was also reflected in the topographical layout of the kingdom and (although not discussed here) its socio-political structure.

Main Elements of the Mount Sumeru World

In Buddhist cosmology, the Mount Sumeru World falls within the metaphysical “Realm of Desire” (*Kāmadhātu* in Sanskrit, *Kāmaloka* in Pali), which includes four heavens above Mount Sumeru and is depicted as being below the “Realm of Form” (*Rūpadhātu*, *Rūpaloka*) and then the “Realm of Formlessness” (*Ārūpyadhātu*,



Landscape and Temples in Ayutthaya, Fig. 1 Mount Sumeru as shaped like a chalice (*left*); a planar view of Mount Sumeru and the seven surrounding square seas and mountain ranges (*center*); and a planar view of Mount

Sumeru, the seventh square mountain range, the four continents, and the circular range of mountains at the perimeter of the Mount Sumeru World (*right*)

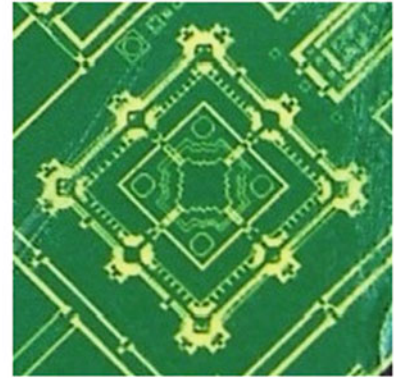
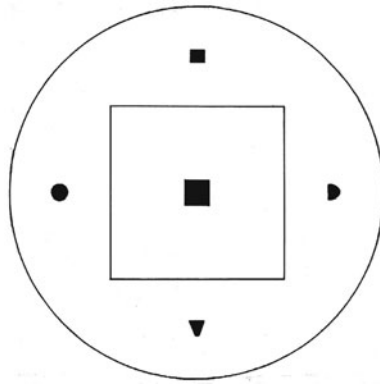
Arūpaloka). Mount Sumeru rises from deep below the horizontal, sea-level plane which cuts it into halves to an enormous elevation above it, and the figures given for the height of Mount Sumeru are 80,000 *yojanas* above the top of the surrounding sea and 80,000 *yojanas* below it; the other two dimensions of Mount Sumeru are each half that of its total height – 80,000 *yojanas* – which suggests that it would appear as a cube both above and below the surrounding sea, although it is described as a shape resembling a chalice or hourglass above the sea because of a somewhat symmetrical tapering that makes the 40,000-*yojana* level 20,000 *yojanas* in breadth and horizontal depth, that is, one quarter of the top and sea-level measurements, as suggested by the drawing at the left in Fig. 1. At the very top of Mount Sumeru is the Heaven “of the Thirty Three” (*Trāyastriṃsha*, *Tāvātimsa*) Deities, a name which refers to its residents, and the lower half of Mount Sumeru above the water comprises another heaven, that “of the Four Great Kings” (*Cāturmahārājika*, *Cātummahārājika*), who along with their subordinates are entrusted with defending the Heaven of the Thirty Three Deities from attack by the Asuras, malevolent deities which live in the sea around Mount Sumeru. These kings occupy the top of the four terraces and each stands guard facing a cardinal direction – *Vaishravana* (*Vessavana*) the north, *Dhritarāshtra* (*Dhatarattha*) the east, *Virūdhaka* (*Virūlhaka*) the south, and *Virūpāksha* (*Virūpaksha*) the

west – while the remaining three terraces are for their subordinates.

Around Mount Sumeru, on the horizontal plane which splits the mountain vertically into halves, are concentric seas and mountain ranges which are contained in a rounded bowl-like structure that keeps things intact. As shown in the diagram in the middle of Fig. 1, there is a sequence of seven seas and enclosing mountain ranges which are each half the width of its predecessor closer to Mount Sumeru, beginning with the 80,000-*yojana* sea around Mount Sumeru out to the seventh mountain range of 625 *yojanas* in width, and the heights and depths of the mountains above and below the top of the sea match their widths. Beyond the seventh mountain range, as shown in the diagram on the right in Fig. 1, is a wider sea which covers 322,000 *yojanas*, contains four continents and (not shown in Fig. 1) adjacent islands, and is bounded by the Cakravāla (Cakkavāla, Circle) Mountains which are 312.5 *yojanas* wide (half that of the previous mountain range) and as tall as the first concentric range (40,000 *yojanas*) and which form the circular, horizontal perimeter of the Mount Sumeru World. The four continents have different shapes – a square for Uttarakuru in the northern quadrant, a semicircle for Pūrvavideha (Pubbavideha) in the eastern, a triangle with the outer tip flattened into a short straight line for Jambudvīpa (Jambudīpa) in the southern, and a circle for Aparagodānīya (Aparagoyāna) in the western – and Jambudvīpa is considered to be

Landscape and Temples in Ayutthaya, Fig. 2

The plan on the right has been rotated forty-five degrees so that the continent which is closest in actual location to the south corresponds to Jambudvīpa on the left



the domain of human beings and, given that the Himavat (Himalaya) Mountains are more or less centrally located within it, corresponds to most of Asia.

An Architectural Example in Ayutthaya: Wat Chaiwatthanaram

Whereas it is possible to draw the Mount Sumeru World so that its shapes and scale are properly expressed, in further detail, than that provided in Fig. 1, architectural versions have had to make modifications based on the land set aside for development, the structures to be built in the compound and their usage, and the materials used for construction. In the case of the major temples in Ayutthaya, for which bricks were the main medium for building, consideration would have been given to how to lay out the Mount Sumeru World along with other structures such as the main hall, ordination hall, and stupas which were to be adjacent to or completely beyond the perimeter mountain range, as well as to how to express the important features of the Mount Sumeru World, including the peculiarly shaped mountain itself. The best example in Ayutthaya today for understanding how the Mount Sumeru World was laid out within a temple grounds so that it made a striking, as well as symbolic, impression is at Wat Chaiwatthanaram (started in 1630), which was modeled on Angkor Wat (from the first half of the twelfth century) in the old Khmer capital and has been restored so that this part of the compound stands out rather

dramatically. How this was done can be seen in Fig. 2, which juxtaposes part of a publicly displayed plan of the grounds of Wat Chaiwatthanaram with the drawing of the Mount Sumeru World at the right in Fig. 1, and in Fig. 3 which offers a ground-level view of the same Mount Sumeru World. In the plan of the temple grounds, Mount Sumeru is the large squarish form in the center, two thinnish octagons symbolize the seven surrounding square mountain ranges, the four continents are small squares, and the Cakravāla Mountains are the outermost square with eight evenly spaced small squares in the corners and the middle of the sides. As seen in the photograph of the compound, Mount Sumeru is centrally positioned as a columnar tower, while the four continents appear next to it as much smaller towers (two are partly hidden in the back) and the conical towers are placed within the Cakravāla Mountains that form the perimeter (three can be seen to either side and one can be made out in front of Mount Sumeru, behind which is hidden the eighth). Two obvious differences from the pictorial expression, then, are that the shape of the Cakravāla Mountains has been changed from a circle to a square and that – because honoring the original shape would have been impossible to do with bricks, although the spirit of terracing the lower half has been maintained – a columnar tower which tapers concentrically at the top has been used to symbolize Mount Sumeru. By coupling what is in the photograph with simple calculations from the information provided in the previous paragraph, it is also clear that the horizontal plane has been



Landscape and Temples in Ayutthaya, Fig. 3 A view of the Mount Sumeru World at Wat Chaiwatthanaram

tremendously compressed vis-à-vis Mount Sumeru. In the model, the ratio of the mountain above sea level (80,000 *yojanas*) to the radius of the horizontal plane (600,437.5 *yojanas*) is 1–7.51, but at Wat Chaiwatthanaram, it ranges from 1 to 0.86 (to the middle of a side, 35 to 30 m) to 1 to 1.21 (to a corner, 35 to 42.5 m); an assumption is that the grandeur of Mount Sumeru was to be emphasized, and this resulted in the seven square seas and mountain ranges being compressed into the brickwork at the bottom of the central tower.

The Mount Sumeru World and Ayutthaya

Another example of the Mount Sumeru World in the landscape of Ayutthaya is Wat Phra Ram (Temple of Lord Rama), which has not been reconstructed to the extent of Wat Chaiwatthanaram and is shown in both pictorial and planar forms in Fig. 4, a publicly displayed

signboard at the temple grounds. It was begun on the site of the cremation of the first king of Ayutthaya, Ramathibodi I (r. 1351–69), and bears the name of Rama, the seventh avatar of the Hindu deity Vishnu and the hero of the *Ramayana* who was born in the Indian city of Ayodhya, after which Ayutthaya was named. Although it might seem strange that a Buddhist establishment would be linked to such a character, it should be noted that variants of what are now known as Hinduism and Buddhism were being practiced in the region prior to the building of Wat Phra Ram and that kings in Thai societies have been considered to be incarnations of the Hindu deities Shiva and Vishnu and many have had names that included “Ram” or “Rama.” The link to Vishnu is strengthened through the architecture of Wat Phra Ram, which can be traced to Khmer models that include Angkor Wat, the temple in northwestern Cambodia which was begun in the first half of the twelfth century, was originally dedicated to Vishnu, but had become a Theravada Buddhist institution by the time that Ayutthaya



Landscape and Temples in Ayutthaya, Fig. 4 A photograph and plan of the grounds of Wat Phra Ram, north to the upper left in the photograph and to the top in the plan

was being built in the mid-fourteenth century. Wat Mahathat (from 1374), Wat Ratburana (from 1424), and Wat Chaiwatthanaram (from 1630) also belong to this architectural genre. That Angkor Wat might have served as the model for Wat Phra Ram would be related to its prestige, but it should be noted that prior to the start of Wat Phra Ram, the new kingdom of Ayutthaya had defeated the city of Angkor after laying siege to it in 1352–1353 and had taken Khmers to Ayutthaya, raising the question of how influential some of these captives might have been in the construction of the first two, Wat Phra Ram and Wat Mahathat. Building these temples on a Khmer model, though, might certainly be interpreted as a symbolic challenge to the old regional power, as if to announce that a shift of the cultural center of gravity was taking place, and putting the Mount Sumeru World of Wat Phra Ram in particular more or less in the center of the island of Ayutthaya was a case of locating the first such architectural microcosm of the new city in the middle of a larger, topographical microcosm.

The city of Ayutthaya was itself at the center of a symbolic Mount Sumeru World, although the shapes and ratios do not match those in the model described in the previous section. At the core of this version was the island which is delineated by the Chao Phraya, Lopburi, and Pasak Rivers and a canal to link the last two and which has a shape that resembles a modified, curvy rectangle, as can be seen in Fig. 5. Overlooking the rivers, a fortified wall was built on the island to protect the city and, in essence, to separate the political and religious center of the kingdom from everything else. Since the island was the home of the king, high officials, and important temples, it was the most sacred part of the kingdom and thereby corresponded with Mount Sumeru, the abode of the Thirty Three Deities and their protectors. The rivers and canal which flow around the island formed the topographical boundary, so in the scheme of the Mount Sumeru World, this watery boundary was the highly compressed, more or less rectangular equivalent of the seven concentrically square seas and mountain ranges.



Landscape and Temples in Ayutthaya, Fig. 5 A publicly displayed map showing the island that is the historical core of Ayutthaya, north to the top

Beyond it lay the profane world of commerce, agriculture, and other livelihoods and activities in the adjacent settlement and the surrounding countryside, territory which corresponded with the great sea that contains the four continents and neighboring islands and is bounded by the Cakravāla Mountains. These mountains themselves would have symbolized the perimeter of the kingdom, and it would be reasonable to think of the “continents” as having been such important settlements as Sukhothai to the north, Nakhon Ratchasima to the east, Nakhon Si Thammarat to the south, and Tavoy to the west.

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Leather Work in Ancient Egypt

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Our knowledge of skin and leather products in ancient Egypt is surprisingly scanty and only a few substantive publications have appeared. Three are of special importance for the present work. Forbes (1966) might be slightly outdated (see below) but still provides a good overview. van Driel-Murray (2000) contains a wealth of information: it predominantly relies on field-work and the study of the leather artifacts themselves. Not only does Van Driel-Murray provide a good overview, she clearly pinpoints the problems and priorities with the study of leather from ancient Egypt. Schwarz's (2000) book deals not only with the artifacts but also with other aspects of leather and compares it with traditional European and African leather crafts. Furthermore, she incorporates texts and depictions in her study and her book contains many illustrations of leatherwork and related objects, making it an important reference. The interest in studies of leather and leather products increased since about 5 years distinctly (Friedman, 2007; Leguilloux, 2006; Veldmeijer, 2009a, 2010a, c, 2011b, c, d, 2013a), although a focus on footwear (Bénazeth & Fluck, 2004; Huber, 2011; Kuckert, 2006; Nauwerth, 2011; Russo, 2004; Smalley, 2012; Veldmeijer, 2009c, d, e, f, g, 2010b, 2011e, f, 2012a, b, 2013b, c, d, e, in press a, in press b; Veldmeijer & Ikram, 2013b; Veldmeijer & Skinner, 2008) and chariots (Veldmeijer, 2009b, 2011a; Veldmeijer & Ikram, 2009, 2012a, b, 2013a; Veldmeijer, Ikram, & Skinner, 2013) can be detected. Various projects are currently running, focusing on skin processing and staining procedures in the Pharaonic period.

Technology

Skin Processing

The processing of skin into leather is rather universal and described in various handbooks. Although most of these are focused on Medieval and later times and from Europe, they give an idea of how this process might have been in ancient Egypt nonetheless. Although we use the term "leather" technically speaking, this term only refers to tanned or tawed [converting (skin) into white leather by mineral tanning, as with alum and salt] skins rather than cured skins. In Egypt, tanned or tawed skin did not occur in Pharaonic times. The following general summary is largely based on Forbes (1966, pp. 1–21) and Van Driel-Murray (299–306). After flaying the skin, the preservation process was started with removal of the underlying fat. Next, hair was usually (but not always) removed (depilation), using urine, ash, or a mixture of flour and salt rubbed into the haired surface. Curing then took place, arresting the degenerative process (irreversible in contrast to tanning). Curing in oil seems to have been the preferred method, although mineral curing was probably also practiced, particularly in the Predynastic period. After soaking in oil, the skin was pulled back and forth over a beam to make it supple (staking). The remaining oil was worked into the skin using stones, wooden or leather pounders, or tools called "slickers." Finally, the skin was dried on a wooden stretching frame (Fig. 1).

Vegetable tanning is the only means of producing chemically stable leather which is not subject to decay, flexible and waterproof. Current scholarly opinion is that this process was unknown in Egypt before the Ptolemaic period and only became common in the Roman period, although such an opinion is not based on scientific analyses. However, there may be a number of explanations for the lack of vegetable tanning and one might be that the arid conditions rendered this more complex process unnecessary for the ancient Egyptians. These arid conditions are in themselves excellent for preservation and



Leather Work in Ancient Egypt, Fig. 1 Skin processing and the manufacturing of objects from leather. From: Davies (1943)

account for the amount of recovered leather items rather than the advanced methods of skin processing. The Romans, however, had experienced wetter environments forcing them to adopt the use of tanned leather.

The Objects

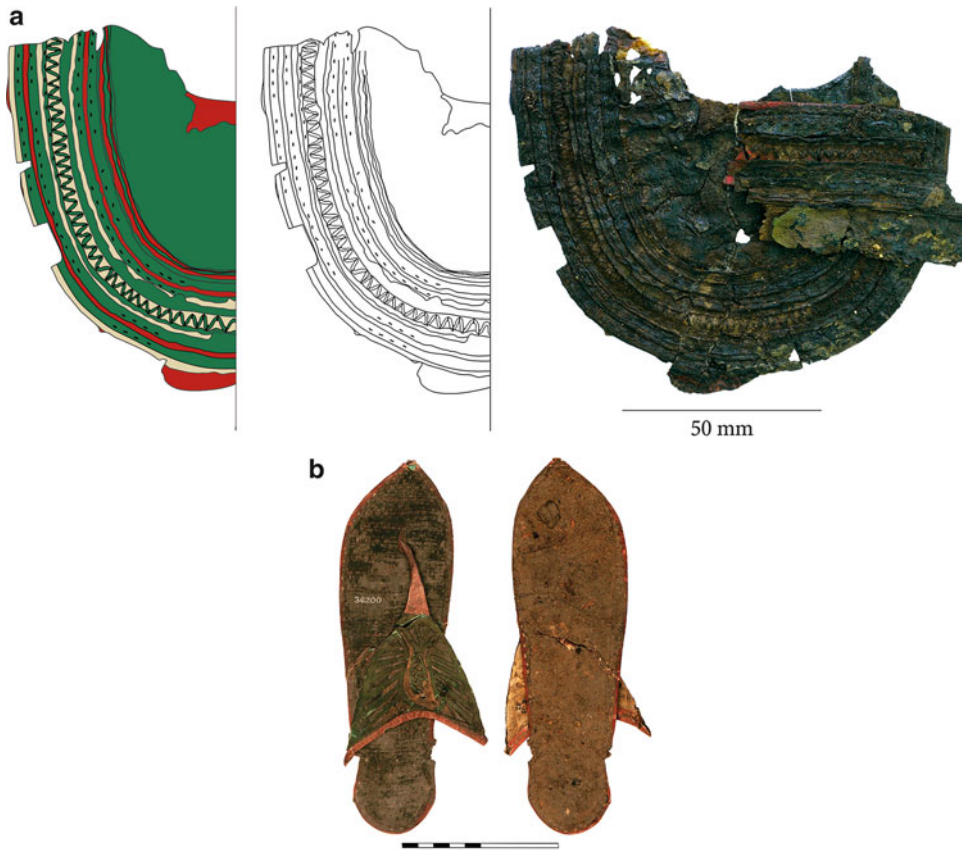
The range of objects made from leather is fairly large and ranges from parts of musical instruments and furniture to clothing, footwear, and cordage. Research in progress suggests that the objects were sewn with simple seams and stitches made of flax but mostly leather thongs (and to lesser extent sinew), although a more economic use of materials as well as an increase of

technological skills in chariot leather that is dated to the later New Kingdom can be noted (see below).

Decoration Techniques

Before the New Kingdom (1550–1069 B.C.), mineral dyes predominated. A full range of colors is hard to establish as their survival is dependent upon the conditions for preservation and the likelihood is that certain shades are more susceptible to discoloration (Fig. 2). Here too, little research has been done, using modern analysis, accounting for our limited knowledge.

According to van Driel-Murray (2000, p. 306) “red was achieved with iron and, perhaps, lead



Leather Work in Ancient Egypt, Fig. 2 (a) Fragment of highly decorated (with appliqué in different colours) from Amarna (*right*; ÄM AM 075). Although much of the colour has faded, enough was preserved to reconstruct the colours (*left*). The fragment could be a flap of a bow-case. Photograph by E. Endenburg. Drawings by A.J. Veldmeijer. Courtesy of the Ägyptisches Museum und

Papyrussammlung, Berlin (b) Sandal with openwork straps in combined red and green (EA 36300). Scale bar in cm. (Photograph by A. 't Hooft. Courtesy of the British Museum, London) (http://www.britishmuseum.org/research/collection_online/collection_object_details.aspx?objectId=167145&partId=1&searchText=36200&page=1)

compounds and green was created with copper compounds.” Leona (2009), however, identified the red in a fragment of possible quiver from the Middle Kingdom as madder lake, pushing the first occurrence of this vegetable dye back several centuries. After the 18th dynasty other vegetable dyes such as indigo (blue) and pomegranate (yellow and black) appear. Favored curing methods produced a very light leather, so white was probably obtained by manipulation of the already pale surface with pastes of chalk mixed with fats such as egg yolk and brains. Blue does not seem to be represented with leather despite the availability of minerals such as cobalt. There

is no explanation for this other than blue may be one of the colors which do not survive. In the New Kingdom, alum is featured as a mordant; other mordants used would have included urine and vinegar. In dyeing leather, the color was confined to the grain surface and was applied after curing to complete skins. Staining and gilding came into use as late as the Coptic period (Fig. 3) (Smalley, 2012, tried to use the decoration for dating the Coptic footwear more precisely).

Stamped decoration becomes very common in the Christian Period (e.g., Veldmeijer, 2011b; Veldmeijer & Ikram, 2013b) (Fig. 4), but less

common before (examples are the extraordinary quivers from Maiharpri, Daressy, 1902). Incised decoration did occur, but was more common in Nubian leatherwork than in Pharaonic material. By far the most common decoration technique in Pharaonic times is appliqué (multicolored): there are many examples, such as the funeral tent of Queen Istemkheb dating from the 21st or 22nd dynasty (1069–715 B.C.), pieces of footwear (e.g., Veldmeijer, 2009d), as well as chariot leather (Carter & Newbery, 1904; Veldmeijer, 2009b, 2011a; Veldmeijer & Ikram, 2009,

2012a, b, 2013a; Veldmeijer et al., 2013). Open-work by the cutting out of figures is well represented in the archaeological record too, although less common than the favored appliqué technique (e.g., Veldmeijer, 2009d, e, see for an example Fig. 2).

Tools

Apart from the large pots for dipping, the trestled beams used for staking, and the low stools and platforms upon which much of the cutting and working was carried out, a leatherworking toolkit seems to have comprised the following items. Needles of bone and probably copper were used for stitching leather from the earliest times. Awls of bone and later of metal were also used for piercing, as were marlinspikes. Horns were used to enlarge the holes.

Most of the leather cutting was carried out using curved, broad, or narrow-bladed knives which seem to have appeared in the New Kingdom (Stocks, 2001, p. 443). Longer knives, still with curved blades, were used in earlier periods.

Leather was often pricked to facilitate easy penetration with a needle. This was done with awls or a comblike tool. Stone and leather or wooden pounders for smoothing, depilation, working in oils and fats, etc. would also have been widely used. Slickers, blades with triangular anti-clogging holes, could have been used for any of the abovementioned purposes and would have been preceded by the flint scraper (Davies, 1943, p. 50; van Driel-Murray, 2000, p. 303; Stocks, 2001, p. 443). There would also have been tools for incised decoration and, although it is not clear exactly what form these tools took, there are plenty of examples of pointed tools which could have served this purpose. Stamps would probably



Leather Work in Ancient Egypt, Fig. 3 Leather Mule, with applied goldfoil decoration. Scale bar is 5 cm. (Photograph by André J. Veldmeijer. Courtesy of the Medelhavsmuseet Stockholm)

Leather Work in Ancient Egypt, Fig. 4 Piece of belt with impressed motifs from the Coptic Monastery of Deir el-Bakhit (Luxor; DB 2393). (Photograph by E. Endenburg. Courtesy of the Deutsches Archäologisches Institut Cairo)



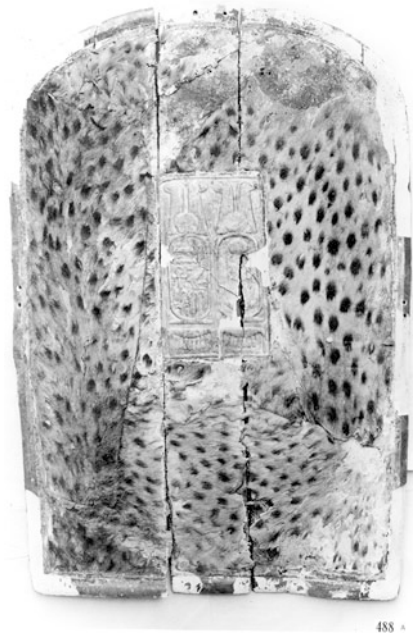
have been cast from metal or carved from stone or possibly wood, although no examples were found or recognised for inclusion in the present work.

A tool which is more difficult to recognize is the bone folder or crease. According to Darke (2006, pp. 104–105) “bookbinders originally used it for folding very thin leathers and papers. [...] For making leather goods the bone folder has a smooth pointed end with a wide bevel on one side and slightly flattened on the back. This smooth point prevents any damage to the leathers when either marking positional points on the grain side or when pushing out corners.” This smooth point prevents any damage to the leathers when either marking positional points on the grain side or when pushing out corners.” This would also be a perfect tool to work on incised decoration, making it more pronounced and deeper. In Egyptian archaeology these tools are usually identified as beaters in the textile industry, which, thus, might not always be the proper identification.

The Importance of Skin Products

Little is known about the status of leather workers, the most well-known source to date being the *Satire of the Trades* which is heavily biased and, therefore, unhelpful (e.g., Lichtheim, 1973). A monetary economy did not exist in dynastic Egypt, but there was an efficient system of exchange in most commodities, which were priced in terms of their equivalent value in *deben*, a standard weight of copper. The only community from which price lists survive is the New Kingdom workmen’s village at Deir el-Medina, which is probably not representative of the rest of the country (Janssen, 1975, p. 562). Furthermore, leather is not mentioned in these lists in sufficient detail to be useful (Janssen, 1975, p. 526).

Perhaps the first thing to consider when discussing the monetary value of leather is the value of the animals from which skin products were obtained. It is tempting to assume a direct correlation between the value of the animal and its hide/skin. If this is the case, then bovid hide will have been the most expensive as Bovidae were the most highly prized animals commonly used for leather. Exotic skins were more highly



Leather Work in Ancient Egypt, Fig. 5 One of Tutankhamun’s shields. It is covered with cheetah skin. (Photograph by H. Burton. Courtesy of the Griffith Institute, Oxford)

priced but used only rarely and restricted to the royals and certain part of the clergy (Fig. 5).

Because taxes were collected in goods in the New Kingdom, and payment for work by the state and the temples was made in things like (leather) sandals, it can be assumed that leather goods had generally recognized values (Stocks, 2001, p. 283). Furthermore, leather sandals could cost as much as a whole sheep or goat, which may imply that the expertise required for the processing of finished leather goods was quite highly prized (Janssen, 1975, pp. 525–526).

The importance of leather to ancient Egyptian civilization seems to have differed over time. According to van Driel-Murray (2000, p. 307) skin was widely used in the Badarian (5500–4000 B.C.) and Amratian (=Naqada I) (4000–3500 B.C.) periods and was handled with considerable skill and confidence but was largely superseded in the Gerzean (=Naqada II) period (3500–3100 B.C.) by cloth (Petrie, 1940, p. 128). This may have been due to the development of a more settled sedentary lifestyle over time

conducive to the large-scale undertaking of craft activities such as weaving (Bard, 2000, pp. 61–62). Cow, sheep, goat, and gazelle have been identified from Predynastic contexts (van Driel-Murray, 2000, p. 308) and remained the most commonly used skins for leather throughout Pharaonic Egypt. Besides those listed, other animal skins known to have been utilized are lion, panther, cheetah, antelope, leopard, camel, hippopotamus (Reed, 1972, p. 86), and crocodile (own observation).

In the Old and Middle Kingdoms, the use of leather declined in favor of fiber and textiles. Skin seems to have been of secondary importance to the meat at this time (van Driel-Murray, 2000, p. 300).

The Second Intermediate Period (1650–1550 B.C.) represents a continuation of early Predynastic traditions in that cattle hides, decorated leather garments, containers, and pouches of high quality occur again but these are mainly associated with the “pan-grave” culture which belonged to a seminomadic tribe of Nubian cattle herders who entered Egypt during the Middle Kingdom and the Second Intermediate Period (Shaw and Nicholson 1995, p. 255). The Nubian C-group people might very well have found a role in the Egyptian society for their skills in leatherworking (Friedman, 2007; Veldmeijer, 2007b). During the New Kingdom leather was much more widely used. New weapons technology such as the chariot was partially responsible for this (van Driel-Murray, 2000, p. 309). Also, the New Kingdom saw a change in slaughterhouse practices with more attention being paid to hides and skins as products in themselves.

It is difficult to say whether the use of leather continued to the same extent into the Third Intermediate Period (1069–747 B.C.) because tombs were becoming smaller with a paucity of grave goods. The range of uses was no longer represented among the goods, most of the surviving items from this and the Late period being mummy braces.

The lack of material from the Late and Ptolemaic periods has been partially explained above. From the Roman period more finds are recorded (Bowen, 2002; Leguilloux, 2006; Phillips, 1999,

2001; Veldmeijer, 2007a; Winterbottom, 1991, 2001). The use of tanned leather became widespread and an increase in the level of technological skill can be seen. According to Forbes (1966, p. 35) skin products were both imported and exported at this time and the sale of leather goods seems to have been free like that of linens.

Technologically, ancient Egyptian skin processing up to the Ptolemaic period remained essentially Neolithic. The idea that it was advanced from the earliest times (Hasanien, 1997) is based upon misconception because full vegetable tanning which produces the leather with which we are familiar today was unknown in Egypt until the Ptolemaic period and was not common until the Roman period. In fact, pre-Ptolemaic skin products, many of which are referred to here as “leather,” are no more than lightly cured pseudo-tannages which only survive because of Egypt’s naturally favorable conditions for preservation.

Beyond the skin processing, however, a development in technological skills is discernible. Still, dyeing techniques seem relatively basic and the properties of alum as a mordant were not appreciated in Egypt until long after her influential neighbor, Mesopotamia, had rendered its use commonplace. When elaborate and colorful decoration was fashionable, it was achieved by appliqué techniques which were often coarsely executed although examples of much better craftsmanship are noted. Compared to the skill and patience needed to produce the exquisitely fine New Kingdom network loincloths (which seems to be from Nubian origin) or the skills seen in the Roman material, the Pharaonic leatherwork might be judged as “poor,” but a more suited term for Pharaonic leather is “pragmatic”: there was no need to produce leather that could survive wet environments, for example, so there was no urge for new technology. As also remarked by Van Driel-Murray, the Nubian material is unequaled in Egypt and leather might have played a much more important role in Nubia than in Egypt (pers.com. Van Driel-Murray). Comparing the so-called Tano chariot leather (Fig. 6), dated to the late 18th or early 19th dynasty, with the earlier leatherwork, it is clear

Leather Work in Ancient Egypt, Fig. 6

The Tano chariot (JE 88962). (a) Fragment of the siding fill of the box (b) Bottom of bow-case, which would have been attached to the side of the chariot (c) Fragment of the neck strap. Scale bars are 5 cm. (Photograph by A.J. Veldmeijer. Courtesy of the Ministry of State for Antiquities/Egyptian Museum Authorities)



that different choices were made. The laborious task of harvesting sinew, which was traditionally used to secure the appliqué, was overcome by using flax thread and limited the stronger sinew for the constructional joins and seams.

The extent to which leather was used varied greatly over time with the periods of greatest use being the early Predynastic and New Kingdom. It is important to note that this is at least partially due to a bias in archaeological record. For example, the amount of material which survives from the New Kingdom is largely due to the fact that elite burials of this period were generally rich and elaborate with a whole range of material deposited with the body for use in the afterlife (Spencer, 1982, pp. 50–51). Because much of the Pharaonic Egyptian archaeological record is constructed from tomb goods, burial practices are a major contributing factor in terms of what survives. Another example is the fact that little archaeology has been done in true Ptolemaic layers. Finally, many Roman settlements have been excavated, largely accounting for the numerous leather finds. It has been claimed that leather was of “marginal importance” in ancient Egypt in all periods (van Driel-Murray, 2000, p. 299), but the existing evidence from the archaeological

record (the amount of surviving material and the range of uses represented), as well as from texts and imagery, does not support such a conclusion. Leather goods were used as currency but their actual value is impossible to quantify accurately. Moreover, the leather industry to produce even the chariot casing and harnessing must have been substantial, considering that estimates suggest that at any given time in the New Kingdom, a few thousand vehicles could have existed (Sandor, 2004, p. 158).

Egyptian leatherwork is still poorly understood and much in need of reassessment which should include a detailed analysis of technology (among which seams and stitches), shape, the organization of the work, and extensive analyses on well-dated samples for both curing and coloring agents as a framework for future investigation. Fortunately, in recent years, interest in leatherwork has increased and various studies are currently being executed.

See Also

- [Dyes](#)
- [Military Technology](#)
- [Writing](#)

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Leo the African

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Secondary Literature: General

- Archaeological Leather Group. Newsletter 1995-... These Newsletters predominantly deal with leather from northwest Europe but occasionally from other areas (among which Egypt) as well. Lots of very useful general information. <http://www.archleathgrp.org.uk>
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Leo the African was born in Islamic Granada as Al-ḥasan ibn Muḥammad al-Wazzān al-Zayyāṭī around 1485 and was educated in Fez, where his family settled several years before the conquest of Granada. He is known primarily for his geographical writings based on four trips. The first, from Fez to Constantinople, probably took place in 1507 and 1508. The second, sometime between 1509 and 1511, was his first to Timbuctu following the caravan route south, probably as far as the Niger river. The third trip (1512–1514) took him across the Sahara via Lake Chad to Egypt, providing important information on the Sudan. The fourth trip (1515–1518) took him to Constantinople as ambassador of the Moroccan sultan, Egypt, and Arabia; on his return he was captured by the Italian pirate Pietro Bovadiglia. In Italy he was given as a slave to Pope Leo X whose name he took upon his conversion to Christianity.

Although he wrote an Arabic-Hebrew-Latin vocabulary in 1524, he is best known for his geographical treatise written and published in Italian as *Della descrizione dell'Africa* (Venice, 1550), although it was no doubt based on an Arabic draft. The treatise is divided into nine books, whose principal significance was to provide European cartographers with detailed information about areas of sub-Saharan Africa practically unknown in the West. Leo also made a substantial contribution to natural history. In his description of African plants, animals, and minerals he points out errors made by ancient writers such as Pliny. Leo's *Description* also contains invaluable information on Islamic institutions such as, for example, his description of the *muhtasib*, or market inspector, of Fez. Leo returned to North Africa in 1529, reconverted to Islam, and died in Tunis sometime after 1554.

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Levi Ben Gerson

J. L. Mancha

Levi Ben Gerson (1288–1344), also known as Gersonides or Leo de Balneolis, his Provençal name, was one of the most original Jewish thinkers of the Middle Ages, and he wrote on logic, philosophy, biblical exegesis, mathematics, and astronomy. He lived in Orange, where the de Balneolis family was prominent, and occasionally in Avignon (France). During the last years of his life he maintained relations with the papal court of Clement VI (1342–1352), to whom he dedicated a Latin version of his work on trigonometry and on the Jacob Staff (*Tractatus instrumenti astronomie*, 1342).

On mathematics, his *Ma'aseh Hoshev* (Work of the Computer, 1321) deals with arithmetic, summations of series, algebra, and combinatorial analysis. At the request of the French musical scholar Philippe de Vitry, he composed his *De numeris harmonicis* (On Harmonic Numbers, 1343, extant only in Latin) to demonstrate that numbers belonging to geometrical progressions of ratio 2 or 3 and first term 1, or generated by product of terms in these progressions, differ by a number greater than 1, excepting pairs 1–2, 2–3, 3–4, and 8–9. On geometry, he wrote a commentary on Books I–V of Euclid's *Elements*, a treatise on Euclid's parallel postulate, preserved incomplete, and commentaries apparently lost on Menelaus' *Sphaerica* and Thābit ibn Qurra's *Risāla fī Shakl al-qattā'* (On the Secant Figure).

Levi's most important scientific achievements are contained in the *Sefer Tekhunah* (Book of Astronomy), in fact, part 1 of the fifth book of his main philosophical work, *Milhamot Adonai* (Wars of the Lord). Preserved in Hebrew and Latin versions, it is a lengthy work, divided into 136 chapters, which contains planetary observations and research from 1321 to 1340, and is based on a profound understanding of the astronomical tradition as well as on a sound criticism of some of his predecessors, mainly Ptolemy and ► *al-Bīṭrūjī*. Levi's purpose was to construct a true astronomy, able to satisfy at the same time the requirements of experience, natural philosophy, and metaphysics. The crucial role attributed to observation led him to construct the Jacob Staff (an instrument for determining the angular distance between two stars or planets widely used in navigation until the eighteenth century, whose precision he increased by inventing a transversal scale for linear measurement, later also applied to the astrolabe), and to investigate successfully the theory of the *camera obscura*, which he used for observing eclipses. Levi employed his own observations both for deriving parameters for his new solar and lunar models and for testing them. Of special interest is his lunar model, which avoided the inadequacy of Ptolemy's model at half-moon phase (when it ought to appear twice as large as at opposition) and eliminated the use of the Ptolemaic epicycle (which

would allow us to see both sides of the moon, again contrary to appearances). Using his own solar and lunar models, Levi composed ca. 1335 a set of tables and canons for computing eclipses, later partially modified when it was incorporated into the *Sefer Tekhunah*, which includes tables for the sine function, spherical astronomy, and solar and lunar mean motions and corrections. The chapters of the work dealing with planetary models are apparently unfinished, but a measure of Levi's originality is his theory of planetary distances and sizes: although Levi considered as not fully decided the problem of the position of Mercury and Venus with respect to the sun, assuming that these planets were placed above it, he computed the distance of the sphere of the fixed stars to be $159 \times 10^{12} + 6.515 \times 10^8 + 1.338 \times 10^4 + 944$ earth radii (instead of Ptolemy's 20,000 earth radii, generally accepted in the Middle Ages).

See Also

- [Al-Bīrūnī](#)
- [Astrolabe](#)
- [Thābit ibn Qurra](#)

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Li Bing

Sun Xiaoli

Li Bing (fl. 322–247 BCE) is famous in Chinese history as an expert in irrigation works. He had a good knowledge of astronomy and geography as well as of engineering and technology. In 316 BCE Shu (Sichuan province) was conquered by the State of Qin. In order to establish the province as an important base and to harness the Minjiang River floods, King Huizhao (r. 306–2551 BCE) appointed Li Bing governor of Shu.

During 277–250 BCE Li decided to build the large waterworks at Guanxian county, from where the river flows into the plain of Sichuan. The whole project is known as Dujiang Yan. Li decided to divide the river into two great feeder canals, the Neijiang (Inner Canal) on the east and Waijiang (Outer Canal) on the west. This was done by means of piled stones, known as *Yuzui* (Fish Snout). The inner canal was used for irrigation, while the outer one, the mainstream, acted as a flood channel, and also carried some boat traffic. In order to construct the inner canal Li made a great rock cut through the end of a ridge of hills. This is known as the Bapoint Kou (Cornucopia Channel). Between the primary division-head and the rock cutting the channels were separated by the Feisha Yan (Flying Sands

Spillway) which was adjusted to regulate the volume of flow into the inner canal.

In order to measure the water level so as to control it, three stone figures were put at three different places at the canal intake. With the help of observing the water level at the inner canal intake the feeding capacity into that canal was controlled by division dams of the Yuzui, Feisha Yan, and Baoping Kou. The whole engineering operation made it possible to supply water for an area of 4.4 million acres to support a population of five million people, most of them engaged in farming, while at the same time remaining free from drought and floods. It can be compared with the ancient works of the Nile, and it is still in use today. Apart from this great contribution, Li also developed the deep-drilling technology for producing well salt and built six bridges near Guangdu (Chengdu). The exploitation of water resources and the manufacture of well salt greatly promoted the development of agriculture, industry, and commerce in the Sichuan area and made it become a famous “Land of Abundance” in China since Li’s time.

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Li Chunfeng

Jennifer W. Jay

Li Chunfeng (602–670) was a Chinese mathematician, astronomer, and early historian of science. A native of Shaanxi province in northwest China and influenced by his Daoist father, Li Chunfeng served as a high-ranking court astronomer and

historian for several decades in the early Tang dynasty (618–906). Both Li Chunfeng’s son and grandson successively occupied the position of court astronomer.

As a mathematician Li Chunfeng is not considered to be original, but he played a role in indeterminate analysis, or the Chinese remainder theorem. He is credited, along with ► [Zu Chongzhi](#) in the fifth century, with developing the *zhaocha* method of finite or divided differences in mathematical astronomy. Using algebra to deal with the *ping* (floating differences) and *ding* (fixed differences) Li Chunfeng calculated the “angular speed of the sun’s apparent motion” (Needham & Ling, 1959).

Li Chunfeng applied this method of finite differences in designing the Linde (Unicorn Virtue) calendar, which was adopted in 665. The new calendar was an improvement over the previous ones in predicting the movements of the planets and in the placing of the long (30 days) and short months (29 days) as well as the intercalary months. To compensate for the extra days in a solar year of 365.2422 days and a lunar month of 29.5306 Úys, 1 intercalary month needs to be added every 3 or 4 years.

Li Chunfeng also earned a place in the history of *hunyi* (armillary spheres), predecessor to the telescope. His armillary sphere had three nests of concentric rings: the inner sighting tube ring, the intermediate nest, and the outer stationary nest. Li’s innovation lies in the intermediate ring, which improved the observations of celestial bodies and allowed for finer accuracy.

Li Chunfeng wrote the treatises on astronomy, calendar, and portents in the official dynastic histories, the *Jinshu* (History of the Jin Dynasty) and *Suishu* (History of the Sui Dynasty), in addition to authoring another extant work, *Yisizhan* (Omen-taking, 645). Typical of astronomers in his time, Li Chunfeng could not avoid the moral and political responsibility of interpreting omens to the country, and included portent astrology and omen lore in his writings.

Li Chunfeng commented on the ten mathematical manuals that were officially designated for curriculum use both in Tang China and in Korea and Japan. These appear below with

translated titles (Ho, 1985): ► *Zhoubi suanjing* (Arithmetical Classic of the Gnomon and the Circular Paths of Heaven), *Jiuzhang suanjing* (Nine Chapters on the Mathematical Art), *Sunzi suanjing* (Mathematical Manual of Sunzi), *Haidao suanjing* (Sea Island Mathematical Manual), *Wucaosuanjing* (Mathematical Manual of the Five Government Departments), ► *Xiahou Yang suanjing* (Mathematical Manual of Xiahou Yang), *Zhuishu* (“Stitching” Method), ► *Zhang Qiujiang suanjing* (Mathematical Manual of Zhang Qiujiang), *Wujing suanshu* (Arithmetic in the Five Classics), and *Jigu suanjing* (Continuation of Ancient Mathematics). *Zhuishu* is not extant and was substituted by *Shushu jiyi* (Memoir on Some Traditions of Mathematical Art).

See Also

- [Armillary Spheres in China](#)
- [Zu Chongzhi](#)

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Li Gao

Hong Wuli

Li Gao was born in 1180 in Zhending (now Zhengding County of Hebei Province) and died in 1251. His surname was Mingzhi, and Dongyuan the Old Man was his nickname. He was an exponent of one of the four major schools of the Jin-Yuan period.

After his mother died of an unknown disorder which was treated to no avail by unskilled practitioners, Li made up his mind to pursue medical studies. His tutor Zhang Yuansu, who advocated the revolutionary idea that “modern diseases cannot be cured by ancient prescriptions,” taught him to probe for new ideas and prescriptions so as to free himself from the yoke of the ancient art of prescribing. He was conversant in the nature and properties of drugs and in their beneficial potentials. The recipes he formulated were all organized according to the theory of “king, minister, assistant, and attendant,” commonly composed of 10–20 kinds of herbal drugs. In line with the classical theory, all the

ingredients were closely related with both complementary and opposing relationships (Jiang, 1963).

He emphasized the role of stomach *qi* during all seasons. *Qi* is the root of all body functions. The spleen and stomach are the roots of growth and metabolism; various disorders arise when their functions are jeopardized. He expounded the etiology and mechanism of disease due to endogenous pathogens (those coming from within), which are different from those caused by exogenous ones, and he stressed the importance of the spleen and stomach in the course of endogenous disorders. He criticized quacks that mix up disorders of different etiology and apply methods for exogenous ailments to tackle the problems of endogenous ones, with ensuing complications. Clinically, he stressed that the spleen and stomach should always be nourished so as to renew the body. He formulated a famous recipe, the *Buzhong Yiqi* (Benefiting-Interior Reinforcing-Qi) decoction, and the *Shengyang Yiwei* (Ascending Yang Replenishing-Stomach) decoction, which are both common remedies still applied today. Due to his emphasis on spleen and stomach, he was given the title of the head of an academic school, the Earth-Replenishing School (Li, 1913). He was also a prolific writer. Among his works, the most famous ones include *Nei wai shang bien huo lun* (*Differentiation for Endogenous and Exogenous Disorders*), *Pi wei lun* (*On Spleen and Stomach*), *Yi xue fa ming* (*Medical Inventions*), *Dong yuan shi xiao fang* (*Dongyuan's Trial Effective Formularies*), *Lan shi mi cang* (*Clandestine Collections in Orchid Mansion*), *Huo fa ji yao* (*Essentials of Flexible Methods*), *Yao lei fa xiang* (*Pharmaceutical Normalcy*), *Yong yao xin fa* (*Mastery of Drug Application*), and *Shang han hui yao* (*Collected Essentials of Disease Due to Exogenous Cold*). In his later years, he passed his academic ideas and works on to his disciple Luo Tianyi (Taki, 1956).

See Also

► [Medicine in China](#)

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Li Shanlan

Jean-Claude Martzloff

Li Shanlan (1811–1882) was a native of Haining, Zhejiang. Although he belonged to a moderately fortunate family and was given formal training in the classics, he never passed government examinations beyond the first level, and had to give up the dream of entering officialdom. Under difficult circumstances, he took refuge in Shanghai, a city newly opened to foreign trade as a consequence of the Opium War.

From 1852 to 1859, Li went into service with the London Missionary Society who employed him as a co-translator of all sorts of Western scientific works. Missionaries had an insufficient mastery of literary Chinese and for that reason they had to rely on Chinese co-workers, even though these, like Li Shanlan, generally had no knowledge of foreign languages. During this period, Li translated with Alexander Wylie (1815–1887) Joseph Edkins (a Protestant Missionary 1829–1890) and others the part of Euclid's *Elements* not yet translated into Chinese (Books 7–15), Augustus de Morgan's *Elements of Algebra* (1835), Elias Loomis's *Elements of Analytical Geometry and of Differential and Integral Calculus* (1851), John F. W. Herschel's *Outlines of Astronomy* (1849), and other manuals on mechanics and botany. But what made Li famous in the eyes of his contemporaries was not so much the numerous translations he was responsible for but his own mathematical works.

Contrary to what might be expected, Li's works were not based on new Western mathematics but on ancient Chinese conceptions, especially the positional algebra *tianyuan shu* developed five centuries earlier during the Song and Yuan dynasties. Li however did not stick slavishly to the venerable discoveries of his ancestors. Rather he used much ingenuity emulating Westerners and trying to beat them at their own game. Using ancient tools, he thus conducted research of his own into logarithms, infinite series, and combinatorics. In particular, he made extensive use of algebraic computations, analogical reasoning and inductive generalizations built on the knowledge of a few particular cases. But he never relied on hypothetical-deductive reasoning. One of his original results, which may be expressed as follows using modern symbolism, is:

$$\sum_{j=0}^k \binom{k}{j}^2 \binom{n+2k-j}{2k} = \binom{n+k}{k}^2,$$

where the $\binom{n}{p}$ represent the usual binomial coefficients occasionally appears in modern books. (Very interesting details (translated into English from the Hungarian original paper), about how this formula became known in Europe are stated precisely in Paul Erdos (1990). See also Martzloff (1997, p. 341).)

Owing to the generosity of Zeng Guofan (1811–1872), a famous general responsible for the suppression of the Taiping revolt, Li Shanlan's collected mathematical works were published in Nanking in 1867 under the title *Zeguxi zhai suanxue* (Mathematics from the Studio "Devoted to the Imitation of the Ancient Chinese Tradition").

The contents of the *Zeguxi zhai suanxue* collection are as follows:

1. Two prefaces

1. Li Shanlan's preface, dated 1867, where he expresses his deep admiration for ancient Chinese mathematics and refers to himself as "Shanlan": "When 10 years old, Shanlan found a copy of the Nine Chapters ... he

read it and found that it was so easy that it necessitated no special study. But from this, he fell in love with mathematics *suan* [...] At the occasion of the provincial examinations, he found a copy of (Li Zhi's) *Ceyuan haijing* (Sea Mirror of Calculations Concerning Inscribed and Circumscribed Circles) and of [Dai Zhen (1724–1777)'s] *Gougu geyuan ji* (Treatise on Cyclotomy by means of Right-Angled Triangles) (1755) [...]"

2. Preface by one of his (now unknown) disciples.
2. Thirteen treatises

1. *Fangyuan chanyou* (The Mysteries of the Square and Circle). The opening sentence starts by a proud assertion of what Li Shanlan considers an erroneous Western conception: "First, we must acknowledge the fact that what the Westerners call 'points', 'straight lines' and 'planes' cannot be dimensionless." Note that this offensive declaration must be taken cum *grano salis* because Li Shanlan was the translator of the *Elements* into Chinese. Then the treatise develops quadratures and developments into infinite series by submitting infinitesimals to all sorts of arithmetical operations and limiting processes. In this way, he obtains, for example, the following result:

$$\pi = 4 - 4 \left(\frac{1}{3 \times 2} + \frac{1}{5 \times 4!!} + \frac{3!}{7 \times 6!!} + \frac{5!}{9 \times 8!!} + \dots \right)$$

2. where $4!! = 4 \times 2$, $6!! = 2 \times 4 \times 6$, ... and where the factorial has the usual meaning.
3. *Hushi qimi* (The Mysteries of the Arc and Sagitta Unveiled). Developments into infinite series of trigonometric functions (sinus, tangent, secant. ...).
4. *Duishu tanyuan* (The Origin of Logarithms).
5. *Duoji bilei* (Accumulated "Heaps" Studied from an Analogical Point of View). Generalised Pascal's triangle with all sorts of finite summations. The term "heaps" used here refers to the fact that Li Shanlan visualised binomial and other combinatorial

coefficients under the form of geometrical heaps of material objects such as small cubes or spheres analogous to marbles. Li Shanlan's formula occurs here.

6. *Siyuan jie* (An Explanation of the "Four Elements"). An interpretation of the meaning of Zhu Shijie's medieval algebra, developed in the famous *Siyuan yujian* [Mirror of the Four Elements] (1303).
7. *Linde shu jie* (An Explanation of the *Linde Canon*). The treatise contains an elucidation of this extremely difficult technical text and, in particular, of its non-linear interpolation formula. The term *Linde* is the name of a reign-period (664–666) of the Tang Emperor Gaozong. Its literal meaning is "unicorn virtue", a classical Chinese allusion to prosperity and happiness. Generally speaking, *shu* means "methods", "set of mechanical rules" or "algorithms" and *li* "mechanical rules for mathematical astronomy and calendrical calculations", but here they are interchangeable. *Linde shu* or *Linde li* means "*Linde canon* (of astronomical calculations)" and not merely "*Linde calendrical calculations*" as is often (and wrongly) said.
8. *Tuoyuan zhengshu jie* [An Explanation of the True *Shu* (here algorithms) of the Ellipse (lit. "flat circle")].
9. *Tuoyuan xinshu* (New *shu* for the ellipse)
10. *Tuoyuan shiyi* (Remaining Considerations on the Ellipse).
11. *Duishu jiantui bianfa shi* (Explanation of a Modified Method for the Calculation of Logarithms).
12. *Huoqi zhenjue* (True Tricks Concerning Fire Machines). This contains an explanation of the parabola in connection with the trajectory of projectiles.
13. *Jishu huiqiu* (The Reversion of Series). Given an infinite development, $y = f(x)$, find x in terms of y .
14. *Tiansuan huowen* (Queries on Chinese Mathematics).

In 1869, Li was appointed Professor of Mathematics at the newly created Tongwen guan, a college in Beijing devoted to the teaching of foreign languages, technology, and science. He based his lectures partly on Western mathematics and partly on Chinese mathematics, and remained in that post until his death. His works were much admired in China by mathematicians and non-mathematicians alike. They can be considered at the same time the most creative mathematics written in China during the whole of the nineteenth century and the swan song of Chinese traditional mathematics.

Unsolved Problems

1. It is customary to refer to the above combinatorial formula as "Li Shanlan's formula" in the same way as we refer to Pythagoras' theorem, Bezout's theorem and the like. Very often, however, these appellations are very loose and do not always adequately reflect historical reality. For example, Pythagoras' theorem was not a "theorem" at first but rather something like an algorithm, and it was known long before Pythagoras.

Thus, it may be that Li Shanlan's formula was buried somewhere in the huge and not wholly explored treasure-house of nineteenth century mathematics, or in Japanese mathematics (*wasan*), where the occurrence of combinatorial formulae in various guises is not so infrequent.

So we can ask ourselves if we can prove or disprove the statement: the appellation "Li Shanlan's formula" is not a misnomer.

2. Is it possible to translate the *Zeguxi zhai suanxue* into a Western language?

It most definitely is. Li Shanlan's treatise is written in a crystal clear and beautiful sort of classical Chinese. Providing a translation, however, might be difficult, especially in view of the very special technical terminology he relied on. Concerning the importance of specific calculations in this work, the would-be translator would have to avoid any reference to "concrete mathematics" as Knuth would perhaps call these. But programs able to manipulate formal expressions and



Li Shanlan, Fig. 1 Li Shanlan



Li Shanlan, Fig. 2 Alexander Wylie

multi-precision arithmetic, like Maple, would help redoing the calculations mechanically, painlessly and exactly (Figs. 1 and 2).

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Li Shizhen

Fabrizio Pregadio

The great Chinese naturalist and pharmacologist Li Shizhen was born in 1518 near modern Qichun (Hubei). Born into a family of doctors, he concentrated on the study of medicine at an early age under the guidance of his father. His reputation as a physician soon reached the prince of Chu, who in 1543 entrusted him with medical and administrative responsibilities at his court in Wuchang. From 1544 to 1549 Li practiced at the Imperial Academy of Medicine (Taiyi Yuan) in Beijing. After that, he returned to his native village, where he worked as a doctor until his death in 1593.

The experience as a physician suggested to Li the need of a thorough revision of the

traditional repositories of pharmaceutical knowledge (*bencao*). Earlier standard sources such as the work by ► [Tang Shenwei](#) had been made obsolete by the adoption of new drugs and prescriptions, along with errors in the identification and classification of some substances. Li apparently began to conceive the compilation of a definitive pharmacopoeia around 1552, and worked on this project for more than 25 years. He spent much of that time reviewing a massive amount of literature, and traveling extensively to collect specimens and recipes.

The result of these efforts represents the culmination of the literary tradition of Chinese pharmacology. Li Shizhen's work, entitled *Bencao gangmu* (The Pharmacopoeia Arranged into Headings and Sub-Headings), contains 1,892 entries, classified into 16 main sections (e.g., Minerals, Trees, Reptiles) and 62 categories. The entries describe 275 minerals, 1,094 plants, 444 animals, and 79 miscellaneous substances (those in the sections Water, Fuel, and Earth). Li Shizhen himself contributed no less than 374 new entries.

Li classified the *materia medica* according to an essentially binomial system, describing species as variants of a genus. His work deals with minerals first, followed by plants, invertebrates, vertebrates, mammals, and humans. A typical entry is divided into sections concerned with nomenclature, places of occurrence, varieties, problems of identification, medical properties, uses, and prescriptions. The *Bencao gangmu* contains more than 11,000 recipes, about 8,000 of which were collected or devised by the author, and more than 1,000 illustrations. The sources, numbering about 1,000, consist of medical and pharmacological works, along with historical, literary, philosophical, and other texts. While Li – like most traditional pharmacologists before him – accepted the authority of the early, pre-Tang pharmacopoeias, he did not refrain from criticizing and correcting the views of later authors.

The manuscript of the *Bencao gangmu*, completed in 1578, went through several revisions until 1590, when Li took it to a ► [Nanjing](#) publisher for publication. It is uncertain whether the author was able to see his work printed before he died in 1593: recent research has suggested that printing may

have not been completed until 1596 rather than 1593 as often indicated. The *Bencao gangmu* was re-edited several times in China and Japan. References in early sinological works reached the attention of eighteenth- and nineteenth-century Western scientists, including Carl von Linnée (Linnaeus) and Charles Darwin, who refer to it in their own works. (Editor's note: More detailed material can be found in Métaillé, 2001).

See Also

- [Ethnobotany in China](#)
- [Medicine in China](#)
- [Tang Shenwei](#)

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Li Zhi (Li Ye)

Ho Peng Yoke

Considered by the historian of science George Sarton as essentially an algebraist, Li Zhi (1192–1279) was one of the greatest mathematicians of his time. He is known by some as Li Ye,

a name that he was supposed to have taken at the later stage of his life to avoid the word *zhi* which was adopted by a member of the royalty. He used an algebraic process known as *tianyuanshu* (method of the celestial element) to set up equations of any degree. He was not the originator of this method, but it was through his writings that the *tianyuanshu* was handed down to later generations. It was introduced to Japan and had a profound influence on Japanese mathematics. Known as *tengenjitsu* to Japanese mathematicians, it enabled Seki Takakazu (also known as ► [Seki Kowa](#), ca. 1642–1708) to develop a formula for infinite expansion, which is now arrived at using infinitesimal calculus. (See the article on Seki Kowa for a more complete description of the method.)

Li Zhi was born in Luancheng in modern Hebei province. He served the Jurchen government as a magistrate in Junzhou (in modern Henan province). In 1232 the Mongols captured Junzhou and Li Zhi made his escape taking refuge in various places and living as a recluse. He became a noted scholar in north China. Qubilai Qan intended to give him an official appointment, but he declined the offer. He read widely and was a voluminous writer. Unfortunately most of his books are lost. According to one source, before Li Zhi died he told his son Li Kexiu to burn all his writings except the *Ceyuan haijing* (Sea Mirror of Circular Measurements) which he wrote in 1248, saying that posterity might find it useful. Somehow, another mathematical text, the *Yigu yanduan* (New Steps in Calculation) which he wrote in 1259, also escaped the fire. It is only through these two works that we know about Li Zhi's contributions to mathematics.

Consisting of 170 problems, the *Ceyuan haijing* begins with a diagram of a circle inscribed in a right-angled triangle. Diameters of the circle parallel to the vertical and horizontal sides of the triangle, and tangents to the circle parallel to these two sides of the triangle produced 15 different right-angled triangles of different sizes. Li Zhi worked out the relations between the sides of these triangles, and between the diameter of the circle and the parallel sides of two of the trapezia formed in the diagram. His understanding of the properties of the circle and

the right-angled triangles enabled him to work out many of his problems with great ease. The same problem that his contemporary ► [Qin Jiushao](#) (ca. 1202–ca. 1261) solved with a tenth degree equation was handled by Li Zhi simply using a quartic equation instead.

The *Yigu yanduan* contains 64 problems involving mainly a square and a circle, with a few cases on two different circles, two different squares, and a circle together with either a rectangle or a trapezium. Again equations of higher degrees are used. This text stabilized the terminology used in Chinese mathematics about equations of higher degrees.

See Also

- [Mathematics in Japan](#)
- [Seki Kowa](#)

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Līlāvati

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The *Līlāvati* is a Sanskrit work on arithmetic and mensuration (computational geometry) composed in or a little before AD 1150 by Bhāskara

II, one of the greatest Indian mathematician-astronomers. The *Līlāvati* is sometimes regarded as the first part of the *Siddhāntaśiromaṇi*, a masterpiece on *gaṇita* (mathematics) in its broad sense (including mathematical astronomy), the other parts being *Bījagaṇita*, *Grahagaṇitādhyāya* (chapter on planetary computation), and *Golādhyāya* (chapter on spherical astronomy), but in manuscripts the four parts have been handed down to us independently.

In medieval India, mathematics proper comprised two major fields, *pāṭīgaṇita* (mathematics of algorithm) and *bījagaṇita* (“mathematics of seeds” or algebra). The *Līlāvati* is the most typical and the most influential work of *pāṭīgaṇita*. More than 600 manuscripts of the work reported so far and more than 30 extant commentaries attest that it was the most popular mathematical textbook in India used by a number of people on the entire subcontinent. Moreover, the work was translated not only into Indian languages of the North and of the South but also into Persian several times in the sixteenth and the seventeenth centuries, into English in the nineteenth century, into Japanese in the twentieth century, and into Chinese in the twenty-first century (Pingree, 1970–1994, A4, 299–308, and A5, 254–257).

The great popularity is due not only to the promotion of his works through a school (*maṭha*) established by his grandson, Caṅgadeva (Pingree, 1970–1994, A4, 299), but also to the elegant but plain Sanskrit and to the well-organized contents of the work itself. The *Līlāvati* consists of about 270 verses of various meters for rules and examples and of prose paragraphs mainly for solutions of the examples: a rule is prescribed for a type of problem, and it is usually followed by one or two examples, which in turn are followed by solutions. The sectioning of the book is not always clear, but it seems reasonable to divide it in 14 chapters. The contents of each chapter are as follows:

1. Terminology (*paribhāṣā*): gives conversion ratios between various units for currency, weight, length, area, and capacity.

2. Determination of the places for numbers (*saṃkhyāsthānanirṇaya*): enumerates the names of the first 18 decimal places from *eka* (1) to *parārdha* (10^{17}). This is the Hindu traditional list that had been fixed in the time of Śrīdhara (eighth century AD) (Hayashi, 1995, pp. 64–70).

3. Eight elementary operations (*parikarmāṣṭaka*): prescribes rules for the eight operations (addition, subtraction, multiplication, division, square, square root, cube, and cube root) in three sections, namely, those for integers, for fractions, and for zero. The rules for integers are based on the place-value notation. For multiplication several additional rules are also given. The first four rules for zero are as follows ($a > 0$): $a + 0 = 0 + a = a$, $a - 0 = a$, $a \times 0 = 0 \times a = 0$, but, when other operations follow, the product, being called *khaguṇa* (a quantity that has zero as a multiplier), retains a besides the zero, and the zero is canceled if the succeeding operations contain zero as a divisor, and $0 \div a = 0$ and $a \div 0 = \textit{khahara}$ (a quantity that has zero as a divisor). The rule, $0 - a = -a$, is not given here because negative numbers are avoided in *pāṭīgaṇita*; it is given in the *Bījagaṇita* of the same author. In that work, the infinity and invariability of the *khahara* is compared to that of God Viṣṇu.

4. Miscellaneous (*prakīrṇaka*) operations: includes the rule of inverse operations, the optional-number computation (the rule of false position), the inequality computation (algorithms for two sets of algebraic normal forms), the square computation (three algorithms for the simultaneous indeterminate equations, $x^2 + y^2 - 1 = u^2$, $x^2 - y^2 - 1 = v^2$), the multiplier computation, the rule of three (which is essential for *pāṭīgaṇita* according to Bhāskara II), the inverse rule of three, and the barter. The “multiplier computation” was an algorithm for the equation, $x - a\sqrt{x} = b$ (the “multiplier” signifies a), which had been treated as one of the “class” (*jāti*) problems by Śrīdhara, by Mahāvīra, and by Śrīpati. Bhāskara II reduced several other “class” problems of similar types, which had

been given different algorithms by his predecessors, to this type, and treated other “class” problems involving simple linear equations under the “optional-number computation.”

5. Procedure for mixture (*miśraka-vyavahāra*): includes interest, investment, and proportional distribution of gain, filling a pond with water through several pipes, buying and selling, equation of properties after the exchange of jewels, purity of gold, and combination.
6. Procedure for series (*śreḍhī-vyavahāra*): treats the sums of a natural series, of the sums of natural series, of a square series, and of a cubic series; the sum, the first term, etc., of an arithmetic progression; and the sum of a geometric progression.
7. Procedure for fields (*kṣetra-vyavahāra*): consists of four sections, namely, trilaterals, quadrilaterals, needle figures, and circle and sphere. The first section deals with the Pythagorean theorem and its application, rational right triangles, and the area, the perpendicular, etc., of a triangle. In the second section, besides the areas of equilateral, rectangular, and equiperpendicular quadrilaterals, Bhāskara II discusses in detail how to calculate the diagonals of an inscribed quadrilateral and criticizes Brahmagupta’s method for its “heaviness” (*gurutva*). The third section, based on the property of similar triangles, deals with the lengths of various segments of a “needle figure” (*sūcī-kṣetra*), which is a trilateral formed by the base of a quadrilateral and by its flank sides extended to meet each other. In the fourth section, Bhāskara II employs the two approximations, $22/7$ and $3,927/1,250$, for π , and gives the formulas, $A = cd/4$, $S = 4A$ and $V = Sd/6$, for the area of a circle and the surface and the volume of a sphere, respectively, where d is the diameter and c the circumference. In his *Golādhyāya*, he criticizes Lalla’s formula, $S = cA$, and derives his own for S and V by decomposing a sphere into a number of annuli in one place and into segments like orange peels in another in the former case and into a number of pyramids in the latter (Hayashi,

1997, pp. 214–217). The same section also contains applications of the relationship, $a^2 = 4h(d - h)$, where a is a chord and h the corresponding “arrow” or the height; a list of the sides of inscribed regular polygons (up to a nonagon); and Bhāskara I’s approximation formula for a chord, $a = (4db(c - b))/(5c^2/4 - b(c - b))$, where b is the corresponding arc.

The next four chapters repeat traditional rules for three-dimensional figures.

8. Procedure for excavations (*khāta-vyavahāra*): deals with the volumes of excavations shaped like a rectangular solid, a truncated pyramid, a pyramid, and a cone.
9. Procedure for brick piling (*citi-vyavahāra*): deals with the relationships of the volume, the height, the sectional area, and the number of the layers of a wall made of bricks, the volume and the height of a constituent brick, and the number of the bricks.
10. Procedure for sawing (*krākacika-vyavahāra*): deals with the total area of the sections of a lumber cut by a saw, in order to evaluate the work of sawing.
11. Procedure for heaped-up grain (*rāśi-vyavahāra*): deals with the volumes of grain heaped up on the ground in the shape of a cone, heaped up against a flat wall, and heaped up inside and outside of a corner. The height of the heap is taken to be one-ninth, one-tenth, or one-eleventh of the circumference of the base according to whether the grain is fine or coarse.

The next chapter inherits the traditional title but treats a different problem.

12. Procedure for shadows (*chāyā-vyavahāra*): based on the property of similar triangles and on the Pythagorean theorem, deals with the shadows made by a gnomon; does not contain the calculation of the time of a day from the shadow of a gnomon, a calculation which was included in this “procedure” by Bhāskara II’s predecessors.

The next two chapters are new to the *pāṭiṅaṇita*

13. Pulverizer (*kuṭṭaka*): deals with linear indeterminate equations of the type, $y = (ax + c)/b$. It is Bhāskara II who for the first time included a whole theory of the pulverizer in a book of *pāṭī*, although Mahāvīra had already treated it to some extent in his *pāṭī* book. This is because it requires neither algebraic symbolism nor “intelligence” (*matī*), which is essential for *bījagaṇita* or algebra according to Bhāskara II. He repeats the same rules for *kuṭṭaka*, together with several additional ones for negative coefficients, in his *Bījagaṇita*.
14. Chain of digits (*aṅka-pāśa*): treats permutations of the nine digits (excluding zero). An example for the last rule, for example, reads as follows: “How many varieties of numbers are there with digits placed in five places when their sum is thirteen? It should be told, if you know.” This was an entirely new topic introduced by Bhāskara II, although a rule for calculating ${}_nC_r$ had traditionally been included in the chapter on “mixture” by Śrīdhara, Mahāvīra, Āryabhaṭa II, and Bhāskara II himself.

The above description of the *Līlāvātī* is based mainly on the Ānandāśrama edition, which differs from the Hoshiarpur edition in many respects, for example, the last mentioned topic, ${}_nC_r$, is placed at the end of the chapter on series in the Hoshiarpur edition (Hayashi, 2002). It has been conjectured that those two editions represent the Northern and Southern recensions, respectively, but the history of transmission (including recensions) of the *Līlāvātī* is yet to be investigated on the basis of all the existing manuscripts.

See Also

- [Algebra in India: *Bījagaṇita*](#)
- [Arithmetic in India: *Pāṭiṅaṇita*](#)
- [Bhāskara II](#)

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Liu Hong

Jiang Xiaoyuan

Liu Hong was a Chinese astronomer (AD 129–210), descended from the imperial family of the Eastern Han Dynasty. Liu Hong

was very interested in astronomy from his childhood. About AD 160, he was assigned to be an officer of the Imperial Observatory. In this position, he participated in determining a series of astronomical dates. In AD 174–175, he offered *Qi Yao Shu* (The Art of Seven Planets) and its reformulated edition *Ba Yuan Shu* (The Art of Eight Elements) to the imperial government. The two works have been lost, but there are indications that they related to Buddhist astrology in Middle Asia. In AD 187–188, he composed the *Qian Xiang Li* (Qian Xiang Calendar), a work of traditional Chinese mathematical astronomy. The method to describe lunar motion in this work was so advanced that the imperial government adopted it immediately. In AD 206, he examined and approved the formal edition of *Qian Xiang Li*. This is one of the best calendars in ancient China. It used new data for the tropical year ($365\frac{145}{589}$ days) and the synodic month ($29\frac{773}{1457}$ days), calculated the advance of the lunar perigee, established the concept of the moon's path, and calculated the regression of node, established the first table of the lunar apparent motion in ancient China, and also made progress in the calculation of eclipses and planetary motion.

See Also

► [Calendars in East Asia](#)

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Logic

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It is believed in the West that logic began with Aristotle and that logic is universal. The core of Western thought – including present-day formal mathematics and the philosophy of science – is premised on the belief that logical truths are universal, that they are necessary truths, and that logical deduction is certain and infallible. These beliefs about logic, however, are untenable, both historically and philosophically, in a larger picture which takes the rest of the world into account.

Philosophically, present-day formal logic, like the twelfth century BCE text, *Organon*, attributed to Aristotle, supposes that deduction relates to two-valued logic. In such a logic, an affirmation A conjoined with its negation ($\sim A$) makes a contradictory pair, from which any conclusion B whatsoever can be validly inferred by the rule of inference known as *reductio ad absurdum*: ($A \wedge \sim A \Rightarrow B$), to put it symbolically, with “ $\sim$ ” denoting “not,” “ $\wedge$ ” denoting “and,” and “ $\Rightarrow$ ” denoting the usual (material) implication. For example, A could be the proposition, “This pot is red,” so that its negation $\sim A$ would be the proposition, “This pot is not red.” From the contradictory pair ($A \wedge \sim A$), one can validly infer something completely unrelated like B : “The age of the cosmos is 8,000 years.” Such proofs by contradiction are common in present-day mathematics. However, such a deduction would be invalid with a variety of logics that one can conceive of. The alleged certainty of deduction, therefore, rests on the belief that two-valued logic is universal or at least special in some way.

However, the various logics used for inference in India, prior to even the historical Aristotle,

were neither two-valued nor even truth-functional. The *Dīgha Nikāya* provides an example. As the Buddha explains in the *Brahmajāla Sutta*, there are four alternatives:

1. The world is finite; this is one case.
2. The world is not finite; this is another case.
3. The world is both finite and infinite; this is the third case.
4. The world is neither finite nor infinite; this is the fourth case.
5. There are no other cases.

The semantic interpretation of the third case is that the world may be finite in one direction, but infinite in another. This presents no inherent absurdity, and could conceivably be in the nature of things.

The meaning of the fourth case, not so well brought out in the English translations of the *Dīgha Nikāya*, may be better understood as follows. Consider a person who refuses to take a position, and denies that he affirms any of the first three cases above. His position can only be described by the fourth case.

The need for such a fourth case is apparent from the thinking then prevalent. Likewise, the absence of any further cases is a reference to further negations used by pre-Buddhist thinkers like Sañjaya the Sceptic, who tried to wriggle out of even this fourth position, and whose comprehensive refusal to take any position whatsoever was described by the Buddha as being like the “wriggling of the eel.”

These four cases are systematically used by later-day Buddhist thinkers like Nāgārjuna and Dinnāga who taught at the University of Nalanda. The latter developed a theory of (logical) quantifiers, “for all,” “for some,” etc., based on this sort of logic. From the perspective of present-day formalist treatments of logic, it should be noted that Buddhist logic is not multi-valued but is rather a quasi truth-functional logic.

The Jains had a related but different logic called the logic of *syādavāda* (“perhaps-ism”), based on the idea of *anekāntavāda*

(no-one-point-of-view-ism). Attributed to Bhadrabāhu, instead of four alternatives, this logic has a sevenfold judgment (*saptabhangīnaya*) based on seven possible combinations of three primary values: *asti* (is), *nāsti* (is not), *avaktavya* (inexpressible), taken one, two, and three at a time.

- *Syad asti*. (“Perhaps it is.”)
- *Syad nāsti*. (“Perhaps it is not.”)
- *Syad asti nāsti ca*. (“Perhaps it both is and is not.”)
- *Syad avaktavya*. (“Perhaps it is inexpressible.”)
- *Syad asti ca avaktavya ca*. (“Perhaps it is and is inexpressible.”)
- *Syad nāsti ca avaktavya ca*. (“Perhaps it is not and is inexpressible.”)
- *Syad asti nāsti ca avaktavya ca*. (“Perhaps it is, is not, and is inexpressible.”)

Haldane sought to interpret the Jaina logic of *syādavāda* by temporalizing the three primary values. Consider an experiment in which a person is asked to judge whether or not a sensory stimulus, at the threshold of perception, is present. If this experiment is repeated several times, a person might in one case judge the stimulus as present, in another as absent, and may remain undecided sometimes. Combining these possible experimental outcomes in all possible ways gives us the seven different judgments used by *syādavāda*. Thus, it is quite possible that a person may, at one time say that a stimulus is present, but may, on a later repetition of the same experiment, say, about the same stimulus that it is absent, and on a third occasion say that he is unable to decide.

Haldane’s interpretation of *syādavāda*, making it intelligible in a mundane context, seems, however, not to be correct. It is one thing to say, “This cat is now alive, and will be dead some time later.” This is true of most known cats, and presents no difficulty: *A* is true at one time, and $\sim A$ is true at another time. However, it is altogether another thing to say, “This cat is both alive and dead at this moment of time.” That sort of thing

happens only to Schrödinger's famous cat (or its kittens). It is the latter sort of statement that is meant in Buddhist and Jaina logic, as is clear from the meaning explained by the Buddha. In fact, on Buddhist thought, as further elaborated by Nāgārjuna, a thing – anything – does not persist for more than an instant of time. Therefore, a statement about a cat, for instance, must refer to that cat at a given instant of time, for an identical cat does not exist at two different instants of time.

In terms of the present-day formal semantics of logical worlds, one might put things as follows. The different possibilities visualized in Buddhist and Jaina logic refer not to multiple logical worlds assigned to different instants of time, but to multiple logical worlds assigned to a single instant of time. In other words, Buddhist and Jaina logics relate to a world view in which time is perceived to have a nontrivial structure, an (atomic) instant of time is perceived not as a featureless geometrical point but as a microcosm. Hence, members of a contradictory pair can well be simultaneously true.

This can be understood at the mundane level as follows. Consider the statement, "This pot is both red and black." We could rewrite this, less informatively, as, "This pot is both red and not red." Since earthen pots made by hand are rarely of a single color, this is a statement about a naturally prevailing state of affairs that is commonly observed. The statement, as framed, seems like a contradiction. But, it could be argued that this is an imprecise natural-language statement which should actually be written more carefully as, "This part of the pot is red, and that part of the pot is not red."

However, such a reinterpretation raises some issues. First, there is the issue of the whole not being the sum of its parts. It is being assumed that the pot can be subdivided into parts. If the pot is physically shattered to carry out this subdivision, one can continue to speak of parts of the pot, but one cannot continue to speak of the pot. Therefore, the reinterpretation does not capture the exact sense of the natural-language statement. Thus, the idea of a thing being both true and false is not such an odd idea, and no catastrophic consequences need follow from it.

Second, how can we be sure that the apparent contradiction can always be resolved by suitably shattering the identity of the pot? Thus, a certain part of the shattered pot may continue to be both red and black, so one may want to divide the pot in a particular way. Now it may happen that, in a certain part of the pot, red and black are so entangled that it may not be clear how to separate them. The remedy obviously seems to be to make a finer division of the pot, and a still finer division, and so on, until the pot is suitably atomized. However, there is an assumption here. The assumption is that the entanglement and the resulting contradiction will somehow eventually resolve themselves with this process of reduction and that the entanglement cannot persist at the atomic level, where a thing either is, or is not. Apart from the fact that atoms are neither red nor black, there are several problems with such an assumption. For example, this assumption is contrary to what our most sophisticated theories of physics tell us. The behavior of physical systems at the atomic level is described by quantum mechanics, which tells us that there may exist entangled states that cannot be disentangled without fundamentally altering the system. The existence of such entangled states, incidentally, provides the hope today for future technology based on quantum computing, and it has various physically measurable consequences.

On the structured-time interpretation of quantum mechanics, these entangled states are interpreted to arise because time really has a microphysical structure (in the sense explained above, in the context of Buddhist and Jain logic) so that the logic of the microphysical world is quasi truth-functional. (In the structured-time interpretation of quantum mechanics, such a quasi truth-functional logic is related to the postulates of formal quantum mechanics.) To summarize, the logic of the empirical world may well be quasi truth-functional: i.e., we might have a situation where a proposition is both true and false at a single instant of time. Hence, we cannot automatically assume that the "contradictory" properties of a pot can be made to disappear by atomizing the identity of the pot.

Theoretically, from the viewpoint of present-day formal logic, one can conceive of an infinity of different logics, such as 2, 3, ..., n -valued logics, or non-truth-functional logics. Among the infinity of logics that are available how can we be sure that two-valued truth-functional logic is the correct and universal choice? Suppose the choice is made culturally. That is, suppose we say that two-valued logic is what has been conventionally used in the West, and this is the logic that should be chosen since the West is culturally dominant. (A similar argument was given against intuitionists; it was argued that they were not adequately socially dominant among mathematicians, hence they were incorrect!) However, if such a weak argument is the ultimate basis of deduction, then deduction can at best give us a local cultural truth. On the other hand, suppose the choice is made empirically, then, as we have already seen above, we might end up with the logic of quantum mechanics, which need not be two-valued. Therefore, it is not clear that there is anyway the existing choice of logic in the West can be justified.

The possibility or necessity of determining logic empirically strikes at the root of another fundamental difference between Western and non-Western perceptions of logic. In the West, logical truths are regarded as necessarily true, and are privileged over empirical facts, regarded as being only contingently true. Present-day mathematical proof is required not to involve the empirical, since that would diminish the sureness attached to a mathematical theorem. Hence, also, the present-day belief in the philosophy of science, that when the conclusions of a physical theory are refuted by experiment it is the hypotheses that stand refuted, and not the process of inference which led from hypothesis to conclusion. (Here it is necessary to distinguish between validity and correctness. The point is that it is believed that no empirical fact can invalidate a correct mathematical proof.)

Therefore, even if one were to go about trying to settle the nature of logic empirically, this would have consequences which would be startling from a Western perspective. Empirical observations are fallible, and subject to revision.

So if the nature of logic is decided empirically, logical truth would have to be regarded as more fallible than empirical truth: deduction would have to be regarded as more fallible than induction, since the nature of the logic used for deduction could only be decided inductively. This would stand much of Western thought on its head.

This would, however, leave much of non-Western thought unaffected. The belief that metaphysical (e.g., mathematical) truths are privileged over empirical truths is not necessarily shared by the non-West. In traditional Indian thought, for example, logical truths are ranked below empirical truths. Thus, the empirically manifest (*pratyakṣa*) is regarded the first *pramāṇa* (proof), and this is a means of proof accepted by all traditional Indian schools of thought, without any known exception. Inference (*anumāna*) or deduction is regarded like estimation as an inferior means of proof by the Lokāyata school and rejected, just as analogy is regarded as an inferior means of proof by Buddhists, and rejected in comparison with the empirically manifest and inference.

Thus, there appears to be no serious way out of this dilemma about the nature of logic, and most of Western thought would hence need to be reworked in the future to avoid this incorrect assumption that two-valued logic is somehow universal.

From a historical perspective we can understand how this Western myth about the universality of logic developed. The word “logic” derives from “logos” meaning “word” or “reason” – a term imbued with deep religious significance by the (Neoplatonist) philosophers of Alexandria, like Proclus, who refer to it as “divine.” The reason for this, as stated by Plato, was that geometrical truths based on reason were thought to be eternal – like the soul, and unlike empirical things (like the body) that are by nature perishable. Proclus explains that mathematics derives from the Greek word *mathesis*, meaning learning, so that mathematics is the science of learning. According to Socratic belief, all learning is recollection of knowledge already in the soul; hence it was thought that mathematics, since it

embodies eternal truths, and stirs the soul reminding it of its past lives, thus justifies its name as “the science of learning” or the “science of the soul.” This belief in eternal truths was also understood quite literally as implying a world which existed eternally, a subject on which Proclus wrote a book.

After the Christian church revised its doctrines of creation and apocalypse in the fourth century BCE, it found this belief in eternal truths, past lives, and an eternal world, implicit in mathematics and logic, contrary to the revised doctrines. The church viciously persecuted the philosophers of Alexandria, burning their books, smashing their temples, lynching them, and eventually making a law declaring a death penalty on them. The philosophers found a more congenial base in Jundishapur in Iran.

This religious significance of logic or reason, however, remained part of early Islamic rational theology (*aql-i-kalām*), and it received a big boost when the philosophers moved from Jundishapur to the Bayt al-Hikmā (House of Wisdom) in Baghdad, with the support of Caliph al-Māmūn. The belief in reason then acquired such force in Islam that even key opponents of the philosophers, like al-Ghazālī, conceded that God was bound by logic and could not create an illogical world or a world in which something might have contradictory properties.

Though incidental to al-Ghazālī’s primary objective, this concession about logic marked a fundamental shift which has gone unnoticed. Plato and Proclus had thought that logical and mathematical truths were necessary truths in the sense that they were eternally true or true for all time. In al-Ghazālī’s vision, Allah continuously created the world afresh each instant; therefore nothing could last eternally. With al-Ghazālī’s concession that Allah could not create an illogical world, the notion of necessary truth acquired a new meaning. That is, al-Ghazālī regarded logical (and mathematical) truths as necessary truths in the sense that they were true in all conceivable worlds (that Allah could create), and not in the sense that logical truths were eternally true.

Western thought developed in European universities from the twelfth century BCE onwards

under the influence of hundreds of Arabic texts translated into Latin. Particularly important were the texts written by al-Ghazālī’s Islamic opponent ► [Ibn Rushd \(Averroes\)](#). For Ibn Rushd, the term “Aristotle” was a generic term for “the Greek sage,” linked to the book called the *Theology of Aristotle*, one of the translations of the Baghdad House of Wisdom. Thus, for Ibn Rushd reason and religion continued together.

This Arabic knowledge flowing into Europe alarmed a section of the church and was regarded as spreading heresy at the time of the Crusades and Inquisition. Aquinas and the schoolmen undertook to make this knowledge theologically correct.

The first step in this process of theological purification was to deny any Arabic-Islamic contribution whatsoever in these eleventh century BCE Arabic texts, and to attribute wholesale to Aristotle, or some other Greek, the authorship of any desirable part of these works. (Theologically unacceptable parts were attributed to various others, like Plotinus.) Since the church could hardly acknowledge publicly that all its knowledge came from Islamic sources, so it had to be pretended that the heathen were mere carriers of what formerly was Western knowledge. The evidence linking these late and obviously accretive texts to the historical Aristotle is expectedly slight, and requires a giant leap of faith, but religious history is no stranger to such leaps of faith. This concocted story based on flimsy evidence has been uncritically accepted and repeated for centuries, but hardly stands up to the slightest critical scrutiny. In the process of denying the Arabic-Islamic contribution, the Indian contribution from the ► [Nyāya](#) school, which used a similar system of syllogisms (with two-valued logic), and was probably translated in the Bayt al-Hikmā, may also have been denied. The point here is not the priority for the syllogism – priority does not have the same importance in the non-West as it has in the West – the point is to understand the historical process by which the syllogism developed. In India, given the wide-ranging nonviolent debates between clashing traditions, it was important to evolve a systematics of argumentation. It is easier to believe that the syllogism developed in

response to some such social need than to believe the tale that a single individual called Aristotle apparently created a complex theory *ex nihilo*.

Could the similarity between the Indian and the “Aristotelian” syllogism be due to transmission? Certainly, there were regular contacts between India and Greece from before the time of Aristotle, as recounted by Herodotus or as evidenced by Alexander’s attempt to find the sea route to India after his army mutinied at the frontiers of India. Second, as a key beneficiary of Alexander’s loot of Egyptian, Persian, and Babylonian books, Aristotle also had the benefit of access to a wide variety of world literature. Third, we know from the rock edicts of Aśoka the Great that he sent an envoy to Ptolemy II to teach righteousness (*Dhamma*) to the Alexandrians and Macedonians. Fourth, India had a roaring trade with Alexandria at the time of the Roman empire, and Roman historians complained that this trade was draining a major part of the surplus of the empire. Fifth, Augustine taunted the Alexandrian philosophers for being interested in “the mores and disciplines of Inde.” So, transmission of knowledge between India and Alexandria certainly could have taken place (in either direction) over a wide-ranging period.

Whether such transmission involved the syllogism is another matter. It seems not to have been much used in Hellenic tradition. Therefore, it lacks credibility to imagine the pre-Hellenic existence of a syllogistic logic, from eleventh century BCE Arabic or later Byzantine Greek texts. The known facts are that the use of the syllogism among Arabs does not begin before the ninth century BCE, and among Europeans not before the twelfth century BCE; everything else is conjecture.

Apart from denying the slightest credit to the non-West in all the accumulated knowledge in the eleventh century Arab texts, the second step in the Christianization process of these texts was to revise the significance of logic and reason. Reason was no longer the window to the soul but was promoted in Christendom as a means of argument used to persuade the infidel who would not listen to arguments from the scriptures, but would accept arguments based on reason. Hence, reason (and the logic used by Aristotle) was

declared to be “universal.” It is in this way that it historically came to be believed in the West that logic began with Aristotle and is universal, although both beliefs are incorrect when a larger picture is taken into account.

In India itself, the ► [Nyāya](#) tradition was attacked by the Advaita Vedantist S’rīharṣa, in the ninth century BCE using arguments similar to those of Nāgārjuna. The Navya-Nyāya (new Nyāya) logic emerged subsequently.

See Also

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- [Nyāya](#)

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Long Count

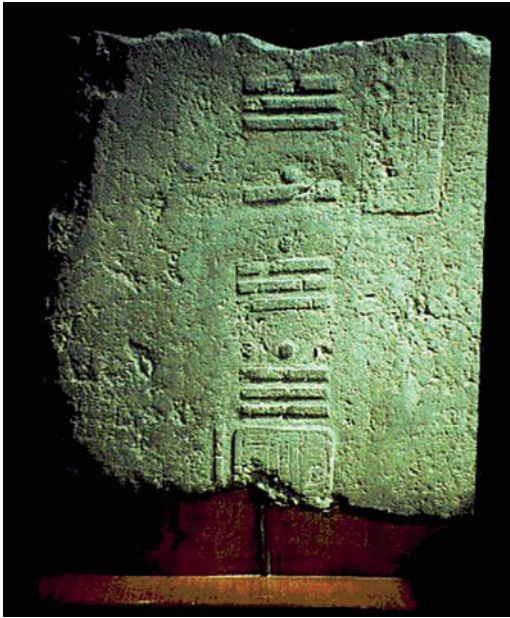
Vincent Herschel Malmström

One of the most original creations of pre-Columbian Mesoamerica was the so-called “Long Count,” a system of recording events in time with unique precision. No parallel system existed in any other society until the Julian Day count was begun in Western Europe in 1582. Because it was most widely used by the Maya,

its development was first credited to them, but subsequent research has shown that the earliest inscriptions which employed the Long Count not only lay well outside of the Maya core-area geographically, but also predated the rise of the Maya historically.

The Mesoamerican Long Count was a meshing of the two time-reckoning systems that had been already been in use in the region for about a millennium: a sacred almanac of 260 days and a secular calendar of 365 days. In both counts a vigesimal system was used to group the days into “bundles,” for a total of 13 in the sacred almanac and a total of 18 in the secular calendar. The five remaining days in the latter count were considered “unlucky” or “worthless.” The basic unit of the count was the day, or *kin*, in Maya. Twenty days constituted 1 *uinal*, and 18 uinals made up 1 *tun*, for a total of 360 days. (The *tun* was the only deviation the Maya allowed from a strictly vigesimal system, and was only employed in their count of days.) Twenty *tuns* comprised a *katun* (7,200 days) and 20 *katuns* constituted a *baktun* (144,000 days). The fundamental premise of the Long Count was that it recorded the number of days that had elapsed from a date in the distant past, which marked the beginning of the present cycle of the world. Because the Maya recorded their Long Count dates by enumerating, in order, the number of *baktuns*, *katuns*, *tuns*, *uinals*, and *kins* which had elapsed from that date, together with the number and name of the day in both the sacred almanac and secular calendar which it represented, any given day was identified by a minimum of nine elements. Thus, in the present convention for transcribing Long Count days, the first day of the Long Count was designated as 13.0.0.0.0. 4 Ahau 8 Cumku (Fig. 1).

Although many attempts were made to reconcile the Long Count with the Christian calendar, one of the first credible explanations was that offered by the American newspaper editor John Goodman in 1905. According to his calculations, the Maya had fixed the beginning of the present cycle of world as 11 August 3114 BCE – a date that accords with Julian Day number 584,283; hence, his correlation has been identified by that



Long Count, Fig. 1 One of the earliest Long Count inscriptions found to date is that recorded on Stela C, discovered by Mathew Stirling at Tres Zapotes in 1939. Although the top of the stela containing the *baktun* value was missing, it was located in 1969 and found to be a seven. In writing numerals, the Maya used a *dot* for values up to four and a *bar* to represent five; hence Stela C's *baktun* value was shown as two dots and one bar. In the photo above we see that the *katun* value has one dot and three bars equaling 16, the *tun* value has one dot and one bar totaling 6, the *uinal* value again has one dot and three bars representing 16, and the *kin* value near the bottom of the inscription contains three dots and three bars for a total of 18. Thus, the full numeric inscription was read as 7.16.6.16.18, and equates to 5 September 31(or 32 BCE). Stela C now reposes in the Museum of History and Archeology in Mexico City (Photo by author)

value. However, because Goodman was not an academic, little attention was paid to his findings until 1926 when a Mexican astronomer named Juan Martínez Hernández recalculated the beginning date of the Long Count as 12 August 3114 BCE, yielding an equivalent Julian Day number of 584,284. The following year, when the British archeologist J. Eric Sydney Thompson made his own attempt to reconcile the two calendars, he determined that the correct date should be 13 August 3114 BCE, for an equivalent Julian Day number of 584,285. Because all three of these correlations produced results within

2 days of each other and have subsequently been shown to accord most closely with known astronomical events, the so-called “Goodman-Martínez-Thompson” is now the accepted means of equating the Long Count with our own calendar. (It should be noted, however, that in 1935 Thompson revised his calculations and adopted Goodman's original formula of 584,283 instead; unfortunately, this “correction” served to confuse the correlation issue for an entire generation because it rendered all astronomical equivalencies impossible. Subsequently, Malmström (1978, 1992), among others, has conclusively demonstrated that the 584,285 correlation is the only one which has astronomical validity.)

As early as 1930, the American mathematician John Teeple concluded that the Long Count had been devised on a date that the Maya recorded as 7.6.0.0.0. 11 Ahau 8 Cumku. Teeple had been struck by the fact that 73 cycles of the 260-day sacred almanac equated with 52 cycles of the 365-day secular calendar and that the day numbers and names of each count then came back into phase with each other. He believed that the Maya had also employed 73 cycles of larger intervals, such as *katuns*, in order to define longer spans of time, and that to fix the beginning of the present era of the world at an appropriately early date, they had projected their count backward for a total of 146 *katuns*, or 7 *baktuns* and 6 *katuns*. This meant that the Long Count had been originated on 18 September 236 BCE – a date that Thompson rejected as being too early because it assigned its creation to a people other than the Maya, who he championed.

In a paper published in 1978, Malmström, using a different premise – namely that the originator of the Long Count was bound by the recognition of the astronomical importance of 13th August as its initiating impulse – reached the same starting date for its origin as Teeple had done. Also in his paper he argued that, by using internal evidence contained in the Long Count, it is possible to establish both the beginning dates of the secular 365-day calendar and the sacred 260-day almanac as well. The former, he stated, was set in motion at the summer solstice around the year 1320 BCE, whereas the latter was



Long Count, Fig. 2 *Baktun 7* inscriptions, which represent the earliest form of the Long Count, are all found in a restricted area stretching from the Pacific coast of

Guatemala and Mexico across the Isthmus of Tehuantepec to the Gulf of Mexico. All of them are associated with early Olmec ceremonial centers (Map by author)



Long Count, Fig. 3 Later examples of the Long Count, all dating to the so-called “Classic Period” (AD 250–900), occur only in areas occupied by the Maya. Apparently the Long Count neither reached other peoples in Mesoamerica

nor, if it did, was adopted by them. Its presence among the Maya helps to explain their preeminence in pre-Columbian astronomic studies (Map by author)

initiated with the zenithal passage of the sun over Izapa in southernmost Mexico on 13 August about the year 1358 BCE. (Each of these dates may vary by as much as 4 years, due to the fact that the indigenous Mesoamerican calendars did not correct for leap years.) All of the earliest, or *baktun* 7, Long Count inscriptions have been discovered along an axis which extends from the Soconusco region of southern Mexico and adjacent Guatemala to central Chiapas into the Gulf coastal plain of Veracruz – an area which constituted the original homeland of the Zoque-speaking Olmec people (Figs. 2 and 3).

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Lunar Lodges in Chinese Astronomy

F. Richard Stephenson

Probably during the first millennium BCE, Chinese astronomers grouped the stars visible from their country into about 280 small constellations, each containing an average of about five stars. Among these star groups, 28 asterisms encircling the sky in the general vicinity of the celestial equator were regarded as of special significance. Although their general appearance was much similar to that of the other constellations, these select star groups, known as *xīu* (lunar lodges) came to be of great importance in astrology and positional astronomy. The expression *xīu* is the derivative of a term *su*, meaning, “to stay the

night”. Although many of the lunar lodges were not near the ecliptic, they represented the nightly resting places of the Moon in its monthly circuit across the sky. During the first millennium AD, the Chinese system of mapping the stars, together with its associated lunar lodges, spread to other areas of East Asia, notably Korea and Japan.

Just when the Chinese first divided the stars into groups is not known with any accuracy and this is also true of the *xīu*. A somewhat idealistic date for the origin of the lunar lodges can be deduced by considering precession of the equinoxes. Chinese astronomy is equatorial, rather than ecliptic, in character. Calculations reveal that in antiquity the mean great circle through the *xīu* was a significantly better approximation to the celestial equator than at present, with the best fit around 2500 BCE. Although attractive, such an artificial date has little to commend it. Several of the individual lunar lodges would still lie at a considerable distance from the mean circle, while there is no evidence of an advanced culture in China at such a remote period.

Direct historical evidence for the existence of the lunar lodges is lacking until about 3,000 years ago. The two earliest sources of information are quite diverse. Several of the ancient folk songs assembled in the *Shijing* (Book of Odes) – some probably dating from around 1000 BCE – allude to about ten star groups in total. Most of these constellations can be identified with lunar lodges as cited in later texts. Again, several bronze vessels which were cast at much the same period as the folk songs were composed are inscribed with the names of a few lunar lodges. It may thus be inferred that at least some of the *xīu* had acquired special significance by early in the first millennium BCE. However, to encounter the earliest preserved list of all 28 lunar lodges we have to move considerably forward in time.

A date of origin of the lunar lodges at least by the middle of the first millennium BCE was established as the result of a major archaeological discovery in 1978. In that year, a lacquer chest was unearthed from a tomb in Hubei province in Central China (see Fig. 1). This chest had been the property of a nobleman by the name of Yi who had died around 433 BCE, during the



彩图版 2 湖北省随县曾侯乙墓出土的漆棺二十八宿图(约公元前 430 年)

Lunar Lodges in Chinese Astronomy, Fig. 1 Laquer chest, with lid engraved with names of all 28 lunar lodges. The chest was discovered during excavations of a tomb dating from 433 BCE (The chest is in Hubei Provincial Museum, Wuhan)

Warring States Period. On the lid of this chest are engraved the names of 28 constellations in a roughly circular pattern. In general, the various ideographs are identifiable with the names of the lunar lodges found in later lists, and are in the correct sequence. Of course, the existence of the 28 *xiu* as an entity could be much earlier, but at present we have no direct evidence to prove this.

Table 1 gives a standardized list (together with translations) of all 28 lunar lodges as found in texts of from the third century BCE onwards. In this table the *xiu* are numbered in their traditional order, commencing with *Xue* (located near the autumnal equinox in Virgo). In groups of seven, the lodges were traditionally associated with four mythical creatures: the first seven *xiu* with the Azure Dragon of the east, the next seven with the Dark Warrior of the north, the third seven with the White Tiger of the west and the last seven with the Red Bird of the south. Among the first seven lunar lodges, a few names relate to various features of the Dragon. However, the remaining *xiu* designations are little more than a random assemblage and in general they are much more mundane than the names of the Western zodiacal signs.

An early almanac known as the *Yueling* (monthly observances), probably dating from the Warring States Period (481–256 BCE), marks the passing months by the position of the

Sun in various *xiu* as well as the culmination of certain lunar lodges at dawn and dusk. By at least the Former Han Dynasty (202 BCE–AD 9), a series of “determinative stars” (*chuxing*) – see Table 1 – were selected to specify right ascension. This coordinate was known as *ruxiudu* (degrees within a lodge). The meridian through each determinative star was adopted as the western boundary of a zone of right ascension bearing the same name as the lunar lodge itself. As a result, the term *xiu* came to mean both the asterism and the range of right ascension which it defined.

Commencing in the late second century BCE, several preserved lists give the equatorial extension of these zones in *du* (“degrees”, of 365.25 to a circle.) Although the mean range in right ascension of each zone was 13°, the widths of individual *xiu* were far from regular. *Dongjing*, the widest lunar lodge, covered 33°, whereas *Zuixi* was only about 1° in extent. Table 1 gives the calculated widths during the Former Han Dynasty. As yet, the reason for this uneven spacing has not been fully explained. In some respects, the *xiu* resembled the Western zodiacal signs, which from ancient times were used to define celestial longitude. However, the signs of the zodiac were each 30° in extent and – unlike the lunar lodges – the effect of precession caused a gradual easterly displacement relative to the 12 constellations after which they were named.

For almost every solar eclipse occurring during the Former Han Dynasty, the official history of the period, the *Hanshu*, gives an estimate of the right ascension of the Sun to the nearest degree, followed by an astrological prognostication. Several later histories follow a similar practice. For instance, on a date equivalent to AD 120 January 18, the following entry is recorded in the *Houhanshu* (“History of the Later Han Dynasty”):

The Sun was eclipsed. It was almost complete; on Earth it was like evening. (The Sun) was 11° in *Xunu* (“Maid”). The Female Ruler was upset by it; two years and three months later, Deng, the Empress Dowager, died.

At this date, the right ascension of ϵ Aqr, the determinative star of *Xunu* was 286° so that the

Lunar Lodges in Chinese Astronomy, Table 1 The 28 lunar lodges

Number	Name	Translation	Determinative star	Width (in°)
1	Jue	Horn	α Vir	12
2	Kang	Neck	κ Vir	9
3	Di	Base	α Lib	15
4	Fang	Chamber	π Sco	5
5	Xin	Heart	σ Sco	5
6	Wei	Tail	μ Sco	19
7	Ji	Basket	Γ Sgr	11
8	Nandou	S. Dipper	φ Sgr	27
9	Niu	Ox	β Cap	8
10	Xunu	Maid	E Aqr	12
11	Xu	Emptiness	β Aqr	10
12	Wei	Rooftop	α Aqr	17
13	Yingshi	Encampment	α Peg	9
14	Dongbi	E. Wall	Γ Peg	9
15	Kui	Stride	Z And	16
16	Lou	Harvester	β And	11
17	Wei	Stomach	35 Ari	15
18	Mao	Mane?	17 Tau	11
19	Bi	Net	E Tau	18
20	Zuixi	Turtle beak	φ Ori	1
21	Shen	Triad	Δ Ori	8
22	Dongjing	E. Well	μ Gem	33
23	Yugui	Ghost vehicle	θ Cnc	4
24	Liu	Willow	Δ Hya	15
25	Qixing	Seven stars	α Hya	7
26	Zhang	Extended net	N Hya	17
27	Yi	Wings	α Crt	18
28	Zhen	Axle tree	Γ Crt	17

estimated coordinate of the Sun would be 297° ; this is in agreement with the computed right ascension of the Sun.

The lunar lodges were also used to specify the right ascensions of other star groups as well as the changing positions of the Moon and planets. The positions of temporary objects – meteors, comets, and novae or supernovae – were often described in this way. For example, the passage of Halley’s Comet in AD 66 through 8 lunar lodges between *Jianniu* and *Yi* is recorded in an early commentary on the *Houhanshu*.

Early measurements of the right ascension of Halley’s Comet have proved of great importance in studying the orbit of the comet. For instance, at the very close approach of Halley’s Comet to the Earth in AD 837, its position in the appropriate *xiu* was estimated to the nearest degree on several

successive nights. At the time, the comet was moving rapidly across the sky at roughly $2^\circ/\text{h}$. The Chinese observations enable the date of perihelion to be estimated to the nearest 0.1 day. In AD 1006, the right ascension of a brilliant supernova was recorded as 3° in the lunar lodge *Di*. This and other contemporary observations have enabled the remnant to be convincingly identified.

The *Xingjing* (Star Manual), a star catalog which has been dated by astronomical computation to around 70 BCE, gives the earliest preserved measurements of north polar distance for the determinative stars of the *xiu*, as well as for many other stars. Individual results are typically quoted to the nearest 0.25° or 0.5° . Using these and similar measurements in later catalogs, together with several carefully executed star

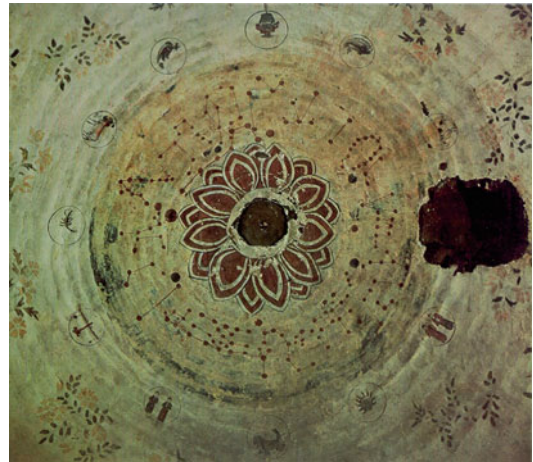
maps from around AD 1000 onwards, it is possible to identify the individual constituents of the *xiu* with stars listed in modern Western catalogs with considerable confidence. Certain lunar lodges, such as *Shen* (equivalent to the central portion of Orion), contain some very bright stars. Other *xiu*, such as *Yugui* (part of Cancer) consist of stars only barely visible to the unaided eye. Such marked differences are perhaps surprising, bearing in mind the importance of the lunar lodges. However, the brightness of a star was regarded as having little bearing on its astrological significance.

The earliest known chart of all 28 lunar lodge asterisms dates from around 25 BCE. This colorful representation is painted on the ceiling of a tomb which is located in the city of Xi'an and came to light in 1987. Many later star maps are extant – some displaying considerable detail and revealing much astronomical skill. These often depict the night sky on a circular plan (a polar projection) with the *xiu* boundaries shown as straight lines radiating from the north celestial pole at the center of the chart (see Fig. 2). Several illustrations of the lunar lodges have been found in tombs in recent decades. It is interesting to note that whereas Western representations of the zodiacal signs almost always use the various symbols – e.g., a crab for Cancer, two fish for Pisces – Chinese illustrations of the *xiu* typically portray the outlines of the constellation patterns themselves (see Fig. 3). In artefacts of a nonastronomical nature, these illustrations are often quite stylised. For example, the blades of several well-preserved Korean swords are engraved with the configurations of all 28 *xiu*.

Individual determinative stars cover a wide range in declination: from around 0 up to some 30° (see Fig. 4). As a result, with the passage of time the differential effect of precession causes the widths of the *xiu* in right ascension to change somewhat. This effect has been most significant for *Zuixi*, historically the narrowest lunar lodge. In the Former Han Dynasty, it had a width of 1.2° . However, measurements made around AD 1280 by the great Yuan Dynasty astronomer Guo Shoujing reveal that by his time the width of *Zuixi* had decreased to almost zero. Over the

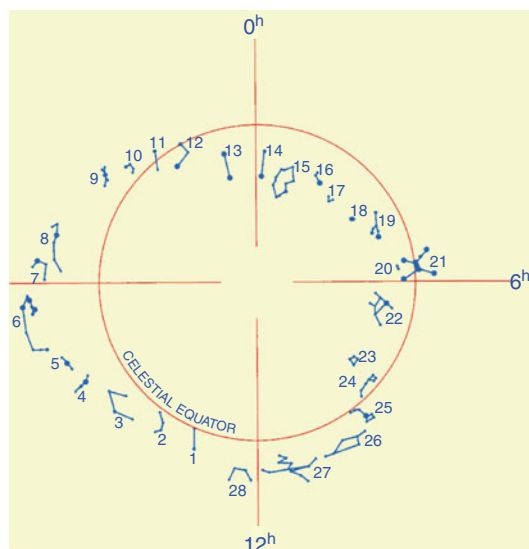


Lunar Lodges in Chinese Astronomy, Fig. 2 Careful drawing of a Chinese star map dating from AD 1453. This was found in Longfeng Temple and is now in the Beijing Ancient Observatory (Drawing: courtesy, Prof Pan Nai, Shanghai)



Lunar Lodges in Chinese Astronomy, Fig. 3 Chinese painting showing the 28 lunar lodges and 12 signs of the Western zodiac. This is painted on the ceiling of a tomb at Xuanhua, near Beijing, and dates from AD 1116 (Photo: Courtesy Prof Chen Meidong, Beijing)

next few centuries, *Zuixi* was tacitly assumed to be of zero width until the seventeenth century, by which time the calculated width was -0.4° ! A well-preserved Japanese celestial globe of the time depicts only 27 lunar lodge boundaries.



Lunar Lodges in Chinese Astronomy, Fig. 4 Celestial positions of the 28 lunar lodge asterisms (This is my own illustration)

Around AD 1650, the Jesuit Adam Schall von Bell, who was then Astronomer Royal of China, took the bold step of reversing the order of *Zuixi* and the adjacent lodge *Shen*, thus assigning a width of 11.4° to *Zuixi*. The revised width of *Shen* was now only 0.4° , but the effect of precession would gradually widen this lunar lodge with the passage of time. Jesuit missionaries, who made such a profound impression on Chinese astronomy in the seventeenth and eighteenth centuries, introduced improved techniques of measurement, as well as knowledge of the far southern stars which were invisible from China. However, they did not attempt to supplant the indigenous lunar lodge system (which was fundamentally equatorial) with the ecliptical scheme which was standard in the West.

Chinese astrology does not seem to have had any significant influence on cultures outside East Asia. In India, a parallel scheme to the *xiu* developed. Although there are similarities between the two systems, there are also marked differences. Vedic texts from at least as early as 1000 BCE list 27 or 28 *nakṣatra* (star groups in the path of the Moon). Like the Chinese lunar lodges, the *nakṣatra* had determinative stars (*yogatārā*).

However, no measurements of the positions of the *yogatārā* can be traced until the fifth century AD. By this time, the *xiu* had already been established in China for many centuries. There is some evidence that a few of the *yogatārā* stars coincided with the Chinese *chuxing*. However, it has been shown that early Indian astronomers did not fully agree on which stars were regarded as *yogatārā*. In any event, most reference stars are quite distinct on the two schemes. The origin of the various similarities is presently unknown.

Today the lunar lodge system has been abandoned in East Asia – except at the popular level – in favor of Western techniques of specifying star positions.

See Also

► [Stars in Chinese Astronomy](#)

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Lunar Mansions in Islam

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The old Arabs, before their acquaintance with Greek-based astronomy, had their own folk astronomy. They knew the fixed stars and used a number of stars and asterisms, the so-called *anwāʾ*, for orientation in nightly desert travels and for fixing seasons and predicting weather, especially rain. At an unknown time, and through

Lunar Mansions in Islam, Table 1 Lunar mansions and their modern identification

1.	<i>al-sharaṭān</i> (also <i>al-naṭḥ</i>)	βγ or βα Arietis
2.	<i>al-buṭayn</i>	εδρ Arietis
3.	<i>al-thurayyā</i>	The Pleiades
4.	<i>al-dabarān</i>	α Tauri
5.	<i>al-haq'a</i>	λφ ^{1,2} Orionis
6.	<i>al-han'a</i>	γξ Geminorum; also <i>al-taḥāyī</i> , ημν Geminorum (to which also γξ Geminorum are sometimes added)
7.	<i>al-dhirā'</i>	αβ Geminorum
8.	<i>al-nathra</i>	ε Cancri or M 44
9.	<i>al-ṭarf</i>	κ Cancri + λ Leonis
10.	<i>al-jabha</i>	ζγηα Leonis
11.	<i>al-zubra</i> (also <i>al-kharātān</i>)	δθ Leonis
12.	<i>al-ṣarfā</i>	β Leonis
13.	<i>al-ʿawwā'</i>	βηγε Virginis (to which δ Virginis is sometimes added)
14.	<i>al-simāk</i>	α Virginis
15.	<i>al-ghaṭr</i>	ικλ Virginis
16.	<i>al-zubānā</i>	αβ Librae
17.	<i>al-iklīl</i>	βδπ Scorpii
18.	<i>al-qalb</i>	α Scorpii
19.	<i>al-shawla</i>	λν Scorpii; sometimes instead, <i>al-ibra</i> , for the same stars or for M 7
20.	<i>al-na'ā'im</i>	γδεησφτζ Sagittarii
21.	<i>al-balda</i>	A starless region between nos. 20 and 22
22.	<i>sa'd al-dhābiḥ</i>	αυβ Capricorni
23.	<i>sa'd bula'</i>	με Aquarii (sometimes Fl. 7 or ν Aquarii are also included)
24.	<i>sa'd al-su'ūd</i>	βξ Aquarii + c ¹ Capricorni
25.	<i>sa'd al-akhbiya</i>	γπζη Aquarii
26.	<i>al-fargh al-muqaddam</i> (or <i>al-fargh al-awwal</i>)	αβ Pegasi
27.	<i>al-fargh al-mu'akhkhar</i> (or <i>al-fargh al-thānī</i>)	γ Pegasi + α Andromedae
28.	<i>baṭn al-hūt</i> (also <i>al-rishā'</i>)	β Andromedae

unknown channels, they received from India the system of the 28 lunar mansions (*manāzil al-qamar*), stars or asterisms or spots in the sky, roughly along the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), near which the moon was seen in the sky during its monthly revolution. Each mansion was identified with one of their *anwā'* stars or asterisms. The complete list is presented in Table 1.

Later, after the spread of Greek-based “scientific” astronomy in the Arabic-Islamic civilization, i.e., from the eighth century onward, astronomers knew about this system and gave exact identifications of the mansions’ stars from among the 1,025 stars fixed up in the star catalogue in Ptolemy’s *Almagest*. But the lunar mansions were not actually used by the Arabic-Islamic astronomers in their work. Their place was mostly in astrology. Here they were included in the numerous systems of divination, and in this context they were also borrowed into the Latin translations of Arabic astrological works, in Spain, in the late tenth century and, more often, in the twelfth and thirteenth centuries. Thus their corrupted, Latinized names are found throughout European astrological writings from that time on.

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Luoxia Hong

Jiang Xiaoyuan

Luoxia Hong was a Chinese astronomer active in the Western Han Dynasty about 100 BCE. He came from southwest China as a folk astronomer.

When the Emperor Wu (140–87 BCE) decided to draw up a new calendar, Luoxia Hong and more than 20 other astronomers were called together in the capital Chang'an. These folk and imperial astronomers put forward their plans for a new calendar. After comparing 18 plans, the emperor believed that the best one was put forward by Luoxia Hong and another astronomer Deng Ping. The new calendar was applied to the whole country in 104 BCE and called *Tai Chu Li* (Tai Chu Calendar). This calendar became the standard model for nearly 2,000 years. It was a lunisolar calendar with the 19-year and 7-leap cycle, and included the calculation for the motion of the sun, moon, planets, and for eclipses. In fact it was a mathematical astronomy system. The emperor intended to confer an official position on Luoxia Hong to cite his achievements, but Luoxia refused it and preferred to live in seclusion.

Luoxia Hong made an equatorial armillary sphere to measure the data of his new calendar. He is one of the candidates for the inventor of this instrument.

See Also

- [Armillary Spheres in China](#)
- [Calendars in East Asia](#)

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Machu Picchu

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with a strong knowledge of hydrology, enabled the Inca engineers and planners to create a grand and operational retreat high in the most rugged of terrain.

Introduction

Machu Picchu, the royal estate of the Inca Ruler Pachacuti, is an awe-inspiring monument to the ancient engineering skills of the Inca people. Machu Picchu was begun in AD 1450. It was finally abandoned in AD 1572. However, it likely ceased normal operation by AD 1540 due to the collapse of the Inca Empire (Maurtua, 1906; Rowe, 1990; Fig. 1).

Although the Inca did not have a written language, the well-preserved remains of Machu Picchu show that they had an advanced understanding of such principles as urban planning, hydrology, hydraulics, drainage, and durable construction methods. By studying Inca engineering techniques as they complement the natural environment, we are able to supplement existing archaeological theory on Inca practices, religion, and the significance of Machu Picchu.

The technical planning of Machu Picchu is surely the key to the site's sustainability and success. Careful use of hydraulic, drainage, and construction techniques ensured that the retreat was not reduced to rubble during its many years of abandonment. These techniques, combined

Site Selection

The Machu Picchu site is extraordinary. The Inca planners and engineers would have judged the site to be well suited for a royal estate because the Inca revered spectacular natural features. First, the site is surrounded on three sides by the steep, roaring Urubamba River. Second, the site is on a graben between two regional faults that created the two sharp peaks of Huayna Picchu and Machu Picchu mountains. Across the river is the steep Putucusi peak that has a rounded profile like a half orange when viewed from Machu Picchu. Even today, all three peaks are considered to be holy mountains by the local Quechua Indians. Further away is the triangular-shaped mountain called Yanantin and the ice-capped flanks of Mt. Veronica. Some 20 km south is Mt. Salcantay at an elevation of 6,257 m. An arrow stone on the Intiwatana summit points toward Mt. Salcantay.

But without the perennial spring on the north slope of Machu Picchu Mountain, there would have been no Machu Picchu. Prior to the emperor's selection of the site for his royal estate, the civil engineers would have had to determine that the water supply would be suitable.



Machu Picchu, Fig. 1 Machu Picchu is laid out along the top of the huge graben ridge between two regional faults

Water Supply

The Inca engineers found and developed a pure and reliable groundwater source on the steep north slope of Machu Picchu Mountain. Nearly 2,000 mm of annual rainfall, a modestly sized tributary drainage basin, igneous bedrock, and extensive faulting associated with the site collectively provided Pachacuti and his engineers with a reliable domestic source of water. This water supply made it feasible for the Inca ruler to build his sanctuary at this spectacular location. Machu Picchu supported a resident population of about 300 people, with a maximum of 1,000 when the royal entourage visited.

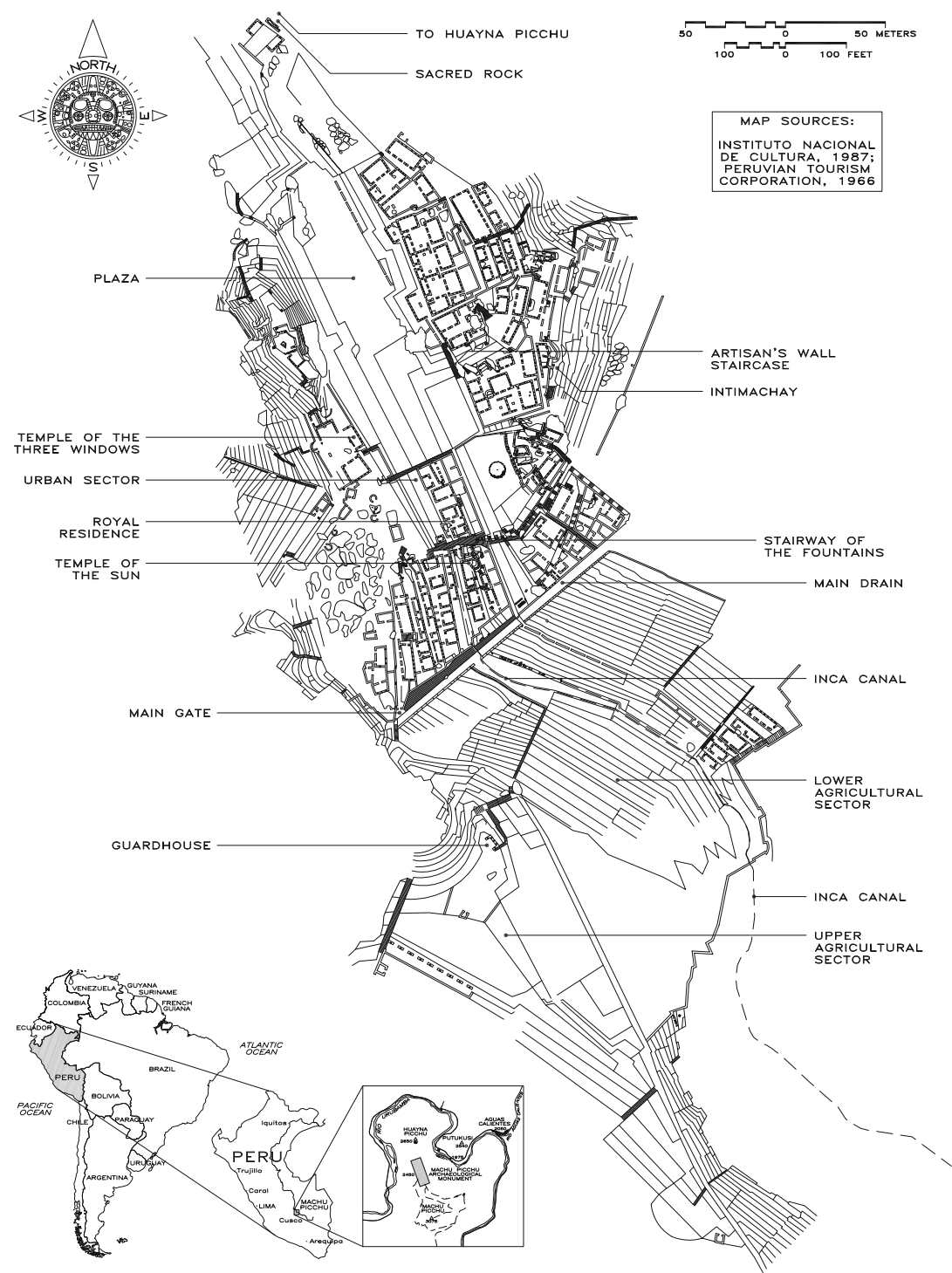
City Planning

After the Inca civil engineers cleared the thickly forested site of Machu Picchu, they saw that an

agricultural area could be laid out apart from an urban area to the north. To help with security, the Inca constructed an outer wall incorporating the natural topography and designed an inner wall between the agricultural and urban areas with only one gate to serve the Inca Trail from the capital city of Cusco. Nearer the city, on the Inca Trail, a three-sided guardhouse controlled access, and the narrow trail to Llaqtapata was also developed. Security for this trail was supplemented by the use of a drawbridge-like structure on the steep cliff of the Machu Picchu fault (Figs. 2 and 3).

The one gate through the inner wall was the Sacred (Main) Gate. It was oriented to frame the view of Huayna Picchu. Just inside the gate, which could be closed, there were storehouses and llama pens to facilitate the delivery and unloading of goods.

Consistent with Inca city planning practices, there were upper and lower sectors in the urban

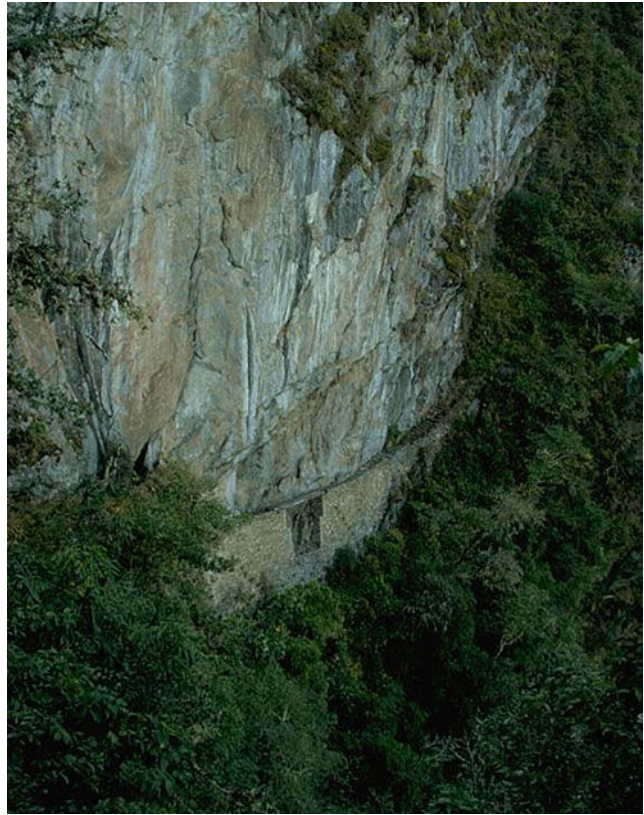


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Machu Picchu, Fig. 2 Key features of Machu Picchu are shown (Source: Wright Paleohydrological Institute)

Machu Picchu,

Fig. 3 The drawbridge on the narrow trail to nearby *Llaqtapata*



area, with a large plaza in between. This required intensive site work, massive walls, and substantial filling to create flat building sites and the central plaza. The plaza may have served originally as a quarry for the granite stones used at Machu Picchu (Wright & Valencia Zegarra, 2000).

Engineering Infrastructure

The grand plan for Machu Picchu included longevity because the longer Machu Picchu endured, the better the legacy of the emperor would be. The civil engineers of Machu Picchu knew from the technology gleaned from preceding empires and other conquered peoples stretching from north to south that a sound and well-conceived infrastructure was needed.

The infrastructure would rely on an incorporated knowledge of hydrology, hydraulics,

agriculture, urban drainage, sanitation, soils and foundation technology, structural engineering, and a “toolbox” of construction methods, along with good survey control of elevations, distances, and alignment.

Water Delivery

Machu Picchu had as its urban focal point the Temple of the Sun, a solar observatory and a religious center, along with a series of 16 fountains. While the water supply for the fountains was derived from a natural spring, an effective spring collection works on the north side of the adjacent Machu Picchu Mountain enhanced the yield of this spring. A canal to carry domestic water by gravity from the Machu Picchu spring to the city center at Fountain No. 1, the uppermost fountain, is built on a series of stone-walled terraces. The locations of the water supply canal and



Machu Picchu, Fig. 4 Water is carried into the urban sector via a small but adequate canal built on special terraces

the fountains are prescribed by the constraints of gravity flow of water from the primary spring (Wright, Kelly, & Valencia Zegarra, 1997; Fig. 4).

Fountains

The operating fountains at Machu Picchu provide a special treat. The sight and sound of jetting water is an attraction, just like in modern cities, especially on a hot summer day. The 16 fountains of Machu Picchu were laid out and designed to provide domestic water for the population, to enhance the urban environment, and as a manifestation of the power of Pachacuti.

Fountain No. 1 was constructed adjacent to the doorway of the residence of the Inca ruler, providing him with the first opportunity to utilize the imported water supply. Fountain No. 3 is known



Machu Picchu, Fig. 5 This carved rock is adjacent to the Sacred Fountain

as the Sacred Fountain because it is adjacent to a stone of adoration (*huaca*) and the enigmatic window of the Temple of the Sun.

The Sacred Fountain has finely finished carved stone blocks and niches for ceremonial objects. As part of the Sacred Fountain, a specially carved rock adjoins the fountain on the east overlooking the Eastern Urban Sector, the Urubamba River below, and the high mountains and sharp peaks in the distance. The carved rock near the jetting water would have provided an impressive backdrop for special ceremonies conducted by the Inca priests (Fig. 5).

The water flows in series, from Fountain No. 1 to Fountain No. 16, where it is discharged to an underground stone conduit. From the stone conduit, water flows to the Main Drain of Machu Picchu via a steeply sloping channel next to a long staircase.

The vertical drop between Fountain No. 1 and Fountain No. 16 is approximately 26 m. Except



Machu Picchu, Fig. 6 Sixteen fountains provided the residents of Machu Picchu with a good and reliable domestic water supply

for Fountain No. 16, each of the fountains can be reached via common stairways and walkways. Fountain No. 16 is a private fountain accessible only from the Temple of the Condor. The spring collection works, the Main Canal, and the 16 fountains of Machu Picchu represent the work of a civilization with sophisticated water-handling capabilities (Fig. 6).

Urban Drainage

The drainage infrastructure constructed by the Inca at ancient Machu Picchu represents a significant public works achievement. The difficult site constraints associated with the nearly 2,000 mm per year of rainfall, steep slopes, landslides, and remoteness all posed drainage challenges which were met successfully by the Inca. Technical analysis of the Inca drainage works



Machu Picchu, Fig. 7 The Inca incorporated drains into their walls to discharge storm runoff

demonstrates that the drainage criteria used were reasonable and the implementation uncanny. For instance, we found that drainage outlets were properly sized for the rainfall, runoff factors, and areas. While in the field examining the drainage system, it almost seems that the Inca had the equivalent of an urban drainage manual similar to the *ASCE Manual of Practice No. 77* (ASCE, 1992), except that the Inca had no written language (Fig. 7).

Agriculture

The agricultural terraces of Machu Picchu provided rich planting soils from the floodplain of the Urubamba River on otherwise impossibly steep slopes. Not only did the terraces serve as flat ground surface for maize production, they protected against erosion and landslides common in the area and helped the Inca demonstrate their dominion over the land. The Inca civil engineers



Machu Picchu, Fig. 8 Machu Picchu's agricultural terraces are integrated into the rugged terrain

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built the terrace walls so well that even after nearly four centuries, the walls were still intact when Hiram Bingham cleared Machu Picchu in 1912. The terraces were constructed not only for agricultural purposes but to create an amenity as they fit the hillsides and ridges like a well-tailored glove on a rough hand. Our study of prehistoric vegetation at Machu Picchu showed that the hundreds of terraces were mostly used for growing the high-status crop of maize (Fig. 8).

Road Building

When the young Yale history professor Hiram Bingham came upon Machu Picchu in 1911, he was impressed with the quality of fifteenth-century engineering. Bingham went back to Machu Picchu in 1912 as director of a Yale/National Geographic Society expedition to clear and document the ruins (Bingham, 1930). Bingham's description of his explorations filled the entire April 1913 *National Geographic*

magazine and brought Machu Picchu to the world's attention; Bingham opined that the "The Inca were good engineers." He could also have stated that the Inca civil engineers were good road builders because by the time Conquistador Pizarro arrived, the Inca were operating and maintaining thousands of kilometers of road system that stretched from Ecuador to Chile and from the Pacific Ocean to high Andean settlements, after crossing mountain passes with 18,000-ft elevations. Bingham described the main Inca Trail leading into Machu Picchu. It was a masterpiece of prehistoric Inca road building (Fig. 9).

One example of road building at Machu Picchu laid undetected in the forest cover of the lower East Flank until 1999 (Wright, Valencia Zegarra, & Crowley, 2000). This Inca Trail extension proved to be a fine example of route selection, slope stabilization, environmental design, and construction, all accomplished without a written language, iron, steel, or the use of the wheel.



Machu Picchu, Fig. 9 A porter walks the Inca Trail leading to Machu Picchu's Main Gate

Foundations

The Inca technique for constructing wall foundations started with the careful placement of smaller rocks in the excavation bottom to create a firm bedding. The rocks became larger as the foundation rose nearer the ground line. One finds a typical wall thickness of 0.8 m at the ground line, though the Inca civil engineers were not bound by this rule. Some of Machu Picchu's structures demanded sturdier foundations, such as the Temple of Three Windows. Here, huge stones were shaped, moved into position, and carefully fitted for stability (Fig. 10).

In some instances, the Inca engineers selected a "living" granite rock or huge in situ rocks for their foundation base, which were then shaped to provide a ledge or platform for founding. Examples include the Temple of the Sun and the Temple of the Condor (Fig. 11).

Construction

The Inca had learned about long-lived infrastructure from their predecessors near Cusco at Pikillacta and Chokepukio. They also derived much about building technology from the Tiwanaku Empire centered near Lake Titicaca, and they learned to avoid building in the floodplain, perhaps based upon the experiences of the Moche Kingdom on the north coast. From all of these earlier people, the Inca ascertained the need to include solid foundations, good drainage, good agricultural soil, and a reliable water supply. As a result, their buildings have withstood the ravages of time and tree roots.

Technology Transfer

The Inca Empire, although short lived, was the culmination of thousands of years of Andean civilization. From their predecessors the Inca inherited a body of statecraft and much of the technology used in the empire. They also inherited and participated in a great Andean culture based on religious ideas that were thousands of years old. That they were the inheritors of these great traditions does not in any way diminish their own achievement. It was the peculiar Inca genius for organization that allowed them to make profitable use of their cultural inheritance. They, alone, of the late Andean societies were able to weave together the disparate elements of thousands of years of cultural inheritance into military prowess, ideology, and extraordinary statecraft. In terms of geographical extension, military power and political organization, the Inca created the greatest of the pre-Columbian empires (McEwan, 2006).

Conclusions

Native Americans built Machu Picchu before the arrival of the Spanish conquistadors. It was abandoned after the Inca Empire collapsed, and it endured under a thick rain forest until the twentieth century. Scientists, engineers, and



Machu Picchu, Fig. 10 The eastern wall of the Temple of the Three Windows is made of enormous polygonal stones

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**Machu Picchu,
Fig. 11** The foundation of the building of the Temple of the Condor is an embellished, natural rock formation



laymen alike continue to marvel at the achievement of Machu Picchu and its magical ambiance and longevity. The sustainability of Machu Picchu is due to its details – the hydrology of the water supply, the hydraulics of the canal and fountains, and the blending of man's work with the challenging natural topography and environment.

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Mādhava of Saṅgamagrāma

R. C. Gupta

During the Muslim rule in north India, there was a decline in Hindu culture. This adversely affected the creative spirit in indigenous art, literature, and science. Southern India was comparatively less affected, and traditional culture and the sciences flourished there. The followers of Āryabhaṭa

I made enormous contributions to the development of mathematical sciences. It was a golden age of Indian mathematics.

Mādhava of Saṅgamagrāma, who flourished about A.D. 1400, was the first great astronomer and mathematician of the Late ► [Āryabhaṭa](#) school, which he in fact founded. Saṅgamagrāma has been identified as the modern Irinjalakkuda, a town near Cochin in Kerala State. Mādhava belonged to the Emprantiri subcaste group of Kerala Brahmins. We have no knowledge about his parents and teachers, or of the exact dates of his birth and death. Various dates ranging from A.D. 1336 to 1418 are used in his works. Hence the period of activity of his life has been roughly fixed from A.D. 1340 to 1425.

There is no doubt that Mādhava was an extraordinarily brilliant man. He used his talent and sharp intelligence to acquire knowledge by private study, and could thus overcome the difficulty of finding a good Guru because of his inferior status in the dominant Namputiri Brahminic community. He was a self-taught genius and not a gifted pupil. He was generally referred to as *Golavid* (Master of Spherics) by subsequent scholars and followers of his School, such as Nīlakaṇṭha Somayāji (A.D. 1444–1545) and Acyuta Piṣārāṭi (A.D. 1550–1621).

Mādhava wrote all his works in Sanskrit, the classical language of India. One of his earliest works is the *Candra-Vākyāni* (Moon Sentences). This was composed as a revision of Kerala's ancient traditional astronomical work attributed to Vararuci, who lived 1,000 years earlier. The *Candra-Vākyāni* gives 248 mnemonic phrases regarding the longitudinal position of the moon for each of the 248 days which comprise a period of nine anomalistic months.

The *Sphuṭacandrāpti* (Computation of True Moon) contains 51 verses and is a work of the *Karaṇa* category. A *Karaṇa* is a handbook on practical astronomy. In this one, he provides an ingenious method for finding the true position of the moon.

Mādhava's *Veṅvāroha* (► [Bamboo Climbing](#)) is an elaboration of his *Sphuṭacandrāpti* and consists of 74 verses.

In this work the author created a facile procedure to find the true lunar positions at intervals of about half an hour. It is dated as A.D. 1403, and is the most popular astronomical work of Mādhava. Acyuta Piṣāraṭi wrote a Malayalam commentary on it.

A recently identified astronomical work of Mādhava is *Aganīta-grahacāra*. It is an extensive work on planetary computations using somewhat novel methodologies. It is a treatise of the *Karaṇa* category and must have been composed just after A.D. 1418 which is the latest date mentioned.

Among other unpublished works of Mādhava there are two short astronomical tracts. One is the *Madhyamānayanaprakāra* (Method for Computing Mean Positions) which is extant in a unique manuscript at the India Office Library. The other is *Lagnaprakaraṇa*, of which at least three manuscripts exist in South India. This work deals with computations of ascendants.

It is possible that Mādhava composed a work on *Golavāda* (Spherics) which earned him the appellation *Golavid*. But the reported manuscript from a private collection has been eaten by white ants. Mādhava was also the author of a number of stray or free verses which have been cited by later authors and commentators.

Scientific Contributions

The traditional “moon sentences” of Vararuci (fourth century), used in Kerala, gave daily longitudes of the moon only up to minutes of the arc or angle. Mādhava computed more sophisticated moon sentences which expressed the longitudes correctly up to seconds. By making use of the popular system of alphabetic numerals, called the *Kaṭapayādi* Nyāya, these mnemonic phrases were made short and aphoristic. Mādhava also provided a value of π using a system of word numerals (*bhūta-samkhyās*).

The knowledge of an accurate value of π enabled Mādhava to obtain a better value of the traditional *Sinus Totus* (Total Sine, or radius). Mādhava’s sine table is quite precise and accurate. He may have used traditional

methods for getting the table or the newly discovered power-series expansion of sine (see below). For computing sine for the argument intermediary between any two tabulated angles, he knew a formula which is equivalent to the modern Taylor series approximation up to the second order. Higher interpolation based on second order finite differences had been known in India since the time of ► [Brahmagupta](#) (seventh century A.D.).

For computing π to any desired degree of accuracy, Mādhava discovered a number of series including the one $\frac{1}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} \dots$, often called the Leibniz series after the German mathematician G.W. Leibniz.

Another formula perhaps known to Mādhava is now called the Gregory Series, after the Scottish mathematician James Gregory (1638–1675). The Indian proof is found in the *Yuktibhāṣā* (A.D. sixteenth century) and other works.

One of Mādhava’s major achievements was the discovery of the power-series expansions of sine and cosine, and which are equivalent to

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \dots,$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \dots,$$

The two Sanskrit verses which embody the method of computing sine based on power-series up to x^{11} are quoted by Nīlakaṇṭha in his commentary on the *Āryabhaṭīya* (II, 17b).

In this connection it is relevant to discuss a small tract called *Mahājyānāyana-prakāra* (Method for the Computation of the Great Sines). It gives the power-series methods for computing *Mahājyās* (Great Sines). Unfortunately there is no mention of an author’s name in it, although Mādhava’s rule for computing sines up to x^{11} is mentioned. Sarma attributed the tract to Mādhava, but Gold and Pingree consider it to be the work of his follower(s). Perhaps Mādhava explained his theory during lectures to his pupils, whose lecture notes may be the basis of the above tract.

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placed in these categories. Magic and science are, in essence, labels used to exclude and include according to an intellectual value system rooted in European history. They are part of the cultural baggage taken abroad by Euro-American travelers, and used to identify “otherness” in foreign cultures. In non-Western cultures, similar practices of “magic” were not necessarily excluded or marginalized by the growth of science as they were in the West.

The European evolution of these two words from the classical (Greco-Roman) era to the twentieth century shows a growing gap between magic as occult or hidden knowledge on the one hand, and science and religion as public knowledge on the other. Increasingly in the European intellectual tradition, science was defined in narrower ways while pushing magic out of the realm of knowledge. This contributed to an evolutionary paradigm applied by Westerners to non-Western societies, of progress from magic to religion to science, a model now called into question by modern anthropologists. Because of this conceptual evolution in the intellectual history of Europe, “magic” and “science” can be used in a number of senses in modern English usage (see the *Oxford English Dictionary*). The gradual transformation of the word science as a distinctive rationality valued above and against magic is part of a uniquely European duality not generally found in non-Western societies, where magic can exist side-by-side with science and religion.

Magic and Science

Karen Louise Jolly

The concepts “magic” and “science” are products of Euro-American history; thus their use in other regions of the globe, from the colonial era to modern anthropological studies, is intertwined with Western intellectual history. Consequently, understanding the meaning of, and relationship between, magic and science in the context of western notions of rationality is essential when examining phenomena in non-Western societies

History of the Terms in the Western Intellectual Tradition

European intellectual history is full of self-imposed oppositions: temporal-spiritual, natural-supernatural, pagan-Christian, devil-God, magic-religion, and magic-science. All of these are subject to a moral scale of Good versus Evil, a distinction in Western thought that has its roots in the Judeo-Christian monotheistic system positing a single, omnipotent, all-good Deity. This way of thinking is very different from, for example, the Chinese world view embodied in

Yin and Yang, opposites that create balance (positive-negative, active-passive forces) without the identification of Evil versus Good. Thus, the Western dualities are not, as some westerners visiting other cultures have assumed, universals found in all cultures; rather, they are a particular product of the belief systems and intellectual history of Europe.

Nonetheless, despite these polar oppositions in European thought, changes in definitions over time caused overlaps and gray areas. Thus magic, as the opposite of religion or science, has a history that complicates the way the word is used at different times and places by different classes of people. The self-defined shape of European history is one of progress from magic to religion to science: from root definitions in classical culture (Greco-Roman), through the medieval magical and religious mentality, through major religious and intellectual changes (renaissances) in the medieval and early modern world, to the development of science as a separate discipline in the modern world. At the same time, this chronological picture is muddled by the slippery definition of magic as it changes in relation to the growth of religion and science. Throughout the development of these distinctions, from the fourteenth through the nineteenth and twentieth centuries, Europeans and Americans went abroad and applied these differing notions to the peoples they met.

The root meaning of magic contains a sense of exclusion found throughout the history of the term: in the Roman world, the Latin *magia*, derived from *magi* (Persian astrologers like the Magi of the Christmas story), implied a foreigner, even when the practitioner was a Roman. This was someone who possessed secret and powerful knowledge both feared and respected, displayed in the ability to manipulate unseen or spiritual agencies, in such arts as divination, astrology, curses, oracles, and amulets to ward off evil (Luck, 1985). Thus the word magic has at its root a sense of marginality in its otherness and its paranormal, unknown, and supernatural associations, but also a strong sense of power held exclusively and secretly by the *magus*. The root word for science, on the other hand, is more normative: *scientia* includes knowledge, art, or

skill. It derives from the Greek heritage a strong sense of human rationality, but comes to include divinely revealed knowledge as well in the Christian era (from ca. 200).

In the progress model, the magic of the European past is associated with the medieval period (ca. 500–1350), in contrast to the rationality of the Renaissance (fourteenth and fifteenth centuries) and Enlightenment (eighteenth century) intellectual revolutions. “Medieval” thinking has earned the label “magic” from later generations on several grounds. The medieval otherworldly emphasis and reliance on divine revelation led to a lack of distinction between natural and supernatural and contributed to an allegorical way of thinking about nature, so that objects such as a flower and events such as storms or illnesses were read as divine messages. Medieval thinking rested on a belief in a wonder-working, ever-present God and also a magic-working evil presence in the devil; sometimes the miracles of God’s saints and the tricks of the devil appear similar in method in the eyes of later thinkers (Flint, 1991; Thomas, 1971). Specifically, the belief in supernatural powers in words is found in both Germanic animism (worship of nature spirits) and the Christian tradition: in Germanic animism charms (ritual words and actions) invoke the inherent virtues of a plant. In the Christian Eucharist, bread and wine are changed into flesh and blood through prayer. The two were joined in Christianized folk medicine in the production of charms using Christian prayers as the powerful words (Jolly in Neusner, Frerichs, & Flesher, 1989). To Protestants (after the sixteenth century) and anthropologists (late nineteenth century), these practices are all magical in their manipulation of nature through word-magic (as opposed to true religious prayer as supplicatory). Yet to the medieval mind, magic was defined by *who* – God or the Devil – not by *how* – supplication versus manipulation. Thus medieval thinking was rejected as backward by later rationalists and was used to describe cultures that had not advanced out of magical or superstitious thinking.

Religion, in the history of European “progress,” moves away from magical thinking and

opens the door for rationalism. The tradition of logic and deductive reasoning dates back to the Greeks and partially survived into the Middle Ages through Roman-Christian church leaders and thinkers; the recovery of Aristotle through Arab sources in the twelfth century helped spur a renaissance in learning among medieval scholars so that human reason was placed alongside divine revelation as a way of knowing truth. This interest in the potential of human reason to understand things in conjunction with divinely revealed knowledge cleared a space for reason to function independently over the succeeding centuries. The separation of natural from supernatural, and reason from revelation, allowed thinkers to focus on the human study of natural phenomena. Magic in this context became things not in the category of the divine (miracles) and not subject to human reason either: black magic associated with the devil and witches, such as curses and evil spells, or the low magic of ignorant persons based on false reasoning, such as herbal charms and love potions. High, white magic was associated with the intelligentsia of the high Middle Ages and Renaissance (twelfth through fifteenth centuries). These early scientists dabbled in the occult, a gray area in between divine knowledge and human reason: occult phenomena were insensible (not subject to human sense perception), such as magnetism, gravity, or the pull of the stars, but might be intelligible (something to be reasoned about); these occult phenomena, classified as "natural magic," became the sciences of astrology, astral medicine, and alchemy, for example.

In the Scientific Revolution, science became a separate, and increasingly higher, discipline from religion; it came to mean exclusively the human (versus divine) study of natural (versus supernatural) phenomena. This secularization of knowledge was the product of the Italian Renaissance of the fourteenth and fifteenth centuries and the Enlightenment of the seventeenth and eighteenth centuries. Simultaneously, Protestant ethical values contributed to this process a utilitarian view of the created order that effectively circumscribed religion into a rational system: God made the world to work by certain laws

that humans could understand and systematize (Tambiah, 1990). Human study could produce a true understanding of reality independent of divine insight. Magic was now clearly marked as something not rational: it could be proven to be a hoax (prestidigitation or sleight-of-hand), and was relegated to the entertainment industry where it could be enjoyed as an illusion, a deception that could be scientifically explained. As science became the religion of the modern west, magic was being exorcised from modern consciousness not as demonic but as irrational and backward.

This simple pattern of progress from magic to religion to science is misleading in two ways: it is anachronistic in applying later definitions of magic back on to earlier periods where the word had different meanings, and it does not take into account the overlaps and continuities whereby magic survives alongside religion and well into science. For example, the Scientific Revolution is compromised by intellectual dabbling in the occult: the great shift from a geocentric worldview (earth at the center) to heliocentric (sun at the center) was founded not just on forward-looking developments in mathematics and astronomy but was motivated by a backward-looking interest in a supposedly Egyptian magical tradition, Hermeticism (Tambiah, 1990). Differences of class in relation to conceptions of magic further complicate this picture of Euro-American intellectual history: the older ways of folk belief, in medicine for example, as a viable, not magical, method of manipulating nature or spiritual agencies was retained among many classes long after the religious authorities or the intellectual elite had dispensed with it, and in some cases had begun investigating it as witchcraft (antireligion) or fraud (unscientific). All of these divergent attitudes toward magic were carried abroad by Europeans and Americans: magic as demonic, evil, and fearful; magic as medieval or backward; magic as unscientific, irrational, or uncivilized; but always as something "other."

Modern ethnography, the study of cultures, is a product of this western history and its

intellectual legacy of magic versus religion or science. The earliest ethnographers were explorers and missionaries, some of whom made an effort to observe and document these “new” peoples. The paradigm of progress some missionaries used in meeting nonurban, preliterate peoples was to categorize them as children needing to be fostered into adulthood; other colonizers used a model to exploit the “Indians” as subhuman slaves. For the missionaries, conversion was one step in the maturing process necessary for the native peoples to reach the “level” of civilization mastered by the Europeans.

Modern anthropology attempted to break with the religiously biased view of these missionaries and take an objective observer stance which was, none the less, still colored by an evolutionary model of progress from magic to religion to science (Herbert, 1991). This model is clearly evident in the works of early nineteenth-century founders Edward Tylor and Sir James Frazer and into the twentieth century in Jacob Bronowski and Bronislaw Malinowski (Tambiah, 1990). The anthropological definition focused on magic as unscientific manipulations of nature or supernatural forces and classified it according to its false premises (imitative magic, contagious magic, sympathetic magic). These notions of magic were assumed as a universally valid construct applicable cross culturally. Consequently, observed peoples were placed into the spectrum of development from magic to science. This model is the subject of debate in late twentieth-century anthropological scholarship, by such authors as Francis Hsu and Stanley Tambiah, who question whether the European concept of magic can be used accurately to classify a set of phenomena in a non-European culture.

Indigenous Views in Non-Western Societies

In Western thought, then, magic has become something marginal, separate from or opposite to a mainstream tradition of religion or science.

Non-Western practices of magic seen in their own cultural context are not the opposite of religion or science, but are complementary to their political, social, religious orders; magic is not the “other” in their worldview, but is part of the norm. Magical practices in non-Western societies can function as part of their cultural identity, alongside scientific development or as a subgroup of religion. In many parts of the world, syncretism is more prominent as a response to alternate worldviews, resulting in coexisting modes of rationality rather than competing ones.

The ancient civilizations of Asia offer examples of traditions developing their own modes of rationality with different dynamics than the European model, between the spheres of religion, science, and magic. In China, the traditions are as complex and overlapping as they are in Europe: ancestor-worship, Confucianism, Daoism, and Buddhism as belief-systems evolved and interacted amid the simultaneous development of science and technology. These belief-systems cannot be easily categorized as religion, philosophy, or magic along Western lines. The Buddhist emphasis on the world as illusory and the Daoist focus on metaphysics lent themselves more readily to practices resembling magic in a Western sense (appeals to supernatural aid, fortune-telling), as did ancestor worship. Confucianism, on the other hand, has both religious and philosophical elements; its concern with the social and political world resembles more the secular humanism of the western tradition. All of these coexist as alternate, and sometimes complementary, modes of rationality in China.

Similarly in the Chinese world, science and technology do not necessarily replace magico-religious belief: villagers’ responses to crisis (for example, a plague) incorporate both medicinal remedies such as serums proven through experimentation in the Western scientific tradition, and rituals seeking to appease the gods. While Westerners would be under some pressure to justify such magical practices with some rational or pseudoscientific explanation, the Chinese do not feel compelled to argue about where or how the practice fits into some duality of true or

false, natural or supernatural, orthodox or heretical, scientific or magical. Ancestor worship and recourse to geomancers (practitioners of *feng shui*, the art of finding spiritually correct locations for buildings) and fortune tellers (Daoist priests or other spiritualists) continue in twentieth-century China and in Chinese communities in the West without shame or apology (Hsu, 1983).

Elsewhere in Asia, “magic” continues as part of mainstream culture because it is closely linked with cultural identity. In Korea, female shamans perform ritual cures and exorcisms (*kut*) as part of the uniquely Korean fabric of life, alongside imported traditions from China and the West; in this way shaman practice is part of a unique Korean identity (Kendall, 1985). Shintoism in Japan, like ancestor-worship in China, is part of the Japanese cultural heritage embedded in everyday life, so much so that it easily accommodated an incoming religious system such as Buddhism or the development of science and technology, with which it has no reason to quarrel. Thus, syncretism, rather than opposing dualities, is a common pattern in the dynamics of magic, science, and religion in Asian cultures.

In many of the ancient near eastern and south Asian cultures, practices resembling magic (fortune-telling, amulets, and sorcery) form a subgroup of either religion or science/medicine. Magicians in India, for example, are closely linked with the religious traditions of Hinduism, Buddhism, and Islam. Indian thought emphasizes the illusory nature of the physical world; religious masters (gurus, yogi, and other mendicants) are able to manipulate the natural world precisely because they have reached a state of enlightenment where the world is truly an illusion to them. Likewise street magicians and stage entertainers practice “deceptions” (sawing people, producing trees from a basket, pulling an egg or a bird out of a bag, making ropes rise) that echo Hindu or Islamic stories and thus embody certain truths about the world as a wondrous, deceptive, and illusory place that one looks *through* to find meaning. Although such

street magicians are a separate, low (Muslim) caste in India, they are a prominent part of India’s cultural landscape, popular as reflections of Indian values (Seigel, 1991).

The interconnection of belief, science, and magic is also seen in Islamic culture. Medieval Islam fostered scientific, technological, and medical research because of their belief in a monotheistic Deity who made all things rational for humans to study (a view that eventually sparked medieval European science). Yet Islam also has magical-mystical subgroups, some of whom were condemned by Islamic law: their explorations of astronomy have astrological connections, as in Europe; their mathematical concepts have occult meaning to some; Sufi mystics distanced themselves from the Islamic intellectual heritage and sought knowledge through other, spiritual or interior, means. While these branches of Hinduism, Buddhism, or Islam may be minority groups, they are not marginal to their own cultures. Rather, they form an important extension of mainstream ideas that influences the whole culture, although not without conflict.

Societies in Africa, the Pacific, and Southeast Asia that did not have the urban, literate characteristics of these older civilizations provide clear examples of how poorly the conceptual dichotomy of magic versus science works as a model for understanding cultures where so-called magical practices are part of the norm. In Mali (Africa), the *Sundiata*, a twentieth-century version of an oral tradition dating back to the thirteenth century, speaks of the war magic used by Malian sorcerers to make a tribe successful so that others feared them; their magic oracles dispensed wisdom for successful living, a combination of prophecy and character insight. Likewise, many Pacific island cultures practiced a kind of potent magic in love, war, and healing that relied on a sorcerer’s ability to conjure nature and spirits.

These practices encompass both white and black magic in the European paradigm, to both heal and curse; such mastery is always dangerous to the practitioner because of the power of the sources he or she is using. In New Caledonia

(Melanesia), sorcerers concoct love potions; in Samoa (Polynesia), chants ward off a headache caused by a god. In Pohnpei (Micronesia), tribal groups employ sorcery to win a war, calling on ghosts or natural forces such as tides; during the Spanish occupation, they used both the borrowed technology of guns and their own tradition of sorcery to hold off attacks (Hanlon, 1992). Marquesans (in French Polynesia) also practiced a kind of war “magic” closely linked to their tribal identity: chants of power specific to their people and location used words ritually to invoke natural/supernatural forces to aid them in battle. The concept of *mana* in Polynesian cultures embodies this sense of powerful forces that can be channeled through words and actions, and is a more authentic construct for understanding their practices than is “magic.”

Such beliefs and practices, prior to European contact, were part of political and social value systems; the practitioners were feared for their power, but were not marginal to an intellectual belief system, as they became in European culture. The retention of these beliefs in the power of the old ways after contact, sometimes in defiance of, and sometimes integrated with, Western beliefs, is a form of cultural resistance and identity.

Many non-Western cultures, confronted with the European intruder, perceived the actions of the newcomer in terms of their own construct of supernatural or occult power. For example, in the Americas, native American Indians identified literate Europeans (mostly missionaries) as shamans, and their books as tools for manipulating natural/supernatural forces. Literacy was a powerful form of knowledge to acquire, and therefore was classified with other powerful forms of knowledge in their culture held by their shamans (magic and magicians to the Europeans). Thus literacy, and the Christian religion wound around it, was incorporated into the native belief system (Axtell, 1988). Indeed, in the same way that the taking of photographs was feared by some groups as a type of sorcery for capturing their souls, so too the writing down of history and

ethnographic observations (by Westerners) is sometimes perceived as a kind of sorcery: the power of shaping and defining cultural identity past and present.

Just as the magic-religion divide is indistinct, so too the magic-science line is easily crossed. Westerners cast doubt on the ancient Polynesians’ ability to navigate the Pacific to reach new islands such as the Hawaii chain without the technological tools used by Europeans to accomplish such tasks. New research and recreated voyages, however, confirm the knowledge of wind, sky, and water, and the skills of navigation contained in the remnants of Polynesian chants and other oral traditions, usually categorized as magico-religious rituals. This ambiguous line between magic and science is also visible in modern globalized medical practices that incorporate both Western medical techniques and traditional medicine from non-Western societies. The Chinese practice of acupuncture, once viewed in the United States as magic or pseudoscience, is now being mainstreamed into American medicine in lieu of drugs. In Java, a doctor claims the ability to produce heat and electricity from his own body for healing purposes and he documents this ability using the Western scientific mode of proof (experimentation, repeatability), performing spontaneous combustion on video (*Ring of Fire*). Such global syncretism is increasing rather than decreasing, blurring the distinctions between magic and science as defined in European intellectual history.

Traditionally, then, magic has been defined in opposition to science or religion in Western intellectual development. However, such practices in non-Western cultures that appear to resemble this category or are similar to practices Westerners label magic, may not in those cultures have been defined as a class in opposition to some concept of religion or science. The realization that “one man’s religion (or science) is another man’s magic” is leading to redefinitions of these terms and the development of meanings and categories unique to each cultural context.

See Also

- [Navigation in Polynesia](#)
- [Navigation in the Pacific](#)

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Magic Squares in China

Ho Peng Yoke

By modern definition a magic square is an arrangement of numbers in a square whereby

4	9	2
3	5	7
8	1	6

Magic Squares in China, Fig. 1 Magic square of 15

4	9	5	16
14	7	11	2
15	6	10	3
1	12	8	13

Magic Squares in China, Fig. 2 Magic square of 34

the sum of the numbers in every individual row, in every individual column and in each of the two diagonals of the square is identical. Figures 1 and 2 are examples of magic squares. In Fig. 1 all rows, columns and diagonals add up to the sum 15 and in Fig. 2 they add up to 34.

Each number occupies a cell. There are 9 cells in Fig. 1 and 16 cells in Fig. 2. Figure 1 is known as a 3×3 magic square or a magic square of the order 3; similarly Fig. 2 is a 4×4 magic square or a magic square of the order 4. Methods for constructing these two magic squares as well as some magic squares of higher orders are given in the *Xugu zheqi suanfa* (Continuation of Ancient Mathematical Methods for Elucidating the Strange), composed in 1275 by ► [Yang Hui](#). Numbers can also be arranged to form a circle or even a cube that shares some of the properties of the magic square. Nowadays all these come under the heading “number theory” or even “mathematical recreation” in libraries. However, the word “magic” in the magic square has lost some of its original meaning.

Chinese magic squares have attracted the attention of modern mathematicians and historians of science. Studies by modern scholars have brought forth many interesting results, but how and why certain Chinese magic squares were constructed cannot be fully understood if one approaches the subject entirely from the standpoint of modern mathematics. The modern

Chinese equivalent of the term “mathematics” is *shuxue*, but prior to the middle of the nineteenth century the same term had a much wider meaning, embracing mathematics, philosophy, astrology, and divination. Studies from the angle of modern mathematics have recently been supplemented by investigations from a different perspective.

The first-century book *Da-Dai Liji* (Record of Rites by the Elder Dai), contains the following arrangement of numbers:

2, 9, 4 7, 5, 3 6, 1, 8.

This set of numbers also occurs in a probably earlier mathematical text, the *Shushu jiji* (Memoir on Some Traditions of Mathematical Art), said to be written in the year 190 BCE by ▶ [Xu Yue](#). This is the earliest magic square on record. It was used mainly in astrology and divination. Then during the twelfth century one of Zhu Xi's (1130–1220) disciples Cai Yuanding (1145–1198) identified the Bright Hall and the Nine-palace arrangement as the legendary Luoshu chart mentioned in ancient texts. Together with another legendary chart, the Hetu River Diagram, the riddles of the universe were supposed to be embodied therein. Hence the two charts were used to interpret not only natural phenomena, but also philosophy and human behavior. They even found their use in Daoist ceremony and magic. Numerology played a profound role in Chinese magic squares. The occurrence of certain numbers, e.g., 5, 9, 25, 49, 50, and 64 in Chinese magic squares is significant. All these were closely associated with the Hetu and Luoshu charts and with the Yijing (I Ching, The Book of Changes).

Yang Hui's *Xugu zheqi suanfa* is the earliest and best source for Chinese magic squares. The methods of construction of some of the larger magic squares remind us of the foot movements of the Daoists performing ceremonies and magic. About three decades later Ding Yidong wrote his *Dayan suoyin* which contains a number of magic squares and magic circles constructed on a similar basis. Then in about

the year 1593 Chen Dawei collected a number of magic squares in his *Suanfa tongzong* (Systematic Treatise on Arithmetic) without involving himself with the theoretical aspect of the subject. In 1661 Fang Zhongtong (1633–1698) wrote the *Shuduyan*, which contains magic circles, cubes, and spheres, besides magic squares. Next comes Zhang Chao's (b. 1650) *Xinzhai zazu* (Miscellanea of Zhang Xinzhai), which includes a Supplement to the magic squares of Cheng Dawei's work. The last description of magic squares by a traditional Chinese scholar came in the latter part of the nineteenth century when Bao Qishou wrote his *Binaishanfang ji* (Collections of Writings in the Binai Mountain Studies).

The Luoshu chart magic square probably first went to India and then to the Arab countries, where other magic squares were later developed in their individual ways. From the Arab countries magic squares were said to be first brought to Europe by a Byzantine, Manuel Moschopoulos (fl. ca. 1295–1316). Transmission of knowledge between China and her western neighbors was seldom unidirectional. In 1956 a thirteenth-century 6×6 Muslim magic square was excavated near the city of Xi'an. Magic squares even had a role to play in trade between China and the Arab countries in the past. In 1906 when Queen Mary of the British Empire visited Hyderabad in India she was presented with a Chinese porcelain plate decorated with Arabic inscriptions and a magic square. This plate is now preserved at the Victoria and Albert Museum in South Kensington. It was manufactured in the eighteenth century at the world renowned Chinese kiln center, Jingdezhen. It was used originally by the Muslims as a medicine bowl, so that the inscriptions were taken from the *Qu'rān*, and the magic square was believed to possess powerful virtues for protecting life, healing the sick, and bringing about a comfortable delivery when a pregnant woman sat on it. Other specimens of Chinese porcelain plates bearing magic squares in a corrupted form are among the collections of museums and private collectors today.

See Also

- [Astrology in China](#)
- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [Xu Yue](#)
- [Yang Hui](#)

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Magic Squares in India

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The oldest datable magic square in India occurs in Varāhamihira’s encyclopedic work on divination, *Brhatsamhitā* (ca. AD 550). He utilized a modified magic square of order four in order to prescribe combinations and quantities of ingredients of perfume. It consists of two sets of the natural numbers 1–8, and its constant sum (p) is 18 (Fig. 1). It is, so to speak, pan-diagonal, that is, not only the two main diagonals but also all “broken” diagonals have the same constant sum. Utpala, the commentator (AD 967), also points out many other quadruplets that have the same sum.

One of the four candidates for Varāhamihira’s original square (Fig. 2), with a rotation of 90°, coincides with the famous Islamic square (Fig. 3), which al-Bīrūnī and al-Zinjānī frequently used as a basic pattern for talismans.

Varāhamihira called his square *kacchapuṭa* (the carapace of a turtle), which reminds one of

Magic Squares in India, Fig. 1 Varāhamihira’s magic square ($p = 18$)

2	3	5	8
5	8	2	3
4	1	7	6
7	6	4	1

a	10	3	13	8
	5	16	2	11
	4	9	7	14
	15	6	12	1

b	2	11	5	16
	13	8	10	3
	12	1	15	6
	7	14	4	9

c	10	3	5	16
	13	8	2	11
	4	9	15	6
	7	14	12	1

d	2	11	13	8
	5	16	10	3
	12	1	7	14
	15	6	4	9

Magic Squares in India, Fig. 2 Magic squares reconstructed from Varāhamihira’s square ($p = 34$)

Magic Squares in India, Fig. 3 The Islamic square of order four ($p = 34$)

8	11	14	1
13	2	7	12
3	16	9	6
10	5	4	15

a	$a-3$	1	$a-6$	8
	$a-7$	9	$a-4$	2
	6	$a-8$	3	$a-1$
	4	$a-2$	7	$a-9$

b	$b-3$	1	$a-6$	8
	$a-7$	9	$b-4$	2
	6	$a-8$	3	$b-1$
	4	$b-2$	7	$a-9$

$a = \frac{p}{2}$ (p : even) $a = \frac{p+1}{2}, b = \frac{p-1}{2}$ (p : odd)

Magic Squares in India, Fig. 4 Patterns for magic squares of order four given in the *Kakṣapuṭa*

the title of a book on magic, *Kakṣaputa* (date unknown). The book contains a method for constructing a magic square of order four when a constant sum (p) is given (Fig. 4). It also contains a square having the sum 100 (Fig. 5), which is attributed to Nāgārjuna.

In his medical work, *Siddhayoga* (ca. AD 900), Vṛnda prescribed a magic square of order three to be employed by a woman in labor in order to have an easy delivery. Its sum is 30 (Fig. 6). This is the first datable instance of a magic square of order three in India, although there is a legend that a Garga, who may or may not be the author of the *Gargasaṃhitā* (ca. first

century BCE or AD), recommended magic squares of order three in order to pacify the *navagraha* (nine planets).

The famous Jaina magic square (Fig. 7a), which is incised on the entrance of a Jaina temple, Pārśvanātha, in Khajuraho (Fig. 7b), is assignable to the twelfth or the thirteenth century on a paleographical basis. It is pan-diagonal. Several Jaina hymns that teach how to make magic squares have been handed down, but their dates are uncertain.

As far as is known, Ṭhakkura Pherū, a Jaina scholar, is the first in India who treated magic squares in a mathematical work. His *Gaṇitasārakaumudī* (ca. AD 1315) written in Apabhraṃśa contains a small section on magic squares that consists of nine verses. He gives a square of order four and alludes to its rearrangement (Fig. 8); classifies magic squares (*janṭa* = Sanskrit *yantra*) into three (odd, even, and evenly odd) according to the order (n), i.e., the number of cells (*kuṭṭha* = Sanskrit *koṭṭha*) on a side of the square; gives a square of order six (Fig. 9), which is an evenly odd square; and prescribes one method each for constructing even and odd squares.

The method for even squares divides the square into component squares of order four and puts the numbers into cells according to the

Magic Squares in India,
Fig. 5 Nāgārjuna’s magic square ($p = 100$)

30	16	18	36
10	44	22	24
32	14	20	34
28	26	40	6

Magic Squares in India,
Fig. 6 Vṛnda’s magic square of order three ($p = 30$)

16	6	8
2	10	18
12	14	4

Magic Squares in India,
Fig. 7 Jaina magic square ($p = 34$) of Pārśvanātha temple at Khajuraho

a

7	12	1	14
2	13	8	11
16	3	10	5
9	6	15	4

In modern numerals



The square in situ, 2011
(Photo credit: Debra Gross Aczel)

a	12	3	6	13
	14	5	4	11
	7	16	9	2
	1	10	15	8
Original Square				
b	1	7	12	14
	10	16	3	5
	8	2	13	11
	15	9	6	4
Rearranged				

Magic Squares in India, Fig. 8 Pherū’s square of four and its rearrangement ($p = 34$)

1	32	34	33	5	6
30	8	28	27	11	7
24	23	15	16	14	19
13	20	21	22	17	18
12	26	9	10	29	25
31	2	4	3	35	36

Magic Squares in India, Fig. 9 Pherū’s square of order six ($p = 111$)

Magic Squares in India, Fig. 10 Pherū’s construction method for “even”-order magic squares

a

15	9	6	4
8	2	13	11
1	7	12	14
10	16	3	5

Standard Square

b

			4				8
	2				6		
1				5			
		3				7	
			12				16
	10				14		
9				13			
		11				15	

First Stage

c

63	33	30	4	59	37	26	8
32	2	61	35	28	6	57	39
1	31	36	62	5	27	40	58
34	64	3	29	38	60	7	25
55	41	22	12	51	45	18	16
24	10	53	43	20	14	49	47
9	23	44	54	13	19	48	50
42	56	11	21	46	52	15	17

Magic Square Obtained ($p=260$)

pattern of a standard square of order four (Fig. 10). That for odd squares first places in the central column the arithmetical progression whose first term and common difference are unity and $(n + 1)$, respectively, and then, starting from the numbers in the central column and proceeding by knight move, successively increases the number by n (Fig. 11). The square thus obtained is the same as the one obtained by the so-called diagonal method (cf. Fig. 21).

Nārāyaṇa wrote a comprehensive work on mathematics entitled *Gaṇitakaumudī* (AD 1356). Its last chapter, called *bhadra-gaṇita* (Mathematics of Magic Squares), comprises 55 verses for rules and 17 verses for examples, and is devoted exclusively to magic squares and derivative magic figures (*upabhadra*) of various shapes (cf. Figs. 22 and 23).

The topics treated are the following: definitions of technical terms; determination of the mathematical progressions to be used in magic squares by means of *kuṭṭaka*, i.e., indeterminate

a

	n^2	
	.	
	.	
	.	
	.	
	.	
	$2n+3$	
	$n+2$	
	1	

Central Column

b

37	48	59	70	81	2	13	24	35
36	38	49	60	71	73	3	14	25
26	28	39	50	61	72	74	4	15
16	27	29	40	51	62	64	75	5
6	17	19	30	41	52	63	65	76
77	7	18	20	31	42	53	55	66
67	78	8	10	21	32	43	54	56
57	68	79	9	11	22	33	44	46
47	58	69	80	1	12	23	34	45

Square of Order Nine Obtained ($p=369$)

Magic Squares in India, Fig. 11 Pherū’s construction method for “odd”-order magic squares

a	<table><tr><td>1</td><td>8</td><td>13</td><td>12</td></tr><tr><td>14</td><td>11</td><td>2</td><td>7</td></tr><tr><td>4</td><td>5</td><td>16</td><td>9</td></tr><tr><td>15</td><td>10</td><td>3</td><td>6</td></tr></table>	1	8	13	12	14	11	2	7	4	5	16	9	15	10	3	6	b	<table><tr><td>1</td><td>14</td><td>4</td><td>15</td></tr><tr><td>8</td><td>11</td><td>5</td><td>10</td></tr><tr><td>13</td><td>2</td><td>16</td><td>3</td></tr><tr><td>12</td><td>7</td><td>9</td><td>6</td></tr></table>	1	14	4	15	8	11	5	10	13	2	16	3	12	7	9	6
1	8	13	12																																
14	11	2	7																																
4	5	16	9																																
15	10	3	6																																
1	14	4	15																																
8	11	5	10																																
13	2	16	3																																
12	7	9	6																																

Magic Squares in India, Fig. 12 Nārāyaṇa’s squares of four made by “horse move” ($p = 34$)

a	<table><tr><td>-5</td><td>9</td><td>19</td><td>17</td></tr><tr><td>21</td><td>15</td><td>-3</td><td>7</td></tr><tr><td>1</td><td>3</td><td>25</td><td>11</td></tr><tr><td>23</td><td>13</td><td>-1</td><td>5</td></tr></table>	-5	9	19	17	21	15	-3	7	1	3	25	11	23	13	-1	5	b	<table><tr><td>-14</td><td>14</td><td>34</td><td>30</td></tr><tr><td>38</td><td>26</td><td>-10</td><td>10</td></tr><tr><td>-2</td><td>2</td><td>46</td><td>18</td></tr><tr><td>42</td><td>22</td><td>-6</td><td>6</td></tr></table>	-14	14	34	30	38	26	-10	10	-2	2	46	18	42	22	-6	6
-5	9	19	17																																
21	15	-3	7																																
1	3	25	11																																
23	13	-1	5																																
-14	14	34	30																																
38	26	-10	10																																
-2	2	46	18																																
42	22	-6	6																																

$a = -5, d = 2$
 $p = 40$

$a = -14, d = 4$
 $p = 64$

Magic Squares in India, Fig. 13 Nārāyaṇa’s squares of four made by an arithmetical progression

a

7	15	22	20
23	19	8	14
10	12	25	17
24	18	9	13

$p=64$
Cf. Fig. 12a

b

16	14	7	30	23
24	17	10	8	31
32	25	18	11	4
5	28	26	19	12
13	6	29	22	20

$p=90$
Cf. Fig. 21

Magic Squares in India, Fig. 14 Nārāyaṇa’s squares of four made by n sets of arithmetical progressions

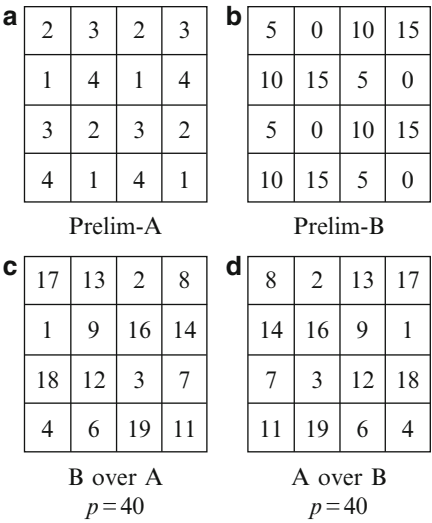
$\frac{35}{2}$	$\frac{49}{2}$	$\frac{59}{2}$	$\frac{57}{2}$
$\frac{61}{2}$	$\frac{55}{2}$	$\frac{37}{2}$	$\frac{47}{2}$
$\frac{41}{2}$	$\frac{43}{2}$	$\frac{65}{2}$	$\frac{51}{2}$
$\frac{63}{2}$	$\frac{53}{2}$	$\frac{39}{2}$	$\frac{45}{2}$

$t = \frac{33}{2}, p = 100$

Based on Fig. 12a

Magic Squares in India, Fig. 15 Nārāyaṇa’s squares of four made by addition of a number (t)

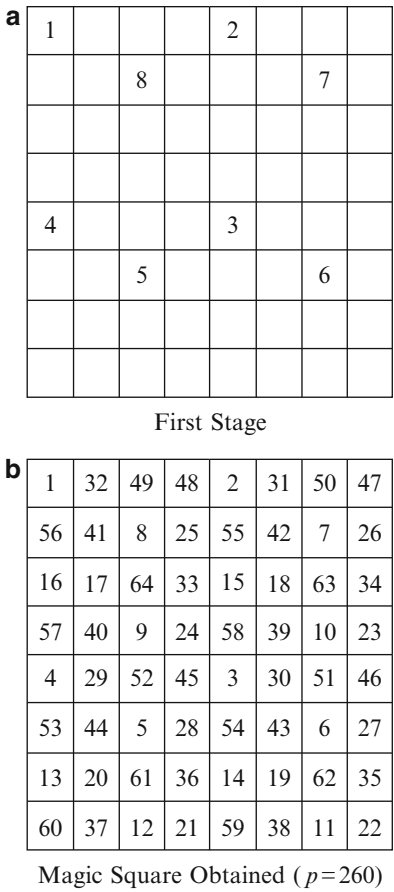
equations of the first degree; how to make a square of order four by *turagaḡati* (horse move) (Fig. 12); and the number of pan-diagonal magic squares of order four, 384, including every variation made by rotation and inversion.



Magic Squares in India, Fig. 16 Nārāyaṇa’s method for “even-womb” squares (I): folding method

Then Nārāyaṇa gives three general methods for constructing a square having any optional order (n) and constant sum (p) when a standard square of the same order is known: (1) by means of an arithmetical progression having an appropriate first term (a) and common difference (d) (Fig. 13), (2) by means of n sets of arithmetical progressions whose common differences are all unity (Fig. 14), and (3) by adding an appropriate number (t) to every term of the standard square (Fig. 15).

Nārāyaṇa next explains two methods each for constructing *sama-garbha* (even-womb) or evenly even, *viṣama-garbha* (odd-womb) or evenly odd, and odd (*viṣama*) squares when the sum is given. The two methods for the first kind are (1) by folding two preliminary squares *karasaṃpuṭa-vat* (just like the folding of two hands) (Fig. 16) and (2) by arranging numbers in the component squares of order four according to the pattern of a standard square (Fig. 17). For the second kind, they are (1) by putting numbers zigzag in the square (Fig. 18) and (2) by transposing certain numbers in the natural square (Fig. 19). These two methods are



Magic Squares in India, Fig. 17 Nārāyaṇa’s method for “even-womb” squares (II): according to the pattern of the standard square (Fig. 12a)

not completely mechanical and require *mati* (intelligence). The methods for the third kind are (1) by folding two preliminary squares just as in the case of the first kind (Fig. 20) and (2) by starting from the central cell of any side of the square and proceeding diagonally (Fig. 21).

In the last section, Nārāyaṇa gives a number of examples for two kinds of derivative magic figures, *saṃkīrṇa* (miscellaneous) and *maṇḍala* (circular). Both kinds are made by rearranging ordinary magic squares (Figs. 22, 23 and 24).

Magic Squares in India, Fig. 18 Nārāyaṇa’s method for “odd-womb” squares (I): zigzag method

1	195	194	193	5	6	190	7	9	10	186	185	184	14
169	27	171	25	173	23	175	22	20	178	18	180	16	182
168	167	166	32	33	34	162	35	37	38	39	157	156	155
141	142	143	53	52	51	147	50	48	47	46	152	153	154
140	139	138	60	61	62	134	63	65	66	67	129	128	127
113	114	115	81	80	79	119	78	76	75	74	124	125	126
112	111	92	88	89	90	98	110	93	94	95	101	100	106
85	86	105	109	108	107	99	87	104	103	102	96	97	91
84	83	82	116	117	118	77	120	121	122	123	73	72	71
57	58	59	137	136	135	64	133	132	131	130	68	69	70
56	55	54	144	145	146	49	148	149	150	151	45	44	43
29	30	31	165	164	163	36	161	160	159	158	40	41	42
28	170	26	172	24	174	21	176	177	19	179	17	181	15
196	2	3	4	192	191	8	189	188	187	11	12	13	183

$n=14, p=1379$

M

100	92	93	94	5	6	7	8	9	91
20	89	83	84	16	15	87	18	82	11
30	29	78	77	75	26	74	73	22	21
40	39	38	67	65	66	64	63	32	31
41	52	43	44	56	55	47	48	59	60
51	42	58	57	46	45	54	53	49	50
61	69	68	37	35	36	34	33	62	70
71	72	28	27	25	76	24	23	79	80
81	19	13	14	86	85	17	88	12	90
10	2	3	4	96	95	97	98	99	1

$n=10, p=505$

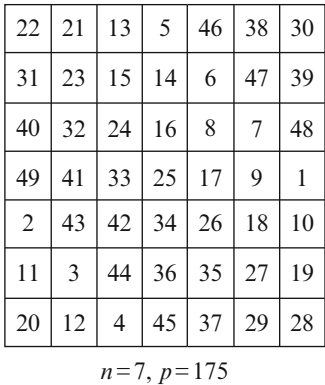
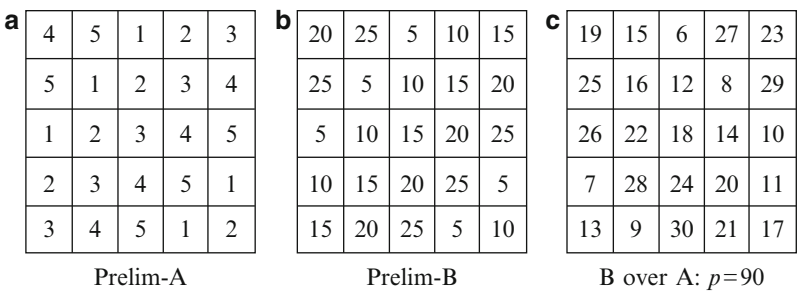
Magic Squares in India, Fig. 19 Nārāyaṇa’s method for “odd-womb” squares (II): transposing method (conjectural reconstruction)

In his encyclopedic work on Hindu Law, *Smṛititattva* (ca. AD 1500), Raghunandana gives a method for making squares of order four having any optional sum that is determined according to the purpose (see Table 1).

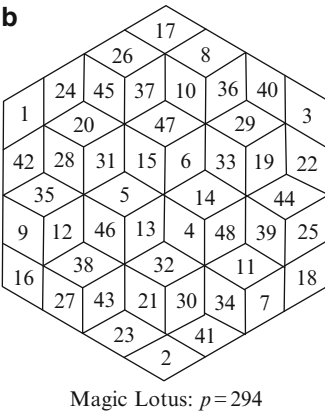
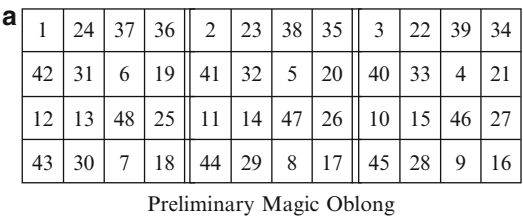
At the end of his arithmetical work, *Caturacintāmaṇi*, Giridharabhaṭṭa devoted six verses for magic squares. There is no indication that he was influenced by Ṭhakkura Pherū or by Nārāyaṇa. Instead, his methods for constructing even and oddly even squares contain Islamic elements.

Significant scholarly work has been done on the history of magic squares in India both mathematically and philosophically. Cammann and Roşu both discussed the significance of magic squares in Indian thought and compared Indian, Islamic, and Chinese magic squares. Hayashi published his studies, with translations, of the

Magic Squares in India, Fig. 20 Nārāyaṇa’s method for odd squares (I): folding method



Magic Squares in India, Fig. 21 Nārāyaṇa’s method for odd squares (II): diagonal method



1	8	$a-7$	$a-2$
$a-5$	$a-4$	3	6
7	2	$a-1$	$a-8$
$a-3$	$a-6$	5	4

$$a = \frac{p}{2}$$

Magic Squares in India, Fig. 24 Pattern for magic squares of four by Raghunandana

Magic Squares in India, Table 1 Purposes of magic squares of order four

Sum (p)	Purpose
20	To neutralize poison
28	To protect crops from insects
32	To accelerate delivery
34	To protect travelers
50	To exorcise evil spirits
64	To protect warriors
72	For women having no children
84	To soothe crying children

See Also

- [Nārāyaṇa Paṇḍita](#)
- [Varāhamihira](#)

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Magic Squares in Islamic Mathematics

Jacques Sesiano

One of the most impressive achievements in Islamic mathematics is the development of general methods for constructing magic squares. A magic square of order n is a square divided into n^2 cells in which different natural numbers (mostly the n^2 first naturals) must be arranged in such a way that the same sum appears in each of

Magic Squares in Islamic Mathematics, Fig. 1 A composite square

31	36	29	76	81	74	13	18	11
30	32	34	75	77	79	12	14	16
35	28	33	80	73	78	17	10	15
22	27	20	40	45	38	58	63	56
21	23	25	39	41	43	57	59	61
26	19	24	44	37	42	62	55	60
67	72	65	4	9	2	49	54	47
66	68	70	3	5	7	48	50	52
71	64	69	8	1	6	53	46	51

the rows, columns, and two main diagonals. If, in addition to this basic property, the square remains magic when the borders are successively removed, we speak of a “bordered square.” If the sum in any pair of complementary diagonals (i.e., pairs of parallel diagonals lying on each side of a main diagonal and having together n cells) shows the constant sum, the square is called “pandiagonal.”

Squares are usually divided into three categories: odd-order squares ($n = 2k + 1$, k natural), evenly even squares ($n = 4k$), and evenly odd squares ($n = 4k + 2$). There are general methods for constructing squares of any order from one of these three categories. Except for the smallest possible order, $n = 3$, there are numerous possibilities of forming magic squares of any given order. There may be, however, some limitations concerning additional magical properties; for instance, there are no pandiagonal squares of evenly odd order.

Information about the beginning of Islamic research on magic squares is lacking. It may

have been connected with the introduction of chess into Persia in early Islamic times. Initially, the problem was a purely mathematical one; thus, the Arabic ancient designation for magic squares is *wafq al-a'dād* (harmonious disposition of the numbers). We know that treatises were written in the ninth century, but the earliest extant ones date back to the tenth century. It appears that, by that time, the science of magic squares was already established. Not only was the construction of a magic square, simple or bordered, explained for various orders, but also several additional conditions or refinements were considered. For example, the construction of “composite squares” was well known: if $n = r \times s$, with $r, s \geq 3$, one may fill successively, according to a magical arrangement for the order r , r^2 subsquares of order s (Fig. 1). Another contemporary achievement was the construction of bordered squares in which the even numbers are separated from the odd ones (Fig. 2).

Treatises explaining general constructions were common in the eleventh and twelfth

Magic Squares in Islamic Mathematics, Fig. 2 A bordered square separating the numbers according to parity

36	16	108	110	10	113	8	116	118	2	34
50	48	24	100	107	97	7	102	18	46	72
52	56	60	103	91	89	23	3	58	66	70
96	54	17	47	51	81	83	43	105	68	26
94	13	29	49	59	57	67	73	93	109	28
11	27	35	45	69	61	53	77	87	95	111
92	117	101	85	55	65	63	37	21	5	30
32	80	121	79	71	41	39	75	1	42	90
38	78	64	19	31	33	99	119	62	44	84
82	76	98	22	15	25	115	20	104	74	40
88	106	14	12	112	9	114	6	4	120	86

centuries. They also explain how to construct a magic square for a given sum, or for a word of n letters or n words to be put in the first row, since a number among the units, the tens, the hundreds, and one thousand is associated with each of the 28 Arabic letters. The words occurring in the first row are either proper names or words of a religious nature (Fig. 3; the five words correspond to the numbers 81, 7, 116, 66, and 80). Pandiagonal squares are constructed in various ways for evenly even orders, but incompletely for odd orders (the method fails for certain orders).

From the thirteenth century on, magic squares become more and more associated with magic and divinatory purposes. Consequently, some texts merely picture squares and mention their attributes. Some others, though, keep the general theory alive, mostly to enable the reader to construct amulets by himself.

Interest in magic squares in Europe first arose toward the end of the Middle Ages, when two sets of squares associated with the seven planets

81	7	116	66	80
79	78	68	64	61
63	56	70	84	77
67	76	72	62	73
60	133	24	74	59

Magic Squares in Islamic Mathematics, Fig. 3 Magic square from a given first row

were learned of through astrological and magic texts (whence the name), but without any information on their construction. Thus, the entire theory had to be built anew, and it is only in very recent times that the extent of Islamic research has come to light. It should also be remarked that the methods of construction

spread eastward around the twelfth century toward India and China.

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Magic Squares in Japanese Mathematics

Robert M. Veatch

The study of Magic Squares in Japan began in the beginning of the Kan-ei period (1624–1643) with the import of *Suan fa tong zong* published in 1592 by Chen Dawei of China. Almost all the famous *wasan* (Japanese mathematics) experts, such as Takakazu Seki (or ► [Seki Kowa](#), ca. 1642–1708) studied squares. On a smaller scale, the study has continued, and we have gained some new insights lately.

The study of squares concerns itself with some aspects of combinatorial mathematics, so some of its general methods are applied as well. For example, some parts of perfect 5×5 squares are made by the “Knight Jump Arrangement”. The study of compositions, which was started by a Russian scholar, is limited to perfect 4×4 squares, but the method was also applied to 8×8 squares, as in the study by Motoaki Abe. Rakuho Abe

obtained a fantastic result of irregular, perfect 7×7 squares. This is shown below:

16	24	20	17	37	14	47
23	28	48	1	38	6	31
39	7	45	9	42	18	15
40	4	29	25	21	46	10
35	32	8	41	5	43	11
19	44	12	49	2	22	27
3	36	13	33	30	26	34

An irregular, perfect 7×7 square.

In this the total of the diagonal or pandiagonal numbers is 175; the total of the four corner numbers ($16 + 47 + 34 + 3$) is 100; the total of the numbers around the centers ($9 + 21 + 41 + 29$) is 100; and the total of the middle numbers of the four sides ($17 + 10 + 33 + 40$) is also 100.

16	24	20	17	37	14	47
23	28	48	1	38	6	31
39	7	45	9	42	18	15
40	4	29	25	21	46	10
35	32	8	41	5	43	11
19	44	12	49	2	22	27
3	36	13	33	30	26	34

An irregular, perfect 7×7 square.

In the middle of the Heian period, i.e., in 970, Tamenori Minamoto edited *Kuchi-zusami* for the education of young nobility. In the 12th chapter we find this sentence: 4 and 2 make a shoulder, left 3 and right 7, legs are 6 and 8, head 9, body 5, tail is 1:

4	9	2
3	5	7
8	1	6

The legs, head, and tail seem to be those of some animal (a tortoise?), and maybe they suggest the arrangement of numerals. We are not sure how Minamoto came by this knowledge of squares, but the 3×3 square in *Kuchi-zusami* is the oldest record as far as we know.

Magic Squares in Japanese Mathematics, Table 1 A general way to make squares

7	4	1	2	9	6	4	9	2	12	19	8
8	5	2	3	5	7	3	5	7	9	13	17
9	6	3	4	1	8	8	1	6	18	7	14
A	B	C	D								

A book by Yūeki Andō (1624–1704), a clansman of Aizu, is the first in the world in which the author explains a general way to make squares by increasing from 3×3 to 30×30 squares (see Table 1).

For example, if we exchange positions in square A so that $1 \leftrightarrow 6$, $3 \leftrightarrow 8$, $9 \leftrightarrow 4$, and $2 \leftrightarrow 7$, we get square B. Then the four corners are all even numbers. If we then turn these four corner numbers 90° clockwise, we get square C.

21	16	11	6	1
22	17	12	7	2
23	18	13	8	3
24	19	14	9	4
25	20	15	10	5

5×5 square, with a 3×3 square inside.

In the 5×5 square like the figure shown above, the thick-lined square is a 3×3 square. Change it into D of Table 1. Next, work on the four corners of the outside square, and exchange positions in the following manner: $1 \leftrightarrow 15$, $5 \leftrightarrow 23$, $25 \leftrightarrow 11$, and $21 \leftrightarrow 3$. Do not turn the four corner numbers, because they are odd numbers. You will complete the work by putting D, the 3×3 square, inside it.

Takakazu Seki commented on the general way of making squares in the books, *Hōjin-no-hō* and *Ensan-no-hō*, written in the third year of the Tenwa period (1683). He divided them into odd-celled squares and two types of even-celled squares. Squares by Katahiro Takebe (1664–1739) are introduced in volume 4 of the *Ichigen Kappō*, written by Shukei Irie.

In 3×3 squares, put the numerals in order, turn the center joined by both diagonals, lines,

and rows 45° leftward. Then turn the center of the lines and rows 180° :

7	4	1	4	1	2	4	9	2
8	5	2	7	5	3	3	5	7
9	6	3	8	9	6	8	1	6

Yoshisuke Matsunaga (1692–1744), a pupil of Seki's pupil, wrote *Hōjin-Shin-jutsu*. There are also studies by Yoshihiro Kurushima (d. 1757), and by Naonobu Ajima (1732–1798). The question on step children is in *Jingōki* by Mitsuyoshi Yoshida. The question is close to that of Joseph's problem in the West.

Shūtārō Teramura (1902–1980) studied how many “parent-child” squares could be made in all, and in 1926 he made 605 squares. Following are some examples.

In the first, the parent square is a perfect 8×8 square. The child one (between thick lines) is a perfect 4×4 square (shown below):

2	29	51	48	1	30	52	47
56	43	5	26	55	44	6	25
15	20	62	33	16	19	61	34
57	38	12	23	58	37	11	24
4	31	49	46	3	32	50	45
54	41	7	28	53	42	8	27
13	18	64	35	14	17	63	36
59	40	10	21	60	39	9	22

A parent-child square, 8×8 , with a 4×4 square inside.

In another example, the parent square is also a perfect 8×8 square, and the child one (upper-middle part) is a perfect 4×4 square, as shown below:

Magic Squares in Japanese Mathematics, Table 2 Making perfect 8×8 squares

a	b	c	d	e	f	g	h
$c + x$	$d - x$	$e + x$	$f - x$	$g + x$	$h - x$	$a + x$	$b - x$
$e + y$	$f - y$	$g + y$	$h - y$	$a + y$	$b - y$	$c + y$	$d - y$
$f - y$	$h + x$	$a - x$	$b + x$	$c - x$	$d + x$	$e - x$	$f + x$
$-e - y$	$-f + y$	$-g - y$	$-h - y$	$-a - y$	$-b + y$	$-c - y$	$-d - y$
$-g + z$	$-h - z$	$-a + z$	$-b - z$	$-c + z$	$-d - z$	$-e + z$	$-f - z$
$-a$	$-b$	$-c$	$-d$	$-e$	$-f$	$-g$	$-h$
$-c - z$	$-d + z$	$-e - z$	$-f + z$	$-g - z$	$-h + z$	$-a - z$	$-b + z$

2	29	51	48	1	30	52	47
56	43	5	26	55	44	6	25
13	18	64	35	14	17	63	36
59	40	10	21	60	39	9	22
4	31	49	46	3	32	50	45
54	41	7	28	53	42	8	27
15	20	60	33	16	19	61	34
57	38	12	23	58	37	11	24

A parent-child square.

To make a perfect 4×4 square, choose optional numbers for x, y, z, u , and t . $X = x + y + z + u$. Make the square as follows:

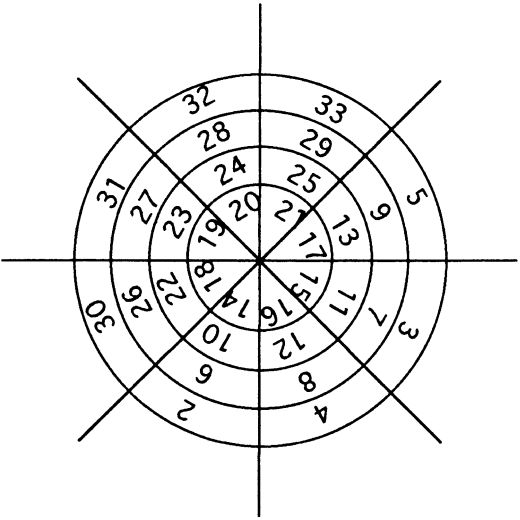
x	y	z	u
$z - t$	$u + t$	$x - t$	$y + t$
$1/2X - z$	$1/2X - u$	$1/2X - x$	$1/2X - y$
$1/2X - x + t$	$1/2X - y - t$	$1/2X - z + t$	$1/2X - u - t$

To make perfect 8×8 squares, choose optional numbers for a, b , and c , and construct the square as in Table 2.

In an N square, in which a line has n divisions, and which consists of n^2 numerals, the total of the vertical and horizontal lines should be the same as that of both diagonals. This square is a Magic Square, and if each sum of the numbers of all the parallel lines is the same, the square is a Perfect Magic Square. The study of Michiwaki and Moriyama (1963) tells how to make it.

There are also many special squares. The best examples of circular squares are introduced in Takakazu Seki's *Hōjin-no-hō* and *Ensan-no-hō* (see Fig. 1).

Star squares were studied by Shigematsu Urata and Rakuho Abe in 1955 (see Fig. 2).

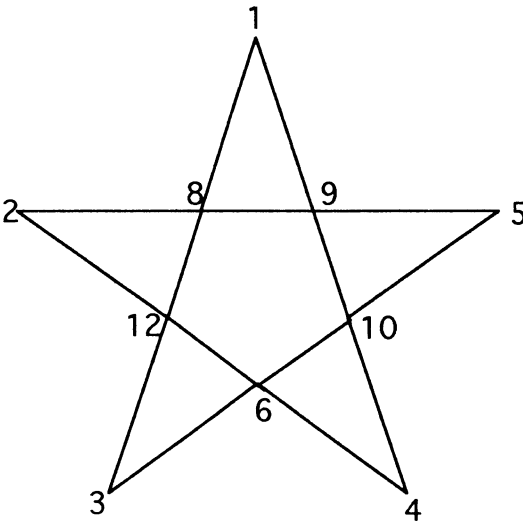


Magic Squares in Japanese Mathematics, Fig. 1 Circular square

The first cubic square in Japan was introduced as “cubic design” in *Rakusho-kan* by Yoshizane Tanaka (1651–1719). In it, he piled up the following 4×4 squares in order:

(1)	<table><tr><td>14</td><td>54</td><td>43</td><td>19</td></tr><tr><td>59</td><td>3</td><td>30</td><td>38</td></tr><tr><td>22</td><td>46</td><td>51</td><td>11</td></tr><tr><td>35</td><td>27</td><td>6</td><td>62</td></tr></table>	14	54	43	19	59	3	30	38	22	46	51	11	35	27	6	62	(2)	<table><tr><td>20</td><td>44</td><td>53</td><td>13</td></tr><tr><td>37</td><td>29</td><td>4</td><td>60</td></tr><tr><td>12</td><td>52</td><td>45</td><td>21</td></tr><tr><td>61</td><td>5</td><td>28</td><td>36</td></tr></table>	20	44	53	13	37	29	4	60	12	52	45	21	61	5	28	36
14	54	43	19																																
59	3	30	38																																
22	46	51	11																																
35	27	6	62																																
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37	29	4	60																																
12	52	45	21																																
61	5	28	36																																
(3)	<table><tr><td>33</td><td>25</td><td>8</td><td>64</td></tr><tr><td>24</td><td>48</td><td>49</td><td>9</td></tr><tr><td>57</td><td>1</td><td>32</td><td>40</td></tr><tr><td>16</td><td>56</td><td>41</td><td>17</td></tr></table>	33	25	8	64	24	48	49	9	57	1	32	40	16	56	41	17	(4)	<table><tr><td>63</td><td>7</td><td>26</td><td>34</td></tr><tr><td>10</td><td>50</td><td>47</td><td>23</td></tr><tr><td>39</td><td>31</td><td>2</td><td>58</td></tr><tr><td>18</td><td>42</td><td>55</td><td>15</td></tr></table>	63	7	26	34	10	50	47	23	39	31	2	58	18	42	55	15
33	25	8	64																																
24	48	49	9																																
57	1	32	40																																
16	56	41	17																																
63	7	26	34																																
10	50	47	23																																
39	31	2	58																																
18	42	55	15																																

Arata Sakai started the study of perfect 4×4 cubic squares in 1938, and Shigematsu Urata



Magic Squares in Japanese Mathematics, Fig. 2 Star square

completed it in 1948. Motoaki Abe made a 5×5 cubic square in the latter part of the Taishō period. A 7×7 cubic square was made by Motoaki Abe and Shōji Shimada.

In 1948 Rakuho Abe made a perfect 6×6 cubic square with a plane 6×6 square as its base, but the diagonal total was not regular. Michiwaki and Moriyama studied the way to make special perfect 9×9 cubic squares, and the way to count their numbers.

See Also

- [Ajima Naonobu](#)
- [Seki Kowa](#)
- [Takebe Katahiro](#)

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Magnetism in Chinese Culture

Chen Cheng-Yih

M

In Chinese civilization, the *ci-shi* (lodestones) and their ability to attract iron are mentioned in a number of Zhou period Classics. It is stated in the *Shanhai Jing* (Classic of the Mountains and Rivers) that lodestones are found at *ao-ze*. A remark in the *Guan Zi* (Book of Master Guan) indicates that the finding of lodestones was once viewed by ancient prospectors as an indication for the possible presence of other mineral deposits. Both the *Gui Gu Zi* (Book of the Devil Valley Master) of the fourth century BCE and *Lushi Chun Qiu* (Master Lu's Spring-Autumn Annals) of 239 BCE mention that the lodestone attracts iron.

The attractive interaction between the lodestone and iron was interpreted as being caused by *xiang gan* (mutual influence), a sympathetic response between two interacting entities. ► [Wang Chong](#), in the *Lun Heng* (Discourse Weighed in Balance) of AD 82 offers the interpretation that some items attract others, while some cannot, because their *qi* is different and consequently they cannot mutually influence one another. The character *qi* literally

means vapor or breath. In the course of time, it took on a number of proto-scientific significances: the basic constituent entity of all things in nature and the media of the ► *yinyang* interactions. There are a number of scholars who translate *qi* as “energy,” “field,” or “matter-energy,” but in ancient times, the concepts of energy and field were not yet explicitly developed. *Qi*, as it is given in the Chinese texts, is not identified by its intrinsic properties, but by its general relationship with others. Though the pattern relationship is identifiable with certain aspects of the modern concept of energy, field, or matter-energy, it is better to preserve the term *qi* and not to translate it.

A later account (AD 300) by Guo Pu also comments on the role of *qi* in such interactions.

The lodestone draws iron, and amber collects mustard-seeds. [Since] their *qi* are invisibly interconnected and their measures are silently met, the mutual influence between them consequently occurred.

Such a view of interaction at a distance involving *qi* is compatible with modern views.

The strength of such attractive interactions was later discussed in terms of the weight of iron pieces or the number of needles that the lodestone was capable of supporting.

Tao Hong Jing stated in the *Ming Yi Bie Lu* (Informal Records of Famous Physicians) that some “[lodestones] could suspend a chain of more than ten needles”.

Based on such quantitative measures of the attractive power, lodestones were graded as follows:

A piece of genuine lodestone is called the *yan nian sha* if it is capable of attracting, on its four sides, one catty of iron piece (the equal weight of the lodestone); called the *ji cai shi* if it is capable of attracting, on its four sides, eight ounces weight of iron piece; and called simply the *ci shi* if it is capable of attracting, on its four sides, four ounces of iron piece (*Lei Gong Pao Zhilun*).

The directional property of lodestones was probably first used in the *sinan* ceremony, a practice evolved directly from the tradition of using a gnomon and the positions of the sun and stars to determine the time and directions. The term *sinan* means “south verification” or “south controller.”

The discovery of lodestone’s south pointing property led naturally to its association with the term *sinan* and the *sinan* (south verification) devices. However, early mentions of the *sinan* devices provide little information on their construction. In the *Gui Gu Zi* there is mention of the fact that when the Zheng people engage in collecting jade, they always carry with them a *sinan* to avoid being lost.

The device described by Wang Chong has been widely considered to be the earliest form of the magnetic compass.

The Chinese literature of the period ranging from the Han to the Tang dynasties provides a number of hints that, by the first century AD, the fact that the directive property of the lodestone could be transferred to small pieces of iron was discovered, and by the seventh century AD, the magnetized needle began to appear in certain compasses, replacing lodestones for greater precision. But the records are not sufficiently specific to provide a definitive account of these developments. Explicit descriptions of magnetic properties and compass construction are found in the work of the Song dynasty.

Properties of magnetized needles are discussed in the work of Shen Gua (1029–1093). We have from his *Meng Xi Bi Tan* (Meng Xi Essays) of 1086, the following description of declination:

Fang Jia uses the lodestone to rub the point of a needle;

The needle is then able to point to the south.

It does not, however, point directly at the south,

It always inclines slightly to the east.

Following this description is the passage on the needle supporting methods:

[The needle] can be supported by making it float on the surface of water, but it is rather unsteady. It may be balanced on the finger-nail, or on the rim of a cup, so that it can turn more easily, but such supports being hard and smooth [mean it] is liable to fall off. The best way of supporting the needle is by suspension. The method uses a single cocoon fiber of new silk to suspend the needle. By attaching silk to the center of needle with a piece of wax the size of a mustard-seed and hanging in a windless place, the needle will then always point to the south undisturbed.

He discusses three types of needle-supporting methods: floating, pivot, and suspension. For the study of magnetic properties, Shen Gua preferred the suspension method using a silk thread. The other two methods of supporting the needle, by floating it on the water surface and by pivoting it on a hard smooth surface, correspond to those used in the wet and dry compass, respectively.

Shen Gua's work also discusses magnetic polarity. He noticed that some needles pointed north and some south. He believed that different natures caused this, just as animals shed at different seasons.

An important discussion of the magnetic compass is found in the *Wujing Zongyao* (Collection of the Most Important Military Techniques) of AD 1044.

When troops encountered gloomy weather or dark night, and could not distinguish the directions, they would let an old horse in the front lead them, or else they would make use of the south-pointing carriage, or the south-pointing fish to identify the directions. Now the carriage method has not been handed down. In the (south-pointing) fish method, a thin leaf of iron is cut into the shape of a fish 2 in. long and half an inch broad, having a pointed head and tail. It is then heated in a charcoal fire until it becomes thoroughly red-hot, taken out by the head with iron tongs, and placed so that its tail is in the *zi* direction (due north). In this position, it is quenched with water in a basin, so that its tail is submerged for several tenths of an inch. It is then kept in a *miqi* (tightly closed box). To use it, a small bowl filled with water is set up in a windless place, and the fish is laid as flat as possible upon the water surface so that it floats, whereupon its head will point in the *wu* direction (south).

The passage not only provides a clear discussion on the construction of a compass, but also reveals a different method for magnetizing iron pieces. Thus no later than the early Song dynasty (960–1279), two methods of magnetizing were known. Other than rubbing with the lodestone, an iron piece could also be magnetized by quenching it from red heat through the Curie point, held in a north-south direction (in the magnetic field) of the earth. The discovery of the

thermoremanence phenomena was of great scientific significance. Since the earth's magnetic field is relatively weak and the soft iron does not retain its magnetism long, questions were raised as to whether such magnetized iron could function satisfactorily as a compass. Recent archaeological evidence revealed a long history of steel development in China, beginning from the later part of the spring-autumn period of the Zhou dynasty. By the second century BCE, two methods for steel production from pig iron were developed, one by the puddling of molten iron and the other by decarbonization of cast iron in the solid state without the formation of graphite. Thus, good steel and steel needles were certainly available in the early Song dynasty.

An important use of the compass is in navigation. Clear and accurately datable statements on such a use are found in the *Pingzhou KeTan* (Pingzhou Table Talk) of 1119, when the author says that ships' pilots look at a south-pointing needle or sample of the mud collected from the sea bottom to determine their whereabouts in dark weather. This is confirmed in other books of the period.

Based on these statements and other sources, Needham has concluded that "description of the use of the compass for navigation on Chinese ships antedates the first knowledge of this technique in Europe by just under a century, but there are indications that it was used for this purpose in China somewhat earlier."

Needham is also of the view that "Chinese sailors remained faithful to the floating-compass for many centuries. Although the dry pivoted compass had been described early in the twelfth century AD, it did not become common on Chinese vessels until it was reintroduced from the West in the sixteenth century by the Dutch and Portuguese by way of Japan. Associated then with it was the compass-card (the windrose attached to the magnet) which had probably been an Italian invention at the beginning of the fourteenth century." The European mariner's compass is characterized by 16 compass points in contrast to the 24 of the Chinese compass. The discovery of the clay depiction of a dry-pivoted compass in the tomb of Zhu Jinan (1140–1197) in



Magnetism in Chinese Culture, Fig. 1 Clay figurine with a dry-pivoted compass in its arm unearthed in 1985 from the tomb of Zhu Jinan

1985 raised a number of pertinent questions. The compass depicted in the arm of the two clay figurines unearthed from the tomb has 16, not 24, compass-points. Since the tomb was sealed in 1198, the compass depicted here could not have been influenced by those reintroduced from the West (Fig. 1).

Both the dry-pivoted and floating compass were used in Chinese ships. The choice was often based on accuracy. It should be noted that, though the gyroscope was invented in China around the first century BCE by Ding Huan, no known reference to its use in connection with the mariner's compass is available.

See Also

- [Compass](#)
- [Metallurgy in China](#)
- [Navigation in China](#)
- [Shen Guo](#)

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Magnetism in Mesoamerica

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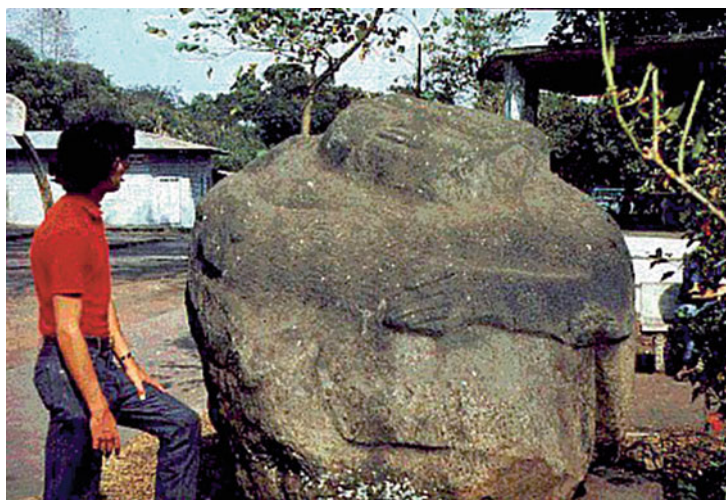
That the pre-Columbian peoples of Mesoamerica were familiar with the property of magnetism has been suggested by several researchers, among them the geographer Robert Fuson and the anthropologist Michael Coe. Indeed, a flattened oblong piece of hematite discovered during Coe's excavation of the Olmec site of San Lorenzo in southern Veracruz state in 1966 has been thoroughly examined by John Carlson, who suggests that it probably was fashioned for use as a compass. (In tests, however, it never aligned more closely than about 35° with the Earth's magnetic field.) In 1975, a basaltic sculpture at the site of Izapa, on the Pacific coastal plain of Mexico near the Guatemalan border, was found to possess a strong magnetic field. Variouslly described as being the representation of either a frog (Norman, 1976) or a turtle's head (Malmström, 1976), it has a north-seeking pole in its snout and a south-seeking pole at the back of its head.



Magnetism in Mesoamerica, Fig. 1 The *black* volcanic sands of the beaches near Izapa are the nesting place of a deep-carapaced black turtle that migrates between the Guatemalan coast and the Galápagos Islands. Perhaps local fishermen associated magnetism with the homing

instinct of these creatures. Interestingly, the Chinese also associated turtles with magnetism, using the term “black turtle rock” for basalt and making their early compasses in the shape of turtles (Photo by the author)

Magnetism in Mesoamerica, Fig. 2 In the sculptures known as the “Fat Boys,” magnetism appears to have been associated with certain qualities of the human being. We can only speculate that when the magnetic pole was located at the navel, it may have symbolized the life force, or the continuity of life, whereas when it was located in the right temple, it may have represented consciousness, memory, or intellect (Photo by the author)



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The discovery led the latter researcher to speculate that the stone’s carver may have associated the property of magnetism with the homing instinct of the turtle. Because it was the only magnetic object found at the site, critics of the notion that it was a human artifact argued that it may have been struck by lightning and its magnetic field had been induced in that manner (Fig. 1).

However, in 1979, several additional magnetic sculptures were discovered in the Pacific coastal plain of Guatemala, including seven which now repose in the central plaza of the town of La Democracia, and two more which were identified at the nearby sugar plantation of El Baúl. Those at La Democracia are extremely crude depictions of human beings, and, because



Magnetism in Mesoamerica, Fig. 3 Because all evidence of magnetism in Mesoamerica is associated with basaltic sculptures whose size prohibited their movement on more than a local scale, the knowledge of this property

apparently was limited to a small area of volcanism on the Pacific coastal plain of southernmost Mexico and adjacent Guatemala (Map by the author)

of their rotundity, have been termed the “Fat Boys” by archaeologists. When an entire body is depicted, the two magnetic poles are usually found on either side of the navel; when only a head is portrayed, the two magnetic poles are almost invariably centered on the right temple (Fig. 2).

The sculptures at El Baúl include a rampant jaguar, with magnetic poles in each upraised paw, and a tablet showing two men seated on a bench with their arms folded over their chests. This single block of stone has four magnetic poles, one north-seeking pole between each of the men’s folded arms and one south-seeking pole below each man in the space beneath the bench. In 1983 a small humanoid sculpture in the plaza of Tuxtla Chica, Mexico, just back of Izapa, was found to be magnetic in the right side of its head. Clearly, the patterns of polarity discerned suggest a conscious intent on the part of the sculptors to fashion their carvings around a known center of magnetic attraction, for in none of the stones has

any inset of foreign material been made. That such recurring patterns could have been the result of random lightning strikes must also be ruled out. Because the “Fat Boys” are considered to date from 1500 to 2000 BCE, it is possible that these sculptures represent the oldest known magnetic artifacts in the world. But to what use, other than art and magic, this knowledge was put, we have no answer as yet (Fig. 3).

See Also

► [Compass](#)

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Mahādeva

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Mahādeva (ca. 1275–1350) composed the extensive set of planetary tables, *Mahādevī*, named after him and dated 28 March 1316. He belonged to a family of astronomers and in his work *Grahasiddhi* describes himself as the son of the astrologer Paraśurāma, son of Padmanābha, son of Mādhava, son of Bhogadeva of the Gautamagotra, a follower of *Sāmaveda* and a performer of sacrifices. The planetary tables contained in the *Mahādevī*, prepared for facilitating the computation of the daily almanac, were extremely popular in the Gujarat and Rajasthan regions, and numerous manuscripts of the work have been located in these places. While the basic text was restricted to 43 verses, the author himself wrote a set of instructions for using the tables, called *Grahasiddhi*, which also were extensively used. The popularity of *Mahādevī* is also attested to by the several commentaries that were written on the work, including that of Nṛsiṃha (1528), Dhanarāja (1635), and Mādhava, and a host of anonymous commentators.

Mahādeva is a synonym of Śiva, one of the trinities of Hinduism, and so formed one of the words commonly used to name Hindus. There are several astronomers of medieval India who bore the name Mahādeva. Among these are Mahādeva, younger brother of Viṭṭhala, from Gujarat, author of *Tithicakranirṇaya*, also called *Tithinirṇaya*, *Tithiratna*, and

Mahādevasiddhānta; Mahādeva, author of *Jātakāpaddhati*, called also *Mahādevapaddhati* after his name; Mahādeva, son of Luṇiga and author of commentaries on the *Cintāmaṇisāraṇikā* of Daśabala and the *Jyotiṣaratnamālā* of Śrīpati; Mahādeva of the Kauṇḍinyagotra, son of Bopadeva and author of *Kāmadhenu* called also *Tithikāmadhenu*; Mahādeva, son of Kahnaji Vaidya, author of *Muhūrtadīpaka* in 57 verses, written in 1640, *Praśnapradīpa* called also *Praśnaratna* (1647), *Bhāveśaphalapradīpa* (1647), *Kālanirṇaya-siddhānta* (1652), and a commentary on his own *Muhūrtadīpaka* (1661); Mahādeva Pāṭhaka (1842–1899), son of Revāśaṅkara and author of *Varṣadīpaka*, called also *Varṣadīpikā* (1861), *Jātakatattva*, written in 1872, *Pitṛmārgapradīpa* in 57 verses (1874), *Varṣapaddhati*, a compilation (1874), and *Āśubodhajyotiṣa*.

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Mahāvira

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The Rāṣtrakūṭa dynasty of the medieval period was founded in the Deccan, South India, by Dantidurga about the middle of the eighth century AD. A king of this dynasty named Amoghavarṣa ruled from AD 815 to 877. The long period of his rule is known for its material prosperity, political stability, and academic fertility. He was rich, powerful, and peace-loving, and he patronized art and learning.

In the later part of Amoghavarṣa's reign there lived a great mathematician named Mahāvīrācārya. Mahāvīra was a Digambara Jaina and wrote an extensive Sanskrit treatise called *Gaṇitasāra saṅgraha* (Compendium of the Essence of Mathematics) about AD 850. It is devoted to elementary topics in arithmetic, algebra, geometry, mensuration, etc. The work is important because it is a collection summarizing elementary mathematics of his time and providing a rich source of information on ancient Indian mathematics. It is written in the style of a textbook and was used as one for centuries in all of South India. Its importance is greater still because the *Pāṭiganita* of ► Śrīdhara (ca. AD 750), written in the same style as the *Gaṇitasāra saṅgraha*, is not extant in full.

Mahāvīra shows sufficient originality not only in presenting older material lucidly, but also in introducing several new topics. A commentary called *Bālabodha* in Kannada was written by Daivajña Vallabha. A Sanskrit commentary was composed by Varadarāja. Dates for these two commentators are not known, nor are their works available in print. There were other translations in the eleventh century and in 1842.

The nine chapters of the *Gaṇitasāra saṅgraha* are as follows:

1. Terminology (70 verses)
2. Arithmetical operations (115 verses)
3. Operations involving fractions (140 verses)
4. Miscellaneous operations (72 verses)
5. Rule of three (43 verses)
6. Mixed operations (337 1/2 verses)
7. Geometry and mensuration (232 1/2 verses)
8. Excavations (68 1/2 verses)
9. Shadows (52 1/2 verses)

The total number of verses, 1,131, shows that the book is quite comprehensive. Another noteworthy feature is that the Jaina tradition of Indian mathematics is also preserved within the scope of the *Gaṇitasāra saṅgraha*.

The authorship of the astronomical work *Jyotiṣapaṭala* is also ascribed to Mahāvīra. Some manuscripts of this title are mentioned in the *Jina-ratna-kośa* and the *New Catalogus*

Catalogorum, but no author is mentioned. Another work attributed to him is *Chattisu*, but this is also a sort of elaboration of part of the *Gaṇitasāra saṅgraha* made by Mādhavacandra Traividyā (about AD 1000). Whatever the case, the reputation of Mahāvīra relies solely on his *magnum opus*.

During ancient times, unit fractions were considered quite important. There are some interesting results in the *Gaṇitasāra saṅgraha* on this topic. One rule gives a practical method for expressing any given fraction as a sum of unit fractions. Let p/q be the given fraction (p being less than q). We add a suitable integer x to q such that $(q + x)$ become exactly divisible by p , say, r times. Then Mahāvīra's rule is

$$\frac{p}{q} = \frac{1}{r} + \frac{x}{(r \times q)}.$$

Mahāvīra made a very significant remark in connection with the square-root of a negative number. He said "A negative number is non-square by its nature, whence there is no (real) square-root from it."

This remark is the first clear recognition of the imaginary quantities in mathematics which had to wait for several more centuries for their formal definition.

Mahāvīra was one of the earliest Indian mathematicians to deal with the lowest common multiple which he calls *niruddha*. It was evolved to simplify operations with fractions.

Arithmetical and geometrical progressions were already handled earlier. An extensive treatment is available in the *Gaṇitasāra saṅgraha*. In the absence of modern theories of logarithms and equations, problems were solved by methods of trial and repetition.

Mahāvīra seemed to be expert in handling all sorts of equations reducible to quadratic forms and gave a variety of examples of them.

In mensurational problems in geometry, Mahāvīra usually gave two rules: one for rough and the other for better or accurate results. He dealt with all the usual plane figures. For π , he conformed to the Jaina values 3 (rough), and $\sqrt{10}$ (better). He was the first Indian to deal with

mensuration related to an ellipse which he calls *āyata-vṛtta* (elongated circle), but his rules are approximate.

For an ellipse of semimajor and semiminor axes his “accurate” results are:

$$\text{Area} = b\sqrt{(4a^2 + 6b^2)},$$

$$\text{Perimeter} = \sqrt{(16a^2 + 24b^2)}.$$

For the exact rectification of the ellipse, one had to wait for about 800 years to acquire the powerful tool of calculus. In this situation Mahāvīra’s first attempt is to be appreciated.

Regarding the volume of a sphere of radius r , Mahāvīra gave the formula

$$v = \frac{9}{2}r^3,$$

which was the practical rule of Jaina tradition. He gave another rule for the purpose, but it gives a better result only with an amendment of the text. For the curved surface of a spherical segment, his rule has been newly interpreted to yield the formula

$$S = \pi r^2 \theta \sin \theta,$$

where θ is the semiangle subtended by a diameter of the base of the segment at the center of the sphere. This peculiar formula gives quite a good result in all practical cases (i.e., for θ up to 60°). The modern exact formula is $2\pi r^2(1 - \cos \theta)$. For the volume of frustum-like solids, Mahāvīra gave a generalization of Brahmagupta’s rule based on the theory of averages.

In the end we mention Mahāvīra’s extensive contribution to the formation of rational figures. He calls a triangle or quadrilateral *janya* (generated) when its sides, altitudes, and other important measures can be expressed in terms of rational numbers.

See Also

► Śrīdhara

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Mahendra Sūri

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Mahendra Sūri (ca. 1340–1400) was a fourteenth-century Jaina astronomer. He was trained by Madana Sūri and was a teacher to Malayendu Sūri. His fame rests on the work *Yantrarāja*, which introduced the astrolabe to the Indian astronomer.

Mahendra Sūri was patronized by the Tughlak ruler of Delhi, Firūz Shāh (r. 1351–1388), who evinced keen interest in astronomy. Firūz Shāh had earlier caused the *Bṛhatsaṃhitā* of Varāhamihira to be translated into Persian.

At the sultan's instance, Mahendra Sūri studied the astrolabe and introduced it to the Sanskrit audience in 1370 in his *Yantrarāja*. The Sanskrit orthodoxy seems to have accorded the work a lukewarm welcome, though. Its circulation was largely, if not wholly, confined to astronomers who worked within the Islamic and Ptolemaic traditions.

The *Yantrarāja* is best described as an astrolabe user's manual. It explains how this king (*rāja*) of instruments (*yantra*) is to be constructed and commissioned for purposes of observation. The *saumya-yantra* (northern instrument) projected from the South Pole and the *yāmya-yantra* (southern instrument) projected from the North Pole are discussed separately, followed by a description of the *phaṇīndra yantra* (the serpentine instrument), which combines both. A detailed discussion on the application of the astrolabe is found in Malayendu Sūri's commentary on the *Yantrarāja*. This commentary is also interesting because it provided, for the first time to the Indian astronomers, tables for ready reference, which helped simplify calculations. The commentator gave latitudes of 75 cities. Islamic tradition is said to have recorded latitudes for as many as 1,022 stars. Malayendu made a list of latitudes for 32 stars, which were identified as relevant for purposes of calculations in India.

See Also

► [Astrolabe](#)

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Makaranda

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Makaranda was a resident of Kāśī (or Benares, Varanasi). In AD 1478, he wrote an extensive astronomical manual with the title *Makaranda*. This was doubly significant, first because the title was reminiscent of his own name and second because it called the computed result obtained *makaranda* (honey) and gave the several astronomical terms names of parts of plants, such as *guccha* (flower cluster), *kanda* (bulb), *vallī* and *latā* (creeper), and the like. Makaranda based his work on the parameters of and practices prescribed by the modern *Sūryasiddhānta*, to which he added certain corrections to insure greater accuracy, and provided a number of astronomical tables for ease in computing the daily almanac.

Makaranda's tables, which are often long and extend to several centuries, involved much labor and ingenuity in their preparation. They cover such subjects as *tithi* (lunar day, 5 tables), *nakṣatras* (asterisms, 4 tables), *yogas* (complementary positions of the sun and the moon, three tables), *saṅkrāntis* (entry of the sun into the zodiacal signs, 3 tables), mean motion of planets and their anomalies (11 tables), length of daylight on different days (1 table), weekdays (2 tables), and eclipses and allied matter (10 tables).

In order to render the work of the user easier, Makaranda provides, in certain cases, two sets of tables, one for single years and the other for groups of years, all from the epoch date of the commencement of Śaka year 1400 (AD 1478). Thus, when calculations are made for a date which is several years after the epoch, multiples of the group years can be skipped, just taking note of the readings for the number of group years skipped and applying the same to the relevant year of the current group. In the case of *tithis*, the group is taken as 16 years; for *nakṣatras* and *yogas*, it is nearly 600 years,

K. V. Sarma: deceased

from AD 1478 to 2054, in 24 year periods. For the precession of the equinoxes, it is nearly 100 years, from AD 1758 to 1838, in 20-year periods, and for *saṅkrāntis* 400 years, from AD 1478 to 1877, in 57-year periods.

Makaranda's tables were widely used in the entire northern belt of India, comprised of Gujarat, Rajasthan, Uttar Pradesh, Bihar, and Bengal, as attested by the profusion of manuscripts of the work found in this region. The work has also been commented on by several authors, from *ḍhuṇḍirāja* (fl. 1590), through Purusottama Bhatta (fl. 1610), Divākara (fl. 1606), and Kṛpakara Miśra (fl. 1815), to Nīlāmbara Jhā (b. 1823). The *Siddhāntasudhā* of Paramānanda Ṭhakkura is based on the work of Makaranda.

See Also

- [Astronomy in Medieval India](#)
- [Lunar Mansions in Islam](#)
- [Sūryasiddhānta](#)

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Mancala

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Mancala is a generic term for a group of board games that commonly consist of two or four rows of cup-shaped holes using a proportionate

number of counters, often seeds, stones, or shells. There are usually two players who take turns spreading counters one by one in consecutive holes around the rows of holes. In most cases the object of the game is to capture the majority of the counters. The wide variety of rules and boards complicates a comprehensive descriptive definition of the game.

Some variations, in particular the games known as Bao in East Africa and Wari in West Africa and the Caribbean (also known as Warri, Awari, Awélé, Oware), are played in competition. They have been instrumental in cognitive psychological research where they allow a contrast with studies on chess. In 1990, Retschitzki conducted research on players of Awélé in the Ivory Coast as part of his studies in developmental psychology. de Voogt (1995) completed a study on expertise with tournament players of Bao in Zanzibar, Tanzania. Both researchers collaborated with Fernand Gobet to show the influence of board game research in the field of psychology in their Gobet et al. 2004 publication.

In computer science a series of studies on mancala variations known as Awari (e.g., Allis, van der Meulen, & van den Herik, 1991), Tchuka Ruma solitaire (Campbell & Chavey, 1995), and Kalah (Russel, 1964) were conducted. More recent studies by Donkers and Uiterwijk (2002) as well as Kronenburg, Donkers, and de Voogt (2006) on Bao and Irving, Donkers, and Uiterwijk (2000) on Kalah show a continued interest in using and exploring mancala variations in computer science. This interest overlaps with studies in the field of Artificial Intelligence and even mathematics as Donkers, Uiterwijk, and de Voogt (2002) have shown in an overview of the use of mancala in these fields. These studies are mainly interested in optimal search functions and strategies that can be tested using individual mancala games.

The interest in mathematics dates back to the work of Zaslavsky (1973) and Deledicq and Popova (1977) whose interest was grounded in the cultural aspects of these games. Manansala (1995) added a mathematical study of a Philippine variation. This was followed by

a similar study by Donkers, de Voogt, and Uiterwijk (2000) on Dakon found in Indonesia. Zaslavsky emphasized African mancala games while Deledicq and Popova included Asian variants, which have now gained as much attention as the African ones. The results of these studies emphasize the ethnomathematical aspects of mancala play, identifying mathematical and computational abilities of players.

Historical and anthropological studies of mancala games go back to the first mention of a mancala game, closely resembling today's game of Bao, by Flacourt in his history of Madagascar (1661). More influential was the work of Culin (1896) and later the seminal work by Murray (1952) who provided one of the first overviews of known mancala variations. They are at the basis of questions concerning the history and distribution of mancala games.

In archaeology Schädler (1998) has shown the likely confusion of mancala with the game of five lines for rows of holes dating to the Roman period. Similarly, four rows of holes may be confused with the Middle Eastern game of Tab (Depaulis, 2001). A series of finds in Sudan (de Voogt, 2012), Syria (de Voogt, 2010), and the Balkans (Bikić & Vuković, 2010) strongly suggest that rows of holes found on monuments and rock faces of archaeological sites in these regions can be traced to an Ottoman presence, contradicting suggestions of a Roman or even an ancient Egyptian practice of playing mancala. As a result the early history of mancala and its possible existence in antiquity remains largely unknown.

The mathematic, psychological, cultural, and historical aspects of mancala games have also given rise to studies in education. The cognitive-developmental studies by Tano (1985, 1989) were followed by developmental studies by Retschitzki (1990) and N'Guessan (1992). de la Cruz, Cage, and Lian (2000) suggested the use of mancala for teaching exceptional children, and de Voogt, Linders, and van den Broek (2010) did the same for people with a visual impairment. Each of these studies found mancala games particularly useful to measure or to challenge the capabilities of children and students.

Mancala has proven to be a rich topic for a series of scientific fields. Together with other board games, they provide a well-defined domain with rules, a multitude of potential tasks, and good ecological validity. In contrast with chess, mancala games feature various sets of rules that allow for different degrees of complexity and diverse cultural affinities.

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Maps and Mapmaking in Africa

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With the exception of medieval Islamic mapmaking, the corpus of precolonial African maps is too small for us to generalize about distinctive cartographic traditions. B. F. Adler (1910) provides the only summary of sub-Saharan mapping, and most of his examples are maps solicited from

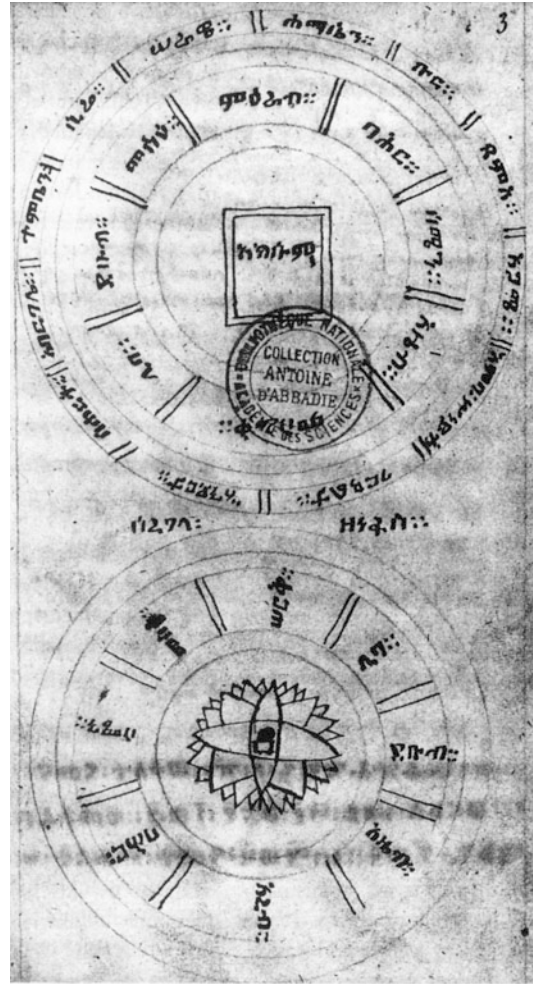
Africans by European explorers. The paucity of extant maps may be explained by a number of factors. First, among literate cultures like the Muslim Hausa and Jula of West Africa, there existed effective substitutes such as travel guides written in Arabic script. These commonly took the form of itineraries that listed the names of towns between a starting point and destination (e.g., the road from Bornu to Mecca). In 1824, Joseph Dupuis provided examples of these “native charts” kept by merchants and pilgrims which he used to construct his own maps of West Africa. Second, the scarcity of maps in nonliterate societies may be explained by a common recourse to drawing maps on the ground. European explorers witnessed this indigenous form of mapmaking and were frequently impressed by its accuracy. However, the ephemeral nature of ground maps has left us with a few traces of this apparently widespread practice (see below). Third, the demand for maps was probably very limited because of the hazards of traveling beyond one’s territory. Even merchants risked being captured by neighboring groups if they did not travel in caravans, carry letters of introduction, or have contacts in distant communities. Under these circumstances, there was a little demand for maps as conveyors of geographical knowledge to outsiders. Finally, in searching for African maps, we should be wary of looking for Western forms of mapping in societies whose spatial concepts and relationships to land are fundamentally different. Western maps are constructed upon culturally specific notions of property, territory, and political authority over bounded areas. One should not assume a priori that African peoples hold these concepts. Moreover, as Paul Bohannon shows in his discussion of the “genealogical map” of the Tiv of central Nigeria and the “rain shrine neighborhoods” of the Tonga of Zambia, there is tremendous variety within Africa itself in the conceptualization of space. Rarely does one find the expression of socio-spatial relationships in two-dimensional maps. Despite this restricted development of mapmaking in precolonial Africa, there are a number of interesting maps to consider.

One of the earliest examples of African mapmaking is an Egyptian map dating from about 1150 BCE. Fragments of the picture map depicting the Wadi Hammamat area between Thebes and the Red Sea port of Quseir are preserved on papyrus in the Museo Egizio at Turin. Other ancient Egyptian examples include plans of gardens and maps of the afterlife painted on stone during the second millennium BCE.

One of the foremost cartographers of the Middle Ages was al-Sharīf al-Idrīsī. He was born in Ceuta, Morocco, in 493 AH/AD 1100 and is believed to have died there in 560/1165. He was the court geographer of the Norman king of Sicily, Roger II, for whom he wrote his celebrated *Nuzhat al-mushtāq fī khtirāq al-āfāq* (The Book of Pleasant Journeys into Faraway Lands, also known as the Book of Roger). This work contains a world map and 70 sectional maps that build upon both the Balkhī and Ptolemaic cartographic traditions. Although written in the twelfth century, al-Idrīsī's work was still influential five centuries later among North African chartmakers. The portolan charts of the al-Sharafī al-ṣifāqī family that thrived in the Tunisian town of Sfax for over eight generations are compilations based on al-Idrīsī and Catalan sea charts.

A distinctive form of schematic mapping dating from the eighteenth century is represented in Ethiopian manuscript maps of Tigre (Fig. 1). These maps consist of three concentric circles in which Aksum, the center of Ethiopian Christendom, is situated in a box in the innermost circle, as in the figure here; the outer circles are divided into segments that contain the cardinal directions and the names of outlying districts. At least five versions of this map are known to exist, two of which are found in the manuscript titled *Kebrā Nāgāst* (The Glory of Kings). Below the circle map is a "wheel of wind" or "wind rose" in which the cardinal directions are again shown with east at the top. More research is needed to examine the relationships between these circle maps and the texts in which they are found.

Evidence of African maps and mapmaking in the nineteenth century is largely found in European accounts of exploration and travel. In many



Maps and Mapmaking in Africa, Fig. 1 Ethiopian map of Tigre. From the Bibliothèque Nationale de France, Collection Antoine d'Abbadie 225 fol. 3-cliché A85/489

instances, African mapmaking was stimulated by European interest in the geography of unexplored areas. A well-known example is the map drawn by Sultan Bello for Hugh Clapperton during his visit to the Sokoto Caliphate in 1824. Clapperton was particularly interested in the course of the Niger River whose outlet was one of the great geographical mysteries of the day. Sultan Bello drew a map in the sand showing the Niger's course and later reproduced this map on paper which Clapperton published in the account of his journey. Although dismissed by some Europeans as a "rude representation," Bello's map and

geographical writings were valued by later explorers like Heinrich Barth in 1859. His map is also of interest because it demonstrates the “rule of ethnocentricity” common to most map-making traditions, in which the territory of a cultural group – in this case the Sokoto Caliphate – is placed in the middle of the map.

There are many other examples of Africans drawing maps on the ground in response to European questions on the geography of a particular region. The explorer Charles Beke was shown the incorrect course of the Gojab River south of Abyssinia by a Muslim merchant named Hádji Mohammed Núr who drew its course on the ground with his stick. In 1881, the Bohemian doctor Emile Holub recounts a similar experience when traveling in the mid 1870s in the Marutse Empire of the upper Zambezi River. Before leaving to explore the headwaters of the Zambezi, Holub asked the Maurtse chief, Sepopo, to suggest a good travel route. To Holub’s great interest, Sepopo drew a map in the sand whose accuracy was confirmed by two other persons familiar with the area. While on a frontier reconnaissance mission in the dense tropical forests of southeastern Liberia in 1899, the French explorer Capt. Henri d’Ollone asked a person named Toolou to draw on the ground with a piece of charcoal the distribution of the different ethnic groups in the region. After a moment’s reflection and to d’Ollone’s great surprise, Toolou drew a detailed ground map showing the location of villages, rivers, and mountains, as well as ethnic groups. The information gained from solicited maps was occasionally incorporated into European maps. For example, sections of the map of the Sahara produced by the French geographer Henri Duveyrier in 1864 were based on maps drawn in the sand by “Cheikh-‘Othmàn.” The German geographer Karl Weule preserved the maps he solicited by requesting that they be drawn on paper that he provided. Three of these solicited maps are found in Adler’s 1910 book.

Among the Luba of central Africa, ephemeral maps were a common feature of initiation ceremonies. During one stage, the initiate is taken into a meetinghouse where elders have chalked

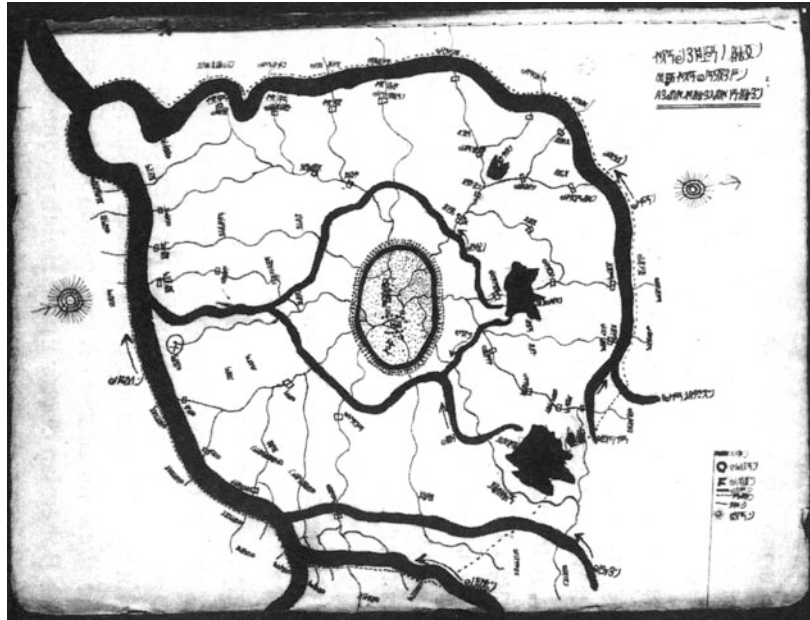
maps on the wall showing major lakes and rivers, the location of various chiefdoms, and the dwelling places of spirits. While facing the map, initiates are quizzed about the residence of certain chiefs and spirits within the Luba kingdom. In the final stage of initiation, elders teach initiates about the origins of Luba kingship and customary taboos. In recounting the origin myths, elders use memory boards (*lukasa*) as mnemonic devices to aid their storytelling. These small rectangular boards are covered with beads and shells that map the migration history of the founding royal family. Rivers and villages are represented by the patterning of beads and shells into configurations that are recognizable to initiates.

An example of cosmographical mapping is found among the Bakongo of Zaïre in their initiation and funerary art. The Kongo cosmos is pictured ideographically as the sun moving through four phases: dawn, noon, sunset, and midnight. The cosmogram is composed of a cross representing the cardinal directions with a small circle at each end point. The horizontal line (*kalunga*) divides the realms of the living and the dead through which all persons travel. Only the most courageous and generous in life return as immortal spirits in natural forms and forces in the landscape.

A more secular and ambitious mapmaking took place in the Kingdom of Bamum in contemporary western Cameroun under the leadership of King Njoya. Njoya stands out as a highly creative and politically astute individual who collaborated with a succession of German, British, and French authorities to consolidate his rule. He was responsible for developing an alphabet which enabled him to write the history of his kingdom in his own language. He also appears to have been a self-taught mapmaker whose earliest preserved work (1906) is composed of a plan of his farm and a route map between Fumban, the capital of Bamum, and his fields. Njoya further honed his mapmaking skills when the German cartographer Moisel visited Bamum in 1908. One of Njoya’s most impressive mapping projects was a topographic survey of his kingdom that employed up to

Maps and Mapmaking in Africa, Fig. 2

King Njoya's map. From the Public Record Office, Kew, CO 649/7 (Crown copyright reserved)



60 individuals. When the British took control of western Cameroun from the Germans in 1916, Njoya displayed his political skills by presenting a map of his kingdom to the British political officer stationed in Foumban. This map with its southerly orientation shows a well-defined territory in which all roads lead to the royal capital and historic center of political authority (Fig. 2). In his letter to the King of England that accompanies the map, Njoya seeks British protection against the Germans. In this context, Njoya's map becomes an instrument of power that legitimates his (contested) claim to be the ruler of Bamum and symbolizes his willingness to collaborate with colonial authorities.

In conclusion, the dearth of African maps seems to imply that mapmaking was not a common means of expressing spatial information. One could even argue that the maps solicited by explorers reflected European mapping traditions rather than African customs. However, the ability of individuals from across the continent to produce consistently accurate ground maps suggests that this was an indigenous practice. Ironically, these ephemeral maps led to the drawing of new and improved maps of Africa by Europeans who ultimately employed them in their partition of the continent into colonies.

See Also

- [al-Idrīsī](#)
- [Balkhī School of Arab Geographers](#)

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Maps and Mapmaking in Ancient Egypt

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Maps, plans, and models present a reduced version of the real world, either existing or anticipated, by incorporating selected properties of reality, while intentionally disregarding others. The selection process is governed by the purpose of the final result. Maps and plans are two-dimensional representations of a three-dimensional reality, usually drawn at a smaller scale. This scale need not be uniform for a map to be useful, as clearly shown by the map of the London Underground, and can in special cases be 1:1 or even larger than reality. Selected details are replaced by symbols (such as the circles representing cities on a modern map of the world) or ignored (like individual buildings on a city plan). Other features are given a distinctive appearance (such as the color of the highways on

a modern roadmap) or size (like the exaggerated width of the roads on the same roadmap). Many maps, plans, and models are not in fact based on the real world, but rather predate reality which is then changed to fit such designs, blueprints, mock-ups, or prototypes. Many of these will have been as perplexing to members of an ancient culture as the Ancient Egyptian maps of the Netherworld, depicting the geography encountered in the afterlife, are to us. Maps and plans from different periods or cultures may not only have an unexpected subject matter, but the scale, symbols, and orientation are often very different from what we have grown used to. Likewise, our convention of having north at the top of a map would not have been understood in Ancient Egypt as this would have the water of the Nile flowing up.

The concept to create reduced, symbolic representations of reality seems to date back to at least the Early Neolithic. One wall in the Neolithic settlement Çatalhöyük (in modern Turkey) preserves a painting, dated around 7000 BCE, which appears to show the settlement from above. Maps were thus most likely known in Ancient Egypt since the beginning of the Old Kingdom (2575–2150 BCE according to the chronology of Baines and Malek, 2000, pp. 36–37). There are no unambiguous examples of maps from this early period, but there is ample evidence that at least certain members of Ancient Egyptian society were able to create and understand reduced representations of reality (Harrell, 2001; Shore, 1987). On the well-known Predynastic Narmer Palette (dated about 3000 BCE, found in Hierakonpolis, now in the Egyptian Museum in Cairo), one of the images seems to represent a walled city in bird's eye view (Fig. 1). This is obviously not a map in the modern sense, nor is it meant to be, but nevertheless a representation of a geographical reality (a walled city) in a way in which it would not have presented itself to the artist, but rather from an imagined perspective. Other early examples of maps include the “topographic design” on a Predynastic ceramic vessel (3700–3100 BCE, provenance unknown, now in the Petrie Museum in London), clearly showing rivers and mountains, and the very schematic “Map of the Netherworld” in the wooden coffin

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Fig. 1 Bird's eye representation of a walled city on the reverse of the Predynastic Narmer Palette (about 3000 BCE), found in Hierakonpolis, now in the Egyptian Museum (Image courtesy of Eternal Egypt <http://www.etermalegypt.org/> created and maintained by the Egyptian Center for Documentation of Cultural and Natural Heritage and IBM)



of General Sepi of the 12th Dynasty (1938–1755 BCE, found in al-Barsha, now in the Egyptian Museum in Cairo), showing the landscape awaiting the deceased according to the “Book of the Two Ways.” (Fig. 2). Such “mythological” maps do not seem to have a complement in reality, but they must be placed in Ancient Egyptian perspective in which the Netherworld must have been deemed a physical reality and objects could magically obtain a measure of reality just by having been drawn.

A remarkable find from the 3rd Dynasty (2650–2757 BCE) is a sketch of a vaulted roof (on a piece of pottery found in Sakkara, now in the Egyptian Museum in Cairo) on which the lengths of the (temporary) supports or (permanent) beams necessary to build such a vault are clearly indicated in numbers (Arnold, 1991; Edwards, 1993). Several more elaborate plans of buildings survive from the Middle Kingdom (1775–1640 BCE). Some were apparently meant as architectural plans, such as the drawing of a garden or a temple on a paving slab from the temple of Pharaoh Mentuhotep of the 11th Dynasty (1775–1640 BCE, found in Luxor, now in the Metropolitan Museum of Art in New York). Others seem to depict an existing structure, such as the drawing of his granaries inside

the coffin of General Sepi (Arnold, 1991; Peck, 1978). Many models, mostly of workshops and boats, are known from the Middle Kingdom, for example, the exquisite series of models from the tomb of chancellor and chief steward Meketre of the 11th Dynasty (1960–1448 BCE, found in Luxor, now partly in the Metropolitan Museum of Art in New York and partly in the Egyptian Museum in Cairo). Plans and models may not only have been used during the building of a structure, but alternatively to demonstrate its appearance to the client or as a votive item to offer to the gods (Arnold, 1991).

As with many other aspects of Ancient Egyptian society, most of our information on ancient maps and plans dates to the New Kingdom (1539–1075 BCE). Examples of mythological maps from this period include those of the Netherworld, for instance, in the tomb of Sennedjem in Deir al-Medina dating to the 19th Dynasty (1292–1190 BCE) and as an illustration with Spell 110 of the Papyrus of Ani (19th Dynasty, found in Luxor, now in the British Museum in London). These maps are based on texts from the “Book of the Dead” (or the “Book of Going Forth Day by Day”). Astronomical (or astrological?) maps can be found painted on the ceiling of the tombs of the royal architect Senmut in Deir

Maps and Mapmaking in Ancient Egypt,

Fig. 2 Map of the Netherworld, illustrating the Book of Two Ways, in the coffin of General Sepi (12th Dynasty, 1938–1755 BCE), found in al-Barsha, now in the Egyptian Museum (Image courtesy of Eternal Egypt <http://www.eternegypt.org/> created and maintained by the Egyptian Center for Documentation of Cultural and Natural Heritage and IBM)



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al-Bahri (near Luxor), dated around 1450 BCE, and of Pharaoh Seti I of the 19th Dynasty (1290–1279 BCE) in the Valley of the Kings. These display individual stars and the signs that were associated with them, which are markedly different from the Mesopotamian signs that are used today (Wells, 1999). A cosmographical map was carved in the lid of the stone sarcophagus of Uresh-nefer of the 30th Dynasty (380–343 BCE, found in Sakkara, now in the Metropolitan Museum of Art in New York). This complicated image shows the goddess Nut, representing the sky, bending herself over an image of the world, depicted as two concentric disks. The god Shu, representing light and air, is also shown, directing the sun in its course (Hernandez, 1992–1994).

There are several plans of buildings and gardens preserved from this period. Some seem to depict actual structures, such as the plan of a house in the tomb of Djehuty-nefer and the plan of a garden in the tomb of Sennefer (both in Luxor and dating to the 18th Dynasty,

1539–1992 BCE); others appear to have served as architectural plans. Examples of the latter include part of a plan of a tomb, possibly of Ramesses IV, on a length of papyrus (1156–1150 BCE, found in Luxor, now in the Museo Egizio in Turin), and another plan of a tomb, possibly of Ramesses IX, on a flake of limestone (1126–1108 BCE, found in Luxor, now in the Egyptian Museum in Cairo). These plans are not drawn to scale, but have the measurements that were evidently deemed important, written out. Another remarkable feature is that the elevations, rather than ground plans, are shown of the passages between the rooms. The fact that such features occur on both plans indicates that these were most likely drawn to certain conventions, much like modern architectural plans.

The first unequivocal maps also date back to the New Kingdom. One depicts the events during the battle between the most famous Pharaoh of the 19th Dynasty Ramesses II (1279–1213 BCE) and the Hittite king



Maps and Mapmaking in Ancient Egypt, Fig. 3 The eastern part of a topographical and geological map of Wadi Hammamat, in the desert between the Nile and the

Red Sea, drawn on papyrus around 1150 BCE (kept in the Museo Egizio in Turin, photograph used with the kind permission of J. A. Harrell)

Muwatallis at Qadesh (near modern Homs in Syria) in May 1274 BCE (Baines & Malek, 2000, pp. 202–203). Examples of this map can be found, among other places, on the first pylon of Luxor Temple and on the northern wall of the great pillared hall of the Great Temple in Abu Simbel. Shown are the Orontes, the city of Qadesh and the placement of the troops.

A second map from this period, drawn on a length of papyrus found in Deir al-Medina (near Luxor), is most reminiscent of a modern map (Harrell, 2001; Shore, 1987). It shows the gold mines, stone quarries, and settlements in the Waadi Hammamat area, about halfway between Luxor and Quseir (on the Red Sea coast), and can be considered the oldest known geological map (Harrell & Brown, 1992). The map, now kept by the Museo Egizio in Turin, was probably prepared by Amennakhte, son of Ipu, for Pharaoh Ramesses IV (1156–1150 BCE) of the 20th Dynasty (Fig. 3).

Another ancient map with a modern appearance is from the Zenon Archive, dating to the Greco-Roman period (332 BCE–395 CE). This map was found on a length of papyrus recovered from the cartonnage of a mummy unearthed at the necropolis of Ghoran and is now kept in the Institut de Papyrologie de la Sorbonne in Paris (Harrell, 2001; Shore, 1987). It shows a schematic plan of the dikes and canals on a plot of land in the Fayum, an oasis southwest

of Cairo, belonging to Apollonius, head of civil administration under Ptolemy II Philadelphus (285–246 BCE). Astronomical ceilings from this period have been preserved in, for instance, the temples of Edfu and Esna as well as in the Hathor Temple in Denderah (now in the Musée du Louvre in Paris). These show both Egyptian stars, similar to those in the tombs of Senmut and Seti I, and the Hellenistic version of the Mesopotamian zodiac, a fusion that had started during the 27th Dynasty (525–404 BCE), the “Persian period.” The belief that the position of the stars can influence human destiny was probably introduced at an even later date.

Alexandria was the capital of Egypt during the Greco-Roman period and by far the most powerful and influential city in the region. Thanks to the patronage of the Ptolemaic rulers and the renowned library of Alexandria (with about 500,000 “books”), scholarly and scientific knowledge advanced greatly. This was partly fueled by a renewed onomastic tradition, compiling existing knowledge in long lists. One of the librarians of Alexandria was Eratosthenes, born in Cyrene (Libya) and invited to Egypt by Ptolemy III Euergetes (246–221 BCE) as a tutor for his son. He is said to have collected a comprehensive geography of the then known world, which was since lost but is cited extensively by the Greek geographer Strabo (63 BCE–24 CE). Eratosthenes was also the first

to calculate the circumference of the earth, by comparing the difference in the height of the sun in Alexandria and in Aswan, and came surprisingly close to the actual figure (Berthon & Robinson, 1991). A compilation of geographical and astronomical knowledge that did survive is that of Claudius Ptolemy, an Egyptian who lived and worked in Alexandria around 150–200 CE (Dilke, 1987, pp. 177–200). His works form the basis of many early Arabic and European maps, especially after some of his works were rediscovered at the end of the thirteenth century CE in Istanbul (Constantinople) by the monk Maximus Planudes (Berthon & Robinson, 1991).

The first maps of Egypt by outsiders were drawn in the early Christian period and have been preserved in, for instance, the fifth-century CE “Nile mosaic,” in Zippori (Sepphoris) in Israel, and the “Mosaic Map” in Madaba (Jordan). The early Christian view of the world, which was developed by Cosmas Indicopleustes (“India traveler”), also has its roots in Egypt. Born in Alexandria in the sixth century CE, Cosmas was a merchant who, according to his moniker, traveled extensively. Later in life he converted to Christianity and settled in Saint Catherine’s Monastery in the Sinai. There he wrote *Christian Topography*, in which he describes the world as a chest, owned by God, of which the lid is the sky and the bottom holds the lands and the seas. The sun orbits a large mountain rising from the bottom of the chest and casting a shadow that is responsible for the night (Dilke, 1987, pp. 261–263; Berthon & Robinson, 1991). This seems a rather unsatisfactory conclusion of a development that started over 3,000 years earlier and had already resulted in the brilliant works of Amennakhte and Eratosthenes. Almost 1,200 years later, between 1789 and 1801, around 160 artists, scholars, and scientists accompanied Napoleon during his short-lived occupation of Egypt. They meticulously recorded many modern, ancient, and natural features of the country and later published their findings in the many volumes of *Description de l’Égypte* (Description of Egypt), which appeared between 1809 and 1826. Along with similar works of a smaller scale, it was this monumental effort

that helped spark a wave of Egyptomania in Europe which marked the beginning of Egyptology as an academic field of study.

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Maps and Mapmaking in Asia (Prehistoric)

Catherine Delano-Smith

There is plenty in Asian prehistoric art to interest the historian of cartography. It is sometimes difficult to draw a line between a picture of a place

and a map of a place and it is, of course, impossible to know the original meaning of any graphic representation made in the period before writing. Nevertheless, there is a great deal of evidence that prehistoric people had both the mental capacity and the communicative and graphic skills to make maps. Such depictions were made on a variety of surfaces and in various ways but most commonly as paintings or engravings (petroglyphs) on boulders, rocks, cave walls, and cliff faces as well as on artifacts (bone, pottery, bronzes, etc.).

The earliest recognizable representation of spatial relationships involves: in Asia as in Europe, a continuous line – representing a boundary or enclosure – within which an event (animal trapping or herding, people standing or dancing) is taking place. For example, a painting on the wall of a Mesolithic rock shelter in Bhimbetka (Madhya Pradesh, India) shows, in profile, a family group mourning a dead child. The scene is placed in a hut, or some special place, which is represented by the encircling line. Similarly, a rock-carved enclosure from Mongolia (Bayan Khongor Province) provides a close parallel with enclosures in the Paleolithic art of the Franco-Cantabrian region of western Europe that have been identified as “hut or game enclosures.” Yet another Asian parallel comes from Armenia. In this case, the enclosure depicted, possibly as early as the third millennium B.C.E., bears a marked resemblance to an early historic petroglyph from Jordan carved into a large stone with a text on another side referring to the enclosure as an animal pen.

Picture Maps

In all these examples, only one element of the composition, the enclosure, is rendered in plan (i.e., viewed from above); all other figures – persons, huts, and animals – are shown in profile (i.e., as seen from ground level). It is the defined space of the enclosure, however, that provides the cartographic key, the intended spatial relationships of the figures. These spatial representations are very simple as graphic compositions.

Nevertheless, they contain the essence of a map and can be thought of as simple picture maps. In contrast, one of the most detailed prehistoric depictions of a village fails to meet the criteria for even a picture map, for there is nothing in it to suggest the critical *spatial* element. The petroglyphs in question, the Boyar *pisanitsas*, are found high on a cliff near Minusinsk, overlooking the Yenesei River in Siberia. They are thought to date from the last millennium B.C.E. The main assemblage is nearly 10 m long but nowhere in it is any feature or figure shown in plan. Nor is it easy to be certain, especially in the absence of an enclosure or frame, that the array of huts and scatter of human figures were created as an assemblage and are not merely a palimpsest of engravings made on quite different occasions, perhaps separated by long intervals of time.

However, another highly detailed rock painting, one of many on the cliffs at Cangyuan (Yunnan Province, China) dating from the last millennium B.C.E., can be thought of as a picture map. Not only are the huts neatly and obviously deliberately positioned along the perimeter of a circular enclosure, but also their arrangement is topologically consistent: the huts on the far side of the enclosure from the viewer have been drawn upside down in order to maintain the relationship between the piles supporting each hut and the line that represents the village boundary or fence. Other lines project from the central enclosure like paths and indeed there are figures, human and animal, shown in profile, walking along them.

Plan Maps

The identification of objects and landscape portrayed from above is always difficult and the more so in rock art where all external evidence is lacking and diagnosis has to rest on intrinsic visual characteristics. However, the visual similarity between certain landscape features, when viewed from high above (i.e., in plan) and some of the rock art found in Asia, suggests that such examples were intended to be mimetic. Thus, included in the assorted petroglyphs of Mugur

Surgol (upper Yenesei) are representations of the local herders' huts (yurts) and their surrounding stockyards. Four different sets of rock markings – “map signs” – are involved: solid outlines (squares or rectangles), rectangular outlines with internal subdivisions or compartments, rectangular outlines filled with stippling, and empty outlines, also rectangular or subrectangular. Each of the petroglyphs in question usually comprises one solid or compartmentalized shape and one or more stippled, or empty, rectangular or subrectangular shapes. These assemblages have been interpreted by archaeologists as plans of the Mongolian-type yurts found among the local Tuva, together with the yards and enclosures around them. Similar “hut and yard” markings are found in the Altai Mountains. All these are strikingly like those dating from the end of the Neolithic and, especially, the middle Bronze Age (third and second millennia B.C.E.) found in the western Alps, as for example in Mont Bègo, France. Another category of plan map is more typical of Mongolian rock paintings. In these, assemblages comprising relatively large rectangles, usually stippled within, associated with human or human-like figures and the outline of a bird (eagle) with wings outstretched, have been interpreted as representations, rich in religious symbolism, of local graves, again as seen from above. This style of burial is known to be ancient and both graves and grave plans may date from the late Bronze Age.

Celestial Maps

Given the long history of astronomy in many parts of Asia, prehistoric representations of at least the major constellations might be expected. Certainly by the end of the last millennium B.C.E., the period of the Han Dynasty in China, the use of “ball and chain” patterns to represent groups of stars was evidently an already established tradition. Fully fledged prehistorical celestial maps, however, have yet to be discovered, in the literature or in the field. There are indications of what is to come. In 1990, the discovery of a very early historical map painted on

the vault of a tomb was reported (*The Times*, 1 February 1990). It shows the heavens divided into 28 lunar mansions, seven for each of the cardinal points, which are personified as a Daoist deity. The map, executed in pastel polychrome, matches the description given by the Han historian Sima Qian (ca. 145–87 B.C.E.). Elsewhere in Asia, representations of constellations, as well as “ingenious calendars” and the solar and lunar motifs associated with cosmological myths, are said to be common in the rock art of Armenia. This rock art dates largely from the third millennium B.C.E., the date also of an astronomical observatory that was excavated at Metsamor (Armenia). Similar motifs may also be found in the pottery decoration of the period.

Cosmological Maps

It would be surprising if cosmological maps were not proven to be by far the most important category of Asian mapping in prehistoric times, just as they have been throughout the historic period (prior to European involvement). A preoccupation with the origin and structure of the universe, and above all with the afterlife and its location, is a fundamental attribute of human life – a manifestation of humanity's “cosmic anguish.” Most, if not all, prehistoric rock art would have been associated with religion, and much of it must have reflected various aspects of local belief. Those responsible for the paintings and peckings, often made in virtually inaccessible places, would have been shamans or members of a priestly élite. One notable characteristic of prehistoric rock art, in Asia as in Europe, is its concentration into what are best seen as former ritualistic or holy places, on or at the base of a particular mountain peak, in or within a close radius of a high mountain pass, for instance, or associated with burial places. Thus the “hut and yard” maps should be seen as a record of a fossilized prayer, perhaps for the safety or prosperity of the homestead and its inhabitants, and represented as an icon rather than as an exact configuration of a nearby homestead, yet to be uncovered by archaeologists. As the Chinese

tomb painting already described demonstrates, celestial cartography and cosmological cartography often overlap in their religious significance. Individual cosmological motifs are widespread in Asian rock art, such as those relating to the structure of the cosmos (the Tree of Life or axis mundi) or to access to the next world (boats, ladders). They are also found in certain types of decoration, such as the bronze drums from Borneo and other parts of Indonesia. However, examples of cosmological maps from the prehistoric period, as opposed to these individual motifs, are few. One Mesolithic rock painting from Madhya Pradesh, India, is thought to represent, with its three bands, the three parts of the cosmos (water, air, and earth).

At present, information about rock art in general in Asia is both chronologically and geographically patchy. Some localities – for example in central and southern India, the peripheral provinces of China and Mongolia, the upper reaches of the great rivers of Siberia (Ob, Yenesei, Lena, Amur), around the high passes of the Pamirs, and the mountains of Armenia in the vicinity of Uchtasar – are comparatively well known, but such regions are separated by vast areas of ignorance, either through lack of exploration or through lack of reporting, especially in literature accessible to western scholars. Undoubtedly, though, future research and the wider reporting of new discoveries will yield a wealth of prehistoric maps and map-like representations throughout most of Asia, characterized by strong regional traditions, most of which will have a close counterpart elsewhere in the world.

See Also

- [Lunar Mansions in Islam](#)
- [Maps and Mapmaking: Celestial East Asian Maps](#)

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Maps and Mapmaking in China

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The Chinese have one of the world's longest histories of mapmaking – more than 2,000 years. An adequate account of this history, however, has yet to be written. For some time spans, the first to the tenth centuries, for example, losses from warfare and neglect have probably been great. Almost no examples of maps remain, so that one must make inferences on the basis of textual sources and other evidence. For other periods, especially from about the seventeenth century onward, so many maps, as well as supplementary textual sources, survive that no one has adequately surveyed them.

Despite these difficulties, it is still possible to make some broad generalizations. Before the twentieth century, mapmaking in China was an activity of the educated elite, those who formed the pool from which posts in the government bureaucracy were filled. In the course of their duties, these scholar-officials developed mathematical techniques and instruments needed to produce measured maps of high accuracy. Such maps have features familiar to users of modern maps – scalar indications, directional markers, conventional signs to represent topographic features, and a lack of perspective. Their look is planimetric, all features being represented as if lying on the same plane and as if viewed from above. Maps like these form only a portion of the

body of surviving works, and partly for this reason, it would be misleading to characterize Chinese mapmaking before the twentieth century as what we in the West now call science. As will be discussed later, although it could involve measurement, it was a broader activity than the word “science” usually connotes.

The foundations for quantitative mapping were established early in China’s cartographic history. The magnetic properties of lodestones, or south-pointers, were known from about the third century BCE. There is textual evidence that during the second century BCE, the idea of map scale was understood. Around this time, Chinese surveyors and mapmakers already had considerable technical resources available to them for producing maps drawn to scale: graduated rods, carpenter’s squares, plumb lines, and compasses for drawing circles and even sighting tubes that could be used for measuring inclination. In addition, a reference frame suggestive of a coordinate system for identifying locations had been hinted at by astronomers who divided the heavens into sectors or lunar lodges (*xiu*).

A few hundred years after these beginnings, Pei Xiu (223–271), a mapmaker known for large-area maps drawn to scale, formulated a set of principles necessary to produce accurate maps. These principles stressed the importance of consistent scale, directional measurements, and adjustments in land measurements to correct for irregularities in the terrain being mapped. The principles had some influence on later mapmakers. Jia Dan (730–805) drew a large-area scale map following Pei Xiu’s principles, as did Shen Kuo (or Gua 1031–1095). But none of the works by these mapmakers survives, so that it is impossible to judge how well they followed Pei’s principles. Moreover, none of Pei’s own works survives, so it is not known how well Pei followed his own ideas.

Some researchers have claimed that maps dating from the fourth to the second century BCE are evidence that mensurational techniques were being applied to mapmaking (Cao, Zheng, Huang, Niu, et al., 1990–1997, Vol. 1, plates 1–2). One of these, discovered in Hebei Province, is a bronze architectural plan of a mausoleum.

Perhaps better-known examples are two silk maps discovered at Mawangdui, near Changsha, Hunan (Cao et al., 1990–1997, Vol. 1, plates 20–21, 25–26). Other early maps are a set of maps drawn on wood discovered at Fangmatan in Gansu (Cao et al., 1990–1997, Vol. 1, plates 4–17). There is some disagreement over what areas the maps found at Mawangdui and Fangmatan represent and how they should be reconstructed. Such questions need to be resolved before it can be determined whether the maps were drawn to scale. Pei Xiu, in articulating his principles of mapmaking, had complained about the lack of accuracy in maps before his time. It is not yet clear whether his assessment of his predecessors was justified.

The unclarity regarding the technical abilities of Chinese mapmakers was resolved about nine centuries after Pei Xiu. A map produced in the twelfth century suggests that mapmakers were capable of following Pei’s principles quite rigorously: this is the much celebrated *Yu ji tu* (*Map of the Tracks of Yu* [the Great, legendary emperor]) (Fig. 1).

It was carved in stone in 1136 and measures 80 × 79 cm. It represents all of China and is impressive for the accuracy of its depiction of China’s coastline. It also represents the courses of the Yellow and Yangtze Rivers, but the information it reflects was outdated at the time the map was inscribed. The map is also notable for the square grid imposed on its surface. According to a note on the map, each grid increment represents 100 Chinese miles. The grid is thus a scaling device, not a coordinate system like latitude and longitude. After the *Yu ji tu*, the best-known examples of grid maps are printed in the *Guang yutu* (*Enlarged Terrestrial Atlas*, ca. 1555) by Luo Hongxian (1504–1564) (Fig. 2).

This atlas is a revision of a map no longer extant, the *Yutu* (Terrestrial map, 1320) by Zhu Siben (1273–1337). It contains a general map of China and individual maps of provinces, border areas, coastal areas, waterways, and foreign lands. All the maps have grids. According to Luo, the grid, in addition to serving as a scaling device, served as an aid in aligning sections of maps drawn or printed on different sheets.



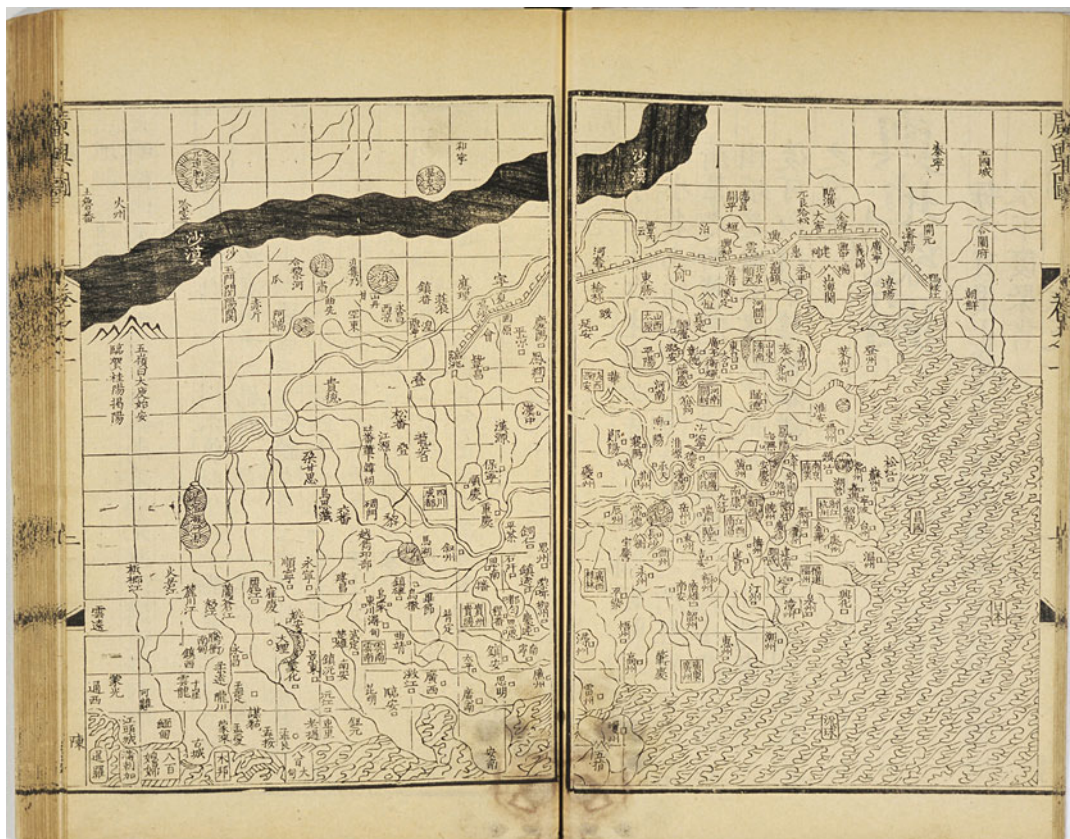
Maps and Mapmaking in China, Fig. 1 Rubbing of the *Yu ji tu* (*Map of the Tracks of Yu*, 1136), the earliest known Chinese map with a scaling grid. The map is engraved on stone. Its title looks back to the age of the legendary emperor Yu, whose realm reputedly consisted of nine provinces. The names of those provinces appear with later toponyms. The map was inscribed during a time

when the empire had lost territory. It thus connects a time of disunity with an age of unity. It may also look forward to a time of restored unity since no political boundaries are indicated. Ink rubbing on paper, 84 × 82 cm (Courtesy of the Library of Congress (G7821.C3 1136.Y81))

The origins of the Chinese cartographic grid are unknown. Its use is certainly consistent with Pei Xiu's call for scale and attention to directions, and it has some similarities with the lunar lodges long used in Chinese astronomy. The polymath Zhang Heng (78–139), credited with an armillary sphere, a seismograph, and a topographic map,

has been suspected of using a grid. But there is no direct evidence that any mapmaker before the *Yu ji tu* employed the device.

On other Chinese maps made at roughly the same time as the *Yu ji tu*, the grid is conspicuous by its absence, perhaps an indication that their makers were not particularly concerned with



Maps and Mapmaking in China, Fig. 2 The general map of the empire from Luo Hongxian's *Guang yutu* (*Enlarged Terrestrial Atlas*, ca. 1555). According to the explanatory notes, each side of a square on the map represents 100 Chinese miles (on an earlier edition the grid

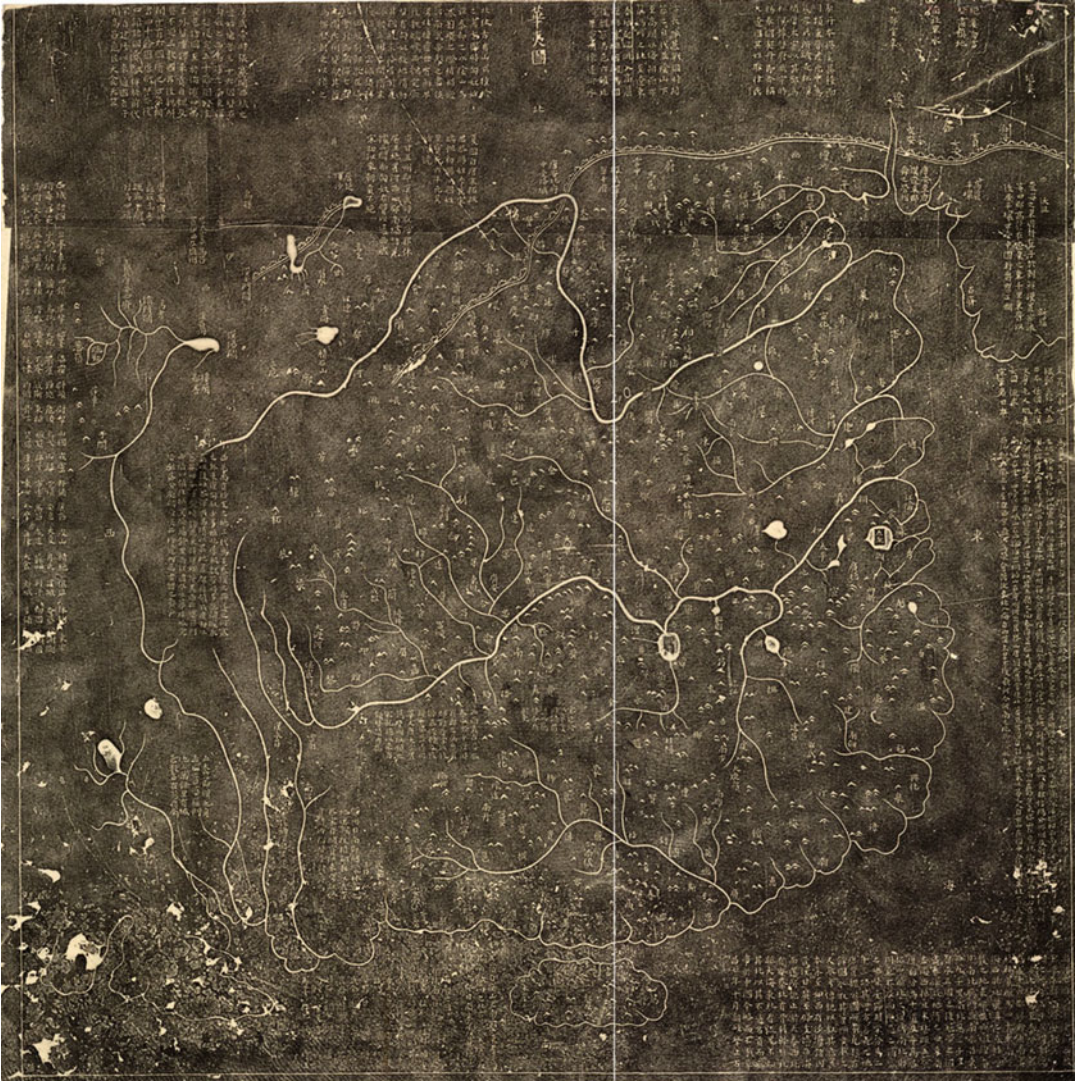
increments represent 500 Chinese miles). Some of the maps in the atlas have legends explaining the signs appearing on the images. Luo's work is the earliest known use of legends on Chinese maps. Woodblock print, 33 × 40 cm. 1564 edition. Toyo Bunko

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measurement and scale. A number of these maps are, like the *Yu ji tu*, engraved in stone but are not considered as accurate as the *Yu ji tu*: for example, the *Hua yi tu* (*Map of Chinese and Foreign Lands*, 1136) (Fig. 3), engraved on the other side of the stone on which the *Yu ji tu* appears, and the *Jiu yu shouling tu* (*Map of the Prefectures and Counties of the Nine Districts [the empire]*, 1121) (Cao et al., 1990–1997, Vol. 1, plates 63–65). As their titles suggest, these maps, like the *Yu ji tu*, represent all of China. An example of a stone map depicting a smaller area is the *Pingjiang tu* (*Map of Pingjiang Prefecture*, 1229) (Cao et al., 1990–1997, Vol. 1, plates 79–81). It too lacks a grid, and its scale has been found to vary from about 1:1,300 to

1:2,800 in the central portion and from about 1:10,000 to 1:77,000 at the periphery.

The evidence thus suggests that by the twelfth century, Chinese mapmakers had the resources to produce measured maps of high quality but in many cases did not make full use of those resources. This is not necessarily a defect. In general, Chinese mapmakers seem to have regarded their task as encompassing more than representation according to a consistent scale. The Chinese word *tu*, commonly translated as map, also means picture, diagram, or chart. As the range of meaning suggests, the forms of Chinese mapmaking extend beyond what are easily recognizable as forerunners of modern measured maps.



Maps and Mapmaking in China, Fig. 3 Rubbing of the *Hua yi tu* (*Map of Chinese and Foreign Lands*, 1136), carved on the other side of the stone on which the *Yu ji tu* appears (Fig. 1), but with the opposite orientation: when one map is right side up, the other is upside down. The two maps cannot be displayed properly at the same time, so that it seems the engravings were meant to be used for producing rubbings. Unlike its companion, the *Hua yi tu*

lacks a scaling grid. Its image mostly represents the Chinese empire; notes along the edge of the map provide information about foreign lands. The map is an example of the complementarity between image and text that characterizes many traditional Chinese maps. Ink rubbing on paper, 80 × 82 cm (Courtesy of the Library of Congress (G7820 1136.H8))

Maps served a variety of functions for which a consistent scale might be necessary or desirable: navigation, water conservancy, public works, defense and military planning, government administration, and record keeping for land tax accounting. But they also served purposes for which attention to scale might not be so

important: they might be used to symbolize political power, to represent unseen other worlds, or to illustrate configurations of energy (or *qi*), knowledge of which was useful in “sitting” (*dili* = land patterns or geomancy or, more popularly, *feng shui* = wind and water or geomancy) (Fig. 4).

Maps and Mapmaking in China, Fig. 4

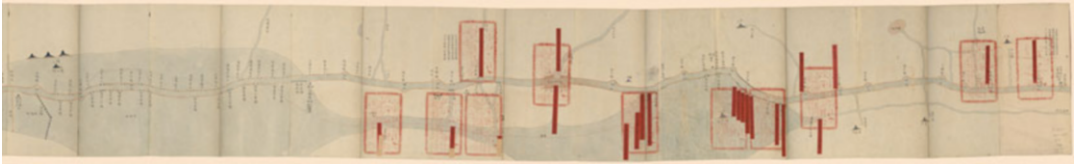
Pictorial map of Hainan Island, made some time between 1820 and 1875. Notes on the map describe marriage and other ceremonies of the Li people. The mapmaker has distorted the shape of the island so that it resembles a rectangle, an auspicious form. North is at the *bottom*. Ink and color manuscript, 184 × 93 cm (Courtesy of the Library of Congress (G7822.H3E62 18-.H3 Vault))



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The media used for mapmaking also show considerable diversity. Already mentioned have been flat maps engraved on bronze and stone; drawn on silk, wood, and paper; and printed

with woodblocks on paper. Maps were also painted on walls of caves and tombs. Three-dimensional relief models were also made. One of the largest of these, described in the *Shi ji*



Maps and Mapmaking in China, Fig. 5 Map of embankment repairs and distances along the Grand Canal in Shandong province (1877). This map, oriented with south to the right and intended to be read from *right* to *left*, shows the course of the Grand Canal from the border between Shandong and Jiangnan to the border between Shandong and Zhili. Red labels pasted on the map image

provide information on distances and note repairs completed. Like other traditional Chinese maps, this one is drawn with variable perspective: waterways are drawn in plan, while mountains are shown in elevation. 23 × 621 cm. Manuscript in color and ink (Courtesy of the Library of Congress (G7822.G7N22 1877.Y8))

(*Records of the Grand Historian*, ca. 91 BCE, by Sima Qian), is contained in the tomb of Qin Shi Huang (d. 210 BCE), founding emperor of the Qin dynasty (221–207 BCE). It supposedly consists of representations of the heavens above and the empire below, with mercury-filled streams representing rivers and the sea.

Mapmaking in pre-twentieth-century China did not develop into a distinct specialty of learning as it did in Europe. As the variety of map functions suggests, mapmaking was located at the intersection of a number of activities and traditions of learning. This is consistent with the educational background of the intellectual elite who made maps. Their education generally emphasized broad learning, frequently encompassed humanistic and scientific disciplines, and often centered around texts. Not surprisingly, the activity of mapmaking often involved textual study. This was the case with Pei Xiu, Jia Dan, Shen Kuo, and Luo Hongxian, those who are credited with advancing quantitative mapmaking techniques.

Among the major sources of geographic information a mapmaker might consult were the dynastic histories, which conventionally included geographic records, and local gazetteers, compendia of historical and geographic information focusing on China or one of its various subdivisions. Gazetteers often included maps, usually at the head of the geographic section. These maps often lack scalar indications and are frequently pictorial. In such instances, they do not seem to have been intended to be used or studied in isolation but were meant to be complemented by the

accompanying text. The map images give an idea of the spatial relationships between geographic features, while the texts provide detailed information on distances and directions. This relationship between image and text does not seem to have been restricted to maps in gazetteers. Jia Dan and Shen Kuo, for example, say that their maps were accompanied by extensive notes, and Luo Hongxian's *Guangyu tu* consists mostly of text. Even the *Yu ji tu* bears evidence of the influence of textual authority. It identifies the origin of the Yellow River as Jishi. In this identification, it follows the "Yu gong" (*Tribute of Yu* [the Great]), a chapter of the *Shang shu* (*Book of Documents*), dating from perhaps the fourth century BC, giving preference to an ancient text over later accounts that give the Kunlun Mountains as the source. The division of labor between image and text is vividly illustrated on a number of nineteenth-century maps. The images and textual portions are made separately and then joined – when labels bearing quantitative information are pasted on top of the map images (Fig. 5).

The relationship between map and text seems to reflect the close ties among painting, calligraphy, and poetry. From about the tenth century on, many Chinese artists, themselves often members of the bureaucratic elite, conceived the highest work of visual art as a combination of all three arts, each contributing in different ways to the aesthetic effect of the entire artifact. *Tu* (maps or pictures) of geographic subjects often had poems inscribed on them, suggesting that maps were valued like other forms of visual representation for their emotional and expressive effects (Figs. 6 and 7).

Maps and Mapmaking in China, Fig. 6

Poetry on scroll bearing map, stamped in red ink (at lower left). The couplet, by the poet Du Fu (712–770), reads: “Most certainly this is Jiangnan’s lovely landscape;/In the season when the leaves fall I meet with you again.” The couplet was stamped in response to a long map, a detail of which appears in Fig. 8. Detail of *Minsheng yanchang quantu* (*Complete map of the salt fields in Fujian*, 1746) (Courtesy of the Library of Congress (G7823.F8H5 1746.M4 Vault Shelf))



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Maps and Mapmaking in China, Fig. 7 *Minsheng yanchang quantu* (*Complete map of the salt fields in Fujian*, 1746; detail). The look of this map belies its use

in law enforcement – as an aid to prevent salt smuggling. Ink and color in silk, 33 × 571 cm (Courtesy of the Library of Congress (G7823.F8H5 1746.M4 Vault Shelf))

In addition to employing quantitative techniques and devising means to present the information gleaned from those techniques, Chinese mapmakers drew upon the resources of the visual arts to express their responses to the land. Mapmaking and landscape painting involved the use of brush, ink, and paper or silk. The landforms represented on maps were often the same as those depicted on landscapes. Pictorial maps and landscape paintings were marked by a fluid treatment of space. Rather than presenting a planimetric

view of the terrain from which the map reader is abstracted, Chinese pictorial maps often place readers in the image. Instead of viewing the map image as if from a distant vantage point, readers must place themselves within the landscape depicted and imagine themselves moving, turning, and viewing particular portions of the map image (see Figs. 8 and 9).

The “language” of Chinese maps thus seems to have been more than one of denotation, of correspondence to material realities. This seems



Maps and Mapmaking in China, Fig. 8 Road map from Shaanxi to Sichuan (after 1750; detail). Unlike many road maps, this one does not place the reader above the road, but close to the ground. The map presents landforms that one would see along the route. At the right

edge, one needs to change one's perspective, imagining oneself turning as if to view the county seat from the *left* from above. The map is oriented with north to the *right*. Colored map on scroll. 31 × 1,672 cm (Courtesy of the Library of Congress (G7823.S3P2 1750.S4))

Maps and Mapmaking in China, Fig. 9 *Yanshi xian he tu* (Map of the Rivers in Yanshi County, ca. 1754–1767). This map presents topographic features from varying perspectives: waterways and the county seat are presented from overhead, in plane, while the mountains are presented in elevation. In addition, one must imagine oneself turned around in order to view the mountains at the bottom of the map properly. Manuscript on silk. 90 × 90 cm (Courtesy of the Library of Congress (G7823.Y4C3 1767.Y4))



to be true even with maps of utilitarian function. Scholars have long noted, for example, that some of the representations on the nautical chart in the *Wubei zhi* (Treatise on Military Preparations, ca. 1621, comp. Mao Yuanyi) resemble elements often seen in Chinese landscape paintings (Cao et al., 1990–1997, Vol. 2, plates 168–171).

One result of the interactions between map-making and other areas of learning seems to be

that grid maps in particular and measured maps in general constitute a small proportion of the surviving corpus of Chinese maps made before the twentieth century. The disparity in the numbers of measured maps and more pictorial maps seems especially pronounced during the seventeenth through the nineteenth centuries, long after the development of woodblock printing, which made possible the relatively quick production of

multiple copies of maps. If measured maps were so important, it seems odd that more examples were not reproduced through printing. This anomaly has fostered the conclusion that after the sixteenth century, Chinese mapmaking declined as mapmakers seemed to pay less attention to quantitative techniques and accuracy.

It is just as reasonable to view Chinese cartographic history after the *Yu ji tu* not simply as a decline in mapmaking but as an implicit, if not conscious, rejection of the measured map as exemplifying mapmaking at its best. A mathematical map is reductive in at least two ways: a quantitative approach regularizes the earth's surface and is less challenging and demanding than a qualitative approach. A mathematical map can be drawn by almost anyone; pictorial maps with their greater detail require more advanced drawing skills. The compilation of a map like the *Yu ji tu* is an impressive achievement. But once it is drawn, it is simple to draw it again, and once engraved on stone, copies are even easier to make. Pictorial maps are visually more complicated.

Chinese mapmakers seem to have noticed the same differences and preferred maps that allowed them to demonstrate artistic skill. An index of this preference is the large number of manuscript maps intended as final products even after the development of printing. In Western Europe, manuscript maps intended as final products are rare after the advent of printing. Mathematical techniques and printing technology made possible the production of large numbers of exact copies of originals. Yet in China, scholar-officials often copied maps by hand, introducing variations, or drew their own maps. The production of manuscript maps was an opportunity to display skill with the brush both in painting and in the art of writing – possibly one reason for the close ties between mapmaking and landscape painting.

Thus, it is no surprise that in China, there were little innovation in measured mapping and little interest in developing quantitative technique further after the twelfth century. Improvements in the mariner's compass and measurements of celestial latitude, for example, do not seem to

have influenced Chinese mapmakers as such developments affected European mapmaking. In addition, Chinese mapmakers did not develop map transformations, or projections, for transferring points from a spherical to a plane surface. Mapmakers seem to have believed the earth's surface was generally flat, so that in their minds, drawing maps on plane surfaces would not result in appreciable distortion.

In 1267, a Persian astronomer presented the imperial court with a “geographic record” that represented the earth as round, but the representation seems to have had no effect on Chinese mapmaking. The Chinese did not begin to adopt techniques of spherical projection until the late sixteenth century, when Jesuit missionaries, notably Matteo Ricci (1552–1610), introduced Ptolemaic cartography with its coordinate system into China. Some Chinese copied Ricci's maps, and in the eighteenth century, Jesuits were commissioned by Chinese emperors to survey and map the entire empire. In carrying out this work, the Jesuits employed Chinese assistants. But even so, Chinese adoption of European techniques was slow since the Jesuits were limited in their access to China and many Chinese intellectuals resisted a view of the earth as round. The bulk of the maps produced in China continued to be made in the traditional manner up to the late nineteenth century. There was little uniformity in mapmaking even within the government. Maps might be planimetric; they might be pictorial; they might be drawn to scale; they might not be; they might have grids (Fig. 10); they might lack them; even if they had grids, they might not be drawn to scale (Fig. 11); and late in the nineteenth century, they might have square grids as well as lines of latitude and longitude. They also varied in physical format and could be made on sheets, scrolls, fan-folded strips, and bound volumes (see section “[Note: Tradition and the Modern in Qing Map Culture](#)”).

Events in the nineteenth century, however, prompted change in this situation. As China weakened as a result of domestic problems and encroachments by European powers, many Chinese intellectuals began to believe that China needed reform. Some pointed out that European

Maps and Mapmaking in China,

Fig. 10 *Huangchao zhi sheng fu ting zhou xian quantu* (Complete map of provinces, prefectures, subprefectures, departments, and counties under the Qing, 1864). This map has a grid in which each grid increment equals 200 Chinese miles. A legend explaining the various signs on the map appears on the right. Woodblock print, hand colored to show provincial boundaries, 57 × 58 cm (Courtesy of the Library of Congress (G7820 1864.H8 Vault))



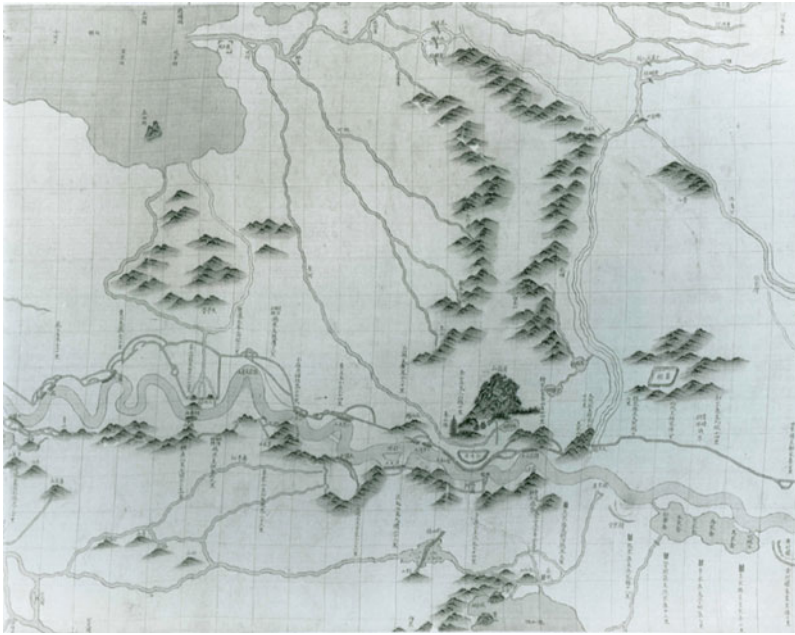
maps were superior to those of the Chinese. In response, the government tried to standardize mapmaking practices, stipulating that standard projections and scales be used. Progress in instituting these changes was difficult since there was a shortage of equipment and of personnel capable of employing the necessary techniques. Not until after the collapse of the empire in the twentieth century did the European conception of cartography as primarily quantitative fully supplant the traditional Chinese idea of a map as an intersection of various lines of learning, including the literary and visual arts.

In the first half of the twentieth century, the quality of measured maps improved as more Chinese were trained in the earth sciences. In the 1930s, China began to develop the capability to carry out aerial surveys. During the Second World War, however, accurate measured maps were still not in good supply – a situation that hampered the Chinese military. To remedy that situation, the Chinese government took steps to promote cartography. In 1956, it established a State Bureau of Surveying and Mapping, which

undertook to produce a series of topographic maps for the whole country. Since then, more institutions have been established to make maps, and others, such as the Wuhan Technical University of Surveying and Mapping, have been set up to teach cartography. As part of China's effort to modernize, Chinese cartography has employed the latest technological advances: remote sensing, satellite photography, and geographic information systems.

Note: Tradition and the Modern in Qing Map Culture

The surveys and atlases produced with Jesuit assistance and described above have been taken as evidence that China entered the early modern world as early as the eighteenth century. According to Needham (1959, vol. 3 [1959]), the Jesuit surveys enabled China, whose mapmaking had fallen behind Western cartography, to move “ahead of all other countries in the world in map-making” (p. 586).



Maps and Mapmaking in China, Fig. 11 *Huanghe tu* (*Map of the Yellow river*, nineteenth century, before 1854; detail). This map is oriented with south at the top and shows flood control works along the lower course of the Yellow River before 1854. Distances between places are given in notes on the map, and from these it does not seem that the mapmaker attempted to maintain a consistent

scale. The *grid* appears to have been drawn after the image was completed, perhaps as an aid to copying. A manuscript map could not be reproduced by woodblock printing without destroying it, so hand-copying skills were important for mapmakers. Ink and color on silk, 38 × 183 cm (Courtesy of the Library of Congress (G7822. Y4A5 18 – H9 Vault Shelf))

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Describing the maps produced by the Jesuits in China as early modern is certainly fair. Such a description emphasizes their departure from traditional Chinese practices. Most maps made under the Qing, however, were not early modern. Maps drawn to scale were part of the Chinese mapmaking tradition, but according to the available evidence, pictorial maps were made in far greater numbers. Traditional Chinese mathematical cartography was not the same as modern mathematical cartography in that it did not employ spherical coordinates or map transformations. Thus, the Qing Jesuit maps were not representative of what Chinese mapmakers were doing or were even capable of carrying out; the influence of the Jesuit surveys was limited primarily to the central government.

Even so, there are those who claim that the Qing court's use of modern maps makes the Qing dynasty in China an example of early modern map culture. Such a claim would be justified if

map use provided the measure of a map culture. But map use does not: cartography is also a matter of technical knowledge and its application. The claim for Qing modernity also seems to imply that the use of maps for political control is a modern invention. Such is not the case. Chinese imperial governments had been compiling geographic information and making maps for centuries before the Qing dynasty. The usefulness of quantitative maps was also understood, as discussed above.

The focus on map use by those who advance claims of Qing modernity overlooks the many ways in which the Qing dynasty in China differed from early modern Europe intellectually, socially, and economically. The predominance of the mathematical map in Europe did not come about simply because of its usefulness for political control and inventory. Modern cartography is not simply a matter of mapmaking technique and map use. There is a philosophy of

nature associated with it. That philosophy implies that certain methods, based on mathematical reasoning, should be used to understand nature. That philosophy of nature and the emphasis on mathematical reasoning were largely absent from the Qing scholarly world until late in the nineteenth century. Chinese evidentiary scholarship, for example, does not yield anything resembling Newtonian mechanics. The inadequacy of the mathematical map as a measure of the modern becomes clear when one recalls that mathematical maps of the entire empire were available in China as early as the twelfth century. On that basis, one could locate, as some have on other grounds, early modern China in the Song dynasty. The problem in that case is that after the twelfth century, Chinese mapmakers generally refrained from the mathematical.

Furthermore, a number of political, social, and intellectual developments occurring in early modern Western Europe did not occur in the Qing dynasty in China – for example, those fostering the formation of modern democratic institutions. One could argue that those conditions still have not fully arisen in China. A case in point is the dissemination of information. Modern mathematical maps were widely circulated among the middle class in Europe; it was simply not the case that modern maps were understood and used only by a few in early modern Europe. Such widespread familiarity with modern mathematical maps was slow to come in the Qing dynasty in China, if it ever did come. It does not seem likely that left to themselves, Chinese mapmakers would have developed the map transformations of modern cartography. In fact, they tended to resist them and what they implied about the world's size and shape. Map transformations are predicated on an understanding that the earth is spherical; Chinese mapmakers before the late nineteenth century generally dealt with the earth's surface as if it were flat. Modern cartographic techniques may be available to anyone in principle, but historically, they have not been acceptable to everyone.

In addition, to describe the Jesuit atlases as Chinese or Qing is to portray the Jesuits simply

as court operatives – a disingenuous characterization at best. The Jesuits had their own purposes for carrying out the surveys. Their information was not intended solely for the Qing court. It was sent back to Europe, where it had more influence on mapmakers than in China. There, it changed the cartographic image of China and made it more accurate, and the importance of that geographic information for economic expansion is well known.

What is being said here is not to deny that European maps and Chinese maps have similarities. Otherwise, it would not make sense to speak of European and Chinese “maps.” In both traditions, pictorial and mathematical mapmaking were practiced. But the two traditions differed in the valuation placed on the two modes of mapmaking. In China, pictorial mapmaking became dominant; in Europe, mathematical mapmaking became dominant. In one history, text was more important than image as a bearer of information; in the other, text was less important and was moved to the margins and eventually off the map. Among Chinese mapmakers, there was much less of a tendency toward marginalizing text. Indeed, practices of evidentiary scholarship made the study of texts central.

As far as mapmaking is concerned, the evidence so far does not allow one to identify a specific dynastic period as equivalent to early modern Europe. The attempt to do so seems to take what happened in Western Europe as a norm when it is by no means clear that all societies are tending toward becoming versions of the West. It still makes sense to distinguish modern Western European culture from the pre-twentieth-century Chinese culture.

See Also

- [Armillary Spheres in China](#)
- [Geomancy in China](#)
- [Maps and Mapmaking: Chinese Geomantic Maps](#)
- [Shen Guo](#)
- [Zhang Heng](#)

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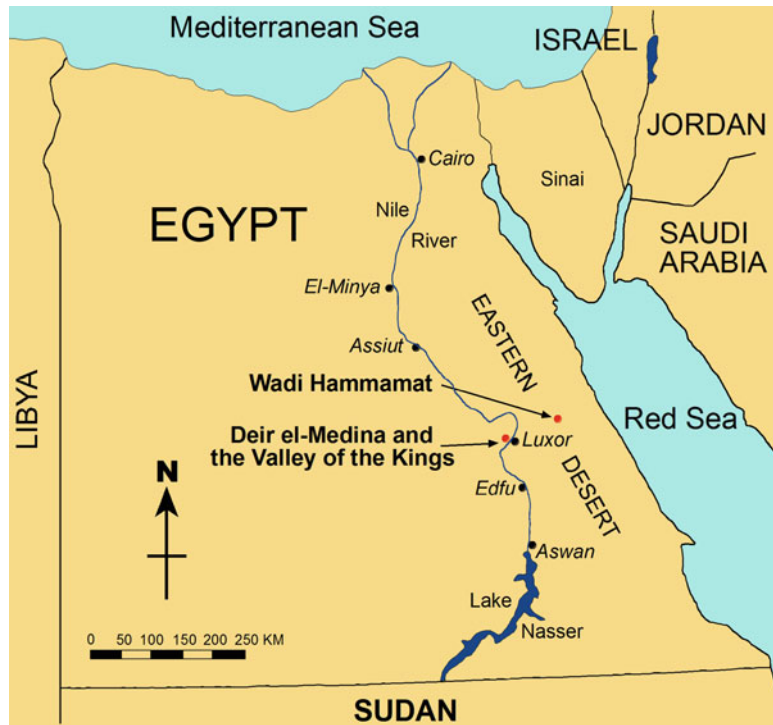
Maps and Mapmaking in Egypt: Turin Papyrus Map

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Discovery and Reconstruction of the Map

An ancient Egyptian map drawn on a scroll of papyrus paper was discovered between 1814 and

Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 1 Map of Egypt showing the locations of Deir el-Medina, the Valley of the Kings, and Wadi Hammamat

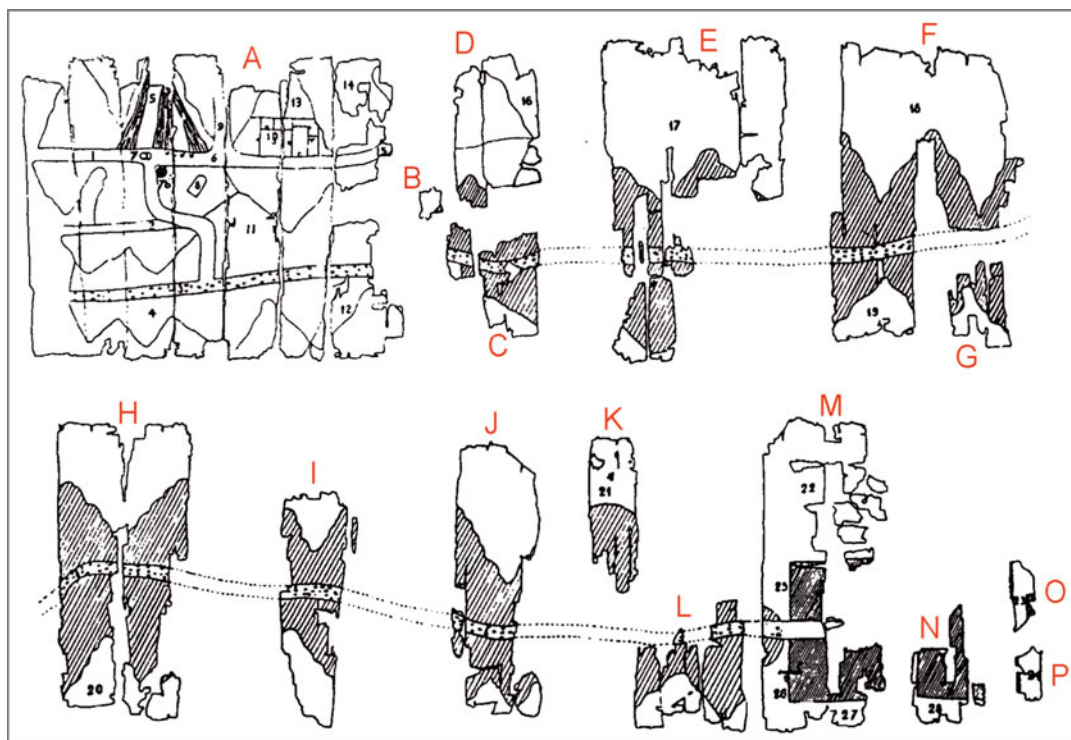


1821 by agents of Bernardino Drovetti, the French Consul General in Egypt. The map came from a private tomb in the ancient village of Deir el-Medina, near the modern-day city of Luxor (ancient Thebes) in Egypt (Fig. 1). This village housed the workers responsible for excavating and decorating the royal tombs of the Egyptian New Kingdom (1539–1075 BCE) in the nearby Valley of the Kings and Valley of the Queens (Bierbrier, 1982; Černý, 1973; Romer, 1984). Soon after it was found, the map was sold to King Charles Felix, ruler of the northern Italian Kingdom of Sardinia and Piedmont. In 1824, this king established the Egyptian Museum in Turin, the kingdom's capital, and here the map has resided ever since. The many map fragments were originally considered parts of three separate papyri that were designated as "Papyrus or P. Turin" 1869, 1879, and 1899. Most of these fragments were eventually recombined to form a single map about 280 cm long by 41 cm wide (Fig. 2). This papyrus has long been recognized as one of the oldest geographic maps to survive from antiquity and much has been written about it (e.g., Gardiner, 1914;

Goyon, 1949; Harrell & Brown, 1992; Janssen, 1994; Klemm & Klemm, 1988; Murray, 1942; O'Connor, 2012, pp. 59–67; Thomas, 1913).

The current reconstruction of the map in the Egyptian Museum, which dates to the early 1900s, is incorrect in several of its details. A new arrangement of the map fragments has been proposed and this is shown in Figs. 3, 4, 5, and 6. The principal changes are the transposition of map fragments H-J and E, the placement of L at the bottom of E, and the narrowing of gaps between many of the fragments (which shortens the map to about 210 cm). This new reconstruction is consistent with the requirements that:

1. The adjoining fragments should correlate closely in terms of the features drawn on the map side, the texts and drawings on the map's backside (Figs. 7 and 8), and the fiber patterns in the papyrus paper.
2. The width of the fragments and the spacing between the breaks within them should match for those fragments that are vertically juxtaposed. The topography and geology of the area



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 2 The arrangement of the papyrus map fragments as currently displayed in the Egyptian Museum in Turin, Italy (Adapted from Goyon (1949), Pl. 1 and 2; and

reproduced in Harrell & Brown (1992), Fig. 2). The texts are identified by numbers (as in Fig. 4 and Table 1), and the fragments are identified by letters (as in Figs. 4, 5, 6, 7, and 8 and Table 2)

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shown on the map should be taken into account. Figures 3, 5, 6, 7, and 8 are computer-generated photomosaics derived from digital scans of photographs taken of the papyrus.

The map was rolled up when discovered and subsequently handled, and this explains the especially poor preservation of the rightmost portion in Fig. 3, which formed the outer abraded surface of the scroll. An unknown amount of the papyrus has been lost at its right edge and so fragments K and N-P cannot be correctly placed. The map is not truncated here, but drawings of an unknown number of stone blocks and the accompanying texts are missing. The Egyptian Museum has many small map fragments that it left out of its reconstruction (and are also missing from Figs. 3, 4, 5, 6, 7, and 8) and eventually these pieces of the puzzle will be added to create a more complete map.

Topographic and Geologic Content of the Map

The Turin papyrus map is notable for being the only topographic map to survive from ancient Egypt and also for being one of the earliest maps in the world with real geographic content. Although there are a few older topographic maps from outside Egypt, they are all quite crude and rather abstract in comparison to the relatively modern-looking map drawn on the Turin papyrus. This map shows a 15 km stretch of Wadi Hammamat (Valley of Many Baths) in the central part of Egypt's Eastern Desert (Fig. 1). The top is oriented toward the south and the source of the Nile River with west on the right side and east to the left. There is no constant scale used on the map, but by comparison with the actual distances in Wadi Hammamat, it is evident that the scale varies between 50 and 100 m for each 1 cm on the map.

Maps and Mapmaking in Egypt: Turin Papyrus Map, Table 1 Translations of the hieratic texts on the map side of the Turin papyrus (Adapted from Harrell & Brown (1992), Table 1)

Text number ^a	Translation
1	The road that leads to the sea
2	Another road that leads to the sea
3	The road of <i>Tent-p-mer</i> [the translation of the last word is uncertain – it may be the name of an unknown locality or it may mean “treasurer” or “harbor”]
4	Mountains of gold
5	Mountains of gold
6	The houses of the gold-working settlement
7	Cistern [or “water reservoir”; the text is written on top of the water sign]
8	Stela of <i>Menma'atre</i> , life, health, and prosperity! [King Seti I, 1290–1279 BCE, of the New Kingdom's 19th Dynasty] ^b
9	The road of <i>Ta-menti</i> [the last word is apparently the name of an unknown locality]
10	The shrine of <i>Amun</i> of the pure mountain
11	The mountains in which gold is worked, they are colored pink
12	Mountains of gold and silver [or perhaps “mountains of electrum,” where electrum is a natural mixture of gold and silver]
13	... the hill of <i>Amun</i>
14	The hill where <i>Amun</i> rests
15	[not translatable; appears to be part of a name for some locality]
16	[too fragmentary to translate, but it appears to be comments on travel from one unnamed locality to another; a travel time of “one day” and “gold” are mentioned]
16'	Mountains of gold [appears to be a continuation of 16 but is a separate text]
17	Distance from the gold-working settlement to the mountain of <i>bekheny</i> , ... <i>khet</i> [this text is repeated three times, apparently for emphasis; the distance in units of <i>khet</i> is missing] ^{c,d}
18	... the <i>bekheny</i> -stone that is found in the mountain of <i>bekheny</i> , the King ... [name lost] life, health, prosperity, having sent the great magistrates to bring the portrait statue of <i>bekheny</i> -stone ... to Egypt. They deposited it in the Place of Truth beside the Temple of <i>Userma'atre setepenre</i> , the great God [i.e., near the Valley of Kings at the mortuary temple of Ramesses II, 1279–1213 BCE, of the New Kingdom's 19th Dynasty; also known as the Ramesseum] ... right it at the enclosure of the Tomb and there it lay being half worked in year 6 ^c
19	[not translatable]
20	The place in which they work in the great business of <i>bekhen</i> -stone which was established as a quarry
21	The measurement of this ...
22	[not translatable]
23	... of stone that is pulled by men from the east ... 3 cubits wide [about 1.6 m] ^d
24	... <i>bekheny</i> ...
25	Breadth of 2 cubits, 2 palms [about 1.2 m]; thickness of 2 cubits, 3 palms ... fingers [about 1.3 m]
26	Breadth of 2 cubits [about 1.0 m]; thickness of 2 cubits
27	... palms ... fingers
28	... palms; thickness of 2 cubits ... palms

^aSee Figs. 2 or 4 for locations of texts. Note that “...” indicates missing text, untranslated ancient Egyptian words are italicized, and comments are given within brackets

^bAll dates in this article are taken from pp. 36–37 of Baines and Malek (2000)

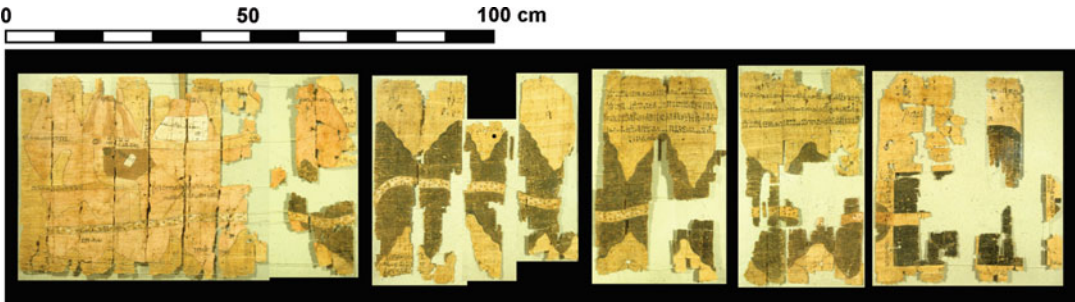
^cTexts 17 and 18 are written in a script that is bold, calligraphic, and near hieroglyphic in style. All other texts are written in a less elaborate hieratic script

^dThe ancient Egyptian units of measure are as follows: 1 *khet* = 100 cubits; 1 cubit (the standardized distance from the elbow to the tip of the longest finger) = 7 palms (palm widths) = 28 fingers (finger widths); 1 cubit = 52.31 cm, 1 palm = 7.47 cm, 1 finger = 1.87 cm

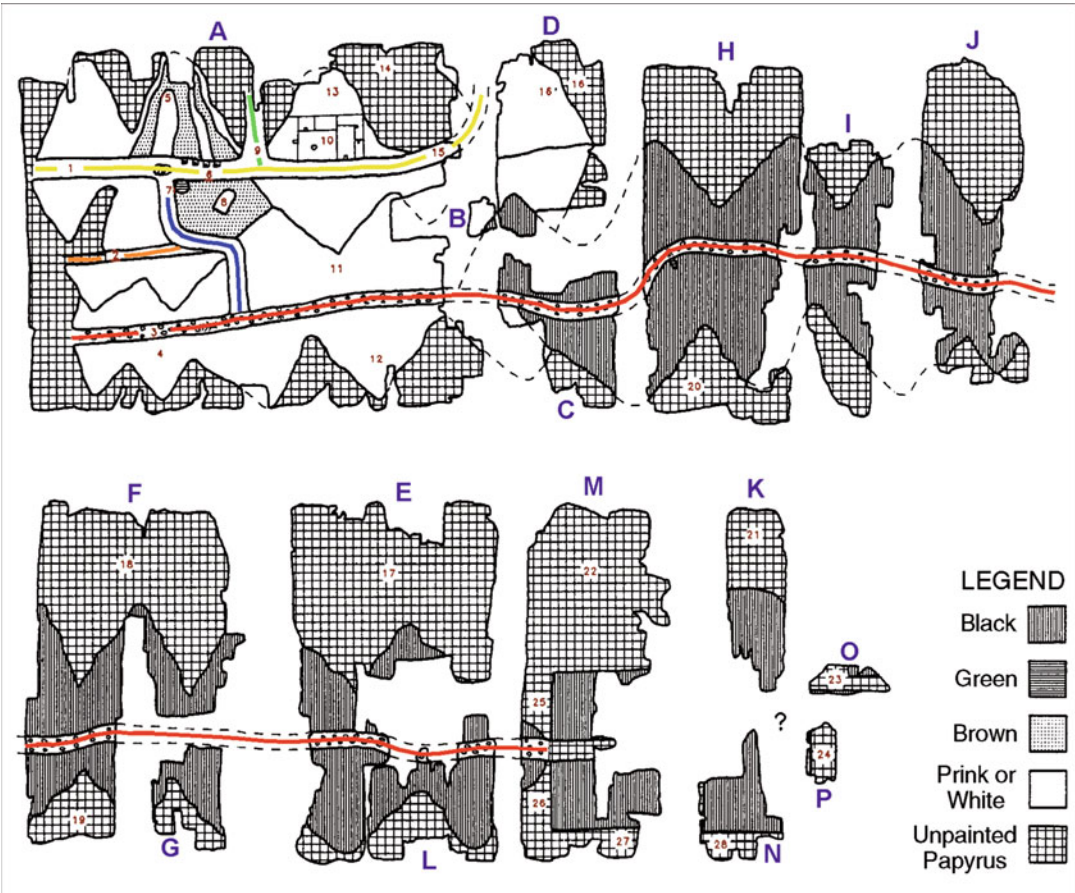
Maps and Mapmaking in Egypt: Turin Papyrus Map, Table 2 Comments on the hieratic texts and drawings on the backside of the Turin papyrus map (Adapted from Harrell & Brown (1992), Table 3)

Map fragment ^a	Comments
A (across top)	Synopsis: Amennakhte, in his house one morning, bears witness to a sworn oath and statement (not recorded in the text) by a “citizen” (name lost). Signed by Scribe of the Tomb Amennakhte (date lost) [this is almost certainly the earliest text written on the backside because Egyptian scribes filled in scrolls from top to bottom and right to left]
A (left half and top of right half)	Synopsis: A wooden statue of Ramesses VI is to be carved, and ornamented with a kilt of gold, and a crown of lapis lazuli (and another mineral?). It is to be placed in the mortuary temple of Ramesses II (the Ramesseum) in the Chapel of Hathor for the purpose of establishing a cult for the worship of Ramesses VI. The required offerings on festival days and the duties of the temple personnel attached to this cult are also described [unsigned and undated, but Amennakhte’s handwriting]
A (the rest of the right half) ^b	Synopsis, Part 1: Hori went to Karnak Temple in Thebes at the summons of Ramessenakhte, the High Priest of Amun. There he was told to gather a large quantity of copper [which would have been used for the tools wielded by the workers excavating the royal and private tombs] and bring them to the Temple. Hori returned to the necropolis in the company of two Guards of the Treasury, Paynodjom and Amenmose son of Tjewenany, and the servant Pnekhemope. Dated year 6, third month of Akhet, day 20 Synopsis, Part 2: Hori returned to Karnak Temple in the company of Paynodjom and Amenmose plus the two Foremen of the Tomb, Nekhemmut (Hori’s brother) and Anherkhe. They met with Ramessenakhte and turned over the requested copper to the Scribe Khonsmose, who received it for the Treasury of Amun. Dated year 6, fourth month of Akhet, day 7. Signed by Scribe of the Tomb Hori, son of Khons
A (upper right edge), B, and D	[Untranslated, but possibly Hori’s handwriting]
A (lower right corner) and C	[Untranslated, but the handwriting is that of either Amennakhte or another, unknown scribe]
D (right edge and upper part of left edge)	[Untranslated, but the handwriting is that of either Hori or another, unknown scribe]
H (right half), I, and J	[Untranslated, but appears to be a list, possibly of statues and their associated festival days; the large, bold, calligraphic, and near-hieroglyphic script in this text is like that in texts 17 and 18 on the map side and probably is Amennakhte’s handwriting in his more formal script]
J (upper right edge) and F (upper two-thirds of left half)	[Untranslated, but appears to be a memorandum plus a hymn, possibly to Horus, that is in Amennakhte’s handwriting]
F (lower one-third of left half)	[Untranslated, but the handwriting may be that of Amennakhte or another, unknown scribe]
F (right half)	[Untranslated, but Amennakhte’s handwriting]
G	[Untranslated, but Amennakhte’s handwriting]
E	[Untranslated, but possibly Hori’s handwriting]
Extending across the bottom edge of A, C, H, I, J, F, G, E, L, and M	[Untranslated, but one long line of text in possibly Hori’s handwriting]
L and M (lower right edge)	Drawing showing a scattering of squarish pebbles (?) plus two curved parallel lines, the latter similar to those used to indicate wadis on the map side
M	A grid square in red ink with fragmentary drawings of the sky goddess Nut, and below, the god of air and light, Shu, or perhaps the god of Earth, Geb; a tiny stickman is standing on Nut’s back
M (top)	Drawing of a crocodile
N	Fragmentary drawings of a tree trunk (palm?) and a wing (either the vulture goddess Nekhbet or the falcon god Horus)

^aSee Figs. 7 and 8 for locations of map fragments. Fragments K, O, and P have no texts or drawings^bThe gist of these two texts has been revised from Harrell and Brown (1992, Table 3) based on a new translation by Janssen (1994)



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 3 Papyrus map as reconstructed by Harrell and Brown (1992)

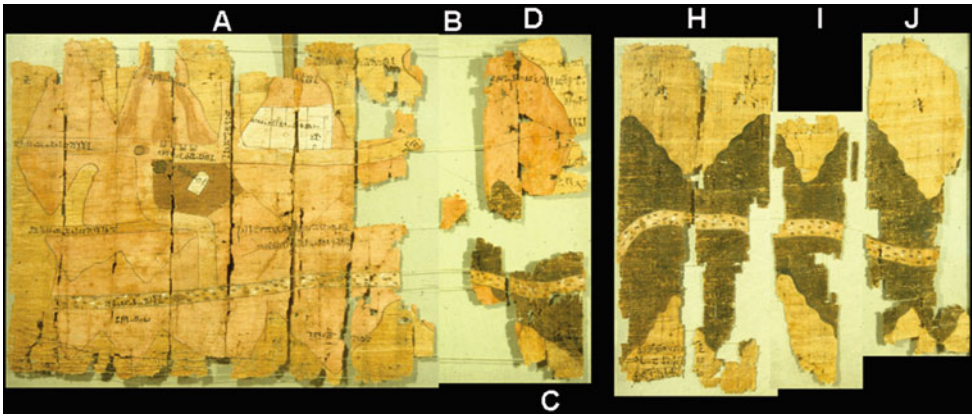


Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 4 Schematic of the papyrus map showing the reconstruction by Harrell and Brown (1992, Fig. 3). The

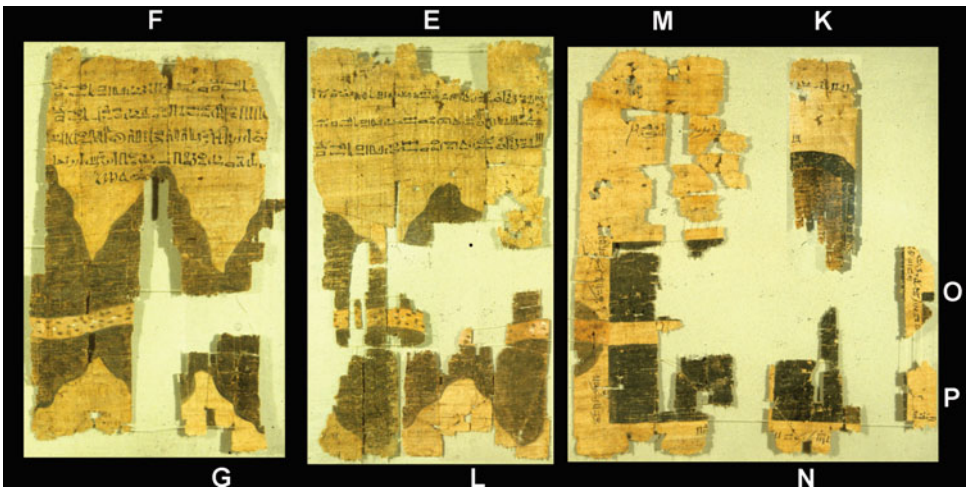
numbers refer to texts and the letters to map fragments as in Fig. 2. Corresponding features on this map and the modern one in Fig. 9 are indicated by the colored lines

The topography and geology of the Wadi Hammamat area are shown in Fig. 9. The corresponding features on the ancient and modern maps are indicated by the colored lines in

Figs. 4 and 9. From the good agreement between these maps, it can be seen that the papyrus clearly depicts Wadi Hammamat's long course and eventual confluence with Wadis Atalla and el-Sid, the



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 5 The left (eastern) half of the papyrus map. See Table 1 for translations of the texts (as numbered in Figs. 2 and 4)



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 6 The right (western) half of the papyrus map. See Table 1 for translations of the texts (as numbered in Figs. 2 and 4)

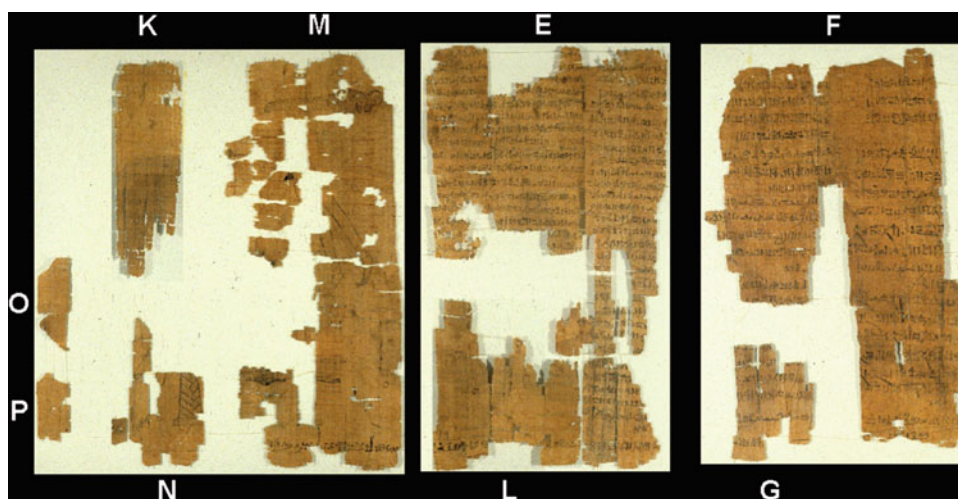
surrounding hills (shown as stylized conical forms with wavy flanks that are laid out flat on both sides of the valleys), the quarry for *bekhen*-stone, and the gold mine and settlement at Bir Umm Fawakhir (Well of the Mother of Pottery). *Bekhen*-stone (geologically, metagraywacke sandstone and siltstone) is a beautiful grayish-green ornamental stone that was highly prized by the ancient Egyptians. The only quarry was in Wadi Hammamat, and this was worked sporadically from the Predynastic period through Roman times (about 4000 BCE to 400 CE). The gold mine at Bir Umm Fawakhir was active

during the New Kingdom and again in the Ptolemaic through Early Byzantine periods (about 1500 BCE to 600 CE).

Fragment A shows five cultural features associated with the gold-mining settlement, including four houses, a temple dedicated to the god Amun (the large white area subdivided by walls), a monument stone honoring King Seti I (1290–1279 BCE of the New Kingdom’s 19th Dynasty), a water reservoir, and, at the confluence of Wadis Hammamat and el-Sid, a water well with an encircling wall that casts a shadow on its right side. The brown patch of ground



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 7 The backside of the left (eastern) half of the papyrus map. See Table 2 for comments on the texts



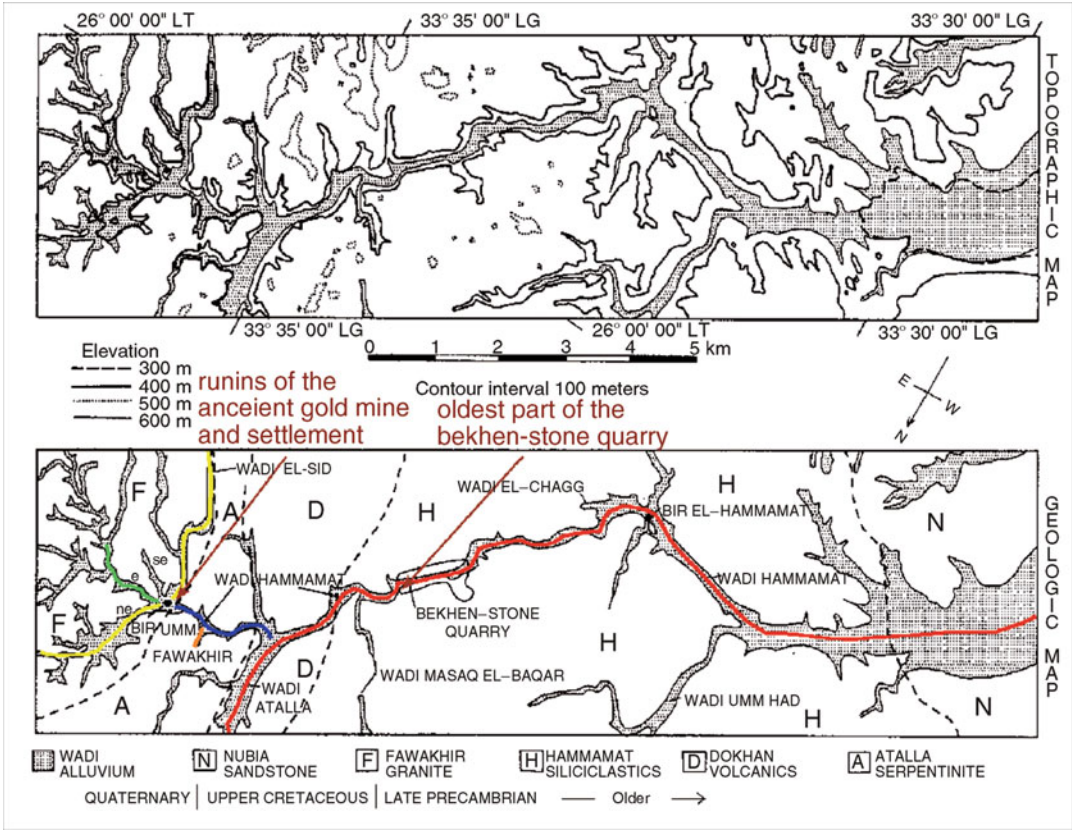
Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 8 The backside of the right (western) half of the papyrus map. See Table 2 for comments on the texts and drawings

opposite the settlement may represent an area where either mine tailings were dumped or farming was practiced.

On map fragments A and H, within the main valley represented by multicolored dots, there are three small drawings of trees, which from their form can be identified as tamarisks. The tree on fragment H (Fig. 10), which is drawn upside down, is just opposite the *bekhen*-stone quarry (the green oval at the base of the brownish black hill) and at the center of the sharp bend in the valley. On the ancient map, this is the only major

bend in Wadi Hammamat prior to its confluence with Wadi Atalla. As seen in Fig. 9, however, Wadi Hammamat actually has many sharp bends as well as wide meanderings. Because the ancient map was drawn on a papyrus scroll, which would have resembled a modern roll of paper towels, the author did not have the freedom to show the true wandering course of Wadi Hammamat and so included only the most important bend, the one near the *bekhen*-stone quarry.

The papyrus map also has numerous annotations written in hieratic script (the cursive form of



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 9 Topographic (above) and geologic (below) maps of Wadi Hammamat (Adapted from Harrell & Brown,

1992, Fig. 4). Corresponding features on this map and the ancient one in Fig. 4 are indicated by the colored lines

hieroglyphic writing) that identify the features shown on the map (see Table 1 for translations), including the destinations of the valley routes (texts 1–3, 9, and 16 on fragment A), the distance between the *bekhen*-stone quarry and gold mine (text 17 on fragment E), the location of gold deposits in the hills (texts 4–5, 11–12, and 16' on fragments A and D), the gold-mining settlement (texts 6–8 and 10 on fragment A), the *bekhen*-stone quarry (text 20 on fragment H), and the sizes of the quarried *bekhen*-stone blocks (texts 23 and 25–28 on fragments M–P). Text 18 on fragment F is especially important for understanding the purpose of the map because it refers to a *bekhen*-stone quarrying expedition and the destination of the quarried blocks. Besides being a topographic map of surprisingly

modern aspect, the Turin papyrus is also a geologic map because it accurately shows the geographic distribution of different rock types (the black hills with Hammamat siliciclastics and the pink hills with Dokhan volcanics, Atalla serpentinite, and Fawakhir granite) and the lithologically diverse wadi gravel (the brown, green, and white dots within the main valley that represent different kinds of rocks), and it also contains information on quarrying and mining (see Table 3 for a description of the geologic units). Additionally notable are the representation of iron-stained, gold-bearing quartz veins with three radiating bands on the pink hill above the gold-mining settlement on fragment A (beneath text 5) and text 11 on fragment A, which reads very much like a legend on modern

Maps and Mapmaking in Egypt: Turin Papyrus

Map, Fig. 10 Detail of the papyrus map (fragment H) showing an upside down tree in the wadi directly opposite from the *bekhen*-stone quarry, which is shown as a greenish oval embedded within the brownish black hillside



Maps and Mapmaking in Egypt: Turin Papyrus Map, Table 3 Geologic units in the Wadi Hammamat area as shown on the map in Fig. 9 (adapted from Harrell & Brown (1992), Table 4)

Geologic age	Name	Description
Quaternary	Wadi alluvium	Sand with lithologically diverse pebbles and cobbles of many colors but especially white, pink, brown, dark gray, and green
Upper Cretaceous	Nubia sandstone	Sandstone. From a distance appears purplish black due to a coating of “desert varnish”
Late Precambrian	Fawakhir granite	Granite and granodiorite with abundant iron-stained, gold-bearing, hydrothermal quartz veins. From a distance appears pink to pale red due to natural coloring
	Hammamat siliciclastics	A variety of slightly metamorphosed sedimentary rocks, including metagreywacke sandstone to siltstone (the ancient Egyptian <i>bekhen</i> -stone) and metaconglomerate. From a distance appears dark brownish gray due to a coating of “desert varnish”
	Dokhen volcanics	A variety of slightly metamorphosed volcanic rocks. From a distance appears pinkish brown due to weathering
	Atalla serpentinite	Serpentinite. From a distance appears pinkish brown due to weathering

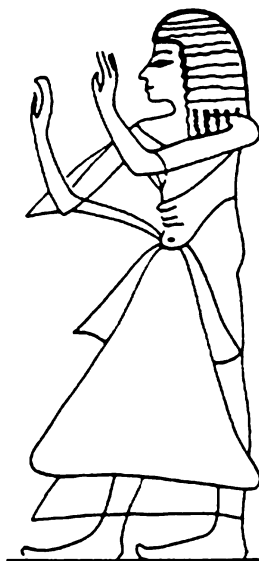
geologic maps by explaining what the pink coloring represents. The Turin papyrus is the oldest known geologic map in the world and it is all the more remarkable considering that it would be another 2,900 years before the next geologic map was made and this was in France during the mid-1700s. There is no reason to think, however, that the ancient author intentionally set out to make a geologic map. From the colors used for the hills and wadi gravel, it is evident that he merely drew what he literally saw in the desert – the real hills and surface gravels have the same general colors as those on the map (Table 3).

The Map’s Author and Purpose

The map was made about 1150 BCE by the well-known “Scribe of the Tomb” Amennakhte, son of Ipuy (Romer, 1984, pp. 106–115; Fig. 11). It was prepared for one of the quarrying expeditions sent to Wadi Hammamat by King Ramesses IV (1156–1150 BCE) of the New Kingdom’s 20th Dynasty (Peden, 1994). The purpose of these expeditions was to obtain blocks of *bekhen*-stone that would be carved into statues of the gods, king, and other notables. A now famous rock-cut inscription or stela (officially designated CM 12) was left on the quarry wall by this king to

Maps and Mapmaking in Egypt: Turin Papyrus Map,

Fig. 11 Amennakhte, son of Ipuy (Modified from Romer, 1984, p. 115). Redrawn from a relief carving on a stela erected in Thebes by his family after his death (now in the New York Metropolitan Museum of Art)



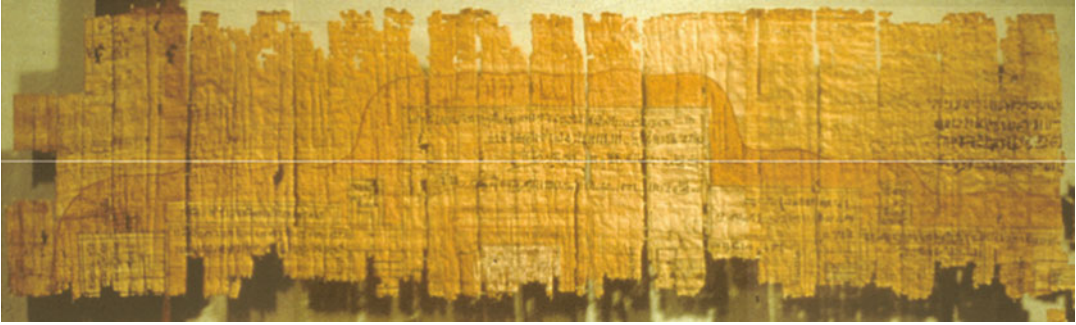
commemorate his final and largest expedition during the third year of his 6-year reign (Christophe, 1948; Fig. 12). According to the inscription, this included 8,362 men, which makes it the largest recorded quarrying expedition to Wadi Hammamat after one about 800 years earlier during the Middle Kingdom's 12th Dynasty. It is almost certainly for Ramesses IV's big expedition that the map was made, but what purpose it served is unclear. It could not have been a road map showing the way to the quarry because it only covers a small area with the 75 km between Wadi Hammamat and the Nile Valley excluded. Conceivably, it was a design for a relief scene in Ramesses IV's vast but now destroyed mortuary temple in Thebes. Most likely, however, it was drawn as a visual record of the expedition to be viewed by either Ramesses IV or Ramessenakhte, the High Priest of Amun in Thebes, who organized the expedition for the king.

Although Amennakhte did not sign his name to the map, it is clear that he is its author. There are two pieces of evidence that support this identification. First, the text on the map side is in Amennakhte's distinctive handwriting, which is well known to Egyptologists who have studied his many other writings. And second, the first and earliest text on the backside of the papyrus (the



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 12 Ramesses IV's year-3 stela (CM 12) in Wadi Hammamat's *bekhen*-stone quarry

first one listed in Table 2) was written and signed by Amennakhte. It is not at all surprising that Amennakhte would have made the map. As one of the two "Scribes of the Tomb" during Ramesses IV's reign (along with Hori, son of Khons, who also wrote some of the later texts on the back), Amennakhte was an important administrative official in the Theban region and this is where the map (text 18) says the blocks of *bekhen*-stone were taken. He is well known from his many other surviving works to be an individual with an unusual combination of scribal, cartographic, and artistic skills as well as a "sense of geology." These attributes are especially well displayed on another of his papyri in Turin's Egyptian Museum. This is an architectural plan of Ramesses IV's tomb in the Valley of the Kings (Carter & Gardiner, 1917; Fig. 13). It is by far the



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 13 Ramesses IV's tomb plan drawn by Amennakhte, son of Ipuy (now in Turin's Egyptian Museum)



Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 14 Ruins of the ancient village of Deir el-Medina, Egypt. Amennakhte's family tomb (no. 1338) is excavated

into the hillside on the *right*, and his house (highlighted in *red*) is inside the *rectangular*, walled precinct at *center*

most elaborate and sophisticated tomb plan to survive from ancient Egypt. It has Amennakhte's distinctive handwriting labeling the parts of the tomb and giving their dimensions, and on the back is his last will and testament. The plan also includes elements of geology, such as a drawing of the king's sarcophagus in the central burial chamber painted to resemble the pink granite of Aswan from which it was carved, and the location of the tomb under a mountain of well-layered, inclined strata, which is an accurate depiction of the situation in the Valley of the Kings.

It is now known that Drovetti obtained both the quarry map and tomb plan, along with many other papyri, from Amennakhte's family tomb at Deir el-Medina. If the map was made for Ramesses IV's big quarrying expedition, then why did Amennakhte keep it, and why did he and others reuse its backside for documents and drawings unrelated to the map? The answer to the first question is unknown, but that to the second is clear. Because papyrus paper was an expensive commodity in ancient Egypt, it was common practice among scribes to use the

Maps and Mapmaking in Egypt: Turin Papyrus Map, Fig. 15

House of Amennakhte, son of Ipuy in the ancient village of Deir El-Medina, Egypt. Only the ground floor (with four rooms) survives, but the remains of stairs (not visible) indicate that there was a roof terrace where people could work or sleep



originally blank backsides once whatever was written or drawn on the front side was no longer needed. In other words, the papyrus map became scrap paper after the quarrying expedition it recorded lost its importance, perhaps following Ramesses IV's death a few years after the map was made.

Amennakhte's family tomb still exists as does, remarkably, his house in Deir el-Medina (Figs. 14 and 15). That it is his house is known from an inscribed door jamb, now removed for safe keeping, that graced its entrance. It is interesting to contemplate that it may be in this very place where one of the world's oldest and most important maps was made over 3,100 years ago.

See Also

► [Mining in Ancient Egypt and Nubia](#)

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Maps and Mapmaking in India

Joseph E. Schwartzberg

In comparison to Europe, the Islamic world, and East Asia, the cartographic achievements of South Asia appear modest and until the 1980s were scarcely recognized by historians of science. In recent years, new archaeological evidence, surviving sacred and secular texts, and other evidence have led to a change in scholarly opinion. We now believe that some form of mapping was practiced in what is now India as early as the Mesolithic period, that surveying dates as far back as the Indus Civilization (ca. 2500–1900 B.C.E.), and that the construction of large-scale plans, cosmographic maps, and other cartographic works has occurred continuously at least since the late Vedic age (first millennium B.C.E.). Because of the ravages of climate and vermin, surviving maps from prior to the eighteenth century are rare and are largely in stone, metal, or ceramic. However, cosmographies painted on cloth date back at least to the fifteenth century, while palm leaf architectural plans from seventeenth-century Orissa are believed to be copies of manuscripts originally prepared as early as the twelfth century. Few surviving maps on paper predate the eighteenth century.

Though not numerous, a number of map-like graffiti appear among the thousands of Stone Age Indian cave paintings; and at least one complex Mesolithic diagram is believed to be a representation of the cosmos. Other map-like graffiti continued to be produced by tribal Indians over most of the historic period. The principal reason for supposing that surveying was a feature of the Indus civilization is that the regularity of its planned grid-pattern urban settlements could not easily be achieved without it. Moreover, excavations have uncovered several objects that appear to have been simple surveying instruments and measuring rods. The uniformity and modular dimensions of the bricks for so much of the architecture over the vast extent of the Indus

civilization are also noteworthy. During the ensuing period of the Vedic Aryans, the building of enormous sacrificial altars was an important religious activity. Texts known as *Śulbasūtras* set forth in great detail how these altars were to be constructed and called for drawing on the ground a plan prefiguring each altar. Again, a system of modular measures was employed. The ancient practice of building gigantic altars, once widespread, has died out over most of India, but survived into the latter half of the twentieth century in the Indian state of Kerala. Hindu temples were also built according to ancient detailed textual prescriptions, known as *Śilpaśāstras*, which also specified drawing on the ground, at full scale, the outline of the structure to be. That practice is still followed. Comparable, though simpler, rules applied, at least in theory, to the building of houses. The *Śilpaśāstras* also contained a variety of models for laying out towns and cities; however, the layout of present-day Indian settlements suggests that such models were seldom closely followed.

For the historic period, one of the earliest surviving artifacts that clearly embodies recognizable map symbolizations is an allegorical wall sculpture from Udayagiri in Madhya Pradesh, ca. A.D. 400, which shows the confluence of the Ganges and Yamuna Rivers in Madhyadesa (the sacred Central Region of India) over which the then Gupta Empire held sway. Other early datable works are sculpted bas relief cosmographies, some of which were quite elaborate. The earliest of these, depicting *Nandīśvaradvīpa*, the eighth continent of the Jain cosmos, was carved in Śaka 1256 (A.D. 1199–1200). It may safely be assumed that cosmographic paintings adorned the walls and portals of many ancient temples and monasteries of India's main religious groups – Hindus, Jains, and Buddhists – just as they still do in Jain religious edifices and in Buddhist establishments in other parts of the world. However, largely because of the ravages of time and partially because of the iconoclasm of Muslim invaders, virtually none of these survive from prior to the twelfth century, apart from fragmentary remains in the Buddhist caves at Ajanta.

Astronomy and its handmaiden astrology were well developed sciences in ancient India. The major texts provided detailed observations that enabled latter-day scholars to prepare elaborate celestial diagrams. Despite these, there is no unequivocal evidence that astronomical charts accompanied those early works or were otherwise drawn. Horoscopes were prepared to show the positions of major heavenly bodies at particular times (especially at times of birth), and iconic representations of those bodies as deities often appeared in sculpture and paintings, as did the signs of the zodiac. But none of these were formed into assemblages that one would readily designate as maps. During the Mughal period (1526–1857), however, planar astrolabes and celestial ► [globes](#) were manufactured in north-western India. One Muslim family practiced the trade in Lahore over a period of several generations. Though some of these works used Sanskrit, rather than Persian, as was the norm, in naming various heavenly bodies, the tradition in which all were made has been dubbed “Islamicate.” A variety of related objects in the form of giant masonry instruments appeared in the astronomical observatories constructed during the period ca. 1722–1739 by the Rajput king, Sawai Jai Singh, in his capital at Jaipur and in Delhi, Varanasi, Ujjain, and Mathura. Many of these are still usable.

At least five Hindu cosmographic globes are known, all based largely on *Purāṇic* texts from the mid-first millennium B.C.E. to the mid-first millennium A.D. The oldest of these is a brass globe, probably from Gujarat, dated Śaka 1493 (A.D. 1571). The largest (diameter ca. 45 cm) and most elaborate, and the only one to contain a substantial component of geographic information along with its mainly mythic elements, is a papier-mâché globe, probably from eastern India, that appears to date from the mid-eighteenth century. One of the other globes is a painted wooden production, also thought to be from eastern India, probably from the mid-nineteenth century. Two are late nineteenth century bronze creations of unknown provenance. Unlike most Western globes, none of these was constructed with the use of gores, the

triangular or moon-shaped pieces that form the surface of modern globes.

A number of planispheric world maps also survive. All but one of these, a crude Marathi map on paper, probably from the mid-eighteenth century, are essentially Islamicate productions, in which mythic elements (e.g., the Land of Gog and Magog) coexist with known geographic places. The largest and most ornate of the world maps is a richly illuminated eclectic painting on cloth, with text in Arabic, Hindustani, and Persian; it probably dates from the eighteenth century and may be of either Rajasthani or Deccani provenance. Additionally, a 32-sheet atlas of the “Inhabited Quarter” (i.e., the part of the world suitable for human life), forms part of a 1647 encyclopedic work by Sadiq Isfahani of Jaunpur in what is now Uttar Pradesh. The orientation on maps made by Muslims is typically toward the south.

Indigenous regional maps, mostly from the eighteenth and early nineteenth centuries, derive mainly from Rajasthan, Kashmir, Maharashtra, and Gujarat, probably in that order of frequency. These range in size from very large (several meters on a side) to page-size productions, the larger works being almost always painted on cloth. No clear schools of cartography emerge, though one can usually distinguish among regions of origin. Map symbols and orientation vary markedly, though some regional tendencies may be noted. No map has a consistent scale, though some contain textual notes on distances between places.

Route maps most commonly appear in strip form, occasionally as lengthy scrolls, and typically show the places and physical and man-made features encountered between two given points. Some route maps, largely relating to pilgrimages, which frequently take the form of circuits, are likely to be more complex. Surviving navigational charts are few in number, entirely from Gujarat, and in a tradition presumably derived from the Middle East. The oldest such known work is dated A.D. 1710.

The most common genre of maps are those that relate to relatively small localities, especially individual towns, as well as plans of specific forts, palaces, temples, gardens, and tombs.

Such maps served many purposes: guides to pilgrims, aids for engineering projects, plans, or documents for military activities, commemorations of historical events, text illustrations, interior adornments, and so forth. Locality maps typically combine a largely pictorial rendition of specific structures, drawn in either an oblique perspective or in frontal elevation, with an essentially planimetric rendition of the encompassing space. Hill features on such maps (as well as on regional maps) are characteristically shown in frontal perspective. Colors for rendering hills, water features, and vegetation are naturalistic and not very different from what one would encounter on Western maps. The largest known Indian map, depicting the former Rajput capital at Amber in remarkable house-by-house detail, measures 661 × 645 cm. (260 × 254 in., or approximately 22 × 21 ft).

Although hundreds of Indian maps have now been studied and described, hundreds of additional recently discovered works await analysis; and it may be safely predicted in light of the interest aroused by recent research that many more maps will soon come to light.

See Also

- [Astrology in India](#)
- [Astronomy: Indian Astronomy in China](#)
- [Jai Singh](#)
- [Observatories in India](#)

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Maps and Mapmaking in Japan

Kazutaka Unno

The first record of Japanese mapmaking is an Imperial edict in A.D. 646 included in the *Nihon Shoki* (Chronicles of Japan), 720, ordering that each province reports its territorial range to the central government by means of a map. However, no fragment of such a map is extant now. The earliest extant maps relate to land ownership and date from the eighth century. These maps are almost all preserved in the Shōsōin, Nara, and consist of a map of Tōdai-ji temple precincts, 756, and over 20 maps of paddy fields. On these maps we can observe the traditional Chinese grid system. The majority of them are drawn on hemp.

The extant early general maps of Japan include: one dated the 12th month, the third year of the Imperial era known as Kagen (1305/1306), now owned by the Ninna-ji temple, Kyoto; *Dai-Nihonkoku Zu* (Map of Great Japan) in the 1548 codex of an encyclopedia, *Shūgaishō* (Collection of Oddments); and *Nansembushū Dai-Nihonkoku Shōtō Zu* (Orthodox Map of

Great Japan in Jambudvīpa) drawn in the mid-sixteenth century (Tōshōdai-ji temple, Nara). These maps show the coastline and the boundary lines between provinces by means of smooth curves, and have the common characteristic of showing the main routes from the province of Yamashiro, where the capital Kyoto had been located since 794, through almost all the provinces. Maps with such characteristics are called “Gyōki-type” maps, because they have an inscription indicating that the author was Gyōki (668–749), a revered Buddhist priest. But no one believes today that they were actually the work of Gyōki, for the capital in his time was not Kyoto but Nara, Yamato Province. Later, in the ritual of *Tsuina* (which had been instituted on Gyōki’s advice in 706 in order to offer prayers for national peace and the health of the people), a map of Japan came to be used to provide a concrete image of the country. It may be imagined that by association maps so used came to be called by his name.

The earliest extant map of the world is the *Go-Tenjiku Zu* (Map of the Five Indies), drawn by Jūkai, a Buddhist priest, in 1364, and now owned by the Hōryū-ji temple in Nara. The actually existing Buddhist continent called Jambudvīpa is drawn; India occupies a great part of the continent, and China, Persia, Japan, and many countries of Central Asia are shown. There are ten other extant maps which are copies made in later periods, and which belong to the same group. Incidentally, the above-mentioned *Shūgaishō* also contains a rough map of Jambudvīpa entitled *Tenjiku Zu* (Map of India).

European cartographical works were introduced to Japan in the late sixteenth century, and the coastlines of the Gyōki-type maps came to be drawn in detail, especially in the area of Kyūshū. This revision seems to have been done by the European pilots and by the Portuguese Ignacio Moreira, who resided in Japan between 1590 and 1592.

Exact maps of provinces were needed for state administration. But there are no known records about the compilation of national maps after the year 646 mentioned above (except for government orders of 738 and 796) until 1591,

when the Toyotomi government embarked on such a project. The extant maps of two counties in Echigo Province are rare examples of the results of this project. The Tokugawa Shogunate, which succeeded the Toyotomi government and held its hegemony for two and a half centuries until 1867, gave orders for cartographical records of all provinces on five occasions during its reign.

These orders were issued in the tenth year of the Imperial era of Keichō (1605); about the tenth year of Kan’ei (ca. 1633); the 12th month of the first year of Shōhō (1645); the tenth year of Genroku (1697); and the sixth year of Tempō (1835). No detailed records remain as regards the first and second projects. After the third project, prescriptions aiming at some regularization of form were issued, for example, the scale was fixed at six *sun* to one *ri* (1:21,600). For the third project, the Shogunate also required the province to submit the plans of cities where the clan offices were located. These maps and plans are huge and beautifully colored. All of the maps of the fifth project, and some earlier ones, are still extant in the National Archives in Tokyo.

General maps of Japan based on the provincial maps were compiled on each occasion except the fifth project. The earliest extant official map of Japan is the so-called Keichō map of Japan, compiled in the mid-seventeenth century and now in the National Diet Library, Tokyo. On this map the eastern half of Honshū is completely curved to the north, and depicted as smaller than it actually is. The island of Shikoku, which actually has projections in all four directions of the compass, is drawn in a rectangular form.

The best of the official maps of Japan compiled during the Edo era is the so-called Shōhō map of Japan, based on the results of the third cartographical project, and completed around 1670. Compiled by the famous surveyor Hōjō Ujinaga, this map shows the shape of the Japanese archipelago which is very close to actuality.

These maps strongly influenced private works of cartography. *Nihon Bunkei Zu* (Map of Japan Divided into Parts), published in 1666, and the

series of works by the painter Ishikawa Ryūsen beginning in 1687, were based on the Keichō map of Japan; the former was the first printed atlas of Japan. Seki Sokō's *Nihon Bun'iki Shishō Zu* (Easily Understandable Atlas of the Regions of Japan), 1698, and Nagakubo Sekisui's works (first edition, 1779) were also based on this "Shōhō map of Japan".

In traditional cartography, little attention was paid to the existence of spherical coordinates, but latitudes are shown in the portolan charts of Japan (ca. 1670, Mitsui Bunko Library, Tokyo; National Museum, Tokyo). The first map of Japan made under the influence of these charts and having a network of parallels and meridians was Mori Kōan's *Nihon Bun'ya Zu* (Astronomical Map of Japan), 1754. In this map, however, parallels and meridians were simply added to the already existing official map. We also find such a network on Nagakubo's maps of Japan, but with only the degrees of latitude. It is evident that they imitated Mori's idea, and moreover had a greater social influence, because these latter maps were often printed, while Mori's remained only a manuscript.

The first map of Japan that was based on actual observation of degrees of longitude and latitude was completed by officials of the Shogunate astronomical observatory in 1821. The surveying began in 1800 and mainly concentrated on the coastlines, as the title *Dai-Nihon Enkai Yochi Zenzu* (Maps of the Coastlines of Great Japan) shows. The supervisor of the surveying throughout was the astronomer Inō Tadataka, and all the maps thus made in this project are called "Inō's maps". The 1821 maps consisted of 214 sheets on a scale of 1:36,000, eight sheets of 1:216,000, and three sheets of 1:432,000.

The making of topographical maps by triangulation began in 1781, and in 1944 the entire country was depicted on maps with a scale of 1:50,000. Western style charts began to be systematically executed by the navy in 1871.

See Also

► [Ino Tadataka](#)

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Maps and Mapmaking in Korea

Gari Ledyard

Korea has a long history, but evidence of map-making comes only from about the fifth century AD, when a nobleman's survivors painted a map of Liaodong city (now in Liaoning Province, China, but then within the borders of the Korean Koguryō kingdom (37 BCE–668)) on a wall of his tomb. Since the tomb is in northern Korea, the map probably was meant to comfort him with an image of his far-off hometown. Koguryō's southern neighbors, the kingdoms of Paekche (18 BCE–663) and Silla (57 BCE–935) are known through written historical sources to have used maps in local administration, but no examples have survived. The same is true for the long Koryō dynasty (918–1392). The people of Koryō times had a sure sense of the peninsular outline of their country and are said to have commemorated it in the shape of the kingdom's standard silver bullion unit. Outlines of Korea also appear on a few Chinese maps of the twelfth century. Toward the end of the dynasty an enterprising scholar composed an elaborate map of the world – probably just the China-Korea region – and this work was probably connected in spirit to the *Kangnido* of 1402,

which, in a copy of about 1470, is the oldest Korean-made map to survive.

The Artifactual Record

The succeeding Chosŏn dynasty built a much stronger and more durable state than had previously been known in the Korean peninsula. A vast amount of mapping was carried out in the fifteenth century, but aside from some prominent exceptions there is little remaining trace of this early production. Most surviving Korean maps are of the seventeenth century or later, and are most commonly found in albums, often hand-drawn but occasionally including wood-block prints. Larger maps are usually found preserved in silk or paper scrolls or on screens. A large sample of this material is now available in published color illustrations.

From the seventh century on, Korean kings presided over a strongly centralized, bureaucratic state. Provincial governors and district magistrates were responsible for producing maps of their areas in response to requests from central authorities for geographical, demographic, and fiscal information. Thus the central government maintained and frequently updated a broad range of data from which provincial and national maps could be compiled. The most complete such compilation to survive in its entirety is the *Sinjuŋ Tongguk yŏji sŭngnam* (Complete Conspectus of Korean Territory, newly expanded; called the *Sŭngnam* for short) of 1531, descended from earlier editions going back to 1481.

Beginning in the late fifteenth century, the government generally limited publication and dissemination of maps for national security reasons, and the maps that were available, such as those in the *Sŭngnam*, were rather spare in detail. But security concerns also spawned the defense map (*kwanbangdo*) genre, which was rich in information relating to logistics and communication.

Geomancy

In the late ninth century, Koreans began to articulate a national geomantic structure for their

country. In its elementary form, geomancy (*p'ungsu*, Chinese ► *fengshui*) is an originally Chinese science employed in siting graves, human habitations, temples and shrines, and towns and cities. The landscape is the locus of forces which deliver energy and power through networks of montane “arteries” (*maek*) or riparian “veins” (*p'a*), which will be determined to be either favorable or unfavorable for the use envisaged for a particular site. Even today, specialists in this kind of knowledge can be found in most Korean communities, and indeed all over East Asia. But Korea is unique in developing this science into a nationwide framework for understanding and defining the physical aspects of the nation itself. From an early date the source of Korea's geomantic forces was seen to be located in Mount Paektu (2,744 m), which through Korea's mountain ranges and water sheds distributed vital forces to the entire country. It was thus of crucial importance to determine and map the mountain ranges of the land, so that the relationship of any particular spot to the overall network of “shapes and forces” (*hyŏngse*) could be clearly understood. Whether on the national or local level, a shapes-and-forces map (*hyŏngsedo*) would clearly configure the mountain ranges and water sheds, so that the physical lay of the land was easily perceived.

In the seventeenth century, following the Japanese (1592–1598) and Manchu invasions (1627, 1637), Korea went through a series of reforms which resulted in enhanced revenues and a more developed military. This was accompanied by economic growth and increased trade with China and Japan. In society at large these changes produced greater occupational diversity, a certain degree of social mobility, and a broader access to education. An intellectual movement in pursuit of “practical studies” (*sirhak*) extended scholarship into new areas of science and statecraft research. Thus it is not surprising that we see a development which might be called the privatization of cartography, leading to works by individual mapmakers that steadily grew in quality and diversity. Maps were no longer restricted to government offices but were much more broadly distributed throughout society. This resulted in a higher rate of preservation of maps into modern times.

In tracking this greater patronage we can notice two different kinds of map collections: administrative, and popular atlases. The administrative atlas typically would consist of a set of maps of Korea's eight provinces. Each provincial map would show the districts of the province, often with a shapes-and-forces accent that clarified the geographical character of the area. It would indicate principal roads and bridges, post stations and military bases, temples and schools, and other sites of official or civic importance. Distances between towns would be indicated either by notations on the map or in a table in the atlas. Accompanying essays would give a general historical and administrative overview of the province, and lists would be provided showing the rank of each magistracy, with statistics on its tax revenues, military reserves, and various other categories.

The popular atlas often had a similar organization, but it was distinguished by the addition of a general map of the world, or *ch'ŏnhado* (map of "all-under-heaven"), a general map of China, sketchier maps of Japan and the Ryukyu kingdom, and a map of Korea as a whole.

Korean Knowledge of Western Cartography

Jesuit missionaries, led by Matteo Ricci, began to introduce western maps of the world to China in the last years of the sixteenth century, and copies of printed editions of Ricci's world maps of 1602 and 1603 each reached Korea within a year of their publication. In 1708, a royal order was given to copy a variant version of the Ricci map, and this occasioned a Korean essay on Western cartography. Western maps continued to be imported throughout the eighteenth and early nineteenth centuries. A Jesuit-directed summation of mathematics and astronomy published in Chinese in 1723 updated Korean understanding of geographic latitude and explained methods of calculating longitude through the observation of eclipses, and Jesuit determinations of latitude and longitude for major Chinese centers and even for Seoul itself were found in the same source.

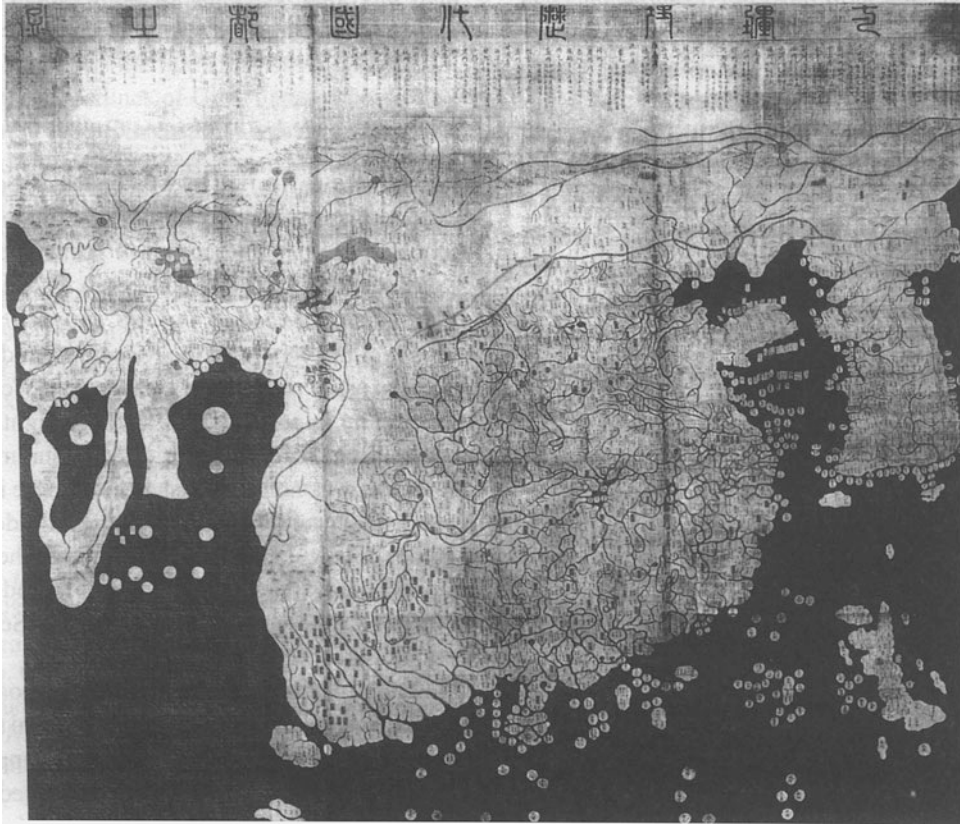
In spite of this more than passing exposure to western maps and mapmaking, one can find no visual trace of western influence on Korean maps themselves. An apparently Anglo-Chinese map from the 1790s was even printed by woodblock in Korea, in 1834, by the greatest Korean cartographer of all, Kim Chŏngho, yet Kim's own maps stay completely within the Korean tradition. On the other hand, there is abundant evidence that by the eighteenth century, Koreans were systematically compiling latitude and longitude data for their country, and although no indication of it is found on any Korean map of Korea, a kind of geodetic measurement did play a role in the accuracy of the data used to make the maps.

The Kangnido

The first rulers of the Chosŏn dynasty sponsored a number of projects designed to strengthen their legitimacy. Among these were a recarving on stone of a seventh century Korean star map and a terrestrial map of the world. The star map reflected a very ancient Chinese astrographical tradition long superseded in both China and Korea, but the terrestrial map, the *Honil kangni yŏktae kukto chi to* (Map of Integrated Lands and Regions and Historical Countries and Capitals) was based on two fourteenth-century Chinese maps. In 1402, Kwŏn Kŭn (1352–1409), a Confucian scholar and royal advisor, was ordered to supervise the compilation of a world map based on these two sources. The actual drawing was the work of Yi Hoe. To his images of China and the greater world, Kwŏn and Yi added Yi's own map of Korea and a recently imported image of Japan, thus, in their understanding, bringing the map to completion (Fig. 1).

While this original *Kangnido* was lost long ago, a Korean copy made around 1470 and seized by Japanese invaders in the 1590s has survived in Japan. This copy contains Kwŏn Kŭn's original preface, which details the source materials.

At first glance, the *Kangnido* seems a collection of distortions. China and India make up a dominating, undivided mass in the center, while Europe and Africa hang from the western side



Maps and Mapmaking in Korea, Fig. 1 *Honil kangni yŏktae kukto chi to* (Map of integrated lands and regions and historical countries and capitals. By permission of the Ryukoku University Library, Kyoto, Japan)

and Korea hangs from the eastern as if these two masses were geographically equal. An upended Japan floats uncertainly in the East China Sea. The *Kangnido* was a conflation of other maps, with considerable relative distortion of the land masses, rather than cartography in the strict sense. As the first East Asian map to include Europe and Africa, and such features as the Mediterranean and Black Seas, the Arabian peninsula and the Persian Gulf, the Nile and the Red Sea, as well as to add Korea and Japan on the east, the *Kangnido* is an epochal achievement in Korean as well as world mapmaking.

Popular Cosmography: The Ch'ŏnhado

The *Kangnido* was in Korea too exotic to pass unrevised into the mainstream of Korean

mapmaking. The unpronounceable names, in many cases Arabic originals filtered through Chinese transcriptions; the unimaginable distances; strange countries of which in many cases nothing was known – very little of this related to the concept of the world known in Korea. This world was essentially of Chinese definition. It was the *tianxia* (*ch'ŏnha* in Korean pronunciation) or “all under Heaven” that was at peace during the reigns of sage emperors, or that fell into disorder during the rule of bad ones. The geography of this world could be known through the Chinese classics and through the geographical sections and accounts of foreign countries in the long chain of Chinese dynastic histories that began to be compiled in the first century BCE. In addition there was the more fantastic and whimsical geography recorded in the *Shanhai jing* (Classic of Mountains and Seas),



Maps and Mapmaking in Korea, Fig. 2 *Ch'ŏnhado* (Map of the world. By permission of the National Central Library, Seoul)

the older parts of which date from around the second century BCE but which evoke even more ancient myths and traditions. This source added to the classical geography such imagined places as the “Land of the One-armed,” the “Country of Women,” “Mount Incomplete,” and many more. This mix of ancient historical places and imagined fantastic ones constituted the world that was mapped in the *ch'ŏnhado* (world maps) (Fig. 2).

Although based almost completely on Chinese source material, the numerous examples of

ch'ŏnhado constitute a completely Korean genre of map. An inner continent dominated by China, with the Korean peninsula always clearly depending from the eastern side, is surrounded by a sea full of kingdoms, which itself is surrounded by a circular land strip with even more amazing places. The eastern and western sides of this ring feature trees near which the sun rises and sets.

The origins of the *ch'ŏnhado* genre are unclear. A number of scholars have believed that these maps were Buddhist in origin, and

some have thought that the basic shape of the map could have been derived from geographic theories popularized by the Chinese naturalist philosopher ▶ [Zou Yan](#) (fl. third century BCE). While morphologically plausible, it is impossible to find any cartographic link over the nearly two millennia that separate Zou Yan from the emergence of the *ch'ŏnhado* in the sixteenth century.

I believe that the core of the *ch'ŏnhado* – its inner continent – evolved from the *Kangnido*. In addition to many geographical and morphological considerations, the Tenri *Kangnido* is also chronologically congenial to this theory, since it contains place names that fix its copying no earlier than 1568, making a plausible bridge to the sixteenth century *ch'ŏnhado*.

Korean National Maps

Under King Sejong (r. 1418–1450), the Korean court pursued a wide range of technical and scientific projects in astronomy, calendrical science, horology, musicology, pharmacology, agronomy, and geography and cartography. Distances between Seoul and the seat of each district, and between the districts themselves, were carefully measured and recorded. Polar altitude observations determined the latitude of the capital and of the extreme northern and southern frontiers, permitting an accurate estimate of the length of the country. Sejong also gave serious attention to the montane structure of the nation, collecting and studying data on the nation's mountain “arteries” and river “veins.” King Sejo (r. 1455–1468), Sejong's son and follower, ordered the complete mapping of the country, including not only a national map but maps of each of Korea's eight provinces and approximately 330 counties.

The national map that resulted from this preparation was the *Tongguk chido* (Map of the Eastern Country), which was presented to King Sejo in 1463 by his two chief cartographers, Chŏng Ch'ŏk (1390–1475) and Yang Sŏngji (1415–1482), but is thought to be principally the work of the former. The general outlines of the peninsula's coastline are astonishingly suggestive of those on modern maps, while the shapes-

and-forces treatment detailing the nation's mountain network and watersheds provides a rich appreciation of its physical geography. Every district of the kingdom is indicated, along with its distance from Seoul and its provincial affiliation. Equally distinctive is the map's chief flaw, an unduly flattened northern frontier. Early Korean mapmakers appear to have had considerable difficulty in grasping the outline of the northern frontier, which was defined by the Amnok and Tuman (internationally, Yalu and Tumen) rivers that respectively flowed off the western and eastern slopes of Mount Paektu. It was not until the eighteenth century that this problem was essentially solved. So for about three centuries the conventional shape of the country was associated with Chŏng Ch'ŏk's outline, and cartographers now refer to such maps as in the Chŏng Ch'ŏk style.

The great summation of the administrative geography promoted by the fifteenth century Korean courts was the *Sinjŭng Tongguk yŏji Sŭngnam* (Complete Conspectus of Korean Territory, newly expanded), which was first drafted in 1481, and went through several revisions before the final one of 1531. Called the *Sŭngnam* for short, this work detailed the administrative history of Korea's provinces and districts. It connected each district to its earliest known organization in earlier dynasties; clarified its rank and position in the administrative and military chains of regional governance; listed its schools, monasteries, Confucian shrines, post stations, signal-fire stations, natural and economic resources, famous native sons and virtuous women; and concluded with a sampling of literature associated with its history and public and private institutions. The final edition of the *Sŭngnam* was so thorough and so well done that it was never supplemented or re-edited.

We know that the cartographer Yang Sŏngji, whose work over the years for Kings Sejo and Sŏngjong (1469–1494) had laid the foundation for the *Sŭngnam*, was well known for his strict views on defense and national security. He argued that maps should not circulate outside of a few designated government offices. These views may have been a factor in the spareness

of detail on the *Sŭngnam* maps that appeared later in Sŏngjong's reign. Another important change on the *Sŭngnam* maps concerned the shapes-and-forces treatment. Even the *Kangnido*'s representation of Korea had displayed the principal mountain ranges of the kingdom. But on the *Sŭngnam* maps, shapes-and-forces indications completely disappeared. The reasons for this change are not clear.

During the first half of the eighteenth century there were new developments in the mathematical and observational sciences which had a strong impact on the maps of the later Chosŏn period. Much of this was connected with western knowledge, which had begun to flow steadily into Korea from Jesuit sources in China. Jesuit participation in the national mapping project of the Kangxi Emperor (1661–1722), which took place from 1709 to 1716, brought Jesuit cartographers who were mapping Manchuria to Korea's borders, and in 1713, Jesuit-trained Manchu and Chinese specialists made surveys and observations within Korea itself. The concepts of latitude and longitude, and related observational and mensurational techniques, were clearly described in Sino-Jesuit manuals which were introduced into Korea at least by 1715. A dramatic improvement in spatial representation is found on Korean maps that were developed during the following 30 or 40 years.

The man responsible for this cartographic revolution was Chŏng Sanggi (1678–1752), a brilliant scholar who labored for decades in the privacy of his home. He developed what he called the "hundred-*li* foot" (*paengni ch' ŏk*), a 100-*li* visual scale bar (metaphorically a "foot," I will call his unit a "scale-foot") calibrated in 10-*li* (4.3 km) intervals, which he inserted just after his introduction to his maps. Chinese books of that period specified a ratio of 200 *li* to one terrestrial degree of latitude or longitude. This ratio was cited and used by late-eighteenth century Korean mapmakers (although the Korean *li* was considerably shorter than the Chinese), and calculations based on their maps show that they probably followed such a formula to determine geodetic distance. Perhaps Ch'ong Sanggi had used the same procedure.

Shapes-and-forces cartography made a strong return on Chŏng Sanggi's maps, and the vernacular painting style of the day depicted the mountain ranges in an attractive manner that created both cartographic clarity and an aesthetic dimension. A variety of symbols marked military bases, post stations, and other facilities. Some copies of Chŏng's map's are works of art as well as cartographic masterpieces. His sons and grandsons continued to be active in cartography throughout the eighteenth century.

The Maps and Writings of Kim Chŏngho

In 1791, the Korean government sponsored the creation of a national grid for the purpose of complete cartographic standardization. While details of this project are uncertain, several albums of local maps copied on standardized *sŏnp'yo* (line guides) survive. Evidently the grid coordinates of each district seat were determined with reference to copies of Chŏng Sanggi maps owned by the government, and then marked on uniform line guides which were sent to district magistrates for development into standard district maps. The detail of these is astonishing. Every river and stream, every principal road and bridge, every public facility and many private ones such as schools, monasteries, and shrines, are indicated.

In 1834, an obscure cartographic genius named Kim Chŏngho (fl. 1834–1864) developed one of these national collections of district maps into a uniform national album, in which he re-edited hundreds of local maps into standard rectangular sheets. This national grid map was called the *Ch'ŏnggudo*, or Map of the Blue Hills, after an ancient poetic sobriquet for Korea.

Kim Chŏngho was himself a professional woodblock carver. It is not known whether he became one in order to market his maps, or began as a blockcarver and branched out into mapmaking. But it is as a blockcarver that he first comes to notice, in 1834, preparing for a famous scholar, Ch'oe Han'gi (1803–1875), a woodblock of a Chinese copy of an English hemispheric map of the world. Ch'oe obligingly

returned the favor, writing an enthusiastic preface for the *Ch'ōnggudo*. But this contact represents the only instance when the Korean world is known to have given any documentary notice to Kim's activities. This is in spite of the fact that in 1861, Kim would produce an even more remarkable national grid map that would bring him enduring fame. He must have been of very humble social status. We have no indication of his ancestry or native place. Traditions speak of endless trips throughout the country to check details and redo existing maps, and of a faithful daughter who took care of him and helped with the blockcarving. The traditional story holds that he was arrested in 1864, supposedly for endangering national security by revealing the nation's geography to potential enemies. But scholars doubt this, reasoning that such a grave incident would surely be reflected in official records, and noting that too many copies of the 1861 map (and of an 1864 recut edition) survive to permit belief that such a thing could have occurred. The 1860s were a time of great tension, with foreign incursions and a large-scale persecution of the country's Catholic community, which had been growing since 1784 in spite of many purges and constant suppression. Could Kim's printing of a foreign map of the world in 1834 have been taken against him? Ch'oe Han'gi, the actual patron of that project, had no problem with this, but then he was an upper-class scholar of influence and repute. Kim had no such insulation, and could have been the victim of petty policemen far down in the official structure. Whatever the reason, he disappeared in 1864 without a trace.

However humble Kim's status may have been, his writing shows that he was an accomplished scholar and a respectable writer of classical Chinese. From 1834 to 1861 his doings and whereabouts are completely unknown. In 1861, under the pseudonym Kosanja (The Master of Old Mountains), a second grid map appeared entitled *Taedong yōjido* (Terrestrial Map of the Great East (Korea)) Fig. 3. Kim's short preface deals mainly with the importance of maps for military affairs.

The *Taedong yōjido* was a completely reconsidered cartographic image of the country.

The shapes-and-forces treatment received here its greatest representation. Mountain ranges were now represented by a solid black line, thinner for lower ranges, thicker for higher ones, with special jagged teeth on the line to represent particularly rugged stretches, or white peaks to indicate snowy heights. The clarity of the overall effect is impressive. With the *Taedong yōjido*, a complete union of cartographic display and woodblock publishing technique was achieved. Kim seems to have wished to present simply the earth and its natural and human features, with the cartographic structure left, so to speak, underground.

The complete printed *Taedong yōjido* is likely to have been very expensive. To make his vision of Korea more cheaply available, Kim produced a single sheet version which put the whole nation on a rectangle of about 115 × 76 cm, giving it the title of *Taedong yōji chōndo* (Complete Terrestrial Map of the Great East (Korea)). The short text that filled the Bay of Wonsan gave the map something of the quality of a patriotic morale poster. After introducing Mount Paektu as "the grandfather of Korea's mountain arteries," giving the dimensions of the seacoasts and northern rivers, and proclaiming the greatness of the nation's legendary founders Tan'gun and Kija, he concluded with his ringing climax: "Tis a storehouse of Heaven, a golden city! Truly, may it enjoy endless bliss for a hundred million myriad generations! Oh, how great it is!"

The District Map

We have seen that in the late eighteenth century, the Korean government had taken special measures to see that all the districts of the country were uniformly mapped. Although the purpose of this program was to create a national standard, in fact local maps reflected the distinctive features of the district. These highly skilled, uniform maps of districts could not displace the traditional local maps in popularity.

The traditional local map must properly be called a map-painting. It was composed and executed by a practiced painter rather than by a



Maps and Mapmaking in Korea, Fig. 3 *Taedong yōjido* (Terrestrial map of the Great East (Korea). Courtesy of the East Asian Library, University of California at Berkeley)

mapmaker, and it set the community into the surrounding landscape in the manner of a landscape painting. The village was seen from a fixed orientation, most commonly with north at the top, and usually in bird's-eye view; roads, rivers, and walls divided up the space in realistic proportions. Distances were indicated by short notes inserted at a focal point in the road. Houses were nestled together in homey elevation, smoke rising from the chimney, a chicken pecking at the ground by the wall. The village well was in its proper place, but visited by ladies and water-boys. The school house with its surrounding pines was a miniature all by itself. In the distance, tucked into the hills, were the familiar shrines and monasteries. In Korean, as in the other East Asian languages, the word for "picture" and "map" was the same, and traditional Korean map-paintings exactly reflected that ambivalence.

City Maps

Seoul was the nation's first city, and was the home of virtually all of the nation's prominent people. Those who lived there seem to have been very fond of maps of the city mounted on folding screens in one of the principal rooms of the house. Although these maps often showed the close urban detail of streets and buildings, one does not get the feeling that those who bought them did so in order to find their way around. The city was large enough so that a bird's-eye view would be unable to reveal the order and scale of its streets and alleys. Thus most maps of Seoul are executed in aerial plan, although the surrounding mountains were characteristically drawn in pictorial elevation.

P'yōngyang is Korea's oldest city. Once a capital of the ancient kingdom of Koguryō, it was always an important regional center in later

dynastic days. As the capital of P'yŏng'an Province on Korea's northwestern border facing China, it had great strategic and commercial significance. Maps of the city are commonly encountered and must have always been a popular souvenir. Although maps in aerial plan are known, the favored orientation for its mappers was a bird's-eye view looking toward the city over the Taedong River from the east. More than maps of Seoul, those of P'yŏngyang took on many of the qualities of the map-paintings of smaller towns.

Defense Maps

After the invasions of Korea by the Japanese in 1592–1598 and the Manchus in 1627 and 1637, Korean statesmen adopted policies that put a high emphasis on defense and military preparedness. Thus for the years of the seventeenth through the nineteenth centuries, a great variety of defense maps (*kwanbangdo*) were produced. Most of them are unique and few were ever copied, accounting for the fact that most of those surviving today are original works. Some, such as the *Yogyŏ kwanbang chido* (Map of the Defenses of the Liaoji Area) are vast panoramas that stretch from the northeastern coast of Korea northward toward the Amur River and westward to Beijing itself. Others show particular sections of the northern frontier. There are many having the character of charts that map Korea's coastal areas. There are detailed paintings of mountain fortresses. One sees in these works a great variety of styles, media, and painting skills. These maps, which in their day were in the category of classified information, are now prized for their unique approach to national and international cartography, and in many instances also for their highly stylized and artistic manner of execution.

Though one of East Asia's smaller countries, and always the object of Chinese cultural influences, Korea has had a proud and distinguished tradition of mapmaking all its own, and not a small number of unique cartographic achievements. The *Kangnido* is East Asia's oldest surviving world map, and by world standards at the

time of its composition in 1402, one of the best realizations of world geography known from that time. The *Ch'ŏnhado*, though it reflects only Chinese geographic views and source material, is a map that China itself never produced. Chŏng Sanggi's maps of Korean provinces achieved a high standard of cartographic excellence and artistic distinction. Kim Chŏngho produced two great grid maps of Korea, and achieved a standard of cartographic imagination and excellence. Korea's great corpus of maps, now in Yi Ch'an's magnificent album, are deserving of serious attention and the further research efforts of the world's cartographic historians.

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Maps and Mapmaking in Mesoamerica

Barbara E. Mundy

When Spanish conquistadores first set foot in Mexico in the early sixteenth century, they found that many of the indigenous peoples they encountered made maps – graphic records of space. Since Mesoamericans had no previous

contact with civilizations outside the New World, their mapping traditions developed independently and thus were distinct from those of Europe and Asia. Maps from central Mexico depended upon pictographic writing to convey place names and geographic information, and they were often drawn on native paper or cloth. Frequently, territorial maps would include historical narratives, also written with pictographic symbols. With the Spanish Conquest, the isolation of Mesoamerican mapping came to an end as it came under the sway of European forms and style. However, native peoples have continued using and making maps that are indebted to the native tradition.

Because preconquest Mesoamerican maps were frequently perishable, few such territorial maps survive today. Scholars therefore depend upon eyewitness Spanish accounts of native mapping in the decades after the Conquest as well as “pre-Hispanic-style” maps – those made in the decades after the Spanish Conquest that show little European influence – to reconstruct Mesoamerican mapping in the century or so before the Conquest. Unfortunately, the maps and mapping of earlier Mesoamerican civilizations – the Olmec, the Classic Zapotec, and the Classic Maya – are lost to time.

Nahua, or Aztec, maps are best known because Nahuatl speakers dominated central Mexico at the time of the Conquest. Nahuas also had the greatest degree of interaction with colonizing Spaniards. Many pre-Hispanic-style maps from the Nahua heartland in the Valley of Mexico (the site of the present-day Mexico City) survive. These maps had practical uses within Nahua society. For individuals, Nahua mapmakers carefully measured house lots, orchards, and gardens to make large-scale maps that documented their property. For neighborhoods, they drew up maps so that ward leaders could apportion lands and collect tribute. For towns, they created cadastral records that included individual maps of each family’s plot. Not all Nahua maps showed such familiar territory: Nahua military spies mapped the layouts of foreign cities to help army commanders in planning their battles of conquest.

In the densely settled Valley of Mexico, scale-model maps were of some importance. Here, precise ways of measuring plots of land using ropes and measuring sticks were in evidence in the years after the Conquest. Two basic units of measurement coexisted in the Valley: the *quahuil*, measuring about 2.5 m, and the *cemmatl* (which ranged from 2.5 to 1.77 m). Lines, representing one linear unit, and dots, representing 20, were used as counters. Fractions of the basic units could be shown with glyphs representing arrows (*cemmitl*), hearts (*cenyollotli*), bones (*omitl*), or hands (*cemmatl*). In some maps, area is also calculated and recorded in square *quahuil*. Such measured precision in maps and specialization among maps may have been unique to the urbanized and hierarchical Nahua.

The Nahua were, however, very much like other Mesoamericans in making community maps, which were perhaps the most ubiquitous maps in the pre-Hispanic world. They are sometimes called *lien*zos, after the Spanish word for “linen,” since many are painted upon cloth. These maps often showed the boundaries or extent of territory of a native city-state that the Nahua called an *altepetl*. To make community maps, mapmakers used pictographs arranged on a paper or cloth sheet to mimic the distribution of places and geographic features in space. Mapmakers did not carry out specific measurements of the contours of the landscape, but rather used symbols standing for the names of both places and physical landmarks, placing them relative to each other on the sheet. Thus community maps depended upon a mapmaker’s knowledge of names – rather than absolute geography – to define the landscape. These community maps aimed not only to map territory, but also to record history. Given the primacy of the oral tradition in Mesoamerica, the maps may have functioned as mnemonic devices, designed to accompany the historian’s account. The map’s historical narrative, written in pictures and in pictographs upon the surface of the map, would often tell of a community’s travels to reach its present territory. It might also show the battles a community fought and alliances it struck in order to cement

its rights to lands. The Codex Xolotl of ca. AD 1540 is perhaps the earliest of such map histories known from the Valley of Mexico; the Mapas de Cuauhtinchan nos. 1–4 are notable map histories made outside of the Valley near the important pre-Hispanic center of Cholula.

The mapping by the Mixtec, who live in the modern state of Oaxaca, centered on community maps similar to those made by the Nahuas, their northern neighbors. Since Mixtec communities tended to be small and independent, never coalescing into the complex hierarchical states of the Nahuas in the Valley, they had little need for the same kind of property, ward, and war maps. The community maps they made in abundance brought together spatial records with historical narratives, again recorded with pictures and pictographs. While Nahuas community maps focused on peregrination and conquest, Mixtec ones emphasized genealogy – specifically the genealogy of each community's ruling family. In a characteristic community map, the Lienzo of Zacatepec of ca. AD 1540–1560, the boundary markers of Zacatepec's lands are written down with pictographic place names to create an inner frame within a rectangular sheet of cloth. Within this boundary map, the important ancestors of Zacatepec's rulers are shown with figures and named with pictographs.

While the Spanish Conquest inexorably changed Mesoamerican culture, native communities continued to make traditional maps to document their boundaries vis-à-vis those of adjacent communities and to keep records of community history. While these maps are best known from Nahuatl- and Mixtec-speaking communities, other ethnic groups in Mexico had their versions of community maps. Among them were the Otomí, Zapotec, Totonac, Huastec, Chinantec, Cuicatec, and Mazatec. Today, many towns and villages in Mexico still hold community maps. While these maps may have been redrawn and reinterpreted in the past five centuries, their roots remain in the native traditions of the preconquest period.

Less is known about the history of Maya mapping, even though the Classic Maya of AD 300–900 left us a rich record, written in a partly

phonetic script, of their dynastic histories. Existing Maya maps from the postconquest period show the heavy influence of European forms and convention. These Maya maps use the European, not the Maya, alphabet to write place names. And other Maya records of territory take the form of written records rather than maps. Such quick conversion of Maya maps to European forms is perfectly understandable: having a writing system of their own, the Maya could easily adapt a foreign one to create territorial records that took a written, rather than a map form. In addition, the few Maya maps that we know of were probably not created to be used among the Maya, but to be presented to Spaniards in courts. Thus the effectiveness of these maps in proving territorial claims was only increased by shedding native conventions and adopting European ones.

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Maps and Mapmaking in Southeast Asia

Joseph E. Schwartzberg

Indigenous maps from Southeast Asia were drawn for a multitude of secular and religious purposes and exhibit remarkable diversity in respect to medium, style, and content. Even within individual countries and cultures the surviving cartographic corpus is likely to be quite varied, though Burma and Vietnam were moving toward a national style in recent centuries. Broadly speaking, maps fall within four main traditions:

1. Tribal, for groups that never came under the cultural dominance of the great traditions of Hinduism, Buddhism, or Islam
2. Hindu-Buddhist, for cultures primarily shaped by influences emanating from India
3. Sinic, for the Vietnamese
4. Malay, for Islamicized peoples in what are now Indonesia and Malaysia

The number of surviving maps is great for Burma and Vietnam, and relatively few for Thailand (largely because of the Siamese tradition of purging documents that were no longer of current utility), Cambodia, Indonesia, and Malaysia. For Laos and the Philippines, indigenous maps are not known to exist. The corpus of known indigenous maps, however, is not a reliable guide to past cartographic output, since the accidents of preservation and documentation depend in large measure on the attitudes of

colonial powers and individual scholars with respect to indigenous culture. It is likely that many maps still await discovery, especially in Buddhist temples and monasteries on the Southeast Asian mainland.

Tribal maps are documented mainly for the Sakai, an isolated Negrito people of West Malaysia, the Bataks of Sumatra, and various Bornean groups collectively known as *Dayaks*. For all of these the traditional medium was ► [bamboo](#), into which designs were etched to create the map image. For the Sakai the mapped images served as magical charms to help insure success in hunting, fishing, and other activities in the places depicted or to ward off diseases and natural hazards associated with those places. Batak maps were mainly cosmographic or divinatory. Dayak maps, the most recent of which are exceedingly vivid designs on paper (supplied and preserved by missionaries), relate mainly to mortuary cults and relate to routes taken by the dead to reach the netherworld or the upper world and to the activities that take place therein. Dayaks also had a system of reading pigs' livers as if they were maps to discern auguries of good or bad outcomes for contemplated actions in particular places. There are no reliable guides to when mapping commenced among Southeast Asian tribal groups.

Hindu-Buddhist maps were drawn on palm leaf, indigenous bark paper (often assembled accordian-style in long folding manuscripts), cloth, and other media. In dealing with maps in this tradition it is necessary to distinguish between essentially religious and secular productions. The former are largely cosmographic, most depicting all or part of the Buddhist cosmos. Maps of the terrestrial plane, centered on Mount Meru, the axis mundi, generally utilized a planimetric perspective. Those that also showed the manifold heavens and hells normally depicted the universe as if seen mainly in frontal elevation, but sometimes rotated the horizontal terrestrial plane 90° so as to maintain the traditional planimetric view for that region. Other Meru-centered maps show the mountain and its seven rings of surrounding mountains in vertical profile. One such depiction, more than 10 m in height, is carved

into a cliff in Central Myanmar (Burma). A sumptuously illuminated cosmographic narrative, quite popular in Thailand, is the *Trai Phum* (Story of Three Worlds, *Traībhūmikathā* in Sanskrit). This work, compiled in ca. 1345, is a variant on the Jataka tales, relating to the past lives and wanderings of the Buddha. It has gone through a number of recensions and exists also in modified form in Myanmar and Cambodia. The longest manuscript, dating from BE 2319 (A.D. 1776), provides a continuous picture on 272 folding panels with an overall length of 32 m. Six of these panels depict Asia from the Arabian Sea coast to Korea. No surviving manuscript predates the sixteenth century. Hindu cosmographies were probably also painted in Southeast Asia, but apart from one attributed to Cambodia, none is known to survive on the mainland. Complex cosmographic works, however, continue to be made in various media in Bali.

The oldest known geographic map in the Hindu-Buddhist tradition, dating from the late seventeenth or early eighteenth century, is a long folded-panel work showing ecclesiastical and other property holdings in what is now southern Thailand. Thereafter, there is a long hiatus in Siamese secular cartography, but the period of the Chabri Dynasty, 1782–1851, saw a following of mapmaking under royal patronage. Maps then produced were mainly topographic and covered much of Southeast Asia. Some related also to maritime commerce, one extending as far as Japan, while others were strictly military. The maps were painted both, incorporated many standardized conventions, and were often quite large, the largest measuring S17 by 416 cm. (roughly 16 × 14 ft). Known Burmese secular maps do not predate the latter half of the eighteenth century. But one may safely assume that the mapmaking was by then a well-established art. Numerous maps, many covering rather large areas, were drawn for Francis Hamilton during his sojourn in Burma in 1795 and attest to the geographic sophistication of educated Burmese at that time. During the nineteenth century, if not earlier, the Burmese state engaged official surveyors and cartographers. Maps on European paper and cloth became increasingly common with the

passage of time. Burmese maps were drawn largely for military and political intelligence purposes, sometimes to plan or to document specific campaigns. Others, showing property holdings and types of land use, were used for purposes of taxation. Many were used as aids for laying out new cities, monastic complexes, irrigation systems, and other public works. A common feature of Burmese maps was the use of a regularly ruled grid, very likely to transfer a sketch from one scale to another, though maps were never drawn to a uniform scale. Many of the maps from what is now Myanmar were actually drawn by ethnic Shans (a Thai people) and other ethnic groups within the Burmese political orbit. From insular Southeast Asia, only one presumably geographic map in an essentially Hindu tradition is known. Drawn on a batik shawl, this ornate and enigmatically patterned work probably dates from the early nineteenth century. It has no text, but is believed to relate to the former princely states of Surakarta and Yogyakarta, which, though ruled by Muslim sultans, maintained a largely Hindu court style.

Vietnamese cartography was mainly secular and, as in Burma, drawn for the military, administrative, and other political needs of the government. (Cosmographic maps did exist, but these were mainly in the Hindu-Buddhist tradition previously described.) The oldest textual references indicate that secular maps existed as early as the late eleventh century, though mapping appears not to have become a serious concern until the government was reorganized along Sinic bureaucratic lines some four centuries later. Thereafter, the map style was a regional variant of a general Sinic tradition, though changes were evident from one period to another. Many of the maps were bound, after the Chinese fashion, into atlases, which, with their abundant text, served also as gazetteers. The oldest atlas, made in the 1270s, related to a royal inspection tour of the then relatively circumscribed Vietnamese state, but it does not survive and its form is not known. In addition to atlases and regional maps, the Vietnamese drew route maps, maps of river systems and coastal maps to facilitate navigation; city plans, some of which were remarkably detailed;

maps of individual forts and other edifices; and maps documenting tribute missions to the Chinese court in Beijing.

Surviving maps from the Malay cultural realm, though few in number, are quite diverse. The oldest, dating from the late sixteenth century, is a large cloth map covering the western third of Java. Most of the map space is given over to the depiction of the small chiefdom of Timbanganten, whose prince commissioned the work. The symbolization on this map is particularly distinctive and has no close analog in any other known work. All the remaining maps show varying degrees of European influence. A map of the Bornean Sultanate of Pontianak and another of part of East Central Java apparently related to administration and/or taxation. Others related to navigation and trade. One shows ports and commercial products of the Malay Peninsula. The others, covering most of Southeast Asia, are detailed hydrographic charts, copied onto cowhide, from an early nineteenth-century Dutch original, but with adaptations indicating independent depth soundings and new coastal observations. These maps were drawn and used by wide-ranging Bugi pirates and contain abundant text written in the Bugi script, though Roman numerals were used to indicate ocean depths. Apart from the surviving nautical maps, there are textual and other grounds for supposing that Indonesians made use of maps in long distance navigation prior to the advent of Europeans in the region.

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Maps and Mapmaking in Tibet

Joseph E. Schwartzberg

For purposes of this article Greater Tibet includes not only the present Autonomous Region of Tibet, within China, but also the Chinese provinces of Qinghai and Sikang, the Indian regions of Ladakh and Sikkim, much of Nepal, and Bhutan, which have all been, greatly influenced by Tibetan Buddhism and other aspects of Tibetan culture. Despite its small population, this region has given rise to a remarkably rich and varied cartographic tradition. Moreover, that anciently rooted tradition still survives, despite attempts by the West, China, and India to impose political and cultural hegemony over the lands of its development.

Given the pervasive role of religion in Tibetan culture, it is hardly surprising that maps serving a variety of religious functions form the greater part of the region's cartographic corpus. These are commonly painted on cloth *thaṅkas*, which frequently occupy a focal position in family and monastic altars. The most abstract of Tibetan religious maps are *maṇḍalas*, which are regarded

as representations of the cosmos and serve as objects of meditation for clergy and laity alike. These assume many forms, in both two and three dimensions, and utilize a wide range of media. Elaborate *maṇḍalas* fashioned from colored sand or carved in yak butter may be created over a period of weeks, but are kept for even less time than it took to construct them, thereby demonstrating the transience of all earthly existence. Many cosmographic maps were divinatory. Others were didactic, for example, paintings of the *bhāvacakra* (wheel of life) depicting the various realms of existence through which souls may transmigrate on the path to *nirvāṇa* (the ultimate aim of existence in which the soul is liberated from the painful round of rebirth). Other forms of didactic painting are essentially hagiographic, showing various incarnations of the Buddha, *bodhisattvas*, or revered lamas surrounded by collages of sacred landscapes depicting particular places associated with their existence, both on earth and in nonterrestrial portions of the Buddhist cosmos. Though largely mythic, such places are often shown with a considerable sense of verisimilitude. Maps showing the cosmos as a whole or major portions of it are numerous. Some of these are large mural paintings. A particularly vivid set of fresco murals in Bhutan shows the evolution of the cosmos as a succession of disaggregations of terrestrial and extraterrestrial elements in space-time as described in various Indian and Tibetan Buddhist texts dating back to the fifth century. In these and many other cosmographic maps Mount Meru, the axis mundi, and four principal surrounding continents in the terrestrial plane figure prominently. Maps of other continents are also painted, two of particular note being Sukhāvatī (the Western Paradise) and the mountain-girt utopian realm of Śambhala (whence James Hilton's "Shangri-la"). Bards used to wander about Tibet illustrating stories of the way to Śambhala with map scrolls on which routes began in recognizable places, but led ultimately to mythic space. To devout Tibetans, however, the distinction between the real and the mythic would seem a false dichotomy.

Geographically identifiable locales do figure prominently in Tibetan religious maps. Many show individual religious edifices and centers such as the Potala and Tashilunpo, the residences of the Dalai and Panchen Lamas, respectively; Lhasa and Shigatse, in which those two residences are, respectively, located; or Samye, Tibet's oldest monastic complex. Others show sacred landscapes in which groups of such centers, especially those proximate to Lhasa, are clustered. Some maps focused on Mount Kailas, in western Tibet, viewed as the earthly manifestation of Mount Meru, around which a complex of sacred pilgrimage places developed. Large sacred maps were displayed along the walls of the monasteries where they were held during certain holidays, when pilgrims would flock to major religious centers. One such painting, displayed annually in the Nepali town of Patan, has a length of more than 25 m and provides a rich panoramic view of the Vale of Kathmandu. Maps were made not only to serve the needs of pilgrims, but were also commissioned to commemorate pilgrimages completed. A particularly beautiful example, dedicated in A.D. 1802, depicts the patron and his entourage at many of the major pilgrimage places in central Nepal.

When Tibetans began to make maps is not known, but the roots of Tibetan cartography run deep. One of the most remarkable maps, depicting the anciently known world, appears in a modern recension of a dictionary of the Zang Zung language (probably Indo-European), formerly spoken in western Tibet. Though the places shown, reaching as far west as Egypt and Greece, were compressed into the form of a rectangular *maṇḍala*, thereby losing much of their geographic logic, most could be related to the period of Alexander the Great (late fourth century B.C. E.). The map itself focuses on Parsogard, the Achaemenid capital from 550 to 522 B.C.E. There are grounds to believe that some version of this map was transmitted from antiquity to the present, despite the fact that no premodern version is known to survive. Another simpler, but equally cryptic, surviving world map was brought to Japan in A.D. 891.

Apart from the two world maps just noted, one map of Nepali provenance (but stylistically akin to Tibetan maps) covers a very large region of Central and Southwest Asia, with western limits at Baghdad and the Russian city of Saratov, on the Volga River. It has been argued that this map was commissioned ca. 1860 in relation to a contemplated, but never consummated, grand alliance to drive the British from Asia. This richly detailed map, despite its late date, includes numerous features that are essentially mythic.

A remarkable series of maps is that of the so-called Wise Collection in London's India Office Library. Wise's identity has not been established; but there are grounds to believe that the maps were prepared by Buddhist recruits (later dubbed *pundits*) from India's Himalayan territories who traveled over much of Tibet in disguise to gather intelligence. British training notwithstanding, the style of these maps is distinctly Tibetan.

With the aforementioned exceptions, regional maps from Tibet seldom cover more than a few thousand square kilometers. None is known to predate the late eighteenth century. As a group, the maps in question are remarkably detailed and utilize a well-developed set of symbolic and color conventions. They typically combine diverse perspectives: planimetric, high oblique, and frontal, depending on the features shown. Important buildings are sometimes shown as if seen from several sides simultaneously. There is no consistent orientation. Regrettably, only a few Tibetan maps have yet been studied as such by scholars with the needed cultural sensitivity and linguistic skills.

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Maps and Mapmaking in Vietnam

John K. Whitmore

The tradition of mapping began in Vietnam just over half a millennium ago. As the state of Dai Viet, led by the young king Le Thanh-tong (1460–1497), adopted the administrative model of the Ming dynasty in China and became more centralized, mapping served as one of the procedures to that end. The new bureaucratic structure placed officials in the provinces and districts and ordered that these officials gather and relay information to the capital of Thang-long (now Hanoi) on the land and people within their jurisdictions. Maps were part of the required information, and they led eventually to an atlas covering the entire country. This atlas and its maps in the Chinese mode set the pattern of administrative cartography well into the nineteenth century.

The same reign also saw the extension of Vietnamese territory to the south as Thanh-tong crushed the forces of Champa in 1471. A map showing the stages of the expedition became the model for military and commercial cartography in the following three centuries. As these centuries were a time of military and commercial expansion, particularly of the *Nam Thien* (Southern Push) further down the east coast of mainland Southeast Asia through Champa and into Cambodia, this style of map came to reflect the dynamics of the Vietnamese population.

International contacts in the late eighteenth and early nineteenth centuries led to a new style of administrative mapping which combined a more realistic Western (particularly French) style with stronger Chinese elements. Yet, by the end of the nineteenth century, as French colonialism controlled the Vietnamese state, there appeared a shift toward a more complete Sinic [Chinese] mode of illustrating maps.

No technical study of Vietnamese maps based on the original documents exists. Looking at reproductions, mainly in black and white, yields the following observations. The maps available to us are almost entirely hand drawn in black ink, some with added color to emphasize their features. Only in the mid-nineteenth century did printing begin to play a major role in cartography here.

The earliest extant map, most likely from the sixteenth century, is quite simple in form and style. Lines were drawn to show the rivers and the land separating them. Nothing indicates water in the streams, and the standard Chinese three-ridge pattern for mountains served to suggest the highland regions above the plains. Names (in Chinese characters) marked location with no other symbol employed.

This changed in the seventeenth century as the earliest existing major corpus of indigenous maps appeared. They had become more artistic. Water was drawn in the streams and off the coast (river currents and roiling sea waves). Mountains retained the same style, but more accurately designated Vietnam's uplands. In addition, palaces, temples, and walls appeared (in frontal elevation), while jurisdictional locations were marked by written characters in rectangular boxes with little sense of hierarchy among them. Other characters showed the locations of natural features and additional human constructions.

In the eighteenth century, Vietnamese cartography took on in places a more artistic and Sinic mode. This change appeared particularly in the style of portraying the mountains. In place of the simpler three-ridge style, there came to be a more naturalistic landscape mode which well fit the vertical karst topography of northern Vietnam (and southern China). In addition, waves lapped

on the shore, and temples and walls received a more Sinic treatment. The maps were drawn in black ink with colors (red, gray, and blue, for example) used to highlight roads, buildings, and mountains.

The nineteenth century saw more sophisticated international influences appear in Vietnamese mapping. Southern political forces had contact with French military figures and adopted the Vauban style of fortification. Simultaneously, the new Nguyen dynasty chose to hew more closely to the contemporary Qing dynasty of China. Though elements of the old Le style would continue, more realistic elements appeared on Vietnamese maps within the context of Chinese forms. A regional division of the country led the north to maintain the old style as French forms appeared in the south. The central region around the capital of Hue gradually forged a national style which, by 1840, showed the country of Dai Nam and its hydrographic complexities in a European perspective.

While becoming more realistic in outline, the artistic style shifted from the earlier sketchiness to a more specifically Chinese mode. This change appeared particularly in the mountains with their vertical and naturalistic mode, continuing to match the karst topography of the north. The new international style developed through the nineteenth century until the French conquest in the 1880s. Thereafter, in the early years of the twentieth century, the reaction against French rule among Vietnamese literati led to the greater emphasis on the Chinese style over the realistic mode.

The first centuries of Vietnamese mapping (fifteenth to eighteenth) produced two different genres: one administrative, the other military/commercial. The first, the atlas, originated in Le Thanh-tong's governmental transformation of the 1460s. In it, each of the 13 provinces had a map showing the location of its prefectures and districts and a list of the types and numbers of villages contained therein. In addition, the atlas included a map of the country, noting the location of each province, and a map of the capital Thang-long. Despite originating in the fifteenth century, the earliest extant atlas, the *Hong Duc Ban Do*

(Maps of the Hongduc Era), comes from the mid-late seventeenth century. As noted above, a single map of the country, showing its administrative units, does seem to be from the sixteenth century. In the atlases, natural features, particularly rivers, and some human construction like city walls and temples were also noted. The maps generally are seen from the sea (the east) and hence have a Western orientation. Since the Le dynasty (1428–1787) rose from the then southern provinces of Thanh-hoa and Nghe-an, these two maps came first after those of the country and the capital.

The other genre involved itineraries of different kinds, each a series of maps showing the way (usually from the capital region around present-day Hanoi) out to a distant location. The genre seems to have originated in Le Thanh-tong's major campaign south against Champa in 1470–1471. Again, the earliest extant example comes from the seventeenth century, the *Thien Nam Tu Chi Lo Do Thu* (Book of the Major Routes of Thien Nam). At that time, the southern route was joined to three shorter routes to China: northeast, northwest, and north (the standard route to Beijing). These maps, and particularly those of the southern route, provide much more detail of daily life than does the atlas. They illustrated features of the land, the rivers, and the sea as well as elements of Vietnamese common and commercial life (markets, inns, temples, military installations, etc.). Another seventeenth-century itinerary, the *Binh Nam Do* (Map of the Conquest of the South), comes from the southern regime of the Nguyen and takes us through their territory of central and southern Vietnam to Cambodia. It shows the path of the Southern Expansion (*Nam Thien*) of the Vietnamese people then taking place.

The eighteenth century produced new, more artistic versions of the seventeenth-century atlas and itineraries. In addition, a new itinerary appeared in various forms – that of the Vietnamese embassy north to the Qing capital of Beijing in northern China. Once across the Chinese border, the delegation traveled mainly by river and canal, and these sets of maps were drawn from that perspective, showing the mountains and

villages stretching away from both sides of the route. Finally, at the end of the century, there appeared the only known map of the brief Tay-son dynasty (1788–1802), a single page showing Siam (Thailand) and the routes through it from north to south. This map, like all other pre-1800 ones, had very little sense of the river systems to the south, particularly the Mekong Delta and the Great Lake of Cambodia.

Three major developments led to cartographic change in the nineteenth century: the international context, the initial regional control of the country (north, center, and south), and the borrowing of the Chinese geography form. The combination of these three brought the gradual emergence of a new form of mapping. This single form, the geography with maps accompanying the text, replaced the Le atlas as an administrative tool. Curiously, the genre of the itinerary disappeared, continuing only in the reproduction of earlier texts.

Just as the northern and southern regional autonomy was finally integrated into the central government during the 1830s, so their styles merged with that of the center and its usage of European and Chinese elements, as seen in the *Dai Nam Toan Do* (Complete Map of Dai Nam). The map of the entire country, now stretching from China to Cambodia, in particular took on a more Western form. The coast and the southern rivers, even the Great Lake of Cambodia, appear much more familiar, and the provincial maps are more realistic in our eyes, showing rivers in a dendritic manner for example [having a branched form].

Blending the new maps with the geography form of the Chinese *yi-tong-zhi* (Vietnamese *nhat-thong-chi*), Nguyen cartography reached its peak first in the *Dai Nam Nhat Thong Du Do* (Maps of the Unity of Dai Nam) of 1861 and finally in the imperial geography, the *Dai Nam Nhat Thong Chi* (Record of the Unity of Dai Nam). The latter, compiled and printed between 1865 and 1882, is a text describing the country of Dai Nam, its capital of Hue, and the 29 provinces and presenting maps of each of them. Even though the French had already seized the six provinces of the south, the Tu-duc Emperor kept this section in the geography together with those

of the center and north as a symbolic representation of the whole.

Mapping of the nineteenth century was thus almost entirely involved with administrative matters, like the old Le atlas. The only itineraries were copies of the seventeenth- and eighteenth-century maps. The country map in the administrative collections did, however, provide a broader international setting than had occurred under the Le. This was done in a form similar to the European mapping of the time.

The major new form of map in the nineteenth century was part of the *dia-bo*, the land registers. Recording the land plots of each village, these documents show them in outline and provide their dimensions and type. The government produced these maps in a number of survey (and resurvey) campaigns through the first half of the century. Another new form of map was the symbolic diagram of the imperial tombs. The resulting drawings emphasized the symbolic relationships of mountains and water, and show the strongly Chinese style adopted by the Nguyen dynasty.

Vietnamese mapping was mainly the result of 400 years of administrative effort. Beginning with Le Thanh-tong's reforms in the 1460s, the need to know the bureaucratic jurisdictions and their villages led to the Le atlases and the Nguyen geographies. The fifteenth-century military campaign began the Vietnamese itinerary which to all appearances became commercial. The Vietnamese cartographic tradition was almost entirely internal, not external. Until the 1830s maps rarely showed much beyond their borders, the major exception being the eighteenth-century embassies to China. In addition, all the routes illustrated were by land, not by sea.

See Also

► [Geography in China](#)

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Maps and Mapmaking of the Australian Aboriginal People

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One of the most common forms of representation in Australian Aboriginal culture is the map. Bark paintings are often maps, as are sand sculptures, body painting, and rock art. Spear throwers and log coffins may be decorated with maps. Message sticks and Toas (waymarkers) may incorporate geographical information. In 1957 the anthropologist Donald Thomson visited the central Australian desert country belonging to the Pintupi people and described his experience:

I was able to...live and hunt with a group of desert-dwelling aborigines who still followed the life of their ancestors... On the eve of our going (return) Tjappanongo produced spear throwers, on the backs of which were designs deeply incised, more or less geometric in form. Sometimes with a stick or with his finger, he would point to each well or rock hole in turn and recite its name, waiting for me to repeat it after him... I realized that here was the most important discovery of the expedition that what Tjappanongo and the old men had shown me was really a map, highly conventionalized, like the marks on a "message" or "letter" stick of the aborigines, of the waters of the vast terrain over which the Bindubu hunted.

Tjappanongo was clearly endeavouring to convey topographic information and hence was non-problematically drawing a map. Peter Sutton argues such maps should be distinguished from iconic representations which, while spatial, are largely symbolic and performative (Sutton, 1998a, p. 362). However, it seems plausible to accept an inclusive definition of a map as a device for organizing knowledge spatially, Courts of law

are now accepting paintings of the Dreaming tracks of the ancestral beings as evidence of ownership and hence the distinction between maps and icons is becoming blurred (Turnbull, 1998). Why then are maps so ubiquitous in a culture that has no written language and, purportedly, has little of the social complexity held to characterize contemporary Western culture? The answer is that Aboriginal culture is far from simple, having as it does one of the richest religious systems in the world, and that its central values are embodied as knowledge; knowledge that is spatially organized because the land and relationships to it underpin everything. Aboriginal culture is spatialized linguistically, socially, religiously, artistically, and epistemologically. Aboriginal ontology is one of spatialized activities, of events and processes, people, and places. To talk of things is to speak of the relationships of processes at named sites, it is to consider the connections between actions of the ancestral beings and humans. Every moment of daily life is replete with spatial references; asking someone to move over may be phrased as "move northwards please". Dreams and narratives are cast in a framework of spatial coordinates. Visiting groups at ceremonial gatherings distribute themselves in a spatial replication of the location of their homelands. Ceremonial and initiation grounds are spatially constructed and oriented either to other sacred sites or to the sun. The pervasiveness of spatiality in Aboriginal daily life jointly derives from the semantic structure of the language in which the subjects of sentences are not things but relations and from the centrality of the land in Aboriginal cosmology. It is the land that is the source of value and meaning, of rights and obligations. Everywhere is sacred since all the land was created in the Dreaming by the activities of ancestral beings as they moved across the landscape. These journeys left Dreaming tracks, knowledge of which is recreated in song, story, and ceremony. Everyone has a spiritual linkage to the land by virtue of birth such that they are the land. Knowledge of the Dreaming tracks, of the activities that created the land of one's birth, is therefore evidence of possession of the land and by the land. Continued prosperity of the land

depends on the fulfillment of the ceremonials and rituals which are in effect both a celebration of ownership and a continuation of the act of creation. The landscape is the source of meaning and value and the repository of history and events and can be read as a map of itself and its own creation (Watson, Helen and the Yolngu community at Yirrkala, 1993, p. 36).

However, it is knowledge that is the primary marker of status and the primary item of exchange (Palmer, 1991). Surface knowledge is the outside knowledge that anyone can speak of; inside knowledge is that which only the initiated can speak of and which is gradually revealed through life as maturity is attained. The way the Yolgnu of Eastern Arnhemland structure their system is typical of the ways in which it is possible for Aboriginal groups to have a detailed understanding of their environment. Their knowledge system is dependent on the joint articulation of two modes of patterning. One is genealogical – *gurrutu* the kinship system; the other is spatial – *djalkiri* the footsteps of the ancestors or the Dreaming tracks (Watson, Helen, the Yolngu community at Yirrkala, & David Wade Chambers, 1989, p. 37). The kinship system provides an unlimited process of recursion that enables all things to be named and related and thus imposes an order on the social and natural world that gives it coherence and value. It provides the framework within which social obligations with regard to life, death, marriage, and land can be negotiated. The other mode of patterning is provided by the stories, myths, or Dreamings that relate the travels and activities of the ancestors in creating the landscape in the form of tracks or songlines that traverse the whole country. The kinship system and the songlines together form a knowledge network that allows for everything to be connected. The concept of connectedness is an extremely powerful one in Aboriginal culture and is exemplified by the Yolgnu term *likan*, which in the mundane sphere means elbow – the connection of the upper and lower arm – and in the spiritual sphere connotes the connections among ancestors, persons, places, and ceremonies. A wide variety of Australian Aboriginal paintings have been

interpreted as being simultaneously geographic and social; they represent both the tracks of the ancestors and detailed maps of places. Hence bark paintings are encoded knowledge of connections.

The Kunwinjku people of Western Arnhemland paint both bark and bodies at the Mardayin ceremony in the “X-ray” style that shows internal body parts. In the Mardayin ceremony the bodies of the initiates are painted so that in effect their own body parts are mapped with a design that represents the body parts of the ancestral beings and features of the landscape. These paintings can be read on one level as maps of the way Kunwinjku “conceive of the spatial organization of sites in their land in terms of an abstract model of the divided yet organically related body parts of the ancestral beings that created those lands. Such sites are described as transformations of the actual body parts of the ancestral being, and all the sites thus created are considered to be intrinsically connected” (Taylor, 1989).

The connective function of bark paintings like this helps children to learn the shape of the *wanga* (territory, land, country) and to have respect for it and the animals in it by integrating the activities of the ancestors, people, and places. Ownership of the land thus means having the right speak of the land, the right to have the knowledge of it, and also to have responsibility for both the land, and the knowledge and for its sustenance and transmission.

While the land may have boundaries that can be known with precision, it is not good custom to display them, because they are permeable rather than fixed entities with rites of access being required and most frequently granted. “Boundaries are to cross” (Williams, 1983), and “the content of ownership is the right to be asked” (Myers, 1986, p. 99). Areas can be owned by more than one group, and routes can be common property. Boundaries are more properly the subject of negotiation and exchange in ceremony, ritual, and protocol. Protocols are exemplified in the formal role of the go-between, the diplomat or *djarrma* the messenger. Moreover Yolgnu conceptions of place do not correspond to Western legal notions of enclosure but are more typically

open and extendable “strings” of connectedness (Keen, 1995). Consequently, while Australian Aboriginal groups constantly map their land, this is a very different process from that of the dominant white society. Being mapped in the white manner may have advantages, for example, in making native title claims. In fact it has become standard procedure for anthropologists to record Dreaming tracks on Western topographical maps as evidence that this knowledge is the property of the claimants. Aboriginal relationships with country do not equate with the notions of boundary precision, exclusion, and individual property rights and the linkages to the state implicit in Western maps. Aboriginal maps keep those relationships alive by celebrating and performing connections between people and land in stories, ceremony, and painting.

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Maps and Mapmaking of the Native North Americans

G. Malcolm Lewis

When considering the topics of maps and mapmaking in native North America, Europeans and nonnative North Americans have until recently tended to treat them as either novel and exceptional or inferior equivalents of their own cartographies. This is particularly so in writings before the last quarter of the twentieth century. Unconsciously but repeatedly, they imposed their post-Renaissance categories in trying to understand facets of cultures epistemologically different from their own. There is no direct evidence that before the encounter and associated acculturation, any of the native North American languages and dialects had lexical equivalents of “map” and the probability of there having been any seems decreasingly likely.

During the last quarter of the twentieth century increasingly rigorous research focused on the

artefactual maps past and present, with an inevitable emphasis on those made in the encounter context. For the most part, native North Americans were either unable or unwilling to participate in this research. From their perspective they could claim to have been uninvited and unaware of it. Most of the research was by historians of cartography, untrained in and largely unaware of cultural and social anthropology, ethnohistory, native North American studies, etc. For the most part they saw themselves as contributing primarily to the understanding of a supposedly universal cartography. The materials they studied were surviving native artefacts or, more usually but less satisfactorily, transcripts and accounts made by earlier generations of Europeans and nonnative North Americans. Almost inevitably, there was a tendency to compare and contrast with what they assumed to be the norms established by post-Renaissance cartography. The following text first summarizes their achievements before attempting to detect early twenty-first-century trends and anticipate future developments.

At or soon after their first encounters, Europeans reported that native North Americans made maps. Most of the early reports were of maps made for Europeans to communicate geographical information, as for example a map of the lower Colorado River made by a Halchidhoma Indian in 1540. Ever since, Europeans and nonnative North Americans have continued to solicit and receive geographical intelligence in this way, whether they were explorers, traders, soldiers, settlers, missionaries, government agents, field scientists, or cultural anthropologists. It was, and until very recently remained, an important aspect of frontier information exchange. Natives communicating in this way included men of every social status, less frequently women, and occasionally even children. It occurred in every culture area and in most, if not all, tribes. Because of the publicity given to nineteenth-century Arctic exploration, it has sometimes been assumed that the Inuit were particularly skilled mapmakers. There is, however, no evidence that the maps they made for Europeans were either better or significantly different from those made by Indians.

In the encounter process, most maps were made with pencil on paper. Occasionally, however, more traditional materials were used, e.g., bark, textile, skin, hard animal tissue, three-dimensional models, and even rock. The distinctive characteristics of these encounter maps were, however, neither the media nor the mapmaking processes. Although Europeans were slow to recognize it, the natives' maps differed fundamentally from their own in three important ways. The geometry was topological, a product of cultural tradition, individual experience, the shape and size of the medium, and the purpose for which the map was made. Unlike European maps, it was not a consequence of plotting locations on a graticule selected to conserve particular properties at the expense of others. They conserved neither scale, direction, nor shape, except for very small areas.

The second important difference was in the categorization and magnitudinal ordering of the phenomena represented. Whereas most European maps were general, serving a range of functions and a diversity of users, each native map was made for a specific purpose and audience. These determined content and emphasis and only the essentials were represented. Hence, large physical features occurring within the area mapped were frequently either omitted, diminutive, or highly generalized, whereas small but contextually significant features were included and perhaps exaggerated. Thus, a large, complexly shaped lake might be represented by a simple circle, ornamented perhaps by a detailed representation of one culturally or contextually significant peninsula. Similarly, an essentially straight line might represent a long, complex, maritime coastline.

The third important difference was in the natives' use of pictographs as the approximate equivalent of the Europeans' combination of words, toponyms, and conventional map symbols. Pictographs were constructed according to culturally established principles to communicate complex mixes of information about size, importance, number, relationships, time, distance, direction, and events, as well as material and organic phenomena. Richer and far more flexible

than the symbols on European maps, their information content was rarely intelligible to the aliens. Indeed, when, as they so frequently did, European's copied natives' maps, they often omitted or generalized the pictographic content. Regrettably, most extant examples of encounter maps are contemporary transcripts or, worse still, printed engravings: a small, debased sample of the many that were made, now scattered in archives, museums, libraries, government departments, and private collections in Europe as well as North America. Nevertheless, in their time, this type of native map served the aliens well; they helped them to open up their *terrae incognitae*, locate resources, plan military campaigns, etc. Though usually unacknowledged, they were frequently incorporated into the first generation of maps made by the aliens. Sometimes, misinterpretation and insensitive incorporation resulted in gross errors on maps made by Europeans, as with the Great River of the West, the Long River, and the gross westerly displacement of the mouth of the Mississippi River on printed eighteenth-century maps.

For some parts of the non-Eurasian world there is uncertainty as to whether precontact natives did or did not make maps. Each culture had a strong oral tradition, an important part of which was concerned with landscape, place, and spatial relations. Place – and feature – names were the “survey pegs” of spatial memory. This was almost certainly so among pre-Columbian North Americans, but there is considerable direct and indirect evidence that they also expressed their oral maps cartographically. For example, in 1540, Francisco Vásquez de Coronado discovered a painted skin in an abandoned Zuni pueblo. The pueblo was the first of the Seven Cities of Cibola ever to be seen by Europeans, and the painting represented their relative sizes and a route, probably the one linking them. Although difficult to date, much, if not most, North American rock art predates contact with Europeans. A very small proportion of these works have map-like appearances, at least when viewed from the European cultural perspective. Lacking texts, however, and in the light of the characteristics of native maps as now known, proof is difficult. Establishing

similitude between a topological representation and its referent is much more difficult than for a projectively constructed map. Some celestial paintings on the roofs of rock overhangs in the Southwest undoubtedly represent exceptional astronomical juxtapositions known to have occurred at precisely established dates in pre-Columbian times. Others, like Map Rock, Idaho (a name given by the earliest white settlers in the lower Snake valley, because the engraving on it looked to them like a map), do appear to represent topologically and pictographically the pattern of geographical features in the regions in which they are sited. These, however, are exceptional cases and irrefutable evidence for terrestrial maps in precontact rock art has still to be established, though the case for plans of small areas and features is much stronger.

Ironically, the strongest evidence for mapmaking in precontact times is afforded by very early postcontact accounts by Europeans of the indigenous use of maps, usage of a kind that could not have been derived from European practices. It is debatable whether at the time of first contact any of the native languages contained nouns equivalent to map, though at later stages many of them certainly did. Nevertheless, some Indians certainly possessed an ability to read network patterns as maps. Montagnais and Naskapi divination by scapulimancy involved inducing random patterns of cracks by heat or percussion on mammalian bones, and these were sometimes interpreted to be maps of actual river systems. Likewise, the women of these tribes sometimes read as trail networks patterns made by biting folded pieces of birchbark, especially when the patterns had emerged in mistake for something else intended. Maps inscribed or painted on the inner surface of birchbark (or on growing trees from which the bark had been conspicuously stripped) were frequently positioned at conspicuous or strategic sites in the Northeastern forests to convey to friends – and sometimes enemies – spatially organized information about recent events or planned activities. There are accounts of maps being made by older men to instruct young braves about to undertake long journeys for the first time. Map modeling

with whatever materials were at hand was sometimes a cooperative activity, at its best leading to a geographical consensus prior to military planings and strategic briefings. Cosmological maps were common and usually combined geographical with mythical elements, the former most frequently near the center. Where geographical features were endowed with religious meaning, they might be topologically displaced. For example, on Lakota maps of the Black Hills, the Devil's Tower, located 60 mile to the northwest, was placed within the so-called Race Track that circumscribed them. Southern Ojibway birchbark midé-migration scrolls preserve the tradition as to how the tribe received its religion: from the east via a great waterway. At the left end of some of the scrolls, the waterways of part of Minnesota are readily interpretable. A little to the right, Lake Superior is highly stylized, but further to the right (east) it becomes increasingly difficult to relate the linework to the Great Lakes-St Lawrence River waterway.

By the beginning of the twenty-first century understanding of the nature and roles of native North Americans maps was diversifying. There were at least three reasons. First, and most importantly, the ferment of ideas generated by Columbus' quincentenary scholarship had begun to influence the field. Secondly, scholars outside the field were focusing attention on often long-known but superficially less map-like evidence, especially behavioral, including ceremonial. Thirdly, least obviously, but hopefully in the longer term most importantly, a younger generation of researchers was beginning to emerge, of which some were native North Americans. It is still too soon to predict all the consequences of these factors but overt recognition of the following would seem to be very likely:

1. Native North Americans often expressed spatial arrangements other than graphically on flat surfaces.
2. Even when expressions of spatial arrangements were graphical, their geometry was not even approximately Euclidean.
3. Spatial arrangements were often expressed in nonmaterial modes, e.g., speech, gesture, and

ceremony. Others in material modes were hitherto unrecognized except by a few specialists, e.g., landscape design and architectural space.

4. A given spatial expression was not necessarily restricted to one discrete world of European epistemology – geographical, celestial, or cosmographical, as reconstructed or remembered from the past, perceived in the present, or envisaged in the future. It could include elements of two or more of these.
5. The determinants of silences in a spatial expression were neither of scale nor metrical magnitude but unimportance in the context of the specific purpose for which it was made.
6. Like all their spatial expressions, geographical maps made for Europeans and Euro-Americans were always made for a specific purpose but they were the graphical components only of a much richer multimode repertoire. Behavioral modes, if any, used in conjunction with them were either misunderstood by or unintelligible to the aliens and were either unreported or misreported.
7. Woodward and Lewis (1998) have provided a platform on which to base comparative studies of native North Americans' maps with those of traditional peoples elsewhere.
8. Geographical Information Systems (GIS) technology will become a powerful tool in studying the geometrical structure of native North Americans' graphical maps.

Most native maps represented relatively small areas and/or were linear, but a few embraced areas as large as one-third of a million square miles. The information upon which a map of a very large area was based could not have been derived from the direct experiences of an individual or even the cumulative experience of one group. Most of the content must have been based on information received by gesture and speech, perhaps over several generations.

Potentially, at least, maps made by native North Americans are significant in four broad contexts: legal, historical, anthropological, and scientific. Though lawyers have been slow to recognize it, an understanding of the fundamental

differences between native and Euro-American maps helps, in some cases, to explain disputes between the two cultures concerning treaty and land sale agreements. Likewise, but with a few notable exceptions, archeologists and historians have been slow to recognize the significance of maps made by natives in such contexts as exploration, mapping, locating resources, place – and feature – naming, etc. Similarly, cultural anthropologists have been slow to explore the relations between maps and other graphical forms or to use them as evidence in establishing worldviews, reconstructing lifestyles, etc. Scientists, including linguists, have not even begun to recognize their potential significance in such contexts as human cognition, genetic epistemology, information exchange, language, categorization of phenomena, etc. These failures stem, in part, from the absence of a cartobibliography to the primary materials. Furthermore, scientists remain unaware of the now considerable body of secondary publications that, for the most part, is confined to the literature of the humanities.

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Maps and Mapmaking: Celestial East Asian Maps

F. Richard Stephenson

For the purpose of this article, East Asia will be understood to comprise the three countries of China, Korea and Japan. In common with many other aspects of culture, mapping of the night sky in both Korea and Japan began much later than in China and closely followed the Chinese tradition.

The origins of celestial mapping in East Asia are lost in the mists of time. Very ancient rock carvings clearly depicting the Big Dipper have been found in North Korea, and these are considered to be date from several thousand years BCE. Occasional stellar names – such as *Dou* (the Ladle: presumably the Big Dipper) and *Huo* (the Fire Star: probably identified with the bright red star Antares) – are recorded on Chinese bone inscriptions from the Shang Dynasty (ca. 1500–1050 BCE). Several of the folk songs in the *Shijing* (Book of Odes) – some of which may date from around 1000 BCE – mention star groups. One of these odes cites the names of four asterisms: the Celestial Han River (i.e., the Milky Way), the Draught Ox, the Winnowing Basket and the Ladle. The description of the Ladle is fairly specific: “In the north there is the Ladle; it raises its western handle”. The apparent motion of the Big Dipper around the north celestial pole has provided a convenient seasonal and hourly marker to a variety of civilisations since remote antiquity.

The first known systematic list of constellation names from East Asia dates from around 433 BCE. This was uncovered in 1978 from a tomb in Hubei province and lists the names of all 28 *xiu* (lunar lodges): asterisms which were of key importance in astrology and positional astronomy. There is a persistent tradition that detailed mapping of the stars began in China during the fourth century BCE with the work of astronomers such as Shi Shen and ► [Gan De](#).

However, the evidence to support this notion is relatively late: no earlier than the seventh century AD. Modern investigations of the measurements in a portion of a star catalogue supposedly compiled by Shi Shen and preserved in the eighth century *Kaiyuan Zhanjing* (Kaiyuan Treatise on Astrology) have indicated a date around 70 BCE.

The earliest catalogue of constellations covering the whole of the sky visible from China is preserved in the *Shiji* (Records of the Historian). This was compiled by Sima Qian around the middle of the Former Han Dynasty (202 BCE–AD 9) and gives brief qualitative descriptions of about 100 star groups. Later catalogues list as many as 280 separate asterisms.

The oldest surviving astral map from China dates from the first century BCE, towards the end of the Former Han Dynasty. Beginning with this dynasty, the development of celestial mapping in China can be traced with increasing confidence, although it is known that many important star charts and celestial ► [globes](#) have failed to survive. Since the stars appear to us as scattered points of light, any attempts to divide them into groups must necessarily be artificial. This is illustrated by the great diversity between the constellation patterns as depicted on Eastern and Western charts of the night sky. Chinese and other East Asian stellar maps further differ from their Western counterparts in the following ways:

- There is virtually no symbolic representation of the constellations by human or animal figures, etc.;
- Star groups tend to be much smaller, typically containing only about five stars;
- Individual stars are represented by circles or dots of almost equal size – regardless of brightness; and
- An equatorial (rather than ecliptic) co-ordinate system is standard, with division of the sky into 28 unequal zones of RA, the *xiu*.

Chinese celestial mapping reveals negligible traces of Western influence (whether of European, Arab or Indian origin) until as late as the seventeenth century when the Jesuits introduced improved knowledge and techniques.

Whereas many Western constellation names are derived from Babylonian and Greek mythology, Chinese names tend to be much more mundane. From an early period, the celestial vault came to be regarded as a direct counterpart of the Chinese empire. Star groups, together with certain individual stars, were regarded as representing members of the imperial family, courtiers and other officials – as well as domestic animals, crops and important buildings (from palaces to prisons). Any event occurring in a particular constellation – such as the appearance of a planet or comet, or “new star” – was regarded as an omen of change affecting the terrestrial equivalent.

Until about 30 years ago, very few Chinese celestial maps were known to be extant from before AD 1000. In his *Shiji*, Sima Qian asserted that an “astronomical chart” was depicted on the ceiling of the tomb of Qin Shihuang, the first Emperor of China, who died in 213 BCE. This has yet to be excavated. However, recent excavations at a variety of sites have brought to light a number of important star charts, mostly decorating the ceilings of tombs. The earliest surviving such artefact depicts only 28 star groups – the lunar lodges. This rather crude but colourful painting adorns the ceiling of the tomb of an official of the Former Han Dynasty. It was discovered accidentally in 1987 during building work in Xi’an, near the site of the Former Han capital. Coins found on the floor of the tomb date from around 25 BCE. Individual constellations are depicted in a ring of approximate diameter 2.5 m; stars – represented by small circles – are joined into groups by straight lines, as in most later astral maps.

No further chart of the night sky is preserved until the sixth century AD, but there is documentary evidence that a number of accurate stellar charts and celestial globes were produced by leading astronomers in the intervening time. Around AD 250, Chen Zuo is said to have produced a map of the stars based on the schools of the ancient astronomers. This was said to represent 1,464 stars in 283 groups – numbers which were to become almost canonical. The purpose of such artefacts was to predict the risings and settings of the constellations as well as to follow the

movements of wandering celestial bodies such as planets and comets. Unfortunately, none of these works survived for more than a century or two.

A star map dating from AD 526 was discovered during excavations at Luoyang – another ancient capital of China – in 1973. This chart is painted on a tomb ceiling of the late Wei Dynasty (AD 386–557), and is some 3 m in diameter. The Milky Way features very prominently, but the constellations are very sketchily depicted. Clearly, there is no particular reason why stellar maps painted on tomb ceilings should compare in quality with those produced by contemporary astronomers.

After AD 526 until well into the tenth century AD, only a single important celestial map survives. This paper chart, measuring approximately 110 × 25 cm, was amongst the vast number of manuscripts uncovered by Sir Aurel Stein in a Buddhist grotto at Dunhuang (Xinjiang province) in 1907. The crude but attractive chart, which is now in the British Library, portrays – in 13 sections – the whole of the night sky visible from China. Stars are depicted in three colours (red, black and yellow), possibly reflecting a tradition which had its roots in the Warring States Period. A suggested date for this interesting artefact is around AD 700.

A few decades ago, two huge star maps, dating from AD 941 and 952, were uncovered from the tombs of Prince Qian Yuanguan and his wife Wu Hanyue. Qian Yuanguan was ruler of the small state of Wuyue in eastern China, the capital of which was close to present-day Hangzhou. The two star charts, each some 2 m in diameter, were engraved on thick stone slabs which formed the ceilings of the tombs. Regrettably, the map from the tomb of Wu Hanyue was destroyed during the cultural revolution, although an accurate scale drawing is preserved. Fortunately, the chart from the tomb of Qian Yuanguan still survives, although it is badly damaged. This latter chart depicts with fair accuracy the 28 lunar lodge constellations, together with a few polar star groups. The celestial equator and north circumpolar circle (circle of constant visibility) are also carefully positioned.

Many astral maps and celestial [globes](#) are known to have been produced during the highly advanced Song Dynasty (AD 960–1279) in

China, but most have long since disappeared. Only one of the *original* artefacts of any consequence, dating from AD 1247, is known to exist today. This remarkable chart was produced by a scholar and was intended for the instruction of a future emperor. It is exhibited at the Suzhou (=Soochow) Museum in Jiangsu province. The circular chart, 1.05 m in diameter, is engraved on a stele measuring 2.2 × 1.1 m. The surface is still in very good condition and rubbings are occasionally taken. Entitled *Tianwentu* (Astronomical Chart), the map portrays the whole of the sky visible from central China on a polar projection. A recent count asserts that it depicts 1,436 stars in 277 constellations. Celestial equator, ecliptic and polar circles are shown, together with radial lines representing the boundaries of the lunar lodges; the Milky Way is also clearly depicted. Modern measurements demonstrate that most star positions are accurate to within about 2°, which represents tolerably good precision (Figs. 1 and 2).

The great Song Dynasty astronomer Su Song is known to have produced a celestial globe 1.7 m in diameter in AD 1092. This was said to represent 1,464 stars in 283 constellations – standardised figures since ancient times. Although the globe was destroyed a few decades afterwards, star charts in extant copies of Su Song's *Xinyi xiang fayao* (New Design for an Armillary and Globe) are believed to reproduce closely the star patterns on the celestial globe. Copies of an these charts, which were first printed in AD 1094, are still available, although the earliest extant version dates from AD 1781; this is now in the National Library at Beijing. The entire night sky as seen from Central China is portrayed in five sections. One of these sections, depicting the southern hemisphere, has a central void; this corresponds to the region of the sky near the south pole which was permanently below the horizon at the Chinese capital (Kaifeng) of the time. Apart from isolated constellations such as *Denglonggu* (Frame of the Lantern, identical with the Southern Cross), no far southern stars appear to have been mapped in any detail until the Jesuit era. Careful modern measurements show that typical positional errors on the Su Song



Maps and Mapmaking: Celestial East Asian Maps, Fig. 1 “Star observing tower” at Kyongju, Korea, dating from AD 647 (Photograph courtesy of Prof Nha Il-Seong, Seoul)

maps – or at least the extant copies – are fairly large, some as much as 4° .

In recent decades, several well-preserved celestial charts have been uncovered during excavations of Buddhist mausoleums of the Liao Dynasty (which flourished in Northern China between AD 916 and 1125). Two of these colorful artefacts, painted on the ceilings of tombs, are particularly interesting. As well as depicting stylised versions of the 28 lunar lodge patterns, they also show symbols – rather signified – representing the 12 signs of the Western zodiac. A large bell, cast in AD 1174, is also adorned with the zodiacal signs. The signs of the zodiac were first introduced into China around AD 600, with the translations of Buddhist *sūtras*. Not long afterwards, during the Tang Dynasty (AD 618–907), horoscope astrology – based on Western methods – became popular in China. However, this had negligible effect on official

practice – e.g., at Court. No significant pictorial relics survive until long after the end of the Tang.

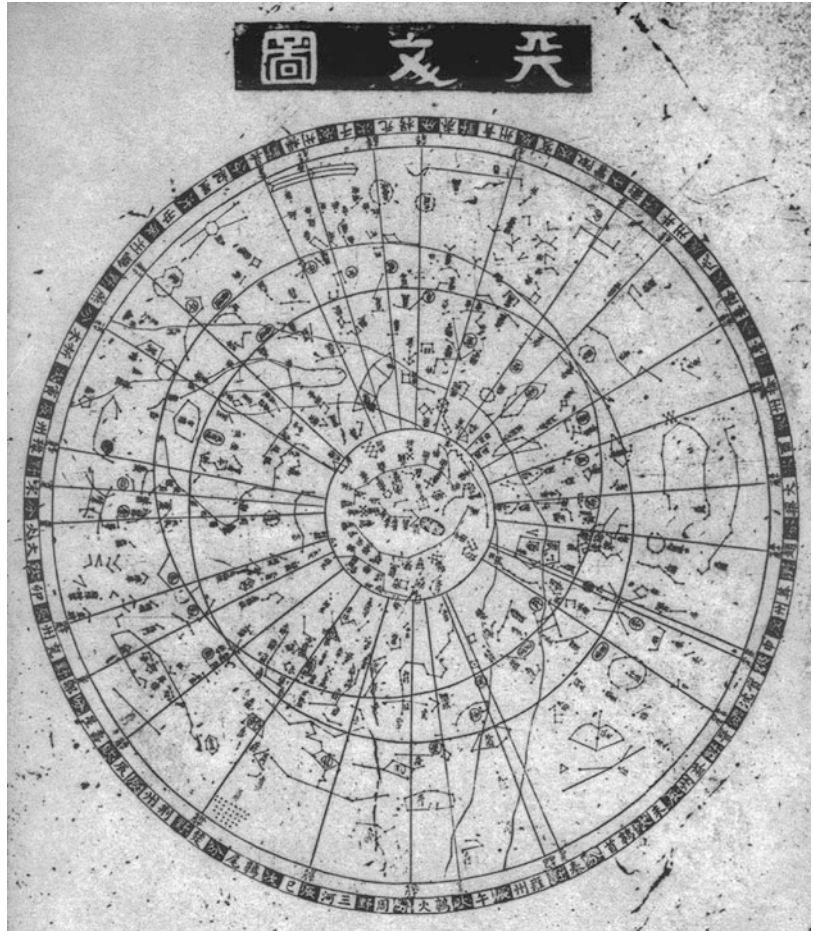
A number of substantial star maps are preserved from the Ming Dynasty (AD 1368–1644), but apart from those revealing Jesuit influence (after about AD 1630), none is of the caliber of the Suzhou chart of AD 1247. Commencing in the late Ming, members of the Society of Jesus made important contributions to astronomy in China, and for nearly two centuries (from AD 1644 to 1826) Western missionaries held the position of Astronomer Royal in China. Today, many fine Jesuit celestial ► [globes](#) and maps produced in China still survive. These include works by Adam Schall von Bell (AD 1634), Ferdinand Verbiest (1673) and August von Hallerstein (1757). The Jesuit astronomers did not try to supplant the Chinese constellations with those of Western origin. However, they measured stellar positions in existing asterisms with hitherto unrivalled precision and in some cases added further stars to individual groups – as well as bringing knowledge of the far southern stars which are invisible from China. All significant representations of the night sky throughout the Qing Dynasty (AD 1644–1911) either directly or indirectly reveal Western influence in these ways and are thus outside the scope of this article.

Korea

The earliest surviving astral map produced in Korea dates from AD 1395. Entitled *Ch'onsang yolch'a punyajido* (chart of the regular division of the celestial bodies), this left a lasting impression on celestial mapping in Korea. Indeed, until the end of the last dynasty (the Yi) in AD 1910, virtually all surviving star charts produced in Korea which do not show Western influence appear to be based on it. History records that the original celestial map, which is 90 cm in diameter and engraved on a marble slab measuring 2.1×1.2 m, is an accurate reproduction of a much older map which had been presented to Koguryo, one of the three early kingdoms of Korea, by a Chinese emperor. Although this stele was abandoned in a river during a battle in the Korean

Maps and Mapmaking: Celestial East Asian Maps,

Fig. 2 Computerised reversal (i.e., black on white) from rubbing of the Suzhou star chart (The star chart is in the Suzhou Museum, Jiangsu Province, China)



peninsula in AD 670, a rubbing still survived in 1395, and this was used to make a new engraving. On the reverse of the stele is a virtually identical copy which may possibly date from AD 1425. Both the AD 1395 chart and a careful stone replica produced in 1687 are still preserved in Seoul museums. They are in good condition, although the earlier artefact has suffered damage down the centuries – notably during a Japanese invasion in AD 1592 (Fig. 3).

Each of the stone engravings depicts the usual circles and lunar lodge boundaries, as well as the Milky Way. However, several constellation patterns differ considerably from medieval Chinese representations, while modern measurements of the star positions suggest an early date – possibly around 30 BCE. Hence the two steles may well preserve traditions of celestial mapping which

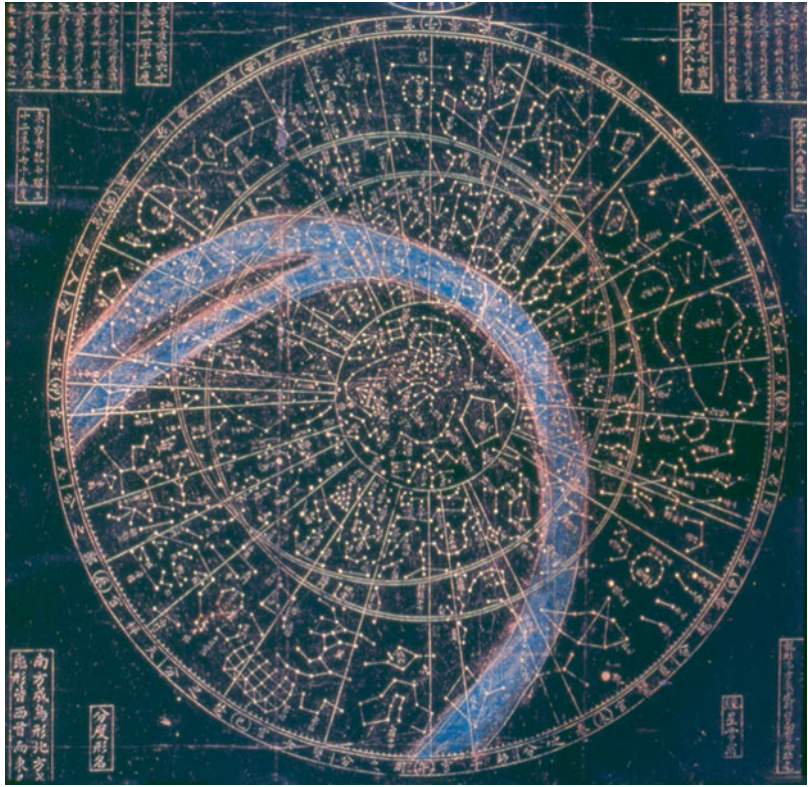
are far older than the detailed Chinese charts which are still accessible today.

Japan

In 1973, a crude chart showing the 28 lunar lodges in a square measuring 80×80 cm was discovered on the ceiling of a Japanese tomb dating from around AD 700. This work, the earliest Japanese celestial chart so far discovered, clearly shows Chinese influence. Detailed maps and globes of the night sky based on Chinese originals are known to have been produced at various stages in later Japanese history. However, none has survived before the sixteenth century. A chart compiled by Ase Yasuyo around AD 1315 was the oldest extant Japanese celestial

Maps and Mapmaking: Celestial East Asian

Maps, Fig. 3 Computer scan of Korean star chart engraved in AD 1687. This chart, engraved on stone, is an accurate copy of a damaged stone chart dating from AD 1395 (Illustration courtesy of Prof Nha Il-Seong, Seoul)



map until it was destroyed near the end of the Second World War. Fortunately, some replicas still exist. The chart – in two sections – showed the Chinese constellations, ecliptic, celestial equator, Milky Way and the lunar lodge boundaries. It was designed to assist the observation of lunar conjunctions with stars.

The two oldest extant star maps of Japanese origin both date from around AD 1540. Each is circular, extending from the north celestial pole to the region of perpetual invisibility (the area of sky always below the observer's horizon), and shows the traditional Chinese constellations and co-ordinates. Both the Suzhou celestial map of AD 1247 and the Korean chart of AD 1395 have had an important effect on Japanese celestial cartography and many copies of each from the seventeenth century onwards can be found in Japan.

In recent decades, the study of East Asian celestial cartography has been enhanced by the growing worldwide interest in records of comets and supernovae recorded in China, Korea and Japan. The positions of these celestial bodies

were often carefully described in relation to specific star groups. In order to trace the movements of comets (notably Halley's Comet) or deduce the locations of past supernovae, it is necessary to make a detailed investigation of the individual constituents of asterisms with reference to modern star catalogues. This work continues.

See Also

- [Kitora Burial Mound](#)
- [Lunar Lodges in Chinese Astronomy](#)

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Maps and Mapmaking: Celestial Islamic Maps

Emilie Savage-Smith

The earliest evidence of Islamic interest in celestial mapping is a vaulted ceiling in a small eighth-century provincial palace, known as Qaşayr ‘Amrah, in the desert of present day Jordan. One of the bathrooms in this palace has a domed ceiling painted to resemble the vault of the heavens. It is the oldest astronomical dome of heaven preserved today. Though the ceiling has badly deteriorated, enough remains to ascertain that the artist was influenced by late Antique and Byzantine two-dimensional flat maps of the skies. The iconography of the constellation figures, the lack of stars, and the method of projection are in keeping with classical and early Western medieval maps of the heavens. The sequence of the constellations on the domed ceiling, however, is not as one would see it when looking up into the sky, but rather as it would appear when looking down onto a celestial globe (see Savage-Smith 1992a).

The celestial globe is the oldest form of celestial mapping, for its origins can be traced to Greece in the sixth century BCE, though the earliest preserved example is an eleventh-century Islamic globe made in Valencia. This

three-dimensional model of the skies presented the stars as seen by an observer *outside* the sphere of stars, so that the relative positions of the stars are the reverse, east to west (or right to left) of their appearance when viewed from the surface of the earth. Islamic celestial ► [globes](#) were made from the ninth through the nineteenth centuries, steadfastly maintaining the basic classical design and encouraging the concept of a spherical universe rotating around the earth.

No flat two-dimensional star maps on paper or parchment from Islamic lands have survived, if indeed any were made, although planispheric maps of the skies drawn on parchment exist today from the Roman and Byzantine worlds. Displaying the entire surface of a sphere on a flat surface – such as parchment or paper or a metal plate – requires a system of mathematical projection. In addition to the method called stereographic projection known in late antiquity, other methods for flat mapping were described in the early eleventh century by the versatile scholar Abū al-Rayḥān Muḥammad ibn Aḥmad ► [al-Bīrūnī](#) (b. 973) working in Iran. Three of his proposed methods correspond in modern terms to orthographic projection, azimuthal equidistant polar projection, and globular projection. His ideas, however, appear to have had no direct effect upon subsequent celestial mapmaking in the Islamic world, and no maps employing these novel methods are known today (see Savage-Smith 1992a).

The evidence for Islamic interest in flat mapping of the entire sky is found only in instrument design and production. The flat, planispheric astrolabe was, in fact, the most commonly used form of celestial map in the Islamic world, for it consisted of a pierced star map placed over a projection of the celestial coordinate system as it related to the observer’s position on earth. The resulting representation of the positions of the stars with respect to the local horizon forms a two-dimensional model of the heavens. The method of stereographic projection required for the astrolabe’s construction was certainly described by the Greek astronomer Ptolemy in the first century AD, though not the instrument

itself. It was also Ptolemy who compiled a star catalog giving coordinates for 1,022 stars, with descriptions of 48 constellation outlines based mostly on Greek mythological characters which served as mnemonic devices for mapping the skies. This star catalog was the basis for all the medieval Islamic star catalogs as well as instruments employing stars (See Kunitzsch and Knappert 1991). It seems certain that the astrolabe was a Greek invention, but its design and production were perfected in the Islamic world, where it was manufactured in many variations from Spain to India from the early ninth through the nineteenth century.

The influence of early modern European celestial mapping is evident in an astrolabe plate engraved in Iran in 1654–1655 by the instrument maker Muḥammad Maḥdī of Yazd. His metal plate reproduces the northern and southern hemispheric maps from a planispheric celestial map printed about 1650 by the Parisian engraver Melchior Tavernier, whose brother Jean-Baptist Tavernier had made six trips to the Near East before his death in 1689 and probably served as the conduit by which the map reached Iran. Tavernier's star map included the new chartings of the southern skies at the end of the sixteenth century, and these were carefully rendered by Muhammad Maḥdī, who changed the labels of the Ptolemaic constellations into Arabic, but did not attempt to give Arabic names to the newer non-Ptolemaic constellations. Muḥammad Maḥdī made at least two additional copies of these plates, but they appear to have had no subsequent influence on Islamic celestial cartography (See Savage-Smith 1992a; and also Savage-Smith and Wakefield 1994).

Celestial space was also often represented by schematic diagrams that did not involve the mathematical determination of coordinates (necessary for ► [globes](#)) or methods of projection (required for planispheric maps or astrolabes). In such diagrams, concentric circles were often used to indicate in general terms the orbits of the planets and the sphere of the stars about the earth, which was viewed as being at the center of the universe. More complex and abstract diagrams illustrating the orbit of an individual planet

employed concentric and eccentric circles to explain the peculiarities of the planet's path (see Van Brummelen 1998).

Mapping the entire sky or heavens was not the only form of celestial mapping to occupy Islamic thinkers. Maps of individual constellations rather than the entire sky had the advantage of not employing a coordinate system or requiring knowledge of projection methods. The most important guide to constellation diagrams in the Islamic world was undoubtedly an Arabic treatise written in the tenth century by 'Abd al-Raḥmān ibn 'Umar al-ṣūfī, a court astronomer in Isfahan. He provided two drawings of each of the 48 classical constellations, one as it would be seen in the sky by an observer on earth and one as it appears on a celestial globe (see Wellesz 1959). According to one account, al-ṣūfī obtained his images by laying very thin paper over a celestial globe and tracing the constellation outlines and individual stars. While taking pains to make clear to the reader the mirror-image relationship between constellations as imagined in the sky and those on a celestial globe, by treating each one individually al-ṣūfī ignored the spatial interrelationships of the constellations to each other. Al-ṣūfī also preceded the discussion of each constellation with a survey of traditional Bedouin constellations visualized in the same area of the sky, such as the constellation of a lion much larger than Leo with gazelles running before the large lion. Numerous copies of this popular treatise exist today, with dress and general presentation of the figures changed to reflect local artistic fashions and conventions, and many later writers incorporated the constellation images into their treatises. Sometimes in later works the constellations were illustrated without stars, with only the animal or human mythological form that gave rise to the constellation outline, and occasionally even the understanding of the mythological figure was lost or confused. The diagrams of individual constellations of stars yielded an easily understood nonmathematical guide to portions of the skies, while giving wide scope to the artist in interpreting the animal and human outlines.

Another form of Islamic celestial mapping was the emblematic or symbolic representation of celestial bodies (planets as well as constellations of stars) and their spatial relationships. The 12 zodiacal signs were often represented as emblematic motifs rather than as constellation diagrams. No attempt was made to represent the stars forming the asterism or even the basic outline of the constellation. Rather, each constellation was represented by a commonly accepted convention, such as a two-headed man sitting cross-legged for Gemini, or for Libra a squatting man with scales over his shoulders or held overhead. The seven classical planets (Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn) were designated by human personifications. Venus, for example, was portrayed as a woman playing a lute-like instrument or Jupiter as a man reading a book. In astrological writings, zodiacal signs were related to the planets by a series of “domiciles.” Thus the moon was most frequently associated with, or domiciled in, Cancer, and the sun in Leo. The remaining five planets were each assigned two zodiacal signs as their domiciles; Venus, for example, was assigned to both Libra and Taurus. Artisans working in metal or with manuscript painting would represent these spatial relationships by depicting Taurus as a bull ridden by a lute player (Venus), or Cancer with a lunar disk, or Leo as a lion surmounted by the radiant disk of the sun. In a second system, the zodiacal signs were combined with the “exaltation” or “dejection” of a planet, which could also be represented symbolically. The lunar nodes (the northern and southern intersections of the moon’s orbit with the ecliptic) were referred to as the head and tail of a dragon, which came to be regarded as a pseudo-planet associated with Sagittarius and Gemini and often represented graphically. Such symbolic representations of celestial bodies and their spatial relations formed an important part of medieval Islamic understanding and graphic interpretation of the heavens. They did not require the difficult technical knowledge necessary for geometrically projected mappings and they were an attractive subject matter for artists to interpret flexibly (see Savage-Smith 1992b).

Each type of Islamic celestial mapping was directed at a different audience. The fairly educated audience who could interpret the symbolic and allegorical representations of celestial bodies was probably more select than those who could appreciate a constellation diagram. Different still would be those who could appreciate as a scientific instrument the celestial globe with its stars positioned by coordinates or the astrolabe with the stellar coordinates projected geometrically onto a flat plate. The Islamic world’s apparent lack of flat stellar maps of the entire visible sky drawn on paper or parchment has yet to be fully explained (see Sabra 1998).

See Also

- ▶ [al-Bīrūnī](#)
- ▶ [al-ṣūfī](#)
- ▶ [Astrolabe](#)
- ▶ [Astronomy in the Islamic World](#)
- ▶ [Globes](#)

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Maps and Mapmaking: Chinese Geomantic Maps

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The Chinese geomantic map is a type of cartographic expression of a landform that portrays a place as geomantically auspicious or inauspicious. In search of an auspicious site for a grave, settlement, temple, or house, geomancers often make extensive field surveys using compasses. Determining an auspicious site, which is often found on a foothill, is a complex business achieved by considering landforms, watercourses, and the direction that the locality faces. The results of important surveys are often recorded in maps. Although the geomantic sketch map is a large-scale map, the scale is not accurate beyond the immediate area of the auspicious site, because the map is normally based on eye measurements and impressionistic descriptions of a locality.

Chinese geomantic maps have basically the same surveying and cartographic methods and identical or similar map symbols. A geomantic map may represent an auspicious site (the geomancy cave; normally designated as a grave or a house site) by the symbol of a small single circle or an even smaller circle inside a small circle. A geomantic map is a topographic map featuring mountain ranges most prominently, because the auspicious vital energy is said to flow through these ranges before accumulating in a geomancy cave. Mountain ranges are expressed in stylized but realistic shapes, using different symbols for different parts of a mountain: a single black line marks the end of foothills and the beginning of flat land; a serrated demarcation line shows slopes along the edge of mountain ridges; the mountain ridges and peaks are colored black. Broken lines symbolize a smaller watercourse. A broken line with a solid line on one side may represent a bigger river. A large lake, river or sea may adopt the symbol of scales, which are also used in other types of maps in East Asia.

The first main characteristic of a geomantic map is that it is a center-oriented map. The focus of the map is on the auspicious site of a given landscape which normally occupies the central position of the map. In the depiction of the topographic formations, only the mountains facing the auspicious site are presented in the map.

The second interesting point concerns the perspectives on the map. The point of perspective on the modern topographic map of contour lines is in the sky directly above the concerned landform. However, that for the relief formations of the mountain slopes on the geomantic map is on the ground at the auspicious site, while that for watercourses on the map is in the sky directly above the waters concerned.

The third point is that there is a lack of map symbols indicating cardinal direction. Unlike modern maps, the top of the geomantic map is assumed to be southward, because an auspicious site is normally facing a southern direction. Although geomancy maps did not adopt a symbol of direction, the exact direction that an auspicious site faces is often noted with Chinese characters which enable a map reader to tell directions.

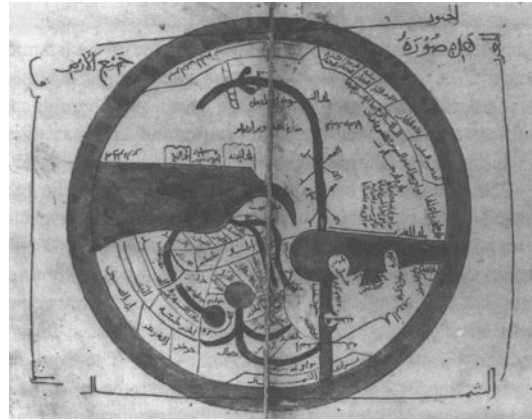
The fourth point is that the geomantic maps are generally large-scale maps focusing on a small catchment area or a small basin. Other non-geomantic traditional Chinese maps are normally small-scale maps.

The fifth point concerns the emphasis on mountain ranges in the map. Especially emphasized are the relationships between the key mountain ranges encircling an auspicious site because mountain ranges are believed to be the route of the flow of *qi* (vital energy) which influences people auspiciously.

The origin of cartographic skills used in the geomantic map is not clearly understood yet by modern scholars. Fully developed geomantic maps had already appeared in a Ming Dynasty (1368–1644) geomantic manual, *Renze Shuji*. The technique of presenting relief formations in Chinese geomantic maps is perhaps more sophisticated than that on any other type of map in traditional China. However, their cartographic contribution is yet to be evaluated.

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Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 1 Ibn Hawqal's map of the world (By permission of the Topkapi Sarayı Müzesi Kütüphanesi, İstanbul (A. 3346))

Maps and Mapmaking: Islamic Terrestrial Maps

Ahmet T. Karamustafa

The cultural boundaries of premodern Islamic civilization (ca. 700–1850) extended from the Atlantic shores of Africa to the Pacific Ocean and from the steppes of Siberia to the islands of South Asia. Widely different traditions of empirical and theoretical cartography developed and coexisted within this cultural sphere. The academic study of these traditions is at its preliminary stages, and it is likely that further research will unveil hitherto unknown aspects of the cultural history of maps in the Islamic world (Figs. 1 and 2).

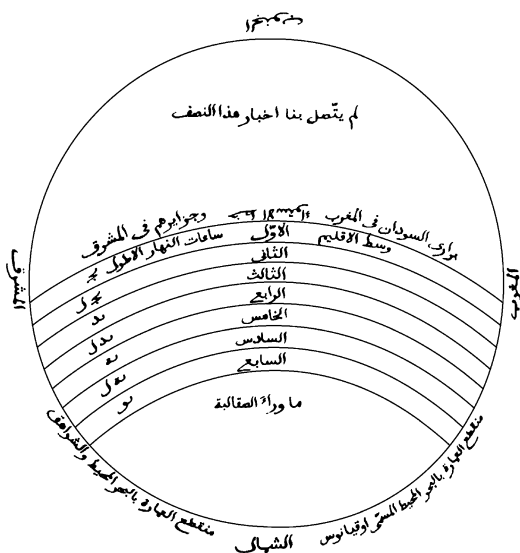
Practice

If one leaves aside purely literary references to maps and map use in historical sources for the first three centuries of Islamic history, the first significant corpus of Islamic terrestrial maps that survive are those that accompany texts written by



Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 2 al-Idrīsī's world map from the Sofia manuscript (By permission of the Cyril and Methodius National Library, Sofia (Or. 3198, fols. 4v-5r))

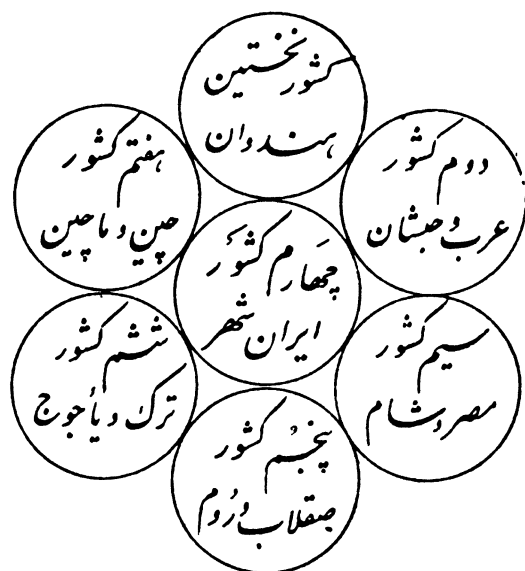
the Balkhī school of geographers (al-Balkhī, al-Iṣṭakhrī, ► [Ibn ḥawqal](#), and ► [al-Muqaddasī](#)) during the tenth century. This set of maps normally comprised a world map, maps of the 3 seas (the Mediterranean, the Indian Ocean, and the Caspian Sea), and maps of 17 regions of the



Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 3 Yāqūt's climate map (From *Jacut's geographisches Wörterbuch*, 6 vols, ed. Ferdinand Wüstenfeld (Leipzig: F.A. Brockhaus, 1866–1873), vol. 1, between pp. 28 and 29 (Fig. 4))



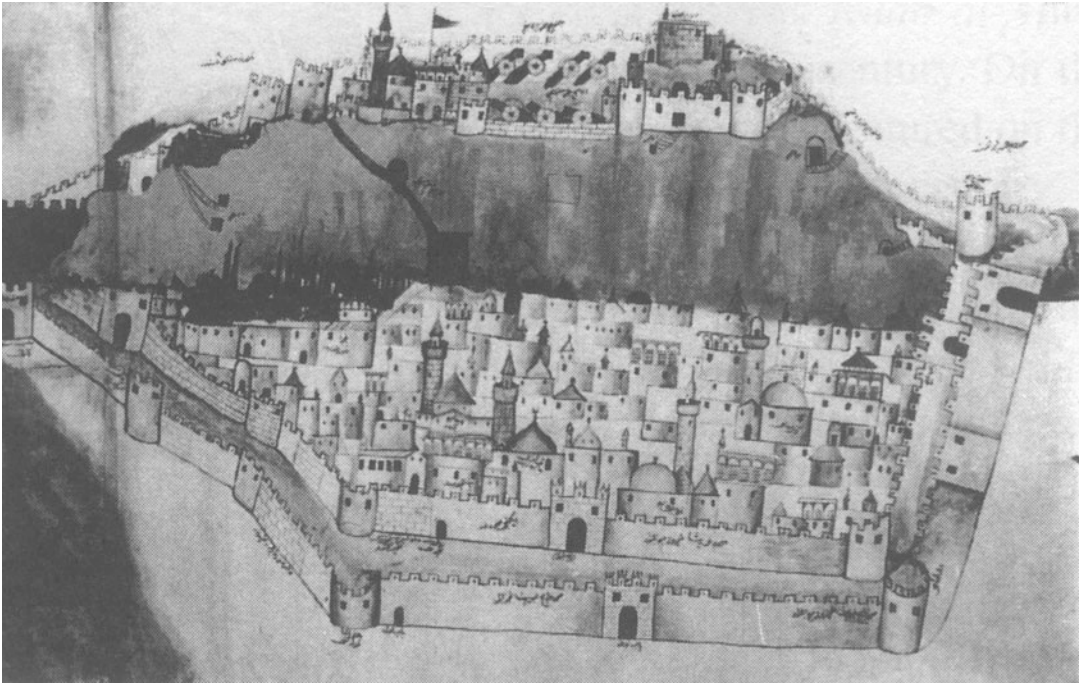
Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 5 Seventy-two section scheme of sacred geography (By permission of the Topkapi Sarayı Müzesi Kütüphanesi, İstanbul (B. 179, fol. 52r))



Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 4 al-Bīrūnī's seven kishvars (From al-Bīrūnī, *Kitāb al-taḥfīm li-avā' il šinā' at al-tanjīm*, ed. Jalāl al-Din Humā'ī (Tehran, 1974), 196)

Islamic world. Not based on any projection and lacking a scale, it is possible that these maps were based on geographical writings that described the postal routes and administrative divisions of the Islamic states.

The other major cartographic school to develop in this period of Islamic history was the Ptolemaic. No early specimen of this school survived – the most spectacular of these seems to have been a world map produced for the 'Abbāsīd caliph al-Ma'mūn (r. 813–33) – and one has to turn to the celebrated geographical compendium of al-Sharīf ► [al-Idrīsī](#), entitled *Nuzhat al-mushtāq fi' khtirāq al-āfāq* (The Book of Amusement for Those Yearning to



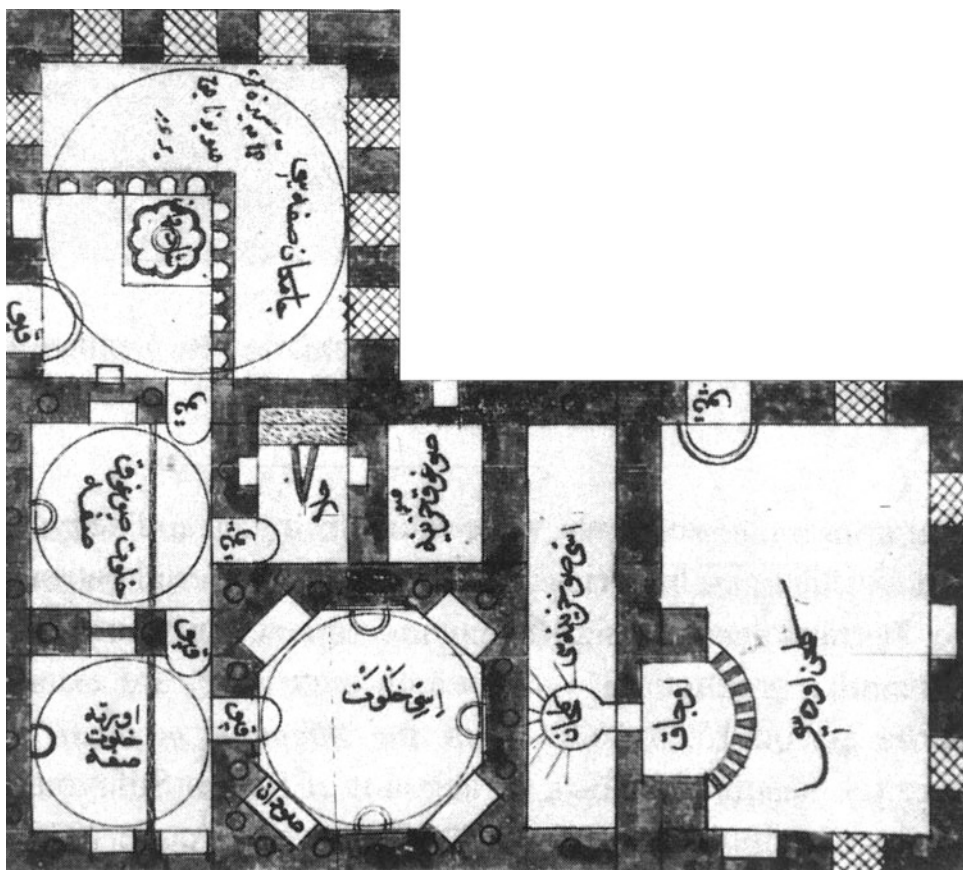
Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 6 Plan of the fortress of Van (By permission of the Topkapı Sarayı Müzesi Arşivi, Istanbul (E. 9487))

Penetrate the Horizons) to appreciate fully the strength of the Ptolemaic cartographic tradition. Al-Idrīsī's work, completed in 1154 and accompanied by a large world map engraved on silver (no longer extant), contained a small world map and 70 sectional maps that collectively represented the whole of the known world. Latitudes and longitudes, not shown on the maps, were given in the text (Figs. 3, 4, 5, 6, 7, and 8).

Cartographic representation of the globe during the High Caliphal and Early Middle Periods (ca. 700–1250) was not confined to geographical mapping of the Balkhī and Ptolemaic schools. In their attempts to depict the world Muslims also resorted to geographical diagrams. At least three different traditions of diagrammatization were used: the seven-*climata* scheme, the seven-*kishvar* system, and the *qibla* charts. The seven-*climata* scheme, Ptolemaic in origin, divided the inhabited portion of the earth into seven zones (Arabic *iqḷīm*) based on latitude calculations. In the seven-*kishvar* system, of

Persian origin, the inhabited portion was represented in seven circular regions (Persian *kishvar*), arranged so that six of the regions totally engulfed the seventh central one. The *qibla* charts, occasioned by the religious prescription to perform various ritual acts in the direction of the Ka'ba in Mecca, divided the world into 4, 8, 11, 12, or more sectors around the Ka'ba.

These cartographic traditions, originally developed during the tenth and eleventh centuries, formed the basis of further cartographic activity during the Later Middle Period and the Period of the Great Regional Empires (ca. 1250–1850). There took place a certain degree of interaction between the Balkhī and Ptolemaic schools, the most notable outcome of which was the attempt to place a graticule on the circular world map by ḥamd Allāh Mustawfī (d. 1339) and ḥāfiẓ-i Abrū (d. 1430). The formation of the ► [Gunpowder](#) Empires during the sixteenth century opened up new directions in Islamic mapmaking. We are particularly well

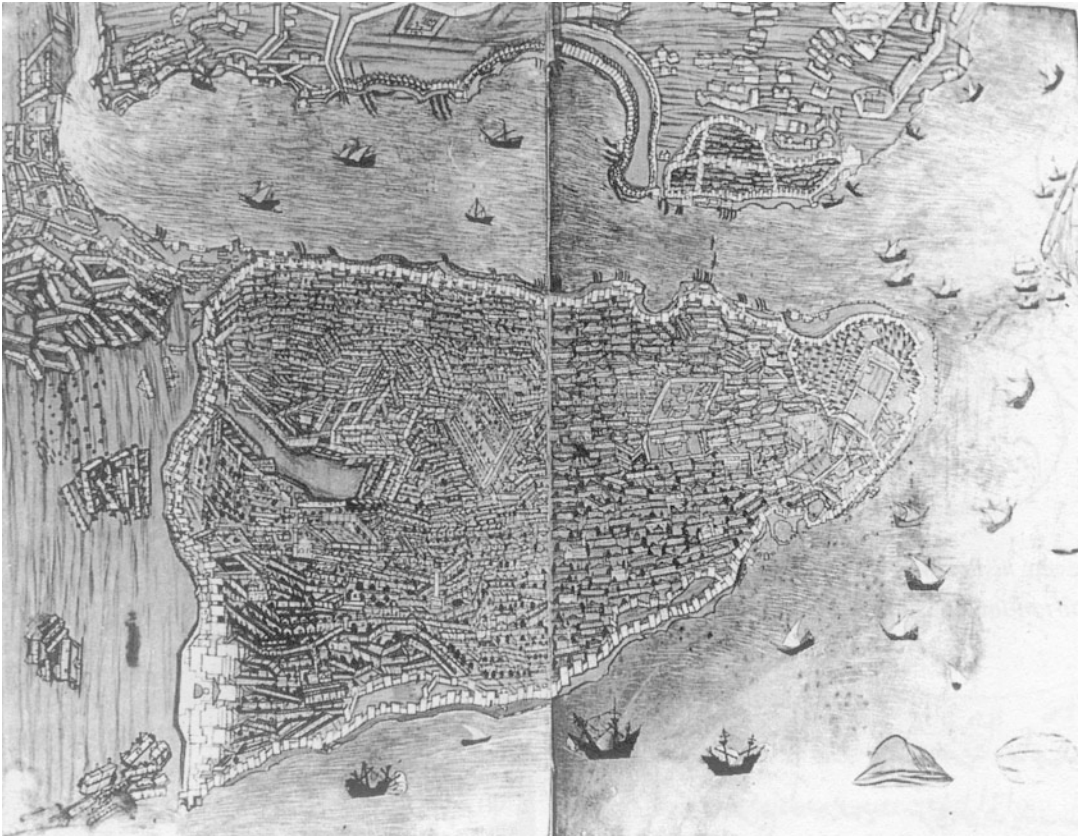


Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 7 Plan of a Turkish bath (By permission of the Bild-Archiv der Österreichischen Nationalbibliothek, Vienna (Cod. 8615, fol. 151a))

informed about Ottoman maps and mapmaking. Graphic representation of space was used systematically for administrative purposes in the spheres of military operation and state-sponsored architectural construction. At least two new genres, visual itineraries and town views, were also introduced and heavily used in illustrated histories produced under imperial patronage. Perhaps the most significant and representative of such spectacular productions – of which over 30 are extant for the period 1537–1630 – is the *Mecmūʿ-i menāzil* of Maṭrakçı Naṣūḥ (d. 1564), an account of Sultan Süleymān I's campaign into eastern Anatolia, Persia, and Iraq in 1533–1535. Not much is known on cartographic production in the Safavid and Mughal Empires.

Theory

Quite apart from cartographic practice and only tenuously related to it, a strong tradition of rigorous investigation of the earth was maintained in Islamic civilization from at least the ninth century onward. In addition to purely narrative geographical accounts, serious attention was paid to geodesy – the measurement of distances, or the determination of exact points, on the curved surface of the earth. As a result, a considerable number of geographical tables exist in Arabic and Persian, normally included in astronomical works. These either list places under climates, with no longitudes given and only the latitude of the climates specified, or assign longitude and latitude values for each place individually. The question of projection



Maps and Mapmaking: Islamic Terrestrial Maps, Fig. 8 Plan of Istanbul from the *Hünernâme* (By permission of the Topkapı Sarayı Müzesi Kütüphanesi, Istanbul (H. 1523, fols. 158b–159a))

was also addressed in some detail. These theoretical aspects of Islamic cartography are perhaps best exemplified in the works of the scholar ► [al-Bīrūnī](#) (d. after 1050), whose output constitutes the culmination point of Islamic geodesy.

Map Use

The extant corpus of Islamic maps, when coupled with purely literary references to cartographic practice, suggest that the mapping instinct in Islamic civilization was by and large harnessed to the cause of scholarship and imperial artistic production. The majority of Islamic map artifacts were produced by the elite for the elite for the purposes of edification, illustration, and propagation of imperial glory. Practical application was the exception rather than the rule and remained confined to military maps

and architectural drawings, which developed into distinct traditions only in the Ottoman Empire. The products of elite high culture, however, were infinitely more likely to be preserved, if only in literary form, than their popular or folk counterparts, so that the surviving cartographic record of premodern Islamic societies is only partially reflective of everyday mapping practices.

See Also

- [al-Bīrūnī](#)
- [al-Idrīsī](#)
- [Al-Muqaddasī](#)
- [Balkhī School of Arab Geographers](#)
- [Geodesy](#)
- [Ottoman Science](#)
- [Qibla and Islamic Prayer Times](#)

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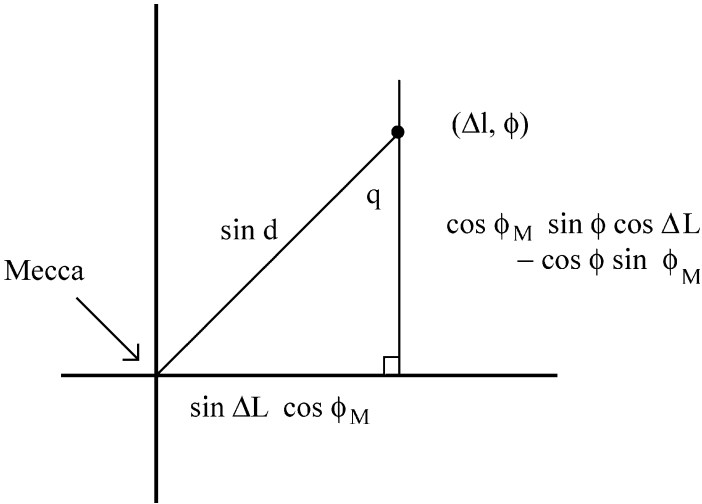
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Maps and Mapmaking: Islamic World Maps Centered on Mecca

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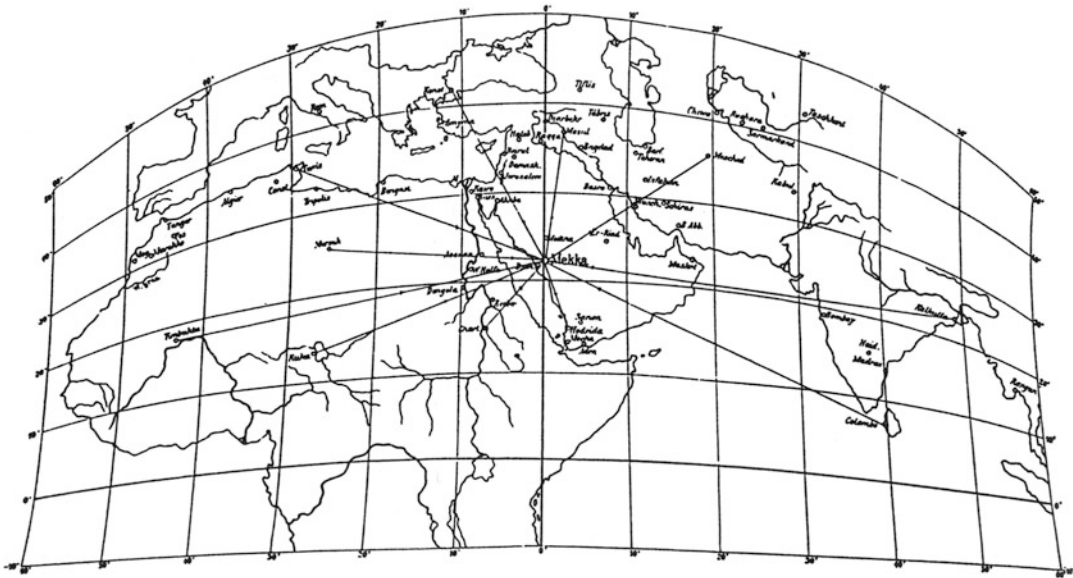
Three remarkable world maps have come to light since 1989. The maps have Mecca at the center and are so devised that the direction of Mecca (*qibla*) and distance to Mecca can be read directly for any locality in the Islamic world between Andalusia and China (see the frontispiece for an illustration of the first world map). The maps are engraved on circular brass plates of diameter 22.5 cm and clearly hail from the same workshop. From considerations of the calligraphy and decoration they can be associated with Isfahan and dated ca. 1675. But they are all clearly copied from different originals, and so they are from a series of such world maps about which until recently we knew nothing.

The highly sophisticated cartographical grid (see Figs. 1 and 2) is to be used in conjunction with the scale around the circumference, on which the *qibla* can be read, and with the nonuniform scale on the diametral rule, on which the distance to Mecca in *farsakhs* can be read. (A *farsakh* is equivalent to 3 mile.) There are some 150 localities marked on each of the maps, but the selection is not identical: their coordinates are at first sight based on those in the *Sulṭānī* ► *Zīj* of Ulugh Beg (Samarqand, ca. 1430), based in turn on those in the *Īlkhānī Zīj* of Naṣīr al-Dīn al-ṭūsī (Maragha, ca. 1250), but there are several localities whose coordinates testify to the fact that they were taken from the common source of both the *Sulṭānī* and *Īlkhānī Zīj*es, namely, the mysterious anonymous *Kitāb al-Aṭwāl wa-l-urūd li-l-Furs*, a source known to us only from citations by the astronomerprince Abu'l-Fidā' (Hama, ca. 1325). The *Kitāb al-Aṭwāl wa-l-urūd* may be as early as the twelfth century. On the other hand several of the localities in India featured on the maps were not founded until the early fifteenth century. In fact, the earliest known geographical table featuring all of the localities on the two maps is found in a treatise on the astrolabe compiled in Najaf in 1702/1703 by one 'Abd al-Raḥīm ibn Muḥammad, who wrote that he compiled his table from al-ṭūsī, Ulugh Beg, "and others." But he also presented the *qiblas* and distances to Mecca for the 274 localities in his list, and at least some of these feature on various Persian astrolabes from the mid-seventeenth century, that is, some 50 year before he compiled his treatise. In fact 'Abd al Raḥīm simply copied a table compiled in Kish near Samarqand in the first half of the fifteenth century. This was, in fact, the actual source of the geographical data on the three world maps. Since 1999, when the first two maps were published, Jan Hogendijk has found two sources, one from tenth-century Baghdad and the other from eleventh-century Isfahan, in which a solution to the *qibla* problem using conic sections is discussed. On the maps the circular arcs for the latitudes are excellent approximations to segments of ellipses. Now



Maps and Mapmaking: Islamic World Maps Centered on Mecca, Fig. 1 The mathematics underlying the theory of the grid on the Isfahan world maps, enabling the user to read the *qibla* on the circumferential scale and the distance on the diametral scale. An approximation

has been used on the world map so that the latitude curves are arcs of *circles*; this produces slight inaccuracies noticeable only on the edges of the map (that is, in Andalusia and China) (Drawn by the author)



Maps and Mapmaking: Islamic World Maps Centered on Mecca, Fig. 2 The world map proposed by Carl Schoy ca. 1920 for preserving direction and distance to Mecca. There are major cartographic distortions for

regions on the other side of the world. On the Isfahan world map, even though it was made ca. 1700, we are dealing essentially with the world as known to Ptolemy (From Schoy, 1923)

that we know what to look for, it is not too much to hope that a reference to a map grid based on this solution to the qibla problem might be found in some other early source.

Although the origin and development of these Mecca-centered world maps is still obscure, it is clear that they are entirely Islamic in their conception. Indeed they represent the culmination of Islamic mathematical cartography, and have no parallel in sophistication between Antiquity (the world map of Ptolemy, ca. 125) and European cartography of the seventeenth century. Prior to their rediscovery it was thought that the first person to construct a world map centered on Mecca from which one could read off the *qibla* and distance to Mecca was the German historian of Islamic science Carl Schoy, who published such a map ca. 1920.

See Also

- [Astrolabe](#)
- [Astronomy in the Islamic World](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Qibla and Islamic Prayer Times](#)
- [Religion and Science in Islam I: Technical and Practical Aspects](#)
- [Ulugh Bēg](#)
- [Zīj](#)

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Maps and Mapmaking: Marshall Island Stick Charts

William H. Davenport

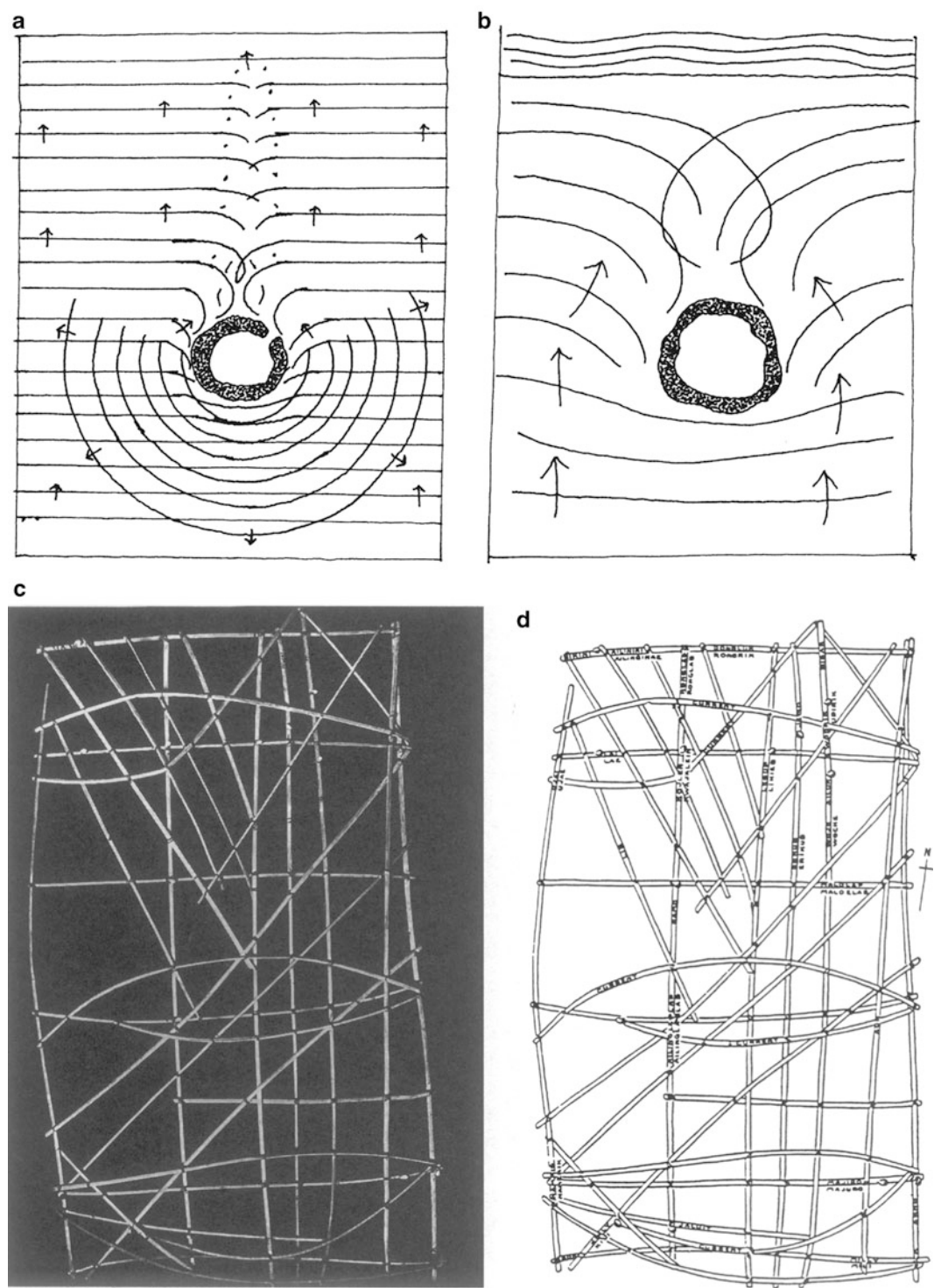
The so-called stick charts of the Marshall Islands in the Pacific Ocean are a rare instance in which a kind of cartography was developed in a nonliterate culture. Their designation comes from the fact that they are constructed of slender sticks and twigs, and sticks lashed together into complex patterns. These patterns represent what occurs when mature ocean swells sweep past one or more of the coral atolls that make up the Marshall Island chain. The charts are not carried to sea, but are used as illustrative devices to train young men in the skills of piloting canoes through the archipelago, out of site of land, by noting various swell phenomena.

The basic concepts that are illustrated on the charts are refraction and reflection of ocean swells. When well-defined swells approach a shore they are bent according to the angle the swell line encounters when it reaches shallow water and the shore. This occurs because the portion of a swell slows down as it encounters shallow water, while the offshore, deep water part continues unaffected. This is wave refraction (Fig. 1).

Refraction occurs as long as a swell is in contact with shallow water and with a small roughly circular atoll this may be entirely around it. As a result, the surface waters off the protected side of the island will be confused by the intersections of opposed arms of the refracted swells. Further off the protected shore the swells reform as they continue on their course.

Wave energy is also reflected from a shore line which sends a smaller reflected wave back at a complementary angle, just as light striking a reflective surface or a ball striking a hard surface bounce back.

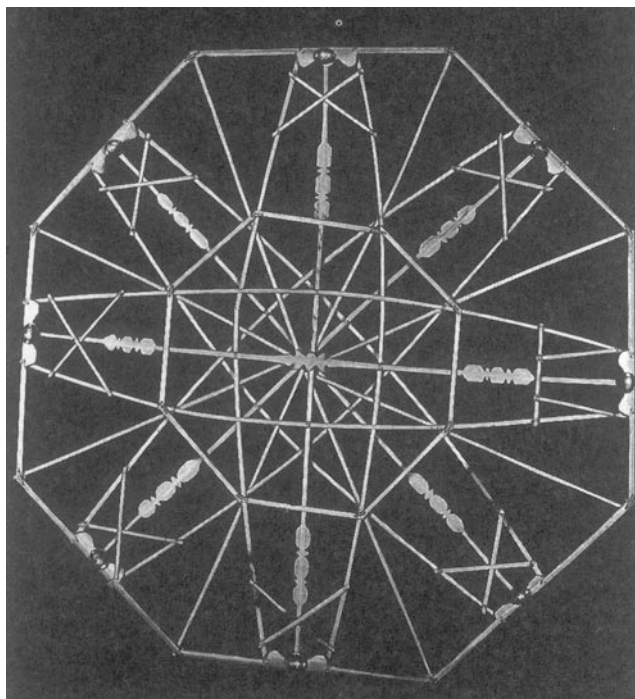
The Marshallese stick charts represent these phenomena: one or several lines of ocean swells approaching an island, their refracted and



Maps and Mapmaking: Marshall Island Stick Charts, Fig. 1 (a) Wave reflection and refraction around an atoll. (b) Wave refraction around an atoll. (c) Meddo chart, collected by Robert Louis Stevenson (From the University

of Pennsylvania Museum of Archaeology and Anthropology (negative number S8-140153). Used with their permission). (d) Key to the Robert Louis Stevenson chart

**Maps and Mapmaking:
Marshall Island Stick
Charts, Fig. 2** Stick chart
from a Marshall Islands
mattang chart (From the
University of Pennsylvania
Museum of Archaeology
and Anthropology
(negative number
S8-79948). Used with their
permission)



reflected swells, and the interactions of these with each other. The stick patterns on a chart can be quite intricate when more than one island and more than one swell system is depicted. In such cases a cardinal direction (rear) is indicated, which is the one generated by the north Pacific tradewind system, *rilib* (backbone), that strikes the Marshall Islands from a northeasterly or easterly direction.

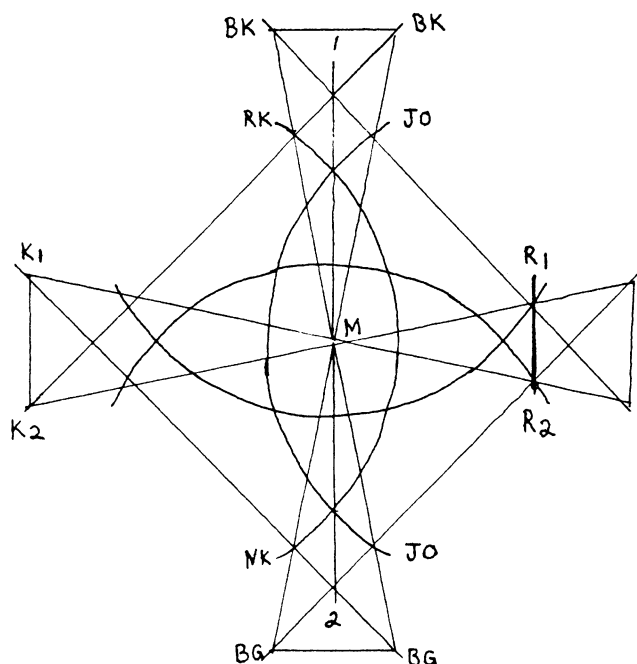
There are three kinds of charts: the *mattang* which illustrates the general principles of swell refraction and the intersection of swell lines; the *meddo* (sea) which depicts the relative positions of more than one island, wave data, and sometimes other pertinent hydrographic information; and the *rebbelith* which is like the *meddo* but includes many islands or most of the group, and has less detailed swell information. Sometimes shells are used to designate islands. There are some indications that the *rebbelith* type may have developed after Marshallese sailors learned about European nautical charts (Fig. 2).

A partial interpretation of the schematic diagram shown here (Fig. 3), taken from an actual *mattang*, will illustrate most of the wave

phenomena used by Marshallese navigators. The center intersection of the chart (M) represents any island; at the right the vertical line R/1-R/2 represents the cardinal direction (rear) and dominant east-to-west swell (*rilib*). As *rilib* encounters island M it is refracted, the upper (northern) refracted arm (RK) is called *rolok*, the lower (southern) refracted arm (NK) is termed *nit in kot*. Opposing *rilib* is a weaker west-to-east swell called *kaelib*, both refracted arms of which are termed *jur in okme* (JO). Two other, usually weak, swell systems, one from the north called *bundokerik* (BK), and its opposed system, called *bundokeing* (BG) are also indicated as they are refracted by island M.

At sea where the *rolok* (RK) or *nit in kot* (NK) arms intersect at a certain angle with *jur in okme* (JO) as well as at other similar intersections of reflected and refracted swells their combined energies cause the water surface to peak up in a characteristic way and briefly break, producing a distinctive kind of white cap. This visible sign is called a *bot* (node). The narrow sector of sea in which *bot* are visible is termed the *okar* (root), because it leads to a tree, i.e., to land where trees

Maps and Mapmaking:
Marshall Island Stick
Charts, Fig. 3 Schematic
 diagram of a *mattang* chart



grow. In the diagram, the line 1-M-2 represents the northern and southern *okar* of the *rilib* and *kaelib* swell systems. In following the *okar*, the navigator notes the change in angle of the intersecting swells, if the angle increases (because the refraction is greater) he is getting closer to land, and the converse. Usually, however, dead reckoning has been good enough for the navigator to know which side of an island he is on.

It is well to keep in mind that a coral atoll is a very low-lying island, and from a distance the trees growing on it are its most conspicuous feature. Even so, from a canoe, atolls are not visible for more than a few miles away. Actually, there are other useful signs that indicate an atoll over the horizon. Among them are flight directions and patterns of certain birds, high accumulations of overhanging clouds, colored reflections from lagoons on the undersides of cumulus clouds, and floating vegetation, and navigator's rely heavily upon them. However, at night and in situations of poor visibility the information derived from swells can be critical. The Marshall-ese navigator does not use the information from swells only for making direct landfalls. Rather, on a voyage which passes in the vicinities of

intervening islands he can mark his progress toward his destination by noting the reflected and refracted wave signatures of unseen islands as he passes by them.

See Also

- [Navigation in the Pacific](#)
- [Navigation in Polynesia](#)

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Marāgha

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The observatory, located just outside Marāgha, the capital of the Ilkhānid kingdom, represents

one of the most comprehensive examples of an astronomical research institution within the context of Islamic civilization. The remains of the observatory buildings still occupy a hilltop near the city in Azerbaijan.

It is reported, on the authority of Naṣīr al-Dīn al-Ṭūsī, its first director, that construction of the observatory began under the patronage of Hūlāgū, Mongol conqueror of the region, in 657 AH/AD 1259. Construction was overseen by Mu'ayyad al-Dīn al-'Urḍī, who wrote a treatise describing his efforts. In addition to the main observatory building, the site included a mosque and a residence for Hūlāgū, who reportedly took an active part in the work of the astronomers. The main building was described by contemporary witnesses as "huge," and there are reports that its library exceeded 400,000 treatises. There is also a report of a "high tower," as well as a domed structure which may have been the central building of the observatory. The dome was pierced, allowing sunlight to enter for the determination of equinoxes, as well as for measuring solar mean motions and elevations. There are still traces of a massive masonry-mounted mural quadrant, probably having a radius of more than 4 m, outside one of the observatory buildings.

Al-'Urḍī also had charge of constructing the observational instruments for the observatory, although it is doubtful that he would have constructed them all personally. He reports completion of their construction during 660 AH/AD 1261–1262. In addition to the mural quadrant, which was used to determine the latitude of the observatory as well as the obliquity of the ecliptic, the observatory included other large instruments: (1) an armillary sphere, consisting of five rings and an alidade (sighting device), and having a maximum radius of about 1.6 m; (2) a solstitial armilla, a bronze circle with diameter of about 1.25 m equipped with an alidade, which was placed in the plane of the ecliptic and used for determining solstice points; (3) an equinoctial armilla, similar to the solstitial armilla but with a second ring that could be aligned with the plane of the equator in order to determine equinoxes accurately; (4) an instrument with two holes on a sighting rod used for determining the apparent

diameters of the Sun and Moon as well as for observing eclipses; (5) an azimuth ring equipped with two quadrants and two alidades to measure angles of elevation; (6) a parallactic ruler which could make measurements equivalent to those made on a circle with a radius of 2.5 m; (7) an instrument for measuring azimuthal altitude and the sine of the complement of that angle of elevation; (8) a similar instrument to measure the azimuthal altitude and the sine of the angle of elevation; and (9) an instrument similar to a parallactic ruler, but not fixed in the meridian plane. In addition to these large instruments, there were many smaller ones, including planispheric astrolabes and quadrants, terrestrial and celestial globes, timekeeping devices, star charts, maps, and representations of the heavenly spheres.

Not only was the observatory the best equipped of the medieval period, it was also the best staffed. In addition to Naṣīr al-Dīn al-Ṭūsī and Mu'ayyad al-Dīn al-'Urḍī, there were luminaries such as 'Alī ibn 'Umar al-Qazwīnī, Fakhr al-Dīn al-Akhlāfī, Fakhr al-Dīn al-Marāghī, Muḥyi al-Dīn al-Maghribī, Quṭb al-Dīn al-Shīrāzī, Shams al-Dīn al-Shirwānī, Najm al-Dīn al-Qazwīnī, 'Abd al-Razāk ibn al-Fuwwatī (the librarian), Kamāl al-Dīn al-Ayta, Athīr al-Dīn al-Abharī, al-Ṭūsī's two sons – Aṣīl al-Dīn and Ṣadr al-Dīn – and even a Chinese astronomer, Fao Mun Ji. (The presence of the latter indicates an interaction between the Islamic and Chinese astronomical traditions encouraged during the period of Mongol domination.) The activities of these scholars were supported by a full complement of technicians, instrument makers, and administrators.

The major result of the of scientific work at the observatory was the production of a new set of astronomical tables, the *Zīj-i Ilkhānī*, completed in 671 AH/AD 1272, nearly 12 years after the observatory opened. Although the treatise contains many new observations, it did not incorporate the sophisticated critiques of the Ptolemaic cosmology being developed at that time in the observatory. These tables were widely used and frequently cited. The organization of the treatise (chronology, movements of stars in longitude and

latitude, determination of times of ascendants, and astrological predictions) often served as a model for later zīj literature.

It was generally argued by astronomers that, in order to produce a full set of astronomical tables, observations should be made over a 30-year period (the time for Saturn to complete one revolution around the sky). Most observatories prior to Marāgha had been forced to adopt less ambitious research programs, for they did not long survive the death of their founding patron. The Marāgha observatory is a notable exception. Hūlāgū, its royal patron, died in 663 AH/AD 1265, and al-Ṭūsī, the founder, died in 672 AH/AD 1274. After al-Ṭūsī's death, the observational activities continued at a somewhat slower pace under the leadership of Ṣadr al-Dīn al-Ṭūsī. Thirty years later, al-Ṭūsī's younger son, Aṣīl al-Dīn, was named head of the institution. This marks the last recorded activity on the site. Thus, this observatory continued to function for nearly five decades before being abandoned and falling into ruins.

Perhaps the extraordinary longevity of this institution derives from the use of *waqf* funds to support the operation of the observatory. (A *waqf* is a grant of property in perpetuity for the support of religious or charitable institutions. Income derived from *waqf* properties not only supported many mosques but also orphanages, soup kitchens, hospices, schools, libraries, hospitals, and similar charitable public service institutions. The Marāgha observatory was a rare example in which an observatory received *waqf* support.) Several sources indicate that al-Ṭūsī, in addition to directing the observatory, was also charged with administering *waqf* funds throughout the state. Some sources indicate that about a tenth of all *waqf* revenues were earmarked for observatory expenses. It is not clear whether this unusual use of *waqf* funds generated any sort of public outcry. If nothing else, it seems to indicate that the work of the observatory was intended to be ongoing, not merely an intense short-term effort.

Perhaps the use of *waqf* funds to support the observatory was easier to justify in light of the extensive instructional activity carried on within

its precincts. It was not uncommon to endow a *madrasa* (an institution of learning, usually focused on religious and legal sciences) with *waqf* funds. Our sources tell us that the observatory was a center of teaching in astronomical as well as related mathematical sciences. The educational program was apparently organized analogously to that of a *madrasa*, although the anecdotal nature of our sources makes these reports too vague to be certain.

In addition to teaching the classics of the ancient mathematical and mathematical astronomy traditions, the Marāgha observatory was also a focus for an important movement that criticized and proposed reforms to Ptolemaic (Greek) astronomical theories. Ptolemy was perceived to have disregarded the essential sphericity and uniformity of the celestial motions postulated by Plato and other early thinkers. Ptolemaic theory described each planet as carried daily from east to west across the vault of the sky by the motion of the sphere of fixed stars. This diurnal motion is complicated by the fact that (a) each planet sets a bit late in relation to the fixed stars and (b) the planets move across the heavens in a path not parallel to the fixed stars. Moreover, most of the naked-eye planets seem, from time to time, to slow to a stop and temporarily reverse their direction of motion (retrograde motion) against the background of the fixed stars. To account for these observations, the Greeks had assumed that each planet must be fixed to a small sphere (epicycle) whose center is carried around by a larger sphere (the deferent), whose axis does not coincide with that of the sphere of the fixed stars, and whose proper motion of rotation (zodiacal motion) is contrary to the east to west direction of the fixed stars in their diurnal motion. The motion of the epicycle center as seen from Earth was not fully uniform, however, implying that the Earth must not be at the geometric center of the motion on the deferent. The distance of the Earth from the center of the deferent sphere (the eccentricity) was established by observational considerations. When this distance is determined, however, the observed angular velocities are only about half what is predicted. To remedy this problem,

Claudius Ptolemy had postulated that uniform angular motion took place about a point (equant) located twice the value of the eccentricity from the Earth along the line from the Earth through the center of the deferent sphere. This postulate allows uniform motion in the sense of sweeping out equal angles in equal time increments when observed from the equant, but uniform motion in the sense of equal arcs traversed in equal increments of time does not occur. In other words, Ptolemy has separated the uniform motion from the spherical motion. Herein lay the central problem that the Marāgha school of cosmography tried to resolve: how to construct a physical model of the spherical universe that fits the assumptions of uniform circular motion in both senses of that term and that yields predictions having the same level of accuracy as Ptolemy's equant model.

Al-Ṭūsī, assuming that Ptolemy's circular motions were intended to be performed by true physical spheres and not just mathematical spheres, developed a system of spheres rolling inside one another to account for the observed zodiacal motions of the planets. The result of these motions, each truly uniform and circular in the Platonic sense, is that the planet follows the spherical path required by Greek cosmography while displaying the observed variations in velocity, thus avoiding the fundamental conceptual disjunction that Ptolemy had introduced by separating the circularity from the uniformity in the motions.

Al-Ṭūsī is best known among historians of science for his modification of a theorem of Proclus which demonstrates that when a circle, whose diameter is equal to the radius of a larger circle, rolls inside the circumference of the larger while rotating on its axis in the opposite direction with the same velocity, a point on the circumference of the smaller circle will execute a simple harmonic oscillation along a diameter of the larger circle. Al-Ṭūsī used his device, now known as a "Ṭūsī Couple," to replace the equant in Ptolemy's description of planetary motions. This geometric device was further exploited by al-Ṭūsī's pupil, Ibn al-Shāṭir, and others at the Marāgha observatory.

Copernicus employed an essentially similar geometric device more than two centuries later for constructing his model of lunar motion. This striking similarity of technique has led to questions concerning the originality of Copernicus. Arabic manuscripts describing al-Ṭūsī's model are known to have been in the Vatican Library by the time Copernicus journeyed to Rome, and some bear Latin annotations. Moreover, a late Byzantine Greek manuscript with a detailed exposition of al-Ṭūsī's scheme was also present in Italian libraries while Copernicus studied there. Tantalizing as such evidence may be, it is still not possible to determine with certainty whether the intellectual antecedents of the Copernican geocentric hypothesis may lie in Marāgha.

See Also

- ▶ [al-Shīrāzī](#)
- ▶ [Al-'Urḍī](#)
- ▶ [Astrolabe](#)
- ▶ [Astronomical Instruments in the Islamic World](#)
- ▶ [Astronomy in China](#)
- ▶ [Astronomy in the Islamic World](#)
- ▶ [Clocks and Watches](#)
- ▶ [Maps and Mapmaking: Celestial Islamic Maps](#)
- ▶ [Naṣīr al-Dīn al-Ṭūsī](#)
- ▶ [Observatories in the Islamic World](#)
- ▶ [Quadrant](#)

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Māshā'allāh

Richard Lemay

Māshā'allāh ibn Atharī was a Jewish astrologer who was born in the southern city of Basra ca. 730 in the later Umayyad caliphate and survived till ca. 815. If he was ever converted to Islam, as his name Mā'shā'allāh seems to imply, it is not made clear in any of the original sources such as the *Fihrist*. His respectful tone toward the Caliphs in his *Fī qiyām al-Khulafā'* would certainly befit a Muslim more than a Jew. At any rate he wrote extensively in Arabic, and he was called upon by the second Abbasid Caliph al-Manṣūr (754–775) to assist in the laying of the foundations of Baghdad in 762. Hence by that time he was surely a well known astrologer active in the Babylonian region, representative perhaps of the Jewish culture long settled in the area.

A celebrated astrologer in his time, Māshā'allāh was either the founder or a leader of a school of Jewish astrologers in Mesopotamia. Apart from his participation in the laying of the foundations of Baghdad, we know rather little of

the circumstances of his life. Though sparse on biographical details, the principal Arab bibliographers al-Nadīm (*Fihrist*, AD 987) and Ibn al-Qiftī (*Tārīkh al-hukamā'*, ca. AD 1248) credit Mā'shā'allāh with a sizeable number of works. On the other hand, the *Jewish Encyclopedia* confuses him in part with Maslama ► *al-Majrīṭī*, probably because of the similarity of names. Paul Kunitzsch has recently established that the Latin treatise on the astrolabe long ascribed to Mā'shā'allāh and translated by John of Seville is in fact by Ibn al-ṣaffār, a disciple of Maslama al-Majrīṭī.

In his astrological doctrine Mā'shā'allāh seems to have depended principally on the Persian tradition, though a late Byzantine translation of one of his works shows that he could also quote from Greek authors such as Plato, Aristotle, and Hermes. Mā'shā'allāh's works have not survived extensively in Arabic and it is thanks to the Latin translations, mostly by John of Seville in twelfth century Spain, that we have access to a large number of those ascribed to him.

Mā'shā'allāh's contribution in Arabic astrology must be linked with the widespread use of astrological prognostication in the Mesopotamian area since very ancient times. The thirteenth century bibliographer Ibn Khallikān recalls the extensive use of this "projective tool" in the politics and social life of the early Arab empire. What has survived of Mā'shā'allāh's works shows that the substance of his astrological knowledge owes but little to Greek philosophy proper. Assuredly, there flourished in Sassanian times a trend to borrow from Greek (Alexandrian) astrology, apparently only to consolidate a native tradition of learning. And it is this Sassanian lore above all that nourishes Mā'shā'allāh's production. On the other hand, it is historically confirmed that the passion for Greek learning among the Arabs was engendered by the caliph al-Ma'mūn's (813–833) enthusiasm for the philosophy of Aristotle, too late for Mā'shā'allāh to share significantly in this outburst. The fresh start taken by "scientific" astrology under al-Ma'mūn's prodding is noticeable in the works of ► *al-Kindī*, of Abū Ma'shar, and the members of the *Bayt al-ḥikma* (House of

Wisdom) founded by al-Ma'mūn. Compared with their works, those of Mā'shā'allāh and of his generation show no clear and systematic use of the axioms of peripatetic philosophy to buttress the principles of astrological science as was done so decidedly a generation later.

Mā'shā'allāh's reputation remained high in the following generation as witnessed by Abū Ma'shar's praise of him, according to the *Mudhākarāt* (Memorabilia) of ṣa'id ibn Shaḍān. Yet, it is mostly for one single astrological topic, the "projection of rays" (*matraḥ al-shu'ā'āt*), that Abū Ma'shar lavishes praise on Mā'shā'allāh.

An important historical factor affecting the preservation of Mā'shā'allāh's works, and consequently of his reputation as a leader in Arab astrology, must be stressed at this point. As stated above, his works were virtually superseded in Arabic astrology by the works of the generation which followed his death. Why then do we possess so many of his manuscripts in Latin translation? This seems to have resulted from the special interest manifested in Mā'shā'allāh's works by John of Seville (Johannes Avendauth, or Ibn Dawūd). Having set about to translate for the benefit of Latin scholars the works of the "prince" of Arab astrologers Abū Ma'shar (no Arab himself but Persian/Afghan since he came from the "Bactrian" city of Balkh), John enlarged his program of translation to include the corpus of Jewish astrologers of the early Abbasid era.

Within the scope of Arab astrological doctrines there developed a side which stemmed from the application of the scheme of planetary conjunctions in relation to the zodiacal signs and various triplicities in which they might occur. But it was Jupiter's special prerogative to foster religious life. The conjunction theory animating astrological history turned principally around the conjunctions of Saturn and Jupiter to signal the emergence, duration, and waning of sects (Arabic *milal*) when referred to religions, or of dynasties and empires (*duwal*) when applied to military domination. A basic element of the scheme was the association of each planet with what was classified as "great civilizations", mostly religions with cultures that set religion

as their guiding light. Saturn as the most distant planet was appropriated to the Judaic faith, the Sun to the Roman Empire, and Venus to Islam. This was in a nutshell the astrological exercise of the "horoscope of religions" as it came to be known in the Latin West.

The most famous of such interpretations was embodied in Abū Ma'shar's *Great Conjunctions*. Associating the spread of the Judaic religion with the rule of the planet Saturn, the sway of the Roman Empire with that of the Sun, and of the Arab Empire with that of Venus, etc., the scheme thereby stressed the primeval character of the Jewish faith in accordance with the status of Saturn, the highest and most distant planet. The vicissitudes of planetary conjunctions thereafter unfolding along the variety of signs in which they occurred successively, rendered Judaic monotheism anachronistic. It was replaced in time by the Roman Empire, which in turn was displaced by "manicheism" when the prophet Mani appeared, until the rise of Islam.

In ninth-century Baghdad there was great concern among the Abbasid rulers and the Arab elites who were confronted with widespread social unrest among non-Arab subjects. One wave of unrest was further encouraged in *shu'ūbīya* (ethnic) groups by astrological predictions hinting at the impending end of Arab domination foreboded by planetary conjunctions. This was the occasion for the consolatory *Risāla fī mulk al-'arab wa-kammiyatihi* (On the Dominion of the Arabs and its Extent) which ► [al-Kindī](#) wrote for the Caliph, a consolatory Epistle in which he calculated that the conjunctions of Saturn with Jupiter held forth a total duration of 693 years for the Muslim Empire, which meant at that time four more centuries of Arab rule, whereas Abū Ma'shar's similar calculations in his *Great Conjunctions* foresaw only 310 years or so for it.

The association of Judaism with Saturn is not present in Māshā'allāh's scheme of astrological history, although his interpretation of planetary conjunctions was extended to Islam and in particular to the rule of the Caliphs. Yet the status assigned to Judaic culture in the scheme of planetary conjunctions of Arab astrology stirred

echoes in Jewish communities in Spain, inspiring their leaders in astrological science to use the scheme of conjunctions to confirm the unique “vocation” of Israel. This endeavor is at the core of the *Megillat ha-Megalle* by Abraham bar ḥiyya of Barcelona. This book purports to illustrate the fate of Israel in the cosmic framework of universal history by referring to Holy Scriptures, Rabbinic literature, and philosophy. Yet the entire last chapter is devoted to the scheme of planetary conjunctions and its significance for the fate of Israel, confirming by “science” the data of sacred literature. The enterprise ostensibly aimed to counteract the “scientific” demoting of Judaic civilization to a lower historical role by Arab astrological writers. Another Jewish astronomer astrologer in Spain, ► [Abraham ibn Ezra](#), also critiqued the theory of planetary conjunctions.

The medieval Anglo-Irish scientific literature used to include two versions of some work by Māshā'allāh' in the form of Chaucer's *Treatise on the Astrolabe*, and an Irish tract following closely the text published by J. Heller in Nurnberg in 1549 under the title *De elementis et orbibus coelestibus*. Since the publication of Paul Kunitzsch's thesis, however, which shifts the authorship of the Latin source used by Chaucer from Māshā'allāh the Jewish astrologer from Iraq, to Maslama, the eleventh century Arab astronomer from Spain, it would appear that this part of Māshā'allāh's claimed influence upon Western literary tradition must be abandoned.

A compilation of Arab “authorities” in astrology called *Liber Novem Iudicum* (Book of the Nine Judges) included Māshā'allāh as one of its principal authorities. The compilation of the Nine Judges did much to carry Māshā'allāh's astrological rules and reputation to the four corners of medieval Europe.

See Also

- [Abraham Bar Ḥiyya \(Savasorda\)](#)
- [Abū Ma'shar](#)
- [al-Kindī](#)
- [Al-Ma'mūn](#)

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Mathematical Texts in Egypt

Annette Imhausen

While there is only indirect evidence for mathematical techniques in the Old Kingdom (2686–2160 BCE) and the New Kingdom (1550–1069 BCE), we do have texts detailing specific mathematical procedures from the Middle Kingdom (2055–1650 BCE) and the Graeco Roman Period (332 BCE–395 CE).

Hieratic Mathematical Texts

The sources of the Middle Kingdom (the Rhind mathematical papyrus was written in the 2nd Intermediate Period, but states to be a copy of a Middle Kingdom original) are (in order of their publication; for respective editions see Collier & Quirke, 2004, 2006; Glanville, 1927; Peet, 1923a, 1923b; Schack-Schackenburg, 1900, 1902; Struve, 1930; a source book uniting photocopies and translations of most sources is Clagett, 1999, for colour photographs of pRhind see Robins & Shute, 1987):

- The Rhind mathematical papyrus (BM EA10057/58)
- The Lahun mathematical fragments (UC 32107A, 32114, 32118, 32134, 32159, 32162)
- The Berlin mathematical fragment 6619
- The Cairo Wooden Boards (CG 25368/8)
- The mathematical Leather Roll (BM EA10250)
- The Moscow mathematical papyrus (E4676)

They are all written in Hieratic (<http://www.digitalegypt.ucl.ac.uk/writing/hieratic.html>), a cursive form of hieroglyphs. Most of the above listed sources were bought on the antiquities market, so that their exact provenance cannot be ascertained without doubt. Exceptional in this respect are the Lahun mathematical fragments, which were found between 1889 and 1899 by W.M.F Petrie during the excavation of Lahun, the pyramid town of Senusret II (1877–1870) (<http://www.digitalegypt.ucl.ac.uk/lahun/index.html>). Nevertheless the form and content of Egyptian mathematical texts often allows us to determine their original context with some certainty.

We can distinguish two types of mathematical texts (and the individual sources listed above are compilations of one or both types): problem (or procedure) texts and table texts. Egyptian mathematical problem texts begin by stating a mathematical problem and then providing step-by-step instructions for its solution. We can differentiate several sections of a mathematical problem text.

1. Title, often in the form “*tp n ir.t . . .*” “method of calculating. . .” and highlighted by the use of red ink.
2. Announcement of the given data of the problem often followed by an explicit question of asking what shall be determined. The data are concrete values.
3. Procedure to solve the problem. This is spelled out via step-by-step instructions using the concrete data. Each instruction usually comprises one arithmetic operation (addition, subtraction, multiplication, division, halving, doubling, etc.). After each step we find an

intermediate result provided (for a technical analysis of the procedures found in the hieratic problem texts see Imhausen, 2003a).

4. The indication of the solution, which usually equals the result of the last step of the instruction.
5. Verification of the solution.
6. Working of some calculations indicated in the instructions (for a recent discussion of some aspects of Egyptian arithmetic see Collier & Quirke, 2004, pp. 85–86).
7. Sometimes a drawing, indicating the object and its dimensions.

The problems teach basic mathematical techniques (e.g., how to determine an unknown quantity from a given manipulation of that quantity and its result [“a quantity, its $1/7$ added to it becomes 19”]) as well as applied mathematical problems, i.e., mathematical problems with a practical background. Practical problems include for example calculating distributions of rations, slopes of pyramids, work rates, exchanges of bread and/or beer and volumes of granaries.

Thus it has been concluded that Egyptian problem texts come from an educational background and were used in training junior scribes in the mathematical practices that they would need in their daily working lives (Ritter, 2000). This was confirmed by administrative and economic papyri, which display the use of the same mathematical techniques (Imhausen, 2003b).

Table texts comprise mathematical information in tabular format. They are often simply lists of mathematical data. Tables include those for fraction reckoning (most notably the $2/N$ table preserved at the beginning of the Rhind mathematical papyrus and in the Lahun fragment UC 32159), but also tables for the conversion of different metrological systems. Note that multiplication in hieratic texts was often carried out in writing, which rendered multiplication tables for natural numbers superfluous. For a description of Egyptian tables (both hieratic and Demotic) see (Fowler, 1999, pp. 268–276).

Demotic Mathematical Texts

The second group of Egyptian mathematical texts dates from the Graeco Roman Period, i.e., a time when several cultures (the native Egyptian culture and the Greek and Roman cultures) coexisted in Egypt (for a description of Demotic mathematics within this cultural context see Cuomo, 2001) and after Egypt had been under Persian rule twice (525–404 BCE and 343–332 BCE). Presumably during this Persian occupation (or earlier), Mesopotamian mathematical knowledge was transmitted into Egypt (see Høyrup, 2002, pp. 405–406; Parker, 1972, pp. 5–6).

These are the extant sources consisting of several papyri (in order of their publication; for their editions see Parker 1959, 1972, 1975):

- Papyrus Griffith Institute I E.7
- Papyrus Cairo JE 89127-30, 89137-43
- Papyrus BM EA 10399
- Papyrus BM EA 10520
- Papyrus BM EA 10794
- Papyrus Carlsberg 30
- Papyrus Heidelberg 663

Ostraca, i.e., stone or pottery sherds were also used as writing material (for a list of Demotic mathematical ostraca see Ritter, 2000, p.134, note 27). It is likely that further sources will be discovered, as collections of Demotic papyri are being edited only now. Demotic (<http://www.digitalegypt.ucl.ac.uk/writing/demotic.html>) is the cursive penultimate stage of ancient Egyptian.

The Demotic mathematical papyri show some similarities with their hieratic predecessors. Again, there are problem (or procedure) texts and table texts, and mathematical techniques are expressed rhetorically using specific numerical examples. On the other hand, there are distinct differences. At least within the extant Demotic mathematical papyri, we find that calculations of operations indicated in the procedures are no longer carried out in writing within the texts. Moreover there is a multiplication table within BM EA 10520, and the instructions for performing a multiplication in the same text are

strikingly different from the Middle Egyptian method. The types of problems also vary, including some well-known Mesopotamian problems like that of a pole leaning against a wall.

Historiography

Earlier historiography has operated on the now outdated assumption that mathematical techniques exist and develop independently from their social and cultural context. These earlier studies focused mainly on the similarities with modern mathematics, using modern mathematical terminology and concepts to analyse the mathematical papyri. In 1989, Jim Ritter made a new beginning, setting new standards for the field (including the knowledge of Egyptian language and culture so the mathematical papyri can be studied in their original form and context). For an English translation see (Ritter, 1995). A similar development has taken place for Mesopotamian mathematics pioneered by Jens Høyrup, Jim Ritter and Eleanor Robson. While older secondary literature is not to be discarded, it should be read carefully and the reader needs to keep in mind that significant progress has been made in Egyptology as well as in the History of Science (especially Gillings, 1972 has to be read with this in mind) in the last 20 years.

See Also

- [Mathematics in Egypt: Mathematical Leather Roll](#)
- [Mathematics in Egypt](#)

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Mathematics

George Gheverghese Joseph

A concise and meaningful definition of mathematics is virtually impossible. Mathematics has developed into a worldwide language with a particular kind of logical structure. It contains a body of knowledge relating to number and space, and prescribes a set of methods for reaching conclusions about the physical world. Also, it is an intellectual activity which calls for both intuition and imagination in deriving “proofs” and reaching conclusions. Often it rewards the creator with a strong sense of aesthetic satisfaction.

Mathematics initially arose from a need to count and record numbers. As far as we know there has never been a society without some form of counting or tallying, i.e., matching a collection of objects with some easily handled set of markers, whether it be stones, knots, or inscriptions such as notches on wood or bone. Also, it is precisely such an artifact that helps us to locate the early beginnings of mathematics.

High in the mountains of Central Equatorial Africa, on the borders of Uganda and Zaire, lies Lake Edward, one of the furthest sources of the River Nile. Though this area, Ishango, is remote and sparsely populated today, about 20,000 years ago a small community lived by the shores of the lake that fished, gathered food or grew crops depending on the season of the year. The settlement had a relatively short lifespan of a few hundred years before being buried in a volcanic eruption. Archeological excavations at Ishango unearthed a bone tool handle which is now on display at the Musée d'Histoire Naturelle in Brussels. The original bone may have petrified or undergone chemical change through the action of water and other elements. What remains is a dark brown object on which some markings are clearly visible. At one end is a sharp, firmly fixed piece of quartz which may have been used for engraving, tattooing, or even writing of some

kind. Along the ► [Ishango Bone](#), as it is now called, is a series of notches arranged in three distinct columns: first column contains four groups of notches with 9, 19, 21, and 11 markings; second column contains four groups of 19, 17, 13, and 11 markings; and third column has eight groups of notches in the following order: 7, 5, 5, 10, 8, 4, 6, 3, with the last pair (6,3) being spaced together, as are (8,4) and (5,5,10), suggesting a deliberate arrangement in distinct subgroups.

Conjectures based on underlying numerical patterns of the notches are well summed up by de Heinzelin, the archeologist who helped to excavate the Ishango Bone. The bone “may represent an arithmetical game of some sort devised by a person who had a number system based on ten as well as a knowledge of duplication (or multiplying by 2) and of prime numbers.” Further, from the existing evidence of the Ishango tools, notably harpoon heads, northward up to the frontiers of Egypt, de Heinzelin supports the possibility that the Ishango numeration system may have traveled as far as Egypt to influence the development of its number system, the earliest decimal-based system in the world.

There is, however, another explanation which highlights a link that has played a crucial part in the historical development of mathematics. The close link between mathematics and astronomy has a long history and is tied up with the need for societies to record the passage of time, both out of curiosity as well as practical necessity. The alternative explanation is that the bone markings constitute a system of sequential notation – a record of different phases of the moon. Whether this is a convincing explanation would depend in part on establishing the importance of lunar observations in the Ishango culture and in part on how closely the series of notches on the bone matches the number of days contained in the successive phases of the moon. Marshak attempted to do both and concluded that the Ishango Bone, with its markings of different indentations, shapes, and sizes, was a lunar calendar where the different types of engraving indicate that it was also a calendar of events, probably of a ceremonial or ritual nature. There

is still a good deal of controversy and interest around this bone.

One of the most ingenious methods of recording and storing information before the emergence of the computer is a *quipu*. The *quipu* (a Quechua word from the language of the Incas of South America) is an arrangement of colored wool or cotton cords with clusters of knots tied in the cords to represent numerical magnitude. In essence, it resembles a mop which has seen better days. It was widely used as a device for storing numerical and other information before the Spanish conquest in an area which would today include all of Peru, parts of Bolivia, Chile, Ecuador, and Argentina. A vast amount of information can be kept on a *quipu* using different colored cords for summation between and within categories and relative placement of the knots for indicating different numerical magnitudes. A *quipu* has been discovered which is a record of a census taken in 1587 of the Andean population of Lupaca disaggregated by province, ethnic groups, size, and age/sex distribution of households, using cords of different thickness, color, and configuration. Altogether 46 different items of information were kept on this recording device no larger than an ordinary kitchen mop.

For a highly centralized society such as the Inca, an essential prerequisite for maintaining good order and efficient organization was the existence of detailed and up-to-date information (or government statistics, as we would describe such information today). A whole inventory of resources which included agricultural produce, livestock, and weaponry – as well as people – was maintained and updated by a group of specially trained officials known as *quipucamayus* (*quipu*-keepers). Each village under the rule of the Inca had its own specially trained *quipucamayu* and certain larger villages had as many as 30. One of the main tasks of the *quipucamayu* was to devise efficient and economical methods of storing information. The more the *quipucamayu* considered the pattern of distribution, taking account of the relative sizes and positions of different cords, the better the logical structure of the final representation. Cord placement, color coding, and number

representation were the basic design features, repeated and recombined to define a format and convey a logical structure. This search for a coherent numerical/logical structure involves mathematical thinking reminiscent of database management in a modern computer and a study of spatial configuration structures of different *quipus* is a good introduction to a field of modern mathematics known as “graph theory.”

It is possible to view the appearance of a written number (or numeral) system as a culmination of earlier developments. First was the recognition of the distinction between more and less (a capacity we share with certain other animals). From this developed first simple counting, then the different methods of recording the counts as tally marks, of which the ► [Ishango Bone](#) is one example. This progression continued with the emergence of more and more complex means of recording information, culminating in the construction of devices such as the *quipu*. Before the appearance of such devices, there must have existed an efficient system of spoken numbers founded on the idea of a base to enable numbers to be arranged into convenient groups.

There is ample historical and anthropological evidence indicating that a variety of bases for counting systems have been used over the ages and around the world. The base of a counting system tells how numbers are grouped and constructed. Our system, a decimal or base-10 system, has words for numbers from one to ten displaying no common root. Beyond ten, the number words generally show a variation of the unit word for the multiples of ten.

To illustrate, take the case of a few counting systems with different bases chosen from round the world. For an indigenous Australian group, the Gumulgal, counting proceeds as *urapon* (1), *ukasar* (2), *ukasar-urapon* (3), *ukasar-ukasar* (4), *ukasar-ukasar-urapon* (5),... to indicate counting by twos (or a base-2 system). In a Melanesian language, Sesake, counting proceeds as *sekai* (1), *dua* (2), *dolu* (3), *pati* (4), *lima* (5), *la-tesa* (6), *la-dua* (7),...*,dua-lima* (10),...*,dua-lima-dua* (20). This suggests a base-5 counting system where words for numbers six or seven use the roots for words one and two; ten is literally

two-fives and twenty is two-fives twice. In a Micronesian language, Kiribati, counting proceeds as *tenuana* (1), *uoua* (2), *tenua* (3), *aua* (4), *nimua* (5), *onoua* (6), *itiua* (7), *wanua* (8), *ruainua* (9), *tebwina* (10), *tebwina-ma-tenuana* (11),...*,vabui* (20), *vabui-ma-tenuana* (21),...*,tebubua* (100),...*,tenga* (1,000),...*,tebina-tenga* (10,000),...*,tebubuna-tenga* (100,000). Here we have a straightforward base-10 counting system. In Kiribiti, number words also vary according to the object being counted. Thus the number word for nine is *ruaman* when counting animals, *ruakai* when counting plants, *ruai* when counting knives, *ruakora* when counting baskets, and *rauawa* when counting boats. In certain other systems, such as the Aztec number system, the choice of the bases would depend on the type of objects being counted. Cloths or tortillas would be counted in twenties, while round objects such as eggs or oranges would be counted in tens.

Counting by tens has been the most widespread system probably because it is associated with the use of fingers on both hands. The other scale (base-20) had its most celebrated development as a written number system during the first millennium of the present era among the Maya of Central America. There have also been other base-20 systems, of which the Yoruba system from Nigeria and the Welsh system from Britain are two well-known examples.

An unusual feature of the Yoruba system is its heavy reliance on subtraction. The subtraction principle operates in the following way. As in our number system, there are different names for the number one (*okan*) to ten (*eewa*), the numbers eleven (*ookanla*) to fourteen (*eerinla*) are expressed as compound words which may be translated into “one more than ten” to “four more than ten.” But once 15 (*aarundinlogun*) is reached the convention changes, so that 15–19 (*ookandinlogun*) are expressed as “twenty less five” to “twenty less one,” respectively, where 20 is known as *oogun*. Similarly, the numbers 21–24 are expressed as additions to 20, and 25–29 as deduction from 30 (*ogbon*). At 35 (*aarundinglogoji*), however, there is a change in the way the first multiple to 20 is referred to: 40 is expressed as “two twenties” (*ogoji*) while

higher multiples are named *ogata* (“three twenties”), *ogerin* (“four twenties”), and so on to “ten twenties,” for which a new word *igba* is used. It is in the naming of some of the intermediate numbers that the subtraction principle comes into its own. To take a few examples, the following numbers are given names which indicate the decomposition shown on the right:

$$\begin{aligned} 45 &= (20 \times 3) - 10 - 5, \\ 108 &= (20 \times 6) - 10 - 2, \\ 300 &= (20) \times (20 - 5), \\ 318 &= 400 - (20 \times 4) - 2, \\ 525 &= (200 \times 3) - (20 \times 4) + 5. \end{aligned}$$

All the numbers from 200 to 2,000 (except those that can be directly related to 400 or *iriniwa*) are reckoned as multiples of 200. From the name *egebewa* for 2,000, compound names are constructed for number in excess of this figure, using subtraction and addition wherever appropriate similar to the above examples.

The origin of this unusual counting system is uncertain. One conjecture is that it grew out of the widespread practice of using cowrie shells for counting and computation. A description of the cowrie shell counting procedure given by Mann in 1887 is interesting. From a bag containing a large number of shells the counter draws 4 lots of 5 to make 20. Five 20s are then combined to form a single pile of 100. The merging of two piles of 100 shells gives the next important unit of Yoruba numeration, 200. As a direct result of counting in fives, the subtraction principle comes into operation. Take the decomposition of 525, given earlier, as an illustration. We begin with three piles of *igba* (200), remove four smaller piles of *oogun* (20), and then add five (*aarun*) cowrie shells to make up the necessary number.

This complicated system of numeration in which the expression of certain numbers involves considerable feats of arithmetical manipulation has certain advantages for computation. As an example of a calculation which exploits the strength of the Yoruba numeration to the full, consider the multiplication: 19×17 .

The cowrie calculator begins with 20 piles of 20 shells each. From each pile, one shell is

removed (-20). Then 3 of the piles now containing 19 shells each are also removed. The 3 piles are adjusted by taking 2 shells from 1 of them, and adding 1 each to the other 2 piles to bring them back to 20 ($-20 \times 2 - (20 - 3)$). At the end of these operations we have

$$400 - 20 - (20 \times 2) - (20 - 3) = 323.$$

While the Yoruba system shows what is possible in arithmetic without a written number system, it is clearly impractical for more difficult multiplications.

However, there are other mechanical aids which are more versatile, such as the Chinese or Japanese abacus (*soroban*). In the speed of addition and subtraction, the abacus still holds its own against the electronic calculator. In a test problem consisting of: first, adding a column of 11 numbers and then subtracting 4 numbers from the result where there was no number of less than three digits and most contained four or five digits, a third-grade abacus operator in China or Japan (i.e., an operator possessing the minimum level of competence acceptable for employment in a bank or similar institution) performed this computation in 30 s. An operator using the calculator took 90 s. A first-grade abacus operator would have been expected to have finished the computation in 20 s. There is even the well-attested claim of an expert operator taking less than 15 s to add ten numbers each of ten digits!

There are two modes of performing arithmetical operations. The first arose in cultures which, either because of scarcity of writing materials or because of the limitation of their written number systems, resorted to physical devices such as cowrie shells or an abacus to carry out multiplication. The second mode involves “paper-and-pencil” methods of written numbers. The origins of many of these paper-and-pencil algorithms are found in parts of the non-Western world which gave birth to different place value number systems: Babylonia during the third millennium BCE, China around the third century BCE, the Maya Empire around the beginning of the Common Era, and in India a few centuries later. And in the process of transmitting the Indian numerals

westward some of the efficient algorithms, initially devised for these numerals, were lost.

To illustrate, consider multiplying 97 by 93. The method favored today involves two sets of multiplication, one requiring the “9-times table,” then adding the results of the two sets of multiplication on paper to get the final answer: 90/21. Of course these days, one would use an electronic calculator but feel rather lost if the calculator was not readily at hand. But there is a startlingly simple yet mathematically profound method available from the distant past.

Take the problem: 97×93 ; 97 is 3 less than 100, 93 is 7 less than 100. Multiply the deficiencies 3 and 7 to get 21. Subtract from 97 the deficiency corresponding to the other number, 93, which is 7 or the other way round. Both subtractions will give 90. The final answer is the merging of the two parts: 90/21. This procedure can be mathematically “productive” if one then proceeds to answer the following “what ifs”:

- What if both numbers to be multiplied are just over 1,000?
- Both just under 1,000?
- One just over and one just under 1,000?
- Both just over or just under 100?
- Or one just over and one just under 100?
- What about numbers near 50?
- Or near 20?
- What if they are not both within the range of the same base?

In all these cases, the procedures devised involve using the principal strength of our number system – the place value principle. An examination of why the method works leads us quite naturally to the interconnection of arithmetic, algebra, and geometry, and also a reminder that algebra is but a generalization of arithmetic. A method claimed to be as old as the Vedas (ca. 500 BCE), it is found in works of later Indian mathematicians, notably ► [Brahmagupta](#) (ca. AD 600) and Bhāskarāchārya (ca. AD 1100). It was known to the Arabs through whom our number system, which began in India, spread westward into Europe. Yet this method was lost and what we have in place are rather cumbersome

procedures, some more suitable perhaps for multiplication with number systems without place value like the Roman numerals.

The rules devised by mathematicians for solving problems about numbers of one kind or another may be classified into three types. In the early stages of mathematical development, these rules were expressed verbally, and consisted of detailed instructions about what was to be done to obtain a solution to a problem, for which reasons this approach is referred to as *rhetorical algebra*. In time, the prose form of rhetorical algebra gave way to the use of abbreviations for recurring quantities and operations, heralding the appearance of syncopated algebra. Traces of such algebra are to be found in the works of the Alexandrian mathematician Diophantus (ca. AD 250), but it achieved its fullest development in the work of Indian and Arab mathematicians during the first millennium AD. During the past 500 years symbolic algebra has developed so that, with the aid of letters and signs of operation and relation (+, −, ×, /, =), problems are stated in such a form that the rules of solution may be applied consistently and systematically. The transformation from rhetorical to symbolic algebra has been a long one and marks one of the most important advances in mathematics. It had to await the development of a positional number system (i.e., the Indian numerals) which allowed numbers to be expressed concisely and with which operations could be carried out efficiently.

As early as 1800 BCE, the Babylonians had developed sophisticated methods of solving equations, building on their invention of a positional number system. A 4,000-year-old Babylonian clay tablet, now kept in a Berlin museum, gives the value of $n^3 + n^2$ for $n = 1, 2, \dots, 10, 20, 30, 40, 50$, from which it is deduced that the Babylonians may have used these values in solving cubic equations after reducing them to the form $x^3 + x^2 = c$. Linear and nonlinear equations in two and three unknowns were also solved correctly within the framework of a rhetorical algebra.

Early Indian algebra also contained solutions of linear, simultaneous, and even indeterminate equations. An example of an indeterminate

equation in two unknowns (x and y) is $3x + 4y = 50$, which has a number of positive whole-number solutions for (x, y) . For example $x = 14, y = 2$ satisfies the equation, as do the solution sets $(10, 5)$, $(6, 8)$, and $(2, 11)$. But it is only from AD 500 that there emerged a distinctive feature – the use of symbols, such as a dot or the letters of the alphabet, to denote unknown quantities. In fact it is this very feature of algebra that one immediately associates with the subject today. A general term in Indian algebra for any unknown was *yāvat tāvat*, which was shortened to the algebraic symbol *yā*. In Brahmagupta's work, Sanskrit letters appear, which are the abbreviations of names of different colors which he used to represent several unknown quantities. Thus the letter *kā* stood for *kālaka*, meaning “black,” and the letter *nū* for *nūlaka* meaning “blue.”

The word *al-jabr* appears frequently in Arab mathematical texts that followed al-Khwārizmī's influential *ḥisāb al-jabr w'al-muqābala* written in the first half of the ninth century AD. There were two meanings associated with *al-jabr*. The more common one was “restoration” as applied to the operation of adding equal terms to both sides of an equation, so as to remove quantities, or to restore a quantity which is subtracted from one side by adding it to the other. Thus an operation on the equation $2x + 5 = 8 - 3x$ which leads to $5x - 5 = 8$ would be an illustration of *al-jabr*. There was also another, less common meaning: multiplying both sides of an equation by a certain number to eliminate fractions. Thus, if both sides of the equation $9/4x + 1/8 = 3 + 5/8x$ were multiplied by 8 to give the new equation $18x + 1 = 24 + 5x$, this too would be an instance of *al-jabr*. The common meaning of *al-muqābala* is the “reduction” of positive quantities in an equation by subtracting equal quantities from both sides. For the second equation above, applying *al-muqābala* would give $18x - 5x + 1 - 1 = 24 - 1 + 5x - 5x$ or $13x = 23$. The words *al-jabr* and *al-muqābala*, linked by *wa* (and), came to be used for any algebraic operation, and eventually for the subject itself. Since the algebra of the time was

almost wholly confined to the solution of equations the phrase meant exactly that.

Apart from giving the name to the subject, the great contribution of the Arabs to algebra was to devise an efficient system of classifying equations. Starting with al-Khwārizmī, they reduced all equations to six main types. For each type they offered solutions and when possible a geometric rationale. Their work culminated in 'Umar al-Khāyyam's geometric solution of the cubic equation in the middle of the eleventh century AD. The Arab work on equations is one illustration of their ability to bring together two strands of mathematical thinking – the geometric approach which had been carefully cultivated by the Greeks and the algebraic/algorithmic methods which had been used to such effect by the Babylonians, Indians, and Chinese.

The development of Chinese algebra was a direct result of their number system – the rod numeral system. Apart from its notational facility, the rod numeral system was helpful in suggesting new approaches to algebraic problems, notably the use of a variant of the modern matrix method for solving simultaneous equations about 1,000 live hundred years before its so-called discovery in Europe and the “method of double false” which constitutes an important algorithm for solving higher order equations in the modern subject of numerical analysis.

The Chinese work on solutions of numerical equations of higher order has its origins in the method of extracting square and cube roots found in their premier text, ► [Jiuzhang suanshu](#) (Nine Chapters on the Mathematical Arts), written around the beginning of the Common Era. The combination of the root extraction procedure with the use of what we know as the Pascal triangle (although it was already known to the Chinese about 500 years before the seventeenth-century French mathematician, Pascal) meant that the Chinese were solving equations of the ninth degree (i.e., equations involving the term x^9) around AD 1250, using a variant of the Horner-Ruffini method which only came into modern mathematics at the beginning of the nineteenth century.

Any definition of the subject matter of mathematics would include activities that relate to

spatial configurations or geometry. There are two theories regarding the origins of geometry. Herodotus, the Greek historian who lived in the fifth century BCE, wrote that geometry arose in ancient Egypt from the need to parcel out, in an equitable fashion, precious agricultural land whose boundaries were annually obliterated by the overflow of the River Nile. The ideas of the Egyptian surveyors (or “rope-stretchers”) were eventually passed on to the Greeks who proceeded to build that most impressive edifice known as “Greek geometry.” However, Egyptian geometry had shown the way, for in the Moscow Papyrus, an important source of Egyptian mathematics from about 1850 BCE, the correct rule for calculating the volume of a truncated pyramid appears.

An alternative explanation sees the origins of geometry in religion and ritual. A good illustration would be a class of ritual literature from ancient India, known as the *Śulbasūtras* dealing with the measurement and construction of various sacrificial altars. They also happen to be the earliest text of Indian geometry dated around 800–500 BCE. They provided instructions for two types of rituals, one for worship at home and the other for communal worship. Square and circular altars were sufficient for household rituals while more elaborate altars involved combinations of rectangles, triangles, and trapezia for public worship. The geometry of the *Śulbasūtras* grew out of the need to ensure strict conformation of the orientation, shape, and area of altars to the prescriptions laid down in the scriptures. They include a general statement of the so-called “Pythagorean theorem,” an approximation procedure for obtaining the square root of 2 correct to five decimal places and a number of accurate geometric constructions including ones for “squaring the circle” (approximately) and constructing rectilinear shapes whose area was equal to the sum or difference of areas of other shapes. The earliest known demonstration of Pythagoras’ theorem is found in an ancient Chinese text, ► [Zhoubi suanjing](#), at least 300 years before Pythagoras (ca. 500 BCE). Over 1,000 years before Pythagoras, the Babylonians knew and used the result now known under his name.

To most of us geometry deals with lines, angles, circles, and polygons. These are the central concepts that appeared in the best-known text in geometry, Euclid’s *Elements* (ca. 300 BCE). To these were subsequently added subjects such as symmetry, coordinates, vectors, and other curves. Many of these concepts appear in different cultures in a variety of contexts: in architecture, drawings, decorations, etc. Do such examples constitute mathematics or can they at best be used as no more than peripheral illustrations of certain geometrical notions? In 1986, Paulus Gerdes posed the following “nonstandard” problems to a workshop of mathematics educators who had some difficulty working them out, although artisans in Mozambique, some of them illiterate, solved them as a matter of course:

- Construct a circle given only its circumference: a problem in laying out a circular floor for a traditional Mozambican house.
- Construct angles that measure 90° , 60° , or 45° with only strips of straw: a problem in basket weaving.
- Fold an equilateral triangle out of a square: a problem in making a straw hat.
- Construct a regular hexagon out of straw: a problem in making a fish trap.

Does solving these problems involve mathematical thinking? It could be argued that the artisans who first discovered the optimal solutions to these problems were engaged in “creative” geometrical thinking. Mary Harris has extended this argument to tasks which are usually seen as women’s work.

Many of the male teachers are so unfamiliar with the construction and shape and size of their own garments that they cannot at first perceive that all you need to make a sweater (apart from technology and tools) is an understanding of ratio and all you need to make a shirt is an understanding of right-angled and parallel lines, the idea of area, some symmetry, some optimisation, and the ability to work from two-dimensional plans to three-dimensional forms ... It is interesting to take Gerdes’ analyses ... and apply them ... in the different context of women’s culture.

All that is needed in many non-Western cultures is to “defrost” the frozen mathematics of the cultures contained in useful objects such as baskets, mats, pots, houses, sand-drawings, sculptures, fish traps, etc.

There is, however, a major stumbling block: the wide spread acceptance of the hegemony of a Western version of mathematics, following from the assumption that mathematics is largely a European creation. Two tactics have been used to propagate this Eurocentric myth.

The first is Omission and Appropriation. Prior to the “Renaissance,” European acknowledgment of the debt it owed to Arab mathematics and its antecedents was fulsome both in words and deeds. Indeed the course of European cultural history and the history of European thought are inseparably tied up with the activities of Arab scholars during the Middle Ages and their seminal contributions to mathematics, the natural sciences, medicine, and philosophy. By the seventeenth century, however, the perception concerning the origins of mathematical knowledge had begun to change, due to the workings of a number of forces. With the European expansion in the American continents, the development of the slave trade, and the imposition of colonial rule in many parts of the world, the assumption of white superiority became dominant over a wide range of social and economic activities, including the writing of the history of mathematics. Moreover, the rise of nationalism in nineteenth- and twentieth-century Europe and the consequent search for the roots of European civilization led to an obsession with Greece and the myth of Greek culture as the cradle of all knowledge and values. This was despite ample evidence of significant mathematical developments in Mesopotamia, Egypt, China, pre-Columbian America, India, and the Arab world, showing that Greek mathematics owed a significant debt to most of these cultures. In recent years a grudging recognition of the debt owed by Greece to earlier civilizations and the important contribution of Arab mathematicians has led to some revisions to a “purely” Eurocentric trajectory of the historical development of

mathematics. But the modifications still ignore for the most part the routes through which Hellenistic and Arabic mathematics entered Europe and take little account of the mathematical knowledge produced by India, China, and other cultures. Even those texts which include the Indian and Chinese mathematics often confine their discussion to a single chapter which may go under the misleading title of “Oriental” or “Eastern” mathematics. That these cultures contributed to the mainstream development of mathematics is rarely recognized, and little consideration is given to the mathematical research that is currently taking place in these and other non-Western regions.

The second tactic is Exclusion by Definition. A Eurocentric approach to the history of mathematics is intimately connected with the dominant view of mathematics as a sociohistorical practice and intellectual activity. Despite the development of contrary trends in the last two centuries, the standard textbook approach sees mathematics as a deductive system, ideally proceeding from axiomatic foundations and revealing, by the “necessary” unfolding of its pure abstract forms, the eternal/universal laws of the “Mind.”

The Indian and Chinese concepts of mathematics were very different. Their aim was not to build an imposing edifice on a few self-evident axioms, but to validate a result by any method. Some of the most impressive works in Indian and Chinese mathematics (the summations of complex mathematical series, the use of Pascal’s triangle in solutions of higher order numerical equations, the derivations of infinite series, and the “proofs” of the Pythagorean theorem) involve the use of visual demonstrations that are not formulated with reference to any formal deductive system. The Indian view of the nature of mathematical objects, like numbers, is also based on a framework developed by Indian logicians and linguists which differs at the foundational level from the set theory universe of modern mathematics.

The view that mathematics is a system of axiomatic/deductive truths inherited by the Greeks and enthroned by Descartes has been traditionally

accompanied by a cluster of values that reflect the social context in which it originated:

1. An idealist rejection of any practical, material (ist) basis for mathematics: hence the tendency to view mathematics as value-free and detached from social and political concerns.
2. An elitist perspective that sees mathematical work as the exclusive preserve of a pure, high-minded and almost priestly caste, removed from mundane preoccupations and operating in a superior intellectual sphere.

Non-Western mathematical traditions have therefore been dismissed on the grounds that they are dictated by utilitarian considerations with little notion of rigor in proof. Any attempt at excavation and restoration of non-Western mathematics is a multifaceted task: confront historical bias, question the social and political values shaping the mathematics curriculum, and search for different ways of knowing or establishing mathematical truths found in various traditions.

See Also

- [Abacus](#)
- [Al-Khwārizmī](#)
- [Bhāskara I](#)
- [Brahmagupta](#)
- [Geometry](#)
- [Gou-gu Theorem](#)
- [Jiuzhang Suanshu](#)
- [Quipu](#)
- [Śulbasūtras](#)
- [Umar al-Khayyām](#)
- [Zhoubi suanjing](#)

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Mathematics and Astronomies of the Ancient Berbers

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Introduction

Northwest Africa is an immense territory extending from the Mediterranean shores to the Niger River and from Libya to the Canary Islands. It is here where Berber culture began to develop about 10,000 years ago and where it has continued to develop until the present.

Despite the antiquity and widespread diffusion of Berber culture, North African studies have traditionally understated its contribution to human history. Camps (1980) aptly summarized the situation in the title of his book: *Berbères: Aux Marges de l'Histoire (Berbers: On the Margins of History)*. Although the overall situation has improved in the last decades, thanks to the

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Fig. 1 Libyans depicted in the tomb of the pharaoh Sethy I after Rosellini (1832)



efforts of a new generation of scholars – one main outcome being the ongoing publication of the *Encyclopédie Berbère*, of which 36 volumes have already appeared – actual research on the mathematics and astronomies of the ancient Berbers remains scarce (Fig. 1).

A faithful exposition of the situation must take into account two main areas of research, each one of them with its own scopes, achievements, and methodological problems: continental Berbers on the one hand and Canary Islands Berbers on the other. While both areas are certainly unbalanced from many points of views, for our purposes they complement one another.

Continental studies are mainly the result of the ethnographic fieldwork performed from the late eighteenth century onward by a constellation of researchers, so they mainly provide information on modern Berbers. Most of these studies are related to astronomy through religion, calendar, and folklore, while those few dealing with mathematics mainly focus on numeral systems and their grammar. While some of the reported traditions are important and thought-provoking, little has been said on the technical aspects underlying them nor on their supposed origin and extent.

Besides that, some preliminary work has also been done on the astral aspects of the religion of the ancient Berbers, as well as on the vague astronomical orientation of different archaeological sites.

Canarian studies deal with the Berber populations inhabiting the archipelago before

the Spanish conquest of the islands on the late fifteenth century. They mainly draw on a collection of written sources originating with the European rediscovery of the islands in the early fourteenth century, complemented with archaeological, ethnographic, and linguistic data.

Numeral Systems

Our knowledge of ancient Berber numerals comes from different sources, and all of them point to a pure ten-base system. The three oldest numeral lists are from the Canary Islands and are summarized in Table 1. The first one appears in a letter describing a Portuguese expedition to the islands in 1341 preserved through a copy by Giovanni Boccaccio made in 1342–1345; it seems to have been first studied by Costa de Macedo (1841). The second one appears in a play written by Bartolomé Cairasco in 1582. The third one appears in a chronicle of the conquest of Grand Canary preserved in a very problematic manuscript from 1682 to 1687; it is most probably a late compilation that dislocates the original list by erroneously introducing two Arabian numerals (*arba* and *canza*) and false forms for the tens.

Continental lists are considerably younger than the Canarian ones. The first one I can document was collected by Jezreel Jones about 1713 in the region of Sous (Southern Morocco) and

Mathematics and Astronomies of the Ancient Berbers, Table 1 The three known lists of Canarian numerals

	Letter 1341	Cairasco 1582			Cedeño 1687
		Hypothesis 1	Hypothesis 2	Hypothesis 3	
1	nait/vait	be	be	be	ben
2	smetti	smi	smi	smi	liin
3	amelotti	amat	amat	amat	amiet/amiat
4	acodetti	aco	aco[s]	aco[s]	arba
5	simusetti	somuset	somu[s]	somu[s]	canza
6	sesetti	–	–	[ses]	sumus
7	satti	–	set	set	set
8	tamatti	tamo	tamo	tamo	set
9	alda morana	–	–	benir ?	acot
10	marava	[marago]	[marago]	marago	marago
11	nait/vait marava	ben-ir-marago	ben-ir-marago	–	venir marago
12	smatta marava	–	–	–	linir marago
13	amierat marava	–	–	–	–
14	acodat marava	–	–	–	–
15	simusat marava	–	–	–	–
16	sesatti marava	–	–	–	–
20	–	–	–	–	linago
30	–	–	–	–	amiago
40	–	–	–	–	arbago
50	–	–	–	–	cansago
60	–	–	–	–	sumago
70	–	–	–	–	satago
80	–	–	–	–	setago
90	–	–	–	–	acotago
100	–	–	–	–	bemaraguin
200	–	–	–	–	limar. .in

published in Jones (1715). Generally speaking, the continental data show that the intense Arabization process suffered by continental Berber-speaking groups from the seventh century onward led to three types of situations, summarized in Table 2 (for a more detailed analysis, see Souag, 2007):

1. Certain groups preserved a purely Berber numeral system (Tuaregs, Mzabits, etc.).
2. Certain groups completely lost the Berber numeral system and counted with some dialectal variant of the Arab system.
3. Certain groups preserved the Berber numerals until a certain point, and after that they counted with some dialectal variant of the Arab system. Among them were Kabylians (counting in Berber up to two) and Shilh (counting in Berber up to 19).

Prasse (1974) undertook the reconstruction of the proto-Berber language. A comparison of his reconstruction with the Canarian numerals and other relevant members of the Afro-Asiatic family taken from Brugnatelli (1982) can be seen in Table 3. It is worth noting the similarity of the Canarian radical for number three with the Egyptian instead of the Berber.

Astronomy, Calendars, and Social Organization

The fieldwork of nineteenth- to twentieth-century ethnographers shows that northwest African people actually used several concurrent calendars (E. B., Gast, & Delheure, 1992; Drouin, 2000). While the Julian calendar was the most used for agricultural purposes and the Hegira was mainly

Mathematics and Astronomies of the Ancient Berbers, Table 2 Tuareg, Kabylean, and Arabian numeral systems

	Tuareg, 19 th century (Hanoteau, 1976)		Kabylean, 19 th century (Hanoteau, 1976)		Classic Arabian (Brugnatelli, 1982)	
	Male	Female	Male	Female	Male	Female
1	iien	iiet	iioun, iiedj	iiuth, iiechth	‘aḥad ^{un} , wāḥid ^{un}	‘iḥdā, wāḥidat ^{un}
2	sin, essin	senatet	sin	senath	‘itnāni	‘itnatāni
3	keradh	keradhet	thletha	id.	ṭalāṭ ^{un}	ṭalāṭat ^{un}
4	okkoz	okkozet	arbāa	id.	‘arba ^{un}	‘arba’at ^{un}
5	semmous	semmouset	khamssa	id.	ḥams ^{un}	ḥamsat ^{un}
6	sedis	sediset	settsa	id.	sitt ^{un}	sittat ^{un}
7	essaa	essaat	sebāa	id.	sab ^{un}	sab’at ^{un}
8	ettam	ettamet	themanian	id.	ṭamān ⁱⁿ	ṭamāniyat ^{un}
9	tezkaa	tezkaat	tsāa	id.	tis ^{un}	tis’at ^{un}
10	meraou	meraout	āchera	id.	‘ašr ^{un}	‘ašarat ^{un}
11	meraou d iien	meraout d iiet	ah’dach	id.	‘aḥada ‘ašara	‘iḥdā ‘ašrata
12	meraou d essin	meraout de senatet	ethnach	id.	‘itnā ‘ašara	‘itnatā ‘ašrata
20	id.	senatet temerouin	ācherin	id.	‘išrūna	id.
30	id.	keradhet temerouin	thlathin	id.	ṭalāṭūna	id.
40	id.	okkozet temerouin	arbāin	id.	‘arba’ūna	id.
50	id.	semmouset temerouin	khamsin	id.	ḥamsūna	id.
60	id.	sediset temerouin	settsin	id.	sittūna	id.
70	id.	essaat temerouin	sebāin	id.	sab’ūna	id.
80	id.	ettamet temerouin	themaniin	id.	ṭamānūna	id.
90	id.	tezkaat temerouin	tesāin	id.	tis’ūna	id.
100	id.	touinest	mīia	id.	mi’at ^{un}	id.
200	id.	senatet touinas	mīithain	id.	mi’atāni	id.
1000	id.	timidhit ?	elef	id.	‘alf ^{un}	id.

Mathematics and Astronomies of the Ancient Berbers, Table 3 General comparative table of numeral systems

	Proto-Berber	Canarian	Egyptian	Acadian	Arabian
1	yīwan	nai/vai, be, ben	w’jw	ištēn	wāḥid ^{un}
2	sīn	sme, smi	snwj	ši/ena	‘itnāni
3	karāḍ	amel, amat	ḥmtw	šalaš	ṭalāṭ ^{un}
4	hakkūz	acod, aco[s]	jfdw	erba	‘arba ^{un}
5	sammūs	simus, somu[s]	djw	ḥamiš	ḥams ^{un}
6	saḍīs	ses	jsw	(ši/eššum)	sitt ^{un}
7	sāh	sa, se	sfḥw	sebe	sab ^{un}
8	tām	tama, tamo	ḥmnw	samāne	ṭamān ⁱⁿ
9	tiṣāh	alda [marava]	psḍw	tiše	tis ^{un}
10	marāw	marava, marago	mḍw	ešer	‘ašr ^{un}

used in religious circumstances, the Gregorian calendar served to interact with administration and modern life and was a common reference between the different systems.

Since these three calendars are non-Berber in origin, it is only necessary here to make a brief

remark on their respective dates of introduction. Certainly, the Hegira was introduced after the Arab invasion in the seventh century and the Gregorian calendar after its inception in 1582, but the introduction of the Julian calendar remains controversial. While many authors

think that it is a remnant of the Roman domination, Servier (1985, pp. 369–371) and Genevois (1975a, p. 5) think it is a Coptic version of the Julian calendar introduced by the Arabs, where the months are divided in lunar mansions.

Besides these non-Berber calendars, Boogert (2002) has argued the existence of a more ancient Berber calendar, while different authors have recorded a set of interesting observational and calendrical practices based on the actual observation of the stars (Bernus & Ehya, 1989; Drouin, 2000).

In addition to all these calendrical practices, a more profound and extensive astronomical tradition has been posed by two different and exhaustive studies carried out in the middle twentieth century by the French ethnologists Jean Servier and Viviana Pâques.

The Doors of the Year

Jean Servier traveled in North Algeria from 1949 to 1961 compiling information about the traditional thinking of Berber-speaking peasants. His work (Servier, 1985) describes a complex symbolic world superposed on an apparently simple material culture. He found that northern Algerian peasants mix a visible world with an invisible world. The invisible world would be related to their ancestors and the rhythms of nature as marked by the *tibburin ussegwass* (doors of the year). The doors of the year are the solstices and the equinoxes. In his opinion, this was part of an ancient system which has disappeared in other parts of the circum-Mediterranean area, but is well preserved by traditional Berber peasants.

Canopus and the Cosmic Tree

From 1953 onward, Viviana Pâques researched in Fezzan, Sahara, Mali, Algeria, and Tunis. She studied the spiritual world which enslaved Black people would have brought with them into these lands. Her results were presented in Pâques (1964). To her surprise, what she found was a conception of the world common to all peoples of North and West Africa, a conception as characteristic for an anthropologist as a typical biface would be for an archaeologist (Pâques, 1964, p. 10).

Everywhere she found one or another variant of the following cosmogony:

1. God created the world by exploding Canopus, the primeval star. From Canopus exited the triple serpent it held in its matrix, which commands all divisions of the world by three. The explosion of Canopus gave birth to six other stars, which command all divisions of the world by seven.
2. The world turned back when a hero (sometimes a smith) decapitated the serpent, which was the prelude to all circumcisions.
3. The hero descended to the Earth through the triple cosmic tree formed by the body of the decapitated serpent.
4. The hero ascended the cosmic tree later, on the occasion of a second sacrifice of the serpent, which was the prelude to all marriages.
5. These mystic events occurred at a determinate point of the sky, at a moment when the sun was in a particular relation with Canopus, for the explosion, and with the Pleiades for the sacrifices. (On the planets' layout, the Pleiades are assimilated with Venus.)

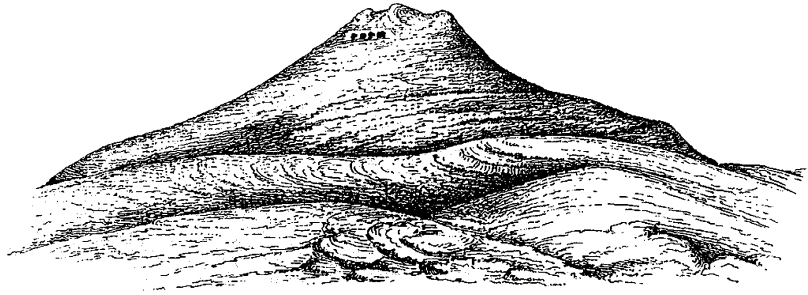
This myth defined the rules that organize every aspect of traditional North and West African life: from political, territorial, and social structures to the division and rhythms of the heavenly movements, from the division of the agricultural year by means of certain constellations to the design of clothes, shoes, coiffures, and everything that could reflect this system in daily life.

The myth is deeply associated with three colors – white, red, and black – respectively related to the triple serpent inside Canopus. Number 3 (and 60-based counts) is associated with women, while number 4 (and 80-based counts) is associated with men. Number 7 ($=3 + 4$) represents the union of a man and a woman.

As to the origin of this African cosmogony, different opinions have been posed, ranging from a Mediterranean to an Oriental or Indian one. Nevertheless, the internal coherence, originality, and distribution map of this myth make Pâques suggest that it originated at a very ancient date in some agricultural community living in a

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Fig. 2 The mountain of Cuatro Puertas after Berthelot (1879)



subdesert territory, perhaps around some of the Saharan oases where these conceptions are most fully preserved (Pâques, 1964, p. 676).

What can be said about the astronomical and mathematical implications carried by the antiquity, originality, and complexity of this cosmogonical system? This is probably one of the most interesting open problems for the history of ancient sciences, and the Canary Islands have something to say here.

The Canarian Evidence

In the fourteenth to fifteenth centuries AD, the Canary Islands were inhabited by Berber populations coming from the nearby continent on different occasions between the first millennium BC and the first millennium AD. These populations remained relatively isolated until the European rediscovery of the islands in the late thirteenth century AD.

At the time, Grand Canary and Tenerife were the more populated islands with about 40–60,000 people, sustaining a developed agricultural (barley, wheat) and stock raising (goats, sheep, pigs) economy. The written sources point out the presence in both islands of a powerful priestly class, in whose religious system the sun, moon, and stars played a very important role.

Grand Canary Island

The Canarians used a synodic lunar calendar for daily life. The lunar year was adjusted to the solar year at the summer solstice. Although nobody mentions an intercalary moon, the first new moon after the summer solstice marked a new

year and was feasted. Actual calendrical figures are very scarce, but they mention a lunar synodic month of 29 days, a lunar year of 12 months, and a certain period of 520 days, which is an exact measure of one and a half eclipse years or three passes of the sun by the lunar nodes (this is the reason why eclipses are located in three fixed zones of the 260-day Mesoamerican sacred calendar; see Lebeuf, 1995).

There are also notices about observation of rising and setting of stars. Sirius is the only explicitly mentioned star, but there is a clear reference to Afarakrak, a Berber name of Canis Major, in Facaracas, the preserved name of an important site where the nobility of the island used to meet.

Archaeoastronomical research undertaken from 1985 at the mountain of Cuatro Puertas (Four Doors) has revealed several methods for observing the solstices and other astronomical dates.

The mountain is an isolated arid volcanic semi-cone oriented east–west with an elevation of 319 m. above sea level. Seen from the north (Fig. 2), its slopes are smooth and rounded. All that stands out is the big artificial cave with four entries located near the top, which gives its name to the mountain. The precise orientation of these doors assures that sunlight only enters the cave at sunrise (Fig. 3) and sunset (Fig. 4) on a few days around the summer solstice.

Seen from the south, its appearance is diametrically opposed, plunging abruptly from its top to the bottom of a ravine. On this slope, there is a group of spacious and sophisticated artificial caves excavated in the rock, among which stands out the cave of Los Pilares (The Pillars).

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Fig. 3 Summer solstice sunrise at Cuatro Puertas cave (Photo by José Barrios García)



Mathematics and Astronomies of the Ancient Berbers,

Fig. 4 Summer solstice sunset at Cuatro Puertas cave (Photo by José Barrios García)



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Mathematics and Astronomies of the Ancient Berbers,

Fig. 5 Winter solstice sunrise from the cave of Los Pilares (Photo by José Barrios García)



This cave is fully illuminated by the rising sun on winter solstice days (Figs. 5 and 6).

At the top of the mountain, there is a little ritual esplanade of some 10×5 m. partially

excavated on the rock (Fig. 7). Open to the east and south, on the wall facing the east, there is a carved sign about 2.4 m. long with JUUU form (Fig. 8).

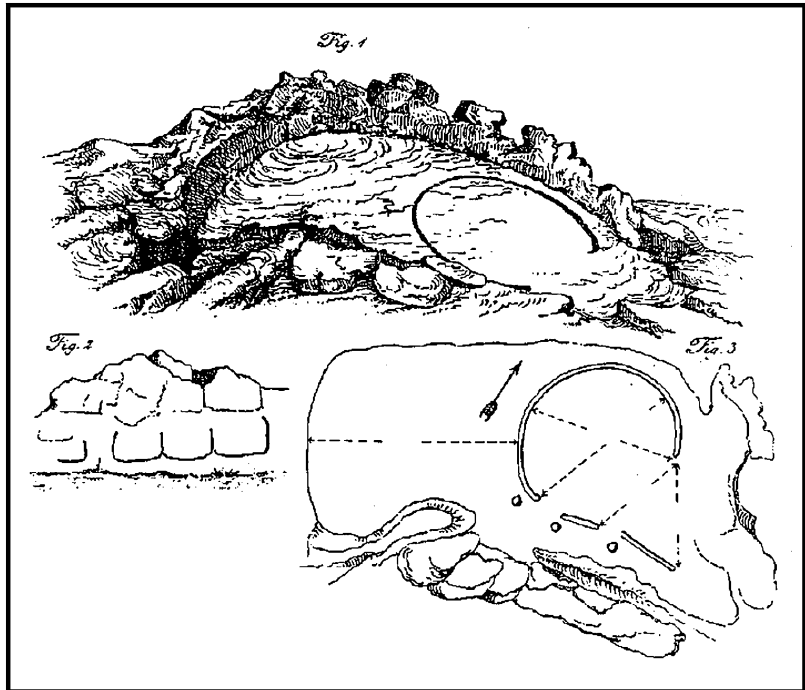
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Fig. 6 Winter solstice
sunrise illuminating the
cave of Los Pilares (Photo
by José Barrios García)



**Mathematics and
Astronomies of the
Ancient Berbers,**

Fig. 7 Ritual esplanade at
the top of Cuatro Puertas
after Berthelot (1879)



Every day at sunrise, the silhouette of the rock located in front of the sign (Fig. 9) casts a certain shadow that changes its position day by day, reflecting the azimuthal change of the sunrise. The left edge of the shadow reaches the different strokes on determined dates, while the whole shadow fits the sign just on the summer solstice days (Fig. 8). At the same time, an observer situated at the sign can mark the summer solstice sunrise as shown in Fig 9.

The Canarians used certain characters to record numerical, astronomical, and calendrical data systematically. These figures were triangles, squares, and circles painted in white, red, and black on wood planks and on the walls of certain caves. The modern reconstruction of the decoration of the Painted Cave of Gáldar strongly suggests the use of a 3×4 chessboard, hereafter named *acano*, to represent 12 moons (Figs. 10 and 11).

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Fig. 8 The shadow at summer solstice sunrise fitting the sign of Cuatro Puertas (Photo by José Barrios García)



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Fig. 9 Summer solstice sunrise from the sign of Cuatro Puertas (Photo by José Barrios García)



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Mathematics and Astronomies of the Ancient Berbers, Fig. 10 The acano chessboard

A systematic analysis of the *acano* as a lunar calendar shows how the vertical numeration of its squares forces the solstitial, equinoctial, and eclipse moons to move across the board in very simple and stable patterns. These patterns

provide a safe and clear mnemonic guide for performing on the *acano* an easy arithmetical calculus of seasonal and eclipse moons over extended periods of time. This calculus establishes the *octaeteris* and the 135-moon eclipse cycle as basic periods of the *acano* (Barrios García, 1997, 1999).

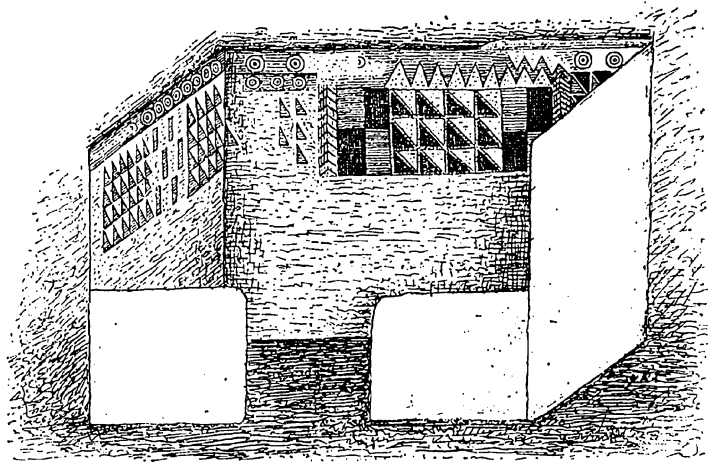
A new and very significant support of the proposed calculus comes from an unexpected place. The Dogon use a 12 ($=2 \times 6$)-square board to represent 12 moons: *D'un façon générale, la figure totale des 12 cases des tables d'instruction constitue un calendrier lunaire et représente également la marche du soleil pendant un an* (Griaule & Dieterlen, 1991, p. 280).

Tenerife Island

The Guanches, as the Canarians, used a synodic lunar calendar for daily life, adjusting it to the

Mathematics and Astronomies of the Ancient Berbers,

Fig. 11 The Painted Cave of Gáldar after Verneau (1889)



Mathematics and Astronomies of the Ancient Berbers,

Fig. 12 A Guanche necklace and different types of clay beads after Berthelot (1879)



solar year at the summer solstice. Written sources mention the use of tally boards and small necklaces of clay beads for recordkeeping, although the absence of well-preserved examples in a reliable archaeological context impedes testing these accounts (Fig. 12).

Nobody mentions an intercalary moon, but the first moon of the year occurred toward the middle of August and was celebrated. This festival persists today in the traditions of the virgin of Candelaria, patron of the island (Fig. 13).

These traditions report that the image of the virgin of Candelaria appeared to the Guanches in

the beaches of Güímar about 100 years before the Spanish conquest in the late fifteenth century. At first, they offered to the image a Guanche cult, but after they learned the Catholic character of the image through a released Guanche slave, they move the image to the cave of Achbinico or San Blas (Saint Blaise), where it remained until the conquest of the island (de Espinosa, 1594).

A close analysis of the Guanche cult (Barrios García, 1996, 2004) shows that it matches a cult to a stellar deity, considered the “mother of the sun” as well as the “mother of the one who sustains the world.” Moreover, besides the main

festival that occurred about the middle of August, there were two other important ones occurring in early February and late April, respectively. These three periods can be readily correlated with the heliacal rise, acronical rise, and heliacal set of Canopus (Fig. 14). Note that the Catholic dates of La Candelaria and San Blas are the 2nd and 3rd of February, respectively.



Mathematics and Astronomies of the Ancient Berbers, Fig. 13 Original image of Our Lady of Candelaria, Tenerife (Painted by Cristóbal Hernández de Quintana in 1717)

On the whole, the gathered evidence proves the presence in Tenerife of the Canopian cosmogonical system described by Pâques (1964).

Further evidence concerning the determination of the year of apparition of the virgin to the Guanches supports the idea that the Guanches used a commensurability period of 19 solar years $\approx$ 21 sidereal lunar years in their calendrical reckonings (Barrios García, 2004, pp. 188–191).

La Gomera Island

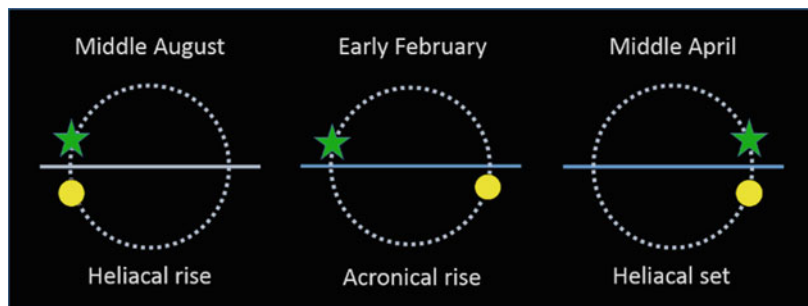
Radiocarbon dates show that this rough and round island, situated west of Tenerife, was inhabited from at least the second century AD. At the time of the European arrival in the fourteenth century, its population was about 2,000–4,000, mainly living from stock raising (goats, sheep, and pigs) and in a lesser extent from agriculture (barley and other grains) and maritime and terrestrial recollection. Written sources are very scarce, but they suggest that astral bodies played a significant role in their religious system (Barrios García, 2004, pp. 48–50).

Intensive archaeoastronomical work conducted from 2010 onward has revealed some astronomical techniques used by the ancient Gomerans. The two main findings until now have been located at the cave of Las Toscas del Guirre (Barrios García, Hernández Marrero, & Trujillo Mora, 2014a) and the mountain of La Fortaleza (Barrios García, Hernández Marrero, & Trujillo Mora, 2014b), respectively.

The cave of Las Toscas del Guirre is a little cave open to the south, situated near the top of a ravine in the oriental sector of the island.

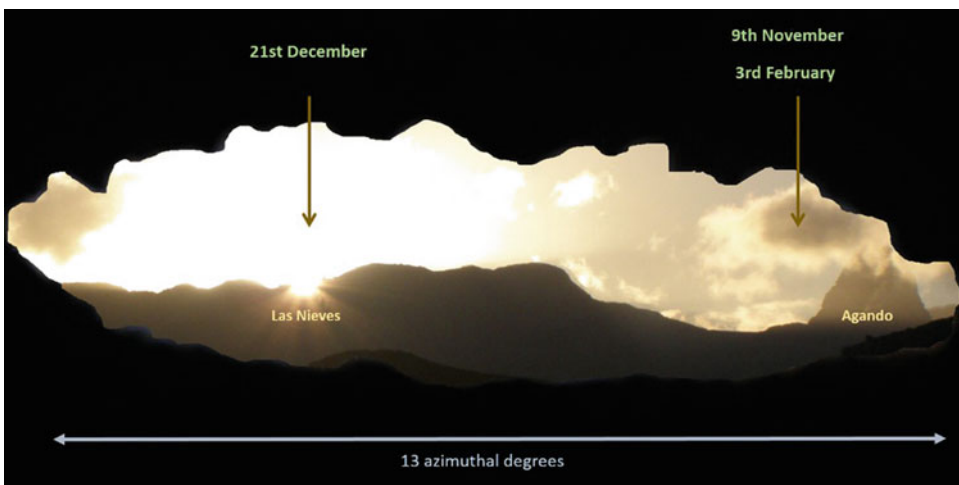
Mathematics and Astronomies of the Ancient Berbers, Fig. 14

Phases of Canopus calculated for the latitude of the Canary Islands in the fourteenth to fifteenth centuries (Graphic by José Barrios García)



Mathematics and Astronomies of the Ancient Berbers,

Fig. 15 The author taking a photo of the western horizon of Las Toscas del Guirre through the hole in the western wall of the cave (Photo by José Miguel Trujillo. Used with permission)



Mathematics and Astronomies of the Ancient Berbers, Fig. 16 Winter solstice sunset at Las Toscas del Guirre seen through the hole in the western wall of the cave (Photomontage by José Barrios García)

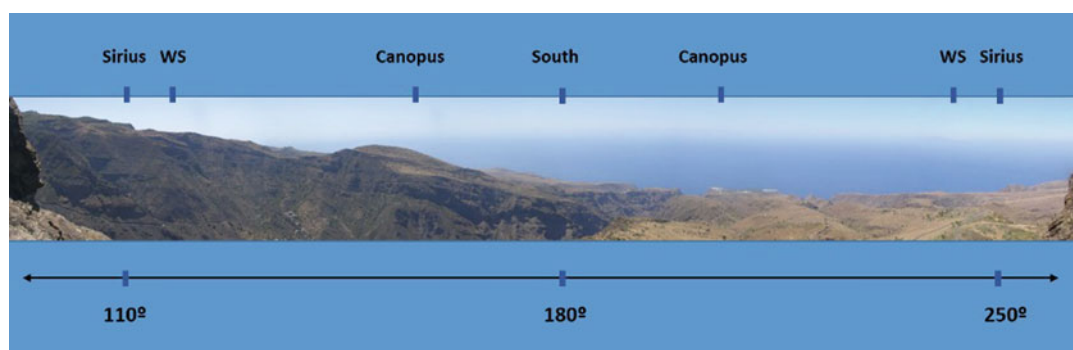
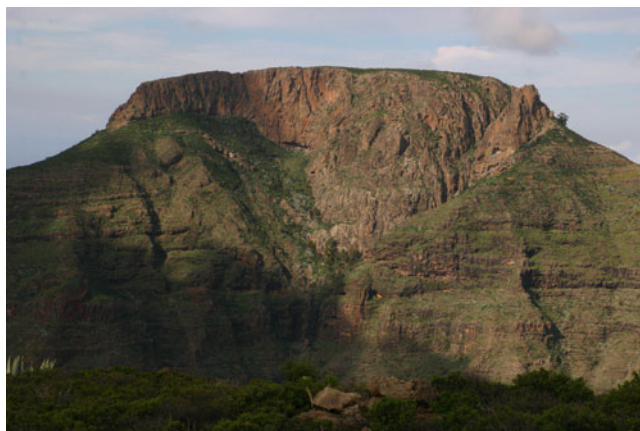
Discovered in 2005, it contains the bigger panel of alphabetic Libyco-Berber inscriptions found until present in the Canary Islands (Navarro Mederos, Springer Bunk, & Hernández Marrero, 2006). The undeciphered inscriptions are located on the oriental wall of the cave occupying a surface of approximately 3.30 m wide by 2.10 m high. The only notable feature in the western wall is a quasi-elliptical hole of about 18 cm wide and 15 cm high through which an observer can comfortably spot a range of about 13° azimuthal degrees of the western horizon, just the place where the sun sets on winter solstice (Figs. 15 and 16).

Confirming the intentional character of the hole, the exact place of the solstitial sunset, as seen from the cave, is marked with one of the oldest catholic hermitage of the island dating from the sixteenth to seventeenth century: the hermitage of Las Nieves.

La Fortaleza of Chipude is a top-flat mountain located at the west of the island and traditionally considered one of the main religious centers of the ancient Gomerans (Fig. 17). The patron of the little village of Chipude is the virgin of Candelaria, and her feast in middle August is one of the main popular celebrations of the island from ancient times.

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Fig. 17 Mountain of La Fortaleza, Chipude, La Gomera (Photo by José Miguel Trujillo. Used with permission)



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Mathematics and Astronomies of the Ancient Berbers, Fig. 18 The astronomical horizon of the cave of San Blas, La Fortaleza, Chipude. Photomontage by José Barrios García

Local tradition sustains that the walls of a certain drystone construction, at present in very bad state of preservation in a ravine close to La Fortaleza, are the remains of the very first hermitage of La Candelaria, abandoned after the construction of the new church of La Candelaria in the village of Chipude, on the early sixteenth century.

On the other hand, the same local tradition has preserved the knowledge of a certain sacred cave in La Fortaleza which in the past hosted a statue of San Blas (Saint Blaise), and so it is called the cave of San Blas, associating the cave with certain summer solstice sunrise rituals performed in the past. Since the cave is completely oriented to the south and Canopus can be traced from it all year without any visual interference, we think that this cave was an observing point of Canopus (Fig. 18).

In this sense, the origin of the cult to the virgin of Candelaria in La Gomera and Tenerife would be quite similar: an adaptation of the indigenous Canopian cults to the Catholic ones.

Conclusions

In this article, I have tried to relate the research on the mathematics and astronomies of the continental Berbers with the Canarian Berbers in a way that tries to emphasize their mutual interdependence.

On the one hand, the research on continental modern Berbers throws a very important light on Canarian Berbers that helps to explain important aspects of their cultural and material world.

On the other hand, those aspects of modern Berbers found among the ancient inhabitants of

the Canary Islands must pertain to an ancient, not-Islamized, cultural background of certain groups of continental Berbers.

Certainly, the Berber populations coming from the continent to inhabit the islands, in addition to their very precious seeds and cattle, ought to bring with them, at the very least, the necessary mathematical and astronomical techniques that would let them not to lose the seed and the cattle. Otherwise, they were condemned to die, and certainly this was not the case.

Once in the islands, they ought to adapt their knowledge to the peculiarities of the archipelago. The extent to which the mathematical and astronomical techniques found in the Canary Islands correspond to those techniques brought from the continent or went through a proper development remains an open question.

As a result of what we actually know of both worlds and their interdependences, the future of the research on the mathematics and astronomies of the ancient Berbers looks very promising for all those interested in the history of science in the antiquity.

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Mathematics Communicating Across Culture and Time

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The truth is that history, as we commonly conceive of it, is not what happened, but what gets recorded and told. Most of what happens escapes the telling because it is too common, too repetitious to be worth recording. . .

The business of making accessible the richness of the world we are in, of making dense and substantial our ordinary, day-to-day living in a place, is the real work of culture. (Malouf, 1998, p. 17)

Mathematics is a method for communicating ideas between people about concepts such as numbers, space, and time. In any culture there is a common, structured system for such communication, whether it be in unwritten or written forms. These systems can form bridges of communication across culture and across time.

So, what is communication? Crowley and Heyer (1995, p. 7) describe communication as “... an exchange of information and messages. It is a process. About 100,000 years ago our early ancestors communicated through non-verbal gestures and an evolving system of spoken language. As their world became more complex, they needed more than just a shared memory...” This led to “the development of media to store and retrieve the growing volume of information.” Communication is about an exchange of information and the techniques humans have developed to store and retrieve that information. It is not necessary to have writing, computer disks, and so on: communication can be verbal (oral traditions), nonverbal (gestures, *quipu*), temporary

(sand drawing), or more permanent (clay tablet, woven cloth).

Communicating in or about the field of mathematics involves taking part in mathematical discourse, whether by reading, writing, listening, or speaking. Discourse is a broader concept than language because it also involves all the activities and practices that are used to make meaning in a particular profession. The discourse of mathematics includes all the ways that mathematics is done: through language, textbooks, mathematicians talking to each other and to a wider public, and popularization and application of mathematical knowledge (Wood & Perrett, 1997).

Discourse does not see the terms *language* and *communication* as synonymous, although it certainly recognizes language as a central resource for the communication process. This view sees language as a resource for making meanings within different situations (Halliday, 1978; Kamp & Reyle, 1993). Communication is seen as a complex process within which natural language supplies a major (but seldom the only) resource for making specific meanings within the framework of specific social practices or areas of knowledge. Readers who wish to know more about the complexities of natural language may consult texts such as Finegan (2003).

When we speak of making meaning within different areas of knowledge, we are referring to different discourse practices. The language used in mathematical discourse is the natural language, but it is a language that has evolved in specialized ways to deal with the demands of expressing mathematical concepts. The most striking difference between mathematical writing and most other types of writing is the extensive use that mathematics makes of symbols and numbers. These are sometimes seen as alternatives to natural language, alternatives that mathematicians value as being more precise and more elegant than the natural language. However, the symbolic language of mathematics is an extension of natural language as much as a replacement for it, just as a pile of cowrie shells or a gesture can represent a number word. Natural language is used to complement the symbolic language of mathematics when mathematicians

talk and write to each other, and it has to replace the symbolic language when mathematicians communicate with non-mathematicians. Thus, we would argue that natural language plays an essential part in doing mathematics.

All cultures are mathematized, in that people within any culture use ideas of mathematics in their everyday life. For this I will take a wide definition of mathematics to include concepts of number, space, chance, and time. A report of the Australian Academy of Sciences *Mathematical Sciences: Adding to Australia* (1996, p. ix) gives this description of modern mathematics:

Mathematics is the study of measurements, forms, patterns, variability and change. It evolved from our efforts to understand the natural world. . .

Over the course of time, the mathematical sciences have developed a rich and intrinsic culture that feeds back into the natural sciences and technology, often in unexpected ways. The mathematical sciences now reach far beyond the physical sciences and engineering; they reach into medicine, commerce, industry, the life sciences, the social sciences and to every other application that needs quantitative analysis.

This description takes mathematics back to its roots. Mathematics has been part of all societies, has been a part of every profession, as well as being used in everyday life. Western mathematics became narrower with the insistence that only deductive mathematics from a set of axioms, following the Greek tradition, was *real* mathematics. The broader view of mathematics, especially with the consideration of computing, validates the work of non-European mathematicians. A majority of mathematicians today are working much closer to the way that Indian, Chinese, and Arab mathematicians worked, as they focus on real applications and better computing algorithms (Horgan, 1993).

Culture too can be viewed broadly. Asher (1991, p. 2) says, "In any culture people share a language; a place; traditions; and ways of organising, interpreting, conceptualising and giving meaning to their physical and social worlds." David Malouf (1998, p. 17) describes the process of acculturation as "The business of making accessible the richness of the world we are in, of making dense and substantial our ordinary,

day-to-day living in a place, is the real work of culture.” The description of mathematics above states that “The mathematical sciences have developed a rich and intrinsic culture.”

Mathematics has often worked on many levels, as part of everyday culture and also as used by subgroups within the main culture. In the Inca culture only a small group would have been able to construct and interpret the *quipu* (knotted cords used by the Inca to convey data, Asher, 1991). In the Babylonian culture of 3000 BCE, few people would have been skilled in the algebraic and computational techniques required for commerce, as is evidenced by the many clay tablets which can be interpreted as instructional textbooks. In Egypt, the Ahmes papyrus consists of instructional material for a mathematical subculture that would calculate the land areas after the annual floods and document commercial transactions. Indeed in many cultures, the mathematics of calendars and astronomy was in the hands of the priestly classes.

The mathematical subcultures communicated their knowledge to future mathematicians in a similar way to classes or apprentices today. Students worked through sets of paradigm problems designed to develop the calculating skills, ideas, and language necessary for their future careers. Some of the ways that mathematics has been taught are remarkably similar across the cultures and centuries. The drill and practice examples on the Ahmes papyrus and some Babylonian clay tablets are close to the way mathematics is taught in many classrooms today (Fowler & Robson, 1998, p. 369). Teachers wrote commentaries and extensions from previous texts. They improved algorithms and compared methods. Høystrup (1994) concluded that mathematics as a discipline began to be systematically organized with the need to teach it to professional scribes in about 3000 BCE.

Communication Without Written Language

We will examine some examples of mathematical discourses in cultures with no written

language. We are dealing with speaking and listening, but also with art, artifacts, and gesture. It is possible to consider the *quipu* (Asher, 1991), for example, as a “written” number system, but for this entry I do not wish to include such artifacts as written language.

How were mathematics and mathematical ideas communicated within cultures without writing? Here we make the assumption that cultures that do not have written language (95 % of cultures, Asher, 1991, p. 2) communicate mathematics by methods that have been documented by outside observers. The reliability of the documentation varies greatly with the biases and the mathematical knowledge of the observer. These snapshots can nonetheless help to extrapolate back into history for cultures that have lived in isolation for some time. For example, the counting system of the Kamilaroi in Southeastern Australia (Table 1) has been documented, and I suggest that this number system has been in situ for thousands of years prior to the arrival of Europeans in Australia in 1788. Similarly the counting systems in Papua New Guinea, documented by Glendon Lean (summarized in Phythian, 1997), would have been used for centuries before the arrival of Europeans and European mathematics. Richard Pankhurst (as cited in Zaslavsky, 1973, p. 89) has made an extensive study of the measures, weights, and values in use among the various Ethiopian peoples throughout their history.

Between the years 1968 and 1988, Lean collected and recorded data on the counting systems of Papua New Guinea and Oceania. There are 1,200 languages in the region and Lean collected data on nearly 900. He also discussed how the number systems were communicated through migration, wars, and marriage. As these languages are not written, he made use of diagrams to show gesture counting and used phonetics to write down number words. His awareness of mathematics has meant that he was conscious of the 2, 5, 10, and 20 cycles that occur in counting systems and gathered enough data to be able to classify each system. From his study, Lean concluded that the counting and tally systems in Papua New Guinea could have covered a period of thousands of years. Due to the fact that many

Mathematics Communicating Across Culture and Time, Table 1 Kamilaroi counting system (As quoted in Petocz, Petocz, & Wood, 1992, p. 164 after consultation with elders)

Kamilaroi words	English translation	
Mal	Finger	1
Bular	Two fingers	2
Guliba	Three fingers	3
Bularbular	Two fingers and two fingers	4
Mulanbu	Belonging to one hand	5
Malmulanbu mummi	One finger and one hand added on	6
Bularmulanbu mummi	Two fingers and one hand added on	7
Gulibamulanbu mummi	Three fingers and one hand added on	8
Bularbularmulanbu mummi	Two and two fingers and one hand added on	9
Bulariu murra	Belonging to two hands	10
Maldinna mummi	One toe added (to two hands)	11
Bulardinna mummi	Two toes added on	12
Gulibadinna mummi	Three toes added on	13
Bularbulardinna mummi	Two and two toes added on	14
Mulanbudinna mummi	One foot added on	15
Maldinna mulanbu	One toe and a foot added on	16

neighboring languages have few number words in common, he concludes that there has been little contact. An extreme example of this is two languages Baruya (6,000 speakers) and Yagwoia (5,000 speakers). Baruya is spoken by people who live north of Marawaka in the Eastern Highlands, and Yagwoia is spoken to the south. Table 2 gives a few examples of differences (Phythian, 1997). Should these two groups meet, they would need to have a good gesture system or concrete materials to come to a mathematical understanding, despite living next to each other. The work of Glendon Lean is collected and available at www.uog.ac.pg/glec/index.htm.

The detailed work in Papua New Guinea contrasts with the work of linguists in the 1800s who recorded Tasmanian Aboriginal languages before they (the aboriginals and the languages) died out.

Mathematics Communicating Across Culture and Time, Table 2 Examples of Baruya and Yagwoia numbers (Phythian, 1997, p. 66)

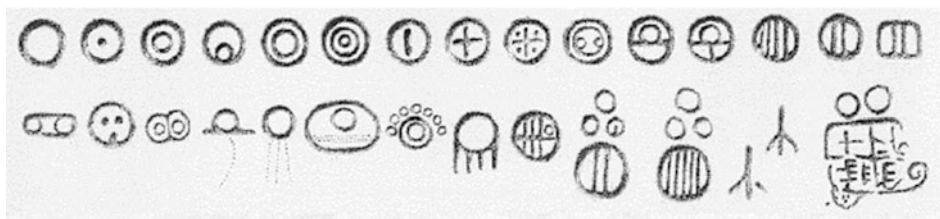
Baruya	Yagwoia	
Da ²	Ungwonangi	1
Da-waai	Huwlaqu	2
Da-waai-da	Huwlaqungwa	3
Da-waai da-waai	Hyaqu-hyaqu	4
At-i	Hwolyem pu	5
At-irai	Hwolye kaplaqu	10

Perhaps due to a lack of mathematical awareness, they did not record details of the counting systems. Some words for numbers are recorded but not in a systematic fashion. For example, one Tasmanian Aboriginal group use the word *karde* for 5 and *karde karde* for 10 (Roth, 1899: Appendix B, xi, xvii), but only a few other numbers are recorded. So we have a tantalizing suggestion of a base five systems but insufficient evidence to come to a conclusion. This lack of evidence for numbers contrasts with the detailed coverage of words for the male and female genital areas (Roth, 1899). I think we can make some conjectures about these Victorian scientists and their cultural proclivities.

In *Hidden in Plain View*, Jacqueline Tobin (1999) records the oral history of several African American quilt makers. They described the meanings and detailed communication that could be passed on by the combination of colors, beads, and knots. They could give routes, times, maps, and instructions all through quilting. Thus, they passed on their African history and made plans to escape from slavery, all under the noses of their masters. The following quote (Tobin & Dobard, 1999, p. 78) discusses the *lukasa*, the memory boards of the Central African Luba people:

The use of stitches and knots, as a kind of Morse code in thread, along with fabric colour and quilt patterns, made it possible to design a visual language.

The *lukasa*, or memory board is a mnemonic device used by the highest level of the Luba royal association. The *lusaka* contains secret mythical, historical, genealogical and medical knowledge. Beads on the front...Engraved geometric patterns on the back...All these serve to recall aspects of Luba history.



Mathematics Communicating Across Culture and Time, Fig. 1 Symbols used in Tasmanian Aboriginal art (Clark, 1986, p. 32)

There are mathematical implications. The quilts are like computer programs displaying information graphically and can be read by those who understand the code. Fortunately the code in this case has been recorded. It is an example of how mathematical (and other) ideas can be hidden in plain view.

Aboriginal art is another area where mathematics has been overlooked by Western eyes. Michael Cooke (1991) spent 10 years in the Yolngu community in northern Australia, and his principal sources were Yolngu teachers. He acknowledges that by taking some of the Yolngu world and fitting it with a Western idea of mathematics, he has lost the full significance of the meanings and some of the intricacy of the Yolngu world. His paper covers many mathematical aspects including how kinship relationships are depicted in song and painting (Cooke, 1991, p. 38):

For the Yolngu artist, painting is a means of schematising Yolngu world order in a way parallel to the Western mathematical theorist who constructs graphs and diagrams. Just as the Western mathematician seeks elegance, symmetry and aesthetic satisfaction in such work, so does the Yolngu artist. Both rely on extensive use of systems of symbolic representation in their abstract modelling of order...

For the Yolngu it is the system of song cycles which provides the theoretical basis and rationale for the Yolngu system of order and relationship.

There are many other examples of mathematical discourse in cultures without a written language:

- *Finger reckoning*. Hand signals for numbers and number operations are used in many

cultures. Examples in Africa are given in Zaslavsky (1973, pp. 239–253) and for Papua New Guinea in Phythian (1997).

- *Weaving or patterns*. Northern Australian aboriginals use painting to illustrate kinship patterns (Cooke, 1991; Harris, 1987, 1991).
- *Cowrie shells for currency*. Again there are many examples in Zaslavsky, 1973.
- *Knotting, quipu of the Incas*. Much has been written on the quipu (such as Asher, 1991, pp. 16–27; Joseph, 2000, pp. 28–37; Smith, 1925, p. 196), and it remains an important example of how mathematics and mathematical ideas can be communicated effectively without a written language or number system.
- *Classification*. For example, Yolngu Aboriginal culture divides the world into two parts, Yirritja and Dhuwa (Cooke, 1991).

All these cultures communicated mathematical ideas without written language. Some of the ideas would have been accessible to all people within the culture, such as the counting systems in Papua New Guinea, and some of the ideas would be restricted to a privileged group, such as the *quipu* makers in South America.

Making meaning from artifacts left to us presents a difficult task. What meaning can a modern observer make of the Tasmanian Aboriginal rock carvings in Figs. 1 and 2? Is this a number system, a pattern of moon phases, or a written language? Even the arrangement by the modern artist may influence our ideas. We are using our Western-trained minds to classify and order the images to fit with our concepts of logic and pattern. Unfortunately there are no Rosetta stones or living speakers to assist with translation.



Mathematics Communicating Across Culture and Time, Fig. 2 Tasmanian Aboriginal rock carvings in situ (Clark, 1986, p. 33)

Cultures with Written Language

Making meaning from history involves examining the discourse of cultures from the information that is recorded and passed on. Written forms of mathematical discourse have largely formed the basis of modern mathematics: thus, mathematical ideas have communicated across time. However, even with written records, there are hazards to successful communication.

It is in part good management and mostly luck that written materials are available to modern readers, even though Rashīd al Dīn (1971 translation), a writer in thirteen-century Persia, went to great lengths to increase the probability that his work would not be lost. He made two complete copies of each work; each was translated into Persian and Arabic. Only the best-quality paper and only scribes with the best handwriting were used. Even so, not all of his works exist today, but those that do give an insight into the mathematics in the lives of everyday people of that era. New materials, such as a letter of al-Kāshī on scientific life in Samarkand, described and translated in Bagheri (1997), are being added to our collection of records of mathematics. Translations, for example, by Al Dīn (1971), make original works accessible to readers who are unable to read ancient languages.

Significant communication of mathematical ideas and techniques occurred between cultures

in the past. An example of how commentaries and improved algorithms occurred between Arabic and Indian mathematicians is explained in Rashed (1994, pp. 143–148) who showed that al-Bīrūnī (tenth century AD) was aware of Brahmagupta's methods of quadratic interpolation, used for trigonometry and astronomy.

However, as David Malouf (1998) states, much of what really happened is not recorded and therefore must be inferred in the same way as for cultures with non-written languages. The information that is recorded is filtered through the eyes of the observer, who has his or her own cultural prejudices. Such cultural prejudices have caused criticism of non-European mathematics, in particular with the idea of proof. Modern mathematicians are in considerable conflict about the status and usefulness of proof (Horgan, 1993), but some commentators feel free to criticize other cultures for not fitting within their own narrow definition.

Much has been made of the Greek concept of proof as the basis of modern mathematics to the extent that many writers (e.g., Kline, 1972, p. 190, quoted in Joseph, 1994, p. 194) have disparaged the Indians for their supposed haphazard ideas of proof. But as Joseph (1994) demonstrates, Indian mathematics does prove theorems though not in the same way as Greek deductions from axioms – in fact the Indian demonstrations are very similar to the way proofs are presented to students studying secondary and early tertiary mathematics. A broader idea of proof, such as that advocated by Mason (1985), among others, would include the demonstrations of Indian and Chinese mathematicians.

Another reason for miscommunication is error of interpretation. We mainly rely on translations of ancient texts. Translations are open to interpretation, compounded by time and cultural differences. Added to this, many translators are not mathematicians and so may miss subtle points which may be critical mathematically. This is not a criticism of translators but a criticism of commentators who do not take these difficulties into account when interpreting discourse over time and culture.

The mistranslation of one word can have critical effects. For example, the mistranslation of the

word *asanna* in the translation of an Indian text has led to considerable misrepresentation of Indian mathematics. In verse 10 of the section entitled *Ganitapāda* from Āryabhata's *Āryabhatīya* (AD 499) appears the following: "100 plus 4, multiplied by 8, and added to 62,000: this will be the "asanna" value of the circumference of a circle of diameter 2000." The Sanskrit word *asanna* has been translated as approximate, inexact, rough, crude, and so on. On the basis of this translation, some Western historians of mathematics have concluded that Indian mathematicians did not realize the irrational nature of π .

George Gheverghese Joseph believes that the word *asanna* has a more fruitful meaning. It incorporates two different meanings that overlap with one another: "inexact" and "unattainable." The second meaning which is closer to the idea of irrationality is what Joseph thinks Āryabhata had in mind, and it was an extremely creative concept that gave the motivation to Kerala mathematicians to work on infinite series (Joseph, personal communication).

Reza Hatami, an Arab-speaking scholar working in Sweden, has translated sections of the work of al-Khwārizmī and 'Umar Khayyām and has found similar difficulties with some of the standard English and Swedish translations (Hatami, 1999).

Many translations are written in the modern discourse of mathematics and include the use of symbols and algebra. The clarity of the symbolism in use today can cause us to underestimate the difficulties that mathematicians faced in the past. There is a good example of a theorem from Cardano (1545) that shows how mathematical writing has changed in the last 400 years. A comparison of this theorem with its modern equivalent shows how useful symbolic notation can be, and also illustrates the relationship of such notation to ordinary language (Smith, 1997, p. 6). Cardano's intention was to provide a solution to the equation $x^3 + mx = n$, where m and n were implicitly assumed to be positive. However, even the *statement* of the theorem was different to modern language. Renaissance Italians referred to this equation as *a cube plus a first power equal to a number*. Cardano gave the solution as:

Cube one-third of the coefficient of the unknown; add to it the square of one half the constant of the equation; and take the square root of the whole. You will duplicate this, and to one of the two you add one half the number you have already squared and from the other you subtract one half the same. Then, subtracting the cube root of the first from the cube root of the second, the remainder which is left is the value of the unknown.

Today we would write something like the following:

Theorem A solution of the equation $x^3 + mx = n$ is given by

$$x = \sqrt[3]{\frac{n}{2}} + \sqrt{\frac{n^2}{4} + \frac{m^3}{27}} - \sqrt[3]{-\frac{n}{2} + \sqrt{\frac{n^2}{4} + \frac{m^3}{27}}}.$$

These examples show some of the difficulties of interpreting works from other cultures and times. The observer brings his or her knowledge and culture into the equation. I take issue with commentators, such as Kline (1980, p. 111), who make strident assertions about the mathematics of another culture:

It is fairly certain that the Hindus did not appreciate the significance of their own contribution. The few good ideas they had, such as separate symbols for the numbers 1–9, the conversion from positional notation in base 60 to base 10, negative numbers, and the recognition of 0 as a number, were introduced casually with no apparent realisation that they were valuable innovations. They were not sensitive to mathematical values.

This is based on flimsy evidence and a very narrow view of mathematics. Notice the use of "mathematical values." Whose values? It may be that future commentators' claim that strictly holding to the Greek view of deductive proof has seriously curtailed the mathematics of the twentieth century.

A Tenuous Link

This art originated with Mahomet the son of Moses the Arab (al-Khowarizmi). Leonardo of Pisa (Fibonacci) is a trustworthy source for this statement (Cardano, 1545, translation Whitmer, 1968).

This is a lovely example of communication. Cardano has acknowledged the originator of his

work, al-Khwārizmī, and the conduit of this knowledge, Leonardo Fibonacci.

The work of al-Khwārizmī (ca. 780–850), through the channel of *Liber abaci* (1202) by Leonardo Fibonacci, became well known in Europe and became the basis of Cardano's work in 1545. This is just one example of how European mathematics was influenced by Arab mathematics, but it also shows how the European mathematicians readily acknowledged the prior work of non-European mathematicians.

Leonardo Fibonacci made considerable contributions to mathematics himself, notably in solving cubic equations, but it is his 1202 *Liber abaci* that was the most influential. Fibonacci traveled widely through Egypt, Syria, Sicily, and Greece and came into contact with Arabic mathematics. He was convinced that the Indian-Arabic numerals and methods of calculation were vastly superior to the current methods in Italy (Eves, 1983). *Liber abaci* can be considered the main reason why Indian-Arabic numerals and the achievements of Arabic mathematicians spread through Europe by the start of the Renaissance. How much would Cardano and others have achieved without al-Khwārizmī and Indian-Arabic numerals?

Making Meaning

Making meaning from the sources available to us leaves most unsaid and unwritten. Many of the ordinary day-to-day practices of mathematics are not recorded. The mathematical contributions of women, artisans, and many workers are not represented. Many records have been lost. Of those discovered, there are risks of mistranslation, misinterpretation, or, in the case of the Tasmanian Aboriginal rock carvings, no basis for interpretation.

It is reasonable to expect difficulties with communication across time and cultures. Even within the same culture, recorders and observers often disagree. However, there have been triumphs of communication across time and culture – Fibonacci's *Liber abaci* brought the ideas of

algebra and Indian-Arabic numerals to Europe giving an excellent starting point for the work of Cardano and others.

Fibonacci displayed what many commentators have not: he displayed an open mind. Fibonacci was open to the work of other cultures and actively disseminated their ideas. Glendon Lean and Richard Parkhurst are more modern observers who have shown cultural sensitivity as well as keen mathematical knowledge.

As Zeilberger (1993) stated during a lively debate in the American Mathematical Society,

Although there will always be a small group of “rigorous” old-style mathematicians... who will insist that the true religion is theirs and that the computer is a false Messiah, they may be viewed by future mainstream mathematicians as a fringe sect of harmless eccentrics...

Mathematics itself is not one culture with one discourse. The dominant paradigm in Western mathematics is shifting from Greek deductive proof to a more experimental and applied mathematics, and with this comes a new discourse. A reappraisal of the contributions of non-European mathematics under the new paradigm will see a better valuing of their mathematical achievements and consequent changes in forms of mathematical discourse.

Let us look forward to a time when we can appreciate the mathematics of all cultures and the contribution of mathematical ideas to the “business of making accessible the richness of the world we are in, of making dense and substantial our ordinary, day-to-day living in a place – the real work of culture.”

See Also

- [Mathematics of Yolngu Aboriginal Australians](#)
- [Quipu](#)

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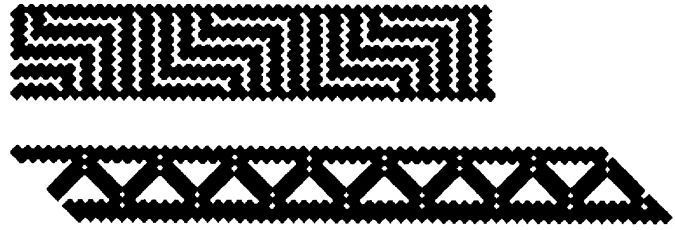
Mathematics in Africa South of the Sahara

Paulus Gerdes

Most books on the history of mathematics devote only a few pages to Africa, and even then only to Ancient Egypt and to northern Africa during the Middle Ages. Generally they ignore the existence of mathematics in Africa south of the Sahara. They often deny that Egyptian mathematics is African. With the publication of Claudia Zaslavsky's *Africa Counts: Number and Pattern in African Culture* in 1973 this dominant Eurocentric view of the history of mathematics in Africa became challenged. When one uses a broad definition of mathematics – including counting, locating, measuring, designing, playing, explaining, classifying, sorting, etc. – it becomes clear that mathematics is a pan-cultural

Mathematics in Africa South of the Sahara,

Fig. 1 Two examples of woven strip patterns on baskets (Mozambique)



phenomenon manifesting itself in many ways. In African history, we have evidence of counting and numeration systems, games and puzzles, geometry, graphs, record-keeping, money, weights, and measures, etc. Mathematics in Africa may not be considered in isolation either from the development of culture and economy in general, or from the evolution of art, cosmology, education, philosophy, natural sciences, medicine, logic and language, graphic systems, and technology in particular. The application of historical and ethnomathematical research methods in recent years has contributed to a better knowledge and understanding of the history of mathematics in Africa.

In this article evidence for early mathematical activity in Africa will be given, followed by examples from geometry, games, riddles, and puzzles with mathematical “ingredients.” Some topics for future research will be indicated and some comments about the development of mathematics south of the Sahara and in other regions, in particular northern Africa, will be presented.

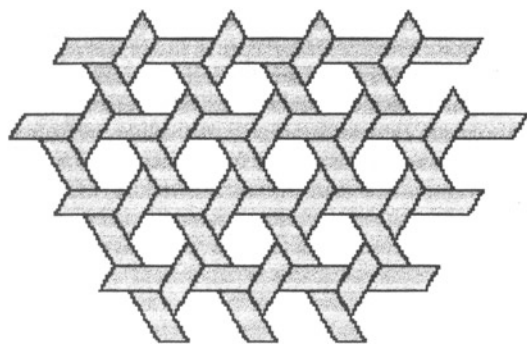
A small piece of the fibula of a baboon, marked with 29 clearly defined notches, may be one of the oldest mathematical artifacts known in the world. Discovered in the early seventies during an excavation of a cave in the Lebombo Mountains between South Africa and Swaziland, the bone has been dated to approximately 35,000 BCE. This bone resembles calendar sticks still in use today by the San (Bushmen) in Namibia. The San hunters developed very good visual discrimination and visual memory for survival in the harsh environment of the Kalahari desert. From the San in Botswana, information has been collected on their counting, measurement, time-reckoning, classification, and tracking. Well known as early evidence for mathematical

activity in Africa is a bone now dated from about 8000 BCE to 20,000 BCE, dug up at Ishango (Zaire). The bone has what appear to be tallying marks on it, notches carved in groups that have been explained as early lunar phase count or as an arithmetical game of some sort.

Georges Njock has characterized the relationship between African art and mathematics as follows: “Pure mathematics is the art of creating and imagining. In this sense black art is mathematics.”

Mathematicians have primarily analyzed symmetries in African art. Symmetries of repeated patterns may be classified on the basis of the 24 different possible types of patterns which can be used to cover a plane surface (these are the 24 plane groups attributed to Federov). Of these, seven admit translations in only one direction and are called strip patterns. This classification has been applied to decorative patterns that appear on the raffia pile cloths of the Bakuba (Zaire), on Benin bronzes, and on Yoruba adire cloths (Nigeria), showing that all seven strip patterns and many of the plane patterns occur. The use of group theory in the analysis of symmetries in African art attests to and underlines the creative imagination of the artists and artisans involved and their capacity for abstraction. These studies do not focus, however, on how and why the artists and artisans themselves classify and analyze their symmetries. This is a field open for further research.

Why do symmetries appear in human culture in general, and in African craftwork and art, in particular? Paulus Gerdes analyzed the origin of axial, double axial, and rotational symmetry in African basketry. He showed how six and five-fold symmetry emerged quite naturally when artisans were solving some problems in (basket) weaving (see Figs. 1 and 2).



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Fig. 2 Hexagonal weaving pattern (Congo, Kenya, Madagascar, Mozambique)

Beehive, conical, cylindrical, and rectangular shapes are common in African architecture. In West Africa the mathematician-scholar and the architectural designer-builder was often the same person. An example of geometrical know-how used in laying out the rectangular house plans in Mozambique is the following. Two ropes of equal length are tied together at their midpoints. A ► [bamboo](#) stick, whose length is equal to the desired breadth of the house, is laid down on the floor, and at its endpoints pins are hit into the ground. An endpoint of each of the ropes is tied to one of the pins. Then the ropes are stretched and at the remaining two endpoints of the ropes, new pins are hit into the ground. These four pins determine the four vertices of the house to be built.

The geometric shapes of pots, baskets, fishtraps, houses, etc. generally represent many practical advantages and are frequently the only possible or the optimal solutions of a production problem. Some scholarly research has been undertaken concerning knowledge about the properties and relations of circles, angles, rectangles, squares, regular pentagons and hexagons, cones, pyramids, cylinders, symmetry, etc. probably involved in the invention of the techniques (Gerdes, 1992a, b). Themes for further research are the geometry of string figures, the geometry of settlement patterns in Africa, and the geometry involved in the ornamentation of the walls of buildings all over Africa (e.g., the

attractive colorful patterns of the Ndebele in South Africa and the *litema* patterns drawn by Basotho women in Lesotho) (Fig. 3).

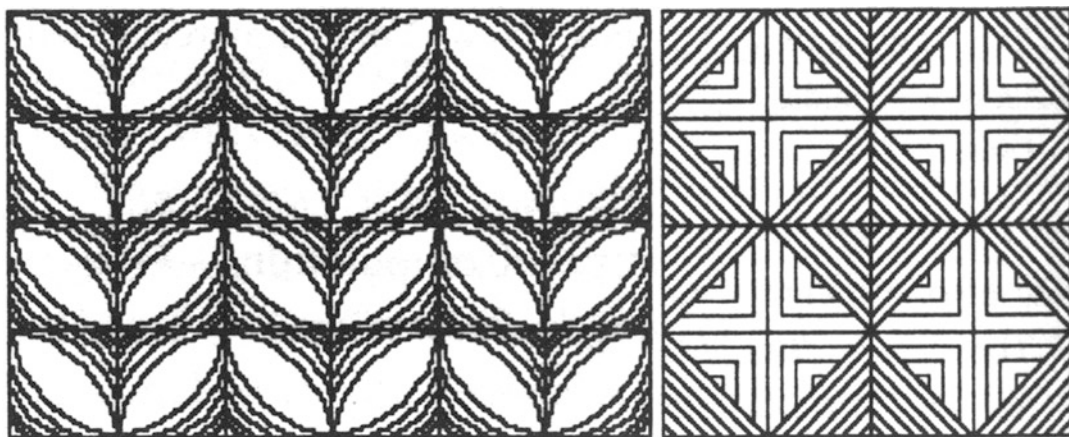
Games

Among the games with mathematical ingredients are counting rhymes and rhythms, arrangements, three-in-a-row-games like *Shisima* (Kenya), *Achi* (Ghana), *Murabaraba* (Lesotho), *Muravarava* (Mozambique), and games of chance. Board games like Mancala games, both two-row versions such as *Oware* (Ghana), *Awélé* (Côte d'Ivoire), *Ayo* and *Okwe* (Nigeria), and four-row versions such as *Omweso* (Uganda), *Tshisolo* (Zaire), and *Ntchuba* (Mozambique) also exhibit use of mathematical knowledge.

Recent research in Côte d'Ivoire showed that the rules of some games, like *Nigbé Alladian*, reveal a traditional and empirical knowledge of probabilities.

Riddles and Puzzles

From the Kpelle (Liberia) a riddle has been reported about a man who has a leopard, a goat, and a pile of cassava leaves to be transported across a river, whereby certain conditions have to be satisfied: the boat can carry no more than one at a time, besides the man himself; the goat cannot be left alone with the leopard, and the goat will eat the cassava leaves if it is not guarded. How can he take them across the river? This type of problem is also known from Ethiopia, Liberia, Tanzania, Uganda, and Zambia. More difficult to solve is the following puzzle from the Valuchazi (eastern Angola and northwestern Zambia) about three women and three men who want to cross a river in order to attend a dance on the other side. With the river between them there is a boat with the capacity for taking only two people at one time. However, each of the men wishes to be the only husband of all the three women. Regarding the crossing, they would like to cross in pairs, each man with his female partner, but failing that any of the



Mathematics in Africa South of the Sahara, Fig. 3 Examples of *litema* wall patterns (Lesotho)

other men could claim all the women for himself. How can they cross? In order to solve the problem or to explain the solution, the Valuchazi make auxiliary drawings in the sand.

The relationships between the development of mathematics in Africa south of the Sahara and the development of mathematics in Ancient Egypt, in both Hellenistic and Islamic northern Africa, and across the Indian and Atlantic Oceans, deserve further study.

Throughout history there have been many and varied contacts between Africa south of the Sahara and North Africa. Since the birth and spread of Islam, relations have been intensified and/or extended. *ʿIlm al-isāb* (arithmetic), as part of the Islamic sciences was introduced some time after the eleventh century in Nigeria, first in Kanem-Borno and later, probably in the fifteenth century in Hausaland. Arithmetic was taught in both secular and Islamiyya schools, was used in the courts for the calculation of inheritance, and for collecting and distributing poor dues, business, and land surveying. A famous mathematician was Muammed ibn Muammed from Katsina (now northern Nigeria), who worked on chronograms and magic squares. He had been a pupil of Muammed Alwali of Bagirmi. He made a pilgrimage to Mecca in 1730, and he died in Cairo in 1741. Recently a manuscript of his was found in Marrakesh, Morocco. Magic squares were used in amulets among the Fulbe, and in Niger, Benin and Timbuktu (Mali). Formal logic was

one of the fields of study in the economic and educational-scientific centre of Timbuktu, where recently three Arabic mathematical manuscripts were found in the Amad Baba Library. One of the three manuscripts, whose calligraphy is typical for Africa south of the Sahara, seems to have been written by a mathematician from Mali, al-Arwani. The other two contain references to medieval mathematicians from the Maghreb. Systematic research in libraries and archives will probably lead to the discovery of more mathematical manuscripts from Muslim scholars south of the Sahara.

What mathematics was brought to the Americas by the slaves? Which mathematical ideas have survived in one way or another? Mancala, and maybe other games with mathematical components, are played in the Caribbean and may be compared with their African “ancestors.” In Africa the slave trade was extremely destructive of the existing mathematical traditions. This is because of breaking professional continuity and depriving Africa of bearers of mathematical knowledge and skills such as that of the drawing experts from Angola and Zambia and that of calculators like Thomas Fuller (1719–1790). Recent ethnomathematical research in Nigeria and Mozambique shows the survival, nonetheless, of a rich tradition of mental calculations among illiterate people.

The destructive impact of colonialism and the slave trade on Africa is one of the principal

reasons Georges Njock gives to explain why mathematics in Africa has had a slower development in the last five centuries than in Europe. Other reasons he gives deal with the geography of the continent (migratory movement) and wars. This also constitutes an important research area that deserves further study.

See Also

- [Geometry in Africa](#)
- [Number Theory in Africa](#)

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Mathematics in Africa: West African Games

Salimata Doumbia

Exploring the sociocultural environment of Africa is an interesting way of learning about concrete mathematics. Games, always a popular childhood activity, should be studied with care in as much as they are a reflection of the society and its fundamental values. Today we are witnessing the introduction of “educational games” to the African continent, as if African games did not exist. In this article, we will describe several African games and the mathematics behind them.

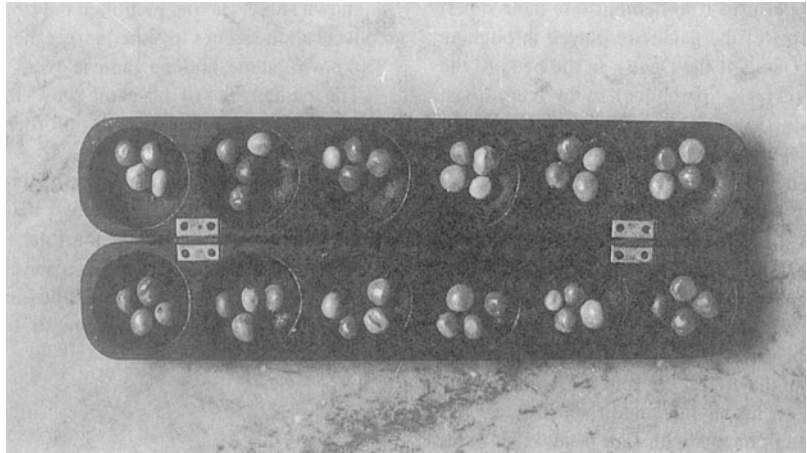
Exhibition Games

In Africa there are games which have hidden underlying algorithms. The person who knows the algorithm is assured of winning, which makes him a “magician” or “sorcerer” to those who do not know it. The “sorcerer” often chants incantations or performs other magic tricks to show his power. We will study two of these games.

1. *The game of the sorcerer*. The game of the sorcerer is very old. Sorcerers perform it to demonstrate their supernatural powers. Forms of the game are played throughout Africa – in

Mathematics in Africa: West African Games,

Fig. 1 Game of the
sorcerer (Photograph by
the author)



Senegal (Game of the Devil), in the bend of the Niger River (the Sorcerer's Apprentice), in the Ivory Coast (*Lokoto*), and in Mali (*Gamma*) (Fig. 1).

There are two players: the sorcerer and his victim. The game is played on a board of 12 compartments set up in two rows of 6 and 48 beads.

Before beginning play, the players place four beads in each compartment. The sorcerer and the victim each take two stones from 11 compartments. From the 12th, the sorcerer takes three beads, the victim one (the sorcerer thus has two extra beads). He must now "magically" pass the two extra beads to the victim. He rubs the beads, chants incantations, blows on his thumbs, and then instructs the victim to fill the compartments with four beads each as he does the same. When the beads are redistributed, three beads are left in the victim's hand, one in the sorcerer's, and the trick is done.

If we analyze the mathematical aspects of the game, we see that it has two parts:

1. The taking of the stones (beads)

$$\text{The sorcerer: } 2 \times 11 + 3 = 25$$

$$\text{The victim: } 2 \times 11 + 1 = 23$$

2. The replacing of the stones

Each player must put four beads in each of the compartments, filling as many as he can with the beads in his hand.

$$\text{The sorcerer: } 25 = 4 \times 6 + 1$$

$$\text{The victim: } 23 = 4 \times 5 + 3$$

After redistributing the beads, the victim has three beads in his hand and the sorcerer, one. The game works whenever the number of compartments is even.

1. *The game of the unknown stone.* The player asks a spectator to select in his mind 1 of 16 different stones. The player must discover the unknown, selected stone. First, he arranges the stones in two rows of eight. Then he asks the spectator to indicate the row that the unknown stone is in. Mentally the player makes two groups of four stones each from the stones in the indicated row. He rearranges them (or distributes each group on different lines) and asks the spectator again to indicate which row has the unknown stone. Upon the indication of the row he makes two groups of two stones each from one of the groups of four stones. Then he rearranges them again.

Again, the spectator indicates the row with the unknown stone. The player then redistributes the only two stones left, which could possibly be the unknown stone, into two different rows. The spectator again indicates the row with the unknown stone. Having identified the stone, the player then collects all the stones together,

mixes them up, pulls out the “unknown” stone, and the game is over.

The mathematics of this game shows that the player must divide the stones into two rows in order to locate the unknown stone.

$16 = 2^4$ where 4 is the number of times that the player must divide the 16 stones, two being the number of rows. More generally, if n is the total number of stones, and k is the number of times the player must divide the stones into two rows, then the following equation holds true: $n = 2^k$. Inversely, if one knows n , one can calculate k from the formula $k = \log_2 n$.

Games of Chance

Men have always played games of chance. In Africa, there are many situations in which chance is called into play: when one needs to make a hard choice (heads or tails, the short straw), or when one needs to be sure of winning. Games of chance are based on theories of probability.

The cowrie is a sea shell with two sides: a front and a back. In Africa, cowries were considered rare and valuable, and so played an important role in African life. Its form, similar to an aura according to the mystics, makes it an instrument of divination. Cowries also play a role in initiations, funerals, and engagements, and in certain regions of Africa, they were – and still are – used as a medium of exchange.

All the cowrie games are collective games. The number of players is two or more. The principle of the game is simple. Two players (or two representatives of two teams) throw the cowries at the same time. The cowries fall on the ground, landing on one of two sides. There are usually four shells. The configurations formed by the cowries are examined so that the results can be read. The results are interpreted according to pre-established rules: heads is given a +; tails is given a –.

Thus, when the four stones are thrown, there are five possible configurations:

Heads (+)	Tails (–)			
++++	----	10 points	----	Win
+++–	++++	5 points	++++	Win

(continued)

Heads (+)	Tails (–)			
++--	++--	2 points	++--	Win
++--	++--	0 points	++--	Lose
----	----	0 points	----	Lose
Configurations	Example 1		Example 2	

The calculation of points varies. There are two ways to compute points, either numerically (Example 1) or not (Example 2). Generally, if points are calculated numerically, the winner is declared when a player reaches a certain total number of points, that number being fixed before play begins.

Word Games and Traditional Learning in Africa

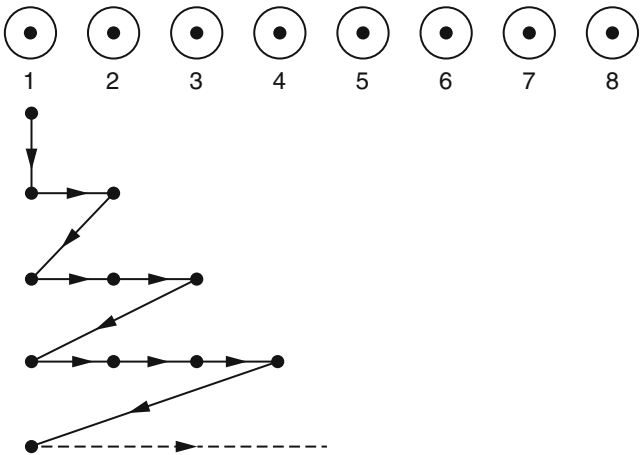
In many African countries, traditional learning is oral. Information and wisdom are transmitted from generation to generation in the form of proverbs, stories, chants, riddles, and games. This provides real lessons in language, history, geography, natural science, arithmetic, measurement, cosmography, etc. Teaching is seen as the natural and traditional way of communicating the secrets of the adult world to a child. Following are some examples of counting games.

Cumulative Chants

Memory Games: The Yé Gonan. The Yé Gonan is a children’s game from the Ivory Coast. There are two players, one who asks questions and one who answers. The players use eight stones and eight holes dug in a line in the sand, each one containing a stone. The player who is answering looks at the game and makes himself/herself acquainted with the rules. One of the rules is to retain correctly the sense of the course imposed by the questioning player. Then the answering player turns his back on the game. For each turn, the questioner taps on the hole and always asks the same question: “Am I taking a stone?” The answerer, who has his back to the game, can only answer “Yes” or “No, it’s empty.” Each time that he has taken a stone, the questioner comes back to the first hole. The answerer who reaches

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Fig. 2 Cumulative chants
diagram



the eighth hole without making a mistake, wins the game. The players then change roles (Fig. 2).

The mathematical problem posed by the game is the following: when the questioner is at hole number n , which contains a stone, which is the total number Z_n of questions posed from the beginning of the game to the taking of that stone? The answer is $Z_n = n(n + 1)/2$.

It is a triangular number. For $n = 8$, one finds that: $Z_8 = 9 \times 8/2 = 36 = 6^2$. The number Z_8 is therefore a squared number: it is the smallest number that is, at the same time, both triangular and squared. The Pythagorean tradition considered the number $n(n + 1)/2$ as a secret value. It is interesting to find this same representation in the Pythagorean tradition both among the moors in Mauritania and the Wolofs in Senegal.

$Z_1 = 1$									1
$Z_2 = Z_1 + 2 = 1 + 2$									2
$Z_3 = Z_2 + 3 = 1 + 2 + 3$									3
									4
									5
									6
									7
									8
$Z_n = Z_{n-1} + n$									n
$= 1 + 2 + \dots (n - 1) + n$									

Riddle problems. In *The Vultures*, a shepherd, spending the night under a baobab tree, heard an old vulture pose the following riddle to some children: “There are 33 baobab trees; on each baobab there are 33 vultures; each vulture had laid 33 eggs; each egg yields 33 chicks; and each chick has 33 barbed feathers – How many barbed feathers are there altogether?” The shepherd, wanting to answer, fell

dead. This is why, they say, the Fulani do not want to answer.
The solution to the problem lies in the calculation of powers. There are 33^6 vultures: $33^6 = 1,291,467,969$.
Magic squares. The Fulani are familiar with simple magic squares. They appear drawn with Arabic numerals as amulets. They are also used as a kind of game. Someone who knows the

magic square proposes it to a group of people who then try to figure it out by putting stones, pebbles, or pieces of dung in a square drawn on the ground.

2 9 4
7 5 3
6 1 8
Saturn square (sum = 15).

21 26 19
20 22 24
25 18 23
Number of Allah (sum = 66).

23134 23137 23143 23127
23142 23128 23133 23138
23129 23145 23135 23132
23136 23131 23130 23144
The Four Angles (sum = 92,541).

In a magic square, the sum of the numbers in each line, horizontal, vertical or diagonal, is the same. The number of Allah is $5 + 30 + 30 + 1 = 66$. In the Square of Saturn, the total is 15, and in the Four Angels, the total is 92,541. Magic squares are well known in Muslim countries, as they are in China and Japan.

See Also

- [Mathematics](#)
- [Mathematics Practical and Recreational](#)

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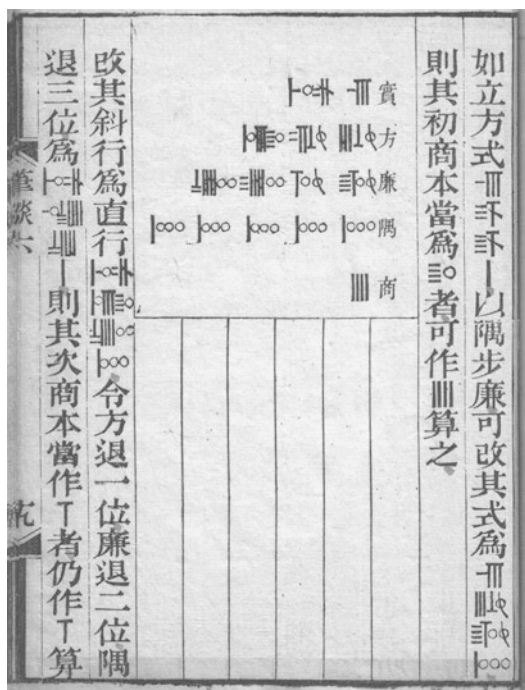
Mathematics in China

Andrea Eberhard-Bréard

Number System and Calculation Tools

Archaeologic finds from the Shang dynasty (fourteenth to eleventh century B.C.E.) show the earliest number symbols inscribed on bones and tortoise shells. By then, different decimal and sexagesimal systems were in use. The use of rod-numerals is also attested on coins as early as from the Wang Mang period (9–23 A.D.). These are related to the instruments in use. For calculations, numbers were represented on a calculation surface by counting rods. The representation follows a decimal positional notation, where nine different signs for the numbers from one to ten consist of either vertical or horizontal bars used to mark units, hundreds, myriads, etc. or tens, thousands, and other odd powers of ten. Three hundred twenty-six for example was thus put down in the following way: III = T. For negative numbers, black instead of red counting rods were used. In printed records (from the eleventh century onwards) they were marked by an oblique bar (Fig. 1).

“Brush calculations” written on paper and the abacus were widely spread by the sixteenth century, but the latter may have existed one or two centuries earlier. Procedures linked to abacus calculation are mostly written in versified form for easy memorization, and historians have shown how these evolved out of earlier procedures for counting rods (Fig. 2).

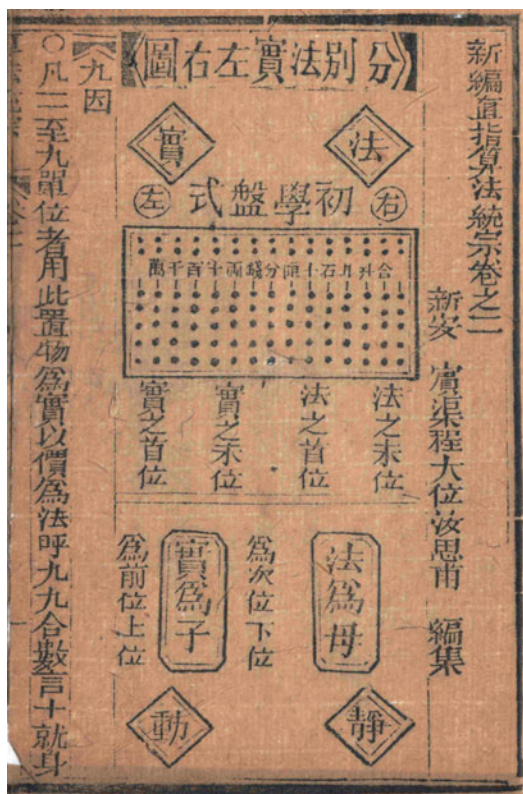


Mathematics in China, Fig. 1 Solving a cubic equation with counting rods as shown in Hua Hengfang, *Xue suan bitan*, 1885

Textual Sources

The scope of research into the history of mathematics in China today is determined by the available source material transmitted to us. The early beginnings of mathematics are closely connected to astronomy. With its non-geometric formal methodology, ► [astronomy in China](#) was oriented towards calendrical calculations and numerical lists, but less concerned with the design of geometric models. The positions of the celestial bodies could be determined by a system of numerical constants derived from observation, interpolation algorithms and cyclical theories. But their choice was also influenced by numerological considerations and political events.

One of the earliest texts that has been preserved is the ► [Zhoubi suanjing](#) (*Mathematical Classic of the Gnomon of Zhou*) compiled towards the end of the first century AC. It is closely related to the cosmographic doctrine

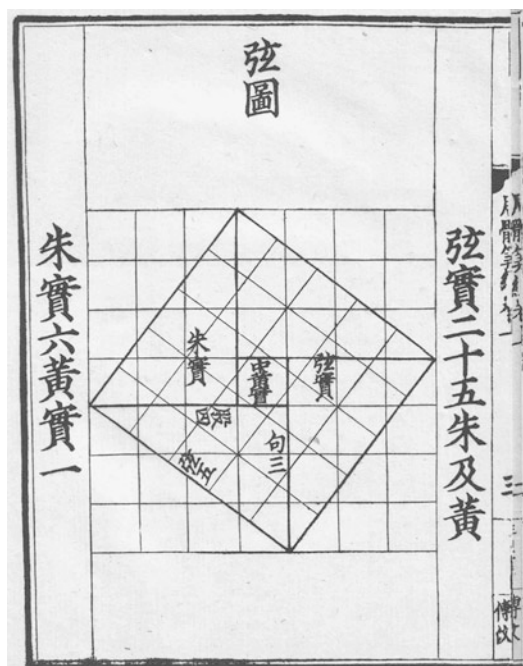


Mathematics in China, Fig. 2 An abacus as represented in Cheng Dawei, *Suanfa tongzong*, 1592

of the “Heaven as a chariot-cover” (► [Gaitian shuo](#)), which was popular during the Han dynasty (206 B.C.E.–220 AC). Among historians, it is mainly known for its proof of a statement analogous to the Pythagorean theorem (Fig. 3).

When the court astrologer ► [Li Chunfeng](#) (602–670) and his staff included the *Zhoubi* and its commentaries in a compilation of *Suanjing shi shu* (*Ten Books of Mathematical Classics*) for the government academy of the Tang dynasty, the text was elevated to the status of a mathematical canon as were the other nine contemporary or earlier treatises. The collection was first printed by the imperial library of the Northern Song in 1084, which is partly still extant from a 1231 reprint.

But there is another context in which mathematics played an important role and which shaped its methods of calculation and notation in China. The administrative tradition of



Mathematics in China, Fig. 3 Proof of Pythagorean theorem from the *Zhoubi suanjing*

registering numbers in the form of tables involved the calculation of the totals of sums or provided multiplication tables for fiscal purposes. Archaeologists found six manuscript sources, which attest of such mathematical activities, at the beginning of the twentieth century in the Buddhist Dunhuang Caves in Northwest China. They date from the sixth to the tenth century and are now stored in the National libraries of France and Great Britain. One of the manuscripts for example, which gives the date of the second year of the Guangshun era (952), tabulates the products in *mu* for the surfaces of all rectangular fields with the lengths of a side less or equal than 60 *bu* (1 *mu* = 240 square *bu*).

Equally important for our understanding of mathematical activities in early China is the recent excavation of a manuscript on 190 ▶ [bamboo](#) strips in a Chinese nobleman's tomb that was closed no later than 186 B.C.E. It represents the earliest document that has survived and provides us with a text outside the government sanctioned *Ten Books*. The stated problems and procedures show a certain connection to the foundational *Jiu*

zhang suan shu (*Nine Chapters on Mathematical Procedures*) and its commentary by Liu Hui (263 AC), which were part of the *Ten Books*, yet this connection still needs to be explored.

The commentaries to the now still extant Song dynasty edition of the *Nine Chapters* also contain fragments ascribed to other mathematicians. Zu Geng (late fifth century to early sixth century), son of the famous Tang mathematician and astronomer, ▶ [Zu Chongzhi](#) (429–500), obviously knew Liu Hui's commentary, when he wrote his “sub”-commentary on the calculation of the volume of a sphere. Later editions contain commentaries by ▶ [Jia Xian](#) (first half of the eleventh century), which are based on the now lost *Huangdi jiu zhang suanjing xicao* (*Detailed [calculation] sketches for the Yellow Emperor's Mathematical Classic in Nine Chapters*).

Among other preserved Song dynasty commentaries on the *Nine Chapters*, we find Yang Hui's *Xiangjie jiu zhang suanfa* (*Detailed Explanations of the Nine Chapters on Mathematical Methods*) printed in 1261 and in 1408 for the copies of the Ming dynasty imperial library named the *Yongle dadian* (*Great Encyclopedia of Yongle reign*). The evidential research scholar Dai Zhen (1724–1777) compiled *Supplements of Diagrams and Errata to the Nine Chapters on Mathematical Procedures* when he worked on the edition of traditional Chinese mathematical sources to be included in the imperially commissioned *Siku quanshu* (*Complete Library of the Four Treasuries*). Since Dai Zhen's compilation project of the *Ten Books of Mathematical Classics*, more than ten other editions of the *Nine Chapters* have been discovered.

The Foundational Mathematical Content of the Ten Books

Wang Xiaotong's *Ji gu suanjing* (*Mathematical Classic in Continuation of the Ancients*, compiled earlier than 626) played an important role in the development of numerical procedures for the solution of algebraic equations. It contains 20 problems, the first one of which concerns a calendrical calculation; problems 2–5 concern

the construction of a geometric solid; problems 6–16 consider the construction of different types of granaries, and the (partially incomplete) problems 17–20 deal with right-angled triangles. All the procedures to solve problems 2–20 involve the solution of a quadratic or a cubic equation, which gives the treatise a certain coherence. Given the daily motion of the sun and the moon, the position of the sun on the ecliptic at the time of the new moon, and the time lapse between new year and new moon, Wang Xiaotong's first problem asks for the position of the moon on the ecliptic at the time of the New Year's new moon which should have ideally happened at midnight of the first day of the 11th month.

Commentaries by Chen Luan (fl. 566) and ► [Li Chunfeng](#) on *Sunzi suanjing* (*Master Sun's Mathematical Classic*, late fourth century) mentioned in the Tang dynastic annals are unfortunately lost. But *Master Sun's Mathematical Classic* itself is the earliest document on arithmetical procedures in China. It describes the positional arrangement of numbers represented by ► [bamboo](#) sticks, and gives detailed multiplication and division algorithms for these tools laid out on the positions of a counting board. The textual structure of the first part of the treatise is distinct from the usual arrangement in problem, answer and solution procedure. In sequential order, measures, weights, large numbers, and standard measure vessels are defined, before expounding the methods and positions for calculations with counting rods. The texts state in general terms, procedures for multiplication, and as its inverse counterpart, the procedure for division, followed by an ordered numerical list of multiplications, division, and summations.

► [Zhang Qiujuan](#) *suanjing* (*Zhang Qiujuan's Mathematical Classic*), probably written between 466 and 485, can – taken in a large sense – be interpreted as a commentary to the *Nine Chapters*, since it recycles certain problems, for which the numerical solution is described through “detailed calculation sketches” by the Sui dynasty astronomer Liu Xiaosun (mid-sixth century). But *Zhang Qiujuan's Mathematical Classic* also contains problem types which in later texts become themselves canonical models. For

example, there is the “one hundred fowls” problem, in which somebody is to buy 100 fowls for 100 monetary units of several kinds. This requires the solution of an indeterminate system of equations. What is characteristic for this text is that problems from the *Nine Chapters* are often given in inverse formulation, which leads to inverse algorithms. In many cases this requires the solution of a cubic equation, which Zhang Qiujuan solves with an extended procedure to the algorithm for root extraction found in the *Nine Chapters*. From the preface one can deduce, that Zhang Qiujuan was familiar with other treatises from the *Ten Classics* and that his main mathematical activity was to rewrite their procedures. His textual work on Antiquity was thus not only limited to commenting on earlier writings, as he also combined and rewrote many of the problems found in the *Nine Chapters*, which gave rise to new mathematical objects.

The Song Yuan Period: Apogee of Mathematical Tradition in China

Judging from the available sources, the thirteenth century was a highly creative period for the development of mathematics in China. Numerous references to now lost treatises show that it was also one of the most productive periods as concerns the publication of mathematical treatises, although now only eight works by four mathematicians in all survive from the late Song to the early Yuan period in China. These are:

1. ► [Qin Jiushao](#). ► [Shushu jiuzhang](#) (*A Mathematical Book in Nine Chapters*), 1247
2. Li Ye. *Ceyuan haijing* (*Sea Mirror of Circle Measurements*), 1248
3. Li Ye. *Yigu yanduan* (*Calculating with Segments in Extension of the Ancients*), 1259
4. ► [Yang Hui](#). *Xiangjie jiuzhang suanfa* (*Detailed Explanations to the Mathematical Methods of the Nine Chapters*), 1261
5. Yang Hui. *Riyong suanfa* (*Mathematical Methods for Daily Use*), 1262
6. Yang Hui. *Yang Hui suanfa* (*Yang Hui's Mathematical Methods*), 1274/1275

rise to a large number of commentaries due to the transmission of Zhu Shijie's earlier book, the *Introduction to Mathematical Learning*. In Korea it was reprinted in 1433 under the reign of King Sejong (r. 1418–1450), and further transmitted into Japan by the end of the sixteenth century. Commentators then also started to see the limits of the *tian yuan* method, in particular for problems with two unknowns that could not be formulated by two independent equations in one unknown each. In China, Zhu Shijie and his precursors were already able to solve such problems

(at least partially) with a method for up to four unknowns, but these writings had not made their way into Korea or Japan.

Zhu Shijie's *Jade Mirror* is now the only preserved witness of a solution procedure for higher degree equation systems with up to four unknowns. The first unknown remains the “heavenly unknown” (*tian yuan*), the other three are the “earthly” (*di yuan*), “human” (*ren yuan*), and “material unknown” (*wu yuan*). The coefficients of these unknowns are then laid out on a counting board as shown in the following illustration:

$d^m \cdot w^k$	...	$d^2 \cdot w^k$	$d \cdot w^k$	w^k	$w^k \cdot r$	$w^k \cdot r^2$	...	$w^k \cdot r^1$
$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
$d^m \cdot w^2$	...	$d^2 \cdot w^2$	$d \cdot w^2$	w^2	$w^2 \cdot r$	$w^2 \cdot r^2$	...	$w^2 \cdot r^1$
$d^m \cdot w$	...	$d^2 \cdot w$	$d \cdot w$	w	$w \cdot r$	$w \cdot r^2$	...	$w \cdot r^1$
d^m	...	d^2	d	$z \cdot w \cdot tai^{d-r}$	r	r^2	...	r^1
$t \cdot d^m$	...	$t^2 \cdot d$	$t \cdot d$	t	$t \cdot r$	$t \cdot r^2$	...	$t \cdot r^1$
$t^2 \cdot d^m$	...	$t^2 \cdot d^2$	$t^2 \cdot d$	t^2	$t^2 \cdot r$	$t^2 \cdot r^2$	...	$t^2 \cdot r^1$
$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
$t^n \cdot d^m$	...	$t^n \cdot d^2$	$t^n \cdot d$	t^n	$t^n \cdot r$	$t^n \cdot r^2$	...	$t^n \cdot r^1$

This way of representation naturally limited the possibilities of solving certain types of equations. On the one hand, this is because not all theoretically possible products of unknowns could be represented; on the other hand, a spatial extension was impossible. The possibilities of a two-dimensional layout were restricted to the four cardinal directions and thus to no more than four unknowns. Besides socio-political factors that influenced the transmission of mathematical knowledge and writings in Chinese society this was probably a structural reason for the end of the development of the *tian yuan method* after Zhu Shijie.

“Minor Traditions” as Reflected in Printed Sources on Arithmetic

The commercialization of print since the Song dynasty brought about several other texts that were not printed under official auspices. The most widely circulating book was Cheng Dawei's

Suanfa tongzong (*Systematic Treatise on Arithmetical Methods*, 1592), which was reprinted and very influential in Japan in the seventeenth century. It is structured into chapters according to the canonical categories of the *Nine Chapters* and three chapters on “difficult problems” (Fig. 5).

At the very end of Cheng Dawei's bestseller, we find a list of books of the time, but unfortunately nearly all of them are lost. But we learn from one comment and from a preface to Ding Ju's *Ding Ju suanfa* (*Arithmetical Methods*, 1355) that they might have been part of what was considered a “low” arithmetical tradition that coexisted in parallel with the tradition of the *Nine Chapters*. This parallels the historiographic trend to portray the Ming dynasty as a time of decline in scientific activity. Since the tradition was characterized by arithmetical procedures for abacus calculations, and often put in versified form, historians have paid little attention to Ming dynasty treatises and interpreted their content as folklore mathematics of little originality. Only Roger Hart has so far taken an

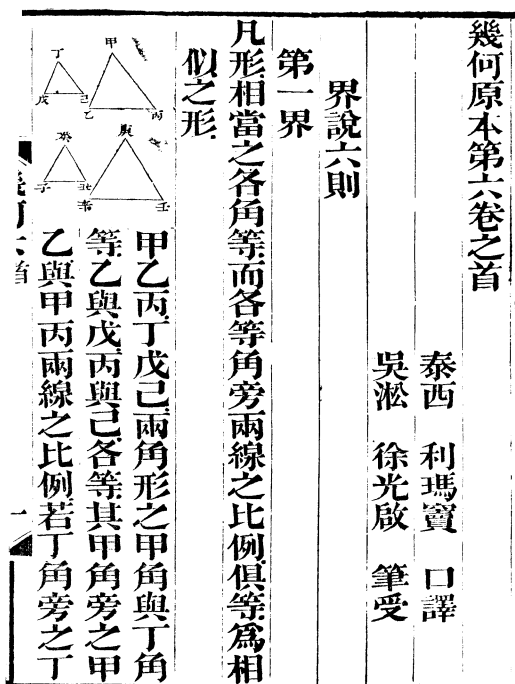


Mathematics in China, Fig. 5 Difficult problems in the *Suanfa Tongzong*, 1592

opposite position on Ming dynasty trends. By analyzing Zhu Zaiyu's (1536–1611) *Yuelü quan shu* (*Complete Compendium of Music and Pitch*) and in particular the mathematics presented in his *New Explanation of the Theory of Calculation* (*Suanxue xinshuo*, engraved in 1604), he claims that Zhu's mathematics is perhaps some of the most sophisticated found in extant texts from the Ming dynasty. There the equal temperament of the musical scale is calculated to 25 decimal places using nine abacuses.

Foreign Influence in the Late Imperial Era

The first wave of transmission of some elements of the European sciences to China, which started in the late sixteenth century, was a systematic enterprise of the Jesuit mission, who sought the



Mathematics in China, Fig. 6 Book 6 of the *Jihe yuanben*, 1607

support of the elite to evangelize from the top down. Matteo Ricci (1552–1610), the founder of the mission, identified the mathematical sciences as a field in which Chinese literati circles were interested. He translated, together with one of his convert students in mathematics, astronomy, hydraulics, and geography Xu Guangqi (1562–1633), the first six books of Euclid's *Elements* (*Jihe yuanben*, 1607). The translation was based on Christoph Clavius' (1538–1612) Latin edition and commentary (Rome, 1574) and aroused Chinese mathematicians and even the Emperor Kangxi's (r. 1662–1722) interest in Euclidean geometry (Fig. 6).

Several other treatises on geometry, trigonometry and methods of root extraction were then written in syncretistic style by Chinese literati, who attempted creatively to come to grips with the new learning. A series of mathematical textbooks was also translated into Chinese and eventually formed the basis of an imperially commissioned compilation on mathematics, the *Shuli jingyun* (*Essential Principles of*

Mathematics in China,

Fig. 7 Biography of Blaise Pascal in the Scientific and Industrial Magazine *Gezhi huibian*, 1880



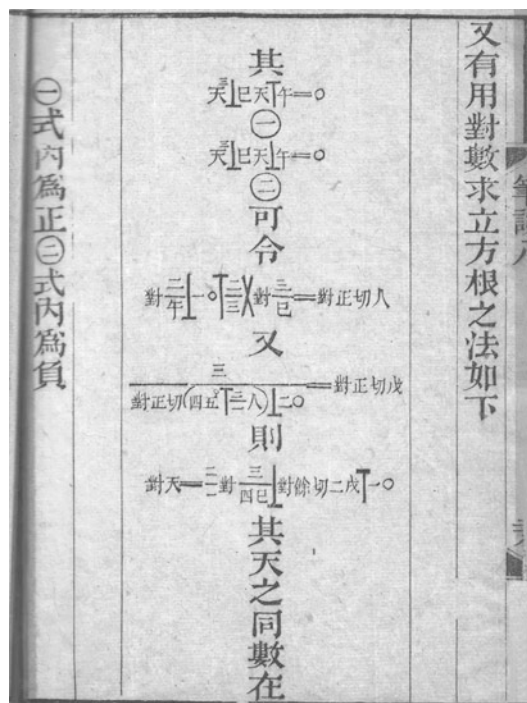
Mathematics, 1723), which played an important role into the mid-nineteenth century.

A second wave of translations of mathematical books related to foreign presence in China following the treaties concluding the Opium Wars. Protestant missionaries, foreign employees of the Imperial Maritime Customs Service connected to its Foreign Language Institute (*Tongwenguan*) in Beijing and private foreign enterprises to promulgate Western sciences in China were the driving agents in that movement in the second half of the nineteenth century (Fig. 7).

It was during that time that Chinese mathematicians started to introduce symbolic algebra into a renewed mathematical discourse. In the assimilation and translation of works on algebra, the late Qing mathematician ► [Li Shanlan](#) (1811–1882) played a key role. Not only he did derive new summation formulas for finite series based on traditional procedures (known as Li

Jen-Shu's formula) and write commentaries on traditional algebraic methods, but also he was instrumental in the transmission of differential and integral calculus. In 1859 he translated, together with the British missionary Alexander Wylie (1815–1887), Elias Loomis' (1811–1889) *Elements of Analytical Geometry and of Differential and Integral Calculus* (1851) and Augustus De Morgan's (1806–1871) *The Elements of Algebra Preliminary to the Differential Calculus* (1835) which were reprinted in Japan in 1872 (Fig. 8).

Both algebra and calculus quickly found their way into late Qing curricula of mathematical education, in contrast to probability theory and statistics, which remained two applied fields of mathematics that had to wait for the 1930s – and for returned students educated abroad – to be fully understood. By then, the Chinese algorithmic traditional style closely related to the written classical language was abandoned. Texts were



Mathematics in China, Fig. 8 Syncretistic symbolism in Hua Hengfang, *Xue suan bitan*, 1885

written in vernacular language and algebraic symbolism was adopted as the universal scientific language. China's mathematicians for the first time had an institutional base, the Academy of Science's (*Zhongguo kexue yuan*) Mathematical Institute and several research centers in universities, where the emphasis was on number theory, operations research and closely related to it statistics and probability. The antirightist campaign of 1957 and the Cultural Revolution at its peak in 1966 involved a major disruption of intellectual activities in China. At the 1978 National Science Conference, Deng Xiaoping again allowed for the progress of all aspects of mathematical research by emphasizing science as one of the "four modernizations."

Mathematics Education in China

Mathematics, together with rites, music, archery, charioteering, and calligraphy, formed the *Six Arts* as defined by traditional Confucian learning.

We know that Li Chunfeng's compilation project, the *Ten Books of Mathematical Classics*, was used as a textbook for the Mathematical Academy (*Suanxue guan*) founded by the Emperor Gaozong in 656. This academy was part of the "director of education" (*Guo zi jian*) responsible for the training of government officials. A "School of mathematics for the national youth" (*Suan li guozi xue*) had already existed since the Sui dynasty. It was taken over by the Tang, but we do not know about its curriculum and the manuals that were used. In Imperial China, there was no such profession as a mathematician; knowledge was mainly transmitted orally from teacher to pupil in private academies. We have little or no biographical information on those who wrote mathematical books except for court astronomers or those who held a government position, like Qin Jiushao in the Song administration. It was only during the late nineteenth century educational reforms that mathematics became part of the standard curriculum in schools and the first universities in China. By then, some government supported students returned from Japan, Europe, or the United States and served as teachers for Western sciences. But it was really only in the 1930s that effective schools were built up and that mathematical research started to be systematically institutionalized.

See Also

- [Abacus](#)
- [Calendars in East Asia](#)
- [Computation: Chinese Counting Rods](#)
- [Decimal System and Measurement in East Asia](#)
- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [Geomancy in China](#)
- [Gou-Gu Theorem](#)
- [Guo Shoujing](#)
- [Li Shanlan](#)
- [Li Zhi \(Li Ye\)](#)
- [Jiuzhang Suanshu](#)
- [Pi in Chinese Mathematics](#)
- [Qin Jiushao](#)

- Shen Guo
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- Zhoubi Suanjing
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Mathematics in Egypt

James Ritter

By “Egyptian mathematics,” we understand the mathematics developed in Ancient Egypt between the end of the fourth millennium BCE, when a centralized state came into being in the Nile Valley and a system of writing was invented, and 332 BCE, when Egypt was conquered by Alexander the Great and Greek cultural elements entered into the hitherto fairly autonomous development of Egyptian civilization. During these 3,000 years, the role of mathematics remained of central importance; the Egyptian educational system was geared principally to produce scribes who could count and calculate the work, rations, land, and grain of the State and the private landowner.

The judgments of Egyptian mathematics ordinarily to be found in histories of science fall into two main schools: either they are dismissive, claiming that mathematics in Egypt was merely of a “practical” or “trial and error” nature; or they are laudatory in the extreme, the Egyptians being seen as the precursors and inventors of all important concepts in mathematics. In fact,

these two judgments share an identical misconception about mathematics itself, namely that it really exists only insofar as it corresponds to a particular Western image of theorem and proof. However recent interest in alternative (algorithmic and effective) methods in mathematics, as well as a better understanding of the complex and sophisticated nature of Egyptian civilization, has opened the way for a deeper comprehension of mathematics in the Nile Valley.

The real question is what mathematics represented for the Egyptians themselves, what they aimed at, what structural, intellectual, and sociological activities were connected with their mathematics. The Egyptians left us no philosophical or self-reflexive works commenting on their own activity; the nature and role of Egyptian mathematics must be pieced together from such texts as administrative and accounting documents, historical annals, and, above all, school texts.

We have, in fact, astonishingly few sources: the choice of excavation sites and the fragility of papyrus under humid conditions means that most written documents come, almost exclusively, from cemeteries and temples in the desert fringe along the Nile valley and only rarely from towns or cities in the fertile band around the Nile and its Delta. In addition, mathematical texts are particularly rare – some five papyri, mostly fragmentary, a pair of wooden exercise tablets, and a small inscribed stone flake. Moreover, with the exception of the last, all the texts are originals or copies dating from the same period, the Middle Kingdom between 2000 and 1700 BCE. The accounting documents are a little more plentiful and from a more balanced time span, but not all have been published and those that have still await a study of the mathematical techniques used in their fabrication.

But there are some things that we do know. In Egypt, there were no centers of mathematical research in the modern sense, no journals or books exposing new results. There is not even an Egyptian word for “mathematics” in our sense: the only two Egyptian titles of

mathematical school books that have come down to us are “The right method for entering into things, for knowing everything that is, every obscurity, . . . , every secret” (Rhind Mathematical Papyrus) and “The right method in matters of writing (?)” (Kahun Papyrus LV.4).

However, Egypt, like almost all societies, needed to create computational skills, to count and keep track of the collection and distribution of material wealth. Indeed, writing in Egypt was created precisely to make permanent records of these numerical data; the earliest signs were used to indicate metrological values along with the titles and proper names of those from whom came and to whom were to be delivered this wealth; mathematics and writing were linked from the very start and were the staple of Egyptian educational training. In particular, the mathematical texts we possess – including the Rhind Mathematical Papyrus – are school textbooks. So it is to the world of apprentice scribes and their teachers that we must look for an understanding of Egyptian mathematics.

Numbers

The third millennium had seen the development of some eight or nine distinct metrological systems – a discrete system, used for counting individual objects; a length system; an area system, used for measuring field surfaces; a distinct system for surfaces of linen; a capacity system for grain, and a weight system for measuring precious metals. The signs used to write the units of each system differed among themselves, as did the ratio between successive units in each system. In all cases though the Egyptians used an additive system of notation, in which a unit was repeated as many times as necessary to express the value desired.

For example, the discrete system is decimal in structure while the length system has four fingers to the palm and seven palms to the cubit. Thus whereas 14 goats would be written with 1 ten and 4 ones – written – a length of 14 fingers would have three palms and two fingers:



By the time of the Middle Kingdom, there is a distinct rationalization of these systems. Some, such as that for linen, simply disappear; some, such as that for lengths, are simplified. In the mathematical texts, all arithmetical operations are performed in the discrete system, now employed as a universal calculational system; an abstract concept of number is born. The discrete system being decimal, the base 10 became the standard. A significant part of mathematical training was devoted not only to learning how to perform mathematical calculations in the decimal system but also to mastering the conversions into and out of the surviving, nondecimal metrological systems.

The Mathematical Texts

The careful organization of the mathematical papyri reflect their pedagogic nature. They are constituted of numerical tables (to which we shall return) and solved problems: each problem is expressed in ordinary language with no symbols aside from the numbers themselves. The data and the results are given as concrete numerical values, and the solutions presented in the form of algorithms, that is a specific sequence of steps leading to the solution, generally followed by a numerical verification of the result obtained.

The subjects of the problems in the mathematical papyri touch on arithmetic calculations involving distribution of rations, work assignments, and the conversion of quantities of grain into beer and bread; mensuration problems involving the determination of volumes of circular and rectangular containers, areas of triangular, rectangular, and circular fields, slopes of pyramidal and conic constructions, and parts of ships, as well as others. The problems are roughly grouped by subject but, more precisely, by the type of algorithm used in their solution. Each group of

problems is a series of exercises in the learning and use of an algorithm.

A typical example is given by the following Problem 26 of the Rhind Mathematical Papyrus; the words in red ink in the original are given in bold-face; the numbering of the steps of the algorithm and phrases in square brackets are my additions:

A quantity; its $1/4$ is added to it. It becomes 15.

1. Calculate starting from 4; you will make its $1/4$: 1.
2. [Add them together.] Total: 5.
3. Calculate starting from 5, to find 15.
 - $\backslash 1$ 5
 - $\backslash 2$ 10
 - 3 is the result.
4. Calculate starting from 3, four times.
 - 1 3
 - 2 6
 - $\backslash 4$ 12
 - 12 is the result.

The quantity: 12. Its $1/4$: 3. Total: 15.

[Verification]

- 1 12
- $[1/2$ 6]
- $1/4$ 3
- Total: 15.

It is important, in order to understand Egyptian mathematics, that each problem in a mathematical text operates on three distinct levels. The first is the global strategy used, embodied by the *algorithm* and is the same for all problems in a group. In our example it is the common Egyptian method, now called “false position.” A (false) solution is supposed, in our example 4; the result of calculation with this value (steps 1 and 2) is compared to the true answer (step 3) and the original choice corrected by the necessary factor (step 4).

The second level is that of arithmetical *operations*: addition, subtraction, multiplication, division, square root extraction, etc., each of which corresponds to one step of the algorithm. It is introduced by a standardized formulation

and includes a numerical computation. In our example, step (4) is a multiplication: as always indicated by “Calculate starting from N , M times”; likewise, step (3) is a division.

The third level is that of *techniques*, that is the set of means for carrying out the operation. Here the Egyptian scribe had a wide range of choices. For the simple operations of addition and subtraction (see step 2 in the example), no details were shown; the scribe was presumed to be able to do these without such aids. In the case of multiplication and division, the computations show what was done.

The multiplication of step (4), in our example, 3×4 , is carried out in the following manner: starting with the first multiplicand, 3, in the right-hand column and 1 in the left, the scribe seeks the value of the second multiplicand, 4, in the left-hand column (since this is multiplication); in this case, the scribe obtains the columns directly by two successive uses of the same technique, namely *doubling*. The 4 is marked and the answer, 12, read off in the opposite column.

The division of step (3), $15 \div 5$, is carried out by putting the divisor 5 in the right-hand column, facing 1, and then, after a single doubling, finding the dividend, 15, in the right-hand column (since this is division), the sum of the two entries. Both are checked and the answer, $3 = 1 + 2$, read off as the sum of the corresponding entries in the left-hand column.

Note that though the two operations, in the particular case treated here, are the inverse of each other, the only technique used to effect both of them is doubling. However, the Egyptian scribe was not limited to this single technique; others, such as halving (illustrated in the verification step of our problem), multiplying or dividing by 10, multiplying by $2/3$, inversing, etc. were equally available. Given a particular arithmetic operation, the scribe chose the set of techniques appropriate to the numerical values in play.

Tables and Fractions

Fractions played a particular role in Egyptian mathematics. A fraction was viewed as the

inverse of an integer; there could thus be only one fraction associated with a given integer N : namely, what we call the “unit fraction” $1/N$ – there being a single exception, the fraction $2/3$. These fractions were manipulated in precisely the same way as integers, using the same panoply of techniques.

Only one fraction of a given kind could be used in the writing of a given number. Thus, for example, the double of the number $1 + 1/5$ was not written $2 + 1/5 + 1/5$ but rather $2 + 1/3 + 1/15$. Finding such expressions is a centrally difficult problem: it occurs each time it is necessary to double an “odd” fraction, calculate two-thirds of a fraction, or add fractions together. It constitutes the core area of Egyptian mathematics, and furnishes the content of Egyptian mathematical *tables*. Such difficult calculations could be done once and for all and the results simply copied and looked up when the need arose in the solution of a specific problem.

The problems in Egyptian mathematical texts were chosen in order to cover the domain of the possible by a *network of typical examples*, a process which permitted the student (and later the practicing scribe) to place any new problem in this framework. The Egyptian approach to the question of generalization was not the discovery and application of a “general formula” in which each case might be enveloped, but rather through interpolation in a pattern of known results – a method equally used in some branches of mathematics today.

If Egyptian mathematics is viewed not as a poor simulacrum of proof-oriented mathematics, but on its own ground, it will be seen as an adequate and rational response to the socio-economic and educational needs of Egyptian society. Mathematics even provided a model of a rational practice, equally applicable to other domains, wherever an efficient mode of action on the world was needed. Egyptian medical texts, for instance, were constructed in the same manner, with tables of remedies and a systematic network of procedural prescriptions.

This approach was not unique to Egypt; one finds analogous underlying principles at work in

the mathematics of other civilizations, such as Mesopotamia, China, and India. It is not a question of borrowing; the mathematical traditions in question developed too early and were too widely geographically spread for this. Rather it shows the success of this algorithmic approach to the solutions of the problems posed by sufficiently advanced societies.

These different civilizations differed in their choices of number system, of modes of writing, of arithmetical operations, as well as the techniques used to carry these out. And the differences determined in turn the very different paths of development that mathematics knew in each society. If similar needs led to similar responses on the fundamental level, the different ways of implementing them created very different mathematics.

See Also

► [Weights and Measures in Egypt](#)

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Mathematics in Egypt: Egyptian Mathematics and African Predecessors: New Insights from Work Sites

Beatrice Lumpkin

Recent archaeological digs have uncovered Middle Stone Age (MSA) artifacts that root the origin of modern behavior in Africa. The MSA dates from 200,000 to 40,000 BP (Before the Present). These recent finds upset the textbook theory that places the origin of modern behavior in Southern France and Spain, only 30,000–40,000 years ago. Modern behavior includes abstract thinking and symbolic representation, essential features of mathematical thinking. It also includes designing sophisticated tools and making plans for the future.

Reports of these MSA finds include stone blades from Kenya by McBrearty (1995), basalt tools from Tanzania by Adelsberger (2002), barbed harpoon points from the Democratic Republic of the Congo by Yellen et al. (1995) and engraved designs from South Africa by Henshilwood et al. (2002). The Kenyan stone blades came from a formation over 200,000 years old and were shaped before they were knocked off the rock core (Gutin, 1995). This required planning by toolmakers who had an abstract picture in their minds of the desired tools. If the toolmakers were anatomically modern *Homo sapiens*, they were among the earliest of their species. Modern humans are believed to have evolved in Africa about 150,000–200,000 BP and migrated to Australia and possibly East Asia by 50,000 BP.

In about 200,000 BP at Laetoli, Tanzania, raw material used by “archaic” *Homo sapiens* was transported from sources at least 20–30 km distant. The ancient toolmakers made a round trip to obtain the stone or some type of trade took place. The basalt from the more distant sites provided a better cutting edge than the local finer-grained rock. The author of the study wrote, “...apparently the archaic *Homo sapiens* of the

Laetoli region comprehended these attributes as early as 200,000 years ago” (Adelsberger, 2002).

At the somewhat later MSA site of Katanda in the Democratic Republic of the Congo, archaeologist Yellen was disappointed when he found a barbed harpoon point. He had hoped the site dated back as far as 70,000 BP. But the bone point was so finely crafted that it resembled European harpoon points that were only 14,000 years old. Disappointment changed to joy when the bone point was dated to ca. 90,000 BP. The Katanda materials included barbed bone points, unbarbed points, and a flat dagger, products of a formal bone industry. Although the Yellen team used three different techniques to date their finds, some archaeologists continue to dispute the date (Yellen et al., 1995) (Fig. 1).

However, sophisticated tools may not be enough to identify modern human behavior. The record was missing what Christopher Henshilwood et al. described as “evidence of abstract or depictional images” (Henshilwood et al., 2002). In 2002, they recovered two engraved pieces of ochre from MSA layers in Blombos Cave in South Africa, dated to 77,000 BP. One piece is inscribed with a design, a row of cross hatches, framed by two horizontal lines and bisected by a third. The second piece has fewer lines but indicates that the design on the first piece is not unique.

Why was the African evidence for sophisticated tool technology in the MSA not discovered sooner? Archaeologists now working in Africa have a simple explanation: nobody had really bothered to look for it. “In France alone there must be three hundred well-excavated sites dating from the period we call the Middle Paleolithic,” archaeologist Alison Brooks said. “In Africa there are barely two dozen on the whole continent” (Shreeve, 1992).

Language is also a factor in the development of mathematics. The logical concepts needed for mathematics are built into all languages, as Karl Menger pointed out in his lectures. For example, all known languages have words for “or,” for “and,” and for counting numbers. By its nature, the development of language has left no records for archaeologists to excavate. However,



Mathematics in Egypt: Egyptian Mathematics and African Predecessors: New Insights from Work Sites, Fig. 1 A barbed harpoon point from Democratic

Republic of Congo. After Chip Clark. *Science* 268, 28 April 1965, p. 495

numerical records have been found from soon after the MSA. The oldest known to date was found in Border Cave in Southern Africa and has been dated to ca. 37,000 BP. It is a fossilized baboon bone inscribed with 29 tally marks. Similar records are still made by San peoples of Southern Africa to record the lunar cycle (Bogoshi, Naidoo, & Webb, 1987). Alexander Marshack gives examples of this type of tally record from many parts of the world (Marshack, 1991). By the time anatomically modern humans left Africa, they may have been counting as well as making relatively sophisticated tools.

Trade played a very important role in the development of early mathematics. No direct evidence is known for a trade in chert, a flint-like quartz that was mined in large quantities in Southern Egypt ca. 33,000 BP. However, the quantities mined appear greater than the needs of local consumption. The miners used complex techniques not known in other parts of the world before 10,000 BP. Also, a grave at the mine site contained the remains of a young miner, buried with his mining tool. Burial goods and advanced mining techniques suggest cultural development at 33,000 BP (Vermeersch et al., 1984).

A Central African fossilized tally record, known as the “Ishango Bone,” has excited discussion because it is more complex than the Border Cave fossil. First studied in 1950, the bone was recently redated back to 20,000–25,000 BP. The ► [Ishango bone](#) shows tallies on one edge for 3, 6, space; 4, 8, space; 10, space; 5, 5, space; 7. The other side is marked on one edge, 11, 13, 17, 19, and on the other edge, 11, 21, 19, and 9 (Zaslavsky, 1999, p. 18). A number of hypotheses suggested that these number sequences were more than a simple count. Many harpoon points were also found at the site. This

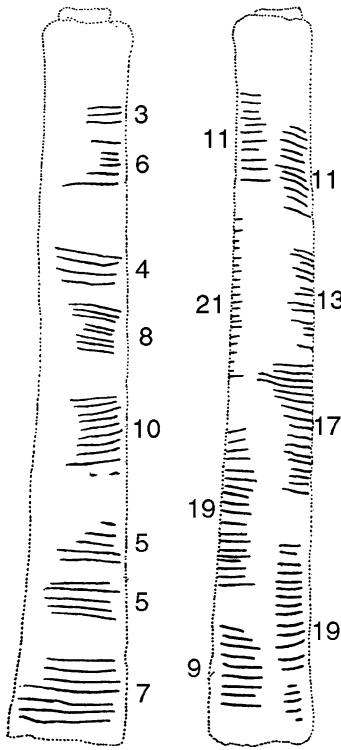
harpoon point technology spread to other parts of Africa, including the Nile Valley. Although not proof, it is suggestive of an Ishango input to the later Nile Valley civilizations (De Heinzelin, 1962) (Fig. 2).

Some 15,000–20,000 years passed between the time of the Ishango bone and the first pharaohs who ruled all of Egypt. Although the record is sketchy, there were many advances made in the period before the pharaohs. Rock drawings from Nubia and Southern Egypt show ships with large crews, implying extensive trade. Evidence of early measurement systems predates writing and embodies a whole corps of mathematical knowledge. For example, Flinders Petrie reported a red limestone balance beam and sets of graduated weights from Southern Egypt, dated to Naqada I, 4500–4000 BCE. The weights are multiples of a base weight, showing that the concept of ratios was already well developed (Petrie, 1920, p. 28, also 1926, p. 18).

In 1998, archaeologists reported a 6,000-year old Stonehenge-type arrangement of large stones at Nabta Playa in Southwestern Egypt. They described a “calendar” circle with stones that align with the summer solstice of 6,000 years ago (Wendorf & Schild, 2000). By 3200 BCE, hieroglyphic numerals were in use. An engraving on a knife handle clearly shows a numeral for 3,000 and other numerals are indicated (Williams & Logan, 1987). The prehistory of Egyptian mathematics was coming to an end and the dawn of literacy had begun.

Egypt of the Pharaohs

The mathematical insights, discussed below, were gleaned from artifacts found at pyramid



Mathematics in Egypt: Egyptian Mathematics and African Predecessors: New Insights from Work Sites, Fig. 2 Ishango Bone, diagram (DeHeinzelin, 1962, p. 114)

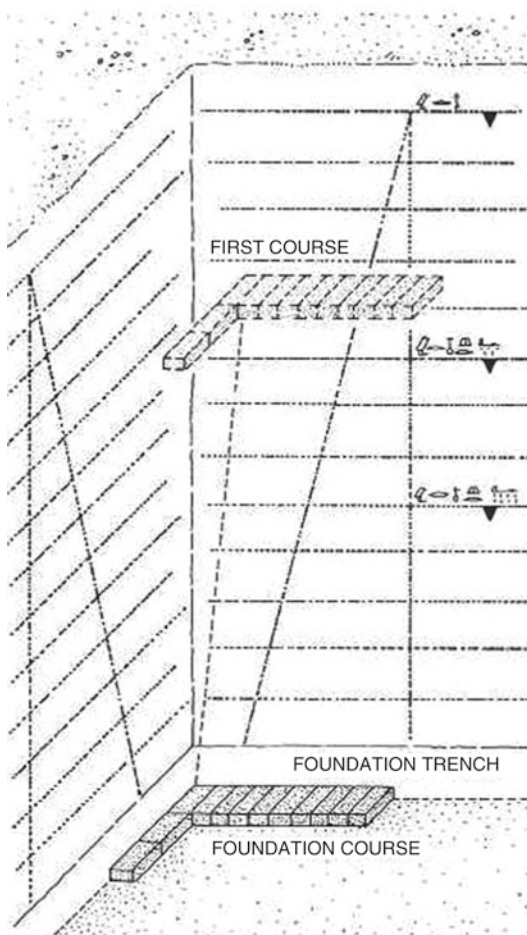
and temple work sites. They have not yet appeared in the textbooks on the history of mathematics. These insights include the use of rectangular coordinates and construction lines labeled with integers and a zero reference point. The same symbol used to label the zero reference point was later used to show zero remainders in a bookkeeping papyrus.

The period of building great pyramids began in Egypt ca. 2700 BCE. Thanks to the findings of Egyptologists such as Dr. Zahi Hawass and Mark Lehner, the Hollywood image of slave labor building the pyramids has been discredited. It is now known that the pyramid builders were well fed and were paid wages. There was a demand for mathematical and engineering skills. Scribes trained in mathematics kept accounts for thousands of workers, maintained the Egyptian calendar, and used a canon of proportions for paintings and statues of kings and nobles.

No mathematical texts are among the surviving papyri from that period. So we must study the pyramids, themselves, to learn about the mathematics used in pyramid design. Because they were so massive, pyramids and the large tombs called *mastabas* required careful leveling to prevent collapse. They also used deep foundations. For leveling purposes, the Ancient Egyptian architects created a system of guidelines with horizontal lines spaced 1 cubit apart. To locate exact distances below and above ground level, they placed a vertical line on the grid of horizontal lines. A zero reference level was used, often near pavement level, and labeled *nfrw*. (Egyptian hieroglyphic writing omitted vowels so the vowel sounds are not known.) Other points on this vertical line were labeled with the number of cubits above *nfrw* or below *nfrw*. In effect, these architects created a number line with a zero reference point and directed, or signed integers.

An example of these number lines appears to the right. These lines can still be seen in a foundation trench at Mastaba 17 in Meydum, Egypt. Horizontal, leveling lines were drawn on the wall of the trench, spaced 1 cubit apart. A vertical line intersected the horizontal lines. Some points of intersection were labeled with “*nfrw*” for ground or zero level, “5 cubits below *nfrw*” and “8 cubits below *nfrw*.” No labels are seen for “above *nfrw*” because the higher lines were not preserved. But at the nearby Meydum pyramid, there are leveling lines marked “6 cubits above *nfrw*” and “8 cubits above *nfrw*.” Dieter Arnold believes the vertical lines were “used not only for horizontal measuring, but also for marking directions” (Arnold, 1991, pp. 17, 18) (Fig. 3).

These findings contradict the oft-repeated statement that, “The Egyptians did not have a zero” (Bunt, Jones, & Bedient, 1976, p. 7). It is true that Egyptian numerals were additive, without place value. There was no need of a zero placeholder. But *nfrw* for zero level was noted by Egyptologists 100 years ago. Also, the related Egyptian word, *nfr*, was used for the zero remainder on the balance sheets of a bookkeeping papyrus. That papyrus is now known as Bulaq 18, written by the scribe Neferhotep, ca. 1700 BCE.



Mathematics in Egypt: Egyptian Mathematics and African Predecessors: New Insights from Work Sites, Fig. 3 Construction lines with zero reference (Arnold, 1991, p. 12)

Neferhotep and his assistants recorded each day's receipts and disbursements of supplies for the Pharaoh and his traveling court. For each type of goods, the sum of the disbursements was subtracted from the sum of the receipts to get the balances. On Day 1, Month 3 of this account, disbursements equaled receipts in four of the eight columns. Subtraction left zero remainders. The scribe wrote the zero quantity as *nfr*. *Nfr* had several meanings. In notes collected by Egyptologist Aayko Eyma, he writes:

This *nfr* particle means 'be at an end,' 'finished,' 'be zero(?),' and occurs in constructions like *nfr n* (+ verbal form) 'not,' *r-nfr n* 'so that not,' and *nfr*

pw 'there is not.' Some think the word *nfr*, 'beautiful,' 'good,' is unrelated but others believe that it may be related, in the sense of 'perfect,' 'ultimate' or 'final state'. (Lumpkin, 2003)

Scharff, the first European to publish Bulaq 18 (in 1922), translated the Egyptian numerals as Indo-Arabic numerals. Naturally, he knew that $52-52$ left a remainder of 0 and that $7-7 = 0$. But instead of writing zero, he wrote *nfr*, with no translation. In his comments, he described these remainders as "*das glatte Aufgehen*," the flat or even outcome (Scharff, 1922). Perhaps he did not want to challenge the established belief that "the Egyptians did not have a zero." The great Egyptologist, A. Gardiner, in 1927 gave "zero" as the meaning of *nfr(w)* and "perhaps" zero as a meaning of *nfr* (Gardiner, 1978, pp. 266, 574). A later writer, Spalinger, had no problem with translating the *nfr* balances as "0" in his 1985 translation of Bulaq 18 (Spalinger, 1985, p. 12). It appears that the Egyptians had a zero, after all. (Bulaq 18 is discussed in more detail in Lumpkin 2002. I thank Frank Yurco for his kind help with Bulaq 18 and other sources for the zero concept in Ancient Egypt).

Few construction plans have survived the thousands of years since the time King Djoser's step pyramid was built at Saqqara ca. 2700 BCE. Fortunately, an architect's detail was found next to a domed structure inside the pyramid complex. The plan, inscribed in red ink on a limestone flake, shows a curve. Evenly spaced vertical lines, a cubit apart, give horizontal coordinates while hieroglyphic numerals state the vertical coordinates for points on the curve. Archaeologist Gunn plotted these points and connected them with a smooth curve. He reported in 1927 that the curve matched the curvature of the domed structure nearby (Gunn, 1926). Somers Clarke and Engelbach, in their classic on Ancient Egyptian construction, called this early use of coordinates "of great importance" (Clarke & Engelbach, 1930, pp. 52–53). To date, this achievement remains little known, perhaps because it does not appear in the surviving papyri (Lumpkin, 2002).

Pairs of construction guidelines may have provided axes for rectangular coordinates to locate

points on pyramid walls. As early as 1865, Richard Lepsius recorded such systems of horizontal and vertical guidelines. The horizontal guidelines were labeled with the number of cubits from “a foundation line,” much as at Mastaba 17, shown in Fig. 3. In a chamber at Khufu’s great pyramid, Lepsius noted a pair of vertical lines intersecting a horizontal line. The line to the left was marked “3.” In fact, that line measured 3 cubits from the vertical line to the right (Lepsius, 2000, pp. 11–13). Since there were both horizontal and vertical reference lines, it is possible that rectangular coordinates were used to locate points of interest during the construction.

Khufu’s pyramid at Giza presents a special challenge in the study of the mathematics and technology used in construction. It is best known for its massive size, covering an area as large as eight football fields. The pyramid measured over 230 m each side and stood 146 m high. Many wonder how these pyramid builders, without modern machines, moved more than two million stones, some weighing 50 tons. But the greater challenge is to explain the extreme accuracy of the 90° angles that varied less than 1/15 of 1°. And what technology did they use to level the foundation platform to within 2.1 cm? How were the walls so closely aligned to the cardinal points?

Egyptologists are divided about how the builders found true North, whether they used star light or sun shadows. Either method required an accurate circle and bisection of an angle. Writers have suggested that leveling was accomplished by flooding the area inside a closed wall. But the pyramid was built on a sloping plateau with a rocky massif that became part of the pyramid. Leveling by water was not an option, Lehner concluded. He studied a double line of holes parallel to the sides of Khufu’s pyramid. It is possible, Lehner writes, that stakes were placed in these holes to support a cord used as a reference level (Lehner, 1997, pp. 214–219).

Many have tried to explain how the Egyptians achieved such accurate square corners. Some Mozambicans and the Kpelle of Liberia compare the length of the diagonals of the base to check square corners for their traditional homes. But the rocky massif precluded this method at Khufu’s

pyramid. It is possible that the pyramid builders used the right-triangle theorem to set nearly perfect square corners. There are reports of 3–4–5 triangles in the design of Old Kingdom temples but Lehner finds the evidence inconclusive.

Some have suggested that intersecting arcs were used to construct a perpendicular, using a cord as a compass. The accuracy of this method has also been questioned. Another method relies on tools invented by Ancient Egyptians. These included square levels, set squares and plumb bobs. A rough perpendicular line could be drawn with the set square. Flipping the square around that line would give a slightly different perpendicular. A more accurate perpendicular would be the line halfway between the two rough perpendiculars. Again, many believe that this method could not produce the accuracy achieved by the Ancient Egyptians.

Another difficult problem solved by Egyptian pyramid builders is less obvious. How did they manage to bring the four sides to a central point at the top? Knowledge of the slope of a pyramid is well attested in the *Rhind Mathematical Papyrus*, Problems 56–60. Actually, they used inverse slope, the ratio of run to rise. For Khufu’s pyramid, it was 14–11. This ratio must be kept constant to achieve the smooth sides of the pyramid. Lehner writes, “There is evidence that guidelines marking the plane of the pyramid face were cut into each casing block. . .” Also, Lehner has found possible postholes for markers to serve as backlights to align the pyramid axes and diagonals. This followed an earlier suggestion by Clarke and Engelbach. Further mapping of holes and marks around the pyramid may supply more insight into the Egyptian method of controlling the run to rise ratio (Lehner). It is hoped that continued exploration of African work sites will yield other exciting discoveries about our mathematical forerunners.

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Mathematics in Egypt: Mathematical Leather Roll

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Henry Rhind purchased the 10 × 17" Egyptian mathematical leather roll (EMLR) and the Rhind Mathematical Papyrus (RMP) on the streets of Cairo, Egypt, in 1858. Upon his untimely death, the EMLR and the RMP were both gifted to the British Museum in 1864. The RMP was published in 1879 and reported as fully decoded in 1927 (Chace, 1927). In 1927 the EMLR was chemically softened and unrolled (Scott & Hall, 1927).

Middle Kingdom hieratic characters were written right to left. There are 26 rational numbers listed. Each rational number was followed by a series of equivalent unit fractions. This entry records the data from left to right for ease of reading.

There are ten binary rational numbers: 1/2, 1/4 (twice), 1/8 (thrice), 1/16 (twice), 1/32, and 1/64. There are seven other even rational numbers: 1/6 (twice – but wrong once), 1/10, 1/12, 1/14, 1/20, and 1/30. Finally, there are nine odd rational numbers: 2/3, 1/3 (twice), 1/5, 1/7, 1/9, 1/11, 1/13, and 1/15.

The British Museum examiners found no introduction or description of how and why the equivalent unit fraction series were computed

(Gillings, 1981, pp. 456–457). At least one equivalent series of unit fractions was uniquely associated with $1/3$, $1/4$, $1/8$, and $1/16$. There was a trivial error associated with the unit fraction series total of $1/15$. It was listed as $1/6$. Another serious error was associated with the rational number $1/13$, a problem that the examiners did not resolve.

The *British Museum Quarterly* (1927) naively reported the chemical analysis to be more interesting than the Egyptian mathematical leather roll's (EMLR's) additive contents.

Improvements to the older Horus-Eye numeration system were made by finding exact finite series for each infinite series. Scribes were asked to replace a version of a Horus-Eye infinite series, a numeration system that used “decimal fractions” similar to our present decimals (Ore, 1948, pp. 311–325):

$$1 = \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \dots,$$

with the last term $1/64$ th thrown away (Gillings, 1972, p. 210), by finding a finite unit fraction series. Answers to the infinite series question corrected Horus-Eye round off errors by scaling each rational number to an exact unit fraction series.

In the 1900 BCE Akhmim Wooden Tablet, a hekat unity and a ro unit were used in volume calculations, and proofs, that reduced five Horus-Eye errors to zero (Vymazalova, 2002). The 1650 BCE RMP included 80 implied uses of the hekat grain unity ($64/64$) and $1/320$ of hekat ro remainders (Gardner, 2008a).

Note that Babylonian scribes wrote in an expanded base 60 system before the Egyptian hieratic system appeared. Babylonian numeration also used properties of “decimal fractions.” Babylonian numeration was written within a positional notation similar to the modern decimal system. Babylonians attempted high accuracy, minimizing errors to $1/3,600$ for two terms and $1/216,000$ for three terms. However, for inverse prime numbers, Babylonians rounded off to the nearest equivalent unit fraction, i.e., $1/91$ rounded to $1/90$, thereby seriously degrading the system's accuracy (Robson et al. 2003).

Because the Middle Kingdom arithmetic was written in an unusual exact series context, modern researchers frequently minimized the EMLR's significance. One minimizing aspect suggested that the older Horus-Eye system's inaccuracies were eliminated in special situations. Several ancient texts, the Akhmim Wooden Tablets, Berlin, Kahun, Moscow, and Reisner papyri, were often read in a low additive manner. The current update of the EMLR demonstrates 26 times that a generalized scaling method was available to a student scribe who wished to convert a rational number to an exact unit fraction series. Therefore, the implicit and consistent EMLR abstract arithmetic could have been reported in 1927. Arguably the more accurate hieratic system that the EMLR student was learning provided more than “bragging rights” to Egyptian science and trade, when compared to the less accurate Babylonian arithmetic.

Restating the problem of fairly reading the EMLR as a decoding process, an end was reached 80 years after the project started. As a review, the majority of early examiners suggested that the EMLR only contained simple additive information. About 80 years later, a vivid form of abstract arithmetic was parsed and confirmed from common EMLR, RMP, and AWT arithmetic operations (Gardner, 2002, 2008a).

The following chronology shows several of the events along the road to understanding Egyptian abstract arithmetic.

For example, the EMLR student scribe reported the answers to:

$$\begin{aligned} 1/8(3/3) &= (2 + 1)/24 \\ &= 1/12 + 1/24; \quad 1/8(5/5) \\ &= 5/40 \\ &= (4 + 1)/40 + 1/10 \\ &\quad + 1/40 \end{aligned}$$

The encoding/decoding method has been attested by cryptanalysis. In addition, five categories (a–e) were found in the EMLR's 26 equivalent unit fraction series. Three categories were identities (a–c) and one (d) was a remainder. The first four categories were basically

understood in 1927. However, one (e) was a complex least common multiple (LCM) scaling method, and sometimes scribes chose one LCM and sometimes two LCMs. The 2008 discovery pointed out that a 2002 EMLR algebraic identity pattern had been misleading. The complex fifth method is demonstrated below (Gardner, 2002, 2008).

The EMLR student selected two scaling multiples 25/25 and 6/6 such that

$$\begin{aligned} 1/8(25/25) &= 25/200 = (8 + 17)/200 \\ &= 1/25 + 17/200 \end{aligned}$$

and scaled $17/200$ $(6/6) = 102/1200 = (80 + 16 + 6)/1200$ meant

$$1/8 = 1/25 + 1/15 + 1/75 + 1/200$$

Interestingly, the EMLR's four $1/8$ scaling multiples, $3/3$, $5/5$, $25/25$, $6/6$, and three unique unit fraction series seem awkward compared to concise RMP $2/n$ th table's entries. The EMLR's single and double LCM scaling multiples were considered RMP training techniques needed to scale hekat quotients by LCM ($64/64$) and remainders by LCM ($5/5$). For example, $1/3$ of a hekat was written as $(64/64)$ times $1/3 = 21/64$ hekat + $1/64(1/3)$ $(5/5) = (16 + 4 + 1)/64$ hekat + $(5/3)(1/320) = (1/4 + 1/16 + 1/64)$ hekat + $(1 + 2/3)$ ro, since ro = $1/320$ of a hekat. A serious error, $1/13$ th, could have been resolved by methods (c), (d), or (e). The error was related to a failed attempt to apply method (e). Mathematics historians have titled a closely related "pick a number" method, found in the RMP, as "false position" (Eves, 1961, p. 40), a method that was not used in the EMLR division method.

The EMLR has been proven to be a student's introduction to an innovative numeration system. The improved Middle Kingdom arithmetic scaled rational numbers by single and double LCMs to concise and exact unit fraction series statements. This subtle conclusion was difficult to reach for a number of reasons, the greatest one being the small collection of surviving fragments of Middle Kingdom texts. Seen in its most basic terms, the

EMLR was the most elementary of the 2000–1650 BCE abstract arithmetic texts, a text that introduced students to higher-level Egyptian numeration and problem solving.

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Mathematics in India

George Gheverghese Joseph

A widely held view is that Indian mathematics originated in the service of religion. Support for this view is sought in the complexity of motives behind the recording of the *Śulbasūtras*, the first written mathematical source dated around 800–500 BCE, dealing with the measurement and construction of sacrificial altars. This view ignores the skills in mensuration and practical arithmetic that existed in the Harappan (or Indus Valley) culture which dates back to 3000 BCE. Archaeological remains indicate a long established centralized system of weights and measures. A number of different plumb-bobs of uniform size and weights have been found that could be classified as decimal, i.e., if we take a plumb-bob weighing approximately 27.534 g as a standard representing 1 unit, the other weights form a series with values of 0.05, 0.1, 0.2, 0.5, 2, 5, 10, 20, 50, 100, 200, and 500 units. Also, scales and instruments for measuring length have been discovered, including one from Mohenjodaro, one of the two largest urban centers, consisting of a fragment of shell 66.2 mm long, with nine carefully sawn, equally spaced parallel lines, on average 6.7056 mm apart. The accuracy of the graduation is remarkably high, with a mean error of only 0.075 mm.

A notable feature of the Harappan culture was its extensive use of kiln-fired bricks and the advanced level of its brickmaking technology. While 15 different sizes of Harappan bricks have been identified, the standard ratio of the three dimensions – the length, breadth, and thickness – is always 4:2:1, considered even today as the optimal ratio for efficient bonding. A close correspondence exists between the standard unit of measurement (the “Indus inch” (33.5 mm) and brick sizes, in that the latter are integral multiples of the former. (An Indus inch is exactly twice a Sumerian unit of length (*sushi*). Twenty-five Indus inches make a Megalithic yard, a measure probably in use north-west Europe around 2000 BCE. These links have led to the conjecture that a decimal scale of measurement originated somewhere in western Asia and then spread as far as Britain, Egypt, Mesopotamia, and the Indus Valley).

This relationship between brickmaking technology and metrology was to reappear 1,500 years later during the Vedic period in the construction of sacrificial altars of bricks. However, a most intriguing suggestion of Subbarayappa is that the Harappan numeration system contains certain similarities with the Kharoṣṭhī and the “Aśhokan” variant of the *Brāhmi* numeration systems which emerged in India about 2,000 years later. He notes the following similarities:

There are identical symbols for the numbers 1–4 and for a 100 in all three numeration systems. All three were ciphered systems employing a decimal base.

He suggests that deciphering the inscriptions on the large number of excavated seals and other artifacts require that they be recognized as numerical records rather than as literary passages. Given the failure so far to decipher the Harappan script, this approach is certainly worth further examination.

The earliest written evidence in India of a recognizable antecedent of our numeral system is found in an inscription from Gwalior dated “Samvat 933” (AD 876) where the numbers

50 and 270 are given as  and . Notice the close similarity with our notation for 270 showing in both an understanding of the place value principle as well as the use of zero. There is earlier evidence of the use of Indian system of numeration in South East Asia in areas covered by present-day countries such as Malaysia, Cambodia and Indonesia, all of whom were under the cultural influence of India. Also, as early as AD 662, a Syrian bishop, Severus Sebokt, comments on the Indians carrying out computations by means of nine signs by methods which “surpass description” (Joseph, 1993).

The spread of these numerals westwards is a fascinating story. The Arabs were the leading actors in this drama. Indian numerals probably arrived at Baghdad in 773 AD with the diplomatic mission from Sind to the court of Caliph al-Manṣūr. In about 820, ► [al-Khwārizmī](#) wrote his famous *Kitāb ḥisāb al-adad al-hindī* (Book of Addition and Subtraction According to the Hindu Calculation, also called just Arithmetic), the first Arab text to deal with the new numerals. The text contains a detailed exposition of both the representation of numbers and operations using Indian numerals. Al-Khwārizmī was at pains to point out the usefulness of a place-value system incorporating zero, particularly for writing large numbers. Texts on Indian reckoning continued to be written, and by the end of the eleventh century this method of representation and computation was widespread from the borders of Central Asia to the southern reaches of the Islamic world in North Africa and Egypt.

In the transmission of Indian numerals to Europe, as with almost all knowledge from the Islamic world, Spain and (to a lesser extent) Sicily played the role of intermediaries, being the areas in Europe which had been under Muslim rule for many years. Documents from Spain and coins from Sicily show the spread and the slow evolution of the numerals, with a landmark for its spread being its appearance in an influential mathematical text of medieval Europe, *Liber Abaci* (Book of Computation), written by Fibonacci (1170–1250), who learnt to work with Indian numerals during his extensive travels in North Africa, Egypt, Syria, and Sicily.

The spread westwards continued slowly, displacing Roman numerals, and eventually, once the contest between the abacists (those in favor of the use of the ► [abacus](#) or some mechanical device for calculation) and the algorists (those who favored the use of the new numerals) had been won by the latter, it was only a matter of time before the final triumph of the new numerals occurred, with bankers, traders, and merchants adopting the system for their daily calculations.

The beginnings of Indian algebra may be traced to the *Śulbasūtras* and later ► [Bakhshālī Manuscript](#), for both contain simple examples involving the solution of linear, simultaneous and even indeterminate equations. An example of an indeterminate equation in two unknowns (x and y) is $3x + 4y = 50$, which has a number of positive whole-number (or integer) solutions for (xy) . For example, $x = 14$, $y = 12$ satisfies the equation as do the solution sets $(10, 5)$, $(6, 8)$ and $(2, 11)$.

But it was only from the time of Āryabhaṭa I (b. AD 476) that algebra grew into a distinct branch of mathematics. ► [Brahmagupta](#) (b. AD 598) called it *kuṭṭaka gaṇitā*, or simply *kuṭṭaka*, which later came to refer to a particular branch of algebra dealing with methods of solving indeterminate equations to which the Indians made significant contributions.

An important feature of early Indian algebra which distinguishes it from other mathematical traditions was the use of symbols such as the letters of the alphabet to denote unknown quantities. It is this very feature of algebra that one immediately associates with the subject today. The Indians were probably the first to make systematic use of this method of representing unknown quantities. A general term for the unknown was *yāvat tāvat*, shortened to the algebraic symbol *yā*. In Brahmagupta's work Sanskrit letters appear, which are the abbreviations of names of different colors, which he used to represent several unknown quantities. The letter *kā* stood for *kālaka*, meaning "black," and the letter *nī* for *nīlaka* meaning "blue." With an efficient numeral system and the beginnings of symbolic algebra, the Indians solved determinate and indeterminate equations of first and second degrees and involving in certain cases more than one

unknown. It is likely that a number of these methods reached the Islamic world before being transmitted further westwards by a similar process and often involving the same actors as the ones that we discussed earlier in the spread of Indian numerals.

The beginnings of a systematic study of trigonometry are found in the works of the Alexandrians, Hipparchus (ca. 150 BCE), Menelaus (ca. AD 100) and Ptolemy (ca. AD 150). However, from about the time of ► [Āryabhaṭa I](#), the character of the subject changed to resemble its modern form. Later, it was transmitted to the Arabs who introduced further refinements. The knowledge then spread to Europe, where the first detailed account of trigonometry is contained in a book entitled *De triangulis omni modis* (On All Classes of Triangles), by Regiomontanus (1464).

In early Indian mathematics, trigonometry formed an integral part of astronomy. References to trigonometric concepts and relations are found in astronomical texts such as *Sūryasiddhānta* (ca. AD 400), Varāhamihira's *Pancha Siddhānta* (ca. AD 500), Brahmagupta's *Brāhma Sphuṭa Siddhānta* (AD 628) and the great work of ► [Bhāskara II](#) called *Siddhānta Śiromaṇi* (AD 1150). Infinite expansion of trigonometric functions, building on Bhāskara's work, formed the basis of the development of mathematical analysis – a precursor to modern calculus to be discussed later.

Basic to modern trigonometry is the sine function. It was introduced into the Islamic world from India, probably through the astronomical text, *Sūryasiddhānta*, brought to Baghdad during the eighth century. There were two types of trigonometry available then: one based on the geometry of chords and best exemplified in Ptolemy's *Almagest*, and the other based on the geometry of semichords which was an Indian invention. The Arabs chose the Indian version which prevailed in the development of the subject. It is quite likely that two other trigonometric functions – the cosine and versine functions – were also obtained from the Indians.

One of the most important problems of ancient astronomy was the accurate prediction of eclipses. In India, as in many other countries,

the occasion of an eclipse had great religious significance, and rites and sacrifices were performed. It was a matter of considerable prestige for an astronomer to demonstrate his skills dramatically by predicting precisely when the eclipse would occur.

In order to find the precise time at which a lunar eclipse occurs, it is necessary first to determine the true instantaneous motion of the moon at a particular point in time. The concept of instantaneous motion and the method of measuring that quantity is found in the works of Āryabhaṭa I, ► [Brahmagupta](#) and Muñjāla (ca. AD 930). However, it was in Bhāskara II's attempt to work out the position angle of the ecliptic, a quantity required for predicting the time of an eclipse, that we have early notions of differential calculus. He mentions the concept of an "infinitesimal" unit of time, an awareness that when a variable attains the maximum value its differential vanishes, and also traces of the "mean value theorem" of differential calculus, the last of which was explicitly stated by Parameśvara (1360–1455) in his commentary on Bhāskara's ► [Līlāvati](#). Others from Kerala (South India) continued this work with Nīlakaṇṭha (1443–1543) deriving an expression for the differential of an inverse sine function and ► [Acyuta Piṣārati](#) (ca. 1550–1621) giving the rule for finding the differential of the ratio of two cosine functions.

However, the main contribution of the Kerala school of mathematician-astronomers was in the study of infinite-series expansions of trigonometric and circular functions and finite approximations for some of these functions. The motivation for this work was the necessity for accuracy in astronomical calculations. The Kerala discoveries include the Gregory and Leibniz series for the inverse tangent, the Leibniz power series for π , the Newton power series for the sine and cosine, as well as certain remarkable rational approximations of trigonometric functions, including the well-known Taylor series approximations for the sine and cosine functions. And these results had been obtained about 300 years earlier than the mathematicians after whom they are now named. Referring to the most notable mathematician of this group, Mādhava

(ca. 1340–1425); Rajagopal and Rangachari (1978) wrote: "(It was Mādhava who) took the decisive step onwards from the finite procedures of ancient mathematics to treat their limit-passage to infinity, which is the kernel of modern classical analysis." The growing volume of research into medieval Indian mathematics, particularly from Kerala, has refuted a common perception that mathematics in India after ► [Bhāskara II](#) made "only spotty progress until modern times" (Eves, 1983).

See Also

- [Acyuta Piṣārati](#)
- [al-Khwārizmī](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Arithmetic in India: Pāṭiḡaṇita](#)
- [Āryabhaṭa](#)
- [Bakhshālī Manuscript](#)
- [Bhāskara I](#)
- [Brahmagupta](#)
- [Eclipse Observations](#)
- [Geometry in India](#)
- [Mādhava of Saṅgamagrāma](#)
- [Nīlakaṇṭha Somayāji](#)
- [Parameśvara](#)
- [Śulbasūtras](#)
- [Surveying](#)
- [Technology and Culture](#)
- [Weights and Measures in the Indus Valley](#)

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Mathematics in Islam

Jan P. Hogendijk

Roughly speaking, one can distinguish two types of mathematics in Antiquity and the Middle Ages: one is “practical” (or subscientific) mathematics, concerned with practical calculation, administration, trade, land measurement, tax collecting, etc. The other is “theoretical” mathematics, studied either for its own sake, or connected with astronomy, philosophy, or religion.

The following survey of the history of mathematics in Islamic civilization will concentrate on “theoretical” mathematics. “Practical” mathematics in Islamic civilization is of great historical interest, but until recently the subject has received less attention than it deserves, perhaps because this kind of mathematics is less exciting from an intellectual point of view. Therefore it is not yet possible to give an adequate survey of its history.

The history of theoretical mathematics in Islamic civilization is intimately connected with astronomy. In Iran there was a pre-Islamic astronomical tradition which simply continued after the country was conquered by the Muslims. When the Abbasids came to power in 750, an interest in astronomy, and hence mathematics, developed in the new capital Baghdad. Iranian astronomy was influenced by Indian astronomy, and around 775 Indian astronomers and mathematicians were received at the court of the Caliph, and Sanskrit astronomical works were translated into Arabic. After 800, the Greek mathematician and astronomical works became increasingly popular, and many of these works were translated into Arabic, including the *Elements* of Euclid and the *Almagest* of Ptolemy, an astronomical compendium full of very complicated mathematics. In the rest of this article, the term “Arabic” will be used in a linguistic sense, referring to Arabic as a scientific language. Thus “Arabic mathematics” is mathematics written in the Arabic language; an “Arabic mathematician” is a mathematician writing in Arabic. The reader should bear in mind that a large number of these “Arabic mathematicians” were actually Persians.

The most important traces of the Indian heritage in the Arabic tradition were the system of numbers and the sine function (which replaced the Greek chord in trigonometry). It is possible that early Arabic algebra was influenced by India to a much greater extent than is recognized today by most modern historians, many of whom assume a Babylonian influence, transmitted in some unknown way. However, the Greek influence was predominant in Arabic mathematics. It was a living continuation of Greek mathematics.

New areas of mathematics were developed (algebra, trigonometry), new problems were solved (such as the *qibla* problem, determining the direction of Mecca), and a lot of creative work was done. However, there was no “revolution” in Arabic mathematics comparable with, for example, the development of analytic geometry and calculus in seventeenth-century Europe.

Arithmetic

Various systems of numeration were used by the Arabic mathematicians and astronomers. Many mathematicians and astronomers used the *abjad* (alphabetical) numeration. In this system, the letters of the alphabet have numerical values 1, 2, ..., 9, 10, 20, ..., 90, 100, 200, ..., 900, 1,000. Almost all astronomical calculations were performed in a ► [sexagesimal system](#) in which the sexagesimals were denoted in the *abjad* system. The Hindu-Arabic system, consisting of nine symbols and a zero, was introduced into the Arabic world by ► [al-Khwārizmī](#) around AD 830, but it was not received with much enthusiasm. It was only used for large numbers, for example the tangents of angles near 90° . In algebraical works, al-Khwārizmī and others did not use numbers but words, for example “three squares and four is equal to seven things” (meaning: $3x^2 + 4 = 7x$ in modern notation). Fractions were denoted in various complicated ways, often without any symbolism. In the tenth century, ► [al-Uqlīdisī](#) used decimal fractions and a symbol equivalent to our decimal point.

Algebra

The name of this part of mathematics is derived from al-Khwārizmī's *Kitāb fī'l-jabr wa'l-muqābala* (Book on Restoration and Confrontation). In this treatise al-Khwārizmī gives a systematic treatment of linear and quadratic equations. The contents were not new, because the Babylonians in Iraq were able to solve quadratic equations 2,000 years before al-Khwārizmī. However, the treatise is very well

written and al-Khwārizmī gives many worked examples. He treats the reduction of any linear or quadratic equation to one of six standard forms $ax = b$, $ax^2 = c$, $ax^2 = bx$, $ax^2 + bx = c$, $ax^2 + c = bx$, $ax^2 = bx + c$, and he then gives the solution of each of these forms: first the procedure for finding x , and in the case of the last three forms, also a geometrical motivation using rectangles and squares. The operation *al-jabr*, which gave its name to the whole field of solving equations, means the “restoration” of a negative term (example: $3x^2 - 7x = 4$ is “restored” to $3x^2 = 4 + 7x$). After al-Khwārizmī, ► [Abū Kāmil](#) solved complicated quadratic equations with irrational coefficients. In the tenth century, ► [al-Karajī](#) treated various properties of quadratic irrationals, which Euclid had proved geometrically. Al-Karajī also discussed cubic irrationalities, and he explained the extraction of the root of a polynomial (which is assumed to be a perfect square). In the tenth and eleventh centuries, cubic equations were solved geometrically by the intersection of conic sections, for example by 'Umar al-Khayyām, and the theory was perfected by ► [Sharaf al-Dīn al-ṭūsī](#). A few mathematicians worked on equations of degree higher than three, but most of this work seems to be lost.

Theory of Numbers

Some Arabic mathematicians were interested in indeterminate equations, i.e., equations with an infinite number of solutions. The solutions had to be rational numbers (in the way of Diophantus of Alexandria, whose *Arithmetica* was translated into Arabic) or integers. Examples of the last kind are: find integers x , y , and z such that $x^2 + y^2 = z^2$ (such numbers x , y , and z are the sides of a right-angled triangle); or the famous problem of “congruent numbers”: find numbers which are the surface area of a right-angled triangle whose sides are all integers. In the tenth century it was believed that no numbers x , y , and z such that $x^3 + y^3 = z^3$ existed, but it seems that this fact could not be proven by means of the mathematical methods then available.

Some progress was made in the theory of perfect and amicable numbers. A number is perfect if it is equal to the sum of its own divisors. Euclid had proved a formula for even perfect numbers, and four such numbers were known in antiquity: 6, 28, 496, and 8,128. In or before the thirteenth century, three more were found by Arabic mathematicians: 33,500,336; 8,589,869,056, and 137,438,691,328. Two numbers are called amicable if they are the sum of the divisors of each other. The example 220, 284 was known from antiquity. ► [Thābit ibn Qurra](#) discovered and proved that if p , q , and r are three prime numbers of the form $P = 3 \cdot 2^{n-1} - 1$, $q = 3 \cdot 2^n - 1$, $r = 9 \cdot 2^{2n-1} - 1$, then the numbers $2^n \dots pq$ and $2^n \dots r$ are amicable. Examples are the pairs 200, 284 ($n = 2$) and 17,296, 18,416 ($n = 4$). Perhaps the subject of amicable numbers was popular because of its magical applications, and such applications may also explain the interest in magic squares, which continued throughout the Arabic tradition.

The reader should bear in mind that the ancient and medieval concept of “number” is not necessarily the same as the modern one. In ancient Greek mathematics, a “number” was always a positive integer number, or a fraction (i.e., a ratio between two positive integer numbers). The Greeks knew that there were proportions in geometry which could not be expressed by this limited concept of number (such as the ratio between the side and diagonal of a square, that is $1 : \sqrt{2}$). Nevertheless, they did not extend their concept of number to include the modern idea of an irrational or real number. The reason is that this involves difficulties with the infinite, which they would have avoided (and which are carefully hidden in naïve presentations of the concept of real number in school mathematics). Instead of working with real numbers, the Greeks developed a theory of proportions of geometrical magnitudes (for example, line segments). This theory is found in Book V of Euclid’s *Elements*, which was widely studied by the Arabic mathematicians. In astronomy, one has to calculate the (approximate) length of segments, which cannot be represented as a number according to the orthodox view. Thus it is understandable that

the Arabic mathematicians, most of whom were also astronomers, came closer to the naive concept of real number, as it is nowadays taught in schools. Many mathematicians, such as ► [Sharaf al-Dīn al-ṭūsī](#), continued to believe that any rigorous treatment of numbers and algebra had to be based on the Euclidean theory of proportions.

Geometry

The basic geometrical work in Arabic mathematics was the *Elements* of Euclid (ca. 300 BCE). This work was very thoroughly studied, and more than 50 commentaries in Arabic were written, most of which have not been studied in modern times. Euclid’s parallel postulate was one of the main points of attention. Most Arabic mathematicians found this unsatisfactory, and attempts were made, by Ibn al-Haytham, Naṣīr al-Dīn al-ṭūsī, and others, to replace it by a more appropriate axiom. Many other Greek geometrical works were translated into Arabic, so the Arabic literature is an important source of new information on Greek geometrical works which are now lost.

The Arabic mathematicians were very interested in geometrical constructions. Such constructions should preferably be made by ruler and compass, that is to say, by successive intersections of straight lines through two known points and circles with known centers and radii (the intersection of such known figures produces new known points). The most interesting problems from Greek geometry (trisection of the angle, construction of two mean proportionals, etc.) cannot be constructed in this way. The Arabic mathematicians also used conic sections as means of construction.

Some of the mathematicians were clearly aware that they progressed beyond the ancient Greeks, and there was a feeling that the authorship of a geometrical construction added to one’s prestige as a mathematician. Some mathematicians even plagiarized others’ works, as in the case of the regular heptagon. This figure cannot be constructed by means of ruler and compass, but the Arabic geometers knew an ancient construction (attributed to Archimedes) by means of a

straight line which had to be moved in an unclear way until two triangles are equal. Around 968 Abū'l-Jūd proposed a ruler- and compass construction of the heptagon. The elementary error in this construction was soon discovered by ► [al-Sijzī](#). The missing link was filled by al- 'Alā' ► [ibn Sahl](#) by means of conic sections, and this was then plagiarized by al-Sijzī (who repented later) and also by Abū'l-Jūd. Other constructions of the heptagon were found by al-Qūhī (ca. 970) and Ibn al-Haytham (ca. 1000), who were both very proud of their achievement. Most mathematicians felt that the heptagon had not really been constructed by the ancients, and thus the “moderns” had gone beyond the level reached by the Greeks. A similar problem was the inscription of an equilateral pentagon in a given square. This was solved by al-Qūhī, who stressed that this problem had not been solved by the ancient geometers.

An important branch of geometry was spherical trigonometry. In the eighth and ninth centuries, spherical trigonometry developed rather chaotically, in the context of astronomy and on the basis of a mixture of Indian and Greek methods. In the tenth century the field became an independent subject of study, and special treatises were devoted to it. The Arabic mathematicians studied the spherical triangle, that is a triangle on a sphere, such that the “sides” of the triangle are arcs of great circles (i.e., circles whose center is the center of the sphere). In the tenth century, “angles” were also defined in a spherical triangle, so that a spherical triangle has six elements, three angles and three sides, like a plane triangle. The main problem of spherical trigonometry could now be phrased thus: if three elements are given, how do we compute the rest? Treatises on this problem were written by Naṣīr al-Dīn al-tūsī and the eleventh century Spanish mathematician ► [Ibn Mu'ādh](#).

The determination of the *qibla* (direction of Mecca) from a locality with given geographical coordinates can also be regarded as a problem of spherical trigonometry. In the eighth and ninth centuries only approximate solutions of the problem were known, but exact solutions were found in the ninth century, and tables were computed in the twelfth century and later.

The Arabic mathematicians devoted much time and energy to the computation of trigonometrical tables (sines and tangents) with ever increasing accuracy. The main difficulty is the determination of the sine of 1° ; since this quantity cannot be expressed in square roots of rational numbers, the standard approximation methods fail. Around 1420, al-Kāshī found a method to approximate the sine of 1° with any degree of accuracy, using algebra. Al-Kāshī was able to express this as a root of a cubic equation with known coefficients, and he developed a very fast algorithm to approximate the root. He also computed the number π to 16 decimals.

Mathematics and Astronomy

It is historically impossible to separate Arabic mathematics from Arabic astronomy. Astronomy was the main field of application of mathematics, and calculations that were done by the astronomers vastly surpassed those of “practical mathematics” (commerce, administration, etc.). Many people studied mathematics in order to become astronomers (or astrologers). One finds a lot of very interesting mathematics in astronomical handbooks (*zījjes*). The astronomical problems were sometimes too difficult to be solved by the methods of medieval mathematics, or, in cases where the problems could be solved, the computations were sometimes too complicated to be performed in a reasonable amount of time. Therefore, such computations were often simplified by clever approximation devices, which presuppose considerable numerical insight.

Mathematics was also important for astronomy on a more philosophical level. The philosophical foundation of Ptolemy's astronomical models was unacceptable for some Arabic mathematicians (such as Naṣīr al-Dīn al-tūsī) because some of the circular motions in his theories of the moon and the planets were nonuniform.

The later Arabic mathematicians sought to remove these flaws by adding one or more circles to these models, producing the same effects as Ptolemy in a philosophically acceptable way. The most famous device is the so-called *tūsī couple*,

consisting of a circle of radius r , which rolls along the interior of a second circle with the double radius $2r$. As a result of this motion, any point on the first circle oscillates on a fixed straight line.

Transmission

Arabic mathematics influenced the development of mathematics in medieval Europe in various ways. In the twelfth century, some Arabic mathematical works (such as the *Arithmetic* and the *Algebra* of ► [al-Khwārizmī](#)) and Arabic versions of Greek mathematical and astronomical works (such as Euclid's *Elements* and Ptolemy's *Almagest*) were translated into Latin, mainly in Spain. These translations were the beginning of the development of mathematics in Christian Europe. The thirteenth century European mathematician Leonardo Fibonacci learned mathematics in the city of Bougie in Algeria and during his travels to other Islamic countries, and he then wrote various influential mathematical works. The transmission of mathematics from Arabic to Latin was far from complete, and until 1450 the level of mathematics in Europe was below that in the Islamic world.

See Also

- [al-Karajī](#)
- [Al-Kāshī](#)
- [al-Khwārizmī](#)
- [Al-Qūhī \(or Al-Kūhī\)](#)
- [al-Sijzī](#)
- [al-Uqlīdisī](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn Mu'ādh](#)
- [Ibn Sahl](#)
- [Naṣīr al-Dīn al-ṭūsī](#)
- [Sharaf al-Dīn al-ṭūsī](#)
- [Thābit ibn Qurra](#)
- [Umar al-Khayyām](#)
- [Qibla and Islamic Prayer Times](#)
- [Religion and Science in Islam II: What Scientists Said About Religion and What Islam Said About Science](#)

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Mathematics in Japan

Jean-Claude Martzloff

At various stages of Japanese history, mathematics developed as a direct consequence of contacts with foreign cultures, both Chinese and Western. Five successive waves of cultural influx may be delineated (1) Chinese wave I, from the seventh to the end of the ninth century; (2) Chinese wave II, from the end of the sixteenth to the mid-nineteenth century; (3) Western wave I, 1543–1639; (4) Western wave II, 1720–1854, and (5) Western wave III, from 1854 onwards. (This mode of periodization is borrowed from Sugimoto and Swain (1978)).

As far as may be surmised, the two Chinese waves developed independently and were separated by an interim period of semi-seclusion from continental influences during which Japanese mathematical activity subsided.

During Chinese wave I, Japanese mathematics did not depart significantly from that developed in China during the same period. This was also the case in Sui (589–618) China. (The short-lived Sui dynasty inaugurates a period of relative stability characterized by the unification of China after several centuries of disunion) and Tang (618–907) (The Tang dynasty is one of the most brilliant in Chinese history where the Chinese were able to extend their influence all over Asia, from Iran, Central Asia, India, and of course Japan.) Japanese imperial authorities are said to have founded an elite school for training future accountants, fiscal officers, surveyors, calendar makers, and other such practitioners. The teaching of mathematics was based on the Chinese *Suanjing shishu* (The Ten Computational Canons) and not on Japanese autochthonous manuals. During that period and the following centuries, mathematics never developed beyond the rudiments. Fragmentary records such as those of a priest from the Kenninji temple show that ca. 1311, the Chinese *Jiuzhang suanshu* (Computational Prescriptions in Nine Chapters) from the Han dynasty was studied in Kyoto. Certain texts known as *oraimono* (didactic exchanges of letters) contain, nonetheless, a number of mathematical recreations such as the problem of *mamakodate* (lit., the standing stepchildren). In this problem, a mother has 15 true children and 15 stepchildren; she must eliminate the latter by placing them in a circle in such a way that starting from some child and counting clockwise she eliminates every tenth child until at last only the true children are still standing. This problem is reminiscent of the Josephus puzzle, where children are replaced by Turks – to be eliminated – and Christians.

During Chinese wave II, a number of Chinese mathematical texts were imported into Japan on the occasion of the Japanese military expeditions in Korea of the 1590s.

One of them, the *Suanfa tongzong* (Comprehensive Treatise on Arithmetic), was a compendium of commercial arithmetic. First published in China in 1592, this manual was mostly intended for abacus calculations and was very often reprinted in China and Japan until the

twentieth century. However, although strongly influenced by its Chinese model, Japanese arithmetic began to develop on its own. In particular, arithmeticians devised a new type of abacus (*soroban*). It was composed of five balls for the representation of the decimal digits of each order of units, instead of seven in the Chinese case. There were four balls valued at one unit each and one ball valued at five units, instead of five balls valued at one unit and two balls valued at five units. For the first time, the Japanese also wrote arithmetical books in their own language. One of them, the *Jingōki* (Treatise on Numbers Ti and Huge) of Yoshida Mitsuyoshi (1578–1672), first published in 1627, became so popular that hundreds of plagiarized versions were published. In its 1641 version, the author included 12 problems left unsolved and bequeathed to posterity (*idai keishō*). Subsequently, this kind of challenge was often issued and played an important role in the development of Japanese mathematics. At first, the custom was limited to more or less trivial arithmetical problems, but gradually amateur mathematicians imagined complex problems relating, for example, to the volume of intricate solids (such as those defined by the intersection of two other solids), or to chains of circles or spheres tangent to other circles, spheres, ellipses, or ellipsoids, respectively. When solutions were found, the solvers published them and in their turn propounded new enigmas.

A development in mathematics more sophisticated than arithmetic, however, was triggered by the introduction into Japan of the *Suanxue qimeng* (Introduction to Computational Science), a Chinese algebraic textbook by Zhu Shijie published in 1299 in Yuan China. Subsequently forgotten in China for five centuries, but universally considered by present historians of Chinese mathematics as representative of the golden age of Chinese mathematics, this manual was first reprinted in Korea during the fifteenth century and in Japan in 1658. At first, the part of this text devoted to *tianyuan* (celestial origin) algebra was not well understood.

This Chinese medieval technique was presented using a series of artificial problems, with some intermediary computations and a few

cryptic and terse sentences apparently having more to do with magic than mathematics. Moreover, known and unknown quantities were not distinguished from each other by special symbols but only by the relative position of numbers on the counting board, so that mere numbers in all cases equally represented both kinds of quantities. Yet, 20 years later, certain scholars began to crack the code and realized that Zhu Shijie's algebra was in fact a powerful weapon capable of mechanically solving all sorts of intricate problems and particularly those of the *idai* new tradition. What is more, these efforts at last enabled Seki Takakazu, also called ► [Seki Kowa](#) (ca. 1742–1708), the son of a samurai who became a chief Palace accountant, to develop algebra well beyond the state he had found it in Zhu Shijie's manual. (Because the ideograms composing his names are liable to be read in two ways, only the first reading is correct, however.)

Seki was so successful as a mathematician that he was retrospectively considered the father of a national tradition called *wasan*. Wasan is literally Japanese (*wa*) and mathematics (*san*). That is in contrast with *yōsan*, Western (*yō*) mathematics; these two terms were coined ca. 1870. Although strongly influenced by Zhu Shijie, and more generally by Chinese models, Seki's work marks a certain rupture with mathematics conceived as collections of isolated problems. Concerning the elimination of unknowns between polynomial equations, he imagined a general method which resulted in an invention of determinants independently of Leibnitz. He also systematized the Chinese Hornerian methods for the numerical evaluation of the roots of polynomials, computed the decimals of π , and used what we now call the Bernoulli numbers. Last, but not least, he created a kind of notational algebra whose symbols consisted of dissections of Chinese characters which enabled mathematicians to perform literal (and not merely numerical) computations in writing rather than by using counting-rods as the Chinese did. In fact, Seki's algebra was not so different from that of Vieta. Seki Takakazu's collected works were published in 1974 (Hirayama, Shimodaira, & Hirose, 1974).

Later mathematicians improved all this. In addition, questions relating to the precise evaluation of the circumference, arcs, and chord lengths became so important that they were conceived as a single domain called *enri* (circular principles). Later, this domain was generalized to the computation of all sorts of infinite series and to various curves in a way which more or less evokes Western calculus.

However, Chinese mathematics was not the sole source out of which Japanese mathematicians developed their own mathematics. During Western wave I, a very limited amount of mathematical knowledge of Western origin (consisting perhaps only of some mathematical recreations) was introduced into Japan as a consequence of the diffusion of Catholicism by Jesuit missionaries. But edicts against Christianity were issued as early as 1612, and in 1630 a ban on the importation of Western books was decreed. During Western wave II, the ban was progressively removed and Western mathematical knowledge gradually permeated into Japan. In the period from 1720 to 1730, elementary geometry, plane and spherical trigonometry, and even logarithms became accessible through the medium of Chinese adaptations of European works such as the *Chongzhen lishu* (Chongzhen Reign-Period Compendium of Mathematical Astronomy), an encyclopaedic work which marked the start of the reform of Chinese astronomy in 1644 on the basis of European knowledge. Later, the Japanese also came into contact with Western works written not in Chinese but in Dutch, the language of the Dutch merchants, the sole Westerners who had relations with Japan. This initiated the development of a new branch of knowledge called *Rangaku* (Dutch learning). A consequence for mathematics of this new learning was the importation of the Dutch version of John Keill's (1671–1721) commentary on Newton's *Principia*.

Consequently, elements of European mathematics were integrated into *wasan* and new results were discovered. For example, ► [Takebe Katahiro](#) (1664–1734) developed an infinite series of the square of the arcsine. Takebe was a disciple of Seki and a Shogunal advisor also

responsible for new developments in geography and astronomy. Ajima Naonobu, another distinguished wasan scholar, independently solved celebrated geometrical problems such as those of Steiner's chains of circles (circles mutually tangent inserted between two non-concentric circles situated one inside the other) or the so-called *Malfatti's problem* about three circles mutually tangent and inscribed in a triangle. Less anecdotally, Ajima and later Wada Yasushi (1787–1840) also elaborated methods for calculating areas and volumes as limits of infinitesimal rectangles or parallelepipeds in a way which is reminiscent of the construction of definite integrals. The achievements of Japanese autochthonous mathematics were thus quite high. A fundamental difference between Western and Japanese mathematics stems from the fact that the latter was essentially algebraic and developed independently of axiomatic-deductive reasoning.

While the search for general and systematic methods concerned more and more mathematicians, an opposite trend towards solving highly artificial problems conceived as isolated puzzles became still more prominent. In fact, mathematics was mainly practiced by 'hobbyists', members of rival schools or even mathematical sects. Works of wasanists were thus not much diffused. Original manuscripts were often copied by the disciples of some master (like Seki) and kept secret. Consequently, no consensus towards uniforming mathematical notations and concepts ever emerged, even though towards the end of the eighteenth century some mathematical works were eventually printed. More importantly, wasan studies were often condemned by Confucian elites who judged them 'mental acrobatics' and thus futile and socially useless. No official schools devoted to the study of wasan were ever created. During the whole Edo period (1698–1868), wasan was often practiced by *rōnin* (lordless samurai) who travelled all over Japan and earned their living by teaching wasan in private academies or becoming private tutors at the service of rich merchants. Unexpectedly, owing to a surprising alliance between mathematics and religion, wasan became more and more visible even in the Japanese countryside. From

the end of the seventeenth century, wasan adepts advertised the achievements of the groups they belonged to by means of votive tablets (*sangaku*). Hung in public view in Buddhist temples and Shinto shrines, these wooden tablets generally displayed problems and beautifully engraved geometric figures (often consisting of mutually tangent figures, especially circles and triangles) with numerical solutions but no intermediary calculations. Hundreds of tablets have survived, and it is still possible to admire them everywhere in Japan. Moreover, printed anthologies of such tablets have been published. Such a practice is unattested anywhere else in the world outside Japan.

Until 1853, despite the importation of a certain amount of knowledge from China and Europe, Japan essentially remained isolated. But the partisans of isolation did not succeed in imposing their policy after Commodore Matthew C. Perry of the United States had forced open Japan's ports. As early as 1855, an Office for Occidental Learning (*Yōgakusho*) was created; 1 year later, this office was renamed Office for Investigating Barbarian Documents (*Bansho shirabesho*). There, government-appointed students learned to apply mathematics to navigation, shipbuilding, armaments, and other military matters. But radical changes had to wait the Meiji restoration of 1868. With the advent of this utterly new era, Western learning was no longer confined to military affairs and other utilitarian goals. Wasan was completely abandoned to Western mathematics. In 1877, the University of Tokyo was founded. At first, four out of five professors were foreigners (one American and three French). The Japanese professor was Kikuchi Dairoku (1885–1917) who later became Minister of Education. Kikuchi was an outstanding student who had been trained at the *Bansho shirabesho* and sent to Cambridge University; he gave his mathematical lectures in English. A few years later, however, the best students of mathematics were appointed professors in their turn. In 1877, the Tokyo Mathematical Society was founded. Japanese mathematicians rapidly attained the same level as that of Western researchers. Many mathematicians, such as Takagi Teigi

(1875–1960) who contributed to class-field theory and gained worldwide fame, were trained during this period.

Extra: Seki Takakazu's Works

Seki Takakazu's collected works were published in 1974 (Hirayama et al. 1974). This thick volume has 871 pages comprising (1) various preliminary data concerning Seki Takakazu: a chronology, his biography, his disciples, a critical note on his portrait, the location of his tomb, his mathematical achievements; (2) the main text of his original works, printed or manuscripts (most often) (576 p); (3) a presentation of the main text in Japanese (216 p); and (4) a presentation of the main text in English (83 p). Given the seminal importance of Seki Takakazu for Japanese mathematics, it is worthwhile to describe his collected works briefly here.

The collection contains the following 29 original works:

1. *Kiku yōmei sampo* (1683) [Essential Methods of Calculation with the Compass and T-Square]. This is his earliest work. It gives simple calculations concerning the circle, arc of circles and the sphere; it has only ten pages and contains the first known Japanese proof of the Pythagorean theorem, in the form of a Chinese-like dissection.
2. *Ketsugishō tōjutsu* [Solutions *Tō* (in the form of *jutsu*, i.e. 'prescriptions') – the Japanese *jutsu* is the same as the Chinese *shu* – [of the 100 unsolved problems] from the *Ketsugishō*]. Here, the *Ketsugishō* is the title of a previous work, published in 1659; the expression *ketsugi* means 'omitted', i.e. the original solutions were not given. *Shō* = manuscript. For example, the fourth problem asked for the dimensions of a right-angled triangle given the sum of its three sides and the difference between the hypotenuse and the shorter side. Other problems are more complex and involve square and inscribed circles in a triangle and solid figures such as wedges, pyramids, or trunks of a cone. The last problem is about the construction of a 19×19 magic square. Most are solved using the algebraic technique known as *tengenjutsu*, a variant of the Chinese *tianyuanshu*.
3. *Futsudankai tōjutsu*. *Futsudankai* is the title of a previous manuscript (1673) containing unsolved problems. The expression *Futsudankai* means 'do not be afraid to change (the answers)'. This is again a collection of specific problems but they are much more complex than the two preceding ones. Sometimes, dissections of plane or solid figures into several pieces of unknown dimensions are given. Again, Seki provides algebraic solutions depending on the establishment of a polynomial, often of high degree, with coefficients composed of ten or more digits.
4. *Hatsubi sampō*. Once again, this work is based on a previous collection of problems. Here, *Hatsubi* means something like 'disclosing subtle [elements]' and *sampō* is exactly the same as the Chinese *suānfā*, 'computational methods' or 'mathematics'. Here the problems have several unknowns and the solutions involve their elimination.
5. *Kaihendai no hō* [Method of Solving 'Transparent' Problems]. This covers the area and volumes of simple plane figures and solids.
6. *Kaundai no hō* [Method of Solving 'Opaque' Problems]. This work is more theoretical than the previous ones. It does not consist of a list of problems but explains how to set and manipulate algebraic equations. A technique of solving polynomial equations analogous to Horner's method is also given.
7. *Kaifuku dai no hō* [Method of Solving Dis-simulated Problems]. Here the expansion of determinants in relation to the process of elimination of polynomial equations is given.
8. *Kaihō honhen no hō* [Method of Solving Various Cases of Root Extractions]. This covers the tentative classification of polynomial equations and the study of elimination procedures.
9. *Daijutsu bengi no hō* [Method for Differentiating Problem Statements and Solutions].

This contains a method of successive approximations.

10. *Byōdai meichi no hō* [Method for Clarifying Flawed Problems]. Here one problem has an imaginary root and its statement is modified in order to let it having a computable root.
11. *Hōjin no hō, ensan no hō* [Methods for Magic Squares and Circles].
12. *Sandatsu no hō, Kempu no hō*. These two titles refer to the Japanese equivalent of Josephus's problem (called here *sandatsu*, i.e. enumerating a series of elements, *san*, while skipping some of them in the count, *datsu*) and another mathematical game consisting of remembering letters written on cards.
13. *Kyūseki* [Finding Volumes and Areas]. These include the area of an ellipse, analogous to the theorem of Pappus-Guldin. It also contains a problem concerning the intersection of a torus and a cylinder.
14. *Kyūketsu henkei sō*. A draft (*sō*) concerning the intersection of solids.
15. *Kaihō sanshiki* [Computational Configurations for Root Extractions]. This describes a technique for obtaining several roots of an equation with an approximation technique equivalent to Newton's method of approximation.
16. -19. *Katsuyō sampō*, 4 vols. [A Compendium of Mathematical Methods]. This contains a finite summation formula for the sum of powers with the discovery of the coefficients usually known as *Bernoulli's numbers*. A method for solving simultaneous congruences of the first degree (Chinese remainder theorem) is also included, as well as a systematic derivation of polynomial equations for calculating the length of the side of regular polygons, from the equilateral triangle to the 20-sided polygon. The compendium also offers inter alia a derivation of the result $\pi = 3.14159265358$.
17. *Happō ryakuketsu* [Abbreviated Mnemotechnical Tricks Concerning Eight Methods]. The content of this book is simpler than the preceding ones; it deals with the equivalence and conversion of units of length, weight, and volume.

The following seven treatises concern astronomical calculations:

1. *Juji hatsumei* [An Elucidation of the *Shoushi li*]. Here, the *Shoushi li* is a set of calendrical and astronomical official techniques, adopted in China from 1281 to 1368, and from 1368 to 1644 with some minor modifications. Seki explains the Chinese approximation method for the mutual expression of the arc and sagitta, by means of special approximation techniques.
2. *Juji rekikei rissei no hō* [Methods for Astronomical Tables in the *Shoushi li* Canon]. Introduction to the question of the tables for the motion of the sun and the five classical planets.
3. *Juji rekikei rissei* [The Astronomical Tables of the *Shoushi li* Canon]. Here the tables are fully reproduced.
4. *Seiki teisho* [Chinese Texts Corrected by Seki]. The text in question is the *Tianwen dacheng jiyao* (An Abridgment of the Great Sum of Astrology), a Chinese astrological treatise published in 1659.
5. *Siyō sampō* [Methods of Calculation of the Four *Yō*]. The 'four *yō*' are four invisible and imaginary celestial bodies used in Chinese astrology.
6. *Shukuyō sampō* [Calculation of the Astrological Chinese Mansions].
7. *Temmon sūgaku zatcho* [Various Mathematical and Astronomical Works]. Various notes, mainly on eclipses, with numerous geometrical drawings.

Lastly, the collection also contains the following:

1. *Sampō kyojō* (Mathematical Diploma). This is an attestation awarded by Seki to one of his disciples, in 1704. The document gives a list of all the subjects mastered by him.
2. *Hatsubi sampō endan genkai* [Explanation of the *Endan* Methods of Solution Concerning Subtle Computational Methods]. Here, the *endan* is a special algebraic notation borrowing its name from Chinese mathematics, but it

is more complex than the original since the unknowns are denoted by special expressions (Chinese characters) and not only by the relative positions of numbers.

The reader will find many more details in the aforementioned book, with some examples of problems and mathematical techniques fully worked out.

See Also

- ▶ [Ajima Naonobu](#)
- ▶ [Magic and Science](#)
- ▶ [Magic Squares in Japanese Mathematics](#)
- ▶ [Seki Kowa](#)
- ▶ [Takebe Katahiro](#)

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Mathematics in Korea

Kim Yong-Woon

During the Shilla dynasty (59 BCE–AD 935), in AD 682, Korea established its official mathematical system under the influence of the mathematics of China (Tang dynasty) whose primary structure was algebra (theory of equations) and whose philosophical background was *yin-yang* theory. It was an educational program designed to train professional mathematicians, and it prescribed the number of mathematicians to be trained and the length of study and curricula, and it remained the official mathematical system to the end of the Chosun dynasty in 1910.

The system soon died out in China. It was revived in the Song dynasty, but failed to become an official system again. Meanwhile, Japan set up its mathematics system under the influence of the Paekche and Shilla dynasties in Korea. The Taihorei of 710 clearly defined its contents, but this too soon became extinct. In China and Japan official mathematics ceased to exist, but civilian mathematics prospered. Korea, on the contrary, was fundamentally different from these two countries (see Table 1).

The arrangement of the Shilla curriculum here is hypothetical; originally only the names of the four subjects were given. The length of study for Korea, 9 years, is for classical studies; whether this applied to mathematics and other technical fields is yet to be explored.

In China during the Tang, there were different qualifications for the *guozixue* (National

Mathematics in Korea, Table 1 Mathematics education systems in Korea, China, and Japan around the seventh century AD

Country	Enrollment age	Admission qualifications	Subjects	Length of study
Korea (Shilla) AD 682	15–30	Taesa (grade 12 in a hierarchy of 17 grades) and those who had no official positions	Six-chapter arithmetic, nine-chapter arithmetic, three opening arithmetic, continuation technique	9 years or longer
China (Tang) AD 624	14–19	Children of grade 8, and lower - grade public officials	Nine-chapter arithmetic, calculation of distance to a far-off island, Sun Zi's arithmetic for five government bureaus, Zhang Guijian's arithmetic calculation and gnomon continuation technique, topics in number three standard mathematics	7 years
Japan AD 710	13–15	Children of grade 8, and higher – grade public and local officials	Nine-chapter arithmetic, calculation of distance to a far-off island, Sun Zi's arithmetic, three opening arithmetic, continuation technique, six-chapter arithmetic	7 years

Academy) in mathematics and other fields. In Korea and Japan, qualifications also differed by field.

The Koryo dynasty (918–1392) continued using the Shilla mathematical system in a slightly changed version. Whereas the Koryo continued to use Nine Chapter Arithmetic, the Continuation Technique, and Three Opening Arithmetic, they discontinued Six Chapter Arithmetic and began to use Saga.

The Chosun dynasty (1392–1907) strengthened the system of its predecessors and the standard text books were completely changed. The texts include Sanmyon arithmetic, Yonghui arithmetic, Sanhak Kaemong arithmetic for bureaucrats, and arithmetic for surveying.

In the Chosun dynasty, the study of mathematics was encouraged to fill administrative needs and was incorporated into the official system. During the reign of King Sejong (AD 1419–1450), a Bureau of Mathematics and an Agency for Calendars were created, and mathematics was revived to match the level of the Koryo dynasty (936–1392). The positions of *Sanhak paksa* (Doctor of Mathematics), *Sanhak Kyosu* (Professor of Mathematics), and *Sansa* (mathematician) were created.

The Chosun dynasty attached great importance to mathematics from the beginning, and

the bureaucrats in charge of the technical civil service examinations in ten fields began to play a greater role, ultimately forming the new social class of *chungin* (middle men). The *chungin* class is considered unique in the history of the world. (The term began to be used officially during the reign of King Sukchong (1675–1720)). As technocrats, they were recruited through comparatively low-level civil service examinations. Most of them came from the *chungin* class. It does not mean that a son inherited his father's position; rather it seems that intermarriage among the *chungin* contributed to the preservation of the tradition. Among them, mathematicians showed an especially strong tendency toward preserving this hereditary tradition. The roster of successful candidates in the tests for mathematicians and the position of *Sanhak Sonaeng* (mathematics teachers) list a total of 1,627 during 300 years from the fifteenth to the seventeenth centuries. Their fathers' occupations were as follows: 124 herbalists, 75 translators, and 6 astronomers; the rest were mathematicians.

The mathematicians of the *chungin* class lived in a very closed society. As many of the books they wrote have been lost, and only fragmentary information is available, it is difficult to evaluate their achievements, either as a group or as individuals. A typical mathematician of the *chungin*

is Hong Chong-ha, a professor of mathematics, who wrote an eight-volume (plus a supplement) *Kuilchip* (Nine Chapters on Arithmetic in One) which is still extant today. He was born in 1684 into a typical *chungin* family of mathematicians; his father, grandfather, great-grandfather, and his wife's father were all mathematicians.

From his book, we find the following. First, mathematicians of the day were quite unfamiliar with the course of events in China, whereas the literati of the *yangban* class maintained direct contact with Chinese culture and with European culture through China. The mathematicians were bound by the old system and continued using only the traditionally handed-down manuals; they had no access to Chinese translations of Western mathematics books. Second, *tianyuan shu* (Horner's approximation theorem for an equation with real coefficients) and the calculation rod thrived in Korea throughout the Chosun dynasty, long after they had ceased to be used and had been replaced by the ► [abacus](#) in China after the establishment of the Ming dynasty. Japanese mathematics in the Edo period (1603–1867) is called *wasan*. The origin of *wasan* is Chinese mathematics, but the Japanese replaced the calculation rod with handwriting and eventually developed it into symbolic algebra. Korean mathematicians were then isolated from the outside world and from European mathematics which had already found its way into China, but they preserved traditional mathematics using the calculation rod.

One of the other mathematical trends in the Chosun dynasty was *yangbans* (nobles). Ch'oe Sok-chong was a mathematician of noble birth who was a great admirer of classical Chinese philosophy. As the author of *Kusuryak* (Concise Nine Chapter Arithmetic), similar in its style of description to that of early European monastic mathematics books, he was a "Boethius (480–525) of the Orient." Boethius's mathematics was theological, metaphysical, and number-theory centered. Both gave a touch of mysticism to numbers, and Ch'oe studied magic squares of various types: circle, square, hexagon, etc. The hexagon denotes "water" in Chinese traditional philosophy, and Korean mathematicians

attempted to indicate some philosophical meanings by means of mathematics.

Culture and Mathematics

King Sejong wanted all the branches of Asian learning – Confucianism, linguistics, music, astronomy, herbal medicine, and agriculture – to be in the service of his country. Unlike the Greek system of learning that branched off into mathematics, natural sciences, and metaphysics, the Eastern system tended to integrate all fields of learning into a whole. This was typified by classical Chinese studies (compare this with the Western trivium and quadrivium). For example, in the reform of music and the creation of the Korean alphabet, King Sejong remained true to the orthodox Asian view of learning and was content with being a true inheritor of Eastern culture. His policy for the promotion of mathematics did not seek any new paradigm.

Sirak

Sirak is the Korean version of the neo-Confucian concept of "practical learning," similar in nature to *jitsugaku* in Japan and *shixue* in China. It was active for about 300 years, from the mid-sixteenth to the mid-nineteenth centuries. Descriptions of some of the prominent mathematicians and their works follow. Yi Sugwang (1563–1628) wrote *Chibong yusol* (Chibong's Miscellany) which treats astronomy, geography, bureaucracy, belles-lettres, human behavior, technology, and even birds, animals, and insects.

Typical of this encyclopedic coverage is *Ojuyon mun-jangjon san'go* (An Oju's Multitude of Articles and Essays) by Yi Kyu-gyong (b. 1788) in 60 volumes, which contained 1,400 entries relating to the problems of all ages and countries. He had a very practical outlook, and in a commentary on the original text of a geometry book, he regarded surveying as the primary purpose of its study.

Ch'oe Han-gi (1803–1879) is said to have broken with the traditional position of

neo-Confucianism and become an activist philosopher, adhering to thorough-going empiricism. But he too remained orthodox in his attitude to arithmetic, as is evident in his comment, “By the degree of knowledge one has acquired in arithmetic, we can judge one’s insight; we can see whether one’s attitude is reasonable or not by judging if one’s reasoning is arithmetical.”

In 1765 Hong Tae-yong (1731–1783) visited a Catholic church in Beijing, China, and acquired first-hand knowledge of Western culture. He conversed with Hallerstein, the Chief Astronomer, and his deputy Gogeisl at a Chinese astronomical observatory, thereby broadening his knowledge of astronomy. His work *Tamhonso* (Tamhon’s Writings) treats mathematics and astronomy in Vols. 4–6 of Book II. Hong consciously discussed the infinite; he was the first Korean to discuss an infinite Universe, and he also mentioned infinite decimals in discussing the value of π .

At the end of the Chosun dynasty a new movement in mathematics arose. Nam Pyong-gil (1820–1859) and Yi Sang-hyok (1810–), perhaps the two greatest arithmeticians at the time, did not belong to the *Sirak* school. None of the *sirak* scholars specialized in arithmetic. But Nam was born into a *yangban* family, and Yi was a professional arithmetician of the *chungin* lineage. They joined hands in the study of arithmetic.

Nam’s works include many arithmetic books, but he made them look new by adding illustrated explanations. There is no trace of metaphysical view, a dominant characteristic of the works of other *yangban* scholars.

Yi Sang-hyok was a typical *chungin* arithmetician. After passing the national test, he was assigned to an astronomical observatory as a budget officer. Among his works are some astronomical books and the following books on arithmetic: *Iksan: Ch’agunbop monggu* (Winged Mathematics: Hypothetical Method for the Theory of Roots) and *Sanhak Kwan-gyon* (A Brief Survey of Arithmetic). The first title probably implies “mathematics of two wings,” one wing referring to traditional arithmetic, and the other to modern arithmetic. *Ch’agunbop monggu* is an explanatory book on European algebraic equations, while *Sanhak Kwan-gyon* presents Yi’s creative study

of mathematics. Yi’s single-minded devotion to higher mathematics, ignoring the traditional patterns of thought when classic arithmetic was reviving, leads us to assume that this type of mathematical research may have prevailed among *chungin* scholars at that time.

Classical official Korean mathematics maintained its continuity without any fundamental changes from the seventh century (Shilla dynasty) to the beginning of the twentieth (the end of the Chosun dynasty).

The Chosun dynasty had three groups of mathematicians: the *chungin*, the *yangban*, and the *sirak*. The *sirak* school searched for new mathematics as seen in collaboration between *yangban* and *chungin* mathematicians. But their study of European mathematics was limited to algebraic equations and geometry at best, and they never went much beyond the traditional Chosun dynasty mathematics even when they accepted European mathematics. The works of Hong Tae-yong, allegedly the most progressive of all *Sirak* mathematicians, differ from other classical manuals only in that they dealt with practical applications of old principles.

At the end of the Chosun dynasty, some of the *chungin* mathematicians attempted an original study in mathematics, breaking with the old traditions. But they too were limited by the prevailing intellectual climate, which hindered understanding and assimilation of modern mathematics.

Korean mathematicians made little effort to change fundamentally the mathematics which originated in China, they did not yield to foreign influence, and they maintained the classical mathematics of the East to the last (to the end of the Chosun dynasty) even when Chinese and Japanese mathematics underwent drastic changes.

See Also

- ▶ [Computation: Chinese Counting Rods](#)
- ▶ [Sun Zi](#)
- ▶ [Surveying](#)
- ▶ [Yinyang](#)
- ▶ [Zhang Qiujiang Suanjing](#)

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Taitang luidian

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with mental capability, and portrays the reverence the ancient Mesopotamians had for the field of mathematics. It is certainly true that the study of mathematics is an intellectual activity that requires both imagination and intuition.

Mathematics arose from the need to count and to record numbers. Many ancient societies had methods for tallying and counting. Thus, they developed a variety of counting systems used over the millennia around the world. Our base-10 system, the most common of all systems because of its association with the number of fingers on both hands, is but one of many.

A concise and meaningful definition of the field of mathematics is virtually impossible. The word was originally used to mean arithmetic. Then simple algebra was introduced, followed by plane geometry and other related concepts. At present, the word mathematics is defined as a language with a particular kind of logic. It contains a large body of knowledge often beautifully expressed in terms of equations, numbers, and symbols. In this article, the word mathematics is used in its most general meaning.

Mesopotamia is a land that nurtured many civilizations – Sumerian, Akkadian, Babylonian, Chaldean, and later on Abbasid. It has a long list of achievements in astronomy and mathematics as well as other disciplines. The Mesopotamians' love for and interest in the study of astronomy led to their development of mathematics. The two fields, being interdependent, grew and prospered side by side.

Originally, mathematical calculations were used to count herds, livestock, produce, and people; later, they were used to help understand astronomical observations. Mesopotamian stargazers had a motto, "When it is clear, observe, when it is cloudy, compute." They observed for long periods of time; the longest uninterrupted period of astronomical observation, and this includes modern day observations, was carried out in Mesopotamia. To understand these observations, they performed very complex mathematical computations.

In this article we present some of the simple mathematical operations that were performed by

Mathematics in Mesopotamia

Sema'am I. Salem

"A mind that does not know accounting, is it a mind that has intelligence?" This ancient Mesopotamian proverb equates mathematical dexterity, to the exclusion of all other disciplines,

early Mesopotamians. We will avoid the more complex calculations more suitable only to the experts.

The ancient Mesopotamians worshipped celestial objects as gods, and they believed that they were created for the purpose of serving these gods. To perform this function properly and to interpret the wishes of these gods, they studied their every move, chartered their paths, and calculated their positions as a function of time, thus creating a strong link between the study of mathematics and astronomy. This link played an important role in the development of both fields and later gave rise to the formulation of the Mesopotamian early calendars.

For our knowledge of Mesopotamian mathematics we are indebted primarily to the work of the Otto Neugebauer, who, between 1935 and 1937, studied all the known mathematical cuneiform tablets and published their contents in three volumes entitled *Mathematische Keilschrifttexte*. In these, he included photographs of original texts, transcripts, and translations into German. He also wrote a comprehensive commentary. A later publication by F. Thureau Danguin contains new transcriptions and French translations of most of the material published by Neugebauer, and a new and valuable commentary. For an extended period after 1937, Neugebauer continued his study of Mesopotamian mathematics; he kept translating and publishing articles about the subject, indicating what type of mathematics the Mesopotamians were interested in and how they solved some of the difficult and involved problems. And in 1945, he and Sachs published another collection – a supplement to Neugebauer's early work. In 1961, E. M. Bruins and M. Rutten produced a volume entitled *Textes Mathématiques de Susi* (Susa). The works of Otto Neugebauer, F. Thureau Danguin, and E. M. Bruins and M. Rutten are our main sources and best references to Mesopotamian mathematics.

The oldest mathematical symbols uncovered in Mesopotamia are Sumerian; they go back to ca. 3000 BCE. They are a short straight line, which stands for unity; a small circle darkened at the top which corresponds to 10; and a

half-moon which represents 60. To add numbers, they wrote them next to one another; to multiply two numbers, they wrote one inside the other. For subtraction they had symbols that stood for the minus sign; to write 8, they wrote $10-2$.

With the advent of cuneiform, wedge-shaped signs replaced the old Sumerian symbols. A one wedge-sign by itself stood for unity, and two such signs placed next to each others meant two, and so on. The symbol for 10 was a small arc inscribed in an angle, and 60 was represented by a triangle. This retained the decimal/sexagesimal system.

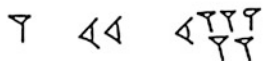
Numerous clay tablets uncovered in Mesopotamia reveal that by 2000 BCE the Mesopotamians had a fully developed number system, which is partly decimal and partly sexagesimal. It has a symbol for 10, but instead of clumping together 6 such symbols to form 60, they had a unique symbol for 60. Although the ancient Egyptians are usually credited with the development of the decimal system, the Mesopotamians made partial use of such a system. These various notations were in use until the advent of the elegant, place-value system, a great leap in the advancement of mathematics. To differentiate between their numerous gods, the Mesopotamians assigned numerical values to these gods. Anu, the god of heaven, was allotted the number 60, and thus in their calculations, they used the ► [sexagesimal system](#). That is, they used 60 the same way we use 10 in our decimal system. The influence Mesopotamian mathematics had on the Western civilization and mathematics is clear, as remnants of their sexagesimal system are still apparent in our method of measuring time (60 min to an hour and 60 s to minute) and in measuring angles (360° , 6×60 , in a complete circle, and there are 60' to a degree).

True to their sexagesimal system, they wrote all their fractions out of 60, the way we write our fractions out of 10. Thus, to write one half, they wrote a symbol that meant 0.30, the way we write 0.50 to mean a half.

Place-Value Numeration System

In our decimal system, if we desire to write 11, we do not need to write 11 straight line

Mathematics in Mesopotamia, Table 1 The place-value numeration system

	is 5
	is 64
	is $60 \times 60 + 60 + 1 = 3661$
	is $60 \times 60 + 20 \times 60 + 15 = 4815$

scratches next to one another, we simply write 11 – the 1 in the first column to the right stands for unity, and the 1 in the second column stands for 10, and when they are placed together they represent 11. Similarly if we write 100 and 11 starting from right to left, we have 1, 10, and then 10^2 giving the desired number of 111. Every time we move one column to the left we multiply by 10. In the sexagesimal system, the second column is 60, the third is 60^2 , and every time we move one column to the left we multiply by 60. With the advent of cuneiform and the place-value numeration system, there was no further need for a symbol for 60. It was dropped, but the symbol for 10 was retained.

This system, which was conceived by the mathematicians and astronomers of Mesopotamia toward the beginning of the second millennium BCE, was a giant step in the annals of mathematics. To comprehend the importance of this giant step and how much simpler it is to perform mathematical operations using the place-value system, one ought to try to multiply two numbers using present-day Roman Numerals. The following table illustrates the use of place-value in the sexagesimal system (Table 1).

As the Mesopotamians had only two symbols to work with, the separations between successive symbols indicate different columns and a multiplication by 60 of the left column, instead of a simple addition of the two symbols. In solving one problem, another was created. The scribes had to determine how wide or how narrow the spaces between the columns ought to be. According to Mesopotamian

understanding, if the spacing was too narrow, the two numbers must be added instead of multiplying the one to the left by 60 then adding. Thus making a symbol for zero became a necessity.

The astronomers and mathematicians of Mesopotamia had to contend with this difficulty for some 1,500 years, before they introduced a sign for zero. It took that long because it is difficult to think of “nothing” and even more difficult to find a symbol that represents “nothing.” But in spite of the shortcomings of their numerical system, they were able to perform sophisticated calculations.

A Symbol for Zero

The history of the development and use of zero played a crucial role in mathematics and was the subject of several scientific publications, papers, and books. In a recently published book, *The Nothing That Is: A Natural History of Zero*, Robert Kaplan wrote that the earliest evidence of the use of zero was found on Sumerian clay tablets uncovered in southern Mesopotamia. The Sumerians, around 3000 BCE, inserted a slanted double wedge between numerical symbols to indicate the absence of a number. This date, if true, corresponds to the earliest use of mathematical notations by the Sumerians, and it comes only a couple of hundred years after the Sumerians invented writing.

It is possible that a symbol for zero was used by one civilization, got lost then rediscovered by another. Kaplan adds that the zero made its way

into the Babylonian Empire and from there to India. In the Greek culture, the zero appears only occasionally, and there is no trace of its use during the Roman Empire. Arab scholars and merchants introduced the zero to the West, providing the earliest steps in the crucial role the zero plays in the world of mathematics. Note that the English word “cipher,” meaning zero, has its origin in the Arabic word *sifr*, meaning empty. Finally, at a date not precisely determined, but either late in the sixth century BCE or early in the fifth century BCE, the Babylonian mathematicians, to indicate the absence of a sexagesimal unit, used a true sign for zero and spread its use over their vast empire and into the Indian subcontinent.

To avoid the difficulty encountered by leaving spaces to indicate zero or the absence of a number, they inserted between the columns one of the following signs:

YY or Y or Δ

For example 132 was written in one of the following ways:

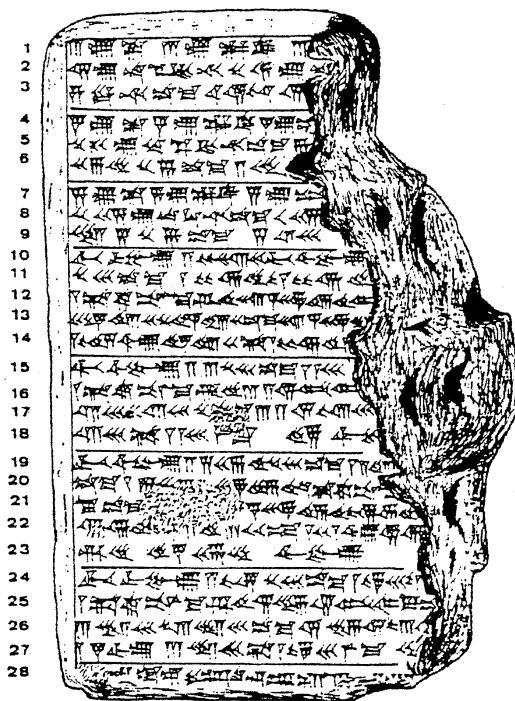
YY YY Δ YY
YY Y Δ YY
YY Δ YY

That is $2 \times 60 + 12 = 132$.

When cuneiform writing became obsolete in the first half of the first century AD, the Babylonian signs for zero were lost with it. But the great mathematician, Muḥammed ibn Mūsā al-Kwārizmī (ca. 800–847), working in Baghdad, reestablished a sign for zero and introduced it into his mathematical computations (Fig. 1).

Recreational Mathematics

Most ancient mathematicians were interested in the solution of practical problems such as dividing geometrical figures into two or more equal parts, or multiplying two numbers to determine



Mathematics in Mesopotamia, Fig. 1 This mathematical clay tablet was uncovered in Uruk. It dates from either the late third or early second century BCE. It contains the earliest known signs of the Babylonian zero (Musée du Louvre, Paris) (Used with the author's permission, from his article in *Dahesh Voice* 8.4 (2003): 14–19)

the area of a field. Such knowledge was used to divide properties among inheritors. For similar practical reasons they worked out the volumes of various solids to measure and store grains and other crops.

The Mesopotamians' interest in mathematics took them beyond its practical aspect and into its recreational, or what we call today pure mathematics. They worked out equations with two and three unknowns, they found solutions for quadratic equations, and they worked on problems such as, “Given the product of two numbers and either their sum or their difference, find the numbers.” For most of their mathematical operations, the Mesopotamians constructed tables; they had tables of multiplication, division, squaring, and extracting square and cube roots. They also had tables of reciprocals, i.e., sexagesimal fractions. They went beyond

all that and constructed tables for the summation of geometrical progression, such as

$$1 + 2 + 4 + \cdots + 2^9 = 2^9 + (2^9 - 1).$$

They also calculated the time required for the alignment of the sun-earth-moon to determine the time of lunar and solar eclipses. They were able to predict these eclipses with great precision.

A truly dramatic clay tablet, written in 568 BCE during the reign of Nebuchadnezzar, states that a lunar eclipse predicted to take place on the 4th July 568 BCE (the date was recently calculated from an ancient Babylonian calendar) “failed to occur.” Modern astronomers have verified that a lunar eclipse did take place on that date, but during the day, when the moon was not visible in Mesopotamia.

Influence on Greek and Western Mathematics

The first known Ionian astronomer, Thales of Miletus (ca. 625–545 BCE) was a statesman fond of traveling. While in Babylon, he obtained lists of observations of the heavenly bodies. From these lists, Babylonian astronomers had already deduced the periodicity of eclipses, and had accurately predicted several solar and many lunar eclipses. With these lists in his possession, Thales returned to his hometown of Miletus. It was reported there that he predicted a solar eclipse that took place in 585 BCE. But Thomas Martin, in his book *Ancient Greece, from Prehistoric to Hellenistic Times*, writes, “Modern astronomers doubt that Thales could actually have predicted an eclipse” (Martin, 1969, p. 91).

Greek tradition indicates that it was customary for young Greek scientists to visit Mesopotamia in search of knowledge. One of the famous Greek scientists, who made the journey, probably after being deported from Egypt, was Pythagoras of Samos (d. ca. 497 BCE). He may have become acquainted with Mesopotamian mathematics, and most certainly with the theorem that bears his name, and which states that in a right triangle,

the square of the hypotenuse is equal to the sum of the squares of the two other sides.

Neugebauer (vol. II, p. 53 and vol. III, p. 22) states that a cuneiform tablet, also belonging to the Old Babylonian period, contains extensive values of the sides of right triangles that satisfy the above-mentioned theorem. And Neugebauer and Sachs collection (pp. 38–41) contains an extensive table of “Pythagorean Triplets.” In addition to the theorem itself, right triangles, which obey the theorem, are also known as “Pythagorean Triangles” and the sets of numbers such as 3, 4, 5 and 6, 8, 10 and 12, 16, 20, etc. which satisfy the theorem are known as “Pythagorean Triplets or Pythagorean Triads.” The theorem, the triangles that obey the theorem, and the sets of numbers that satisfy the theorem should be named Babylonian instead of Pythagorean.

This is not an isolated case. Through the work of Neugebauer, it became clear that the work of the mathematicians and astronomers of ancient Mesopotamia greatly influenced the mathematics of the Greeks, and through them that of the Western world.

In Babylonian algebra, quadratic equations of the four standard types occur frequently:

$$\begin{aligned} X + Y &= A, & XY &= B, \\ X - Y &= A, & XY &= B, \\ X + Y &= A, & X^2 + Y^2 &= B, \\ X - Y &= A, & X^2 + Y^2 &= B. \end{aligned}$$

They also appear in Euclid’s *Elements*: Theorem 5–6 and 9–10 of Book II without reference to their origin, and Neugebauer pointed out that the Greek geometrical solutions of these equations were exactly the same as the Babylonian algebraic solutions; for example, whenever the Babylonians wrote, “Take the square root of A.” The Greeks changed it to read, “Take the side of the square of area equal to A.”

The great interest the Mesopotamians showed in the solutions of pure mathematical problems – recreational mathematics, which has no practical applications – indicates that they viewed this endeavor as a mental exercise. This kind of mathematical intelligence greatly benefited both the Mesopotamians and the civilizations which followed them.

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Mathematics in Native North America

Michael P. Closs

The mathematical development of the Native American peoples is highly variable among different cultural groups. In this article, I will treat two areas of interest: the wonderful diversity in the formation of number words and the use of tally systems to record information. Other articles in this volume give more explicit details on the mathematics of two particular indigenous groups, the Aztec and the Maya.

Number Words

Often numbers have a digital origin, indicating that counting began, or at least was remembered, by finger counting or by counting on the hands

and feet. Here, I look at only a few examples. For a more extensive treatment, see Closs (1986a, b).

The relationship between the method of finger counting used and the creation of number words may be very explicit. The Bacairi of Mato Grosso in Brazil have the number sequence shown below:

1	<i>tokale</i>	
2	<i>ahage</i>	
3	<i>ahage tokale; ahewao</i>	2 + 1; 3
4	<i>ahage ahage</i>	2 + 2
5	<i>ahage ahage tokale</i>	2 + 2 + 1
6	<i>ahage ahage ahage</i>	2 + 2 + 2

The second of the number words for 3 is not used more often than the form made up of 2 and 1, nor is it used in the formation of any of the higher number words. The word for 1 comes from the word for bow. It has been suggested that since each man has only one bow but many arrows, the bow came to exemplify ‘oneness’. The word for 2 and the word for ‘many’ derive from the same source. Thus, the two basic terms in the number vocabulary have a non-digital origin. The number sequence is an example of an additive two-system, i.e. a system in which the terms are formed by using addition (implicitly) and groups of twos.

In finger counting, a Bacairi starts with the little finger of the left hand and says *tokale*, grasps the adjacent finger and joins it with the little finger and says *ahage*, goes to the middle finger and, holding it separately beside the little finger and the ring finger, says *ahage tokale*, goes to the index finger and joining it to the middle finger says *ahage ahage*, grasps the thumb and says *ahage ahage tokale*, places the little finger of the right hand along side it and says *ahage ahage ahage*. He then goes to the remaining fingers of the right hand and touches each finger in turn while saying *mera* ‘this one’. He continues by touching the toes of the left and right foot and each time says *mera*. If he is still not finished he grasps his hair and pulls it apart in all directions. The number 6 marks the end of the use of two-groups in finger counting. Nevertheless, the finger counting still continues on to 20 by a straight one-to-one correspondence without the use of number words.

Mathematics in Native North America, Table 1 Creation of number words

Apache	2	naki	From <i>ki-e</i> ‘feet’
Micmac	2	tabu	‘Equal’
Omaha	2	nomba	‘Hands’
Micmac	3	tchicht	Cognate with Delaware <i>tchicht</i> ‘still more’
Abipones	4	geyenknute	‘The ostrich’s toes’
Yana	4	daumi	From <i>dau</i> ‘to count’
Pawnee	5	sihuks	From <i>ishu</i> ‘hand’ and <i>huks</i> ‘half’
Kutchin	6	neckh-kiethei	From <i>nackhai</i> ‘2’ and <i>kiethei</i> ‘3’
(NW) Maidu	6	sai-tsoko	From <i>sapu</i> ‘3’ and <i>tsoko</i> ‘double’
(E) Pomo	7	kula-xotc	From <i>kula</i> and <i>xotc</i> ‘2’
(NW) Maidu	7	matsan-pene	from <i>ma-tsani</i> ‘5’ and <i>pene</i> ‘2’
Crow	8	nupa-pik	From <i>upa</i> ‘2’ and <i>pirake</i> ‘10’
Kansas	8	kiya-tuba	From <i>kiya</i> ‘again’ and <i>tuba</i> ‘4’
(NW) Maidu	8	tsoye-tsoko	From <i>tsoye</i> ‘4’ and <i>tsoko</i> ‘double’
(E) Pomo	8	koka-dol	From <i>ko</i> ‘2’ and <i>dol</i> ‘4’
(NW) Maidu	9	tsoye-ni-masoko	‘4 with 10’ (i.e. 4 towards 10)
(E) Pomo	9	hadagal-com	From <i>hadagal</i> ‘10’ and <i>com</i> ‘less’
Gabrieleño	10	wehes-mahar	From <i>wehe</i> ‘2’ and <i>mahar</i> ‘5’
(NW) Maidu	10	ma-tsoko	From <i>ma</i> ‘hand’ and <i>tsoko</i> ‘double’
(E) Pomo	10	hadagal-com	From <i>hadagal</i> ‘10’ and <i>com</i> ‘full’
Unalit	10	kolin	‘Upper half of the body’
(E) Pomo	11	hadagal-na-kali	From <i>hadagal</i> ‘10’ and <i>kali</i> ‘1’
Cehiga	12	cape-nanba	From <i>cape</i> ‘6’ and <i>nanba</i> ‘2’
(E) Pomo	12	hadagal-na-xotc	From <i>hadagal</i> ‘10’ and <i>xotc</i> ‘2’
(NW) Maidu	13	sapwi-ni-hiwali	‘3 with 15’

Mathematics in Native North America, Table 2 Larger number words

Biloxi	1,000	tsipitcya	‘Old man hundred’
Choctaw	1,000	tahlepa siponki	‘Old hundred’
Delaware	1,000	ngutti kittapachki	‘Great hundred’
Wiyot	1,000	kucerawagaatoril piswak	‘The counting runs out entirely once’
Kwakiutl	1,000,000	tlinhi	‘Number which cannot be counted’
Ojibway	1,000,000	ke-che me-das-wac	‘Great thousand’

Number words are not always derived from words associated with counting on the fingers. Frequently, the meaning of even relatively small number words is transparent. In some languages the word for 1 is related to the first person pronoun. Often the word for 2 comes from roots denoting separation or pairs. Moreover, not only large numbers but also small ones may be formed by using arithmetical principles. In the simplest case, this takes the form of doubling but there are instances in which addition, subtraction, multiplication, and division are used. Number words may also be created in more exotic ways (see Table 1).

Larger number words may be formed by using superlatives or other expressions which are indefinite (see Table 2).

There are many number systems developed in the New World that follow unusual principles of grouping. The number sequence of the Coahuiltecan of Texas shown in Table 3 exhibits an extensive use of additive and multiplicative principles early in its development. It is also very unusual in the heavy reliance it places on three-groups.

The word for 3 is an additive composite of the words for 2 and 1. That pattern, seen in the earlier

Mathematics in Native North America, Table 3 The number sequence of the Coahuiltecan of Texas

1	pil	
2	ajte	
3	ajte c pil	$2 + 1$
4	puguantzan	
5	juyopamáuj	
6	ajti c pil ajte; chicuas	3×2
7	puguantzan co ajti c pil	$4 + 3$
8	puguantzan ajte	4×2
9	puguantzan co juyopamauij	$4 + 5$
10	juyopamauij ajte	5×2
11	juyopamauij ajte co pil	$(5 \times 2) + 1$
12	puguantzan ajti c pil	4×3
13	puguantzan ajti c pil co pil	$4 \times 3 + 1$
14	puguantzan ajti c pil co ajte	$4 \times 3 + 2$
15	juyopamauij ajti c pil	5×3
16	juyopamauij ajti c pil co pil	$5 \times 3 + 1$
17	juyopamauij ajti c pil co ajte	$5 \times 3 + 2$
18	chicuas ajti c pil	6×3
19	chicuas ajti c pil co pil	$6 \times 3 + 1$
20	taiguaco	
30	taiguaco co juyopamauij ajte	$20 + 10$
40	taiguaco ajte	20×2
50	taiguaco ajte co juyopamauij ajte	$20 \times 2 + 10$

two-system, is not continued and new words are introduced for 4 and 5. The number 6 is expressed in two ways, either as a composite of 3 and 2 or by a new word. The next new term introduced is for 20. The number sequence rises from 6 to 20 by a regular use of three-groups and the use of the arithmetic operations of addition and multiplication. Below 12 the development of the number system is not consistent. The Coahuiltecan sequence might be classified as a 2-3-20-system.

The number systems employed within closely related linguistic groups may also exhibit considerable variation. For example, the four Yukian languages of California belong to the same family but have very different number systems. In three of the four, the numbers up to 3 are related. However, from 4 on all the languages employ composite number terms whose meanings are completely different. Moreover, the methods of forming the numerals also differ since one of the four is an 8-system, two others are 5–10-systems, and the fourth is a 5–20-system.

Mathematics in Native North America, Table 4 The number sequence of the Yuki (Round Valley dialect)

1	pa-wi	
2	op-i	
3	molm-i	
4	o-mahat, op-mahat	'Two forks'
5	hui-ko	'Middle-in'
6	mikas-tcil-ki	'Even-tcilki'
7	mikas-ko	'Even-in'
8	paum-pat	'One-flat'
9	hutcam-pawi-pan	'Beyond-one-hang'
10	hutcam-opi-sul	'Beyond-two-body'
11	molmi-sul	'Three-body'
12	omahat-sul	'Four-body'
13	huiko-sul	'Five-body'
14	mikastcilki-sul	'Six-body'
15	mikasko-sul	'Seven-body'
16	hui-co(t), '8'	'Middle-none', '8'
17	pawi-hui-luk, '9'	'One-middle-project', '9'
18	opi-hui-luk, '10'	'Two-middle-project', '10'
19	molmi-hui-poi, '11'	'Three-middle-project', '11'
20	omahat-hui-poi, '12'	'Four-middle-project', '12'
24	'8'	'8'
26	'10'	'10'
35	'19'	'19'
51	'19'	'19'
64	omahat-tc-am-op	'Four-pile-at'

The number sequence of the Round Valley, or Yuki proper, dialect is shown in Table 4, together with an analysis of the numerals.

The Yuki number sequence is inextricably linked to their method of finger counting. Rather than counting the fingers themselves, the Yuki count the spaces between the fingers, in each of which, when the manipulation is possible, two twigs are laid. Except for the words for 1 and 2, common to all the Yukian languages, and the word for 3, common to all but one of the Yukian languages, the number words are descriptive of this method of counting. The number words have no relation to those used in the other related languages. From 9 to 15 the number words are formed by addition to a base of 8. Those from 10 to 15 include the term *sul* 'body', suggesting

that 'body' represents the full count of eight spaces between the fingers.

Many of the terms given for the larger numbers are residue representations as can be seen below:

$$\begin{array}{ll} 16 = (8) + 8, & 24 = (16) + 8, \\ 17 = (8) + 9, & 26 = (16) + 10, \\ 18 = (8) + 10, & 35 = (16) + 19, \\ 19 = (8) + 11, & 51 = (2 \times 16) + 19, \\ 20 = (8) + 12. \end{array}$$

The above terms suggest that 16, as well as 8, may be used as a base for constructing the higher numbers. Indeed, the term for 64 is literally '4-pile-at' and 64 would be 4 piles of 16. It has been reported that 64 is also used as a higher unit in the Yuki count. This has been taken as evidence that the Yuki had evolved a pure eight-system. Nevertheless, because of the term for 64, it seems better to classify it as an 8–16-system.

The Yuki number sequence illustrates that one may employ the fingers and hands in counting and not end up with a decimal or vigesimal system. This lesson could also have been drawn from the finger counting of the Bacairi who evolved a two-system. It can also be seen that the Yuki had precise concepts of number and counting which went far beyond their formal number sequence. The existence of variant terms for the same number and the use of residue expressions for larger numbers attest to this.

The facility with which different indigenous peoples dealt with large numbers also shows considerable variability across the Americas. The Pomo of California have a deserved reputation as great counters. Large counts were commonly performed by them at the times of deaths and peace treaties. An example of such a count is related in a Pomo tale about the first bear shaman who gave 40,000 beads in pretended sympathy for the victim whose death he had caused. One investigator reports that his informant has observed counting in excess of 20,000.

Although the Pomo were able to express numbers reaching into the tens of thousands, the published lists of Dixon and Kroeber contain numbers which do not exceed 200. From these lists, I present the number sequence of the Eastern

Pomo which is shown in Table 5. The second last column gives a simple analysis of the number words while the last column gives a second-order arithmetical analysis so as to exhibit the structure of the numerals more simply.

It can be seen from the above number list that the Eastern Pomo employed a 5-(10)-20-system. The term '1-stick' is used to represent 20. The phenomenon of overcounting (i.e. referring a count upwards to the next higher level) is also employed. For example, 50 is expressed as 10 towards 60, and 70 is expressed as 10 towards 80. Fortunately, the absence of higher numbers in the list has been remedied by Edwin Loeb. He provides the sequence for large counts among the Eastern Pomo in Table 6.

The Pomo number words are closely connected with the method of counting. For example, in counting small amounts, the word for 20 is *xai-di-lema-tek*, 'full stick', and when that number is reached a stick is laid out for this primary unit. When 20 such sticks were accumulated they formed a larger unit of 400 that also was represented by a stick.

There is evidence that 1-stick represents counts of 20, 40, 80, or 100 in different Pomo number sequences. This simply indicates that variant grouping practices prevailed in different Pomo areas at different times. Using different sizes of groups to represent 1-stick would yield different number sequences even though the same techniques of stick counting were applied. There is evidence for distinct Pomo systems which may be classified as 5-20-400, 5-40-400, (5)-80-400, and (10)-100-400.

Tally Records

A tally is a simple method of representing the cardinal number of a group of objects by making a one-to-one correspondence between the objects being counted and special marks made by a counter. Today, many tallies are made by using automated counted devices. However, throughout history, tallies were made by more personalized methods such as marking vertical strokes on a flat surface, cutting notches on a stick, tying knots on

Mathematics in Native North America, Table 5 The number sequence of the Eastern Pomo

1	kali		
2	xotc		
3	xomka		
4	dol		
5	lema		
6	tsadi	1-di	$(5) + 1$
7	kula-xotc	kula-2	$(5) + 2$
8	koka-dol	2-ka-4	2×4
9	hadagal-com	10-less	$10 - (1)$
10	hadagal-tek	10-full	10
11	hadagal-na-kali	$10 + 1$	$10 + 1$
12	hadagal-na-xotc	$10 + 2$	$10 + 2$
13	hadagal-na-xomka	$10 + 3$	$10 + 3$
14	xomka-mar-com	3-mar-less	$(3 \times 5) - (1)$
15	xomka-mar-tek	3-mar-full	(3×5)
16	xomka-mar-na-kali	$3\text{-mar} + 1$	$(3 \times 5) + 1$
17	xomka-mar-na-xotc	$3\text{-mar} + 2$	$(3 \times 5) + 2$
18	xomka-mar-na-xomka	$3\text{-mar} + 3$	$(3 \times 5) + 3$
19	xai-di-lema-com	stick-di-5-less	$20 - (1)$
20	xai-di-lema-tek	stick-di-5-full	20
21	xai-di-lema-na-kali	$\text{stick-di-5} + 1$	$20 + 1$
30	na-hadagal	na-10	$(20) + 10$
40	xotsa-xai	2 sticks	2×20
50	hadagal-e-xomka-xai	10-e-3-sticks	10 towards (3×20)
60	xomka-xai	3 sticks	3×20
70	hadagal-ai-dola-xai	10-ai-4-sticks	10 towards (4×20)
80	dol-a-xai	4 sticks	4×20
90	hadagal-ai-lema-xai	10-ai-5-sticks	10 towards (5×20)
100	lema-xai	5 sticks	5×20
200	hadagal-a-xai	10 sticks	10×20

a string, or placing pebbles in a bowl. It is the most ancient form of record keeping used by humans.

Biographical and chronological records formed of strings with simple knots tied in them existed among the interior Salish and neighbouring tribes of southern British Columbia and the region about Yakima, Washington. More sophisticated knotted string records, *quipus*, were used by the Inca.

For this discussion, I consider three types of tally records employed by the Ojibway:

1. The pictograph in Fig. 1 was transcribed from the sides of a blazed pine tree found on the banks of a tributary of the Upper Mississippi in 1831. On the upper right is the totem of an

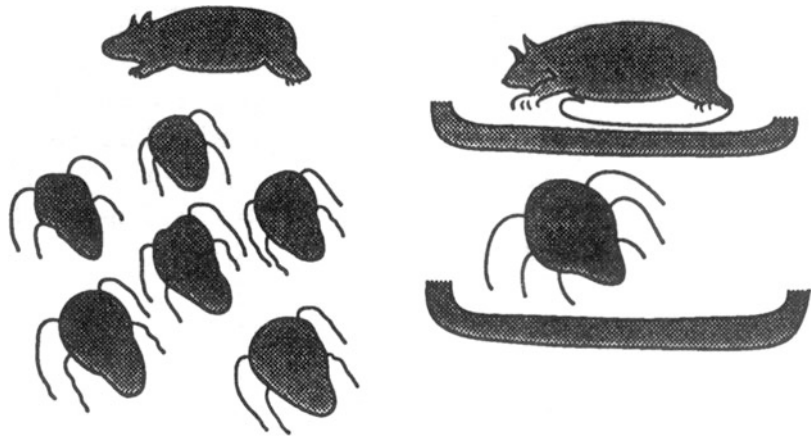
Ojibway hunter who had encamped at that spot. It represents a fabulous animal called the *copper-tailed bear*. The two parallel lines beneath it, curved at each end, represent the hunter's canoe. The next sign, on the same side, below, is the totem of his companion, the cat-fish, and below that a representation of his canoe. The upper figure on the left represents the common black bear, the six figures below it denote six fish of the cat-fish species. The interpretation is this: the two hunters, whose totems were cat-fish and copper-tailed bear, while encamped at the spot, killed a bear, and captured six cat-fish in the river. The record was designed to convey this piece of information to any of their people who should pass the locality.

Mathematics in Native North America, Table 6 The number sequence of the Eastern Pomo for large counts

80	dol-a-xai	4 sticks	4×20
100	lema-xai	5 sticks	5×20
200	hadagal-a-xai	10 sticks	10×20
300	xomka-mar-a-xai	15 sticks	15×20
400	kali-xai	1 (big) stick	400
500	kali-xai-wina-lema-xai	1 (big) stick + 5 sticks	$400 + (5 \times 20)$
800	xote-guma-wal	2 (big sticks)	2×400
2,400	tsadi	6 (big sticks)	6×400
3,600	hadagal-com	9 (big sticks)	9×400
4,000	hadagal	10 (big sticks)	10×400

Mathematics in Native North America,

Fig. 1 An Ojibway pictographic record (Drawing by M. P. Closs from Schoolcraft, 1851)

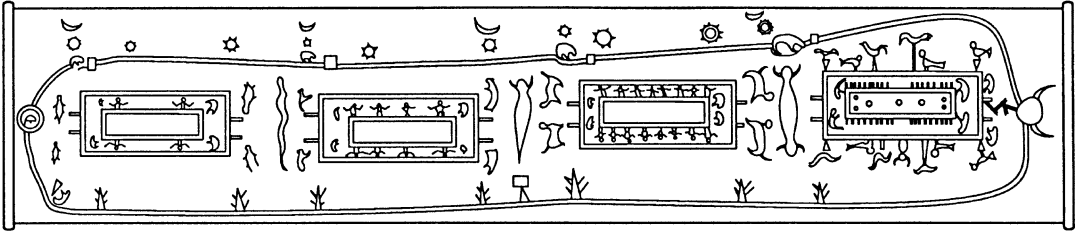


2. Tally records were also carved on Ojibway grave posts. Babesakundiba, or Man with Curled Hair, was the ruling chief of the Sandy Lake band of the Ojibway on the Upper Mississippi. He died in the late 1840s, after a long life of usefulness and honour, and was buried on a prominent elevation, on the east bank of the river, where his grave and an ensign which waved over it were visible to all who navigated the stream. A drawing of his inscribed grave post is shown in Fig. 2.

The upside down bird denotes his family name, or clan, the crane. Four transverse lines above it signify that he had killed four of his enemies in battle. This fact was declared by the funeral orator at the time of the deceased's interment. At the same time, the orator dedicated the ghosts of the four men, whom the departed had killed in battle, and presented them to the dead chief, to accompany him to the land of the spirits.

The four lines to the right and also the four corresponding lines to the left of the central marks denote eight eagle feathers and are commemorative of his bravery. Eight marks made across the edge of the inscription board signify that he had been a member of eight war parties. The nine other transverse marks below the sign of the crane signify that the orator who officiated at the funeral and drew the inscription had himself participated in nine war parties.

1. The Midéwewin was a set of ceremonials conducted by an organized group of men and women among the Ojibway people who had occult knowledge of 'killing' and 'curing' by the use of herbs, missiles, medicine bundles, and other objects which possessed medicinal properties. The records and teaching of the Midéwewin were inscribed on birchbark scrolls. These form a body of pictographic material in which one can



Mathematics in Native North America, Fig. 2 The grave post of Babesakundiba (Drawing by M. P. Closs from Schoolcraft, 1851)

find various tallies and graphic notations exhibiting a ritual use of number among the Ojibway.

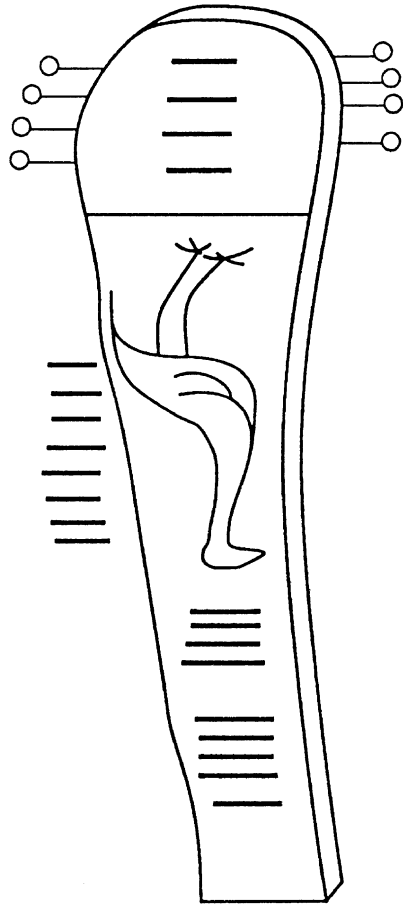
The scroll depicted in Fig. 3 was used for instruction in the lore and rites of the Midéwewin. It is characterized by four rectangular floor plans corresponding to four lodges (and degrees of initiation) which a candidate had to pass through before achieving the status of a Midé master.

The inner rectangle in each lodge represents the path that is followed when processions are made around the interior of the lodge. There are four bear *manitos* (archetypal spirits) in each lodge, two guarding each entrance. In addition, there are 4 officials shown in the first lodge, 8 in the second, 16 in the third, and 36 in the fourth.

Lurking between the lodges are evil *manitos* that block the entrances. The first three lodges are each blocked by four *manitos*, two near each entrance. The fourth lodge is uniquely surrounded by 12 bird-like figures, possibly sky *manitos*, with an additional horned figure and two bear figures. These seem to be beneficent entities.

The network of lodges is bordered by the Ojibway universe. It begins with a small circle containing Bear and terminates with the horned symbol of Everlasting Life. Along the upper border, close to the upper left-hand corner of each lodge, is a figure of Bear seated before his sacred drum. Outside of this border are lunar and solar symbols. Along the lower border is a sequence of trees which represents a forest.

The scroll emphasizes the number 4, sacred to the Ojibway, in many ways. It is the number of lodges, the number of bears in each lodge, the number of evil *manitos* adjacent to the entrance of



Mathematics in Native North America, Fig. 3 The Midé master scroll kp-1 (Drawing by M. P. Closs from Dewdney, 1975)

the first three lodges, the number of bear and drum figures on the boundary, and the number of lunar signs. Also, the 12 bird *manitos* about the fourth lodge and the series of officials in the sequence 4, 8, 16, and 36 are based on multiples of 4.

See Also

► Quipu

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Mathematics in Oceania

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The historical and contemporary practice of mathematical concepts in Oceania and their intentional and unintentional expression in various fields of written literatures negates, from the start, the possibility of pinning down their elements entirely. This is to be expected since a bibliographic tour is not only limited to what writers have thought relevant or important enough to mention since the start of

anthropological inquiries into Pacific societies. It is also limited to depictions of real life, culture, and society in written words. But the available representation of these concepts throughout the past several decades nevertheless allows one to grasp ethnomathematical essences in their indigenous contexts – such as the application of knotted plants or leaves for mnemonic purposes or for the determination of one’s fate using a system of 256 possible results originating from the sky god *Supwunumen* who bore the destiny faces of *pwee* before allowing them to emerge into 16 human forms. They then descended in a heavenly constructed canoe to teach the art of knot divination to a few select men in the Caroline Islands. The two major schools of the art of the *pweewunus* were distinguished by whether one conceived of the celestial canoe as having been a sailing canoe or a paddling canoe (Goodenough, 2002).

Knots for memorization or recall take several forms throughout the Pacific, although none of the forms serves as a society’s definitive method of memorization. They instead reflect environmental needs and practices, such as the tying and untying of knots to mark the passage of days before a particular event in Papua New Guinea (Blackwood, 1935) or, in “former times,” the tying and untying of knots on various types of leaves and strands for deaths and the successful revenge for each death among the Parevavo people of Papua New Guinea (Hallpike, 1979; Wolfers, 1971). In 1832, Typerman and Bennett described the practice of a Hawaiian “tax-gatherer” in the district of Waerua who kept “very exact accounts” of each inhabitant’s tax debt on a line of cordage of 4–500 fathoms in length and which were individually distinguished with “knots, loops, tufts, of different shapes, sizes, and colors” (p. 71). While knotted cords were used in the Marquesas Islands to measure time, record genealogies, and as mnemonics for the singing of religious songs (Barthel, 1971), one women in Papua New Guinea kept track of the number of times her husband beat her by tying knots in a leaf cord and eventually presented it to authorities as concrete proof of his treatment of her (Hallpike).

Of course people count objects using base systems, terms, objects, and even themselves (most extensively practiced in Papua New Guinea) for transaction and gifting practices (each society having particularly prominent objects to enumerate – pigs and yams, for example, in Papua New Guinea), for the distribution of food and objects in accordance with statuses or roles, and for the counting of material objects and people for other reasons. Objects themselves can take on quantifying terminology separate or derived from words that form base systems unique to societies as well as those acculturated through time from neighboring villages and islands. Among Elsdon Best's condescending though detailed work on Maori society in the 1920s is a reference to a system used by the Maori people in the Waikato district for counting eels (Best, 1921) (44 eels forming the smallest unit for tallying large numbers of eels (Best, 1929)), and the encapsulating of four birds in a single brace or *pu* (Best, 1924). Koch (1983) notes terms used in Tuvalu for bundles of 10 coconuts (*fui*) and a larger bundle ranging from 10 to 70 coconuts (*fikau*) while MacGregor (1937) cites use of terms for units of 10 recently harvested coconuts in counting coconuts to 1,000. Fox (1931) observed that among the Arosi people, Solomon Islands, counting was sometimes done "by ones, sometimes by pairs, sometimes by fours, sometimes by fives; the pair, or four or five being reckoned as a unit and given a distinct name" with numerous object centered variations and terms existent for yams, coconuts, banana-shoots for planting, pigs, dogs, fish, breadfruit, dogs' teeth, and shell currency.

These distinctions evolved in the context of counting systems and their bases that, as Lean (1991) demonstrated primarily in Papua New Guinea, extend from a vast array of counting systems in numerous languages. Lean classified these systems into several distinct types with a particular emphasis on a number system's expression of its "frame pattern" and "cyclic pattern" although others before and after Lean used other organizational standards. (See for example Berndt, 1954; Joseph, 2000; Laycock, 1975; Philp & Kelly, 1977) Descriptions (sometimes

with illustrations) of body-part counting systems of indigenous peoples of Papua New Guinea, based on the extent of numbers before an extension beyond that number is employed, sometimes note a reversal in counting direction (characterized further by descending or ascending directions) or the use of another body in this relatively unorganized literature.

These descriptions appear to be characterizing these societies in an ethnomathematical context, as does a perhaps peculiar concern with indigenous Pacific peoples' abilities to count to large quantities and with their concepts of infinity. Although Clark maintained in 1839 that Hawaiians "seldom had occasion for any complex combination of numbers" (a perception usually tossed at atoll inhabitants in Micronesia as well), he still intermittently listed Hawaiian words for 4 (considered to be "the lowest class or collection of numbers") to 400,000 as well as a word for four million. He maintains however that this number "is not often brought into practice as their minds become confused with so great a number as is implied by the meaning of the word [*nalowale*]. A great but indefinite number is expressed by the repetition of the word *kini*, or *lehu*, as *kinikini*, *lehulehu*." Other, at least partial, depictions of the numerical extent of counting systems usually have indigenous counters falling off at a certain numbers (the highest numbers usually thought to be employed infrequently) and into a shout of the greatness of quantities that are like sands of the beach, stars in the sky, etc. (See for example Beaglehole & Beaglehole, 1938; Elbert & Pukui, 1979; Kaleva, 1995; Seidenberg, 1962; Taylor, 1957). The Beagleholes (1938, p. 354) maintained in their study of the ethnology of Pukapuka that it was "a little hard to see the function of high numerical concepts in an atoll culture" although such large numbers "indicate not so much a definite number as a progression of increased greatness that is more sensed or felt than definitely apprehended." Drawing from his own experiences in learning mathematics in Papua New Guinea schools and his knowledge of the Wisai language from the Buin district of Bougainville, Kaleva also notes that while the word

for a chicken represents 10,00, and for 2 chickens 2,000, and so on, there comes a point at which this numerical progression ceases and people say that “the chicken went into the bush and never came back” (Beaglehole, 1938, p. 144) – a phrase Kaleva also identifies as an expression of infinity.

Numerical, spatial, and linear elements common to the western assigned cultural boundaries of Melanesia, Polynesia, and Micronesia vary in accordance with both the demands and the nurturing characteristics of the distinctive environments and social and cultural histories embodied in these boundaries. Arguing that the counting systems and their bases have developed and changed from indigenous environments and not from some Babylonian or other Western source (as Pospisil and Price (1966) suggested but which Bowers (1977) strongly rejected), Lean’s extensive study of these systems throughout Papua New Guinea and into the Pacific islands demonstrates the depth to which functionality in an environment characterizes the individual elements of ethnomathematical concepts and practices in these three vast regions of the Pacific. While the existent literature (scattered with unintended and sometimes unindexed mathematical references) might enable one to identify Melanesia with the presence of counting systems, linguistic structures and principles of terminology, measurement, agricultural and lunar based calendars, and methods of conveying currency values for exchange (buoyed in particular by studies done in Papua New Guinea), ethnomathematical practices in the far flung atolls of Micronesia are much more distant and spatial in nature. Most aspects of counting, measuring, astronomical methods of determining time and creating the calendar, the intentional expression of geometric forms, determination of distance and numerous other elements of ethnomathematical practices span across Oceania. But each of these three Pacific regions originally created by European cartographers has its own physical circumstances and historical connectedness to make, for example, Papua New Guinea the central area for expanded

enumeration concepts but Polynesia (and particularly Hawai’i and Easter Island) for past practices of aligning stone structures with stars to mark the occurrence of the equinox and solstice. Meanwhile in Micronesia, linear concepts in voyage dead reckoning, using what is often considered to be a dividing of a voyage into segments via linear associations of stars with an out-of-sight reference island en route through the *etak* concept, are generally lacking in Polynesia. While this *etak* concept is absent in Papua New Guinea (where some interesting topographical associations with ancestors and directions are reminiscent of Australian Aboriginal practices), it is also absent in island Melanesia.

Here we are again dealing also with the limitations not only of what has been of interest to writers – and particularly the earliest writers in the case of Polynesia – but what was accessible to them. Perhaps Captain Winker’s tenacious but sidetracked attempts (1901) to comprehend the then secret essences of Marshallese stick charts and their use for interpreting swells refracted by atolls is somewhat demonstrative of this now incurable problem. Centuries of interaction between Papua New Guinea tribal peoples and the centrality of exchanges and gift protocols, the impacts of indigenous diffusion where it occurred, as well as the contemporary acculturation of contact with Europeans has its passages and forms in the many enumeration systems Lean examined. Enumeration descriptions occur elsewhere in this literature but not anywhere to the degree that it has in regards to Papua New Guinea. There are nevertheless a few examples available for Micronesia. Alkire (1970), for example, describes how Woleai’s enumeration bases of four and eight not only reflect dualism in Woleai (central Caroline Islands) concepts of enumeration but also emphasizes their importance in the knot diviner’s interpretation of 256 knot combinations (ultimate destinies) formed by knots representing those 16 traditional divination spirits whose two pairs of leaflet knot quantities do not each exceed four. In a somewhat sensationalized note, Ballinger (1978) discusses the recording by the 1908 Thilenius South Seas Expedition of a “mysterious” counting

system on the atoll of Faraulep in the central Caroline Islands with its “regular, stepped, series of ‘characters’” representing numbers from 100,000 to 60,000,000 (again noted as being impractical for an atoll environment) and symbols being used with no apparent derivations from other Pacific islands. And while noting that the “ethnonavigators” of the Caroline Islands, in contrast to Western navigational practices, employ rigid spatial concepts that close off the potential for new information to be introduced into this nongeometrical or nonalgebraic system, Freedman (1980) still pointed out the Pukapuka system of numerals running from 1 to 12 and extending by 100 s to 2,000 along with its quantitative class names for the counting of specific objects.

The presence of Polynesian enumeration in the literature (comparably marginal when referenced against the literature on enumeration in Papua New Guinea) in Polynesia either reflects a lack of attention by European writers, the long and early impact of European acculturation on enumeration systems, or both. We have Conant’s (1893) survey of “primitive number systems” (including Polynesia) whose origins of numbers among “the savage languages of the human race” are unknowable as well as Thomas’ attempt to link the Marquesas Islands to India via Malaysia through the presence of vigesimal systems of enumeration.

Even so, mathematical characteristics in each of these three giant regions of Oceania were and are expressible on the basis of the environments that have prompted and sustained them. It is clear, for example, that the large ocean areas separating small atolls and higher level islands, the relatively recent scholarly interest paid to the prehistoric exploration and settlement of the Pacific, and the remaining availability of indigenous, noninstrumental navigational techniques on the Caroline atolls of Polowat and Satawal in a larger context of the importance of such exploration and techniques to contemporary Pacific cultures, all make distance and linear associations prominent in Micronesian ethnomathematics. These distances are inherently linear in a forward

moving fashion. A universal kind of fascination with the capacity of indigenous navigators to maintain and essentially harness distance in movements from one point to another is energized by both scholarship and cultural pride. The concept of *etak* as a technique for segmenting these voyages into manageable parts (as well as at least one alternative explanation that dismisses this segmentation (Hutchins, 1983) and the expression and explanation of wave refraction and interpretation in the linear expressions of the Marshallese stick charts remain prominent parts to this literature on Micronesian mathematical ideas and practices.

On the other hand, spiritual, material, and societal needs have also encouraged recognition and study of land-based uses of mathematical concepts. The knot divination practices passed on by the sky-god *Supwunumen* to determine the outcomes of certain events and the 256 possible fates of people for days and years to come probably registers as the most unique mathematical element in Micronesia. However, measurement concepts that may employ a small variation of lengths by the use of the same body part but from different bodies for canoe and house construction, axis concepts, calendar development (primarily lunar and somewhat stellar referenced in Polynesia and Micronesia but more agriculturally based in Melanesia), circular displays and conceptualizations, cosmology, and geometric concepts and applications are generally found in the written literature on all of Oceania although each region has its distinctive marks. Late nineteenth and early to lower-mid twentieth century literature on Hawaiian cosmology and lunar calculations of the days and thus the months are, for example, coated with Hawaiian genesis traditions of the cosmos and the role of the Pleiades and the moon. Chauvin (2000, p. 116) notes that, “the Hawaiian names for the 30 nights of the moon indicate an ancient ability to make accurate naked-eye observations of lunar phases and then to record those observations in descriptive appellations. Thus the first appearance of the waxing crescent moon in the west marking the first night of the

month was called Hilo – meaning ‘twisted’ or ‘threadlike,’ as a braid.”

There is very little mention of base properties in Micronesia (as compared to their propensity in writings on Papua New Guinea enumeration systems), little or no recognition of any body part counting practices, no references to archaeoastronomy research (in comparison to those available for Easter Island, Hawai’i, and, to a lesser extent, Tonga), very little concern with any mathematical elements of debt calculation and payment or base properties (again, in comparison to a much stronger presence in the literature on Papua New Guinea), and no mathematical elements of birth order names. However, the presence of horizontal concepts and their role in dealing with ocean distances are far more present in the literatures on Polynesia and Micronesia than for Melanesia and specifically Papua New Guinea. Horizontal lines on the tattoos of an elder Marshallese man in Barclay’s novel (2002) on the Marshall Islands have numerous horizontal elements which themselves are intended to reflect their conceptual presence at sea. The earth’s horizon itself often figures prominently not only in relation to stellar references to cardinal points (see Brower (1983), Finney (1998), and Babayan (1987) for examples) but it also has a crucial role in traditional Hawaiian and Chuukese conceptualizations of a series of domed heavens. (See Chauvin, 2000 also for their Hawaiian expression in a gourd.) Chuukese conceptualizations of these layered heavens involved paths for the dead where the “Singing Place” (*Neechiichi*) level or path tended to turn these voyaging souls toward irresponsible dance and song, thus distracting them from their final abode. Riesenbergs (1972) focuses on the centrality of metaphor in several categories of mnemonic navigational knowledge on Polowat and the expression of relationships between real and mythical geographic elements and star courses. Riesenbergs also examines the importance of the horizon in stellar courses that are thought of in terms of navigators pursuing a reef fish from one island to another with their associated stellar alignments. The Breadfruit

Picker (*fééyah*) category of courses, Riesenbergs notes, “are not necessarily on a straight line under the star named in the directions but include one star to each side of it, thus covering a sector of the horizon three stars wide” (Riesenbergs, p. 24).

The ethnographic and anthropological literatures of Melanesia, Polynesia, and Micronesia all have seemingly inevitable references to the triangular or rectangular or square joining of cross beams, weaving threads, planks, and canoe pieces that emerge from practical applications but which would not only be difficult to isolate entirely (and what would be the point?) but would probably also be difficult to align with conscious ethnomathematical concepts. The appearance of squares, circles, and triangles in the numerous available descriptions of string figure practices in the Pacific are likewise natural consequences of string designs with a few exceptions of figures named after geometric shapes and the direct intent to convey these figures in the end result of the dexterity of string and fingers. One might point to these natural consequences of material needs as being indicative of the ultimate weakness with which bibliographic overviews of subjects are not only guided by the literature that is actually available but more importantly, by the human dynamics of history that will always defy anything resembling a complete inventory.

Thus environmental factors and geographic realities (linear spaces associated with stellar concepts in Micronesia, enumeration systems for social traditions of exchange and possession in Papua New Guinea) serve to define and stress the kinds of mathematical concepts employed in different Pacific societies. The piecemeal fashion with which these concepts have been identified and extended in both scholarly and contextual terms actually underlines the intricate place of ethnomathematical practices in individual cultures. Their emergence comes and came over the past several decades through their sometimes chance recognition in other ethnographical terms, the scholarly concerns that happen to be prevalent for given societies, and of course the extent

to which access was allowed to outside observers. At times it was the particular practice wrapped up in ethnomathematical principles that was the primary reason for an ethnographic focus – such as Bernard A. Deacon’s detailed descriptions (1934) of the geometrical sand drawings from Malekula (Vanuatu) and most notably that which the *Temes Savsap* ghost half erased and expected the dead souls traveling to the afterlife to reconstruct before passing on or face being devoured – for a particular society. The same was true for selected other works on mathematical principles. Price and Pospisil’s theory (1966) of a Babylonian influence on enumeration structures among the Kapauku people in Papua New Guinea was strongly rejected by Bowers (1977) while conjectures by Ross (1936) and Heyerdahl (1961) that an apparent presence of two distinct counting systems on Easter Island at the time of early European contact was indicative of outside, non-Polynesian influences were challenged by Métraux (1936). Works on Papua New Guinea enumeration systems sometimes draw from previous works while scholarship on the challenges Papua New Guinea students face in successfully comprehending and using Western enumeration and mathematical principles – particularly in the acknowledged context of their social and environmental origins – represent the pocket of literature on the presence of Pacific ethnomathematical principles that is most responsive to the works of others.

While arguing that a predominant belief in Western worlds of the universality of mathematical principles underlines the ongoing use of these principles “as one of the most powerful weapons in the imposition of western culture,” Bishop (1990, p. 60) also recognizes the nebulousness of the term “ethnomathematics” itself. Perhaps, he suggests, “it would be better not to use that term but rather to be more precise about which, and whose, mathematics one is referring to in any context.” This issue of the foremost inclusion of contextual realities stresses the “humanly constructed” nature of mathematics – a nature that Bishop maintained can be imperialistically manipulated as reflected for example in the fact

that the 180° sum of the angles of a “perfect triangle” was predetermined by a dominant western epistemology. In extending linear and horizontal concepts to a Micronesian concept such as *etak*, to the practice of backsighting against prominent points of an island as it sinks below the horizon, and even to the “linear series” of ancestral and contemporary movements that embody a “lineal segmentation” from a point of unity (Rumsey, 2001), one speaks directly to the representation of cultural ideas and realities subverted by the idea of there being a universal and culturally free field of mathematics to which all can refer. The interpretations of mathematically related ideas throughout the Pacific and the anthropological and other literatures that have attempted by happenstance or intent to express them have always prompted the possibilities and appropriateness of this extension. The legitimacy that they are afforded speak not only to Bishop’s concerns but to the relevancy of practices that in many cases have become more “past” through colonial hegemony as well as an acculturation that was once more indigenous in nature but of course finds its niche in the far reaching influences of western society.

This is where, however, the depiction of “real life” in specific societal and cultural dynamics resides when lineal and spatial manifestations from that life are acknowledged in their own right. In Rumsey’s examination of “topographic objectification” in a landscape of totemic references in the Morehead River area of Papua New Guinea and among the Iatmul people of Sepik, the concept of spatial unity derived from ancestral tracks that emanated from a featureless pit at the beginning of the world and from which ancestral movements in space and associated phenomena designated clan properties, features linear and spatial ideas and actions of both practical and spiritual value. The difference between this kind of ancestral tracking and that of Australian aboriginal peoples is the greater abstraction of actual places from the empowering force of their names in Morehead River cosmology than is true of Aboriginal approaches to such inscriptions. However, admitting these ideas of spatial unity and ancestral tracks and property

segmentation into ethnomathematical levels of describing societies bodes well for their relevance in the intricate nature that mathematical ideas in a society play in understanding social structures, values, and perceptions. Perhaps we can be reminded here of Bishop's suggestion that even a universal term such as "ethnomathematics" for indigenous contexts may not serve the Sepik and Morehead River areas (or those of Maekula or perhaps of any other area discussed above) very well. Environmentally based concepts of lines, distances, division and segmentation, topographical and oceanic references (both practical and mythical), enumeration by systems of indigenous diffusion and acculturation (and now those of an influential western world), perceptions of space and measurement, and any number of mathematical principles that have emerged from various literatures on the Pacific clearly underline the centrality of these cultural contexts.

See Also

► Quipu

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Mathematics in Vietnam

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Introduction

Prior to the late twentieth century, only a few efforts were made to locate and study the extant Vietnamese mathematical treatises. The first attempt was made by the Japanese historian of mathematics Mikami Yoshio 三上義夫 (1875–1950) who in his paper (Mikami, 1934) analyzed the contents of the Vietnamese treatise *Chỉ minh toán pháp* 指明算法 (Guide Towards Understanding of Computational Methods) and provided several quotations from it; the current whereabouts of the book studied by Mikami are unknown. (For the ancient and medieval Chinese personal names, terms, and titles of treatises, I use the *pinyin* transliteration system adopted in Mainland China and in European sinology. For Vietnamese terms, I use their original form in Chinese characters adopted in Vietnam since the first millennium AD together with their Vietnamese transliteration in *Quốc ngữ* 國語 system and, in some cases, with their Chinese reading in *pinyin*. For personal names, titles of books, and technical terms in Chinese, I provide *traditional* Chinese characters and replace them with their simplified versions currently used in the P.R. of China only when referring to publications in which the simplified versions were originally used.) His quotations suggest that the treatise Mikami had at his disposal was either identical with, or textually close to, the extant treatise *Chỉ minh lập thành toán pháp* 指明立成算法 (Guide Towards Understanding of the Ready-made Computational Methods) (see below) (Volkov, 2013a). In 1938, the Chinese mathematician and historian of science Zhang Yong 章用 (1911–1939) visited Hanoi and explored the collection of old Vietnamese books preserved in the French School of

the Far East (École française d'Extrême-orient). Unfortunately, soon after this visit he passed away and his findings remained unpublished. Zhang Yong's study of the discovered materials was summarized by Li Yan 李儼 (Li, 1954). General works by colonial French scholars, such as Huard and Durand (1954, pp. 120, 144, 1963, pp. 538, 540) and by modern Vietnamese authors (e.g., Tạ, 1979), contained only scarce and often unreliable information on traditional Vietnamese mathematics (Volkov, 2002, p. 375). The first systematic attempt to describe the extant Vietnamese astronomical and mathematical texts was made in 1991 by Han Qi 韓琦 (Han, 1991); in his work he used the partial copies of Vietnamese treatises made by Zhang Yong in Vietnam, while the original texts preserved in Vietnamese and French libraries remained unexplored. As for the publications on the history of mathematics in Western languages, only a short paragraph was devoted to the topic by J.-C. Martzloff who drew upon secondary sources (Martzloff, 1997, p. 110). Soon after that, I started publishing papers based on my study of the original mathematical treatises preserved in Vietnam and in France (Volkov, 2002, 2004, 2005, 2006, 2009, 2012, 2013a, 2014a, 2014b).

Vietnamese Mathematics: An Outline

In China, a state-run School of Computations (*Suan xue* 算學 or 筭學) was open during the Northern Zhou 北周 dynasty (557–581), yet there are reasons to suggest that a prototype of the School already existed during the Northern Wei 北魏 dynasty (386–534) (Lee, 2000, p. 515; Volkov, 2014a, p. 58). (In some sources, the character *suan* 筭 is used instead of the character *suan* 算 in the titles of treatises or names of educational institutions. The original meanings of these two characters were different: according to the etymological dictionary *Shuowen jiezi* 說文解字 by Xu Shen 許慎 (AD 55?–149?), the character *suan* 筭 meant “counting rods,” while *suan* 算 meant the operations performed with them). The School was re-established during the Sui 隋 (581–618) and Tang 唐 (618–907)

dynasties and operated, with interruptions, until the early ninth century in two metropolitan cities, Chang'an 長安 (now Xi'an 西安) and Luoyang 洛陽 (Li, 1933 [1977], pp. 260–264; Volkov, 2014a, p. 63.). Vietnam (which at this time occupied a relatively small area in the North of the present-day Vietnam) was dominated by various Chinese dynasties from 111 BC to AD 544 and became a province of the Chinese Empire from 602 to the fall of the Chinese Tang dynasty in 907; it remained under control of ephemeral Southern Chinese dynasties even longer, until 938. This means that in the first millennium AD gifted Vietnamese students, at least formally, had the same right to be admitted to the metropolitan educational institutions as the candidates from other Chinese provinces, and the history of mathematics education in Vietnam prior to 938, technically, is identical with that of mathematics education in the rest of China.

When Vietnam gained independence from China in AD 939, the Vietnamese state took shape based upon the blueprint of its Chinese counterpart, and a State University 國子監 (Viet. *Quốc Tử Giám*, Chinese *Guozijian*, literally “Directorate [of Education of] Sons of State”), an equivalent of the Chinese University of the Tang dynasty, was established in 1076; for the location of this institution in Hanoi, see, for example, Volkov, 2013b, p. 119, Fig. 1. There are records about the metropolitan examinations in “computations” 算 (Viet. *toán*, Chinese *suan*) that took place in 1077, 1261, 1363, 1403 or 1404, 1477, 1507, and 1762, yet the contents of these examinations, with one exception, are unknown (Volkov, 2013b, p. 121, 2014a, p. 68). An attempt to reconstruct the examination procedure is presented below.

In China, the second century of the rule of the Song 宋 dynasty (960–1279) was marked by several attempts to restore mathematics education of the first millennium. The mathematical textbooks were reedited and block-printed in 1084; a new governmental School of Computations was established in the same year. It was closed and opened again several times, and ceased to function in 1120 (Volkov, 2014a, p. 66). After the



Mathematics in Vietnam, Fig. 1 The block-print *Cửu chương lập thành tính pháp* 九章立成併法. A copy preserved in the Institute of Han-Nôm Studies, Hanoi (call number AB.53)

transfer of the capital to Lin'an 安 (modern Hangzhou) in 1127, no attempts to restore the School are known, except the reprinting, in 1200–1213, of the set of mathematical textbooks of 1084 (Friedsam, 2003; Lee, 1985, pp. 96–102; Li, 1933 [1977], pp. 273–280; Volkov, 2014a, pp. 66–68; Yang, 2003, vol. 2, p. 120). The fact that the first mathematics examination in the independent Vietnam took place in 1077, that is, *before* the re-establishment of state mathematics education in China, may suggest that in the eleventh century the Vietnamese mathematics education and examination system functioned according to the Chinese regulations of the first millennium AD. However, the mathematical textbooks supposedly used in Vietnam at that time for mathematics instruction were lost, most likely, prior to the early fifteenth century. One of the possible reasons for this loss may have been the destruction of books by fire in the metropolitan area during the military conflict with Champa in 1371. Champa (占城, Vietnamese Chiêm Thành, Chinese Zhan Cheng) was a state

located in the Central and Southern part of present-day Vietnam; it was defeated by Vietnam in a series of wars and ceased to exist as an independent political entity in 1832. Another reason for the loss of books may have been their massive removal from Vietnamese libraries and transfer to China during the Chinese occupation from 1407 to 1427. After this period, two successive orders of the newly established Lê 黎 dynasty prescribed to look for ancient books all over the country and to deliver them to the court, yet there is no available information concerning any mathematical books found during these campaigns. Moreover, a large number of books were destroyed or lost during the battles that took place in the capital in 1516 and 1592 (Boudet, 1942, p. 233). The state of mathematics and mathematics education in Vietnam of the eleventh to the early fifteenth centuries thus cannot be reconstructed on the basis of the extant sources, even though some hypotheses can be advanced, mainly on the basis of comparison with contemporaneous systems of mathematics education in China, Korea, and Japan; for an outline of these systems, see, for example, Volkov, 2014a.

The last mathematics examination mentioned in historical documents took place in 1762, yet a relatively large number of the extant mathematical treatises dated of the nineteenth and even of the early twentieth century suggest that the traditional Vietnamese mathematics education survived the French invasion (which started in 1859) and existed in some form until the early twentieth century. In particular, the reign of the Emperor Minh Mệnh (Minh Mạng) 明命 (temple name Thánh Tổ 聖祖, personal name Nguyễn Phúc Kiểu 福咬 or Nguyễn Phúc Đảm 福膽, 1791–1841, r. 1820–1841) was the time when traditional Chinese scholarship of the Ming 明 dynasty (1368–1644) was highly appreciated. And even though some elements of the European mathematics and astronomy may have been known to Vietnamese court astronomers in the seventeenth century directly from Western missionaries or via Chinese translations of Western books, the Vietnamese treatises of the nineteenth and even early twentieth century still looked

surprisingly similar to Chinese mathematical texts compiled prior to the advent of the Western mathematics to China in the early seventeenth century. On the interaction between the European missionaries and Vietnamese astronomers, astrologers, and geomancers (indiscriminately referred to as “mathematicians”), see Borri, 1631, pp. 178–190, 1931, pp. 372–381; Baldinotti, 1629, p. 196; De Rhodes, 1854, pp. 111–113, 185; Volkov, 2008.

The catalogs *Cổ Học Viện Thư Tịch Thủ Sách* 古學院書籍守冊 (Inventory of Books [Preserved] in the Hall of Ancient Learning), *Nội Các Thư Mục* 內閣書目 (Catalog of Books [Preserved] in the Inner Pavilion), *Nội Các Thủ Sách* 內閣守冊 (Inventory [of Books Preserved] in the Inner Pavilion), and *Tự Khuê Thư Viện Tổng Mục* 聚奎書院總目 (General Catalog of the College of Advanced Scholarship) of the Imperial library currently preserved in the Institute of Han-Nôm Studies (Hanoi) contain the titles of a number of Chinese books on mathematics. Among them there are the treatises of the first millennium AD *Zhoubi suanjing* 周髀算經 (Computational Treatise on the Gnomon of the Zhou [dynasty]), *Sunzi suanjing* 孫子算經 (Computational Treatise of Master Sun), *Wucaosuanjing* 五曹算經 (Computational treatise of Five Departments), *Haidao suanjing* 海島算經 (Computational treatise [Beginning with a Problem about a] Sea Island), *Xiahou Yang suanjing* 夏侯陽算經 (Computational Treatise of Xiahou Yang), and *Qigu suanjing* 古算經 (Computational Treatise on the Continuation [of Traditions] of Ancient [Authors]); in the catalog *Cổ Học Viện Thư Tịch Thủ Sách* 古學院書籍守冊 all these treatises are dated in the 41st year of the (Chinese) Qianlong 乾隆 reign period (i.e., 1776), and this date may suggest that these copies were based on the editions of the respective treatises preserved in the Chinese Imperial collection *Siku quan shu* 四庫全書. Another group of Chinese mathematical treatises listed in these catalogs consists of later mathematical works such as the *Xiangjie jiuzhang suanfa* 詳解九章算法 (Detailed Explanations of the Computational Methods of Nine Categories) (1261) by Yang Hui 楊輝 (1238?–1298?) (the *Jiuzhang suanfa* 九章算法

is a variant title of the well-known classic *Jiuzhang suanshu* 九章算術 (Computational Procedures of Nine Categories) also known as “Mathematical Procedures in Nine Chapters”), the *Suanfa tongzong* 算法統宗 (Interrelated Origins of Counting Methods) (1592) by Cheng Dawei 程大位 (1533–1606) (listed as *Suanfa tongzun* 算法統尊 printed in the year *gui-si* 癸巳 of the era Wanli 萬曆, i.e., 1593), the *Gougu yinmeng* 勾股引蒙 (Introduction for Beginners to [Methods] of Right-Angle Triangles) by Chen Xu 陳訐 (1650–1722), the collected works of Mei Wending 梅文鼎 (1633–1721), namely, *Mei Shi Leshuan Quanshu* (Complete Books on Calendar and Computations of Mr Mei) (1723) and *Mei Shi Congshu Jieyao* (Compiled Essentials of the Collected Books of Mr Mei) (1759), the *Yang Hui suanfa zhaji* 楊輝算法札記 (Reading Notes on the Computational Methods of Yang Hui) by Song Jingchang 宋景昌 (dates unknown; active in the mid-nineteenth century) printed in 1842, and the *Zhiming suanfa* 指明算法 (Guide Towards Understanding of Computational Methods). The author and date of publication of the latter treatise are unknown, but it is quite possible that this book was not identical with the aforementioned Vietnamese treatise *Chỉ minh toán pháp* 指明算法 studied by Mikami Yoshio, because there existed several Chinese mathematical treatises bearing the same title; for instance, the catalog of the old Chinese mathematical books (Wu & Li, 2000) lists six treatises with the same title *Zhiming suanfa* 指明算法 published during the Ming and Qing dynasties (p. 366). One more comment is in order here: the catalog *Cổ Học Viện Thư Tịch Thủ Sách* lists the treatise *Xiangjie jiuzhang suanfa* as “a block-print [made] in the year *wu-chen* of the era *Shaoxing* of the Song dynasty” 刻宋紹興戊辰年; this year corresponds to AD 1148, which is inconsistent with the conventional dates of life of Yang Hui. The Vietnamese Imperial library also preserved a number of Chinese works on calendar and mathematical astronomy, yet it remains unknown how much the Chinese books from this impressive collection were available to the Vietnamese scholars interested in mathematics and mathematical astronomy.

The Extant Vietnamese Mathematical Treatises

This section contains an annotated and alphabetically ordered list of the extant Vietnamese mathematical treatises currently preserved in libraries and in private collections. The book conventionally considered the oldest, the *Toán pháp đại thành* (no. 16 below), is credited to the authorship of one Lương Thế Vinh 梁世榮 (1441–1496?), a high-rank official of the Lê 黎 dynasty (1428–1789) (see below). Another book (no. 3 in the list) was compiled in the early eighteenth century. The other dated books were published either in the nineteenth century or even in the early twentieth century. The remaining books are not mentioned in the bibliographic chapter of the *Đại Việt thông sử* 大越通史 (Complete History of the Grand Viet) published in 1749 by the famous Vietnamese literatus Lê Quý Đôn 黎惇 (1726–1784?), and therefore one can be tempted to date all the remaining books as compiled not earlier than the late eighteenth century (Gaspardone, 1934, p. 149; Tran, 1938, pp. 97–98). On the other hand, the mathematical contents of all these books are similar to that of Chinese mathematical treatises antedating the introduction of European mathematical methods to China by the Jesuits in the early seventeenth century.

1. *Bút toán chỉ nam* 筆算指南 (Compass of Handwritten [lit. “Brush”] Computations)

This text was authored by one Nguyễn Cẩn 謹 (also written as 謹 elsewhere; dates unknown) and revised by Kiu Oánh Mậu 喬瑩懋 (1854–1912), the two extant block-printed copies are dated 1909. The book is formally devoted to the explanation of the Western method of written calculations (the practitioners of Vietnamese mathematics traditionally used counting instruments such as counting rods and abaci to perform arithmetical operations), but actually it covers a rather wide range of topics characteristic of traditional Chinese and Vietnamese mathematics. The book contains

five chapters (*quyển* 卷). Chapter 1 is entirely devoted to detailed explanations of four arithmetical operations performed in written form and exemplified with relevant problems. Chapter 2 contains problems of various types, from simple division to solution of simultaneous linear equations. Chapter 3 deals with the “measuring fields,” that is, calculation of the areas of plane rectilinear and curvilinear figures, and chapter 4 is devoted to square and cube root extraction. The concluding chapter 5 deals with right-angle triangles and is mainly devoted to methods of distance surveying with one or several gnomons using the methods found in ancient and medieval Chinese mathematical treatises. The Institute of Han-Nom Studies hosts a manuscript titled *Toán pháp* 算法 (Computational methods) authored by Nguyễn Cẩn 謹 and revised by Kiêu Oánh Mậu 喬瑩懋; the copy is dated 1909 (Tran and Gros 1993, v. 3, p. 352, no. 3791). It is possible that this is a manuscript copy of the *Bút toán chỉ nam* 筆算指南.

2. *Chỉ minh lập thành toán pháp* 指明立成算法 (Guide for Understanding of the Ready-made Computational Methods)

This treatise completed by Phan Huy Khuông 潘輝框 in 1820 opens with a picture of an abacus which is an exact reproduction of the picture found in the aforementioned Chinese mathematical treatise *Suanfa tongzong* by Cheng Dawei. The picture is followed by tables representing powers of 10, monetary units, units of length, weight, and volume. The following pages contain 32 diagrams of various “fields’ shapes,” that is, various rectilinear and curvilinear plane figures; similar shapes can be found in the *Suanfa tongzong*, even though the list found in the Vietnamese treatise differs in spots. The treatise contains a “mock examination problem” with a solution and explanations; it was translated and discussed in the work of Volkov (2012).

3. *Cửu chương lập thành tính pháp* 九章立成併法 (Ready-made Methods of Addition of Nine Categories)

As the conventional dates of publication of the inspected editions suggests (namely, 1713 and 1721), this is the earliest extant Vietnamese mathematical text (here the word “earliest” refers to the date of physical production, i.e., printing, of the text and not to the date of its actual compilation). The treatise is relatively short and written partly in Nôm and partly in classical Chinese. There exist block-printed editions of the treatise (Fig. 1) and one manuscript version of it was altered by a later editor, arguably, in the early nineteenth century. The catalogue of Tran and Gros (1993, v. 1, pp. 375–376) suggests that the treatise was compiled by one Phạm Hữu Chung 范有鍾, literary pseudonym (字) Phúc 福; however, the name of the author is specified in one of the editions as Phạm Hữu Chồng (?) 范有鍾 and the pseudonym as Phúc Cẩn 福謹, while another source provides the pseudonym of the author of the treatise as phonetically identical yet written with a different character Cẩn (福謹).

The treatise is not subdivided into chapters and consists of short sections devoted to discussions of various topics such as multiplication table, calculation of areas of plane figures, proportional distribution, and operations with common fractions, often in versified forms. The treatise also contains a number of mathematical problems presented in the traditional format “problem – answer – solution.”

4. *Cửu chương lập thành toán pháp* 九章立成算法 (Ready-made Computational Methods of Nine Categories)

The author and actual time of compilation of this treatise are unknown; there exists a manuscript copy of it made in 1899 and preserved in the National Library of Vietnam (Hanoi). The text introduces the names of the “large numbers,” a multiplication table, and computation of areas of rectilinear and curvilinear figures.

5. *Cửu chương toán pháp* 九章算法 (Computational Methods of Nine Categories); another title: *Cửu chương toán pháp lập thành* 立成 (Ready-made Computational Methods of Nine Categories).

The catalog of the collection of the Institute of Han-Nom Studies (Hanoi) lists two manuscript copies of this treatise produced in 1882. It opens with the section titled “Nam toán” 南算, “Southern (i.e., Vietnamese) computations” containing explanations of arithmetical operations, a list of names of the large powers of 10, and the multiplication table 9×9 . Next comes a long “historical” section in Nôm containing explanations of basic mathematical operations and a legendary history of Vietnamese mathematics originating from the traditional Chinese mathematical curriculum. The following sections contain rhymed descriptions of various mathematical methods, such as extraction of square roots, reduction of common fractions, calculations needed for conversion of units of measure and monetary units, calculations of areas of plane figures, simple and weighted distribution. In this part, short rhymed descriptions are accompanied by relevant detailed computational procedures. The next section contains a large number of mathematical problems of various kinds, including several problems of indeterminate analysis, such as, for example, the classical problem concerning the unknown number of rabbits and roosters having together 36 heads and 100 feet.

6. *Đại thành toán học chỉ minh* 大成算學指明 (Guidance and Explanations for the Great Compendium of Mathematical Learning)

The treatise is authored by one Phạm Gia Kỳ 范嘉紀, a governmental functionary (dates unknown), and edited by Phạm Gia Chuyên 范嘉璵 (b. 1791, a doctoral *tiến sĩ* 進士 degree holder since 1832), a scholar from the state University *Quốc Tử Giám*. The treatise preserved in the Han-Nôm Institute is a meticulously handwritten text without a cover, yet the title and the names of the compilers are mentioned on the first page of the copy. The dates of compilation and of publication are not specified. The treatise contains 20 subsections; some of them fit into traditional Chinese classification of “Nine categories,” for example, section

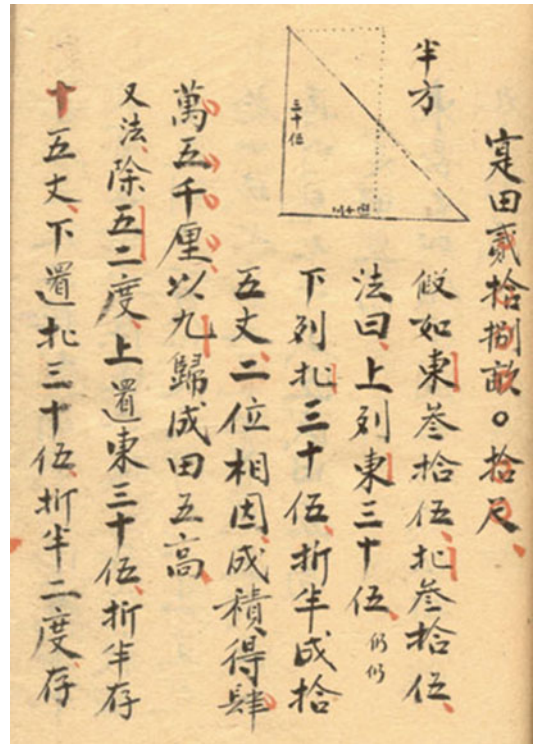
16 is devoted to the method of double false position. However, certain sections appear rather original; for example, section 1 contains a classification of rectilinear solids containing 15 different types, to the best of my knowledge, not found in the extant Chinese treatises.

7. *Đại thành toán pháp* 大成算法 (Computational Methods of Great Compendium)

The cover page of this manuscript treatise preserved in the Institute of Han-Nôm (Hanoi) is missing, and the title *Cửu chương toán pháp* 九章算法 that appears on its second page refers to the multiplication table and thus hardly can be the title of the treatise. Another title, *Đại thành toán pháp* 大成算法, appears on p. 5a of the manuscript, yet it remains unclear whether this is the original title of the treatise. The text is written in classical Chinese yet contains a number of paragraphs in Nôm explaining certain procedures. It is not subdivided into chapters and contains descriptions of arithmetical operations, measure units, and a list of problems devoted to the calculation of areas of plane figures, simple and pondered distribution, calculation of land taxation, currency conversion; square and cube root extraction procedures are not found among the topics discussed. The latter fact suggests that this treatise is different from the *Cửu chương toán pháp* 九章算法 of 1882, despite the fact that these two books are listed together in Tran and Gros (1993).

8. & 9. *Lập thành toán pháp* 立成算法 (Ready-made Computational Methods)

An anonymous manuscript of unknown date in classical Chinese bearing this title is preserved in the Institute of Han-Nôm Studies (Hanoi). It contains a standard introductory part devoted to arithmetical operations and a multiplication table followed by a long section devoted to the computation of the areas of plane figures accompanied by relevant diagrams. The remaining part is devoted to mathematical problems of various types. The library of the Institute of History (Hanoi)



Mathematics in Vietnam, Fig. 2 Page 75 of the *Thống tông toán pháp* 統宗算法 (Picture courtesy of the National Library, Hanoi)

hosts another manuscript cataloged under the same title *Lập thành toán pháp*; however, a cursory analysis shows that these two texts are not identical. The actual title of the latter treatise and the date of compilation remain unknown, since the first pages of the manuscript are badly damaged while the last pages are missing.

10. *Thống tông toán pháp* 統宗算法 (Counting Methods of Interrelated Origins)

This is a manuscript of unknown date authored by one Tạ Hữu Thường 謝有常 (dates unknown) and preserved in the National Library (Hanoi) (Fig. 2).

Its title makes an obvious allusion to the aforementioned Chinese treatise *Suanfa tongzong* 算法統宗 (Interrelated Origins of Counting Methods) (1592) by Cheng Dawei 程大位 (1533–1606). Indeed, certain parts of the Chinese treatise are quoted *verbatim*, as, for example, the versified

rules of calculation of areas of plane figures, the problem of two walkers, and so on. Nevertheless, the compiler of the Vietnamese treatise considerably modified sections of the Chinese prototype and added a large number of problems not found in the original, adapted the Chinese original to the Vietnamese measure units, and provided his explanations in Nôm.

11. *Toán điền trừ cứu pháp* 算田除九法 (Nine Methods of Division for Computation [of Areas of] Fields)

A manuscript copy of this anonymous treatise of unknown date is preserved in the Institute of Han-Nôm Studies (Hanoi). The treatise, as its title suggests, is devoted to calculation of areas of plane figures. The text is written in classical Chinese, yet contains commentaries in Nôm.

12. *Toán học cách trí* 算學格致 (Exploration [of Things] and Extension [of Knowledge] in the Science of Computations)

The first page of the manuscript preserved in the Institute of Han-Nôm Studies (Hanoi) is missing and the treatise was listed under the bogus title *Toán pháp* 算法 (Computational methods) in the catalogue of Tran and Gros (1993). However, the actual title of this treatise is reproduced at the beginning of each chapter; it reads *Toán học cách trí Hoàng Phong Dự gia thụ chính bản* 算學格致黃豐裕家書正本, that is, “The rectified copy of the manuscript of the Exploration [of Things] and Extension [of Knowledge] in the Science of Computations [preserved] in the family of Mr Hoàng Phong Dự.” The name of the actual compiler (s) thus is (are) unknown. According to the table of contents, the book originally contained four chapters and an appendix discussing matters related to construction works. However, the extant copy contains only chapters 1–2 and the first four pages of chapter 3; the rest is irretrievably lost. The opening chapter is devoted to numerical notation, execution of arithmetical operations with a counting instrument (an abacus is mentioned but not pictured), and metrological units.

It also contains a number of problems illustrating these topics, such as distribution of a given sum of money among a given number of persons. Chapter 2 is devoted exclusively to the calculation of the areas of rectilinear and curvilinear plane figures accompanied with detailed explanations. Chapter 3 is devoted to extraction of square and cube roots. The contents of chapters 4 and 5 cannot be restored on the sole basis of their titles provided in the table of contents.

13. *Toán học để uẩn* 算學底蘊 (Secrets of the Science of Computation)

Since the first page of the treatise is missing, the name of the author is unknown. The title *Toán học để uẩn* under which the treatise is found in catalogs is apparently determined solely on the basis of the line “Table of Contents of the Secrets of the Science of Computation” 算學底蘊目錄 found on the first page of the only extant manuscript copy of the treatise preserved in the Institute of Han-Nôm Studies. The date of the compilation is uncertain either, but, since the name of the reign era of the emperor Gia Long 嘉隆 (r. 1802–1820) is mentioned in the manuscript, one can suggest that the treatise was compiled no earlier than 1802. The book contains 6 chapters devoted to the following topics: arithmetical operations; computation of areas of plane figures; extraction of square and cube roots; a brief presentation of the methods according to the traditional Chinese classification 九數 (“Nine [types] of numerical [computations]”); construction works; and a mathematical theory of music. A cursory analysis of the book reveals that it contains a large number of quotations from the aforementioned Chinese treatise *Suanfa tongzong* 算法統宗 (Interrelated Origins of Counting Methods) (1592) by Cheng Dawei 程大位.

14. *Toán học tâm pháp* 算學心法 (Mental Methods of the Science of Computation)

The cover page of the manuscript copy of this treatise hosted in the Institute of Han-Nôm studies is missing and its title is restored on the basis of the title of the preface

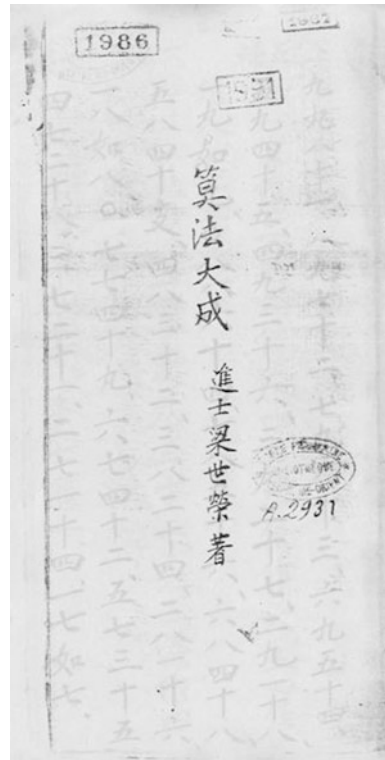
signed by Hoàng Phong Dụ 黃豐裕 in 1850. The table of contents lists five chapters: operations with numbers, calculation of areas of plane figures, square and cube root extraction, computations related to construction works, and computations related to land taxation. However, the chapters are not clearly separated and their titles are inserted in the body of the text, which suggests that the original layout was altered by the copyists. The treatise also contains items not corresponding to the five announced topics, such as methods of remote surveying.

15. *Toán pháp* 算法 (Computational Methods)

The actual title of the book remains unknown; the bogus title “Computational Methods” was apparently given to a manuscript with missing first pages by the copyist(s) or by librarians on the basis of its contents. The author and the date of the compilation are not known either. A manuscript copy and a microfilm of the book are preserved in the Han-Nôm Institute (call number A.3150). The book is not subdivided into chapters; it contains a sequence of 250-odd problems devoted to topics including calculation of surfaces, applications of the right-angle triangles, extraction of square and cube roots, among others. A cursory analysis shows that the book is but a copy-and-paste style compilation made on the basis of the Chinese mathematical treatise *Suanfa tongzong* 算法統宗 (Interrelated Origins of Counting Methods) (1592) by Cheng Dawei 程大位. For instance, problems devoted to the calculation of areas of plane rectilinear and curvilinear figures, the related computational procedures as well as the related geometrical diagrams of the Vietnamese treatise are found in chapter (*juan*) 3 of the *Suanfa tongzong*, problems devoted to root extraction and solution of polynomial equations were copied from chapter 6 of the Chinese treatise, and so on.

16. *Toán pháp đại thành* 算法大成 (Great Compendium of Mathematical Methods)

The date of compilation and the name (s) of the compiler(s) are unknown.



Mathematics in Vietnam, Fig. 3 The cover page of the *Toán pháp đại thành* 算法大成 preserved in the collection of the Institute of Han-Nôm Studies, Hanoi

A treatise with the same title was credited to the authorship of Lương Thế Vinh 梁世榮 (1441–1496?), a functionary of the Lê 黎 dynasty (1428–1789), in his biographies (see below); however, the authorship and the actual date of compilation of the treatise preserved in the Library of the Institute of Han-Nôm Studies (Hanoi) are unknown, and some parts of the treatise can make one doubt that the book was compiled in the fifteenth century. There exist two manuscript copies of the treatise, one produced prior to 1934 (Fig. 3) and its copy made in 1944.

The treatise is not subdivided into chapters and contains 138 problems, if one counts the problems per se as well as several procedures that do not correspond to any particular problems; the presence of those most probably resulted from loss of parts of the text. Some geometric problems are not

explicitly stated, but introduced with a diagram of a figure with given dimensions. The problems found in the treatise are related to such popular topics of traditional Chinese mathematics as the partitioning (proportional distribution), proportions, “rule of three,” rule of double false position, square root extraction, calculation of the areas of rectilinear and curvilinear plane figures, calculation of volumes of solids, conversion of monetary and metrological units of various types, indeterminate analysis, and “numerical divination.” The treatise also contains a large and relatively independent section devoted to land taxation (for more details, see below; see also Volkov, 2002).

17. *Toán pháp đề cương* 算法提綱 (Presentation of the Key Points in Computational Methods)

The title *Toán pháp đề cương* 算法提綱 of this treatise hosted in the National Library (Hanoi) is not the actual title of the book. The first page(s) of the manuscript is (are) missing and *Toán pháp đề cương* is but the subtitle of its first remaining section. The first part of the treatise contains a very detailed explanation of the operations performed with the abacus and provides numerous diagrams representing configurations of beads on the abacus (the instrument featured is the standard Chinese 2+5 beads abacus with 11 bars). The remaining part of the manuscript is a compilation featuring nine categories of Chinese traditional mathematics most likely made, as a cursory analysis suggests, on the basis of the Chinese treatise *Suanfa tongzong* 算法統宗 by Cheng Dawei 程大位.

18. *Toán pháp ký diệu* 算法奇妙 (Mysteries of Computational Methods)

The title of this anonymous treatise was established by Tran and Gros (1993) most likely on the basis of the first page of the single manuscript copy preserved at the Institute of Han-Nôm Studies in Hanoi. However, both the table of contents and the opening part of the treatise following it specify its title as *Tập thành chư gia huyền nghì toán pháp* 集成家幻儀算法 (Complete collection of

the counting methods [using] magic devices of all schools [of mathematics]). The date of compilation of the treatise is uncertain; however, since it contains an appendix featuring the taxation norms adopted during the reign of the Emperor Minh Mạng 明命 (r. 1820–1841), one can conclude that the received manuscript copy was made no earlier than 1820 (it remains unclear whether there existed a printed edition of it). The treatise is not subdivided into chapters, even though the title page (possibly added later) suggests that the treatise originally contained “three chapters united in one.” The received manuscript contains a short introductory section providing information about the numerical notation, units of measures, and other auxiliary topics; the main section contains a number of problems, tables, and explanations related to the traditional topics such as calculation of areas of plane figures, operations with common fractions, and extraction of square and cube roots.

19. *Toán pháp quyển* 算法卷 (Volume on Computational Methods)

This mathematical work signed by one Đỗ Đức Tộ 杜德祚 was completed in 1909. The book opens with a multiplication table and a set of prescriptions for operating a counting instrument, and contains problems related to proportional distribution, calculation of volumes of solid figures, calculation of areas of plane figures, extraction of square roots, calculation of the harvest collected from a field with a given surface, etc.

20. *Tổng tụ chư gia toán pháp đại toàn* 總聚家算法大全 (Great Compendium of the Computational Methods of All Schools)

The manuscript copy preserved in the Han-Nôm Institute is incomplete; it contains only chapters 3 (48 problems) and 4 (32 problems), and the first two pages of an Appendix (containing one problem). The problems deal with weighted distribution, calculation of volumes, and other topics relevant mainly to construction works, mass labor, and other issues related to administrative duties. It is possible that the treatise contains problems

proposed at state mathematics examinations (chapter 3 opens with a mention of such an examination).

21. *Trùng訂 Toán học chỉ nam tân biên* 重訂算法指南新編 (New Edition of the Re-established [text of the] *Compass for Methods of Computations*)

A manuscript copy of this anonymous treatise is preserved in the library of the Institute of History (Hanoi). It contains problems dealing with calculation of areas of plane figures, extraction of square and cube roots, applications of right-angle triangles to remote surveying (including the method involving two gnomons and its justification with diagrams), use of gnomons for land surveying, as well as other methods. The text mentions the system of measuring units established during the reign of the Emperor Gia Long (1802–1820) and is written in classical Chinese, thus appearing to be compiled in the first half of the nineteenth century; however, it contains a large number of Western-style calculations written with Arabic numerals inserted into the text, thus giving the impression that its authors or at least its later editors or copyists were well familiar with the Western methods, and the extant copy was produced much later.

22. *Ý Trai toán pháp nhất đắc lục* 意齋算法一得錄 (A Record of What Ý Trai Understood Correctly in Methods of Computation)

This treatise was completed in 1829 by Nguyễn Hữu Thận 有慎 [=Nguyễn Ý Trai] (b. 1736?-?) who occupied high positions in the government and stayed in China between 1809 and 1813 where he obtained books related to astronomy and communicated with local astronomers. For more information on the author and the contents of the treatise, see Volkov, 2014b, pp. 254–255. The compilation consists of eight chapters devoted to the basic arithmetical operations performed with a counting instrument, metrology, computation of areas of plane figures, weighted distribution, “extraction of square roots” (i.e., in modern terms, solution of quadratic equations), properties of the

right-angle triangles (especially those related to their use for remote surveying), “extraction of cube roots” (i.e., numerical solution of cubic equations), and other topics of the traditional mathematical curriculum. The book contains the author’s explanations concerning the numerical operations to be performed, the etymology of the mathematical terms, the rationale of the procedures, and thus may have been used as the mathematical manual for professional training of governmental astronomers and mathematicians. My paper (Volkov, 2014b) contains annotated translations of excerpts related to the method of weighted (or proportional) distribution.

The Structure of a Mathematical Treatise: The Example of the *Toán pháp đại thành*

There are two manuscript copies of the treatise *Toán pháp đại thành*, both found in the Han-Nom Institute, Hanoi; their call numbers are VHv.1152 and A.2931. When manuscript A.2931 was produced is unknown (but it certainly happened prior to 1934), while the date when the copy VHv.1152 was made (1944) is written on its front page; a comparison of the copies suggests that the MS VHv.1152 is a copy of A.2931. Neither manuscript has a preface or a postface, or any other data which would suggest the date when the treatise was compiled or would specify the identity of the author(s). The name of the presumed author (“Doctor Lương Thế Vinh”) is written only on the first page of each manuscript next to the title; however, it is possible that this page was added later (Gaspardone, 1934, p. 149, n. 1).

The treatise is compiled in the traditional “Chinese” way, as a collection of problems with numerical answers given along with the procedures (algorithms) for their solution. There are also several procedures that do not correspond to any particular problems; most probably this is the result of loss of parts of the text containing the corresponding problems and answers. The total number of problems in the treatise amounts to 138. Some geometric problems are not explicitly

stated, but introduced with a diagram of a figure with given dimensions. In one case neither numerical data nor a problem accompanied an algorithm, yet the algorithm may well be a fragment from the famous Chinese “Sunzi remainders problem.”

The text of the treatise can be subdivided into eight parts:

Part 1 (problems 1–35) contains problems devoted to partitioning, and, in particular, to division. Part 2 (problems 36–42) contains problems devoted to the calculation of the areas of plane figures: a square, a rectangle, a figure approximated by the area of a trapezium, a circle, and a segment of a circle. Part 3 (problems 43–69) contains problems devoted to proportions, the rule of three, and the rule of double false position, as well as to rather simple cases of multiplication and division. This part also includes a method for calculating the height of an object when the height of another object and the length of the shadows of both objects are given. Part 4 (problems 70–85) contains problems devoted to root extraction and to an auxiliary algorithm used for the conversion of monetary units of one type into another. Part 5 (problems 86–93) is a sequel to Part 3. The reader is asked to solve problems on the calculation of interest and on multiplication and division. However, there is a problem devoted to the calculation of the volume of a solid figure and a fragment on divination. Part 6 (problems 94–131) is related to various subjects, such as calculations of the areas of various figures. Here one finds such shapes as rectangles, circular segments, a “horn of the bull,” circles, “drums,” ellipses, rings, an “eye-lid” (or “eye-brow,” i.e., the intersection of two circles), an isosceles triangle, a trapezium, a rectilinear figure composed of several adjacent trapezia, a quadrilateral with four given sides, and the figure formed by two adjacent squares. The remaining problems in this group are devoted to the extraction of square roots, calculation of the volumes of rectilinear solids, and to the conversion of metrological units. Part 7 does not contain mathematical problems; this is a large independent text devoted to land taxation. Part 8 (problems

132–138) embraces various problems devoted to “numerical divination,” the calculation of the height of a tree when the length of its shadow is given, a rhymed solution to a problem of indeterminate analysis, and the calculation of the area of a quadrilateral.

Several “earmarked” mathematical problems and methods found in the *Toán pháp đại thành* studied in order to suggest the possible origins of the contents of the treatise were discussed in the work of Volkov (2002). The analyzed topics included: (1) the counting instruments to be used; (2) the 9×9 multiplication table featured in the treatise; (3) the lists of the so-called large numbers; (4) rhymed algorithms for computation of areas; (5) problems of remote surveying; (6) problems related to numerical divination; and (7) problems on indeterminate analysis. The results of the comparison of the abovementioned mathematical methods, problems, and instruments with their Chinese counterparts can be summarized as follows (for more details, see Volkov, 2002):

1. The lack of explicit references to the abacus in the treatise suggests that either the *Compendium* was compiled before Vietnamese mathematicians were acquainted with any Chinese books devoted to abacus calculations, or it was compiled later solely on the basis of Chinese and Vietnamese mathematical books written prior to 1573 when the first extant Chinese mathematical treatise devoted especially to the use of the abacus, Xu Xinlu’s 徐心魯 *Counting Procedures for Pearls on a Plate* (*Panzhu suanfa* 盤珠算法), was published.
2. The text of the treatise does not contain any information confirming that it was indeed authored by Lương Thế Vinh, the fifteenth-century literatus and governmental officer.
3. It is not impossible, however, that the book may well have been a compilation made exclusively on the basis of mathematical treatises compiled in China prior to the late fifteenth century and later available in Vietnam. However, the compilation of the treatise involved a substantial “localization,” that is

the adaptation of the problems and methods to local measure units, currency, tax system, as well as to the names of specific local objects mentioned in the problems (plants, drugs, kinds of food, animals).

4. The seeming similarity between certain methods in the *Compendium* and in the Chinese treatise *Suanfa tongzong* 算法統宗 (1592) by Cheng Dawei 程大位 does not necessarily mean that the Vietnamese text was compiled on the basis of the book of Cheng. The similarity can be explained by the fact that Cheng himself based his manual on numerous mathematical texts compiled in the thirteenth to sixteenth centuries available to him, firstly and most importantly, the treatises of Yang Hui 楊輝 (fl. ca. 1275) and Wu Jing 吳敬 (fl. ca. 1450). It is not impossible that the compilers of the *Compendium* also had access to these treatises, or to other older Chinese treatises containing similar materials and later lost.

The preliminary exploration of the contents of the Vietnamese treatise *Toán pháp đại thành* presented in Volkov (2002) thus did not permit a clear picture of its origins. An exploration of the materials related to the life and activity of its presumed author, Lương Thế Vinh, thus appeared necessary to establish the origins of the book. The obtained results of this exploration (Volkov, 2005, 2006) are summarized in the following section.

Lương Thế Vinh: The Case of a “Mathematical Agiography”

The biographies of Lương can be provisionally subdivided into two categories, the “historical biographies” and the “legendary accounts.” The “historical biographies” of Lương Thế Vinh are found in the collections of biographies *Đăng khoa lục* 登科錄 (*Records of Successful Examinees*) by Nguyễn Hoãn 阮 (1712–1791) et al., in the manuscript entitled 登科錄本 (Manuscript copy of the *Records of Successful Examinees*), and in the treatise *Lịch đại đại khoa lục* 歷代大科

錄 (*Records of Great Examinations Through Generations*). All these texts present rather short descriptions of Lương’s official career and specify his birthplace and his official duties within the Hàn lâm 翰林 Academy. The second and third treatises mention a mathematical book he wrote, yet provide different titles for the book. The second and the third biographies mention Lương’s diplomatic activities, the details of which, however, remain unspecified.

The second group of the extant Lương’s biographies focuses primarily on the supernatural circumstances of his life and death. A short description of these biographies is found in Volkov (2005), and the translation of one of them is published in Volkov (2006). The preliminary analysis of the legends suggests that the early legends of Lương were created in two nonintersecting social circles (that can be dubbed “Palace” and “Village”), yet both groups of legends portrayed him as possessing supernatural powers or divine origin. One can conjecture that the reason he became associated with mathematics may have been related to his official duties during his lifetime such as, for example, his participation in diplomatic activities and in military operations against the Cham, probably related to his work in cartography, briefly mentioned in some of his biographies. His legendary capacities of “counting” and “measuring” (in a broader sense) in this case would have merged with his established status of supernatural being and thus may have made him the patron saint of professional mathematicians by the early eighteenth century (Volkov, 2005).

The temple devoted to Lương Thế Vinh 梁狀元祠 located in his native village Cao Hương (Nam Định Province, Vụ Bản district) hosts the statue of Lương, his portrait, details of his official costume (boots and hat), and a number of Imperial edicts related to the establishment and functioning of the temple (Volkov, 2005). The official portrait of Lương preserved in the temple (Fig. 4) depicts him as a state functionary without making any visual reference to the miraculous circumstances of his birth and life; only one inscription mentions a mathematical work he presumably authored.



Mathematics in Vietnam, Fig. 4 The portrait of Lương Thế Vinh preserved in his temple, Cao Hưong village

Conclusions

The available materials do not suggest any reliable picture of traditional Vietnamese mathematics prior to the fifteenth century, and no information is available concerning the transformation of the system of mathematics education that most likely resulted from the Chinese occupation of Vietnam in the early fifteenth century. However, numerous sources suggest that mathematics and mathematical astronomy occupied in Vietnamese society a position similar to that of its Chinese counterpart in the first millennium AD and remained a discipline supported by the state until the early twentieth century.

The extant Vietnamese mathematical treatises were produced, most likely, during the period from the early eighteenth to early twentieth centuries on the basis of older Vietnamese mathematical treatises which presumably were based upon their Chinese counterparts of the Ming dynasty (1368–1644). A preliminary investigation of the extant treatises suggests that the Vietnamese mathematicians were not aware of the elements of the contemporaneous Western mathematics introduced by Western

missionaries in China in the seventeenth and eighteenth century, or were not willing to mention them in their texts. Instead, the Vietnamese mathematical treatises appear rather similar to the corpus of the “practical” or “popular” Chinese mathematical treatises of the late Yuan (1279–1368) and Ming dynasties dramatically different from the high-level mathematical texts devoted to the higher degree polynomial algebra of the late Song (960–1279) and early Yuan dynasties. In Ming dynasty China, traditional mathematics was transformed into an applied discipline used for practical ends by low-level state officials, merchants, and artisans, while remaining the subject of the research conducted by isolated scholars without the ideological and material support of the state. It was no longer one of the subjects of the state examinations, as it had been during the Tang (618–907) and Song dynasties. In Vietnam, on the contrary, the discipline remained embedded in the framework of the old Chinese-style state education, employed traditional didactic practices, and was linked to the bureaucratic hierarchy via the system of state mathematics examinations (Volkov, 2014b).

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Mathematics of the Hebrew People

Tony Lévy

A “Hebrew mathematical text” is any text or work whose language is Hebrew (usually written in Hebrew characters), and whose content is mathematical in a narrow sense, that is, does not include astronomy (apart from relevant mathematical sections), astrology, or calendar calculations.

Apart from a few passages that are to be found in biblical and postbiblical (rabbinical) literature and which are relevant to the history of mathematics (number words and fraction words, practical rules of geometry), the oldest mathematical tract in Hebrew is the *Mishnat ha-Middot*, by an unknown author. This tract gives practical rules for the measurement of areas and volumes, and then deals with the measurements (*middot*) of the Tabernacle erected by the Jews in the desert. It has been recently shown that its composition was probably influenced by the geometrical part of al-Khwārizmī's *Algebra*. This tract remained unknown to most medieval Jewish scholars and its Hebrew mathematical terminology was of no consequence.

Two famous scholars are central in the eleventh and twelfth centuries in Spain: Abraham bar Hiyya (ca. 1065–1145) and ► [Abraham ibn Ezra](#) (1092–1167). This period saw the actual birth of Hebrew mathematics.

Abraham bar Hiyya, also called Savasorda (latinized from the Arabic *ṣāhib al-shurta*), flourished in Barcelona in Christian Spain, but was probably educated in the Arabic kingdom of Saragossa. Bar Hiyya wrote books in Hebrew on mathematics, astronomy, astrology, and philosophy. He clearly indicated that his Hebrew compositions were written for Jews living in southern France (in Hebrew, *Ereṣ Sarfat*) who were unacquainted with Arabic scientific culture and unable to read Arabic texts. Bar Hiyya can thus rightly be considered the founder of Hebrew scientific culture and language, and specifically the father of Hebrew mathematics. We know of two mathematical compositions by Bar Hiyya: the extant parts of a scientific encyclopedia and a geometrical compilation.

The first of these books, *Yesodey ha-Tevuna u-Migdal ha-Emuna* (The Foundations of Science and the Tower of Faith), is presumably an adaptation from some unknown Arabic composition; the geometrical and arithmetical parts are extant. The study of its content sheds some light on eleventh century mathematical literature in Western Islamic lands and its diffusion.

The *ḥibbur ha-Meshiḥa we ha-Tishboret* (The Composition on Geometrical Measures) enjoyed

a very large diffusion as the *Liber embadorum* in its Latin translation by Plato of Tivoli (1145). Much has been said by ancient and modern scholars concerning the importance of this text for traditions of practical geometry in Europe.

Abraham ibn Ezra was born in Tudela in Aragon. Raised in Arabic culture, and probably knowing Latin, Ibn 'Ezra spent the last part of his life traveling over Europe. He was a poet, a grammarian, an astronomer-astrologer, and a biblical commentator of great reputation. Ibn Ezra, one generation after Bar ḥiyya, also created a new scientific language, different from that of his predecessor, closer to biblical Hebrew and less influenced by Arabic. His mathematical work consists essentially of the important book *Sefer ha-Mispar* (The Book of Number), but numerous arithmetical and numerological remarks are scattered in his others works, including his biblical commentaries.

His *Book of Number*, written probably before 1160, expounds for the first time the decimal positional notation including zero. The foundations of arithmetic are then discussed in the following order: multiplication, division, addition, subtraction, fractions, proportions, and square roots.

In the thirteenth and fourteenth centuries, the works of both Abrahams opened up to the Jewish communities unfamiliar with Arabic access to basic mathematical knowledge. They obviously mention the names of classical authors, Greek or Arabic, and of their works, but these works themselves only became partly available in Hebrew during the thirteenth century. This first major period of translations continued until the first third of the fourteenth century.

Several of the translators were members of a single family of scholars. The first, Yehuda [ibn Tibbon](#), left Granada in the middle of the twelfth century, at the time of the arrival of the Almohads in al-Andalus, and settled in Lunel in the south of France. There, he undertook the translation into Hebrew of ethical and philosophical works written in Arabic by Jewish scholars from Spain. His son, Samuel ben Yehuda, translated the famous *Guide for the Perplexed* of

Maimonides from Arabic into Hebrew. The third and fourth generations of this family include translators of scientific works.

Thus, Jacob Anatoli (ca. 1194–1256), working in Italy under the patronage of Frederic II of Sicily, translated Ptolemy's *Almagest* and Ibn Rushd (Averroes)' *Compendium on Astronomy*, lost in the Arabic original. According to recent findings, he is perhaps the first translator into Hebrew of Euclid's *Elements*. Moses ben Samuel ben Yehuda of Montpellier (active between 1240 and 1283) translated, among others things, works by Euclid (*The Elements*), Theodosius (*Sphaerics*), al-Fārābī (The Commentary on *The Elements*), Ibn al-Haytham (The Commentary on *The Elements*), and al-ḥaṣṣār (The so-called *Arithmetic*) Lastly, Jacob ben Makhir of Montpellier (ca. 1236–1305) also translated works by Euclid (*The Elements*, the *Data*, and perhaps the *Optics*), Autolycus of Pitane (*On the Moving Sphere*), Menelaus (*Sphaerics*), Jābir ibn Aflah (*Astronomy*), and Ibn al-Haytham (*Astronomy*).

To this period belongs a Jewish scholar from Toledo, who also had contacts with Frederic II of Sicily during the first half of the thirteenth century. Yehuda ben Solomon ha-Kohen (probably b. 1215) wrote in Arabic a (lost) encyclopedia of sciences, which he translated himself into Hebrew, *Midrash ha-hokhma* (The Learning of Wisdom). This book includes a redaction, or free translation, of Euclid's *Elements* (Books I–VI and XI–XIII).

A generation after Jacob ben Makhir, Qalonymos ben Qalonymos (Maestro Calo) of Arles (b. 1287) translated Archimedes (*The Sphere and the Cylinder* and the commentary upon it by Eutocius, perhaps also *The Measurement of the Circle*), Nicomachus of Gerasa (a lost Arabic paraphrase of the *Introduction to Arithmetics*), Thābit ibn Qurra (on the *Figura Sector* of Menelaus), Jabir ibn Aflah (on the same problem, a text apparently lost in Arabic), and Ibn al-Haytham (a part of the commentary on *The Elements*, already translated in part by Moses ibn Tibbon). Qalonymos also translated several texts for which the original Arabic has not yet been identified, or is now lost: thus we have important fragments of a *Treatise on Cylinders*

and *Cones* by Ibn al-Samḥ of Granada (eleventh century), perhaps extracted from a larger book of this Andalusian scholar. Qalonymos is also probably the author of an important mathematical and philosophical composition on the nature of numbers, the *Sefer ha-Melakhim* (The Book of Kings).

Thus, we possess more or less complete Hebrew versions of the treatises of the following classical authors: Euclid, Archimedes, Autolycus, Theodosius Menelaus, Ptolemy, Nichomachus. The conspicuous absence of the name of Apollonius does not mean that he was not known to the Jewish scholars.

The diffusion of the Hebrew versions of important mathematical works created the conditions for the composition of original works by Jewish scholars who were also excellent astronomers. This, at least, is the case of two scholars that we will mention here, as much for the depth of their talent as for the importance of their works. Levi ben Gershon, also called Gersonides (1288–1344) is the author of an important mathematical work. His writings on harmonic numbers (extant only in a Latin translation), on arithmetic and combinatorics (*Ma'aseh ḥoshev*, Work of the Reckoner), and on the geometry of Euclid have been recently studied from the point of view of their contents, of their Arabic and perhaps Latin sources, and their possible influence on later works.

Immanuel ben Jacob Bonfils of Tarascon, one generation after Gersonides, must be mentioned in connection with two mathematical areas: that of the introduction of decimal fractions, and that of calculations related to the measurement of the circle. The sources and the scope of his developments in both areas have not yet been fully investigated.

In fifteenth-century Italy, there were a number of translators and commentators of note. The movement toward Italy is not only geographical: the Hebrew texts which we possess, and which have been only partially studied, show an increasing influence of Latin and also the vernacular languages.

Mordekhai (Angelo) Finzi of Mantua (active between 1441 and 1473) is without a doubt the

best known of these translator-scholars. He translated several compositions of Abū Kamīl (a tenth-century Arabic scholar); he seems also to have been the translator (or perhaps the author) of a compendium on geometry in 11 chapters. Finzi is the author of a *Ma'amar be-ḥeshbon Medidut ha-Gigiyyot we ha-ḥaviyyot* (Treatise on the Measurement of Buckets and Barrels) in which he quotes Bar ḥiyya and “the masters of the abacus,” and whose analysis should yield useful clues on the history of stereometry before Kepler. Finally, we must emphasize Finzi’s role in the diffusion of algebraic knowledge: in addition to Abū Kamīl’s *Algebra*, Finzi translated from Italian or Latin into Hebrew the noteworthy algebraic composition of a certain Maestro Dardi of Pisa (who wrote in the fourteenth century), dealing with complex equations involving powers up to the twelfth degree.

The contacts of Jewish scholars in Italy with those in Constantinople, especially after the arrival of the Ottomans, constitute perhaps one of the channels by which ideas or texts of the Arabic East diffused.

There is also some mathematics of note in the Judeo-Byzantine scholarly world of the fifteenth to sixteenth centuries. The specific interest in studying this scholarly milieu – besides the talents of its representatives – lies in the use made therein of a triple heritage: that of texts available in Hebrew (Bar ḥiyya, Ibn ‘Ezra, the Greek and Arabic classics in translation, Gersonides, etc.), Arabic texts (sometimes not extant in Arabic) not translated into Hebrew but quoted in Hebrew compositions, and finally the Greek-Byzantine texts.

From this point of view, attention of scholars must be drawn to the mathematical works of Mordekhai Komtino (1402–1482) and of his two students Kalev Afendopulo (1460–1525) and Eliahu Mizraḥi (1455–1526).

The *Sefer ha-ḥeshbon we-ha-Middot* (Book on Reckoning and Measurements) of Komtino shows a direct knowledge of ancient Greek sources such as Hero, and probably also of Byzantine-Greek texts. The *Sefer ha-Mispar* (The Book of Number) by Mizraḥi of which extracts were published in Latin in the sixteenth

century, should be analyzed in the light of recent studies on the history of Arabic and Greek-Byzantine arithmetic. Finally, the commentary by Afendopulo of the Hebrew version of Nicomachus' *Introduction to Arithmetics* is a long text which includes several excursuses on philosophy, astronomy, and astrology.

In this very brief – and far from exhaustive – survey of Hebrew mathematics, an attempt has been made to indicate the importance of these texts and to describe their transmission as a general set of mathematical ideas of Hellenistic origin between the eleventh and the sixteenth centuries, that is, before the rediscovery of Greek original texts and the relaunching of activity in the Renaissance.

See Also

- [al-Khwārizmī](#)
- [Ibn Tibbon](#)
- [Moses Maimonides](#)

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Mathematics of the Maghreb (North Africa)

Ahmed Djebbar

In discussing the mathematical activity which occurred within the framework of Arab-Islamic civilization, it is not possible to speak of one specific tradition from the medieval Maghreb, nor still less of specific traditions from each of the three regions of the Maghreb-Ifriqyā, the central Maghreb, and the far Maghreb. Indeed, there has been one Arab mathematical tradition, born and developed in the East, partially transmitted to the Muslim cities of the west of Central Asia and then, later, to southern Europe by the intermediary of Latin and Hebrew translations. This

tradition was assimilated, revived, and enriched by different scientific milieux.

Mathematics in the Maghreb from the Ninth to the Eleventh Centuries

Considering the close economic, political, and cultural ties which linked the Maghreb with the Andalus, it is not possible to separate the mathematical activities which took place in these two regions of the Muslim West. Indeed, the period which extends from the end of the eighth century to the end of the eleventh was characterized by the development of two scientific traditions linked to each other and brought to life by scholars who, apart from social divisions and differences in laws and religion, were united by the cultural and scientific environment which was made up of exchanges between the Andalus and the Maghreb, and of frequent contacts with the cities of the east – Baghdad, Damascus, and, later, Cairo.

That being said, the beginnings of scientific activities in the Andalus and the Maghreb are not well known. Indeed, information on the earliest mathematical activities of the region is rare and not very specific. But it is reasonable to state that, during the period of installation and consolidation of Arab-Islamic power, the development of the study and teaching of the Arabic language and of the different religious sciences of the period probably favored the teaching of sciences like medicine and arithmetic, which answered the needs of certain fringes of urban society (in particular, caring for the wealthy and administering the distribution of inheritances).

In the Andalus, it is likely that from the beginning of the ninth century, the first translations of Greek and Indian works appeared in Cordoba from the centers of the empire and served to bring scientific learning to everyone from children to rulers. This was the case, for example, for ‘Abd ar-Raḥmān II (822–852) who benefited from this education and, in turn, actively supported further scientific activity by financing the establishment of an important library with works bought in the East. But it was not until the middle of the ninth century that scientific

centers began to exist independently, outside the walls of palaces and princely mansions, in Cordoba, Toledo, Seville, and Saragossa.

During the last third of the ninth century and throughout the tenth the activities of teaching and research in the different branches of mathematics were greatly stimulated by the patronage of two great Umayyad caliphs, ‘Abd ar-Raḥmān III (912–961) and his son al-ḥakam II (961–976). These activities continued in the eleventh century with the blossoming of important scientific centers in capital cities of principal states which, in turn, stemmed from the brilliance of the caliphate of Cordoba.

The information which exists today about scientific activities in the Maghreb leads one to believe that the beginnings of mathematics, on the scale of all of the Maghreb, occurred in Ifrīqyā (present day Tunisia) as early as the end of the eighth century. Among the scholars whose names are still known is Yaḥyā al-Kḥarrāz, who had as a student Yaḥyā al-Kinānī (828–901), the author of the first book of *ḥis’* (control of weights and measures) written in the Maghreb.

From the ninth century, the name of only one mathematician remains, Abū Sahl al-Qayrawānī, of Iraqi origin. He is also the first Maghrebian mathematician whose book is known: *Kitāb fī al-ḥisāb al-hindī* (Book of Indian Mathematics). As the title indicates, the book was in the new Arabic arithmetical tradition, of Indian origin, which had been inaugurated by mathematicians in Baghdad at the end of the eighth century and the beginning of the ninth.

As in other regions of the Islamic world, patronage of scientific activity was prevalent in the Maghreb and functioned as it did in the great cities of the East, with the purchase of books, the financing of manuscript copies, grants to scholars, and the construction of schools and institutions. The only precise information we have is on the *Bayt al-ḥikma* (House of Wisdom) founded by Ibrāhīm II (875–902) in Raqqāda. This institution, which survived as a scientific center until the Fatimid dynasty, welcomed mathematicians, astronomers, and astrologers.

Maghrebian mathematical activity of the tenth century is not well known. It seems that the

patronage initiated by the Aghlabids in the ninth century continued and that the study of mathematics and astronomy flourished, particularly in the course of the first two decades of the reign of the Fatimid Caliph al-Mu'izz (953–975). But biographers have given us only a few names of people who were known for their mathematical activities or their interest in the discipline, such as Ya'qūb ibn Killīs (d. 990) and al-Huwarī (d. 1023). To these names must be added the names of scholars who came under the influence of the intellectual centers of the Umayyad Andalus or of Fatimid Egypt, like Ibn Yāsīn and al-'Utaqī.

We are somewhat better informed about mathematical activity in the eleventh century, but information is still fragmentary. Some scholars of this period are well known, for example Ibn Abir-Rijāl (d. 1034–1035) and Abū'l-ṣalt (1067–1134). They wrote on mathematics, astronomy, and astrology, but only certain of their works in the latter two disciplines survive.

Mathematics in the Maghreb in the Almohad Period (Twelfth to Thirteenth Centuries)

Much is known about the importance of the twelfth century in the political and economic history of the Maghreb. But the cultural and scientific history of that period remains a vast, unexplored field. For example, in the field of mathematics, only three scholars of this period have been the subject of research studies. They are Abū Bakr al-ḥaṣṣār (twelfth century), ► [Ibn al-Yāsāmīn](#) (d. 1204), and ► [Ibn Mun'im](#) (d. 1228). These three scholars are important because of several factors. The first is that they were the first mathematicians in the Maghreb whose writings have survived.

The full name of al-ḥaṣṣār is Abū Bakr Muḥammad ibn 'Abdallāh ibn 'Ayyāsh al-ḥaṣṣār. It appears that in addition to his mathematical activities, he was also a reader of the *Qur'ān* and a specialist in inheritances. It is also probable that he lived a long time and that he taught in Sebta, since he seems to have had ties

with other mathematicians in that city. Only two of his writings have survived. The first, entitled *Kitāb al-bayān wat-tadhkār* (Book of Demonstration and Memorization) is a manual of calculation dealing basically with arithmetical operations on whole numbers and fractions. His second book is entitled *Kitāb al-kāmil fī ṭinā'at al-'adad* (Complete Book on the Art of Numbers). It was in two volumes, but only the first volume is extant. It takes up the themes of the first book, with new chapters on the breakdown of a number into prime factors, on common divisors, and on common multiples.

Reference to al-ḥaṣṣār in two Andalusian works which are now lost leads us to the conclusion that, in one way or another, the Andalusian arithmetical tradition was present in the Maghreb in the twelfth century. This presence was reinforced, moreover, both by the direct diffusion of Andalusian works on algebra, geometry, and astronomy and by the utilization of the contents of the works of al-ḥaṣṣār by later Maghrebian mathematicians like Ibn Mun'im, ► [Ibn al-Bannā'](#) (d. 1321), and Ibn Ghāzī (d. 1513).

It appears that al-ḥaṣṣār lived before Ibn al-Yāsāmīn, but there is no way to verify that fact. However, the contents of their mathematical writings are quite similar insofar as they are written in the Andalusian tradition of the twelfth century, and they expand that tradition by the introduction of symbolism for certain objects and certain arithmetical operations and by the important development of a chapter on fractions.

We can say nothing about the works of Ibn Mun'im on geometry or on the construction of magic squares, as they have not yet been discovered. But we are better informed about his writings on combinatory analysis, arithmetic, and number theory. The *Fiqh al-ḥisāb* (Science of Calculation), his only surviving text, contains the usual chapters of calculation manuals, dealing with the four arithmetic operations applied to whole numbers and to fractions, but also chapters at a higher level which deal with extraction of the exact or approximate root of a number, the properties of figurative numbers, the sum of series of whole numbers, and the determination of amicable numbers.

It is not known what the importance of mathematical activity in Marrakesh was at the time that Ibn Mun'im settled there. He himself is not specific about the Maghrebian mathematicians of his time or their predecessors. On the other hand, he refers very specifically to Andalusian scholars, citing their names, titles of their works, and even passages of their writings. This only serves to confirm the important scientific ties between the Maghreb and the Andalus, ties which were considerably strengthened in the fields of science and philosophy during the reigns of the first four Almohād caliphs, from 1130 to 1213.

It is important to note that the writings of al-ḥaṣṣār, Ibn al-Yāsimīn, and ► **Ibn Mun'im** were not the only writings which were studied. Indeed, one can cite the names of several whose work may have been just as important: Abū'l Qāsim al-Qurashī (d. 1184) who taught algebra in Bougie, al-Qāḍī al-Sharīf (d. 1283) who was a student of Ibn Mun'im in Marrakesh, al-Qalī (d. 1271) who also lived in Bougie and who taught the science of inheritances, and Ibn Ishāq al-Tūnusī (d. after 1218), who was known for important work in astronomy. Unfortunately, none of the mathematical writings of these scholars remains, and we cannot even speculate on their contents.

The Mathematics of Ibn al-Bannā' and Commentaries on His Work (Fourteenth to Fifteenth Centuries)

In the history of scientific activity in the Maghreb, the fourteenth century is a special time, not only because of the quantity of mathematical work, but also because of the content of that work and its influence on the teaching of mathematics in the Maghreb in the centuries to follow.

The majority of mathematical work done in this century was reviews, in the form of commentaries and summaries of work which had already been discovered or assimilated in the course of previous centuries. New contributions were the exception. The work of the mathematician ► **Ibn**

al-Bannā' (1256–1321) becomes even more important in this light, since he was both one of the last innovators in the great Arab mathematical tradition and also one of the initiators of a new tradition in the teaching of mathematics.

Ibn al-Bannā' was born and raised in Marrakesh where he also died, but he also lived and taught in Fez for a period. He seems to have been one of the last scholars to have engaged in research activity in that he grappled with problems which were new at that time and to which he found original solutions, for example in combinatory analysis. He also introduced original ideas or processes in algebra (on the existence of solutions to a second degree equation) and in calculus (on nondecimal bases).

Ibn al-Bannā' was also notable for the richness and diversity of his work. In the inventory which Ibn Haydūr (d. 1413) made of his writings, he records 98 titles, 32 of which deal with mathematics and astronomy. This may have been the reason for the high social status he enjoyed, being honored by the highest authorities in the far Maghreb, which led him to leave Marrakesh and settle in Fez for a period of time.

Ibn al-Bannā' wrote on geometry and an important work on algebra which was used as a teaching text in the Maghreb until the fifteenth century. But it is his writings on the science of calculation which have made him famous. Three of them remain in existence: the *Talkhīṣ a'māl al-ḥisāb* (Summary of the Operations of Computation), *al-Qānūn fī l-ḥisāb* (Canon of Mathematics), and the *Raf' al-ḥijāb* (Lifting of the Veil).

While the third title is the most important in mathematical terms, it is the first which is best known. A manual on the operations of calculation, it is characterized by great conciseness, rigor in its formulation, and especially, by a total absence of mathematical symbolism. For these reasons, many mathematicians after Ibn al-Bannā' have published commentaries on this manual.

A comparative study of the most important chapters of these commentaries leads to the following observations on their content and on the general level of mathematics at that time. First, that the level of mathematics was not lower than

that of earlier periods but that certain themes which had been taught since the tenth century no longer appear. Second, there are no new contributions in the commentaries, neither on the theoretical level nor on the level of the applications of ideas or earlier techniques. The most significant innovation in the commentaries is in the progressive utilization of a relatively elaborate symbolism. This symbolism had already appeared in the writings of al-ḥaṣṣār and ► [Ibn al-Yāsāmīn](#), but its use seems to have taken hold throughout the thirteenth century and the beginning of the fourteenth. It reappeared in certain commentaries in the fourteenth and fifteenth centuries, both in arithmetic and in algebra.

Mathematics in the Maghreb After the Fifteenth Century

The activities of mathematicians from the Maghreb who lived between the sixteenth and nineteenth centuries are not clearly known, but it is possible to get an idea of their contributions from the titles of writings which still exist. The mathematical disciplines which were taught or treated in the writings are metric geometry and calculation. It is possible to affirm that the content of these works differs from that of earlier mathematical writing both in form and level. There are poems, for example, those of al-Akhḍarī (d. 1575) and al-Wansharīsī (d. 1548), glosses and commentaries like those of Ibn al-Qāḍī (d. 1616) and Muḥammad Bannīs (d. 1798), and summaries like those of Ibrāhīm al-Ribāṭī (d. 1926). But the level of these works is inferior to those of the fifteenth century, which are themselves much poorer than works of the thirteenth and fourteenth centuries, both in ideas and techniques. The same is true in other sectors of intellectual activity in the Maghreb which were characterized by a narrowing of the respective domains of investigation and an impoverishment of their contents. This situation, the result of a long process of decline, had an indirect effect in mathematics in a gradual reduction both of content and in the field of application. Thus, the only activities left to mathematicians, aside from

teaching and editing manuals, were mathematical practices linked directly to activities or preoccupations of a religious nature, like the distribution of inheritance, and donations to rightful claimants, the determination of times for fixing moments of prayer, or the construction and use of astronomical instruments.

See Also

- [Ibn al-Bannā'](#)
- [Ibn al-Yāsāmīn](#)
- [Ibn Mun'im](#)

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Mathematics of Yolngu Aboriginal Australians

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Yolngu Aboriginal Australians live as members of around 20 different clan groups in northeast Arnhem Land in Australia's Northern Territory. They organise their collective and individual lives through a mathematics system very different to the modern system of abstracting through number and quantification. The modern system is incorporated as a subsidiary to their indigenous mathematical system. The Yolngu form of indigenous mathematics can be understood as

exemplifying the many similar systems that have life in hundreds of Aboriginal Australian communities.

To consider notions of Aboriginal mathematics usefully in a short space we need to avoid the academic controversies over what mathematics is about and how we know it, while still demonstrating something held in common between the two arenas we identify as Western and Yolngu Aboriginal mathematics. Before we can say anything about mathematics in the life of Aboriginal Australian communities it will help to look briefly at the cluster of meanings associated with the term 'mathematics' in Western life.

Bowing to the antiquity of the notion of mathematics we can note the Greek origins of the words mathematics and mathesis/mathetic. This cluster of words coming to us in English through Latin carries original ideas of learning, seeing and mental discipline. To these are added overtones of systematicity: arithmetic, geometry and reasoning. Western mathematics involves rigorous and systematic ways of seeing and working things out, and is intimately tied up with the constitution of the social order at both the macro- and micro-level. That much is uncontroversial. But asking about the objects which constitute mathematics brings us to less solid ground. Most people want to answer that mathematics is constituted of abstract objects. But constrained to ask what abstract objects are, we find ourselves amongst the disagreeing philosophers and mathematicians and in the realm of metaphysics.

The objects of Western mathematics are forms that inhabit an arena seen as somehow beyond the concrete here-and-now. Those mathematical forms, glimpsed through material objects and arrangements, are usually taken as representations of mathematical objects. In contrast the objects of Yolngu Aboriginal mathematics have life in the concrete here-and-now in that they are performed or enacted. In their being performed or collectively enacted, 'The Dreaming' or *Wangarr*, which is the origin of Yolngu mathematical objects, is remade in the present. There are significant differences between Western mathematics and Yolngu Aboriginal

mathematics at the metaphysical level. I will not explore those differences here. Rather I look for a similarity that can be seen as lying within this overarching difference.

A commonsense way of beginning is to take numbers as representative of the sorts of objects we find in mathematics. Many of us are comfortable with seeing numbers embedded in very practical matters like tallying with fingers or stones. We continue to talk of 'digits' alluding to a historical role for fingers, and perhaps for toes. We do not, however, expect that numbers should remain tied to those practical origins. Most people are quite comfortable with numbers being highly mobile, working so as to pattern and order, in almost any situation. Of course, there are many mathematicians and philosophers who would disagree with this way of coming up with a working definition of mathematical objects because it seems to downgrade the significance of numbers and other mathematical objects, a significance deriving from their proper status as 'abstract'.

My approach emphasises instead the ways numbers are embodied and embedded in ongoing collective life, irrespective of whether that is the rarified halls of university departments of mathematics, or the aisles of supermarkets and the anxiety ridden rooms of weight-loss clinics. Nevertheless taking this everyday collective and materialist understanding of number as a mathematical object seriously I suggest that it can provide a minimalist basis for comparing and contrasting Western mathematics with the mathematics in Aboriginal Australia.

Can we identify an arena of collective Aboriginal Australian life with the characteristics of rigor and systematicity, which is tied up with the working of entities involved in patterning and constituting order in multiple heterogeneous contexts? We could point to any Aboriginal Australian community and identify just such an 'Aboriginal mathematics', although it is likely that among the many different Aboriginal Australian communities such an arena would go under different names. Here I confine myself to considering some mathematical elements in the life of contemporary Yolngu Aboriginal

Australians. We look at *gurrutu* a mathematical-like discourse and set of practices embedded in Yolngu life. In Yolngu life, *gurrutu* is expressed in the many and heterogenous material practices of doing kinship relations, including land ownership, although to render the term *gurrutu* in English is just as difficult as expressing mathematics in the cluster of Yolngu languages. This mundane way of describing *gurrutu* would not satisfy my Yolngu friends. However, recognising that caveat while putting it aside, just as I have put the concerns of mathematicians aside, I go on to explore some interesting similarities between Western and Yolngu Aboriginal mathematics. I begin by speculating about possible material origins of the contrasting mathetic objects in Western mathematics and *gurrutu*.

A familiar story about origins of numbers in Western mathematics sees them as originating in the practices of material tallying. This is modeling an event or episode in the world with a material encoding process. We can see this as using a finger to encode the passing of a sheep through a gate, the placing of a pebble to encode the pointing at a soldier, or the engraving of a line on a bone or a piece of wood to record the filling of a vessel with grain. This imagines the involvement of fingers and toes in tally keeping in a non-linguistic way. One separated digit codes for one separated item. But if we then extend the coding operation and say a word which codes for the finger or toe, we have done something much more complex and ended up with a code which is much more useful than the material code of fingers and toes or display of objects like dropping stones into a bucket or adding another shell to the pile.

In saying a word as a finger is held up to code for an item involved in some event we understand that the word we say does not name either the item or the finger. It names a position in a progression. Numerals are words that code for a position in a series. A set of number names, a numeral system, is characterised by having a sequential base pattern and recursivity. Numerals constitute an infinite series by having a base about which repetition occurs, and a set of rules by which new elements are generated.

The contemporary numeral system which has developed in association with Indo-European languages like English has ten as its base; in other words ten is the point in the series which marks the end of the basic set of numerals. As each ten is reached, the basic series is started again, each time recording in the numeral how many tens have been passed. The rule by which new elements are devised is addition of single units and base ten units.

A similar story can be told of origins of one set of mathetic objects in Yolngu Aboriginal life. Imagine Yolngu people plotting the spatial pattern of land sites owned by related groups of people. Stones and shells might be taken to represent positions in the mesh of family relations and the sites owned by the various groups. The shells/stones symbolise the links between people and land, and placed on sites through which land is owned they both express and demonstrate the pattern of the network of linkages between related groups of people and their lands. Naming can codify the relations, just as position in a sequence can be codified by names in numbering. But codifying relations with names is more complicated than codification of an event signalled with a finger. In fact two contrasting relations need to be encoded to begin. In *gurrutu* the relation between brother and sister is contrasted as a formal opposite to that between husband and wife. By positing an ideal form of marriage a system of reciprocal names can be devised. So just as we find human bodies embedded in Western mathematics through numbering, so too we find human bodies embedded in *gurrutu*. On biological grounds of life expectancy we could expect a way to express family links which recognises the presence of three generations; necessarily these will be differentiated along matrilineal and patrilineal lines.

The first mathetic objects are moieties. Brother and sister belong to the same moiety. Husband and wife belong to opposite moieties. In Yolngu life these formal opposites are named *Yirritja* and *Dhuwa*. This formal opposition of the organising categories of Yolngu life – patrilineal and matrilineal lines allows a matrix in which everything can be located with respect to all

other things. Humans and non-humans, living and non-living, material and non-material, everything is locatable – people, places, concepts, images, languages, animals and plants.

The matrix is elaborated in naming a series of family relations. Reciprocal pairs of names code for relative positions in the kinship mesh. They do not name individual people or clans or places, but relations between them. *Gurruṯu* names are code for positions in a formal series, but not a series with a linear form as in numbers. This is a series with the form of a net or a matrix.

Gurruṯu is a form which is primarily a formal map. Just as the number series is used to ‘reveal’ value in the material world, the *gurruṯu* matrix is used to reveal relative location in the material world. For example it codifies the location of places in the landscape. Table 1 is a list the eight reciprocal pairs which constitute the base of the *gurruṯu* recursion. The easiest way to begin to understand these categories is to personalise them in terms of my kin relations.

Or I could do it the other way around: the person I call *gathu* (child) calls me *mukul bapa* (aunt – father’s sister) and so on through to the person I call *dhuway* (husband) who calls me *galay* (wife). The dual names in some rows on the left-hand side of the pairs represent male and female holders of a position, necessarily brother and sister. Each of those pairs has the reciprocal relation of *yapa* (sister) and *wawa* (brother). The reciprocal pair *yapa* and *wawa* enable the pattern of names to work as a true recursion; they are not themselves members of the base set of reciprocal name pairs. Elaborating the list of names of *gurruṯu* relations is analogous to listing the set of numerals from one to ten. In that set zero holds a pivotal position, enabling iteration of the number pattern. Zero is not itself a member of the base set of names and can be understood as having a similar function to *yapa* and *wawa*. In just the same way as number, the name series of *gurruṯu* constitutes a recursion where elements, i.e. positions constituted in the series, provide the basis for further constitution of elements.

The matrix formed by naming these relations is understood as re-emerging across history. But the image of time embedded in history here

Mathematics of Yolngu Aboriginal Australians, Table 1 Kin relations

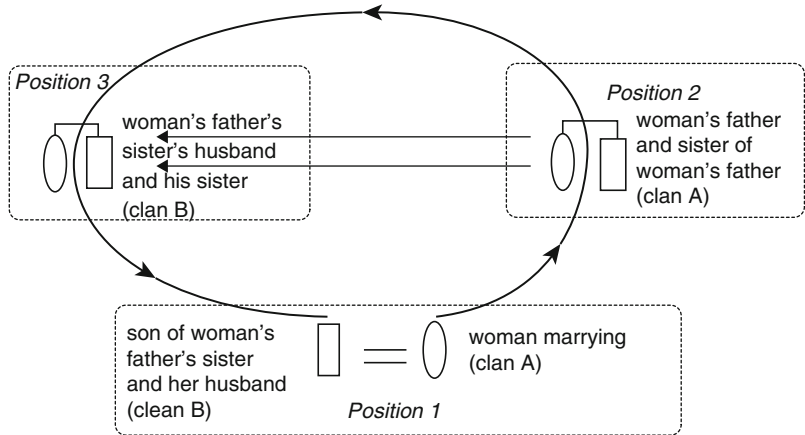
The person I call	Calls me
<i>bāpa</i> (man) – father	<i>gāthu</i> – child
<i>mukul bāpa</i> (woman) – father’s sister	
<i>ngāṇḍi</i> (woman) – mother	<i>waku</i> – child
<i>ngapipi</i> (man) – mother’s brother	
<i>māri’ mu</i> – father’s father and father’s father’s sister	<i>marratja</i> – grandchild
<i>ngathi</i> (man) – mother’s father	<i>gaminyarr</i> – grandchild
<i>momu</i> (woman) – mother’s father’s sister and simultaneously father’s mother	
<i>māri</i> – mother’s mother and mother’s mother’s brother	<i>gutharra</i> – grandchild
<i>mumalkur</i> (woman) – mother’s mother’s brother’s wife	<i>dhumungurr</i> – mother’s brother’s mother-in-law
<i>ngathiwalkur</i> (man) – mother’s mother’s brother’s wife’s brother	
<i>mukul rumaru</i> (woman) – mother’s brother’s wife	<i>gurrung</i> – mother-in-law
<i>maralkur</i> (man) – mother’s brother’s wife’s brother	
<i>galay</i> – mothers’ brothers’ daughters and sons simultaneously brother’s wife and her brothers	<i>dhuway</i> – sister-in-law

is not linear; it is not the form of time Westerners are familiar with. For Aboriginal Australians time is cyclical. History accretes in place in going through the cycle mapped out by the matrix of *gurruṯu*. The cycle of the *gurruṯu* matrix can be mapped by the ideal cycle of marriage and child bearing in Yolngu life. This cycle is shown in diagrammatic form in Fig. 1.

The father of the man marrying (and the father’s sister) constitute one position (clan A – moiety 1), the mother of the man marrying (and her brother) a second position (clan B – moiety 2) and the wife (and her brother) of the brother of the mother of the man marrying constitute a third position (clan C – moiety 1). In the Yolngu case, the pattern of this

Mathematics of Yolngu Aboriginal Australians,

Fig. 1 Pattern on a Yolngu genealogical idea



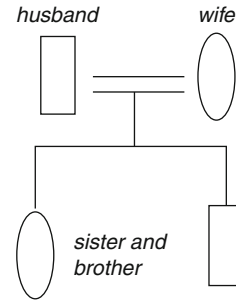
geneological ideal implies either two *Yirritja* clans and a *Dhuwa* clan, or *Yirritja* clan and two *Dhuwa* clans.

One way to begin describing the structure of this matrix is to map it in the conventional form that anthropologists map genealogies. The basic unit in this map is the hypothetical ideal family tree shown in Table 2. This 'ideal unit' illustrates the fundamental contrast between the two different sorts of relations which constitute the *gurruṭu* system of relations: that between wife and husband and brother and sister.

Exhaustively specifying the primary positions generated in this genealogical ideal across the generations from grandchild to grandparent, constitutes eight reciprocal pairs, 16 positions: two groups and three reciprocal positions in each: two sets of two to the power of three. Naming this set of 16 positions constitutes a primary template, just like naming the set of ten fingers constitutes a primary template. The eight pairs of reciprocals name across generations or across matrilineal or patrilineal lines. The brother/sister reciprocal pair completes the set of named relations and enables continuing iteration. Together the names and rules of generation form an infinite series. When we map the series of eight reciprocal kin relation pairs with this unit we get this diagram of the relations named (Table 3).

Laid out in this way it becomes obvious that in the *gurruṭu* system where every person and everything is exhaustively located with respect

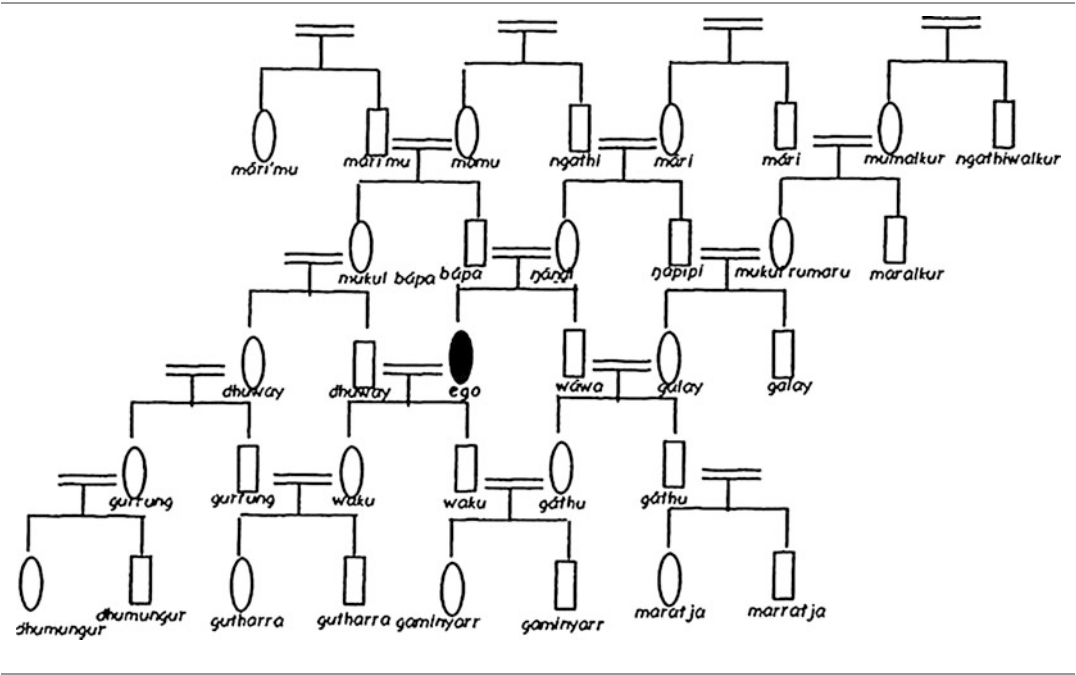
Mathematics of Yolngu Aboriginal Australians, Table 2 A conventional genealogical map of the basic elements in Yolngu *gurruṭu*



to every one else and everything else has a three generational interval known as the *marigutharra* (grandmother/father-granddaughter/son) relation.

The triple generational/dual moiety recursion constitutes an encompassing pattern of Yolngu life and social order. Right from the beginning of their lives, Yolngu babies are instructed on the relation that this or that person has to them. The set of relations involve notions of hierarchy and equivalence, but not as a single-centralised hierarchy. Each position plays different roles in several different hierarchies; the many hierarchies are woven together to form a decentralised orderly mesh of hierarchies. *Gurruṭu* carries a powerful ideology; it achieves a general ordering of both the social and the natural world. It maintains an image of continuity and permanence across both time and space. And it is not only

Mathematics of Yolngu Aboriginal Australians, Table 3 A genealogical mapping of the base set of *gurrutu* elements



people who have *gurrutu* positions; all entities in the Yolngu world have positions in the *gurrutu* matrix.

I am presenting the number and *gurrutu* recursions as analogous, but they are very different in their content. Should that worry us? These two great recursions – the tallying recursion codified in counting, and the genealogic recursion codified in ordering descent and ancestry – are of a kind, albeit different in form. They differ in structure: each number has one direct antecedent and one direct successor, and each *gurrutu* position has two direct antecedent positions and one successor position. However the two systems are characterised by recursive definition. A recursive definition formalises the idea of ‘and so on’. We can define *gurrutu* positions as the members shared by all classes that contain a *gurrutu* position, and the successors of all their own members. Similarly we can define the natural numbers as the members shared by all classes that contain one and the successors of all their own members.

Both these recursions are manifest to varying extents in all human societies. By noting the

emphasis on the genealogic system in Yolngu society I am not saying that the tallying recursion is entirely absent from Yolngu life; it is not. Nor, in noting the predominance of tallying in European derived Australia, I am saying that the genealogic recursion (arranging matters on the basis of close and distant kinship) is entirely absent from Western life. What I am saying is that in Yolngu life the tallying recursion does not carry the ordering burden that the genealogic recursion carries. Conversely in Western society the genealogic recursion carries very little by way of ordering knowledge or productive processes.

Nor I am suggesting that the ‘great recursions’ operate quite independently of one another. In the Western world the tallying recursion predominates; it is the recursion by which most social relations are effectively ordered. This is not to deny the influence that the genealogic recursion retains. Yet genealogic classifications are not exhaustive and applicable as objective classification throughout the community as we see them in Yolngu life. In Western life kinship classifications are discontinuous and discrete.

They are variously regarded as important or not. Westerners can reject their genealogy and invent ancestors with impunity. They can lie about their genealogic relations. The genealogical recursion is taken as significant only in the biological sense. In the social sense people can choose to invoke or not to invoke the recursion.

In contrast to the dominant place of the tallying recursion as a foundation for reasoning in Western life, it is involved in Yolngu life in only a secondary way. Distributive arrangements for turtle eggs invoke an indigenous tallying recursion; here a recursive material arrangement – base 5 is engaged and linguistically encoded (each group of five is one *rulu*). In contemporary Yolngu society the use of base 10 tallying recursion predominates when the community or individuals are dealing with the white social order, but in exchanges involving only Yolngu the tallying recursion, as expressed in money for example, is subordinate to the working of the *gurrutu* system. It does not carry the deterministic weight, the aura of inevitability it carries in non-Aboriginal Australia. People can choose or not to invoke quantification.

We should not go away with the idea that all genealogic recursions of Aboriginal Australia are worked in exactly the same way. Just as the tallying recursion can be worked differently for different purposes and by different groups, so Aboriginal Australian communities work with the genealogic recursion in different ways. In Yolngu life there are two distinct genealogical recursions which serve distinct functions. The distinction between them is something like the distinction between ordinal and cardinal numbers.

Juxtaposing number and *gurrutu*, the primary principle embedded in these contrasting forms becomes evident. The primary principle for manipulating the categories constituted in the patterns derives ultimately from the practical, material system which formed the template of the recursion in its symbolic constitution. Going back to numbers we can see that the primary rule of that recursion is a version of the process of holding up another finger as another sheep leaps through the gateway. The important thing about this operation from the point of view of recursion

is that each finger is exactly equivalent to each other finger. And any collected set of fingers has a precise and identifiable relation to any other collections of fingers; they relate to each other as a specific ratio. The primary principle of the number system is the principle of ratio: the ratio of any term to another is determined by the number of times one contains the other.

The primary principle of working the set of mathetic objects in *gurrutu* is quite different. Going back to the ideal marriage arrangement which underlies *gurrutu* we can see that an inherent reciprocity marks the form. Husband taker and wife taker are reciprocally related. Clan A and clan B together constitute a unity – the offspring of the marriage. This is an instantiation of the principle of reciprocity – two opposing elements constituting unity. A reciprocal is an expression so related to another that their product is unity. It is the inherent opposing duality constituting a unity, which is the fundamental principle of *gurrutu*. Every position in the *gurrutu* matrix is necessarily constituted by a two-way naming. The elements of the recursion must be specified from both ends before they come to life as an entity within the recursion.

Reciprocity can be pictured as two sides of a coin. On the old Australian penny (which had the head of the current king or queen of England on one side and a kangaroo on the other), ‘head’ and ‘tail’ constitute reciprocals, and together constitute a unity. The notion of reciprocal is often difficult for learners of Western mathematics centred around numbers to understand; they need to understand fractions before it is possible to understand reciprocals in a rigorous manner.

In *gurrutu* reciprocity is primary. If you take any base family relation as a unit, for example *mari-gutharra* – the matrilineal relation across two generations (mother’s mother or mother’s mother’s brother) – you can understand it as constituted by the mutual engagement by both sides. The descendant and the grandmother/great uncle are equally important in constituting the unity described by *mari-gutharra*. Each side is necessary to constitute the unity held between them. And just as reciprocity can be secondarily derived in the system of numbers pivoting around ratio,

similarly the notion of ratio can be secondarily derived in *gurrutu*. *Milmarra* is a name given to this way of rendering *gurrutu*. A simple ratio involves juxtaposing a *yothu-yindi* (mother-child) relation with a *mari-gutharra* (child-mother's mother) relation: "If the two clans of the *yothu-yindi* are A and B, what is the Mari clan?" There is always only one correct answer which can be understood as expressing the ratio of the two reciprocals. Such puzzles are often set for learners of the *gurrutu* system.

Number and *gurrutu* are contrasting generalising logics. Perhaps the most challenging aspect of this is the notion that there are contrasting generalising logics in a contemporary way of life. Such a situation implies the need for continual translation between logics in that life-way. Recognising that need opens the possibility for reflexive consideration of how different peoples might collectively go on, doing their differences, including their different generalising logics, together.

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Mathematics Practical and Recreational

Jens Høyrup

The geographical distribution of so-called "recreational" mathematical problems does not respect ideas about distinct mathematical

cultures. The familiar conclusion is that they reflect “age-old cultural relations between Eastern and Western civilizations” (Hermelink, 1978). This inference is indubitably true but does not exhaust the matter. The reasons that these kinds of problems reflect relations between civilizations that are less visible in other mathematical sources are informative, both regarding the conditions and nature of mathematical activity in different civilizations and about the sense (or nonsense) of the concept of distinct mathematical cultures.

“Recreational problems” are pure in the sense that they do not deal with real applications, however much they speak in the idiom of everyday (some examples will be cited later). Nonetheless, their social basis is in the world of know-how, not that of know-why (the world of “productive,” not that of “theoretical” knowledge, in Aristotle’s terminology). The distinction between these two orientations of knowledge is of general validity but has particular implications for mathematics.

Beyond this distinction between orientations, it is also useful to distinguish two main ways in which “productive knowledge” can be transmitted. One is through master-apprentice networks and on-the-job training. This type of knowledge, whose results may be labeled “subscientific,” is explained later. The other is through institutionalized schools, where training is separated from actual practice and taken care of by teachers whose own connection to the practice for which they prepare is reduced; the outcome may be labeled “scholasticized knowledge.”

It is important not to identify practitioners’ knowledge (whether subscientific or scholasticized) with practical knowledge alone. The difference has to do precisely with the influence of the social systems which carry the knowledge in question.

The larger part of the practitioners’ fund of knowledge is evidently applicable in practice, at least according to the convictions of the social totality within which they function (whether we regard the knowledge of seventeenth century physicians as medically useless is irrelevant to the seventeenth century existence and prestige of

their profession). As far as this part is concerned, problems – the problems which the craft or profession is supposed to confront – are fundamental, and appropriate techniques have been developed which allow it to deal with these problems. But the training of future practitioners, even when done on the job, will have to start from simpler tasks than those taken care of by the master, in part from tasks which have been prepared with the special purpose of training the techniques which the apprentice should learn but which have no direct practical relevance. Here, techniques and methods are by necessity primary, and problems are secondary, derived from the techniques which are to be trained. Anybody familiar with schoolbooks on arithmetic will recognize the situation, and scholasticized systems are indeed those where problems constructed for training purposes dominate. Apprenticeship-based systems, for their part, tend to train as much as possible on real, albeit simple tasks.

Scholasticized systems often make some use of recreational problems as a means to create variation. However, the genuine basis for the invention and spread of these problems – problems that distort everyday settings so as to create a striking or even absurd situation – is what we can call the subscientific knowledge system. This system is oral in character, while scholasticized systems have always been geared to writing. Recreational problems are riddles for specialists, sharing with other riddles that eristic (given to dispute or argument) character which distinguishes oral cultures in general. Often, when they enter written problem collections or manuals, they contain phrases like “if you are an accomplished calculator, tell me...” – or they are presented as a way to impress the nonspecialists who do not understand. In the premodern world, this type of knowledge was neither “folk” nor “popular,” but a possession of the few to a significantly higher degree than scientific knowledge today.

Phrases of this kind indicate how we are to understand the function of the “recreational” problems, which were not primarily recreational (whence the quotes) – no more recreational,

indeed, than the potentially lethal riddle of the sphinx. They served as a means to display virtuosity, and thus, on one hand, to demonstrate the status of the profession as a whole as consisting of expert specialist, and, on the other, to let the single members of the profession stand out, and discover themselves, as accomplished calculators, surveyors, etc.

This function puts some constraints on the problems, which explains their character. They must arouse immediate interest, which explains the “recreational surface”: if a camel is to transport grain from one place to another, being able to carry only one third of the grain in one turn, and seems as a consequence to devour exactly everything in the process, then the expert solution allowing a net transfer is impressive. A less striking formulation might provoke the reaction “so what?” The problems, furthermore, must appear to belong to the domain of the profession – skill in singing does not enhance the professional prestige of an accountant, since it does not demonstrate professional valor; according to their form, the problems have to be practical. But they must also be more difficult than the tasks that any average bungler in the profession performs without difficulty. This, together with the quest for the striking or absurd, is the reason that the problems are pure in substance, i.e., separated from real practice – and more truly so than the simplified problems of school teaching.

Like school problems, however, recreational problems are determined from methods, namely from the characteristic methods of the profession. Often they come from a peculiar trick (in the case of the camel, an intermediate stop and return) that will be known within the subculture of the profession but not outside.

Such tricks will often not be generalizable; moreover, as several mathematicians from the Islamic Middle Ages tell, the practitioners using them would often be ignorant of why their tricks worked. The purpose of posing and solving the problems is not to provide insight but to show off. The pure level of knowledge is thus neither a direct nor an indirect underpinning of practice, nor is it a critical reflection on the principles underlying practice. In this respect, it differs

fundamentally from what Aristotle and al-Fārābī would speak of as theoretical knowledge and from what we call scientific knowledge.

But there is another point in the term “subscientific”, namely that all levels of the subscientific knowledge system, the pure or recreational no less than the applied, have served as inspiration in the development of scientific mathematics. This process can be followed in the Greco-Islamic area (and its European offspring), in India, and in China; Japanese *wasan* may even offer an instance of direct transformation of a subscientific into a scientific system.

In the Greco-Islamic-premodern-European area (the most sensible delimitation of “Western” culture if the long historical run is considered), in contrast, the theoretical knowledge system may have been socially segregated from the subscientific systems to an extent which in other cultural areas was reserved for different domains, as courtly music in Japan, or poetry as bound up with the writing system in China. While the distinction between different orientations of knowledge systems and the effect of scholastization versus apprenticeship learning hold in general, the social segregation and the high social prestige falling to philosophical and scientific knowledge in this broadly defined Western culture have tended to make the rupture between scientific and practitioners’ mathematics more visible than elsewhere and to hide the whole subscientific complex from view. Another reason for its invisibility in the contemporary European orbit is evidently that the originally autonomous subscientific traditions were displaced from the late Renaissance onwards by methods that were ultimately derived from scientific mathematics. Increasingly since the late nineteenth century, this process has occurred globally.

Few sources survive that tell how practical computation was performed in former times, in particular by practitioners not trained from school books. Moreover, most practical computations and geometrical constructions have relied on such simple techniques that questions of diffusion versus independent invention cannot be decided; this simplicity is precisely the reason that they could not serve as a basis for

professional self-esteem. Even “wrong” formulae can be so intuitively near at hand that independent invention demonstrably happens time and again. For instance, Isabel Soto Cornejos observed when teaching illiterate peasants in Chile during the Allende era that they reinvented the “surveyors’ formula” for approximately rectangular areas (average length $\times$ average width) spontaneously after having been taught how to calculate the area of true rectangles. Only problems that are complex enough to serve as display are by the very fact also so characteristic that they may function as index fossils. This is why the recreational problems are crucial for the understanding of the subscientific knowledge system and its relations to the scholasticized and scientific systems.

Often the recreational problems go together in clusters which, although some exchange takes place, are relatively closed. As an example we may look at a cluster – better documented than most others – which appears to be connected to communities of merchants interacting either along the Silk Road trading network or in the sea trade between China, India, the Near East, and the Mediterranean but which certainly also had an impact on local communities of accountants and calculators (whatever their social status and organization) wherever they were in contact with the merchants’ communities.

One favorite problem from this cluster was the doubling of unity, repeated either 30 or 64 times and ending by a summation. The first occurrence is in a text from Mari (Northern Babylonia) from the eighteenth century BCE. Then it turns up in a papyrus from Roman Egypt, and next in a Carolingian problem collection (*Propositiones ad acuendos iuvenes*) based on material which had circulated since late antiquity in the Gallic region – all of these instances deal with 30 doublings. In the early ninth century, ► [al-Khwārizmī](#) wrote a treatise on the other (chessboard) variant, which appears to have passed via India, even though actual Indian attestations are later. In the following centuries, both versions are found in India, in the Islamic world, and from around 1200 even in Latin Europe.

Another problem from the cluster that was highly popular in the Islamic and European

Middle Ages was the “purchase of a horse”: three men go to the market in order to buy a horse. The first says that if he may have half the money belonging to the others he will be able to buy the horse; the second needs only one third, and the third only one fourth (the number of purchasers and the fractions may vary, but invariably they exhibit a striking pattern). Sometimes the price of the horse is told; sometimes the problem is left indeterminate and thus is not only striking but outright absurd (in the present case, any multiple of the set [10,22,26] will do for an answer). The earliest Western source to state the problem (without the equestrian dress) is Diophantos’ *Arithmetic*; slightly earlier is an occurrence with a different dress in the Chinese ► [Shushu jiuzhang](#) (Nine Chapters on the Arithmetic Art, first century AD). A passage in Book I of Plato’s *Republic*, however, reveals that the problem could be expected to be familiar for the Athenian public of the fourth (and probably the fifth) century BCE (“buying a horse collectively” is said to be a situation where one needs an expert).

A third problem from the cluster is “the hundred fowls”: Somebody is to buy 100 fowls for 100 monetary units, given that (e.g.,) a rooster costs 5 units, and a hen 3, while chicks are sold 3 for 1 unit. It occurs in a Chinese fifth century source, as well as the Carolingian *Propositiones*, and ► [Abū Kāmil](#) describes it as widespread in his environment among people who do not understand the mathematical principles involved but just give one answer without adequate reasoning. A variant has been located by Jean Christianides in a Greco-Egyptian papyrus.

It is thus true that the distribution of these (and other) problems from the cluster bear witness of “age-old cultural relations between... Civilizations” (in Hermelink’s words as quoted initially). It is no less true, however, that they highlight the absence of cultural relations at other levels. The *Nine Chapters* as well as Plato’s remark and the reflections of the subscientific corpus in Diophantos’ *Arithmetic* demonstrate that the literate cultures of China and of the Mediterranean world (to take these as the paradigm) knew about the anonymous

tradition, and would take over appropriate material without credit. The wholly different methods applied by the Chinese mathematicians and by Diophantos to solve the same problems also show that what they took over was inspiration, in particular problems, and not full mathematical structures. The high cultures did not really communicate with the low oral culture (no more in mathematics than in other cultural domains); they drew on them and exploited them. Nor did they communicate with each other through the low cultures. Moreover, what happened at the level of oral culture may not be adequately described as cultural relations. The very possibility of distinguishing particular clusters shows that even oral cultures had their sharp boundaries across which only limited communication took place. But these boundaries did not coincide with the geographical boundaries between high cultures, and only in part were they at all geographical in nature. It was, so it seems, a common subscientific merchants' culture which inspired the Chinese and the Alexandrian mathematicians, and which thereby creates the illusion of general cultural relations (similarly, jugglers might move between China and ancient Rome; neither Roman nor Chinese gentlemen ever did).

The cluster just used as an example belonged with a calculators' and caravan merchants' culture. A cluster dealt with elsewhere in this volume, surveyors' "algebra", was carried by practical geometers from the Syro-Irano-Iraqi region. Even in this case, just enough evidence from the Greco-Roman world has survived to show directly that the tradition was known (one Greek papyrus, a problem in one agrimensur [surveyor] treatise). Indirect evidence shows that Diophantos drew inspiration even from this source, and that Book II of Euclid's *Elements* is closely connected to the tradition. For the present argument, however, the relation between surveyors' algebra and Babylonian scribe school algebra is more important, as an unusually articulate instance of the relation between subscientific and scholasticized mathematics.

According to what can be concluded from combination of the evidence presented by the various written traditions that it inspired,

the stock of quasialgebraic recreational which problems that were current among the practical geometers of the region was quite restricted:

- To find the side of a square when the area; the diagonal; the sum of the area and the side; or the sum of the area and all four sides was known;
- To find the sides of a rectangle when the sum of its sides was known together with the area or the area augmented by the difference between the sides;
- When the difference between the sides together with the area or the area augmented by both or by all four sides; or
- When the diagonal together with the sum of or difference between the sides.

Each problem type was presented by only one or at most two examples, which would permit even those who did not understand to learn them by heart, and everything concerns the entities really present in the geometrical configuration – *the* area, not some multiple; the side, or the sides; etc. From indirect evidence, we may assume that the diagonal of the 10×10 square was taken to be 14.

The technique was taken over by the Old Babylonian scribe school and developed into its central discipline – a quasialgebra based on geometric cut-and-paste procedures. It still appears to have served professional self-esteem on the part of the scribes. But becoming a discipline (etymologically: a subject which is to be learned) it was systematized. We find texts which vary the coefficients of both the area and the sides systematically, others which replace the length of a rectangle with the product of the length and the ratio between length and width, and the width with the product of the width and the ratio between width and length (formally the outcome is a problem of the sixth degree; the solution combines a second-degree and a homogeneous third-degree equation, that is, well-known stuff), and still others where the geometrical entities represent prices in artificial commercial problems. Mathematical irregularities like the diagonal of 14 have been eliminated.

Beyond professional pride, this systematically drilled technique served the purpose of normal school mathematics: through the introduction of coefficients and other complications, the discipline could function as a training ground for the use of the sexagesimal place value system, which was fundamental for the daily engineering and accounting practice of scribes (while all second-degree problems were completely artificial and pure). On the same occasion, the problems lost most of their recreational character.

But the introduction of systematic drills and the elimination of mathematical irregularities were not the only changes. The sixth-degree problems, however much they constitute a trivial extension, and the use of the geometrical technique as a representation of nongeometrical entities, have to be understood as systematic attempts to test the carrying capacity of the professional tools, including the trick of the quadratic completion that was the basis even of the surveyors' algebra. The outcome may be claimed to be really an algebra, while the "surveyors' algebra" was not – an algebra being understood as the application of a functionally abstract standard representation (in terms of x and y , Greek *arithmós*, or Arabic *šay'* [thing] and *māl* [possession]) in the analysis of complex relationships involving entities of any kind. If the scribe school had possessed the intellectual drive for that, a transformation into scientific mathematics might have occurred, as it appears to have occurred in the case of *wasan*, and as it occurred – but then in interaction with already-present scientific mathematics – in the Islamic Middle Ages.

Lest anybody believe that the process of scholastization, with all its tediously repetitive drills, should be a characteristic of non-Western civilizations (or of some of them), one may point out that it reached a high point in the Humanist schools of the Renaissance and Early Modern period – the very cradle of the Western ideology.

See Also

- [Mathematics in Japan](#)
- [Sexagesimal System](#)

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Mathematics: Aztec Mathematics

Michael P. Closs

The tribal records of the Aztecs indicate that they left their legendary homeland in AD 1168 and founded their capital Tenochtitlan (present day Mexico City) in 1325. By the fifteenth century, their capital had become the center of an expansionist empire. When Cortés arrived in 1519, Tenochtitlan dominated all other cities and had reached the height of its power and magnificence. The language of the Aztecs,

Mathematics: Aztec Mathematics, Table 1 The Nahuatl number sequence

1	ce	
2	ome	
3	ei, yei	
4	nahui	
5	macuilli	
6	chicuace	(5) + 1
7	chicome	(5) + 2
8	chicuei	(5) + 3
9	chiconahui	(5) + 4
10	matlactli	
11	matlactli once	10 + 1
12	matlactli omome	10 + 2
13	matlactli omei	10 + 3
14	matlactli onnahui	10 + 4
15	caxtolli	
16	caxtolli once	15 + 1
17	caxtolli omome	15 + 2
18	caxtolli omei	15 + 3
19	caxtolli onnahui	15 + 4
20	cempoalli	one score
30	cempoalli ommatlactli	20 + 10
37	cempoalli oncaxtolli omome	20 + 15 + 2
40	ompoalli	2×20
60	eipoalli	3×20
100	macuilpoalli	5×20
400	tzontli	
401	centzontli once	$(1 \times 400) + 1$
405	centzontli onmacuilli	$(1 \times 400) + 5$
500	centzontli ipan macuilpoalli	$(1 \times 400) + (5 \times 20)$
8,000	cenxiquipilli	$1 \times 8,000$

Nahuatl, is still spoken today in Central Mexico. An overview of the Nahuatl number sequence is given in Table 1.

The term for five, *macuilli*, derives from *mailt* “hand”, *cui* “to take” and *pilli* “fingers”. It means something like “fingers taken with the hand”. The term for ten, *matlactli*, comes from *mailt* “hand” and *tlactli* “torso”. The term for 15 is a new basic word for which there is no known etymology. The vigesimal nature of the number system clearly shows up in the introduction of new basic terms for 400 and 8,000. The word for 400, *tzontli*, means “hair” or “growth of garden herbs”. In either case, it signifies multitude or

abundance. The word for 8,000, *xiquipilli*, refers to a “bag of cacao beans”.

The Aztec had written numerals for the first four vigesimal powers: $20^0 = 1$, $20^1 = 20$, $20^2 = 400$ and $20^3 = 8,000$. These symbols are shown in Fig. 1: (a) a dot represents the unit 1; (b) a flag represents 20; (c) a hank of hair or garden herb represents 400; (d) a bag of cacao beans is used for 8,000. It can be seen that the symbol for 400 reflects the word for that number, *tzontli*, “hair” or “growth of garden herbs”. Similarly, the sign for 8,000 reflects the word for that number, *xiquipilli*, “bag of cacao beans”.

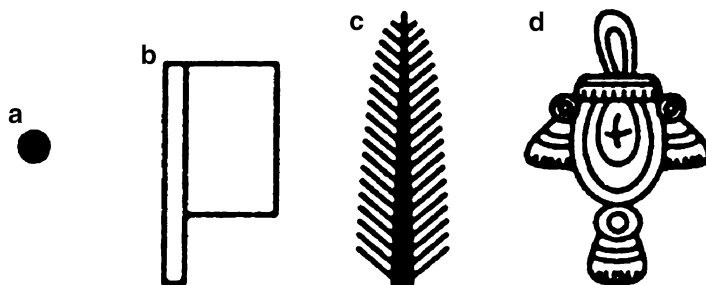
A tally of these four numerals was used to represent other numbers. Thus, quantities from 1 to 19 were represented by the appropriate number of dots or circles. In the same way, multiples of 20 less than 400 were represented by repeating the sign for 20 as many times as necessary. Similarly, the symbols for 400 and 8,000 were repeated to form multiples of 400 and multiples of 8,000, respectively. The largest number I have seen recorded with these numerals occurs in the Vatican Codex. It is composed of 2 signs for 8,000 and 9 signs for 400 yielding $(2 \times 8,000) + (9 \times 400) = 19,600$.

Numerals are found in a variety of contexts. One of the most common of these is as numerical coefficients in calendar dates. The Aztecs, along with other Mesoamerican cultures, employed two major calendrical cycles, a sacred almanac of 260 days called the *tonalpohualli* and an annual calendar of 365 days. The *tonalpohualli* was constructed from a sequence of numbers from 1 to 13 paired with a sequence of 20 day names. The 260-day and the 365-day calendars were combined so that each day could be specified by both a sacred date and an annual date. Since the least common multiple of 260 and 365 is 18,980 ($=52 \times 365$), the combined cycle of the two calendars repeats after 52 years of 365 days each. This 52-year period, known as the *xiuhmolpilli* “sacred bundle,” played a significant role in Aztec religious life.

A given 365-day year was designated by the sacred almanac name of its 360th day. We refer to this name day of the year as the year bearer. Because of the structure of the calendar, only

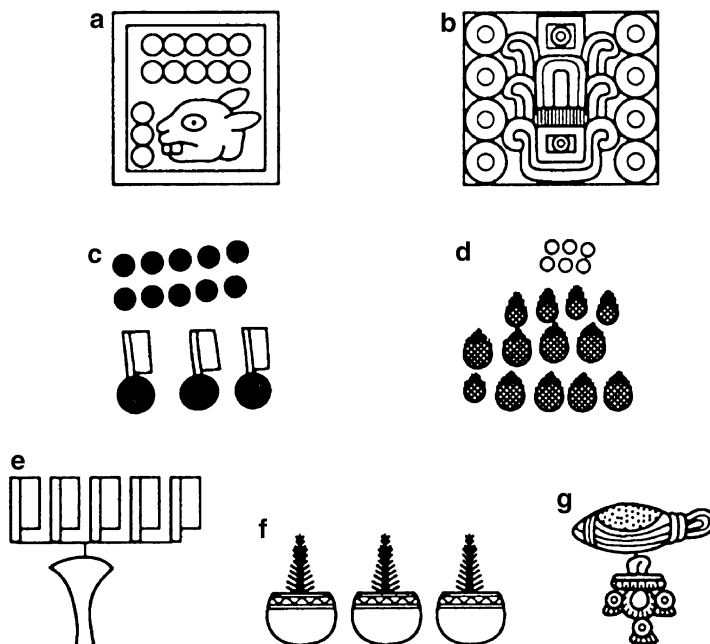
Mathematics: Aztec Mathematics,

Fig. 1 Aztec numerals: (a) 1; (b) 20; (c) 400; (d) 8,000 (Drawing by Closs)



Mathematics: Aztec Mathematics,

Fig. 2 Contexts of Aztec numeral usage. *Calendar dates (year bearers):* (a) 13 Rabbit; (b) 8 Reed. *Chronological counts:* (c) 70 years; (d) 5,206 years. *Tribute records:* (e) 100 copper hatchets; (f) 1,200 coarse clay pots; (g) 8,000 balls of unrefined copal (incense) wrapped in palm leaves (Drawing by Closs)



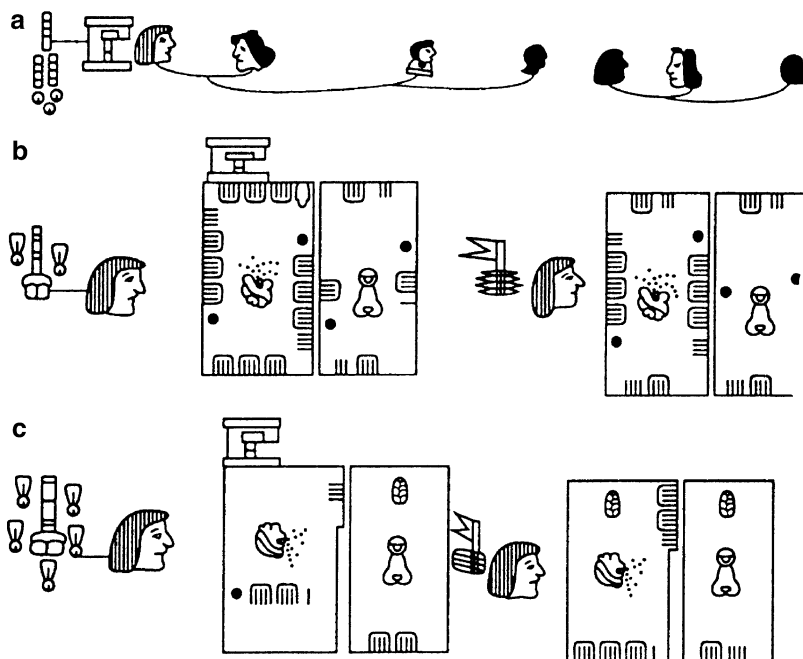
4 day names could function as year bearers. The 13 numerical coefficients with the 4 day names yield 52 year bearers, one for each year in the 52 year period. In the Aztec codices and stone monuments, such years are frequently named. In these cases, the numerical coefficients are represented by a tally of from 1 to 13 small circles. Examples of the year bearer dates, 13 Rabbit and 8 Reed, are shown in Fig. 2a, b.

The Aztecs also used numerals in chronological counts which varied from a few days to thousands of years. One section of the Mendocino Codex gives the different stages in the education that a boy or girl receives from its parents. The tasks which children must learn are depicted and their daily food ration is shown by a tally of tortillas that appears over their heads. The ages

are indicated by a simple tally of blue disks representing the number of years. These run from 3 up to 14 as one progresses through the manuscript. The corresponding daily ration rises from half a maize cake to two per day. The largest chronological interval of this type is depicted in another portion of the Mendocino Codex where an elderly male and female are shown drinking a fermented beverage denied to those who are younger. Both persons are 70 years old and their age is indicated by a tally of ten blue disks together with three disks marked with the flag symbol for 20 as shown in Fig. 2c.

The Vatican Codex contains other chronological counts which measure far larger intervals. A count which refers to the years of the second age of the world is shown in Fig. 2d. Each of the

Mathematics: Aztec Mathematics, Fig. 3 A land record from the *Codice de Santa Maria Asuncion* (Drawing by Closs from Harvey & Williams, 1986)



cross-hatched disks with hair on top is blue in the original and represents a period of 400 years, being a conflation of the standard blue disk for the 365-day period and the numeral for 400. (In this regard, recall that the Aztec term for 400 is *tzontli*, “hair”.) In the upper row is a tally of six smaller disks marking 6 years. The total count measures a period of $(13 \times 400) + 6 = 5,206$ years.

Some of the Aztec codices contain lists in which the quantities of the various tribute items to be received from conquered towns are recorded. In these documents, the towns are represented by hieroglyphic toponyms, the tribute items by hieroglyphic signs, and the quantities by numerals or by a simple tally of the items. If the total is less than 20, the item is often represented by a simple tally of the sign for the object itself or by a single depiction of the tribute item with an attached tally of numerals. For larger totals, a combination of the two types of tallies is often used. Some examples of tribute records are shown in Fig. 2e–g.

In the land documents of the Texcocan Aztecs a more concise and sophisticated system of numerical notation was employed. It was used

for recording the measurements of perimeters and areas of land holdings in at least two locations in the Valley of Mexico. The system made use of only four symbols – a vertical tally stroke, a bundle of five strokes linked at the top, a dot and a corn glyph (*cintli*) – and position to indicate the value of measurements (Harvey and Williams 1980, 1986).

An example from the *Código de Santa Maria Asunción*, dating from around 1545, is illustrated in Fig. 3. The land record is divided into three parts. The first section (*tlacatlacuiloli*, *tlacanyotl*) contains a census by household. The name for each head of household is written in glyphic form beside a conventional symbol for household head. In the present example, the *tlacatlacuiloli* shows the head Pedro, his wife Juana, their two young daughters Ana and Martha, and the head’s younger brother, Juan Pantli, his wife Maria and their son Balthasar. The shaded heads indicate that the individual is deceased.

The second section (*milcocoli*) consists of a record of land parcels associated with each household. In this section, the scribe drew the approximate shape of each field. The

measurement of each side was recorded using lines and dots, a line equal to one linear unit and a dot equal to 20. In the Texcocan area, the usual unit of linear measure was the *quahuítl* of approximately 2.5 m. Units less than one quahuítl were indicated by symbols such as a hand, an arrow, or a heart. The modern equivalents of these signs can only be estimated at present. In addition to recording linear measurements around the field perimeters, each field contains a hieroglyph in the center which indicates the type of soil. In particular, the milcocoli section for our example records the approximate shape, perimeter measurements, and soil type of four fields belonging to the household, two to the household head and two to his brother. The hand glyph in the first field indicates a fraction of a quahuítl.

The third section (*tlahuelmantli*) is a second record of the same lands as in the milcocoli section. However, in this case, the lands are shown in a stylized form as rectangles of the same size. Interestingly, the Nahuatl term *tlahuelmantli* literally means “smoothed, leveled, equalized.” The majority of these fields have a protuberance in the upper right-hand corner. In addition to the standardized field shapes, the placement of numbers in the tlahuelmantli is different from in the milcocoli. The numerical quantities using lines and dots are entered either in the center or on the bottom line of the rectangle and in the protuberance. When numbers, never exceeding 19, are entered on the bottom line, a cintli glyph occurs near the top border of the rectangle. In addition, most fields contain a number ranging from 1 to 19 in the upper right corner of the protuberance. It has been determined that these numbers report the area of the field in square quahuítl by use of positional notation.

The system of recording area is dependent on three separate registers. The first register is located in the upper right protuberance and is used to record a unit count from 0 to 19. When the value of this register is 0, the protuberance is left empty or is not drawn. Otherwise, 1–19 strokes are recorded with groups of five being bundled together by a connecting line. The second register is the bottom line of the rectangle. It is used to record from 1 to 19 multiples of

Mathematics: Aztec Mathematics, Table 2 The length of the sides, in *quahuítl*, of the four fields in the *milcocoli* section and the area, in square *quahuítl*, of the corresponding fields in the *tlahuelmantli* section

	Sides	Area
Field 1	39, 15, 39, 15+	$(31 \times 20) + 4 = 624$
Field 2	25, 8, 26, 8	$(10 \times 20) + 0 = 200$
Field 3	38, 9, 39, 8	$(16 \times 20) + 13 = 333$
Field 4	20, 9, 20, 8	$(9 \times 20) + 0 = 180$

20 (the vigesimal numbers from 20 to 380) by using a simple tally of 1–19 strokes. The third register is in the central portion of the rectangle. It is used to express higher multiples of 20, that is multiples of 20 which are greater than or equal to 400. In this register, a dot has value 400 and a stroke has value 20. The second and third registers are never used concurrently. If there is no entry in the third register, the cintli glyph is drawn toward the top of the rectangle. This may signify 0 in that register. In order to compute the area, the number in the second or third register is multiplied by 20 and added to the number in the first register.

In the example under consideration, the length of the sides, in quahuítl, of the four fields in the milcocoli section and the area, in square quahuítl, of the corresponding fields in the tlahuelmantli section is shown in Table 2.

The problem of how the areas in the tlahuelmantli were determined remains to be resolved. In general, the area of a quadrilateral cannot be determined from the lengths of its sides. As a result, the information in the milcocoli section is not sufficient to obtain the true areas of the fields.

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Mathematics: Maya Mathematics

Michael P. Closs

The common numerical notation of the Maya employed combinations of “bars”, having value 5, and “dots”, having value 1, to represent the vigesimal digits from 1 to 19. For example, the kneeling scribe in Fig. 1 appears on a Classic Maya vase dating from around AD 750. From his armpit emanates a vegetative scroll containing bar and dot numerals. Beginning at the armpit, the sequence of numerals runs 13, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Often, non-numerical crescents or other fillers were used to create a more aesthetic balance for the numeral.

In some records, these simple numerals are used to count objects, in particular to specify the quantity of offerings of a particular type. However, the overwhelming usage occurs in calendrical and chronological contexts. In the former, the numerals appear as coefficients in the Maya calendars of 260 and 365 days. The former consisted of the cycle of numbers from 1 to 13 paired with a cycle of 20 day names. As the days went by, both the number and the day name would simultaneously advance in their respective cycles, thus generating a sequence of 260 distinct dates. The second calendar was a civil year composed of 18 “months” of 20 days each and a residual “month” of 5 days. The days within a given month were numbered consecutively from the first to the penultimate by prefixing the proper numeral to the appropriate month name. The last day was sometimes indicated by prefixing a special sign having the sense of “end” to the month name. However, the more common practice was to prefix a sign signifying “seating” to the following month and thereby identify the last day of 1 month as the seating day of the following month. Frequently, the Maya would describe a day by giving its dates in both the 260 and 365 day calendars. This generated a cycle of 18,980 paired dates known as the “calendar round”.

A characteristic of Maya writing is that it often uses many distinct signs to represent the same linguistic value. This is the case with numerical terms where, in addition to bar and dot numerals, the Maya represented numbers by head forms and even full body figures. Some examples of bar and dot numerals in calendrical contexts, with alternative representations of the same dates using head variant numerals, are illustrated in Fig. 2. All of these examples come from the same ancient Maya city of Palenque and demonstrate the scribal variation to be found in Maya writing even at the same location. For a more extensive description and additional examples of Maya numeral forms, see Closs (1986).

The Maya frequently recorded the chronological interval separating two calendar dates. For this purpose they employed a vigesimal count of *tuns* (360 day periods) and separate counts of *winal*s (20 day periods) and *k'in*s (days). A given interval would be expressed as a count of the respective time periods into which it could be minimally decomposed. Each of the time periods was represented by a characteristic sign and the appropriate count was indicated by a numerical prefix. In recording such chronological counts, it is necessary to have a symbol for zero so as to indicate an empty count of a particular period if this occurs. The Maya did have a zero symbol for that purpose. In fact, as with other signs employed in Maya writing, there are several variants of the zero symbol.

In many cases, and typically in the codices, Maya scribes would represent chronological counts using a system of positional notation. In this system, counts were written vertically with the lowest position being occupied by the count of *k'in*s, the next higher position by the count of *winal*s, the next higher position by the count of *tun*s, and successively higher positions by the corresponding count of successively larger vigesimal multiples of the *tun*. Any chronological count could be recorded in this system by using the 19 vigesimal bar and dot digits and a symbol for zero.

In the monumental inscriptions, it was customary to indicate the interval between two



Mathematics: Maya Mathematics, Fig. 1 A kneeling Maya scribe (Drawing by Closs after Clarkson, 1978)

successive dates of the text by recording the chronological interval separating them. Such chronological counts are referred to as “distance numbers” and might be added or subtracted to a given date to reach the following date. The initial date in an inscription is often anchored in an absolute chronology by recording the chronological count separating it from a common base date far in the past. These chronological records are referred to as Initial Series and have a characteristic format. An example of an Initial Series on Stela 1 at Pestac, employing positional notation and incorporating a zero, is illustrated in Fig. 3. It shows a count of 9 baktuns (=3,600 tuns), 11 k’atuns (=220 tuns), 12 tuns, 9 winals, and 0 k’ins (a total of 1,379,700 days or approximately 3,777 years) and leads to a date in AD 665. This is the oldest securely dated Maya text incorporating the system of positional notation with a zero sign.

In nonpositional contexts, the zero sign is found in Initial Series at a much earlier time. For example, the zero sign occurs on Stela 18 and 19 at Uaxactun, dating from AD 357. The most ancient nonpositional chronological count of this type, but without a zero, is found on Stela 29 at Tikal, dedicated in AD 292. It is interesting to note that the system of positional notation is very ancient in Mesoamerica and is found on monuments that predate those of undisputed Maya origin. However, none of them exhibit a zero sign. The oldest of these monuments goes back to 36 BCE.

In several instances, the Maya worked with negative chronological counts. These are used when counting backward from the zero point (base date) of the absolute chronology. They are distinguished from positive counts by a peculiar notation that has engendered the term “ring number”. An example of a ring number from the Dresden Codex, one of the few surviving Maya hieroglyphic books, is illustrated in Fig. 4. The ring number of 1.7.11 is a negative chronological count with reference to the zero point of Maya chronology and leads to a mythological date.

Among the mathematical problems faced by the Maya were those of determining the calendar round date when a chronological interval is added to or subtracted from a given date and of determining the chronological interval between two given calendar round dates. The Maya also used other calendrical cycles of 4 days, 9 days, and 819 days. This led to other problems such as determining the station in the 819 day cycle closest to a given calendar round date. It is clear from artifactual evidence that the Maya performed their calculations using residue arithmetic.

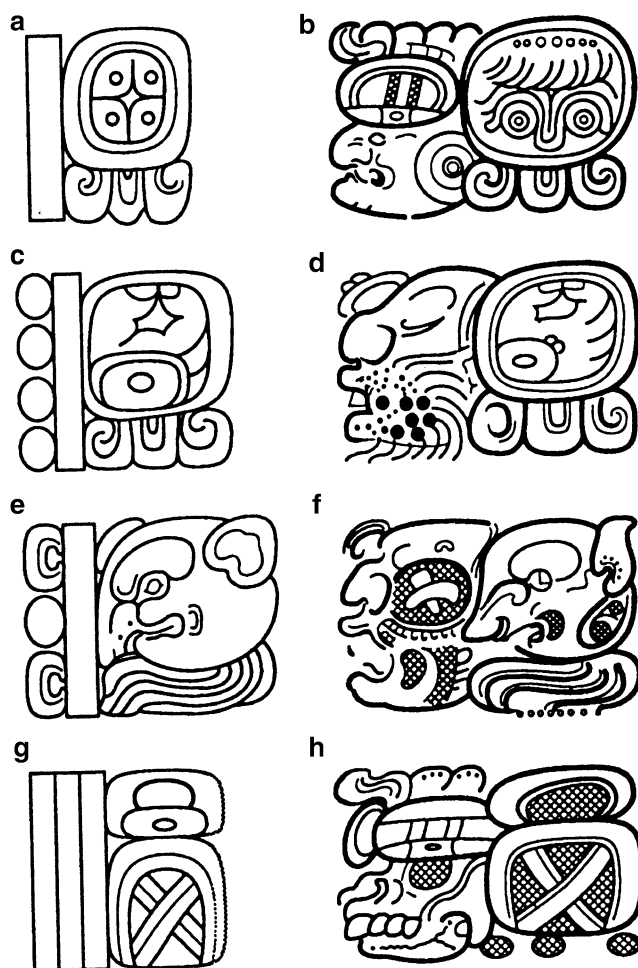
The most sophisticated accomplishments in Maya mathematics are found in their arithmetically based astronomy. Here I will touch on three areas.

1. From the earliest days, the Maya scribes kept track of the moon through a lunar calendar. We have a large number of moon age records

Mathematics: Maya Mathematics,

Fig. 2 Maya numerals in a calendrical context. Dates in the 260-day calendar:

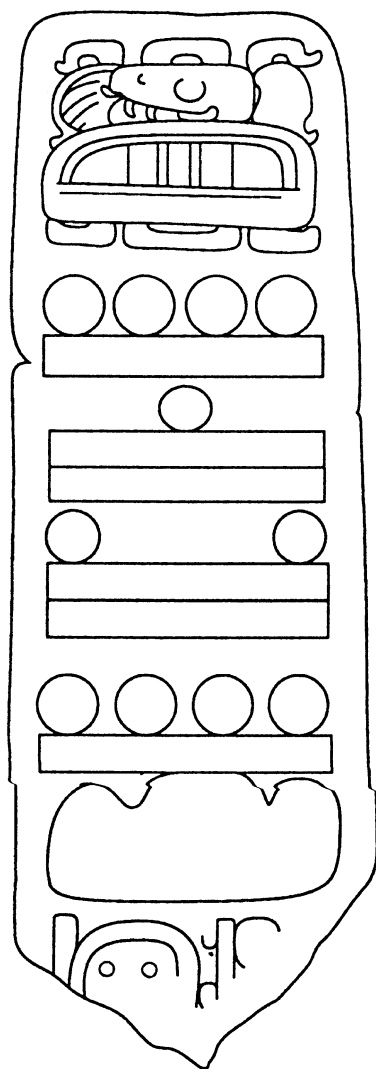
- (a) 5 Lamat, Palenque, Palace Table, R4;
 (b) 5 Lamat, Palenque, Tablet of the 96 Glyphs, D4;
 (c) 9 Manik, Palenque, Dumbarton Oaks Panel 2, J;
 (d) 9 Manik, Palenque, Tablet of the 96 Glyphs, H1.
 Dates in the 365-day calendar:
 (e) 6 Xul, Palenque, Palace Tablet, N15;
 (f) 6 Xul, Palenque, Tablet of the 96 Glyphs, C5;
 (g) 15 Uo, Palenque, Tablet of the Slaves, H5a;
 (h) 15 Uo, Palenque, Tablet of the 96 glyphs, G2
 (Drawing by Closs)



giving the current age of the moon within a cycle of 29 or 30 days. If a moon age was greater than 19 days, a special symbol for 20 was employed along with a regular bar and dot numeral to make up the balance of the count. Occasionally, a similar notation was used in the chronological counts discussed above. Since a lunation is around 29.5 days, the Maya used varying proportions of 29-day and 30-day months to keep their moon age records in agreement with astronomical reality. This gives an idea as to how the Maya avoided the necessity of fractions in their integer-based arithmetic. We have a few examples of moon age calculations from contemporaneous dates into mythological

time, thousands of years earlier, from which it has been possible to recover the moon-age formulas that were used. These are formulas of the type “ x moons = y days” where x and y are integers. Dividing through by x , one can say that a particular Maya formula is equivalent to estimating an average lunation as y/x days. This can then be compared with modern estimates and the precision of the Maya results can be recognized. Nevertheless, it can be misleading because the Maya did not look at things in this way.

2. The Dresden Codex contains a Venus table that permits the prediction of first appearance of the planet as morning star and as evening star over a period of about 104 years. The introductory



Mathematics: Maya Mathematics, Fig. 3 The front of Pestac, Stela 1, with an Initial Series of 9.11.12.9.0 employing positional notation and a zero sign (Drawing by Closs)

page to the table has several features of mathematical interest. It has a mythological base date marked by a ring number. To this is added a companion number leading to a canonical base date of the table in the historic era. The companion number spans a period of 1,366,560 days (more than 3,741 years). It has the prime factorization $2^5 \cdot 3^2 \cdot 5 \cdot 13 \cdot 73$ and so is highly divisible into a product of relatively

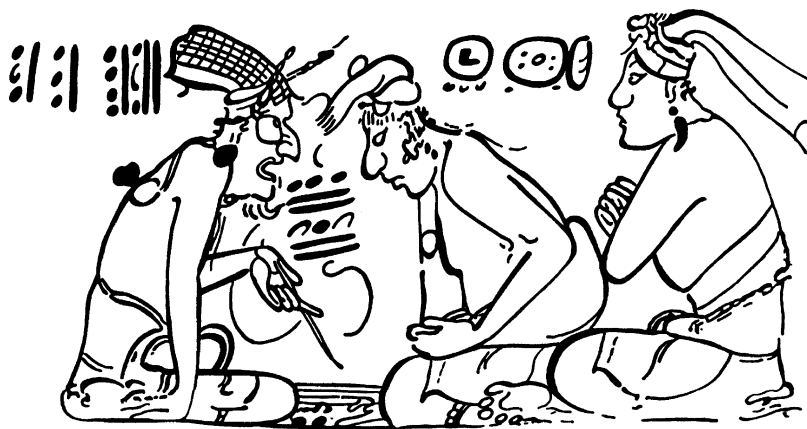
Mathematics: Maya Mathematics, Fig. 4 A Maya ring number of 1.7.11 from the Dresden Codex, p. 58 (Drawing by Closs)



small prime numbers. This is fairly typical of other companion numbers associated with ring numbers in the Dresden Codex. It is a contrived number constructed using a knowledge of residue classes. The page also includes a table of multiples of 2,920 days. The importance of this number stems from the formula “5 Venus years of 584 days = 8 solar years of 365 days” commensurating the Venus and solar cycles. The existence of tables of multiples is habitual in the Dresden Codex and indicates that the Maya worked from such tables rather than depending on algorithms for multiplication. The table of multiples and other calculation factors provide a mechanism for advancing from the canonical base date of the Venus table into the Venus table proper at a contemporaneous date. Still other calculating factors on the same page permit the Venus table to be recycled over time so that it maintains its astronomical integrity over several hundreds of years, much longer than the actual span of the table.

3. The Dresden Codex also contains an eclipse table that identifies dates of potential solar and

Mathematics: Maya Mathematics, Fig. 5 An ancient Maya mathematics lecture (Drawing by Closs from Kerr, 1989)



lunar eclipses. It records a commensuration of the eclipse cycle with the sacred calendar of 260 days. This table also has mechanisms for recycling so that it can remain useful over many runs of the table. It is one of the great mathematical and astronomical achievements of the ancient Maya.

We also have some indications of geometrical knowledge among the Maya but nothing derived from written texts. Information that has been obtained comes from the study of architecture and site plans. For example, there are reasons to believe that an arrangement of three major temples at Tikal – at the vertices of an isosceles right triangle – is not coincidental. Many other alignments suggesting intentional geometrical concerns have been proposed at various Maya sites, but no adequate synthesis of the geometry involved has yet been achieved.

The idea of mathematics was sufficiently concrete in Maya thought that it has a presence in Maya art and iconography. In a number of almanacs in the Madrid Codex, deities are shown holding a vessel of black paint in one hand and a brush for painting or writing in the other. This type of scene is now known to depict the deity in the act of writing or painting. In at least two instances, an extra feature has been added to the scene. This consists of a scroll containing numbers issuing from the mouth of the deity. The added element indicates that the writing which is being performed

is of a mathematical nature. By using this device, the Maya artist testifies to the visibility of mathematics as a discipline in Maya society.

The notion that mathematics was also considered a distinct discipline within the scribal curriculum is demonstrated on a Classic Maya vase (ca. AD 750). The scene on one side of the vase, illustrated in Fig. 5, shows a classroom scene in which Pauhahtun, an aged god with a characteristic netted headdress, instructs two disciples in the mathematical art. Pauhahtun, who is known to be a patron of scribes, is seated with a codex in front of him and a brush pen in his left hand. From his mouth issues a speech scroll containing the bar and dot numbers 11, 13, 12, 9, 8, and 7. The hieroglyphic caption behind the head of the first student is a name glyph. On the other side of this vase, there is a near identical classroom scene in which hieroglyphs are recorded in the speech scroll. In that case, the spoken text begins with a verb indicating “to teach.”

A pair of deities in a detail from another Classic Maya vase is shown in Fig. 6. The god on the right has the facial features of a monkey and carries a codex in his right hand. An effigy head rests on top of the opened codex. The god on the left rests one hand on the back of the previous figure and holds a conch shell ink-pot in the other. Of special interest is a vegetative scroll, containing bar and dot numerals, which emanates from his armpit. There is also a curl,

Mathematics: Maya Mathematics,

Fig. 6 Maya gods of mathematics and writing (Drawing by Closs from Coe, 1978)



with single digits, running down from his cheek. Coe has suggested that these deities are patrons of mathematics and writing. The pairing of the two deities in this manner distinguishes between mathematics and writing in Maya thought. It reinforces the idea that mathematics was recognized as a separate discipline.

It is apparent that a scribe who was a mathematical specialist must have mastered calendrical and chronological calculations. The most detailed information on Maya civilization at the time of the Spanish conquest is found in Bishop Landa's *Relacion de las Cosas de Yucatan*. This work was written shortly after the conquest and draws heavily on data provided by educated native informants, members of the former scribal class. Landa refers to the mathematical techniques of the Maya scribes as the computation of the *katuns*. He writes that this "was the science to which they gave the most credit, and that which they valued most and not all the priests knew how to describe it" (Tozzer, 1941). This informs us that not all scribes were mathematical specialists and that those who were had greater prestige. It supports the idea that mathematical specialists were recognized as a specialized subgroup of the scribal class. In this regard, the situation at the time of the

conquest seems to have been no different than it was during the Classic period.

See Also

- ▶ [Astronomy](#)
- ▶ [Calendars in Mesoamerica](#)
- ▶ [Eclipses in the Americas](#)

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Mausoleums of the Islamic World

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Early Islam, as recorded in the traditions of the Prophet Muhammad (*hadīth*), was skeptical towards monumental funerary architecture. Since funerals should be kept as simple as possible, the veneration of the dead mourning practices such as wailing, processions, and prayer at tombs was avoided (Halevi, 2007; Leisten, 1998). Monumental architecture to mark a grave was prohibited, and the grave was supposed to be level with the ground. More elaborate burial practices soon emerged, even though the practice of burying the dead in a shroud remained. The latter was made out of more and more precious textiles, at least in the case of the wealthy elites. At the same time, architectural markers began to appear on the graves of rulers. The so-called Qubbat al-Sulaybiyya, a ninth-century structure in the Abbasid capital of Samarra in today's Iraq, is probably the earliest surviving Islamic mausoleum (Grabar, 1966).

Iran, Central Asia, and India

In Central Asia, a funerary architecture developed under the rule of the Samanids (r. 819–999), a dynasty whose mausoleum is in Bukhara (today in Uzbekistan), built in 907, is a cubic structure with elaborate brick decoration on all interior and external surfaces (Fig. 1). Another dynasty, the Great Seljuks, in their expansion from Central Asia into Mesopotamia and Anatolia brought this proclivity towards the construction of monumental mausolea with them. The mausoleum of Seljuk Sultan Sanjar in Merv (c. 1157–1160), even though today largely in ruins, is one of the most impressive examples of funerary architecture from that period. In the eleventh century, constructing mausoleums officially became an important part of Persian



Mausoleums of the Islamic World, Fig. 1 The Samanid mausoleum in Bukhara, Uzbekistan (Photo: P. Blessing)

architecture and culture. Many of these mausolea were erected to honor famous Sufis and religious masters, including the tomb of Bayazid Bastami (first dated structure c. 1120), a famous Persian mystic who lived in the ninth century, in Bastam (Iran). Like other mausolea, it was a place for pilgrimage. In the late thirteenth and early fourteenth centuries, the building was redecorated with stucco and tile and expanded with the addition of a monumental portal and an enclosing wall and an iwan across the courtyard from the portal [an iwan is a rectangular hall or space, usually vaulted, walled on three sides, with one end entirely open]. In later times, mausolea grew to more monumental size, as testified by the mausoleum of the Ilkhanid Sultan Uljaytu near Tabriz in western Iran (c. 1314) and the so-called Gur-i Mir (Fig. 2), the mausoleum of Timur (d. 1405) in Samarqand (Uzbekistan), built in the early fifteenth century. In this monument, a domed funerary chamber

Mausoleums of the Islamic World,

Fig. 2 Gur-i Mir,
Samarqand, Uzbekistan
(Photo: P. Blessing)



contains the burials of Timur and several members of his family, creating a dynastic mausoleum. With the advent of the Safavid dynasty in Iran in the early sixteenth century, royal tombs were concentrated around the shrine of Shaykh Safi at Ardabil, while other locations such as the shrine of Fatima al-Ma'suma in Qom were promoted as pilgrimage sites (Rizvi, 2011). Around the same time, a strong connection between funerary monuments and gardens was also present in Mughal India; mausolea have been preserved that date back to the mid-sixteenth century, such as the tomb of Humayun (r. 1530–1540 and 1550–1556) in Delhi. The most famous of all is the Taj Mahal (1622–1628), the tomb that Shah Jahan built for his wife Mumtaz Mahal (Koch, 2006). Here, the mausoleum is situated within a garden landscape that is designed to highlight its structure and to provide a pleasant setting evoking the gardens of paradise.

Anatolia

Following the Seljuk conquest of Anatolia in the late eleventh century, the construction of tower-shaped mausolea with conical roofs took hold there as well. Even though no examples have survived from this earliest period of Islamic rule in Anatolia, examples from the twelfth and

thirteenth centuries are numerous. The mausoleum of the Seljuk sultans, one of these conical structures built in stone, is located in the courtyard of the Alaeddin Mosque in Konya (Turkey). Built in the 1180s, it was used as a dynastic burial site well into the thirteenth century, and the tile-covered cenotaphs of several Seljuk sultans are located in its center. Similar mausolea, many of them freestanding, were built for members of the Seljuk nobility, such as the Çifte Kümbet in Kayseri, built in 1247, or the Döner Kümbet, a late thirteenth-century monument in the same city (Fig. 3). At the same time, mausolea were often integrated into larger architectural complexes, such as the Huand Hatun Complex in Kayseri (began in 1237–1238) where the mausoleum is combined with a madrasa and mosque and fused with one of the madrasa's walls. This type of multifunctional complex continued to be used under Ottoman rule, even though the mausolea were more often freestanding structures within a larger complex that was connected under one endowment. A famous example is the complex of Ottoman Sultan Mehmed I, built in Bursa in 1419–1421 and also known as the Green Mosque and mausoleum after the tile-clad exterior of the tomb tower. After the conquest of Constantinople in 1453, such complexes only expanded in size and reached their peak during the rule of Süleyman the Magnificent (r. 1520–1566) with



Mausoleums of the Islamic World, Fig. 3 Döner Kümbet, Kayseri, Turkey (Photo: P. Blessing)

the work of the architect Sinan. In the Süleymaniye Complex in Istanbul (1550–1558), the mausolea of Süleyman (d. 1566) and of his wife Hürrem Sultan (d. 1558) stand in the garden behind the *qibla* wall of the mosque. Both are small, octagonal domed structures built of marble and extensively decorated with Iznik tiles in the interior. Over time, the funerary complexes of the Ottoman sultans, particularly the large domes of the mosques that usually overshadowed the mausolea, came to dominate the cityscape of Istanbul. In the late sixteenth and the early seventeenth centuries, mausolea became increasingly used for multiple burials, to the point that cenotaphs crowded the space, for instance, in the Yeni Valide Mosque in Istanbul (1597–1603 and 1661–1663). Here, the mausoleum, while structurally similar to earlier ones housing single burials, contains the tombs of Turhan Hatice Sultan, Osman III (r. 1618–1622), Mehmed IV (r. 1648–1687), Mustafa II (r. 1695–1703),



Mausoleums of the Islamic World, Fig. 4 Mihrab and cenotaph in Madrasa Zahiriyya, Damascus, Syria, 1277 (Photo P. Blessing)

Ahmed III (r. 1703–1730), and Mahmud I (1730–1754) and other members of the Ottoman dynasty.

Greater Syria and Egypt

In Greater Syria (i.e., today's Lebanon, Jordan, Israel, Palestine, and Syria) and Egypt, the earliest mausolea to have survived in greater numbers date to the eleventh century. In Cairo, during the rule of the Ismaili (Sevener Shia) dynasty of the Fatimids in particular, a great number of mausolea on the real or imagined graves of the family of the Prophet Muhammad (*ahl al-bayt*) were constructed in addition to those of local saints. Mostly, these are square structures, often with a *qibla* wall that contains three prayer niches, such as in the Mashhad of Sayyida Ruqayya in Cairo (c. 1133), one of the larger and better-preserved examples. These mausolea are all covered with domes set on squinches, and



Mausoleums of the Islamic World, Fig. 5 Funerary complex of Sultan Qalawun, Cairo, Egypt (Photo P. Blessing)

stucco decoration has been preserved on several prayer niches. Nothing has remained of the tombs of the Fatimid caliphs that were located in the palaces, completely destroyed in the twelfth century when Egypt returned to Sunni rule under Salah al-Din Ayyub (r. 1171–1193). These mausolea were, for the most part, small domed structures standing on their own; multifunctional complexes similar to those observed in Anatolia a few decades later soon emerged. In Damascus, the tomb of Nur al-Din Zengi (d. 1174), one of the early proponents of the Sunni Revival, is attached to a madrasa. This combination can also be found under Mamluk rule, first in the Madrasa al-Zahiriyya in Damascus, where Sultan Baybars I (r. 1260–1277) was buried (Fig. 4), and was to become increasingly common in Egypt and Greater Syria. In Ayyubid and Mamluk Egypt, mausolea were generally built into such a larger complex, in some instances combining several

functions: the funerary complex of Sultan Qalawun in Cairo, built in 1284–1286, contained a madrasa, mausoleum, and hospital (Fig. 5). The tombs of ulema [the educated class of Muslim legal scholars] were also the objects of patronage, such as the mausoleum of Imam Shafi'i (d. 820) in Cairo that received extensive attention under Ayyubid rule. During Ottoman rule, similar complexes continued to be built, although patronage was generally in the hands of governors, rather than the sultans themselves, whose focus lay on Istanbul, rather than on cities in the provinces.

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Maya Blue

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Maya Blue is a unique blue pigment used on murals, pottery, sculpture, and codices in ancient Mesoamerica (e.g., the Madrid Codex, Buti et al., 2014). Unlike organic pigments, or those produced by minerals such as azurite or lapis lazuli, Maya Blue is a unique nanostructured clay-organic complex of the clay mineral palygorskite

Maya Blue,

Fig. 1 Closeup view of Maya Blue on the Venus Platform, Chichén Itzá, in May 2008. Exposed to the weather for at least 700 years, the blue shown here has not lost its color although the limestone underneath and around it has deteriorated

**Maya Blue,**

Fig. 2 Closeup view of a floor painted with Maya Blue at Mayapán in May 2008. Its color remains vivid even after 600 years



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and indigo. It is resistant to dilute acids, alkalis, solvents, oxidants, reducing agents, moderate heat, and bio-corrosion, and its color has persisted for hundreds of years in one of the world's harshest climates – the tropical lowlands of Mesoamerica.

Although found in many parts of Mesoamerica including Aztec central Mexico, Maya Blue was used predominantly by the Maya beginning in the Late Preclassic period from 300 B.C. to A.D. 300 (Vázquez de Agredos Pascual, Doménech Carbó, & Doménech Carbó, 2011) and persisted until the Spanish conquest. It is found most frequently in Maya Classic and Postclassic contexts such as Chichén Itzá (Fig. 1), Mayapán (Fig. 2), and on codices in the early colonial period (Haude,

1998, p. 256), although its production probably did not survive past the Spanish conquest.

The color blue was sacred to the Maya and was the color of sacrifice. It symbolized water, rain, and fertility and was used for sacrifices to the rain god *Chaak* (Fig. 3).

According to an account written by Father Diego de Landa, a Spanish priest in Yucatán shortly after the conquest, human sacrificial victims and the altars upon which they were dispatched were painted blue presumably to symbolize the link with rain (Tozzer, 1941, pp. 117–119).

Although no information survives about how Maya Blue was made, the modern Maya still know and use its components for a variety of purposes. One component, palygorskite (called



Maya Blue, Fig. 3 Urn of *Chaak*, the Maya rain god, covered with Maya Blue, from the Maya site of Mayapán and now in the National Museum of Anthropology and History in Mexico City

sak lu'um by the Maya), is recognized and used by the inhabitants of Sacalum and the potters of Ticul, Yucatán, for medicinal purposes (diarrhea, stomach problems, bad burns, infections, and goiter) and as a pottery temper (Arnold, 1967, 1971, 2008, pp. 191–220). Although deposits of palygorskite have been found in several parts of the Yucatán Peninsula (Arnold, Neff, Glascock, & Speakman, 2007; Krekler & Kearns, 2009; Sánchez del Río, Suárez, & García Romero, 2009), the ancient Maya probably used two massive (~1 m thick) layers of palygorskite for Maya Blue. One was from the large mine (and thin layers) in the sinkhole in the plaza of the village of Sacalum (the hispanicized version of the Maya *sak lu'um*), and the second location is where Ticul potters obtain their temper. Other deposits exposed by road building, explosives, and modern construction technology were not likely to be available to ancient Maya using their extraction

technology and are the result of a landscape altered by modern technology. Further, the amount of palygorskite extracted at Sacalum and Ticul and ethnohistoric and archaeological data further indicate that these two sources were indeed the principal ancient sources of palygorskite used to make Maya Blue (Arnold, 2005; Arnold & Bohor, 1975; Folan, 1969). Analyses of some Maya Blue samples from Chichén Itzá and Palenque indicate that at least some of the palygorskite from Chichén Itzá came from the Sacalum source (Arnold et al., 2012).

The other component of Maya Blue, indigo, is a dye that is a product of the processing of the leaves of several species of the genus *Indigofera*, of which *Indigofera suffruticosa* is the most common in the New World (Arnold et al. 2008). The Maya believed that the indigo plant, like palygorskite, possessed medicinal properties such as antispasmodic, diuretic, and stomachic properties, and it was used among the Mayas in Yucatán as a treatment for convulsions and epilepsy.

One of the puzzles driving the Maya Blue research is how the ancient Maya made the pigment, and scholars have proposed several preparation techniques (Cabrera Garrido, 1969; Reyes-Valerio, 1993; Torres, 1988). It can be synthesized in the laboratory by mixing ground palygorskite with a small amount of indigo (usually between 0.3 % and 3 %) and heating it to 150 °C for several hours or for a longer period at 100 °C. Some evidence that the ancient Maya used this technique comes from a bowl of melted incense with Maya Blue recovered from the sacred cenote at Chichén Itzá, a natural sinkhole resulting from the collapse of surface limestone that exposes the groundwater underneath (Fig. 4).

This bowl of incense indicates that palygorskite and indigo powder (or perhaps indigo leaves) were placed together with incense in the bowl and then heated enough to melt the incense and creating the Maya Blue in the process. The burning of the incense apparently was interrupted when it was thrown into the cenote. This context suggests that at least some Maya Blue was created in a ritual context as an offering to the rain god *Chaak*; combining indigo (or indigo leaves) and palygorskite with burning incense brought a new



Maya Blue, Fig. 4 A grater bowl covered with Maya Blue from Burial 6 in the Grave of the High Priest excavated by Edward H. Thompson in 1896 and currently in the collection of the Field Museum of Natural History, Chicago (Image by Sarah Rivers, Courtesy of the Field Museum, identifier CL0000_48158_without scale)

symbol of the god into being as Maya Blue. Since rainfall brings restoration to a land needing moisture, the healing constituents of indigo and palygorskite were combined with the heat of burning incense to bring *Chaak* with his restorative rainfall. Nevertheless, several other possible preparation methods have also been suggested, and it appears that the techniques for the preparation of the pigment have changed through time (Doménech, Doménech-Carbó, & Vázquez de Agredos Pascual, 2007).

As one of world's most unusual pigments, Maya Blue has greater stability in sunlight and acids than indigo or its derivatives, and its chemical bonding to the palygorskite appears to be the reason for its stability (Sánchez del Río, Martinetto, Reyes-Valerio, Dooryée, & Suárez, 2006). Sepiolite, another fibrous clay mineral like palygorskite, occurs in some samples of Maya Blue, but although a Maya Blue-like pigment can be produced by heating sepiolite with indigo, the mixture is not as resistant to dilute acids, alkaline solutions, and low heat as is Maya Blue.

The unique blue color of Maya Blue and its unique chemical and physical properties have

stimulated the interest of chemists, physicists, and material scientists, who have analyzed the pigment using many different techniques in order to discover how the indigo molecule binds to the palygorskite clay (summarized in Sánchez del Río et al., 2006). Since palygorskite crystallizes in long fibers with water in its interior channels, it was thought that heat drives off the water loosening one of the hydroxyl bonds in the clay that then binds to the indigo that is taken up in the channels. Others believe that the pigment binds to the open ends of the channel. Still others, however, dispute these models, arguing that the indigo binds to the empty channel grooves on the external surface of the fiber, forming a hydrogen-bonded organic/inorganic complex (Chiari, Guiustetto, Druzik, Doenne, & Ricchiardi, 2008; Doménech, Doménech-Carbó, & Edwards, 2011; Sánchez del Río et al., 2011).

Although palygorskite is widespread in the Maya area and found by many investigators, except for those noted above, almost all of the sources are the product of a modern alteration of the Maya landscape and likely do not represent the sources of the ancient landscape. Matching palygorskite sources to Maya Blue thus can be problematic because analyses of such sources must take into account the variability of different deposits and that within each deposit in order to match the palygorskite in the pigments to that found in ancient sources. Rather than simple comparisons of composition, multivariate analyses of elements are necessary to determine if the palygorskite in the Maya Blue samples occurs within the range of variability of palygorskite within that found in the samples from the proposed ancient sources.

The unusual stability and persistent color of Maya Blue have stimulated chemists and material scientists to explore its use as a commercial paint. Although relatively simple and inexpensive to produce in the laboratory with minimal indigo, the pigment is fugitive and is easily washed off of an object unless some kind of binder holds the pigment together and allows it to adhere to a surface. Smectite (montmorillonite) sometimes occurs within deposits of palygorskite, and it may have served

as a natural binder for the ancient Maya painters and potters because of its case-hardening qualities. The association of Maya Blue with copal incense also suggests that copal may have served as a binder for murals, pottery, and sculpture.

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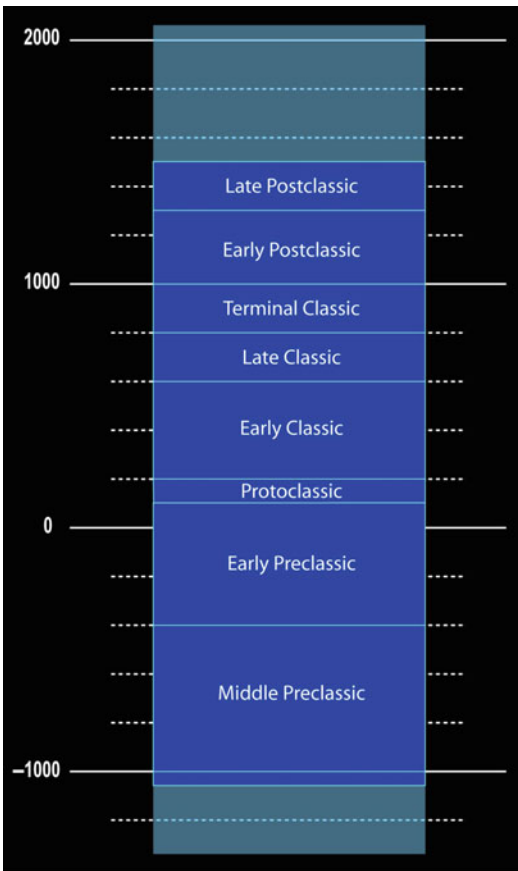
Maya Lithic Production

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Introduction

From the Preclassic period to the Spanish conquest (Fig. 1), the Maya relied exclusively on lithic (stone) tools for most cutting and blunting



Maya Lithic Production, Fig. 1 Maya archaeology time frame

activities, from agriculture to crafts, war, sacrificing, and butchering, as well as quarrying and stone carving for architecture. One of the main reasons for this is probably that chert (sedimentary rock) was easily available in the Maya lowlands. In fact, with the exception of a few coastal zones in Yucatan and Quintana Roo (Andrieu, 2009; Hearth & Fedick, 2010), regular-quality chert sources are evenly distributed in the limestone bedrock of Yucatan, Guatemala, and Belize where most of the Maya cities were located (Fig. 2). Fine-grained chert sources were more localized and sometimes exchanged over hundreds of kilometers. Conversely, in the highlands of Guatemala, chert is scarce, but obsidian, a volcanic glass, was used instead for producing everyday tools and exchanged in the lowlands where it was employed for the production of prismatic blades.

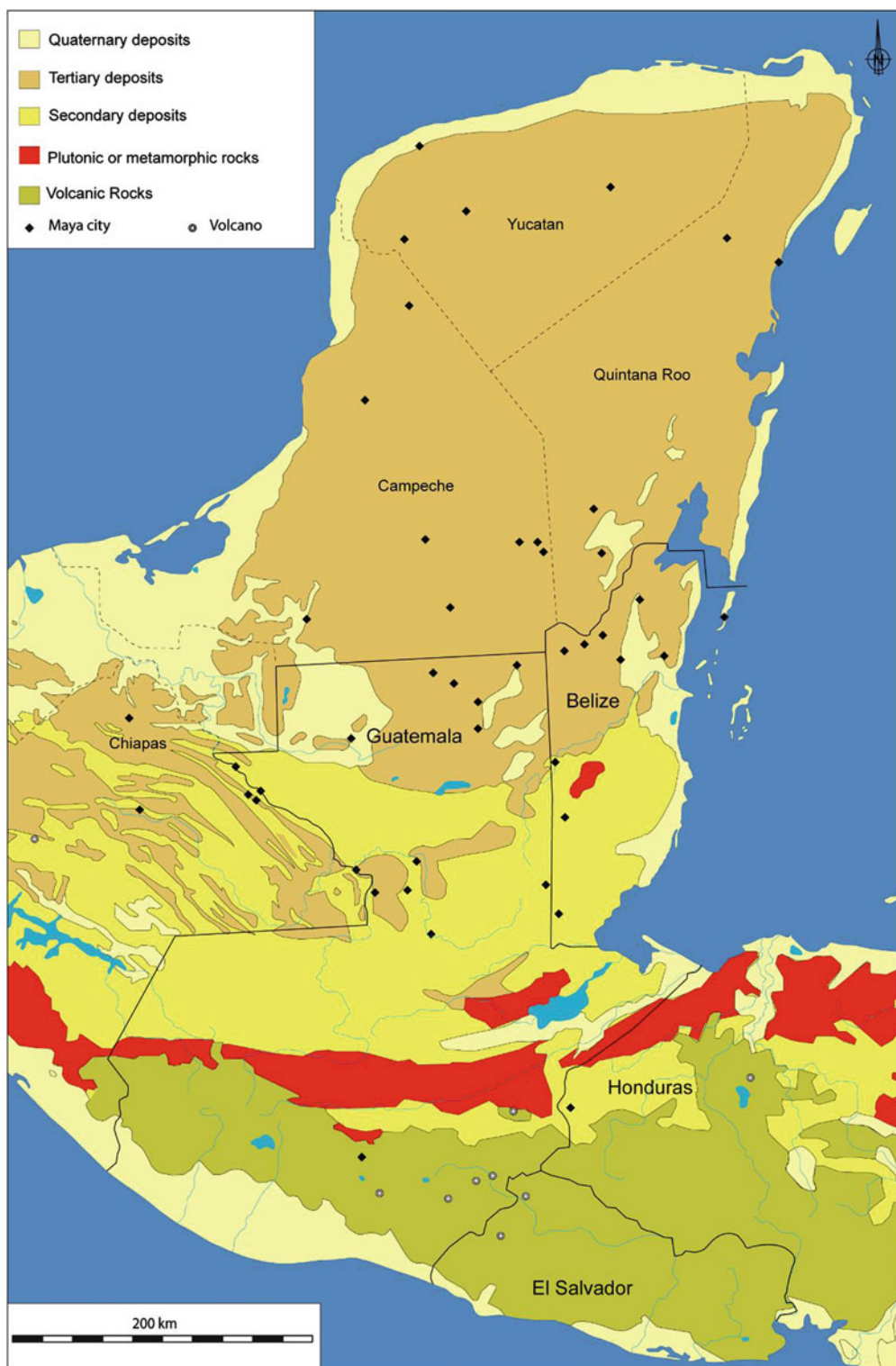
Maya lithic production is varied and includes a variety of different levels of know-how corresponding to different production organizations: homemade production such as percussion flakes or coarse chopping tools is found in most lowland Maya households but also very good quality highly normalized work that was produced by part-time specialists. The quantities of each tool vary from one city to another and represent a rich source of information on the organization of production and exchanges as well as a major insight for the understanding of Mayan economies and their evolutions over time.

Expedient Production

In most lowland sites, the vast majority of the recovered tools are percussion flakes produced on unipolar – and more rarely multipolar – local chert cores (Andrieu, 2009; McAnany & Peterson, 2004; Moholy-Nagy, 2003a; Rovner & Lewenstein, 1997; Willey, 1978). Some flakes were retouched by percussion to produce scrapers and drills, but except in a few specific sites, these are much scarcer than the non-retouched percussion flakes. Thick coarse bifaces and chopping tools made by hard percussion on local chert blocks are also relatively common and probably homemade according to requirements.

Specialized Production

However, Maya lithic collections also contain far more complex production that require a higher level of know-how and were carried out by part-time specialists. The definition of specialization has been hotly debated (Clark, 1986, 2007; Costin, 1991, 2007; Rice, 2009; Schortman & Urban, 2004). Here I suggest using a very modest definition, namely, the production of goods in a greater quantity than for one's own consumption, in other words, "production for use by others" (Costin, 2007, p. 150). This definition includes all production for the purpose of exchange, without regard to



Maya Lithic Production, Fig. 2 Geological map of the Mayan area (Map by Grégor Marchand)

the quantity, scale, or context of production. Because they are meant to be exchanged, the study of the distribution of these specialized productions is crucial for the understanding of the degree of interdependence between households as well as the structure of the economy.

Obsidian Prismatic Blade Production

Among the most representative items of specialized production are prismatic blades that necessitated regular practice to keep up the necessary skills required to make them and were therefore produced in larger quantities than those required for consumption (Clark, 1987, p. 268, 1997).

These blades were common tools in the Maya lowlands and produced on obsidian imported from the highland sources of Guatemala and occasionally from highland Mexico. We owe our understanding of the techniques used for their production – called the Mexican technique – to experiments carried out by Don Crabtree (Crabtree, 1968) and John Clark (Clark, 1982) who, by crossing these with analyses of the historical texts of the colonial contact period, succeeded in understanding that these fine regular blades were made by pressure with a crutch used in a sitting position (for a discussion, see Titmus & Clark, 2003). Such a technique has been attested for the Aztecs and probably had different variants throughout Mesoamerica (Hirth & Flenniken, 2002). For instance, using feet to hold the cores would only be conceivable for large ones but not for cores measuring less than 8 cm in length and 2–3 cm in diameter. The smaller cores were therefore probably handheld when worked (Flenniken & Hirth, 2003).

Another variation appears when we look at the shapes of the cores found in the lowlands: most Maya cores are cylindrical (Willey, 1972, Figs. 191, 192; 1978, Fig. 142c), corresponding to a circular method of production. However, other types of cores are also attested in the Classic lowlands such as “asymmetrical prismatic cores” (Trachman & Titmus, 2003, p. 108) that only have a single face presenting scar remnants of the pressure blade removal. These are attested at Dos

Hombres (Trachman & Titmus), at Tikal (Moholy-Nagy, 2003a, Fig. 69f, 69o) as well as at Holmul and Piedras Negras (Hruby, 2006, p. 217; Hruby & Araki, 2004) and Uaxactun (Kidder, 1947, p. 15). These two very different morphologies result from two different production process methods of the prismatic blades, but we still need to understand whether the two methods correspond to different workshop and distribution networks or to a chronological evolution.

A last variation in prismatic core production is the degree of preparation of the platforms. During the Classic period, most platforms were simply scratched to facilitate the adherence of the crutch, but many authors have observed an evolution over time, as from the Terminal Classic (AD 800–1000) until the Postclassic (1000–1519 AD), pecked and ground platforms become increasingly common (Braswell, 2013; Braswell et al., 2004, p. 184).

The Particularity of the Kaminaljuyu Technique

We also need to understand another variation of the pressure technique, namely, the Kaminaljuyu technique. Many of the pressure blades found in the highland site of Kaminaljuyu are about twice as long as the ones found in the lowlands, measuring between 15 and 22 cm in length and 2 cm in width (Hirth, 2003, p. 176). To date this specific technique remains little understood since these obsidian blades are still difficult to reproduce by experimentation. Interestingly, these very long blades were not exported very far as this specific technique is not attested in the Maya lowlands and disappeared after the early Classic period (AD 250–600).

Chert Bifacial Production

Thick Bifaces

These tools are among the most common ones in the lowlands but seem to be very scarce in the highlands. These thick bifaces, also known as “general utility bifaces” (Kidder, 1947; Willey,



Maya Lithic Production, Fig. 3 Thick biface from Calakmul (Photo by Chloé Andrieu)

1972) and “ovate” or “oval” biface (Aoyama, 2007, 2009; Moholy-Nagy, 2003a), were probably handled as axes or adzes and used for a variety of agricultural and construction activities. These tools are found in residential compounds but are often heavily reused and rejuvenated. Their bifacial edges were produced by hard percussion flaking on both sides of relatively thin nodules, but unlike the expedient coarse bifaces, these tools were then carefully retouched using soft hammer percussion (Fig. 3), resulting in large and extended flaking all around the pieces. The outlines of the bifaces are rectilinear. This suggests very good control of the retouching, which is all the more difficult given that the raw material used was often irregular and coarse.

Chert Thin Bifaces

The second category of bifacial products is much thinner (Fig. 4). Their production process consists of a very careful use of soft hammer percussion on both sides of large flakes or small blocks followed by delicate soft hammer retouching to give the final shapes to the pieces. Some rare



Maya Lithic Production, Fig. 4 Brown chert thin biface from Naachtun (Photo by Claudine Escobar). This very fine quality raw material of unknown source was exchanged over the entire lowlands during the Classic period (Andrieu, 2013)

pieces were also finalized by parallel pressure retouching. This category includes projectile points and laurel leaves.

Regional Variations

There are important different types of thick bifaces, although it should be stressed that no unified typology is available to date for the Mayan area (Barrett, Shafer, & Hester, 2010; Fowler, 1991). Thin bifaces and projectile points also show a high diversity of shapes and dimensions over the entire Mayan area, as well as an important variety of raw materials, as they tend to be produced on better quality cherts than the thick ones. Projectile points and thin bifaces in particular were very rarely produced in Guatemalan obsidian in the Maya lowlands, at least during the Classic period. However, a precise

cartography and systematic typological comparison has yet to be carried out.

In general, the Colha workshop in Northern Belize and its distribution area is a region that seems to concentrate many lithic specificities; chert macroblade technology, tranchet technique, and T-shaped adzes appear to be specific to this region.

Eccentrics

The definition of eccentrics is complex as this category regroups all lithic objects with an unusual aspect that are considered to be nonfunctional. Most eccentric typologies rely on their shapes, but I suggest a distinction according to their support. In fact we can distinguish three main categories of eccentrics.

- Thick bifacial eccentrics, whose production resembles that of the thick bifaces. Despite their variety of shapes and forms, the main difference with the production process of the thick bifaces is that they sometimes have concave bifacial edges (not only convex ones), probably made by indirect percussion (Fig. 5). Up to now, these thick chert bifacial eccentrics have been specific to the Northern Belize area.
- Eccentrics on laurel leaves that were made by carefully notching a laurel leaf in order to draw the shape, which can be either geometric in the simplest examples or anthropomorphic in the more complex ones. This work was probably carried out by indirect percussion and by pressure for the last stage of the thinnest ones. Experimentation has shown that the very large (and most famous) ones were probably made by two craftspersons, with one holding the piece and the other working it (Titmus and Woods 2003, p. 134).
- Eccentrics on obsidian cores, flakes, or macroblades, that is to say, on prismatic production waste. This category represents most obsidian eccentrics in the Maya lowlands. They are usually easier to produce than the other ones and have a slightly coarser aspect.



Maya Lithic Production, Fig. 5 Bifacial eccentric from Lamanai (Photo by Chloé Andrieu with permission of the Institute of Archaeology, Belmopan, Belize)

A few more elaborate obsidian eccentrics have been found in Yaxchilan (Brokmann, 2000) or Altun Ha (Pendergast, 2003), but they were imported from Central Mexico.

The function of these objects is still very enigmatic; many authors have suggested that they were representations of gods or lineage symbols (Hruby, 2006; Iannone, 1992). Use-wear studies have shown that these artifacts were often manipulated, burned, painted, and wrapped, probably during rituals (Meadows, 2001).

The strict distribution of eccentrics in elite contexts suggests a form of elite control over these ritual items, at least of their distribution, but very little is known about their production context. Some were produced in workshops at Colha, but the question of the autonomy or affiliation of these workshop in relation to the elite is yet unsolved (Barrett, Shafer, & Hester, 2010; Speal, 2009). The fact that eccentrics are often buried together with flakes in caches could indicate that their production was itself part of a ritual (Hruby, 2007). In all cases, we should stress that this category of Maya lithics is extremely vast and encompasses a wide diversity of different

technique investments. We now need to understand how this variety of techniques, know-how, and raw materials influenced the way they were exchanged and their social status.

Organization of the Production: The Workshop Problem

Despite the fact that many Maya lithic artifacts implied regular training, and even though many of them are found in abundance within most Maya houses – implying that they were produced in certain quantities – very few workshops (in the sense of a place where a specialized production took place) have been found in the Mayan area, especially in the main civic ceremonial cities.

This is due to various factors, the first of which is location. It seems that during the Classic period (AD 250–1000) at least, most Maya workshops had the same configuration, which consisted of relatively modest, small-sized structures, situated in residential areas located outside the urban centers or within secondary centers. With a few exceptions, most were involved in chert biface production: general utility bifaces, tranchets, or lenticular or thin bifaces. The fact that they are mostly in secondary centers could explain their apparent scarcity. Indeed, until recently, more attention has been paid to the civic ceremonial centers than to their peripheries.

Variation in the intensity of the production is another reason (Rice, 2009). Production intensity seems to vary considerably from one site to another, with some workshops restricted to a single structure and others such as Colha, El Pedernal, or Chan Chich having a concentration of various workshops involved in biface production (Lewis, 2003; Meadow, 2000). In places where production intensity was low, workshops could be harder to find.

Other reasons might be evoked to explain the lack of workshops, for instance, the reuse of production waste in secondary contexts, such as caches and offerings. That practice was very common in the southern lowlands and could explain the scarcity of primary hints of lithic

specialized production in the civic ceremonial centers during the Classic period.

Finally other systems of production distribution such as itinerant craftspersons could explain the lack of workshops (Hirth, 2008). Such a system has been demonstrated in southern Campeche for the production distribution of a fine, good quality, brown chert (Andrieu, 2013), but it should also be considered for obsidian production in regions where it is scarce and the level of production would not be sufficient to maintain the know-how over long periods of time.

The scarcity of workshops within the epicenters seems to be a particularity of the Classic period. For the Preclassic period, workshops have been found in Kaminaljuyu (Hirth, 2003; Michels, 1979), and they also seem to be more clearly defined in Mayapan for the Postclassic (Masson & Freidel, 2013; Rovner, 1974).

Conclusion and Further Directions

Despite the fact that over time specific changes can be observed in Maya typologies, technology, and raw material procurement, the changes are too gradual to make Maya lithics a good dating element. What does change significantly in time and space is the quantity imported and exchanged, the structure of the exchange systems, and the social contexts of production. These are all elements that make lithic material a valuable tool for understanding Maya economies.

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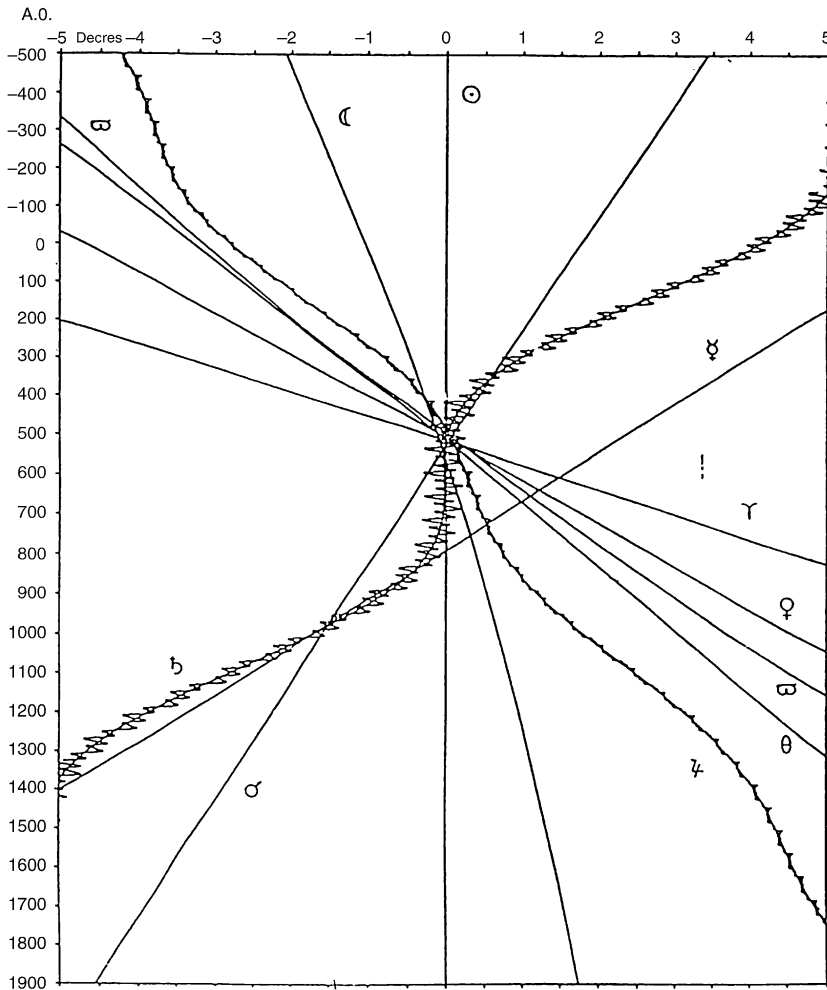
Mean Motions in Indian Astronomy

George Abraham, J. Samuel Cornelius and
N. Gnanamalar David

This article is a follow-up of a very important contribution to the understanding of Indian astronomy by Billard (1971, 1977; van der Waerden, 1980, 1988) who has calculated the mean longitudes of the sun, moon, moon's apogee and node, and those of the five known planets, from the numerical data in the main astronomical texts. The errors of these longitudes

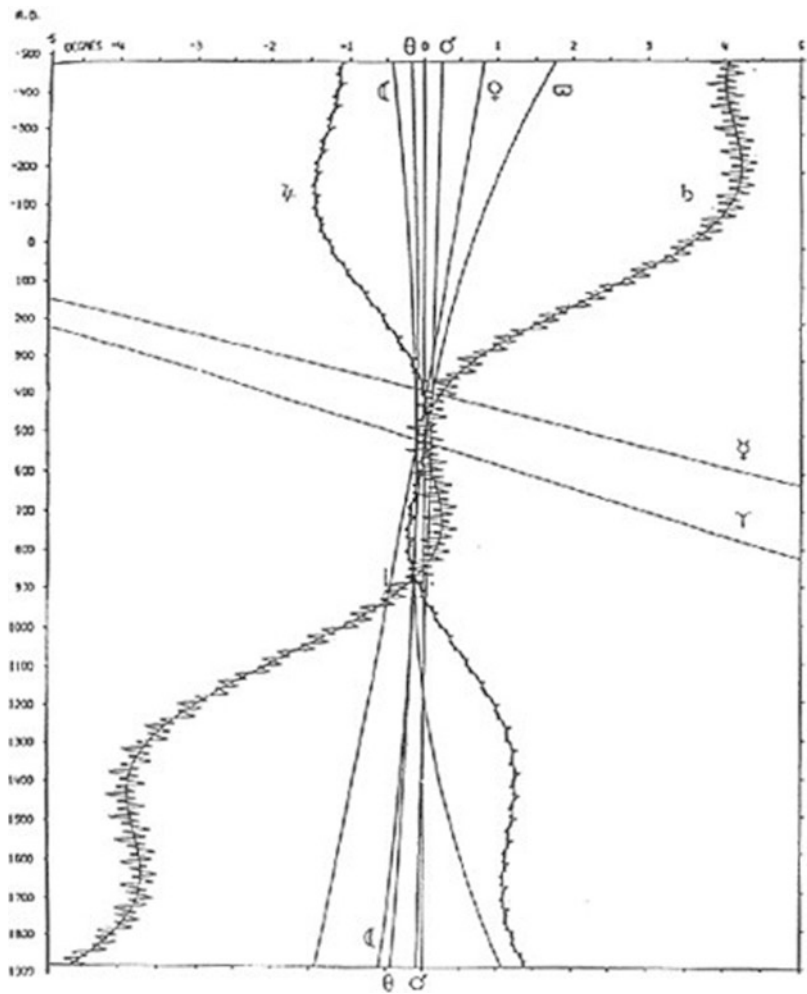
are determined by comparing them with the results of the modern formulae.

Billard uses the methods of mathematical statistics to find the most probable dates of the observations. His graphs, in which the errors of the longitudes are plotted against time from BCE 500 to AD 1900, illustrate his most important conclusions. For example, the ► [Āryabhaṭa](#) graph, Fig. 1, of this article, (Fig. 6 in Billard's book) shows that he made accurate observations at about AD 510. The error lines are for the Sun (☉), Moon (☾), Moon's apogee and node (ω, θ), Mercury (☿), Venus (♀), Mars (♂), Jupiter (♃), and Saturn (♄). There are large errors on earlier and later dates, showing that the rate of change of longitudes, the mean motions, are far from correct.



Mean Motions in Indian Astronomy, Fig. 1 K. Āryabhaṭa

Mean Motions in Indian Astronomy,
Fig. 2 K. Lalla



The synodic graphs of ► [Lalla](#) and ► [Nīlakaṇṭha Somayāji](#) (our Figs. 2 and 3 and Figs. 18 and 42 of Billard’s book) stand out conspicuously, compared to the other graphs, because as many as six lines are close to the zero-line for most of the time span; therefore their mean motions are very accurate.

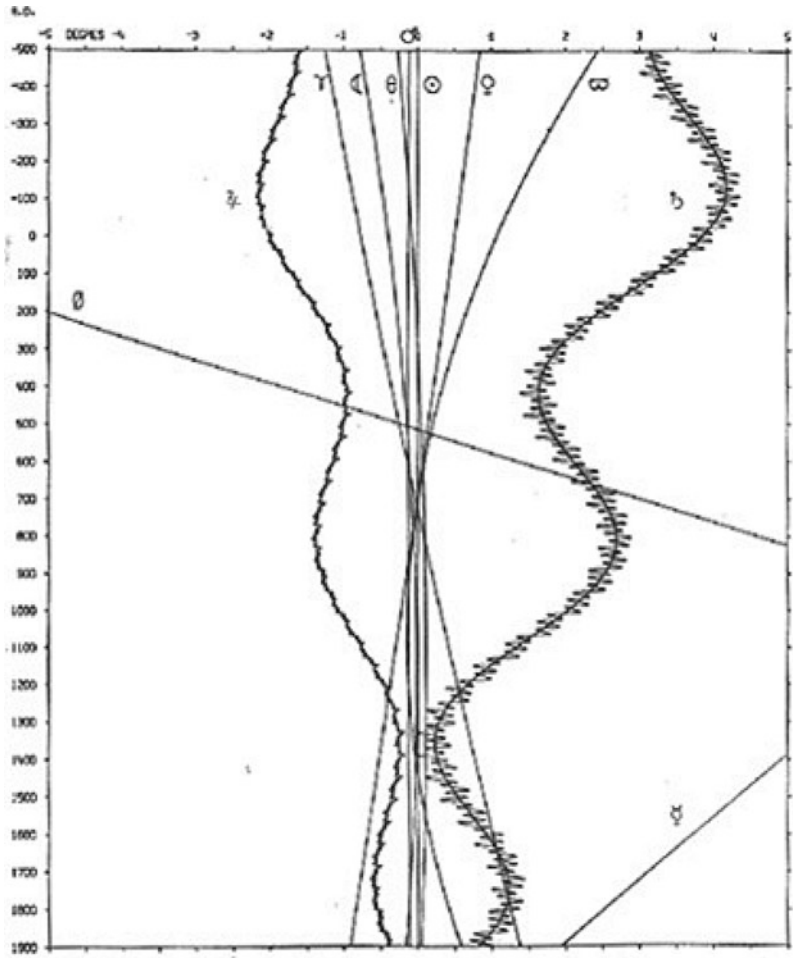
Another important finding of Billard, strongly supported by Raymond Mercier (1993) is that the date of the *Mahāsiddhānta* is the early sixteenth century, against the AD 900 estimate of Dikshit (1985).

In this article, the focus is on mean motions, instead of longitudes. To begin with, we consider the following Babylonian period relations (Table 1) (Neugebauer, 1975):

From these relations, we can calculate the ratios of the velocities of the Moon and planets to that of the Sun. The resulting numbers are in the first row of Table 2, denoted by O_1 . The next row M_1 are the corresponding ratios calculated from modern theory of Simon et al. for the year BCE 300 (Simon et al., 1994). The third row numbers are the errors defined by $\bar{E}_1$.

We now compare these Babylonian values to those of Ptolemy. His daily motions of the Sun, Moon, and planets are given in Billard’s book (1971, p. 53). From these velocities, we calculate the same ratios as for the Babylonian observations and the resulting numbers, denoted by O_2 are in the fourth row of Table 2. The fifth row M_2 are from the modern theory (Simon et al., 1994)

Mean Motions in Indian Astronomy,
Fig. 3 K. Tantra



Mean Motions in Indian Astronomy, Table 1 Babylonian period relations

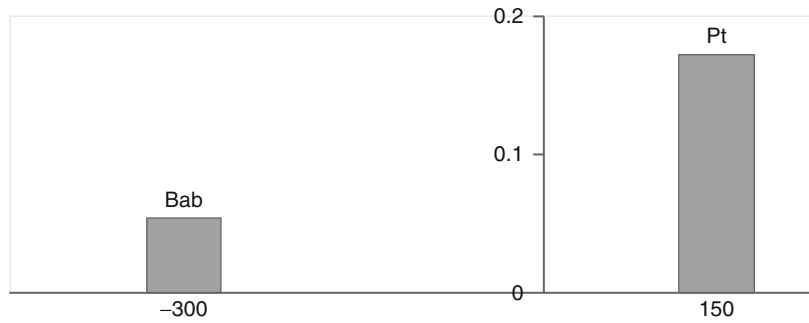
	Moon	Mercury	Venus	Mars	Jupiter	Saturn
No. of revolutions	235	1,993	1,871	151	36	9
No. of years	19	480	1,151	284	427	265

Mean Motions in Indian Astronomy, Table 2 Ptolemaic values

	Moon/Sun	Mercury/Sun	Venus/Sun	Sun/Mars	Sun/Jupiter	Sun/Saturn
O_1	12.36842105	4.15208333	1.62554301	1.88079470	11.86111111	29.44444444
M_1	12.36827354	4.15197000	1.62549917	1.88075194	11.85681389	29.42471118
$E_1 \times 10^{-5}$	1.19	2.73	2.70	2.27	36.24	67.06
O_2	12.36841579	4.15197630	1.62549378	1.88076904	11.85763221	29.43201683
M_2	12.36827213	4.15196976	1.62509912	1.88075181	11.85680702	29.42460065
$E_2 \times 10^{-5}$	1.16	0.16	0.33	0.92	6.96	25.20

Mean Motions in Indian Astronomy,

Fig. 4 Babylonian and Ptolemaic errors



Mean Motions in Indian Astronomy, Table 3 Seven Indian canons

No.	Treatise	Canon page no.	Approx. date	$E_1^1, E_1^2, E_1^3, E_2^1, E_2^2, E_2^3, E_2^4, E_2^5$	$\bar{E}_1; \bar{E}_2$
1	<i>Sūryasiddhānta</i>	<i>k. SūryS</i> , p.75	500	0.17,1.30,1.17; 0.88,4.10,1.94,1.25,2.56	0.88; 1.94
2	<i>Āryabhatīya</i>	<i>k. āryabh</i> , p.78	510	0.36,1.11,0.98; 0.71,4.12,1.96,1.33,1.58	0.82; 1.94
3	<i>Pañcasiddhāntikā</i>	<i>k. PañcS</i> , p.100	550	0.16,1.32,1.17; 2.06,1.45,0.86,0.41,0.96	0.88; 1.15
4	<i>Brāhmasphuṭasiddhānta</i>	<i>k.BrSpS</i> , p.115	600	0.34,0.83,0.53; 0.80,4.24,1.80,1.33,1.57	0.57; 1.96
5	<i>Sisyadhivṛddhidatantra</i>	<i>k.Lalla</i> , p.143	900	0.03,0.26,0.08; 0.35,0.27,0.03,0.22,1.39	0.05; 0.76
6	<i>Vateśvarasiddhānta</i>	<i>k.VatesvS</i> , p.149	900	0.28,1.20,0.90; 0.46,3.66,1.75,1.25,1.48	0.79; 1.72
7	<i>Siddhāntaśiromani</i>	<i>k.BrSpS2</i> , p.152	1,050	0.25,0.56,0.39; 0.40,3.78,1.59,1.29,1.40	0.38; 1.74
8	<i>Sūryasiddhānta</i>	<i>k. SūryS2</i> , p.148	1,100	0.09,1.36,1.01; 0.45,3.64,1.53,1.27,1.46	0.82; 1.67
9	<i>Dṛggaṇita</i>	<i>k. DṛgGan</i> , p.155	1,400	0.05,1.67,1.08; 0.45,3.64,1.53,1.28,1.46	0.93; 1.67
10	<i>Mahasiddhānta</i>	<i>k.PārāS</i> , p.157	1,500	0.19,0.33,0.42; 0.47,3.51,1.49,1.26,1.38	0.31; 1.62
11	<i>Tantrasamgraha</i>	<i>k.TantraS</i> , p.161	1,500	0.05,0.24,0.02; 0.52,0.34,0.04,0.25,0.43	0.10; 0.32

for AD 150 and the errors E_2 , defined in the same way as in (1), are in the last row.

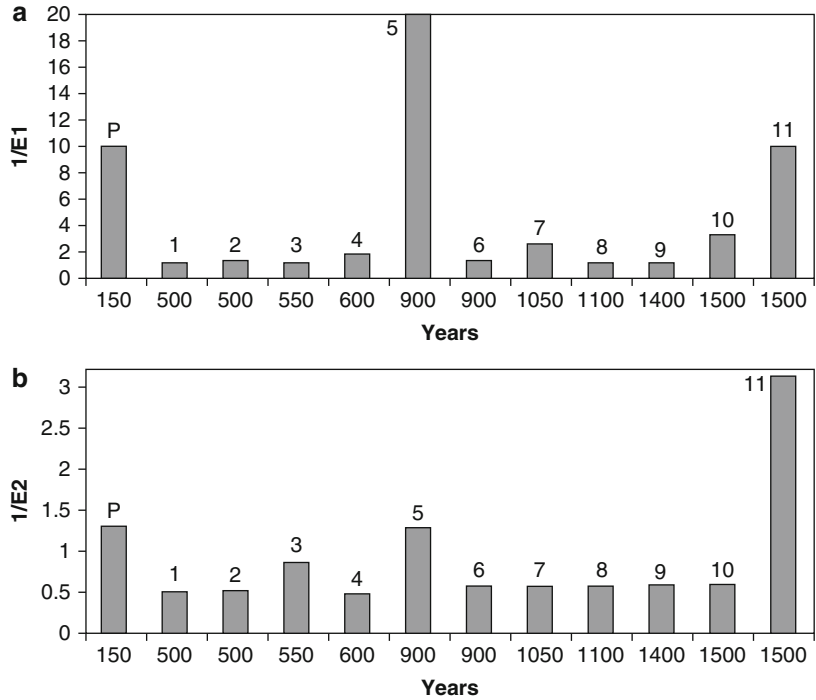
The mean values of the Babylonian and Ptolemy's errors are $\bar{E}_1 = 18.7$, $\bar{E}_2 = 5.8$. The reciprocals of these numbers are plotted in Fig. 4. Ptolemy is more accurate by a factor of about 3.

In an earlier paper, we calculated the errors of the mean lunar and planetary motions of Ptolemy and the most prominent Indian astronomers, ► [Āryabhaṭa](#), ► [Brahmagupta](#), Lalla, and Nīlakaṇṭha Somayāji. We now extend our

investigation to include another seven Indian canons, which have been analysed by Billard. These are listed in Table 3. The first two columns give the names and the page reference in Billard's book (1971); the next column gives the approximate dates. The fourth column has the three lunar errors E_1^1, E_1^2, E_1^3 (synodic, anomalous, draconitic) and the errors E_2^2 to E_2^5 of the synodic daily motions of the five planets. The last column gives the mean lunar and planetary errors $\bar{E}_1$ and $\bar{E}_2$. In Fig. 5a, b we have plotted the values of $\sqrt[3]{\bar{E}_1}$ and $\sqrt[3]{\bar{E}_2}$, which

Mean Motions in Indian Astronomy, Fig. 5 (a)

Lunar accuracy, (b)
Planetary accuracy



are a measure of the accuracy of the Indian observers. The corresponding numbers for Ptolemy are also shown, based on the errors calculated in the earlier paper (Abraham & Samuel Cornelius, 2003). In these figures P stands for Ptolemy and the 11 Indian canons are numbered 1–11 as in Table 3.

In Fig. 5a, b Ptolemy, ► Lalla and Nīlakaṇṭha Somayāji's *k.TantraS* are the most prominent. Their accuracy is the result of their own observations, also taking into account the observations of others, spread over a long period of time. Āryabāṭa's poor mean motions are due to his assumption of the conjunction of planets, at the beginning of the Kaliyuga (van der Waerden, 1988).

The *Pancasiddhantika*'s corrections to the *Sūryasiddhānta*'s planetary motions make a significant improvement, indicating further accurate observations.

The improvements of the later *Sūryasiddhānta* over the earlier version, and of Siddhanta-siromani's *k.BrSpS2* compared to that of Brahmasphutasiddhānta are insignificant.

The planetary motions of the later *Sūryasiddhānta* and those of Parameshwara's *Dṛggaṇita* are remarkably close as pointed out by David Pingree (1987, p. 613), leading to the same errors in our approximation. The lunar motions of the two canons are slightly different, perhaps due to Parameshwara's new observations.

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Meat Preservation in Ancient Egypt

Salima Ikram

The ancient Egyptians consumed all types of meat: mammalian, piscian, and avian. It was an important source of protein, but one that was not always equally available to all levels of society. While piscian and avian meat sources were readily obtainable through fishing, hunting, and trapping, mammalian meat was sometimes harder to acquire due to restrictions on hunting wild game and the expense of killing livestock. Thus, mammalian meat tended to be more frequently consumed by the wealthy elite, although it would have been consumed by other social classes on feasts or at festive occasions.

Once slaughtered, the meat had to be consumed immediately to prevent spoilage, or it had to be processed and preserved for later use. There were several ways of preserving meats available to the ancient Egyptians – drying, salting (dry and wet), smoking, a combination of any of these methods, pemmicaning, or using fat, beer, or honey curing. Preserved meat provided a supply of protein for lean times, a commodity that could be traded, as well as a convenient food to take on all types of expeditions, whether exploratory, military, or commercial.

The evidence for the different types of meat preservation in ancient Egypt comes from two- and three-dimensional representations, mummified and preserved meat that comes from tombs, and artefacts, such as labeled pottery jars pertaining to meat. Additional information can be gathered from ethno- and experimental archaeology.

Drying

Drying is the easiest and most common way to preserve meat. Pieces of meat are cut from the carcass and hung in the sun to dry. The entire animal can be preserved in this way, although certain cultures seem to prefer specific cuts for drying. Drying time depends on the temperature and the thickness of the cut; generally it takes between 1 and 3 weeks. Dried meat can last up to 2 years, depending on storage conditions. Artistic and archaeological material shows evidence of such preservation practices.

Pounding meat before it is hung up to dry is a variation on this process. Some representations found in tombs support the idea that such a method was used to preserve meat in ancient Egypt. The pounding of the meat forces out the liquid in it that could cause spoilage, thereby making it possible for the meat to last longer. As a further protection, salt can be rubbed into the meat before it is dried. The term, *iwfdr*, suggests this method of preservation for meat.

Dried meat can also be prepared by boiling small pieces of meat, and then putting these in the sun to dry. This method tends to lower the nutritive value of the meat.

Fish can also be dried very effectively. Tomb representations show fish being cleaned, opened, and dried. Actual examples of these have been found at Deir el-Medina, and there are several references to dried fish found in Egyptian literature.

Birds were probably not generally dried. Only a handful of images suggest that poultry was dried, but these are inconclusive.

Salt

Salt curing is a simple and effective means of preserving meat, and salt was readily available in ancient Egypt. Both dry and wet (brine) salting would have been possible in ancient Egypt, but it is more probable that the former method would have been more commonly used. The basic idea was to immerse the meat in salt or brine, and then to seal it. The salt not only draws out the liquids in the meat that could cause spoilage, but also deters bacteria. This was the same precept governing mummification. Salt curing was faster and more efficient than simple drying, and the meat thus preserved would have lasted longer than dried meat.

Archaeological and artistic evidence suggest that dry salting was the most common method of meat preservation employed by the ancient Egyptians. Meat, fish, and poultry were all dried and salted. Scanning Electron Microscopy carried out on samples of preserved meat found in tombs supports this theory. Drying and salting fish is the most common way to preserve fish, actual examples of which were recovered from the tomb of Kha, and references to salted fish appear in texts, notably in the tale of Wenamun. Salt fish continues to be a staple of the modern Egyptian diet, especially for peasants. Mullet roe, the earliest caviar, also used to be preserved in salt and is still kept in this way today. Birds were also salted, and examples of these have been recovered from Kha's tomb.

Smoking

Although smoking meat in order to preserve it was hypothetically possible, it is unlikely that this method was used in ancient Egypt. The main reason for not using it was the relative paucity of wood, especially wood of any aromatic nature.

Fat

Animal fat is commonly used to conserve meat. Goose, mutton, or cow fat could have been used for this. Meat was cut up and then cooked with fat

and salt and then placed in a container. Once cool it would have been sealed. This method, called *lahma mahfooz*, is still in use in Egypt today.

Honey

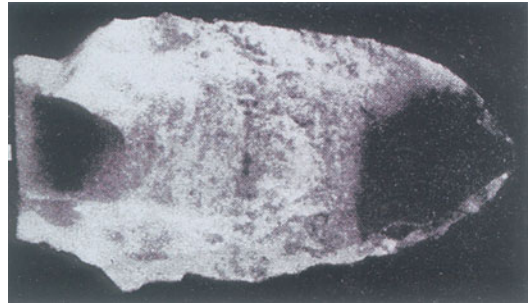
Honey might have been used to preserve food in ancient Egypt. Certainly, honey has preservative qualities. Indeed, Alexander the Great's body allegedly was preserved in honey. However, it is unlikely that this would have been used, as honey was a valuable commodity and the only sweetening agent available to the Egyptians.

Thus, although a significant variety of technologies were available to the ancient Egyptians, it is clear that drying and salting meat were the ones that were most commonly used.

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Mechanical Technology and Instruments of China,
Fig. 1 A stone arrowhead unearthed in Shuo County, Shanxi Province (From Hua, 1997)

Mechanical Technology and Instruments of China

Tong Qingjun and Feng Lisheng

China was among the earliest countries to develop mechanical technologies, and its long history is full of achievements in technology for mechanical engineering.

Archeological work since the twentieth century has unearthed a large amount of prehistoric relics that provide a wealth of information about the evolution of technology for manufacturing tools and instruments in antiquity.

Paleolithic artifacts were mainly made of stone and wood, although sometimes bone was used. They were mostly chipped stone vessels that were formed by hammering and primary truing. Later, polished stone vessels were shaped to serve as tools that could chop, break, or scrape. Hammers, knife-edged tools, spheres, spears, and arrowheads made of stone can also be seen from this period. Arrowheads were found in a late Paleolithic site in Zhiyu, Shanxi province, that dates to about 28,000 years ago (Fig. 1) (Du, 1984, p. 6) and the appearance of arrows themselves indicates that a relatively high level of mechanical technology had been attained. Also at the site are wooden sticks and polished needles made of other materials.

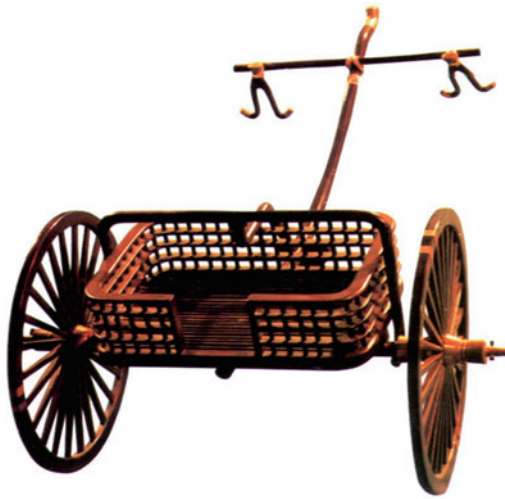
Neolithic artifacts were mainly made by a polishing technique that demanded selecting,

cutting, polishing, and boring the stones. Copperware also appeared at this time. A sword and some fragments made of copper were unearthed in the early layers of Majiayao, Dongxiang, Gansu province, and date to 2575–2500 BCE according to carbon-14 analysis. Some scholars consider the sword to be the earliest bronze in China (Shen, 1987, p. 919), but others have disagreed (An, 1993). Plenty of tools for production – including adzes, axes, shovels, chisels, millstones, burnishers, pestles and mortars, spinning wheels, plows, swords, and hoes – have been found from this period, when the types of tools increased considerably and had special uses (Fig. 2). Also at this time, such complex machinery as original textile machines and pottery wheels appeared.

From the late Neolithic to the Western Zhou Dynasty (1046–771 BCE), animals and wind were used as the main sources of energy, as attested to by chariots and sails from these times. There is little evidence to demonstrate a relationship between the chariots of China and those of Western Asia, and although the earliest appearance of chariots has been recorded differently in the literature, we can conclude that two-wheel wooden carriages were used as early as the Shang Dynasty (ca. 1600 BCE, Fig. 3). Carriages of this time commonly had two wheels, a rectangular or square wagon box, a single thill (one of two shafts extending from the body of a cart or carriage on either side of the animal that pulls it), a crossbar, yokes at either side of the crossbar, and leather straps for pulling the cart.

Mechanical Technology and Instruments of China, Fig. 2

A tool to level soil, unearthed in Qiansanyang, Wuxing, Zhejiang Province (From Du, 1984)



Mechanical Technology and Instruments of China, Fig. 3 A restored model of a chariot from the Shang Dynasty (From Hua, 1997)

Cattle were used to cultivate the land, plows were widely used, but the agricultural machines and devices varied a lot. Booms, windlasses, and other such composite machines also existed in antiquity.

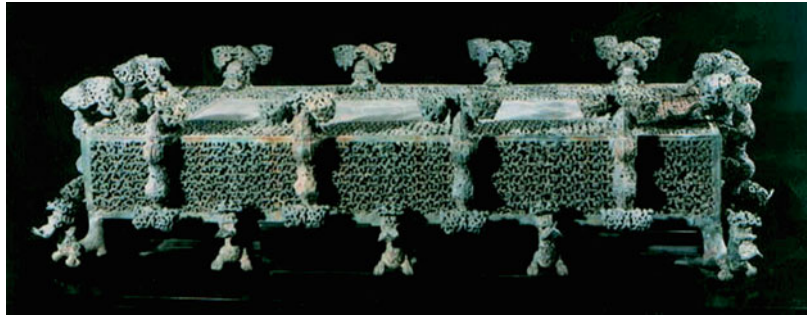
Bronze tools and instruments began to be widely used during the Shang Dynasty, and the techniques for smelting metals and casting utensils were at their highest even before the Western Zhou. Having begun with small-sized implements that had single-side and double-side patterns, the Shang eventually yielded large implements with composite patterns around a core, while advanced techniques such as separate casting were widely used in the middle of the

dynasty and pottery patterns became more complex in its later stages. The largest known bronze vessel is the Simuwu Ding, which was unearthed in Wuguan village, Anyang, Henan province in March 1939. It weighs about 875 kg and embodies the high level of casting under the Shang. Figure 4 shows the large-scale bronze wine table (*jin*) with a cloud design that was unearthed in Xichuan county, Henan province in 1978 and is the earliest known product cast according to the so-called “lost-wax process” (*shi la fa*) (Hua, 1986, pp. 231–232).

Ironware has been in use since the Spring and Autumn (Chunqiu) Period (771–476 BCE). The appearance and development of techniques for ironware casting made it possible to produce tools that were highly efficient. Techniques such as founding, forging, and softening that employed heat developed rapidly during this time, when many kinds of machines and devices, especially farm implements, were made from cast iron. In the Warring States (Zhanguo) Period (475–221 BCE), techniques for softening cast iron were developed.

The *Kaogong Ji* (Records of the Artificers, Fig. 5) is the earliest literary work on the techniques used in the handicraft industry in China. Most of it was compiled in the late Spring and Autumn and the early Warring States Periods, but some parts were added late in the Warring States. It includes information about how to manufacture carriages, weapons, sacrificial vessels, bells, and chime stones, as well as about architecture, hydraulics, dyeing, and techniques for other handicrafts (Dai, 2003). Such problems as the

Mechanical Technology and Instruments of China, Fig. 4 Bronze wine table unearthed in Xichuan County (See uji www.chnmus.net)



Mechanical Technology and Instruments of China, Fig. 5 A page from the *Kaogong Ji* (From Hua, 1997)



elasticity of bows, rapidity of arrows, and stability of flight are also addressed thoroughly.

Many instruments for astronomy originated in early China. The gnomon, which utilizes directions and lengths of the shadow of the sun to determine south and north as well as the seasons, existed under the Shang and Zhou. Water clocks which measured time by means of the liquid were first developed in the Spring and Autumn or the Warring States Period (Fig. 6). An intact bronze clepsydra which was unearthed in Inner Mongolia in 1976 has a year engraved on it that dates it to the Western Han Dynasty (206 BCE–8 AD). Instruments utilizing lodestones that pointed to

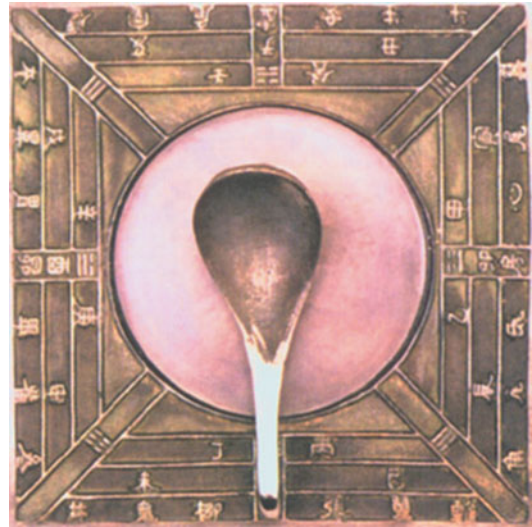
the geomagnetic poles were called *si nan* by the ancients (Jin, 1999, p. 103). According to the reconstruction by Wang Zhenduo in Fig. 7, a natural lodestone shaped like a spoon was placed on a plate with the directions labeled, and the handle of the spoon when stabilized would point to the south. From the Qin or early Han Dynasty, the solarium with a graduated circle to indicate the time according to the position of the sun, and based on the gnomon, became widely used (Fig. 8). Furthermore, astronomical instruments such as armillary spheres and celestial spheres designed according to mechanical principles appeared in the Han Dynasty, and according to



Mechanical Technology and Instruments of China, Fig. 6 A Western Han bronze clepsydra (From *Zhongguo Gudai Keji Wenwu Zhan*)

the *Tianwen Zhi* (Records of Astronomy) in the seventh-century *Jin Shu* (History of the Jin Dynasty), the armillary sphere and celestial sphere made by ► [Zhang Heng](#) during the Eastern Han Dynasty (25–220 AD) were of a fairly high level. The celestial sphere was in a closed box, was driven by water, and indicated the time that stars appeared and disappeared according to astronomical observations.

Mechanical technology during the Qin and Han Dynasties also progressed in other respects. The bronze chariots, warriors, and horses unearthed from the tomb of Qin Shihuang (r. 221–210 BCE) demonstrate a high level of mechanical fabrication, and their scales were one half of reality for the chariots and lifelike for the horses (Fig. 9). Even such details as the

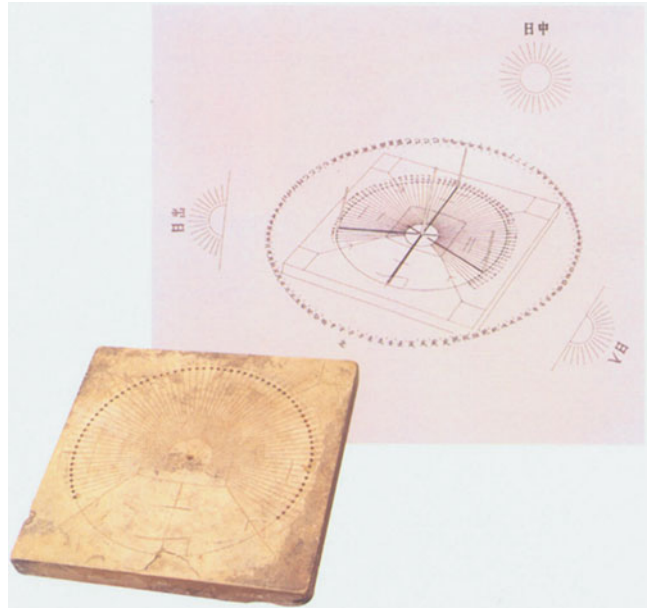


Mechanical Technology and Instruments of China, Fig. 7 A si nan (From *Zhongguo Gudai Keji Wenwu Zhan*)

wheels that allow the chariots to move, the horse gear, and ropes were molded in realistic shapes. These artifacts are not only unrivalled throughout the world but also outstanding examples of mechanical engineering under the Qin. When hydraulic power came to be added to wind and animals as a form of energy in the Han Dynasty, water-driven machines and devices that included such mechanical breakthroughs as gears, cams, and toggle levers were created. Among the machines and devices were the waterpower reciprocator, hydraulic trip-hammer, south-pointing carriage, incense burner, and Zhang's armillary sphere and seismograph, all of which reflected quite a high level in mechanical engineering.

The earliest records related to bellows driven by water power are in the *Du Shi Zhuan* (Biography of Du Shi), in the fifth-century AD *Hou Han Shu* (History of the Eastern Han Dynasty), which notes that a water-power reciprocator (*shui pai*) had been invented, while the *San Guo Zhi* (History of the Three Kingdoms) records that Han Ji made *shui pai*. Besides an explanation of the structure of a *shui pai*, the *Nong Shu* (Book on Farming) by Wang Zhen includes illustrations to show the structure and

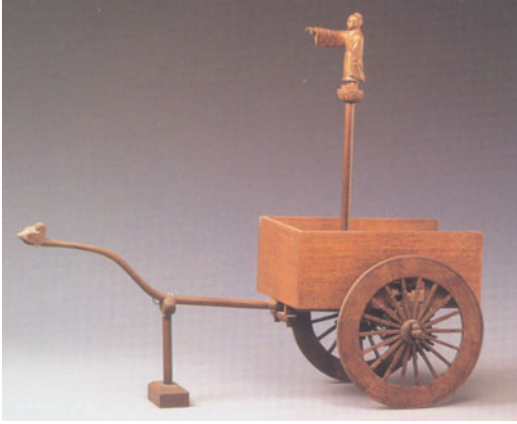
Mechanical Technology and Instruments of China, Fig. 8 A solarium from the Han Dynasty (From *Zhongguo Gudai Keji Wenwu Zhan*)



Mechanical Technology and Instruments of China, Fig. 9 Bronze chariots and horses, unearthed from Qin Shihuang's tomb (From *Qin Shihuang Ling Tongchema Fajue Baogao*)

how it operated. A *shui pai* (Fig. 10) included two horizontal wheels that were connected by a shaft, and when the lower wheel was driven by flowing water, the upper wheel rotated and, via a driving-belt, moved a pulley that was set with an eccentric lug or crank to move a connecting rod. This rod pushed two levers back and forth to make a piston rod move. The effect was that the rotation of the lower horizontal wheel was linked to the reciprocating motion of the piston rod (Animation 1).

The south-pointing carriage (*zhi nan che* or *si nan che*) was said to have been invented by Huang Di – the Yellow Emperor – or Zhou Gong. In the *San Guo Zhi*, a person called Ma Jun from the state of Wei (220–265 AD) is noted as having manufactured a south-pointing carriage, while ► [Zu Chongzhi](#), Yan Su, and Wu Deren are known to have made such a carriage later. Only for that by Yan, however, are there extant, detailed records about the shape and inner structure (Fig. 10).



Mechanical Technology and Instruments of China,
Fig. 10 Model of a south-pointing carriage (From
Zhongguo Gudai Keji Wenwu Zhan)



Mechanical Technology and Instruments of China,
Animation 1 A shui pai

The south-pointing carriage by Yan was driven by four horses and had two wheels and a rectangular wagon box. Inside was a gear linkage system that had nine gears in all, five serving as a transmission. In the box and connected with the other gears was a big horizontal gear, at the center of which stood a pole with a wooden person on top. Whenever the carriage moved, the hand of the person always pointed to the south, mechanically made possible by the automatic clutch system for the gears.



Mechanical Technology and Instruments of China,
Fig. 11 Model of a li-recording drum carriage (From
Zhongguo Gudai Keji Wenwu Zhan)

Figure 11 shows a drum carriage that recorded *li* (a distance of about half a kilometer) and was refitted from a drum carriage dating to the Han Dynasty. Mechanisms such as the decelerating drive gears and cam-and-lever devices were installed inside. As the carriage moved one *li*, the cam and a cord caused a wooden person to beat the drum with its right hand. The *Yu Fu Zhi* (Records of Carriages and Dresses) in the *Nan Qi Shu* (History of the Qi Dynasty) has a record of the *li*-recording drum carriage, the *Kui Tan Lu* (Records Ashamed of Tan) by Yue Ke of the Southern Song Dynasty (1127–1279 AD) records and explains how the gears worked, and the *Yu Fu Zhi* in the *Song Shi* (History of the Song Dynasty) has details about the devices and how motion was generated.

► **Zhang Heng** is noted in the *Hou Han Shu* as having invented the machine known as

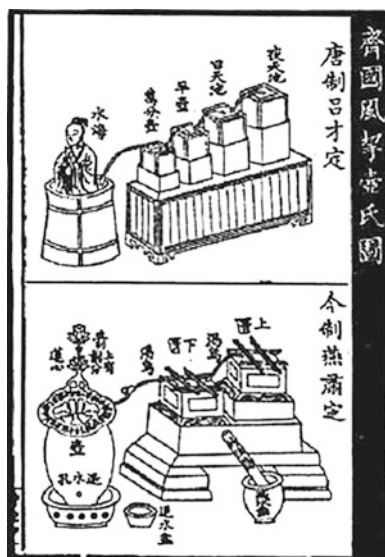


图1 《六经图》中的齐国风车图

Mechanical Technology and Instruments of China, Animation 2 Chang's seismograph (From *Zhonghua Keji Wu Qian Nian*)

"Chang's seismograph." According to the restoration by Wang Zhenduo, its inside structures include a pole, with a thick upper part and a thin lower part in the center, and eight curved levers around. The upper part of each lever is connected to the upper jaw of a dragon, whose lower jaw holds a brass ball. When the earth shakes, the pole falls down in the direction of the earthquake and presses the lower part of the corresponding curved lever, causing the upper jaw of the dragon to open and the ball in its mouth to drop down to a toad's mouth that is facing it. This makes it possible to recognize the direction from which the earthquake came (Animation 2).

Agricultural machines and implements developed rapidly during the Han Dynasty. The three-legged seed plow and the fan wheel (Fig. 12), which was a highly efficient processor of grain, were other noteworthy inventions. Other grain processing machines such as mills and trip-hammers not only appeared but also were improved. Mills with transmission gears and pestles driven by waterpower appeared during the Eastern Han Dynasty, and moldboards appeared



Mechanical Technology and Instruments of China, Fig. 12 A fan wheel (From *Tiangong Kaiwu*)

under the Western Han, when the design of the plow was finalized. Hand reeling machines, looms, jacquards, and other important machines were also invented, while techniques for building ships during this period were highly developed. Such components of ships as sculls, helms, and sails became well established, and large ships with upper decks as well as warships were easily made at the time of the Han.

In this period, many kinds of machines and devices used natural rather than artificial power, and their operation changed from direct to indirect means. Transmissions of power and movement were completed by the machines and devices themselves, while the control of the machines by humans became indirect. Machines and devices such as the *shui pai*, pestles, and the *ma pai* (horse-powered reciprocator) were provided with three basic composite elements – prime motors, actuating mechanisms, and operating mechanisms – and their appearance demonstrates that the mechanical system had reached a high level of development. From the subsequent Three Kingdoms Period (220–280 AD) until the Yuan Dynasty (1206–1367 AD), the overall technical level of traditional machines and devices progressed considerably.



Mechanical Technology and Instruments of China,
Fig. 13 A *gao zhuan tong che* (From *Nong Shu*)

From the Three Kingdoms Period into the Sui (581–618 AD) and Tang Dynasties (618–907 AD), the techniques were substantially developed. Forged implements became dominant among the tools for farming, and as founding techniques developed, large-scale casts appeared. Progress was made in hydraulic machines, while the Jin Dynasty (265–420 AD) saw the appearance of automatic mill wheels (*mo che*), pestle-wheels (*chong che*), and water mills (*shui nian*). The water-lift chain-pumps (*fan che*) invented during the Eastern Han Dynasty were improved and popularized. Tools for irrigation such as a “noria for high lifts” (*gao zhuan tong che*; Fig. 13) were also invented, while the structure of the plow was improved under the Tang, and movable plow pan devices appeared. Shipbuilding techniques developed further, and paddle-boats were invented.

Moreover, developments could also be seen in astronomical instruments. The *Tian Wen Zhi* in the eleventh-century *Xin Tang Shu* (New History of the Tang Dynasty) has detailed records about such an instrument designed by the monk Yi Xing and Liang Lingzan in the 13th year of Kaiyuan (725 AD). It had two wheel rings to represent the sun and the moon as well as a celestial sphere that was driven by waterpower. Two puppets inside marked the time by beating its drum and striking its bell. Earlier in the Tang Dynasty, Lü Cai (ca. 600–650 AD) had improved the water clock by adding several compensating clepsydras

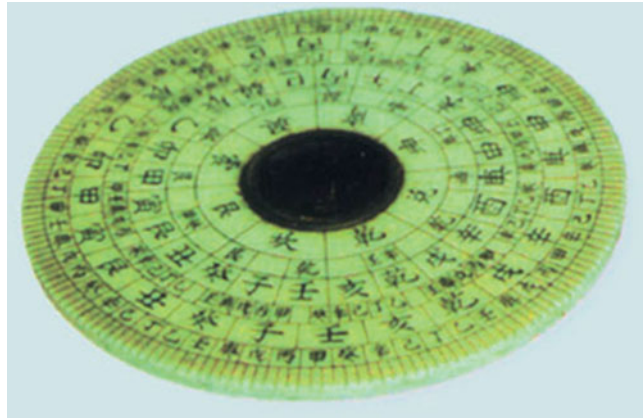


Mechanical Technology and Instruments of China,
Fig. 14 The “*Qi Guo Feng Qiehusi Tu*”(Illustration of the official who lifts the water clock according to the *Balladry of Qi*) in *Liu Jing Tu*

above the main clepsydra to make the time more accurate. Thereafter, Yan Su of the Northern Song Dynasty (960–1127 AD) created a lotus clepsydra (*lianhua lou*) which was widely used at that time. Figure 14 shows the style of these water clocks as presented in an illustration in the *Liu Jing Tu* (Illustrations to the Six Classics) by Yang Jia and printed in 1153.

Incense burners made of silver or gold have been found in several tombs from the Tang Dynasty (Fig. 15). Among them are the elaborately constructed, elegantly encased ones unearthed at Shapo village, Xi'an in 1963 and from the Famen Temple in Shaanxi province in 1987. Incense burners were first recorded in the *Mei Ren Fu* (Ode to Beauty) of the Western Han Dynasty by Sima Xiangru (179–117 BCE) and the *Xi Jing Za Ji* (Miscellanies of the Western Capital) of the Jin Dynasty by ► [Ge Hong](#) (284–364 AD). There were two or three concentric rings between the outer shell and the hemispherical body for burning the incense in the center. This hemispherical body had minor axles at both ends of its diameter so that, supported by the two radial holes of the inner ring, it was capable of moving freely. The inner ring was supported by the outer ring, which itself was supported in the same way by the inner wall of the outer shell. The supporting axles for

**Mechanical Technology
and Instruments of
China, Fig. 15** Incense
burner (From Hua, 1997)



the body of the burner, the inner ring, and the outer ring were perpendicular to each other, and because of the force of gravity, the burner remained horizontal at all times regardless of how the shell rotated.

During the Song and Yuan Dynasties the development of traditional machines and devices in China peaked, and a great deal of progress was particularly made in those for agriculture. The plow colter (the cutting arm of a plow) appeared under the Song, and new farm implements like cramp irons (*tie da*) and hoof plows (*ta li*) were widely used while many kinds of hydraulic machines became more widely used. Among the monographs on agricultural machines that were published, the nonextant *Nong Qi Pu* (Book of Faming Implements) by Zeng Zhijin of the Song Dynasty discussed various kinds of farming implements. The *Nong Qi Tu Pu* (Illustrations of Faming Implements) in the *Nong Shu*, by Wang Zhen during the Yuan Dynasty, introduced and explained contemporary agricultural machines and many tools for production, making the work a base for later research and records. Weaving machines had also been developed, while the spinning wheels driven by waterpower, foot-powered wheels for spinning cotton, and other machines in the *Nong Shu* reflected the high level of such contemporary machinery.

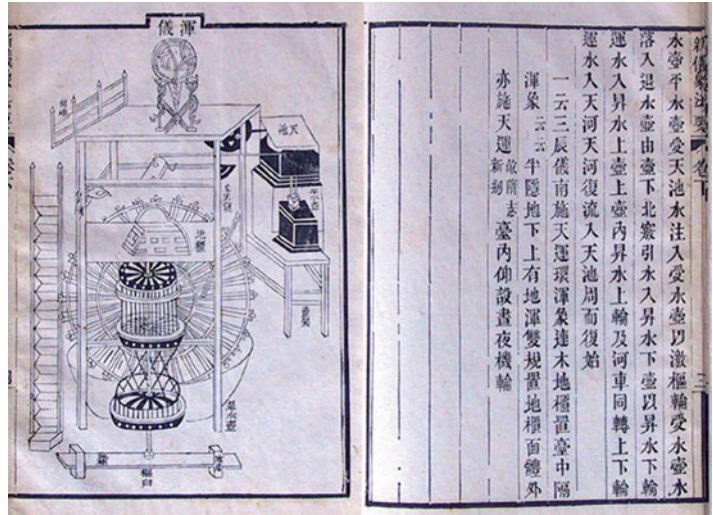
Techniques for manufacturing weapons developed rapidly and included new weaponry such as tubular firearms and jet-fire arrows. While shipbuilding became more sophisticated,

breakthroughs were made in instruments for astronomy to bring their traditional development in China to a peak. Among the different kinds that appeared were lotus clepsydras, Taiping armillary spheres (*tai ping hun yi*), “pseudo astronomical instruments” (*jia tian yi*), a water-driven astronomical clock tower, and “simplified instruments” (*jian yi*). Among the other important inventions at the time, typography, a two-way ram-acting air box, and cold-forging and cold-drawing techniques should be noted.

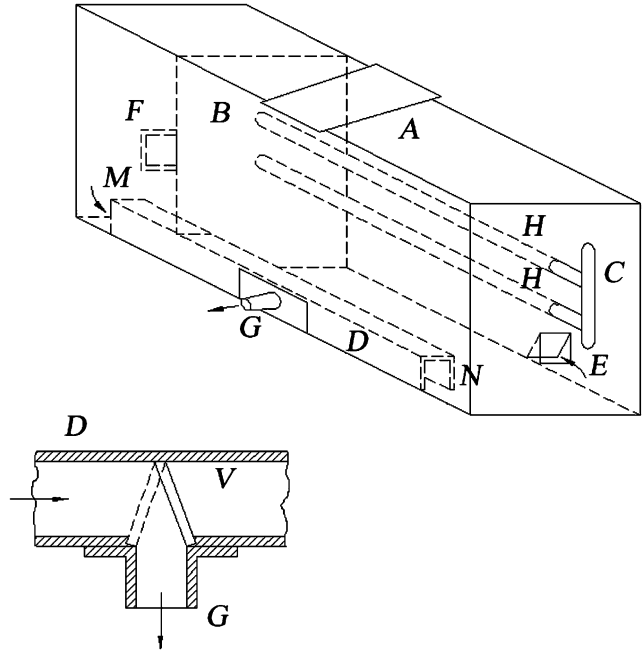
The magnetic needle was an instrument made by utilizing the property of lodestones to point to the geomagnetic poles. Early needles were simply made with natural lodestones and were improvements on the *si nan*. In the *Wu Jing Zong Yao* (General Military Principles), compiled by Zeng Gongliang in the early Northern Song Dynasty, is a record of how to construct a south-pointing fish that was precise whenever it was placed on a surface of water. The manual method of rubbing lodestones to magnetize steel needles was developed during the Northern Song Dynasty, when carved wooden south-pointing fish or tortoises with magnetized needles in their stomachs became rather popular. The dry land compass with a fixed point of support was invented in the Southern Song Dynasty, but water compasses which made use of buoyancy remained in general use (Figs. 16 and 17).

The water-driven astronomical clock tower in Animation 3 was the earliest astronomical clock in the world. Having included an armillary

Mechanical Technology and Instruments of China, Fig. 16 A floating magnetic needle (From *Zhongguo Gudai Keji Wenwu Zhan*)



Mechanical Technology and Instruments of China, Fig. 17 An ivory water compass dating to the Qing Dynasty (From Jin, 1999)

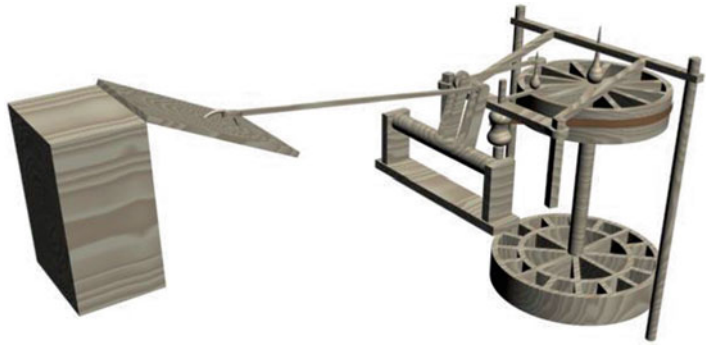


sphere, celestial sphere, and water clock, and being the work of Su Song in the seventh year of Yuanyou (1092), it was a square platform-like wood construction that measured about 12 m in height and 7 m in width. Its upper part was narrower than the lower part, and it had upper, middle, and lower layers. At the top was the copper armillary sphere that illustrated observed celestial bodies, in the middle was the celestial

sphere which marked about 1,400 stars and was used mainly as a planetarium, and at the bottom was the mechanism for indicating time. The machine was driven by a gear system which was assisted by chain drives (or a high ladder) and levers. “Celestial balances” (*tian heng*) and driving wheel (*shu lun*) comprised the coordinated escapement, which as a whole is regarded as a remarkable invention in mechanical history.

Mechanical Technology and Instruments of China, Animation 3

Su Song's astronomical clock tower (From *Zhonghua Keji Wu Qian Nian*)



Mechanical Technology and Instruments of China, Fig. 18 A page from Su Song's *Xin Yixiang Fayao*

The driving wheel was the principal component of the clock tower, with 36 water boxes (*shou shui hu*) along the circumference. When the water in the box reached a certain weight, a series of control systems would be triggered, causing the driving wheel to rotate intermittently. The rotation was transmitted to the “celestial pole” (*tian zhu*) by the “terrestrial hub” (*di gu*), and then to the operating mechanisms by a drive system.

There was an escapement mechanism designed to keep the driving wheel rotating isochronally.

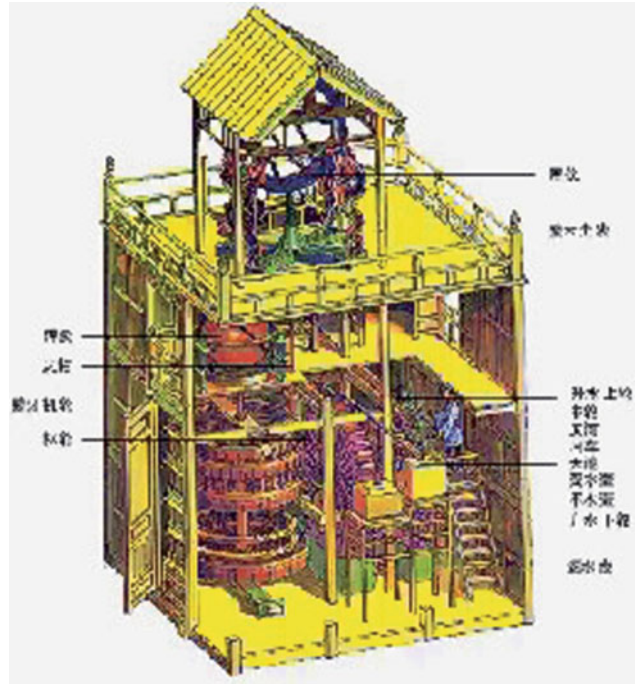
The astronomical clock tower was destroyed in the war between the Northern Song and the Jin in 1127. Fortunately, Su wrote the book *Xin Yixiang Fayao* (New Design for an Astronomical Clock, Fig. 18) after the instrument was completed in the

early years of Shaosheng (ca. 1094–96 AD). Because it is the most detailed extant monograph on astronomical instruments and has illustrations of the clock tower as a whole as well as of its components, spare parts, and star images, it has been possible to recreate the astronomical clock.

The air-blast apparatus was first a leather bellows, then a *ma pai* and a *shui pai*, and finally an box-bellows with piston. As shown in Fig. 19, the piston-bellows was made of wood and had a blowing piston-board (B) in the middle and a square tube at the lower left. Two holes (M, N) were connected to the box, with a flow mouth (G) pointing outward in the middle. The free valve inside the tube could connect either part of the tube with the flow mouth freely, as illustrated below. The two free valves (E, F) at both ends of the box could only open inward, making the outer air flow into the box when the handle of the piston-board was pushed forward. Since the air behind the piston-board is of lower pressure, the air outside presses valve E inward and flows into the box. At the same time, the air in front of the board is of higher pressure, so valve F gets closed. The air before the board therefore flows into the tube and pushes the valve to move backward, causing the air to flow into the smelting furnace through G. As the handle moves forward and backward, the higher-pressure air flows almost continuously and keeps the fire burning. Animation 4 shows how the box-bellows works.

The machines and devices of this period not only reached a high technical level, but they were also varied and many resulted from especially creative talent. Among their many makers were Ma Jun, ► [Zu Chongzhi](#), ► [Li Gao](#), Zhang Sixun,

**Mechanical Technology
and Instruments of
China, Fig. 19 A**
box-bellows



**Mechanical Technology and Instruments of China,
Animation 4** How the box-bellows works

Yan Su, Su Song, Guo Shoujing, and Wang Zhen, and many Chinese machines and devices spread to other countries.

From the late Yuan Dynasty into the Qing (1616–1911 AD), there were a few developments in traditional machines and technology. Still, there were fewer great inventions in this period, although traditional mechanical technologies were still progressing. Cold-forging and cold-drawing techniques were improved during the Ming Dynasty (1368–1644 AD). The *Tiangong Kaiwu* (Exploitation of the Works of Nature) by Xu Guangqi records the cold-forging technique for making saws and the cold-drawing technique for making steel needles, while the many kinds of wrought products that existed demonstrate the

development of forging techniques. In the Ming Dynasty there was one called “cold quenching,” which suggests that the understanding of quenching had advanced. Weapon-making techniques improved quickly as many kinds of weapons appeared and monographs on weapons such as the *Huolong Jing* (Book of Fire Dragon) and *Huolong Shenqi Zhenfa* (Array of Magic Instruments of Fire Dragon) were published, while shipbuilding continued to develop as China became a powerful maritime country. Furthermore, it was during this time that the hourglass, an important marker of time, was invented.

Toward the end of the Ming and into the Qing Dynasty, missionaries from the West brought Western science and technology to China. Machines and devices were also imported, and translations of works on machinery such as the *Yuanxi Qiqi Tushuo Luzui* (Illustrated Books of Western Magic Instruments) were published. From early in the eighteenth century to the 1840s, however, the Qing government opted for a policy of seclusion and broke communications with the Western world. The development of machinery in China then stagnated, and there were no notable inventions for more than

a 100 years. Because it was at that time that the Industrial Revolution took place in the West, mechanical science and technology developed there rapidly and took the West far beyond the level of Chinese technology.

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Medical Ethics

Robert M. Veatch

The medical ethics of non-Western cultures are not as cleanly differentiated from the rest of their

religious and cultural value systems as they are in the West. There the traditional medical ethic of organized professional medicine is summarized in the Hippocratic Oath and the tradition surrounding it. This ethic that guides health care professionals is often in conflict with religious and philosophical traditions that provide more general ethical frameworks. By contrast, in non-Western cultures, medical ethical questions are often addressed in the core ethics literature of the group, such as religious texts and philosophical writings.

The ancient cultures of Asia provide an example. Generally, they turn to classical texts for their medical ethical insights.

China

Although Chinese medicine has a history of at least 2,000 years, the first explicit medical ethical writing is usually attributed to Sun Simiao (also called ► [Sun Simo](#), ca. AD 581–682). His “On the Absolute Sincerity of Great Physicians,” which is part of the massive *Qianjin Yao Fang* (Important Prescriptions Worth a Thousand Pieces of Gold, or the Thousand Golden Remedies), is sometimes referred to as the Chinese Hippocratic Oath. Sun Simo, who is primarily associated with Daoist thought, but who also reflects Buddhist influences, is credited with differentiating medicine from more general social practices by demarcating a core group of “Great Physicians.” This core group is held out as the normative ideal. The emergence of this concept of the great physician is thought to be the beginning of the professionalization of medicine.

Great Physicians practice the virtues of compassion and humaneness. They are committed to preserving life, a traditional Daoist moral orientation. In a manner typical of ancient Chinese medical ethical writings, but normally omitted from the Greek Hippocratic tradition, Sun Simo says that the Great Physician “should not pay attention to status, wealth, age, neither should he question whether the particular person is attractive or unattractive, whether he is an enemy or a friend, whether he is Chinese or a

foreigner, or finally, whether his is uneducated or educated. He should meet everyone on equal ground” (Unschuld, 1979). Paul Unschuld argues that this professionalization of the practice of medicine begins the effort to control the practice of medicine and its material and nonmaterial rewards.

About 150 years later, Lu Zhi (AD 754–805) provided a Confucian response in his *Luxuan Gonglun*. It also emphasizes the virtues of humaneness and compassion, but, according to Unschuld’s interpretation, the classical Confucian perspective resisted the professionalization of medicine, holding that medical skills and knowledge should be distributed among all people, not just specialized professionals. The theme of the duty to treat all in medical need, regardless of status and concern over elitist professionalization, occurs throughout ancient Chinese medical ethics. In the seventeenth century Li Ting (fl. AD 1615) wrote his often cited *Ten Maxims for Physicians; Ten Maxims for Patients*, which repeats these themes, beginning with the necessity of mastering Confucian teachings. While the Daoist and Buddhist strands of Chinese thought have reflected strong prohibitions on killing, generally including condemning of abortion and insisting on prolongation of life, Confucian views have been more tolerant of such practices.

India

India, like China, incorporated its medical ethical teachings within its classical philosophical/religious literature. Among the Vedic texts, the *Āyurveda*, initially developed beginning in the first millennium BCE, contains the most important medical writings. Three such texts, the *Carakasamhitā*, the *Suśrutasamhitā*, and the *Vāgbhata*, include medical ethical writings. The first two also include oaths of initiation taken by students of medicine when they began their training.

The oldest, the *Carakasamhitā*, dates from the first century AD, but contains older material. Like the Hippocratic Oath, it requires the student to pledge loyalty to his teacher, to “dedicate thyself

to me and regard me as thy chief.” Reflecting Hindu reverence for animal species, it requires praying for the welfare of all creatures beginning with cows and Brahmanas, a large domestic fowl. In an unusual provision, though one understandable given the Hindu doctrine of karma, in which a person’s conduct during the successive phases of his existence determines his destiny, the student pledges not to treat those “who are hated by the King or who are haters of the King,” or those “who are extremely abnormal, wicked, and of miserable character and conduct.” It also proscribes treating “those who are at the point of death.” In spite of this reluctance to treat those who are dying, Hindu medical ethics stresses the importance of the proscription against killing.

The Hindu notion of *ahimsā*, the avoidance of suffering, is another central theme in Hindu medical ethics. It is sometimes interpreted as requiring caution in order to avoid injuring, a concern often reflected in Western medical ethics with its slogan *primum non nocere*, first of all do no harm.

Buddhist Culture

Some of these notions are also reflected in the Buddhist medical ethic of various Asian countries. The prohibition on killing, the concern about *ahimsā* and a commitment to veracity all contribute to the Buddhist tradition of medical ethics. These commitments are often in tension both with indigenous pre-Buddhist religious traditions (Confucianism and Daoism in China, Hinduism in India, and Shintoism in Japan) as well as with modern Western culture. Ratanakul (1988), commenting on the penetration of traditional Thai Buddhism by Western individualism, traces conflicts over four central themes of Buddhist medical ethics: veracity, noninjury to life, justice, and compassion. Hippocratic Western medical ethics has never manifested commitments to any of these until recent efforts have begun reflecting them at least in a modest way.

In Japan, Buddhist thought has provided the foundations for medical ethical thought. For example, in the sixteenth century a school of medicine, commonly known as the *Ri-shu* school,

manifested classical Buddhist commitments. Students in this school were bound by *The 17 Rules of Enjuin*. Killing of any creature was proscribed. Even hunting and fishing were not acceptable. In contrast to the Hindu *Carakasamhitā*, the duty to rescue was extended even to those whom the physician disliked or hated. But virtuous acts were to be performed secretly so that they did not become known to people. Doing good deeds secretly was considered a part of virtue. In a fashion similar to the Hippocratic Oath, students were sworn to secrecy, being prohibited from disclosing any medical knowledge to outsiders. Unless a successor trained in this school was found, those of the Ri-shu school were even required to return all medical books to the school when a disciple ceased to practice.

In Japan, Buddhist medical ethics has survived in an uneasy tension with both modern Western thought and indigenous beliefs known as *kami no michi* (the way of Kami), or Shinto, according to the Chinese. For example, while killing is clearly condemned according to Buddhism, suicide and mercy killing receive more sympathetic assessment both by some proponents of the patients' rights movement imported from the West and by those reflecting traditional Shinto openness to *kyoshi* (love suicide) and *shinju* (group suicide). It is these latter influences that undoubtedly account for what could be called mercy killing in Japan.

The traditional influence is also seen in the resistance of Japan to the Western brain-oriented definitions of death. Japan is the only country that has not adopted such a legal definition. It is argued that the traditional Japanese notion of a life force penetrating the entire body clashes with Western notions of life related to brain or mental function.

The Near East

Near Eastern cultures have perspectives on medical ethics that date back at least to the second millennium BCE. Zoroastrianism of ancient Persia saw the physician as a force for good in the struggle between good and evil. It is suggested

that this provides a foundation for a medical ethic that would oppose euthanasia. In both Assyria-Babylonia and in Egypt, suicide was proscribed. There are records of abortifacient remedies in ancient Egypt, but there is doubt concerning abortion's legality. It was, however, by the middle of the second century BCE prohibited by Assyrian law as it was in Persia.

The Babylonian Code of Hammurabi (1727 BCE?) provided stiff penalties for incompetent surgery. The surgeon's hand was to be severed if surgery was performed on a nobleman that resulted in death or loss of an eye. If death was caused by a medical procedure on a slave, the physician was obliged to replace the slave. This "sliding-scale" punishment was matched with a similar sliding-scale fee structure in both Assyro-Babylon and Persia. The higher the status of the patient, the higher the fee.

In Islam, medical ethics is grounded in the *Qur'ān*. A ninth century work, *Adab al-tabib* (Practical Ethics of the Physician, by al-Ruhawi) reflects the Islamic synthesis of Hippocratic, Greek, and Arabic medicine. In the thirteenth century an Arabic version of the Hippocratic Oath is found in *Lives of Physicians* written by Ibn Abī Uṣaybi'ah. Nevertheless, the core of Islamic medical ethics is explicitly grounded in the *Qur'ān* and its central teaching, "There is no god but Allah, and Muhammad is Allah's Apostle." This has sometimes given rise to a kind of fatalism in Islamic folk medical ethics. It is sometimes reported that Muslims oppose medical manipulations such as birth control for this reason. But a sophisticated ethical framework in Islamic medical ethics includes a rigorous commitment to the preservation of life, and opposition to all killing including killing for mercy and abortion.

Whoever killeth a human being for other than manslaughter or corruption in the earth, it shall be as if he had killed all mankind, and whoso saveth the life of one, it shall be as if he had saved the life of all mankind (*Qur'ān* 5:22).

Islamic medicine, in contrast to Western Hippocratic medicine, is thoroughly theocentric.

This is reflected even in contemporary Islamic medical ethics. In January of 1981 Muslim

scholars from throughout the world gathered in Kuwait at the First International Conference on Islamic Medicine. They produced the "Kuwait Document," a now-definitive Islamic Code of Medical Ethics. It contains 12 chapters outlining in detail Islamic positions supported by reference to the *Qur'ān*, culminating in "The Oath of the Doctor", a summary of the code. Among the prominent characteristics are a pledge to "protect human life in all stages and under all circumstances, doing my utmost to rescue it from death, malady, pain and anxiety." It also includes an exceptionless pledge of confidentiality that stands in contrast to the Hippocratic provision, which implies that some information ought to be disclosed to others. It also embodies a commitment to provide medical care for all, "near and far, virtuous and sinner and friend and enemy." Other chapters include an explicit recognition of the duty of the Islamic physician to society (a contrast to the exclusive focus on the individual in traditional Hippocratic medical ethics), further expounding on the sanctity of human life (including prohibitions on all abortion and mercy killing), and a full endorsement of the legitimacy of Islamic involvement in new biotechnological advances including organ transplantation. This last provision contrasts with the folk ethic that sometimes reflects a kind of fatalistic yielding to the power of Allah.

African Societies

Many African cultures have taken positions on matters related to medical ethics. Unfortunately, with the exception of ancient Egyptian views, relatively little is known about their specific medical ethical stances. In some sub-Saharan African tribal groups understandings of moral conduct related to life and death are closely tied to the religious culture (*Wiredu*). Since the cultures and languages are so diverse, it would be a mistake to assume that all African societies hold the same medical ethical views. Nevertheless some common patterns are reported. Although euthanasia is not widely discussed, it was and is reportedly practiced by family relatives for incurable and

distressful mental illness and severe congenital malformations in many African societies. Likewise, abortion, though viewed with moral skepticism, appears to be practiced as it is elsewhere in the world.

Pre-Columbian Western Hemisphere

Among the most poorly understood medical ethical systems are those of the pre-Columbian Western hemisphere. There has never been any formal analysis of the medical ethics of the great Inca, Aztec, or Maya cultures or of the Native American tribal groups of North America. Most of what is known pertains to views about abortion, suicide, human sacrifice, and related practices.

The Incas viewed children as an asset, and, while abortion was known (by means of fetal massage, beatings, and special drugs), it was punished by execution of both the woman who aborted and those who aided her. Nevertheless among the Inca human sacrifice was practiced. Male children could be demanded for sacrifice, although the practice was apparently rare. Sacrifice of one's young children was reportedly a last resort to attempt to win the favor of the spirits. The yearly sacrifice of two infants was a part of the ritual of the most important temple. In contrast to Greek and modern infanticide, Inca sacrifices had to be of children without blemish.

Human sacrifice was also practiced by the Mayas, either by "heart-rending" or by throwing the one to be sacrificed into a cenote or large sink hole. The Mayas also offered sacrifices of their own blood by piercing their cheeks, tongues, or lower lips. The blood was considered to express "vital principles". Suicides were held by the Mayas to be sacred, deserving of their own special heaven. Human sacrifice was more common among the Aztec as it was in the society of the Caribs. By contrast in these pre-Columbian cultures, there are few reports of killings of either infants or adults for the purpose of euthanasia or the sparing of the afflicted. The close integration of religion, magic, and medicine in these cultures makes the differentiation of a uniquely medical ethic implausible.

Inca doctor-sorcerers, called the *camasca*, or *soncoyoc*, are said to have employed deception in their practice of medicine. They earned entrance into the profession by telling stories of vivid dreams or miraculous recoveries from fatal diseases. Once they had obtained the status of *camasca* or *soncoyoc*, they staged dramatic procedures. One example is surgery in which the doctor would claim that he had removed worms and stones – the supposed causes of disease – from the patient's body, when in actuality, he had recovered said items from no other place than his own pocket, using sleight of hand to make it seem as though they were being extracted from the body. In addition, the Inca physicians would create mixtures of herbs that they claimed to be deadly, in order to generate fear – and revenue – from their clientele. Despite all of this activity, to kill with magic charms was considered a serious crime. Like healers in many cultures, the practitioners were very exclusive about the practice of medicine, claiming that only they, the chosen ones, could practice it properly. Another source says that in some tribes, as in ancient China, herb healers were family based, and all professional information as to the nature of different herbs was kept as a family secret.

Medical ethical stances are derived from more general systems of ethics and belief. It is not surprising then to find that there are as many medical ethical systems as there are systems of ethical thought. To say that behavior in the medical sphere is ethical is, after all, simply saying that the behavior is ethical – at least according to some standard of ethics. Even those practicing medicine within Western culture will inevitably encounter patients who come from other cultures whose medical ethical values and beliefs may be quite different. Only by knowing the range of medical ethical systems will one's own positions be brought into focus.

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Medical Ethics in China

Angela Ki Che Leung

For most pre-modern civilizations with a certain degree of cultural sophistication, medical ethics were strikingly similar: hard work and concern for the poor and needy. A good doctor not only excelled in his medical skills, but also cared for the sick and poor. Material benefits should not be his major pursuit. In the West, such tenets naturally conformed to Christian morality; in China, Confucianism, Buddhism, and Daoism mostly contributed to the formulation of such ethics.

Despite the universality of these basic ethical requirements, there were specific features in the historical development of Chinese medical ethics which can be said to have gone through several stages of formation: the mythical period of Antiquity (ca. 771 BCE–AD 265); the period of Buddhist and Daoist influences of the early medieval era (265–960); the period of medical professional maturity of the late medieval era (960–1368); and lastly the late imperial period of Confucian influence (1368–1911).

In the period of Antiquity some of the basic tenets of medical ethics were put forward. From some of the earliest records of Chinese oracle bone writings and other texts, we know that medicine was then mixed with divination and magic. The shaman/doctor had a relatively high social position and a respectable one should, according to opinion of the time, have the quality of perseverance or stability (*heng*).

With the gradual emergence of professional doctors around the sixth century BCE, clearer notions of medical ethics appeared. In the ► [Huangdi Neijing](#) (Yellow Emperor's Inner Canon) attributed to the mythical Yellow Emperor, the basic medical classic compiled throughout a period of not less than 400 years beginning in the Warring States period (475 BCE–221 BCE), qualities such as erudition, rich experience, wisdom, humility, and hard

work were evoked as necessary for a good doctor. Renowned doctors of this period were reputed to have most or all of such qualities.

Another major quality said of the early doctors was their concern for the poor and lowly. They did not only cure the wealthy and the powerful, and profit was never their major pursuit.

Prominent doctors of this period, such as ► [Bian Que](#) (fifth century BCE), Chunyu Yi (b. 205 BCE), Zhang Zhongjing (second to third centuries AD), and Hua Tuo (d. ca. 208), were later to be venerated as deities of the medical profession, and symbolized the very virtues of good doctors. The deification of these doctors, especially Hua Tuo, was based not only on their exceptional medical skills, but also on their outstanding and legendary morality.

In the Early Medieval period, Buddhism and Daoism had a marked influence of, not only on medicine itself, but also on medical ethics. For many modern historians of Chinese medicine, true medical ethics were not systematically composed in China until the seventh century, when one of China's greatest doctors Sun Simiao (also called ► [Sun Simo](#), 581–682) wrote systematically on the duties of a physician in his book *Qianjin Bao Yao* (The Thousand Golden Remedies). In this work Sun not only reiterated the qualities already mentioned for model doctors of Antiquity, but also emphasized the importance of retribution as a safeguard for good virtues: "Lao Zi, the father of Daoism, said, 'Open acts of kindness will be rewarded by man while secret acts of evil will be punished by God.' Retribution is very definite. A physician should not utilize his profession as a means for lusting. What he does to relieve distress will be duly rewarded by Providence." The notion of retribution, though here thought to be essentially Daoist, was in fact much influenced by Buddhism in this period.

The medical ethics put forward by Sun Simiao reflected other aspects of Buddhist-Daoist influences: to attend to all patients equally, disregarding their social and economic position, their age, and their physical appearances. Enemies and friends, foreigners and Chinese, the stupid and the wise should all be treated alike. All these categories should be considered as one

single, general class by the doctor. This “equality” before medical care was something unfamiliar to Confucian morality but which has remained significant in medical ethics since the seventh century.

In the Late Medieval period, Chinese medicine reached maturity, both as an institution and a clinical art. The formal division of medicine into different branches or specialties (notably *fuke*, the branch of medicine specializing in women’s diseases; *erke*, in children’s diseases; and *waike*, in bone fractures and operations) implied a finer division of labor amongst physicians, and this was also reflected in a more elaborate and systematic training program for officially approved doctors in this period, and increased state intervention in the management of medical resources. Though some scholars think that in this period medicine was “a respectable field of study...but as a career and mode of life was highly controversial,” one can still see the emergence of a certain medical professionalism, and with it, new elements in medical ethics.

One such element was the frequent caution against *yongyi* (common practitioners). The term was frequently evoked in Song medical texts. A *yongyi* is the antithesis of a *liangyi* (fine doctor), comparable to a *liangxiang* (fine minister). This comparison was first put forward by the famous Song minister Fan Zhongyan (989–1052), who had once considered becoming a doctor himself. The medical profession in the Song period took greater pains than before to draw lines between good and bad doctors, reflecting the emerging professional consciousness of doctors of the period.

However, the reputation of a fine doctor was not entirely based on his curing skills. A fine doctor now combined the religious selflessness and charity of the early Medieval period, as well as neo-Confucian ethics. One of the greatest *fuke* specialists of the Song, Chen Ziming (1109–1270), wrote that he came from a family of three generations of doctors, with an excellent private library of medical books. But his appetite for prescriptions and medical texts was so large that whenever he traveled in the southeast, he collected large quantities of texts which he

studied in his free time. Obviously, a good doctor was now likened to a good Confucian scholar, for whom family tradition and textual learning were considered essential for professional success.

The increasing influence of Confucian morality on medical ethics was yet to be seen in the late imperial period. This was a period of relative political continuity and economic prosperity, accompanied by a significant growth in medical knowledge. However, this period was not one of institutional renovation and regulation in medicine. Consequently medical professionalism, in the sense of the maturation of a completely independent professional category, might have suffered. As Unschuld (1979) has said, “The Chinese physician as a definable entity did not exist.” The respectability of a physician was, besides his curing technique, increasingly linked to Confucian morality.

One prominent sixteenth century physician, Xu Chunfu (1526–1596), wrote in his major work *Gujin Yitong Daquan* (Medical Tradition of the Past and of the Present) that “Confucianism and medicine cannot be separated.” His contemporary, also a famous doctor, Gong Tingxian (1522–1619), put forward ten requirements for physicians, the first two being to cherish kindness and to understand Confucian principles. Another doctor, Li Ting (d. 1619), in his *Rules for Medical Studies* stated from the outset that, “Since medicine comes from Confucianism, unless one studies and understands the [basic] principles, one remains mediocre, vulgar and stupid...” At the same time, detailed instructions on treating female patients were increasingly provided in order to avoid transgressing the Confucian principle of the separation of the sexes.

However, it was also prominent “Confucian doctors” of this period that further defined medical ethics in more systematic ways. The above-mentioned Xu Chunfu was among the first to list the main “vices” of *yongyi*, including taking on the appearances of good doctors with a few tricks, extorting money out of patients, and freeing themselves of responsibility by any means in case of misdiagnosis leading to death.

Another famous doctor of the seventeenth century wrote the first Medical Code in 1658. Yu Jiayan (ca. 1585–1664) wrote detailed technical diagnostic guidelines for professional doctors. He made the doctor responsible for all avoidable diagnostic errors, and in so doing, attempted to draw a clearer line constructed on technical considerations between a *liangyi* and a *yongyi*. In other words, development, though limited, was still perceptible in the professional consciousness of doctors despite the overwhelming influence of Confucianism in this period.

However, the incomplete growth of an autonomous medical profession inevitably left areas of ambiguities in medical ethics. One such is the transmission of “secret prescriptions.” For some historians of medicine, “the dispensing of secret prescriptions was never considered to be unethical in China. Some even deemed it an honor for a physician to know a secret formula.” However, there are indications that not all approved of this attitude. Among others Xu Youzhen (1407–1472), a scholar-official, accused contemporary doctors of preserving secret prescriptions for private profit. For him, effective prescriptions should be published in order to save more lives and to be passed onto posterity. An early nineteenth century physician, Bao Xiang’ao, wrote in the preface of his compilation of “effective prescriptions” that those who did not make effective prescriptions public were despicable.

This ethical ambiguity of the necessity of keeping prescriptions and healing techniques secret obviously was a consequence of the basic structure of the medical institution in late Imperial China: the lack of centralized control in the production of medical knowledge, either by the state or by a self-regulatory medical corps, and the accompanying uncontrolled distribution of medical resources in society. Each family or school of medicine thus had to preserve its share of the resources in order to be competitive in the field, though morally such an attitude was obviously questionable. Such a characteristic only encountered effective challenge when western medicine was introduced into China in the late nineteenth century, together with its ethics and institutions.

See Also

- [Bian Que](#)
- [Huangdi Neijing](#)
- [Sun Simo](#)
- [Zhang Ji \(Zhang Zhongjing\)](#)

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Medical Ethics in India

Prakash N. Desai

The origins of medicine in India stretch back to antiquity. The Harappan city culture flourished in and around the Indus Valley ca. 2500 B.C.E.; it is known for its elaborate bathhouses and drains and sewers built under the streets leading to soak pits. In the second millennium B.C.E., the northwestern parts of India were host to a series of Indo-European immigrants and invaders from Central Asia. With them began the classical culture of India. Vedas, the sacred lore of the Indo-Europeans, celebrate the *Bhesaj*, one knowledgeable in medicinal herbs. One of the four Vedas, the *Atharvaveda*, contains many chants, mantras, and herbal preparations to ward off evil, enemies, and diseases. The priest-physicians prescribed preparations of plants and herbs, and prayers and fasts for their patients. The Indian medical tradition, *Āyurveda*, meaning the science of vitality and long life, is considered a limb of the *Atharvaveda*.

A more formal system of medicine evolved from around the time of the Buddha (ca. 500 B.C.E.). It became organized in textual form in the first century A.D., and reposes in a vast body of literature redacted and updated from that time to the present. There are six principal texts of the Āyurveda. The older three are the two compendia, *Carakasamhitā* and *Suśrutasamhitā*, named after the two legendary physicians, ► [Caraka](#) and ► [Suśruta](#), and the *Aṣṭāṅgahṛdaya*, the eightfold essence attributed to an eighth century physician named ► [Vāgbhaṭa](#). The younger three are the *Mādhavanidāna* (ninth century), *Śārṅgadharaśamhitā* (thirteenth or early fourteenth century), and *Bhāvaprakāś* Bhāvamīśra (sixteenth century). The word *caraka* also means one who moves about, and may have referred to the itinerant Buddhist and Jain monks who played a pioneering role in the evolution of the Indian medical tradition. In the realm of King Aśoka (273–232 B.C.E.), who embraced Buddhist ideals, Buddhist monasteries served as institutions, like hospitals and hospices, for the care of the sick and the dying.

The earliest medical writings known as the Bower manuscripts, discovered in a Buddhist Stupa in Kashgar (modern China), and translated by Rudolph Hoernle, are considered to have been written by Buddhist authors around A.D. 450. These texts contain medical treatises which describe the virtues of garlic in curing diseases and extending the life span, elixirs for a long life, ways of preparing medical mixtures, eye lotions, oils, enemas, aphrodisiacs, and procedures for the care of children. Early Indian medicine was carried to Tibet along with Buddhism and was best preserved there, as well as in China. Travelers to and from China, Greece, Persia, and Arabia contributed to the spread of Indian medicine outside India.

The basic assumptions of Indian medicine are rooted in the religious and philosophical traditions of India. Early developments exhibited great diversity in opinion and formulation in keeping with the diversity in Indian thought, tied to Hindu, Buddhist, or Jaina philosophies in various measures. Similarly the system allowed for significant geographic variation as knowledge

spread through the subcontinent over a long period of time.

The medical ethics which are closely linked to these religious and philosophical perspectives (*darśanas*) reveal variable, shifting, and accommodating attitudes.

Āyurvedic constructs of the body and the self, central to the medical enterprise, grew in tandem with the faith traditions. The primary vehicles of ayurvedic pathophysiology are the *doṣas* (humors): *vāyu* or *vāta* (wind), *pitta* (bile), and *kapha* (phlegm), and the *dhātus* (body substances). The three humors represent movement, heat, and moisture, respectively, in the body. The primary body substance, *rasa*, organic sap, is derived from food, moves throughout the body, is stored in various reservoirs, and is finally excreted as waste products. In processes of sequential transformation, the *dhātus*, flesh, fat, bone, marrow, and semen, are derived, semen being the purest and most vital product of this process.

The Indian system of medicine views health as a state of balance of body substances, *dhātusamyā*, and illness as a state of disequilibrium. The body responds to many kinds of inputs: physical, as in food and drink, psychological, as in emotions of anger or jealousy, and social, as in affection, praise, or scorn. Each input is a potential source of a disease or a cure.

The theory of *guṇas* (lit. strands or qualities) introduces the notion of ethics as a material basis in the ayurvedic pathophysiology. Inherent and substantial, *sattva* (goodness), *rajas* (vitality or activity), and *tamas* (inertia) are qualities or traits found in all substances in various combinations. The balance determines the overall dispositions of persons, foods, activities, bodily substances, and so forth. *Sattva*, which is cool and light, produces calmness, purity, or virtue; *rajas*, which is hot and active, produces passion, happiness, or sorrow; and *tamas*, which is dark, heavy, and dull, produces sloth, stupidity, and evil. Contemplation, meditation, silence, devotion, and fasting promote goodness; love, battle, attachment, pleasure seeking, and emotionality enhance vitality. Sleep and idleness increase inertia. In a hierarchy of values, the *sattva* categories reign supreme and

become less material, closer to the idea of *sat* (truth or essence), and often the same as the mind or self. The object of the therapeutic is to transform a person from lower to higher strands or qualities, which is accomplished through the prescription of foods and activities which build goodness. Thus the therapeutic and the ethical become coterminous.

In the Indian view life is not the opposite of death; birth is the opposite of death. Life begins when an embryo is formed out of the union of male and female germinal substances. Defining when human life begins was neither easy nor uniform and straightforward. Some texts maintained that life began with the aforesaid union, and others at the moment of quickening or the descent of the fetus into the pelvis; the latter was more frequently understood as a point of viability. Abnormal pregnancies, congenital deformities, multiple pregnancies, and infertility were explained in terms of defective germinal substances, unnatural coitus, failure in nourishment, or disturbances in humors in the mother or the fetus.

Among the religious obligations, having male progeny was imperative in order to secure a passage to the land of forefathers through the performance of funerary rites. In situations in which a woman failed to have a son, the man was to take another wife, or otherwise adopt a son. If the problem appeared to be male impotence or infertility, the husband's younger brother or another suitable man was to impregnate the wife (a custom called *niyoga*). Early medical texts elaborate on the ways of enhancing conception, and later texts discuss problems of contraception. Mythology also testifies to in vitro fertilization and embryo transfer.

The *Suśrutasamhitā* describes various forms of arrested fetal development or obstructed deliveries and describes ways of inducing labor and/or destroying the fetus, especially in the case of danger to the mother's life. A seventeenth century text also describes ways of inducing labor for purposes of abortion in cases of women in poor health, widows, and women of liberal morals.

In contemporary problems of medical ethics, no problem has caused as much furor as has

amniocentesis. Preference for a male child, with an easily available technology to determine gender prenatally, has resulted in inordinate and indiscriminate use of abortions. Some states in India have enacted laws to restrict the scope of indications and use of amniocentesis.

There are three categories for the etiology of diseases in *Āyurveda*. External or invasive diseases are caused by foreign bodies, injuries, infestations, and possession by evil spirits. Internal diseases are disturbances of humors, in part caused by lapses in discretion, as in faulty or unseasonable diets, overexertion, sloth, sexual indulgence, or mental disturbances. In either case, the final pathway for the pathology of a disease is an imbalance of humors. The third category contains the diseases which are the fruits of karma, the operative principle of Hindu ethics. A very simple explanation might be "every action has a reaction" or "as you sow, so shall you reap," but the logic extends beyond one life. In *karma* theory, when a person dies his self moves to the other world, enveloped in the part material and part ethereal covering which carries the traces of all actions performed, and comes to determine its condition in the next life. Thus some diseases are the fruits of actions from past lives. The unseen hand of *karma* is invoked to explain the not so easily explicable. Events like epidemics and disasters are a result of bad actions of a whole community or the actions of a king.

Mental illnesses also arise from these etiologies: possession states, disturbances in humors, and lapses in discretion. Some disease states are also seen as the workings of time, as in aging.

Physicians in ancient India did consider *karma* in etiology, but they agreed that the passivity that results from assumptions of predetermination made the whole medical enterprise meaningless. Human effort was always a factor in the workings of *karma*, and caring and healing must be actively pursued by the physician. There was also a recognition of incurable diseases, in the face of which human effort was futile. The physician was prudent if he avoided heroic efforts to prevent the inevitable, which not only led to loss of income but also loss of prestige. If the case was hopeless, the physician was to do no more than

attend to the nutrition of the dying patient, and even that might be withdrawn at the request of the family.

A category of “willed death” was also recognized in the various religious traditions and was understood to be different from suicide. Suicide was regarded as an act of desperation and willed death an act of determination. It involved permission of the religious order and was resorted to only when the quality of remaining life was likely to be poor.

The ayurvedic physician, called a *vaidya*, was esteemed for his powers but also shunned because of his contact with impurities such as body products, suppurative lesions, and corpses, and his mingling with common people. Taboos around touching ultimately resulted in palpation falling into disuse.

The physician was enjoined to strive constantly to acquire new knowledge, advance through practical experience, and enter into learned dialogues with practitioners from other places. His education began as an apprentice, with the teacher and pupil choosing each other. A good teacher was free of conceit, greed, and envy, and a student had to be calm, friendly, and without physical defects. Later on the *vaidya* became a subcaste or occupational division, and the profession passed from father to son.

The *Caraksamhitā* contains an extensive list of ethical directives in the form of an oath to be taken by one entering medical practice. Among these were injunctions never to abandon a patient even if that interfered with one’s livelihood, to be modest in dress and conduct, gentle, worthy, and wholesome. A physician must not enter a patient’s house without permission, and be mindful of the peculiar customs of a household. He was to avoid women who belonged to others and maintain confidentiality.

Quacks and charlatans were known by their pretense and arrogance, boastfulness and superficial knowledge. The fate of their patients was worse than death. The *Caraksamhitā* says that one can survive a thunderbolt but not the medicine prescribed by quacks.

Medical ethics was an integral part of ancient Indian medicine. The texts addressed ethical

issues that arose at both ends of life, birth and death. Their approach was pragmatic and flexible, and the purpose of alleviating an illness was always considered in the context of geographic locale, time (the era and the stages of a patient’s life), and the particularities of a person. The physician’s conduct was also to be always above reproach both in his professional and personal conduct.

See Also

- [Caraka](#)
- [Medicine in India: Āyurveda](#)
- [Suśruta](#)

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Medical Ethics in Islam

Azim A. Nanji

The ethical assumptions underlying the practice of ► [medicine in Islam](#) are inspired by two foundational texts: the Qurān, the divine message revealed to the Prophet Muḥammad; and the *Sunnah*, the paradigmatic life of the Prophet Muḥammad which complemented and exemplified the Quranic message. A secondary source of influence resulted from the Muslim conquest and expansion of the seventh to the eleventh centuries, when the cultural and scientific heritage of Antiquity was translated into Arabic and came selectively to be appropriated, refined and developed by Muslims. The integration of this heritage into Muslim civilization led to a new synthesis, not only of the science of medicine but also of the moral values supporting it. Although some of the medical traditions and values of Antiquity were sustained, they were set in Islamic contexts which allied their meaning and purpose to different goals.

The early centuries of Islam also represented a tremendous flowering of intellectual sciences. Muslims were encouraged by their faith and by the *Qurān* to engage actively in the pursuit of knowledge. This impetus translated itself into significant advances in the study of the natural sciences, cosmology, geography, mathematics, history, law, languages, and medicine to name some of the major disciplines. The emergence of Muslim medical ethics has to be situated within this matrix of scientific interest and intellectual commitment.

Muslim views regarding medicine evolved from that of a predominantly Arab cultural setting to that of a diverse and cosmopolitan civilization. The reconstruction in Muslim thought of a prophetic medicine, emphasizing the spiritual dimension and the role of faith in healing, represented an attempt to associate with the Prophet those practices of human life and healing promoted by the rise of a tradition of scientific medicine. The perception of Muslim adherence to prophetic medicine has often been misconstrued as promoting a kind of fatalism, but it would be misleading to extend this interpretation to the whole spectrum of medical ethics and values among Muslims. Prophetic medicine developed alongside professional medicine, which cultivated its own frame of reference for integrating ideas.

Adab is the Arabic term that best describes the pattern of medical ethics and conduct which evolved as a result of the synthesis of the Islamic message and Hellenistic thought. The term represents a set of cultural and moral assumptions articulating the linking of knowledge to appropriate behavior. Ishāq ibn ‘Alī al-Ruhāwī, a ninth-century Christian physician, translated one of the earliest texts dealing with medical ethics into Arabic. His work already reflects the vocabulary of Islam and a heritage of Prophetic religion integrated within a moral framework attributed to Galen and the ancient philosophers. According to al-Ruhāwī, medicine is a divine art granted to humanity by the Creator, whose healing role the physician imitates. Prayer, as the first and last act of the day, is recommended as part of the personal conduct and moral beliefs of physicians.

Within the larger harmony of moral and religious principles is the ethical concept of moderation. Muslim medicine did not accept the body/soul distinction of the Greek tradition but conceived of human beings as entities formed in symmetry and harmony. One of the most illustrious physicians of early Muslim history, Abū Zakariya ► [al-Rāzī](#) (Rhazes) argued for a healthy, moral life based on moderation between excessive indulgence and abstinence and an adherence to a life of knowledge pursued to balance physical, moral, and intellectual needs.

The *Qurān*'s message of social justice, developed into the notion of public welfare and charitable works toward the poor, influenced medical values in ways quite different from that of the Hippocratic tradition. The hospital, founded through royal acts of patronage or endowments, is an Islamic institution traceable to the eighth century. This larger social role, engendered by Islamic values of concern and care for the indigent, represents perhaps one major difference with the practice of Antiquity, where the emphasis lay mostly on the physician's concern and relationship with an individual patient.

The rise of the physicians and the medical ethics that guided the emergent profession in Muslim society cannot be separated from the general tenor of the civilization and the polity that had emerged after the founding and spread of Islam. The moral discussions and intellectual forces that emerged stimulated a concern for how moral and religious perspectives could be reconciled with intellectual modes of inquiry. But professional medicine was only one of several therapeutic systems available. As Sufism, the mystical and spiritual dimension of Islam, grew in influence and became institutionalized through a system of orders, the heads of these organizations came to be regarded as having the power to intercede in moments of crisis, including disease. In time this led to an extensive use of amulets, granting of prayers and recitations from the *Qurān* as aids to healing. Such traditions and practices came to occupy a relatively prominent place beside that of professional medicine during the premodern period, and continue to be influential in many Muslim societies.

Whereas the eighteenth and nineteenth centuries marked a new impulse in medical and ethical thinking in Europe, the events leading to the encounter of modern Western culture and political power with the world of Islam created a different context for the assimilation and practices of modern medicine. Muslims were faced with new tools and methods of healing which called into question all of the normative assumptions that previously had been integrated into their *adab* of medicine. The institutionalization of Western medical practices also resulted in moral

and ethical consequences. Muslim responses reflected all of the ambiguities in the face of the challenge the new authority and its civilization brought. For some, Islam would serve as a moral sanctuary from which to combat secular ways of staving off disease. For others, it led to an acceptance of modernity and provided the impulse to shape it in conformity with the sources and perceptions of their past heritage. The process of change as it affected medical practice and value thus cannot be separated from the larger issues entailed by the colonial encounter and the patterns of medical education and practice, as well as attitudes to disease and healing that came in the wake of Western contact and influence. The measures instituted through European doctors and medicine eventually received acceptance by a new generation of professional physicians and led to the assimilation and emulation of the new practitioners and their values. The duality that resulted caused a failure to ground the new training and knowledge within Muslim theological moral and cultural contexts and separated the "new" physicians from traditional counterparts and their moral world. In many ways, this sense of duality and the effort to recover the center constitute the story of ethical issues facing twentieth and twenty-first century Islam. The most important challenge however remains the formulation of an *adab* that will guide the practice of medicine while remaining engaged with its past ethical underpinning and taking account of the dramatic changes brought about by population growth, poverty, and national policy.

In the field of medicine as in other scientific and technological areas, Muslims are faced with complex choices and newly emerging issues that raise moral dilemmas. There is a greater need to harness resources that advance skills in moral reasoning and enhance sensitivity, and to integrate these into perspectives of medical education, institutional development and the Islamic commitment to ameliorate poverty and disease.

See Also

► [al-Rāzī](#)

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Medical Paintings of Tibet (*Sman thang*)

Zhen Yan

Sman thang is the abridged form in the Tibetan language for Tibetan medical painting, in which *Sman* stands for medicine, while *thang* refers to *thangkha*, a hanging scroll commonly mounted on a piece of silk with vignettes of various backgrounds.

There is no definite conclusion as to exactly when the *Sman thang* appeared in history. However, in so far as the painting art of *thangkha* is concerned, there are some studies written by scholars outside China. The prestigious Italian Tibetologist, G. Tucci, provided very detailed descriptions on these works of art (1949).

Generally, it is claimed that the *thangkha* originated from religious demand, beginning with the painting of Buddhist icons. The paintings, in

addition to the main Buddhist icons, provided contrasts with other items such as clouds in the sky, trees, birds, or beasts; later, landscape painting also appeared. Such primitive religious paintings were owned by lamaseries, and were hung in the Buddhist hall for worship by monks and devotees. Sometimes, the secular population also used them when storytellers were narrating their tales, so as to keep the attention of the audience and strengthen its attraction. Scholars claimed that the modern *thangkha* was systematized and flourished under the auspices of the Sa skya sect of Lamaism from the thirteenth century. This is based on Tucci and Pal's descriptions. The provenance of Tibetan medical *thangkha* might be so early, based on our investigation on the whole series of modern *Sman thang* and the in-depth study of the history of Tibetan medicine as a whole.

In the mid-seventeenth century, during the reign of the fifth Dalai Lama, because of the diversity of various patterns and styles of earlier *Sman thang* painting, there are differences regarding the recognition of Tibetan drugs, therapies, and ► [moxibustion](#) points. The Regent of Dalai Lama made up his mind to rearrange and systematize the existing *Sman thang*. After approval by the Dalai Lama, ► [Sde srid sangs rgyas rgya mtsho](#) used his *Baidurya sngon po*, the most prestigious commentary on the medical canon, *Rgyud bzhi*, as a basis, and painted a new whole series of *Sman thang*. Altogether 60 paintings were completed in the year 1688.

But the Regent was not satisfied, considering there was a need to further expand the series. With the members of the original team, based on some new materials, including the diagnosis and points for moxibustion included in *Sman dpyad zla ba'i rgyal po* of the Tubo Dynasty, drugs newly discovered and applied to different points and vessels for moxibustion and bloodletting in both Northern and Southern Schools, new *Sman thangs* were drawn. Ultimately, in 1703, the total number increased to 79. This might be the mother *Sman thang* series of modern colored *Sman thang* series.

When the fifth Dalai Lama died, 50 of the paintings were used as funeral objects and buried

in the *chod rten* (mausoleum), since they had been viewed as treasures by the ruling class. New versions were duplicated during the reigns of the sixth and seventh Dalai Lamas.

The 13th Dalai Lama (reigned 1895–1933) also treasured the *Sman thang* series, which were reproduced, either individually or in a series, in 1918, 1923, and 1933 separately.

In 1923, the then director of the Sman rtsi khang (now Traditional Tibetan Hospital of Tibet Autonomous Region) painted a new *Sman thang*. Being the 80th in the whole series, this *thangkha* is very unique and different from the others. It is entitled “famous physicians of successive ages.” Altogether 12 physicians are included. On the back of this *thangkha*, the date of printing was given, which was never seen in the previous ones.

The total number of the whole series of *Sman thang* is 80. It deals with the whole picture of Tibetan medicine based on the *Baidurya sngon po*. This includes the history of Tibetan medicine, the physiology, anatomy, pathology, diagnostics especially pulse taking and urinalysis, medical instruments, all clinical aspects, including the causes, manifestations, treatments of all diseases in internal medicine, sensory organs, gynecology, pediatrics, dermatology, Tibetan *materia medica*, recipes, drug forms, all sort of therapies, medical ethics, and macrobiotics.

All paintings in the current series were not painted at the same time, so the paintings in the whole set are not identical in their sizes. Some might be smaller, others bigger, measuring 75.0 – 86.0 × 58.0 – 68.0 cm in size. All the illustrations contain vivid Tibetan characters, architecture, clothes, natural scenes, and folk vignettes. A few special points need to be pointed out here.

First, the reader can learn the wisdom of the ancient Tibetan people and their customs and habits. The paintings contain such elements as national clothing, especially the special hairstyles and decorations with which comparative studies on clothing of ancient and modern periods can be made.

The expression of the Tibetan language throughout the *Sman thang* is unique. As shown

in the second, third, and fourth *thangkhas*, there are special manifestations of a tree, the so-called “base wood,” “allegorical,” “unfolded,” or “wish-fulfilling” tree. Of course, it is hard to say that the trees in these paintings are exactly the base wood; however, it is quite similar to the actual tree (referring to the original paintings, not to the reproductions drawn elsewhere). Through the roots, trunks, branches, leaves, flowers, and fruits of these trees and so on, the physiology, pathology, diagnosis, and treatment of Tibetan medicine are fully laid out. Through this imagery, it is easier to remember the three-factor theory, the seven materials and the three excreta, the etiology and causes of diseases, and the transmission routes, locations of lesions and the rules governing them, the sequelae, classification of diseases and causes of death, all kinds of diagnostic methods, food and drink, daily life, treatment, medication, and topical therapies. In short, by these three base woods, all the contents of Tibetan medicine are included, embodying the wisdom of the Tibetan people.

The application of a measuring system by ancient Tibetan people is, again, a unique one. The unit for anatomical measurement, for example, is *tong shen cun* (homophysical inch), namely, applying the length of certain part of the patient’s own body as a unit for measurement, such as the finger or the fist, the thumb, or the two points between the ends of the radial creases of the second phalanges when the middle finger is flexed.

There are some very interesting paintings. In the painting of embryology, two points must be mentioned. First, the painting shows the development of an embryo beginning from the combining of the father’s semen and mother’s blood. The simple fertilized ovum develops gradually into a complex structure and increases in size and changes its structure gradually. Unlike some ancient embryologists who claimed that an embryo is nothing but a miniature baby that simply increased in size, without any other changes which is the so-called “preformation theory,” popular at the time before being superseded by the scientific embryological theory of the modern age, Tibetan embryology is rather scientific as

compared with the Western theory. Another point is that the painting shows that during the developmental processes of an embryo, there are three stages through which it should pass. These stages are called fish stage, tortoise stage, and pig stage. The ancient Tibetan embryologist might recognize this problem on the basis of the morphology of the embryo. Whatever the condition, this idea is exactly in line with the theory of modern embryology which claims that the human embryo is developed as a miniature of the evolutionary process of the animal kingdom, moving from simple water-borne organisms through the early stages of vertebral animals living in water and then passing on through the birds and mammals, until a human being was finally formed. The description in the painting, therefore, coincides with modern embryology, a very high achievement of Tibetan medicine.

Painting no. 51 is an anatomical illustration. In this painting, there are six illustrations. Among them, four show a sitting position, while the remaining two depict a standing position. The two sitting pictures at the center show an anterior and posterior view. The anterior view shows the internal viscera. The key points are the position and the contour of the heart. Here, the heart is in the shape of a lotus flower bud, with the round end situated in the middle lower part of the chest, while the sharp end is pointing upward, which is based on the description in the *Rgyud bzhi*, saying that "the heart is sitting on the throne like a king." Hence it is sitting solemnly in the middle of the chest with its tip pointing upward.

This goes against the actual structure of the body in which the heart is situated in the left middle part of the chest, with the tip pointing leftward and downward instead of upward. During the reign of the fifth Dalai Lama, Lho brag sten zin nor bu, a physician and painter, through observation of cadavers, found the actual condition of the anatomical structure and produced a drawing to check the errors, declaring that this was "what I witnessed." He also produced drawings of the gallbladder, lungs, stomach, intestine, bladder, kidneys, liver, and *bsam se'u*, all appended at the sides of this *thangkha*.

This painting is the most unique one in the whole series. It is evident that this *Sman thang* was prepared by at least two persons: an anonymous painter for the original painting and Sten zin nor bu for the revised one. This is the only case of its kind in the whole series and is of utmost scientific importance.

During the reign of the fifth Dalai Lama, Tibet was still a society ruled by a unified political-religious system, Lamaism, with Tibetan Buddhism being the highest ruling spiritual discipline, and the Dalai Lama being the secular and religious head. He was in the position as shown in the painting as the King of Tibet sitting in the middle.

To change this situation of supremacy according to the actual conditions, the painter risked being accused of blasphemy. The formal drawing of this *Sman thang* demonstrates, on the one hand, that the fifth Dalai Lama was open-minded enough to tolerate and respect natural science in order to publicize the real situation to the populace, and Sten zin nor bu was brave enough to insist on upholding this scientific spirit and the truth. This explains, at least, that, by then, anatomical science was respected and its dignity and purity was protected.

People now call *Sman thang* the gem of Tibetan medicine; and it is treasured by people all over the world. This whole series of paintings have been now published in atlases or albums in several languages with elaborate commentaries.

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Medical Texts in China

Richard Bertschinger

The texts of Chinese medicine are extremely voluminous. They have a continuous history of more than 2,000 years, of which little is known in the West. Standard works up to AD 1900 number around 190, and if popular writings are included this rises to at least 1,500. There has been great activity since the 1949 establishment of the New China, and a modern dictionary of traditional Chinese medicine written in Shanghai in 1988 refers to over 4,000 individuals and 8,000 works. And yet there are barely a dozen translations of these texts. The whole corpus also includes works on massage, diet therapy, and therapeutic exercise similar to the contemporary popular *Taiji Quan* (Supreme Ultimate Boxing) and *Qi Gong* (Breathing Therapy). These have been largely omitted from the following entry, which describes, in chronological order, the most important texts on medical theory, acupuncture and ► [moxibustion](#), and herbal medicine.

The earliest extant systematic writings, which formed the cornerstone for all ► [medicine in China](#), Japan, Korea, and the Far East, are collected in the large compilation made during the Han dynasty (202 BCE–AD 220), named the ► [Huangdi Neijing](#) (The Yellow Emperor's Inner Canon). Extracting itself from the notion of ancestral curses and demonic attacks as the cause for illness, the reasoned tone of this compilation (and it is only one of many Han classics) laid a foundation for the next 2,000 years of medical writing, and its influence soon spread to Korea, Japan, and beyond.

The basic theory of Chinese medicine, as spoken in the *Huangdi Neijing*, involves the interplay and interfusion of *yin* (quiescent) and *yang* (active) forces, producing both health and disease. This alternation occurs both within the human body, and between the body and the natural world. Chinese medicine pays particular attention to natural rhythms and the *wuxing*, five fundamental elemental associations of

vegetation, fire, soil, minerals, and fluids (wood, fire, earth, metal, and water), both within the natural world and as symbolic agents of change within the body. Illness is seen as a disorder of the *qi* (vital energy), perhaps enhanced by some external factor but primarily involving a deficiency within the individual.

The *Shennong Bencao* (Shennong's Herbal) appeared soon after the *Huangdi Neijing*. It is the earliest surviving materia medica, believed to have been compiled during the first century BCE. In this work 365 kinds of medicinal substances are listed and divided up into three classes: major remedies, medium remedies, and minor remedies.

An almost contemporaneous and equally important text is the ► [Shanghan Lun](#) (Discussion on Cold-Induced Disorders) which was written by Zhang Zhongjing (ca. AD 150–219) at the close of the Han, and which has proven to be one of the most influential texts in Chinese medicine. This was the first to advocate the analysis of medical conditions in accordance with the six channels (*taiyang*, *yangming*, *shaoyang*, *taiyin*, *shaoyin*, and *jueyin*) and eight syndromes (*yin/yang*, outer/inner, hot/cold, and excess/deficient). Along with the *Huangdi Neijing*, it formed a straightforward basis for the development of traditional Chinese medicine. Its companion text is the *Jingui Yaolue Fang Lun* (Concise Prescriptions from the Golden Casket, ca. 220), also by Zhang Zhongjing.

The importance of these two texts, the *Huangdi Neijing* and the *Shanghan Lun*, is that they illustrate the building up of a well worked out and heuristic, classificatory framework, involving the *yin* and *yang*, the five phases, the six channel types, and the eight principle syndromes of diagnosis, into which the results of any doctor's medical observations could be fitted.

The first textbook on acupuncture and moxibustion was the *Zhenjiu Jiayi Jing* (A-Z of Acupuncture and Moxibustion), written by ► [Huangfu Mi](#) some time around AD 280. Much of this text actually repeats verbatim the *Huangdi Neijing*, but it also gives the first systematic description of acupuncture points, each listed according to its position on the body, and

also their function. In addition, the first book on pulse diagnosis, the *Mai Jing* (Pulse Classic, ca. 300), appeared during this period. The author, Wang Shuhe, perfected the art of pulse taking, describing in detail nearly 30 separate categories of pulse. This work, along with Li Shizhen's *Binhu Maixue* (Pulse Studies of Master Binhu), written later during the Ming, formed the core texts for this unique method, which is characteristically Chinese.

It is recorded in the Tang dynasty histories that the Imperial medical colleges based their teachings upon the ► [Huangdi Neijing](#) and Huangfu Mi's *Zhenjiu Jiayi Jing*. Among the books also at their disposal would have been the famous, and charmingly titled *Zhouhou Beiji Fang* (Emergency Remedies to Keep Up One's Sleeve, ca. 340), by the ardent Daoist ► [Ge Hong](#). Ge Hong was also the compiler of the early alchemical and dietetic work *Bao Pu Zi* (The Work of Master Puzi).

Sun Simiao (also called Sun Simo), in 652, published the *Qianjin Yao Fang* (Remedies Worth their Weight in Gold) and its sequel the *Qianjin Yi Fang* (More Remedies Worth their Weight in Gold). These two volumes were extremely diverse, and together they summarized the medical achievements of the Tang, including practices as diverse as incantation, prayer, love philtres, exorcism, dietary restraints, as well as acupuncture and herbal remedies. They also contain the first known charts of the channels and points of the human body, with front, side, and back views. Sun Simiao's work also contains the early *Yinhai Jingwei* (A Detailed Study of the Silver Sea) which describes 81 eye conditions and their treatment, although this work has also been attributed to an author from the Yuan dynasty.

During this period, the earliest official pharmacopoeia ever to be published was sponsored by the Tang government, based upon the work of the earlier Shennong Herbal. The *Tang Xinxiu Bencao* (Tang Newly Compiled Materia Medica) was compiled by Su Jing along with 22 other scholars, and it lists some 844 medical substances.

In AD 1027, at the establishment of the Song dynasty, two bronze statues were cast by edict of

the Emperor, fashioned by a doctor, Wang Weiyi, who incorporated into them all the known acupuncture points. These statues were accompanied by his *Tongren Zhenjiu Shuxue Tu Jing* (Illustrated Canon of Acupuncture Points based upon the Bronze Figures, 1026). This text is still popular and used for point-location in acupuncture colleges throughout the world. Also around this time appeared the earliest work on bone setting, the *Lishang Suduan Mifang* (Secrets of Treating Wounds and Bone-Setting, ca. 946), put together by Lin Daoren. This outlined the use of traction, fixation, reduction, and reunion for fractures and dislocations.

The fixed attitude to traditional knowledge began to subside gradually during this period. With greater political stability and urbanization, medicine became more intensive and specialized. The number of medical publications during the Song exceeded those of all previous ages put together, and it is largely the Song view, and Song editions of texts, which are now extant. The work begun by Lin Yi, with his editing and reprinting between 1068 and 1077, produced the classical editions most in use today. This was also the century which initiated the massive Daoist patrology, the *Dao Zang* (Storehouse of the Dao).

The monumental *Shengji Zonglu* (Imperial Encyclopedia of Medicine), compiled by a board of physicians under the emperor around AD 1111, was composed of 200 volumes. Other specialized works include the small pamphlet the *Yanglao Fengjin Shu* (Looking After the Aged, early eleventh century) by Chen Zhi, on the care and feeding of old people, and the famous monograph on beriberi, the *Jiaoqi Chifa Zongyao* (Every Essential on the Treatment of Beriberi, 1078) by Tong Zhi.

During this time, another influential book was the *Sanyin Jiye Fang Lun* (Discourse on the Three Causes Ultimately for Any One Disease, 1174) by Zhen Yan. In this the cause of disease was seen as belonging to one of three categories: either internal (including emotional disturbances), external (climatic change), or neither (malnutrition, over-feeding, animal or insect bites and stings, wounds, hoarseness through shouting, drowning, etc.). There was also the

gynecological *Furen Da Quan Liang Fang* (Collection of Excellent Prescriptions for Women, AD 1237) by Chen Ziming, consisting of 260 articles in eight divisions, and numerous books on children's illnesses and surgery. One of the earliest was the *Xiaoe Yaozheng Zhijue* (Treatise on Pediatric Pharmaceutics, 1119) by Qian Yi. This small book exerted a profound influence on pediatrics, giving valuable insights into measles, scarlet fever, chickenpox and smallpox, along with innovative methods of diagnosis and treatment. Also, in 1461, the Dr. Gou Bing produced the *Quan You Six Jiao* (Directions for Those Working in Pediatrics), in which indigestion or wrong feeding was held to be the probable cause of most ailments. The first treatise on forensic medicine also was published at this time, the *Xiyuan Jilu* (Instructions to Coroners, 1247), written by Song Zi. This too proved to be a foundation text.

Around this time medical colleges became well organized, and this setting of academic boundaries resulted in differing schools of thought. One considered disease to be caused by excessive heat in the body and advocated cooling medicines; another emphasized the use of purgatives and emetics; another extolled the use of tonics. The most influential book surviving from these debates was probably the *Piwei Lun* (Treatise on the Stomach and Spleen, ca. 1230) by Li Dongyuan, who put all disease down to disorders in life style and the digestive tract. Also notable is the *Rumen Shiqin* (A Literati's Dutiful Care of His Parents) by Zhang Zihe (1156–1228), which advocated the use of sweating, emesis, and purgation.

Arriving at the Ming dynasty (1368–1644) we find scholarship bearing remarkable results. The *Bencao Gangmu* (A Materia Medica Compendium, 1590) by ► [Li Shizhen](#) (1518–1593) is one of the most important works ever produced in China. It was a gigantic text in 52 volumes, listing nearly 2,000 medical substances, including plants, minerals, and animal products, with over 10,000 prescriptions. It detailed the appearance, properties, methods of collection, preparation and function of each substance. This was a truly encyclopedic work commenting on all

branches of natural history, botany, zoology, mineralogy, and metallurgy. Mention should also be made of its forerunner, the *Puji Fang* (Prescriptions for Universal Relief, 1406), produced by Teng Hong, which contained an astonishing 61,000 prescriptions.

Great textbooks on acupuncture also appeared during the Ming. Again these were truly comprehensive, reproducing the best of the old along with reworkings and selections from the new. Most notable are the *Zhenjiu Daquan* (Acupuncture and ► [Moxibustion](#) in its Grand Entirety, 1439) by Xu Feng, the skillfully compiled *Zhenjiu Juying* (Gatherings from Outstanding Acupuncturists, 1537) by Gao Wu, and the last in this tradition, the monumental ► [Zhenjiu Dacheng](#) (Acupuncture and Moxibustion, the Grand Compendium), written by Yang Jizhou in 1601 – a book “still of the highest usefulness today” (Needham, 1980).

Mention should also be made of the reordering of the ► [Huangdi Neijing](#), the *Lei Jing* (Classified Classic) by Zhang Jiebin, which appeared in 1624; with this work, and its illustrated appendices, the summit of *Neijing* scholarship had been reached.

During the later centuries little work of influence appeared. An exception is the *Yizong Jinjian* (Golden Mirror of Medicine, 1749) by Wu Qian. It is mostly made up of extracts, revisions, and corrections of earlier writings. A government decree in 1822 actually eliminated acupuncture from the medical curriculum. And, although China's indigenous medicine survived, it met with disfavor from the established government until, as late as 1929, the Guomindang banned traditional Chinese medicine altogether. However, that same year, Mao Zedong wrote that both Chinese and Western medicines should be used to serve the population, and this has been the prevailing view ever since.

Since the founding of the People's Republic (1949) several medical colleges have been established, combining modern Western and traditional Chinese medicine, and an increasing number of texts have been reedited and published. Many new areas of research have been opened up: acupuncture anesthesia, ear-needling, the discovery of new points; and

the translation of texts has begun. Finally, to appreciate the resilience and accuracy of Chinese medical texts we can compare two extracts.

One is from the first page of the first acupuncture book ever produced for the West (Beijing 1980):

The theory of Yin and Yang holds that every object or phenomenon in the universe consists of two opposite aspects, namely, Yin and Yang, which are at once in conflict and in interdependence; further, that this relation between Yin and Yang is the universal law of the material world, the principle and source of the existence of myriads of things, and the root cause for the flourishing and perishing of things.

The second is from the *Huangdi Neijing* (ca. 100 BCE):

Yin and Yang are the grand method of heaven and earth, the rule and pattern of the ten-thousand things, the father and mother of change and transformation, the fundamental origin of living and killing... (Ch. 5).

The continuously resilient nature of Chinese medical texts could not be more clearly shown.

See Also

- [Huangdi Neijing](#)
- [Li Shizhen](#)
- [Sun Simo](#)
- [Zhang Ji \(Zhang Zhongjing\)](#)

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Medicinal Food Plants

Nina L. Etkin

The connection between diet and health is recognized by all human societies, and for many, healthful eating is a pivotal construct of their medical ideologies. How central a role food plays in disease prevention and therapeutics ranges along a continuum, one pole of which represents such indefinite notions as “healthy foods.” This is a feature of all cuisines, although which particular foods are so regarded varies with both place and time. Toward the other end of the continuum, more specific explanations of the healthful nature of foods are based both on physical characteristics or effects and on abstract qualities.

Among the abstractions that people apply in their assessment of medicinal foods are paradigms of binary opposition such as heating/cooling and wet/dry, representations of intangible qualities that are not related to actual thermal or hydrous states. These are expressions of health conceptualized as a balance between certain key qualities that can be mediated by diet. In China, for example, cooling foods such as carrot and seaweed restore equilibrium in the case of rash, constipation, and other hot disorders. This general kind of food therapy also characterizes the medical traditions of India, Southeast Asia, Latin America, the Near East, parts of Africa, and much

of Europe, although the attributes ascribed to particular foods and diseases vary across, and even within, cultures. In China these binary oppositions intercalate with older traditions that symbolize the more cosmic yin/yang philosophy, take into account the theory of Five Phases (*wuxing*: earth, metal, fire, wood, water), and address the concept of *pu* (strengthening, patching up). These statements oversimplify, but they make the point that the healthful qualities of foods are manifold and are integrated in complex ways into different food cultures.

Regarding the physical characteristics of medicinal foods, the cultural dicta by which people interpret the appearance, taste/smell, or physical effects of foods are as varied as the religious beliefs, languages, marriage customs, etc. that distinguish societies from one another. A common link between food plants and diseases is the taste that defines their curing properties. Consider this complex example. The medical tradition of a Hausa population in northern Nigeria advises that the treatment of measles be aimed at several stages, beginning with efforts to expel disease substance from the body's interior. As soon as the measles spots appear, bitter and astringent foods and medicines are sought to chase out internal sores so that the rash matures. Foods and medicines that occur later in the therapeutic progression are cold and aromatic because the illness likes those qualities. In the event that nausea and fever accompany the rash, acid/sour tastes are indicated, to calm and cool. When there is evidence that all sores have been externalized (that is, when other internal signs such as fever and lymphatic inflammation have subsided), the rash is treated with astringent and emollient medicines, no longer with medicinal foods. In this example, taste features prominently in the selection of medicinal foods.

Among another physical attributes by which people identify foods for medicinal use, color, location, texture, and shape may be evoked as part of a "doctrine of signatures." This fundamental tenet in plant selection maintains that these attributes are signs of a plant's intended use. Some of these associations conform as well to theories of sympathetic magic, which is based on

the idea that like affects like. Thus, for example, in US Colonial and Chinese medical traditions, the shape of walnut kernels suggested their effectiveness as a brain tonic, in Taiwan red foods such as tomato, red crab, and carrot are considered nutritious because red symbolizes prosperity and good fortune; in several Southeast Asian cultures, where red protects against spirits, red eggs are used to ensure fertility; and in Ecuador the red flowers of the amaranth plant are made into a beverage to restore menstrual regularity and purify the blood. That other medical traditions identify plants with red flowers or leaves to fortify blood finds a parallel in the US, some decades ago, when "good red meat" (beef) defined the core of an "all American," healthy cuisine. Similarly, yellow plant foods are designated for such liver disorders as jaundice in which the skin and white of the eye take on a yellowish tone, and plants whose leaves are shaped by several lobes are used in the treatment of lung disorders. These associations are not as simple as outlined here, because although appearance and other physical attributes are presented as the primary distinguishing feature of certain medicinal foods, they are understood to protect or interfere with disease processes in variable and complicated ways that bear on other characteristics that different medical cultures describe through such metaphors as "strength," "neutralization," and the like.

By the same token, foods also have negative health connotations, many of which have been systematically codified as food taboos, the symbolism of which is especially rich. Food prohibitions play a pivotal role in the traditional medicine of Thailand where there are five general taboo units: meats (cow, water buffalo, pig, and chicken; frogs and scaleless fish); seafood; pickled food; and certain vegetables (cucumber, gourd, and jackfruit). Further, specific foods and beverages are prohibited in particular conditions, and specific tastes such as sweet, fat, and sour are additionally proscribed in certain instances – for example, sour is discouraged because it is understood to result in the accumulation of pus, which should be avoided when one is treated for wounds. Similarly, for Hausa in Nigeria, food

plants (e.g., okra, cat's whiskers) that are otherwise appreciated for the gelatinous quality they impart to soup, are avoided when one has congestion from flu, and in the case of certain backaches that are understood to be caused by an accumulation of phlegm within the body. For altogether different associations, Hausa understand that peanuts aggravate leprosy and offset the effect of medicines for anemia.

The cultural and social aspects of medicinal foods are especially apparent in circumstances in which their consumption extends beyond the sick person to include others. Among the Nekematigi of New Guinea, for instance, ceremonial therapeutic meals are shared by the entire community and consist of all purpose medicinal foods – ginger, for example – that are intrinsically healthful regardless of the cause of illness, and specific antidotes against the acts of enemy sorcery that account for most sickness in this society and that always originate from outside the village. If the illness persists, the meal is repeated, again involving the community and thus reaffirming solidarity in the face of malevolence introduced from outside the social body. Conversely, for Nigerian Hausa, whereas healthy foods such as fish and peanuts are shared among family members who eat from the same pot, specific medicinal foods are consumed only by the sick person. In other medical traditions the healer and patient consume the medicinal foods, usually at the same time, both to cement the therapeutic relationship and to empower the healer's empathy toward the patient.

Since people everywhere recognize the relationship between a mother's health and that of her nursing infant, one is not surprised to find, as among Hausa, that when a baby is ill, medicinal foods are also consumed by the mother, and exclusively so if the infant has not yet begun to eat solid foods. And on the Western Pacific island Espiritu Santo (Vanuatu, formerly New Hebrides), food taboos for children who have become ill as a result of malevolent magic are extended to the parents. The general point made here is that the consumption of medicinal foods occurs in a variety of social contexts that range cross-culturally along a continuum of

inclusiveness with respect to patients, their families, and their communities.

The interpretation of these cultural expressions by social and health scientists has largely replicated a central idiom in Western thought – i.e., that food and medicine are separable categories. This is apparent, for example, in studies that inventory medicinal or food plants, overlooking the possibility that plants are not simply one or the other. In this way, whether or not a food is considered healthful depends on its intrinsic nutritional value. For the first half of the twentieth century nutrition scientists concentrated on identifying the nutrients that help the body's immune system fight infectious disease and whose deficiencies result in such discrete disorders as scurvy (vitamin C), rickets and osteomalacia (calcium, vitamin D), and beriberi (thiamin). (This can be related to the Chinese example above through observation that insufficiency of the vitamins found in carrots and other cooling vegetables typically eventuate in skin disorders.)

During the latter 1900s nutritional scientists focused on foods linked to chronic disorders, some revealing negative associations: foods high in salt, sugar, and fat have been implicated in hypertension, diabetes, and cardiovascular disorders, respectively. Conversely, other nutrients have healthful effects on chronic diseases: dietary fiber – such as provided by whole-grain cereals, fruit skins, vegetables, legumes, and nuts – has been linked to diminished risk of colorectal and stomach cancers, high blood pressure, diabetes, high cholesterol, atherosclerosis, and coronary heart disease. Vitamin A – present in yellow and orange fruits and vegetables (carrots, bell pepper) and dark green leafy vegetables (spinach, kale) – has been reported to protect against lung and prostate cancers and to decrease the severity of measles. Vitamin E (found mostly in green leafy vegetables) and C (high in fruit, especially citrus) both have been linked to lower cancer risks as well.

In sum, to date the frame of reference has been the nutritional composition of medicinal foods, and apart from the conventional nutrients – vitamins, minerals, protein – foods have been

regarded as chemically inert, thus of no salience to specific disease processes. But foods are not chemically mundane. Most people are aware of toxins in potentially nutritious foods, so why not drugs? The line between toxin and medicine is in any case an uncertain one – toxic in what dose, and for whom? Many of the toxic “secondary” metabolites produced by plants are a primary defense against fungi and bacteria, microorganisms not unlike the pathogens with which human societies contend. Accordingly, people have taken advantage of these characteristics of plants, in some cases modifying that chemistry through selective breeding and special planting of food plants to exaggerate certain features and to reduce or eliminate others.

In view of this, a more recent development in medicinal food study is to focus on the drug-like qualities of plants. Attention has been paid especially to spices, perhaps because their role in the early history of Western medicine has made this category of plants the more likely subject of pharmacologic inquiry. In a biomedicine so strongly informed by the germ theory of disease, the antimicrobial action of many spices merits attention; and because spices – like pharmaceuticals – are small (in quantity) and powerful (in smell, taste), they fit an allopathic model of healing. Evidence for pharmacologic activity in spices includes: capsaicin in chili pepper diminishes risk of cluster headaches and stomach cancer; sulfides in garlic and onion inhibit blood clotting and promote cardiovascular integrity; West African black pepper has anticonvulsant activity; ginger is effective in the treatment of motion sickness and nausea; cricetine in saffron has antiatherosclerotic activity; vanillin and catechin in vanilla have, respectively, liver protective and anticariogenic actions; and caffeine, theophylline, and theobromine in chocolate elevate mood.

More recently attention has been directed as well to more ordinary foods: sulforaphane in broccoli protects against certain cancers; gamma-amino butyric acid in tomatoes is hypotensive; rhubarb has antibacterial activity; epicatechin gallate from tea leaves lowers serum cholesterol; and pigeon pea is helpful in diminishing the symptoms of sickle cell anemia.

These catalogs offer only an incomplete story of the medicinal potential of food, since much of what is reported is based only on laboratory studies of purified substances and/or on animal studies using healthy subjects. Thus, although some medicine-like action may be confirmed, one cannot be certain that this will indeed be the outcome when the plants are ingested by sick humans. One gains more insight by considering food use in its broadest physiological and cultural contexts, in order to take into account preparation and incidence and quantity of consumption.

In many traditional societies the same plants are used as both food and medicine, their function and preparation depending on how they are identified for a specified context of use. Over the last two decades, anthropologists have been especially adroit in detailing how foods and medicines overlap. This is significant on at least two levels. First we recognize that the use of plants in more than one context extends the range across which people are exposed to active constituents. Second, we begin to appreciate how very complex human-environment interactions are. For the latter it signifies that foods tend to be prepared in ways that diminish the risk of toxicity, especially cooking, thereby allowing the consumption of otherwise potentially dangerous foods in relatively large volume and at regular intervals. The same plants intended for drug use may be prepared differently – neutralizing pharmacologically active constituents only partially or not at all – and are consumed in small quantities, allowing the action of toxin against pathogen or symptom without overwhelming the human host.

Hausa people of northern Nigeria are a case in point that food plants overlap conspicuously with medicines. Ninety-six per cent of the 119 plants that one Hausa village identify as foods number as well among the 374 plants that make up the local pharmacopoeia. Hausa clearly distinguish foods from medicines by parts used, preparation, and, especially, intended outcome (nutritive or preventive/therapeutic). Further, Hausa have much more to say regarding the healthful qualities of a medicine compared to a food. While medicines address specific symptoms, dislodge phlegm, expel spirits, and so on, foods simply

strengthen, fortify blood, or promote growth. Extending overlapping use beyond foods and medicines reveals that all of the 20 plants used cosmetically have medicinal uses, five are foods as well; of the 16 plants used in personal hygiene, all are used as medicines, six are foods, and three are cosmetics. The point, again, is that attention to the different contexts of plant use accounts most fully for the range of people's exposure to the drug-like actions of botanicals.

An interesting question is raised in the rank ordering of use: medicine first or food first? These are not, of course, mutually exclusive positions; pharmacopoeias and cuisines are created in increments, not all at once, so that one pattern or another may apply for a given plant. A sizeable number of plants used today as food were first appreciated for their medicinal qualities. Throughout the Andes and Mesoamerica the ritual and medicinal uses of red amaranth pigments were once more common than the use of these plants as a source of food grain. In the Mediterranean and Near East licorice was domesticated for medicinal use (it has estrogenic and antimicrobial activities), as were a variety of other plants that are used today as flavorings. Soybeans and *Mo-er* (black tree fungus) of Chinese cuisines were first cultivated as medicines. The latter demonstrates the kind of antiplatelet activity that might provide protection against atherosclerosis. In light of the especially uncertain distinction between medicine and food in Asian cultures, other plants also are likely to have been cultivated first as medicine. Drawing attention again to Hausa in Nigeria, a significant number of their wild plant foods have been "identified" first as medicines. This is revealed by the inventory of Hausa medicinal plants, which is considerably more inclusive of local flora than lists of Hausa foods and other useful plants; the list of medicines includes all plants from those other categories, whereas the reverse is not the case. Hausa oral tradition further reinforces the primacy of medicinal use over food use for some plants. This perspective cannot be applied wholesale to all societies, since the cultural and environmental circumstances under which pharmacopoeias and cuisines are created involve different patterns of

need and knowledge about particular plants. But this does challenge a conventional, unidirectional view that people learn about medicines only secondary to their search for food.

A comprehensive perspective on plant use better characterizes the interconnected histories of human food and medicine, and accommodates both nonfood first and food first models to explain the development of botanical knowledge. Thus, whereas it is customary to talk about the "traditional" medicines and foods of a people, region, or religion, in fact therapeutics and diet are dynamic. Transformations in the content and intent of medicines and diet are shaped in part by shifting concerns with health.

Today, in the West, an analogue to medicinal foods exists in the growing popularity of food supplements. This term is apprehended by the consuming public as a range of products that include conventional supplements (e.g., vitamins) and extend as well to a great diversity of plant and animal products. The popularity of these products bears on several interrelated issues – dissatisfaction with biomedicine and the search for holistic and natural medicines; patients' seeking agency in their own health care; and the commodification of health and healing.

Finally, a timely issue relates the topic of medicinal foods to concern with environmental protection. Contemporary debates on the preservation of global biodiversity have focused on plants that development planners and national polities identify to be at risk. This cross cuts other international efforts directed at alleviating or preventing the effects of famines and lesser food shortages. Collectively these programs highlight staple foods in their efforts to assure that "important" and varied foods are available to the world's peoples, or that other "interesting" plants are preserved for their potential contribution to the pharmaceutical industry of the West. Thus, Western scientific paradigms and various economic and political agendas have been instrumental in shaping the direction of environmental protection and restoration efforts. These programs should be credited with the results achieved to date, as well as with their more recent

inclusion of local populations in the planning of sustained efforts. In light of the present discussion of medicinal foods, one might wish to add certain refinements that assure that local cognitive categories and the specific contexts of plant use are given attention, including an examination of what the existing or restored diversity affords in human cultural terms. More specifically, to the extent that the same plants serve dietary and medicinal objectives, their significance to local populations is greater than what development planners might have considered; additional contexts of use elevate the local value of those plants even further.

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Medicine and Colonialism in India

Ranès C. Chakravorty

Ancient India

The Indian subcontinent was well inhabited by the first millennium B.C.E. The inhabited territory extended west into areas that today are in

Pakistan and Afghanistan. These ancient Indians had a well-developed system of medicine termed Āyurveda (The Science of Life). Ayurvedic physicians practiced medicine and to a lesser extent, surgery. The system and its practitioners were held in high regard and Indian physicians are known to have been in the courts of the Muslim rulers. Some of the Ayurvedic texts were translated into Arabic early in the history of Islam.

The basic thrust of Colonialism is to exploit the colonized for the benefit of the colonizers. Usually after a long period of colonization the two groups come to a situation of better parity. Both these phenomena are well illustrated in the colonization of India.

Muslim Invasion

From the early eighth century, India was invaded by the Muslim kings ruling in the west across the Himalayas. Initially these Muslim pockets were small and often short-lived. By the twelfth century, a Muslim kingdom had been established in Delhi, though the ruler(s) recognized their western center outside India as the capital. By the thirteenth century Muslim occupation in India had become permanent, and ultimately the Muslim rulers assimilated into the Indian culture. The Turk, Babur, established his capital in Delhi in 1526, though it was not until his grandson, Akbar (1556–1605) ruled, that the Mughals considered themselves Indians. The Muslims had brought with them the Islamic system of medicine, Unani or Tibbi, based largely on translations of Greek Medicine. However, Āyurveda was also in use, not only in the Hindu population, but also among the Muslims.

With the arrival of the Europeans, European physicians also practiced in India though in small numbers. From the time of Shahjehan, Akbar's grandson, some European physicians are known to have practiced in royal courts. Thus, Niccolo Manucci (1639–1717) was an artilleryman to Shah Jahan's eldest son Dara Shukoh. He later took up the profession of medicine (even though untrained) and practiced both professions (!) in various royal courts. Manucci's memoirs name

some other European physicians practicing in India. François Bernier, a Frenchman with a medical degree from Montpellier, served Dara Shukoh and later his brother, the Mughal emperor Aurangzeb (Majumdar, Chaudhuri, & Chaudhuri, 1994).

European Colonization

Portuguese

From the middle of the sixteenth century, European nations turned their eyes eastward for territorial expansion and trade. The Muslims had established themselves in the Middle East from today's Syria southwards to Egypt and across North Africa to the southern half of Spain. Trade with India and further East had become dangerous and expensive. There was also the need to spread Christianity.

The first to arrive in India was the Portuguese Vasco da Gama who landed at Calicut (now Kozhikhode) in southwest India on 20 May 1498. By 1510 the Portuguese had an established presence in Goa on the west coast. Goa remained a Portuguese possession until 1949 when it joined the Republic of India. In the 450 years of its association with Portugal, Goa became a medical center of sorts. It had the oldest European-style hospital and medical school in the East.

The Royal Hospital was started in 1510 and by about 1546 western medicine was being taught. The Hospital was fully supported by the Portuguese rulers and was a showpiece in its time. The continuing rivalry between the Dutch and the Portuguese, however, caused a decline in Goa's prosperity and the Hospital started to decline by the mid-seventeenth century. In order to have a cadre of assistant physicians, non-Portuguese natives were taught the rudiments of medicine.

Some Portuguese physicians and apothecaries traveled to Goa and some even stayed behind. The most prominent among them was Garcia d'Orta. A converted Jew, Garcia d'Orta was born to Jewish parents who had been expelled from Spain in 1492. They were converted to Catholicism but were always looked down upon. D'Orta studied medicine in Spanish

universities and returned to Portugal in 1523. He then joined the faculty at the medical school in Lisbon. In 1534 he left for Goa with his friend, who was to become the Governor-General of Goa and the Portuguese territories in India.

D'Orta became a very successful practitioner, not only for the rich Portuguese in Goa, but also for the rulers of neighboring Hindu and Muslim kingdoms. (Other Portuguese physicians also became court physicians and many rich Indians came to Goa for treatment.) D'Orta is remembered today for his book *Coloquios dos Simples e Drogas da India* – an Indian materia medica, which was published in 1563, in the first printing press in India. The book gained great renown and was very popular in Europe. D'Orta died in 1568, probably quite poor as the Catholic hierarchy had turned against him. His bones were burnt at an auto-da-fe in the cathedral in Goa some years after his death. D'Orta remains the first author of a western-style medical book from India.

A woman medical doctor, Dona Juliana, came to Goa and later on moved to the court of the Great Mughal Akbar. Nicolau Manucci, mentioned above, came and practiced in Goa for a short while but was then thrown out by the authorities.

Around 1842 a formal medical school, Escola Medico-Cirurgica de Nova Goa was established in Goa. The number of graduates (strictly limited to Christians) from this school was never very high, though many of them went on to achieve professional distinction in Goa, in India and in the Portuguese territories elsewhere (Pandya, 1982). The school was discontinued at the time of Goa's admission to the Republic of India.

Following the Portuguese, the French, the Dutch, and the Danes established trading centers in India. The latter two countries had undistinguished and short stays in India. The French remained in Chandernagore, Pondicherry, Mahe, Yaman, and Karikal, all isolated enclaves until Indian independence in 1947. During this period they had no significant medical establishments either as medical schools or hospitals.

British

Starting with small trading posts in the seventeenth century, the British ultimately occupied

all of the Indian subcontinent and the history of colonial medicine in India is almost exclusively that of the development of medicine during British rule (1857–1947).

Medical practices under the British will be described in two phases. The first was under the East India Company, the next under the British crown as a part of the Empire.

Phase 1: The East India Company

The East India Company was a profit-making body administered by local administrators in India. In theory the Board of Governors in England were responsible for the supervision with some generally minimal oversight by the British Parliament. Under the Company, fortune making and profiteering were rampant and generally tolerated. Only a very few people were ever brought to justice in the courts or impeached in the Parliament. The entire western-style medical setup was for the British, largely the armed forces; the native population depended upon the indigenous medical systems.

Each ship coming to India had a (naval) surgeon on board. (The training and career of a naval surgeon of the times are well detailed in *The Adventures of Roderick Random* (1748) by Tobias Smollett (1721–1778) who was himself a physician trained at the University of Aberdeen.) They sometimes deserted (often without punishment when captured), settled as surgeons to the trading settlements on land and not infrequently fought as soldiers in the many and frequent battles between the British, the French (the Carnatic and Mysore Wars), (The Carnatic and Mysore Wars were fought in the latter half of the eighteenth century by the British against the Marathas, rulers of Mysore, and the French to establish British power in southern India.) and the native Indians.

While a number of the naval surgeons were of great service to the British, two are of special interest, signifying different aspects of the duties of the navy surgeon. William Hamilton of Dalziel in Scotland is hardly remembered today (Fig. 1). However his epitaph (still to be seen in the graveyard of St John's Church in Kolkata, India) states "...his Memory ought to



Medicine and Colonialism in India, Fig. 1 The tombstone and epitaph (in English and Arabic) of William Hamilton in St. John's church, Kolkata, India (Photograph by author)

be dear to this Nation for the Credit he gained ye English in curing FERRUKSEER the present king of Indostan. . . by which he made his own name famous at the court of that great monarch; and without doubt will perpetuate his Memory in Great Britain as well as in all other Nations of Europe." Hamilton was apparently trained as a surgeon and did not have a university degree in medicine. He was attached to the small Company trading post in Calcutta. The Company had been trying to get a *firman* or permit to carry on trading with the local populace under advantageous terms and lowered customs duties. The Company sent a delegation to the Surman Embassy to the court of Farrukhshiyar, the reigning Mughal monarch in Delhi. On arrival at Delhi, the delegation found that Farrukhshiyar was seriously ill with infected lymph nodes

in the groin. He had been treated by the court (native) physicians unsuccessfully. Hamilton treated the emperor (apparently lancing the boils) which resulted in rapid recovery. The emperor also had an anal fistula that Hamilton successfully treated.

The grateful monarch issued a firman in favor of the British, munificently rewarded the young surgeon, and wanted him permanently in his employ. Hamilton died soon thereafter and was buried in the Company cemetery in Fort William, Calcutta (Wilson, 1911).

John Zephania Holwell (1711–1798) was quite a different type of physician. Born to well-established parents (his father was a timber merchant in London) Holwell studied in England and Holland and trained as a surgeon in Guy's Hospital, London. He came to India in 1732 and to Calcutta, which had the most important British factory in India, in 1736.

In 1756 the British settlement in Calcutta was attacked by Siraj-ud-Dowlah, the ruler of Bengal. The Governor left the Fort with all the ladies and most of the men for a safe refuge on the river Ganges. Holwell remained as the governor of the fort, put up a stiff fight, was defeated and captured. He with the 156 other captives was put in a small chamber termed the "Black Hole." Only 23 survived the night (Holwell's description of this event has been seriously criticized. Probably the numbers reported were exaggerated though the confinement did happen. A monument erected by Holwell to recall the event was later removed but can still be seen at the back of St John's Church.)

Holwell became the temporary Governor of Bengal after Robert Clive's return to England and finally returned to England in 1761. He wrote a number of books on his experience, knew a number of languages including Arabic, and was one of the first to study Hindu antiquities.

Phase 2: The British Raj

In 1857, there was a revolt by some of the Indian regiments and Indian rulers against the East India Company. Known variously as the Sepoy Mutiny (by the British) and the First War of Independence (by the Indians) the immediate result of

this conflict (which the British won) was the takeover of the Indian territories by the British Government. The Government sent representatives of the Crown (Governor Generals) to rule over the Indian territories.

Even though the Government was mainly geared to British interests, there was some beginning interchange between the Indians (mainly the Hindus) and the British rulers. Calcutta remained the capital and the seat of government (until 1911) so most of the action occurred there (Arnold, 2000; Bala, 1991).

With the establishment of the Raj, the early British officials were very interested in native customs and learning. In 1776, (Sir) William Jones, a superb linguist, and a Judge of the Calcutta High Court, established the Royal Asiatic Society of Bengal with the support of the Government specifically for oriental studies and research. Both he, Warren Hastings, and other high-ranking officials encouraged the study of the Indian systems, and this helped establish the Calcutta Madrassah for the study of Arabic and Persian and the Sanskrit Colleges of Calcutta and Benares for the study of Arabic (Majumdar, Pusalker, & Majumdar, 1979).

Because of the lack of practitioners trained in Western medicine, the local British physicians would train their assistants for 1 or 2 years and then certify them as being capable of practicing western medicine independently. In order to increase the number of better-trained medical practitioners and the number of assistants to the European physicians, the Government started a Native Medical Institution in 1824 in Calcutta (and later in Bombay) mainly to produce assistants, dressers, etc. Auxiliary Medical sections were also established at the Sanskrit College in Calcutta where Āyurveda was taught together with some western medicine. (A hospital with 30 beds was started for these students in 1830.) At the Calcutta Madrassah, rudiments of western medicine were taught together with Unani or Tibbi – the Arabic medical system. The western system had a therapeutic armamentarium that was possibly inferior to the native systems. Its nosology (classification of diseases) was different but not much better; the main difference was

in the study of human anatomy by dissection and surgery (without anesthesia).

A Bengal Medical Service had been started in 1763 – similar provincial services started in Madras and Bombay. Membership was limited to the British for many years and when Indians started to be admitted to the Indian Medical Service they were usually assistant or subassistant surgeons. Created to serve the needs of the Empire, the IMS had a prime responsibility to the armed forces and military matters; service to civilians was secondary.

Arrangements for the institutionalized treatment of the employees of the East India Company and the soldiers and sailors had existed from the beginning at the three main British centers – Calcutta, Madras, and Bombay. Madras had a hospital since 1664. A hospital for Europeans was started near St John's Church in Calcutta in 1707. In 1768 a General Hospital for other Europeans (including indigents) and visiting European sailors was started in Calcutta. This Presidency General Hospital still exists.

Lord William Bentinck was the Governor-General from 1828 to 1835. He was convinced that education was to be Europeanized. In 1835 the Native Medical Institution and the medical sections of the Sanskrit College and Calcutta Madrassah were abolished. The Bengal Medical College was opened in Calcutta with three British and one Indian faculty (Anon, 1935). The Indian, Madhusudan Gupta had been a student (and later a teacher) of the Vaidyaka Sreni or medical section of the Sanskrit College. A remarkable person in all respects, Gupta initiated cadaver dissection in 1836 (Chakravorty, 1997) (Fig. 2). In 1857, with the establishment of the University of Calcutta, the College changed its name to the Calcutta Medical College. The Madras Medical College also started in 1835. Amongst other achievements, this institution was the first to formally train women in medicine. The Grant Medical College of Bombay was started in 1845.

Women

The first special attention paid to native women by the British physicians followed a law enacted in Britain. From 1805 to 1833 and again from



Medicine and Colonialism in India, Fig. 2 Painting by Madhusudan Gupta by Mrs. Belnos in the Anatomy Department, Medical College, Kolkata, India (Photograph by author)

1868 to 1880, venereally infected prostitutes and soldiers were kept in “lock hospitals.” Christian women missionaries from the west played a large role in looking upon native women's health, although the main object was probably conversion to Christianity (Balfour, 1929). The first was Clara Swain, who in 1869 established the American Methodist Episcopal Mission in Bareilly. Here she also trained Indian women in nursing and midwifery. Many women missionaries came from Great Britain, Canada, and the United States to render service to native women and men.

Ida Scudder, an alumna of Cornell University Medical School, opened a medical college and hospital for women in Vellore, Madras Province. In 1945 the college was opened to men also. Today it is the biggest Christian hospital in the world and one of the best-teaching institutions in the country. India was a haven for women medical graduates from the British Isles. They had

problems in being accepted in Great Britain but had much better opportunities in India.

A specialized case was that of Lady Dufferin's Fund (Lal, 1994). Initiated by the wife of the Viceroy, Lord Dufferin, this organization collected donations to start hospitals for women and train nurses and midwives. Though always short of funds, the Fund played a significant role in women's health care. It also helped establish the Lady Hardinge Medical College for Women in Delhi in 1916.

As in all other countries, women had difficulty in receiving formal education in medicine. Among the first woman physicians of India was the English woman (Dame), Mary Scharlieb who was the wife of a prominent lawyer of Madras. Her husband's family was well known to the Governor and the Superintendent of the General Hospital in Madras. She first took courses in midwifery but later with three other Anglo-Indian ladies was allowed to attend classes and sit for the final Licentiate examination in 1878. Of her colleagues, Dora White became a physician to the Nizam's Government in Hyderabad and D'Abreu (who had come to Madras as she had not obtained admission in Calcutta) became a medical missionary. She later returned to England and became very well known as a physician.

The first Indian woman to graduate was Kadambini (Basu) Ganguli (1861–1923). She was the first woman to get the Bachelor's degree at Calcutta University (together with Bidhumukhi Bose). She obtained her licentiate from Calcutta University in 1886. Later she went to Great Britain and obtained degrees from Glasgow and Edinburgh. She was a very successful practitioner of medicine, obstetrics and gynecology, and surgery.

Anand(a)ibai Joshi of Pune graduated from the Women's Medical College of Pennsylvania in 1886. She returned to practice in India in charge of the Female Ward of the Civil Hospital in Kolhapur, Maharashtra, but died of tuberculosis soon thereafter.

Diseases, Public Health, and Research

India has its own spectrum of diseases, many of which were unknown to westerners. I will discuss only three of the most devastating.

Malaria had been a devastating disease in India and the countries around the Mediterranean for centuries. Because of the lethality of malarial fever, the British Indian authorities had established a Fever Commission (of which Madhusudan Gupta – see above) was a member. Later “Burdwan fever” – a malignant febrile illness, generated a great deal of discussion, without any effective resolution of its nature and treatment. The use of Jesuit's Bark, Cinchona (quinine), was known and in fact had been used by Ayurvedic physicians since 1860. However it was not until Ronald Ross (1857–1932) working in the Presidency General Hospital in Calcutta established the life cycle of the malarial parasite in the mosquito that the disease was finally understood. Born in India and educated in England, Ross joined the Indian Medical Service in 1881. He was awarded the Nobel Prize in 1902. He left India for England in 1901 and died there in 1932.

In 1859, the prevalence of infectious diseases and a high mortality amongst Europeans in India had resulted in the formation of a Royal Sanitary Commission with Dr John Snow (who had written the book *On the Mode of Communication of Cholera* in 1855) as its chairman. In 1863 a Commission was setup to inquire into the Cholera Epidemic of 1861 in Northern India. With Robert Koch's identification of the causative organism in the water of a reservoir in Calcutta in 1884, the possibility of controlling cholera through sanitary measures became practicable. (Koch became a Nobel Laureate in 1905.)

Smallpox had been a devastating disease all across the world for centuries. Variolation – the introduction of live smallpox from a patient to a healthy person by scarification had been used for immunization for centuries. The Indian Medical Service accepted and used this method till the discovery of vaccination (the introduction of cow pox by scarification) by Edward Jenner (1749–1823) in 1796. Both variolation and vaccination were used in India for immunization for a while until the Smallpox Commission in 1850 stated that the latter was superior and safer than the former.

Research

Though Ronald Ross was the physician to get the highest accolades, the members of the Indian Medical Service carried on investigations into common local diseases. In later years some Indians (outside the IMS) also became well known for their research findings. Thus Sir U. N. Brahmachari discovered the cure for Kala-Azar (Leishmaniasis), and Sir K. N. Das was a pioneer obstetrician who wrote a classic text on the discovery, development, and use of the obstetric forceps.

In the 190 years of British occupation of India, the relationship between the colonizer and the colonized had equalized considerably. In 1887, Dr R. G. Kar and colleagues started the Carmichael Medical College as the first non-Government Medical College in the country. Today the R. G. Kar Medical College is one of the prime teaching and research institutions in the country. In the earlier half of the twentieth century, the medical programs in the country were more and more in the hands of the Indians, though postgraduate education abroad, especially in the British Isles was almost mandated for a teaching position and even for successful private practice. Indian physicians today occupy many prestigious chairs outside India, especially in English-speaking countries. This is one of the legacies of colonial medicine in India.

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Medicine and Colonialism in Sri Lanka

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It has been argued that Western medicine introduced by European colonizers and missionaries saved millions of lives in Africa, Asia, and the Americas (Comaroff & Comaroff, 1992). In this context, Western medicine represented a higher civilization and social order that lifted people to modern ways of life. David Livingstone, known for his religious zealotry, chose a medical career to heal the suffering of Africans: “In the glow of love which Christianity inspires, I soon resolved to devote my life to the alleviation of human misery... and therefore set myself to obtain a medical education, in order to be qualified for that enterprise” (Livingstone, 1858; Moffat, 1969). Medical missionaries believed that the eradication of fatal diseases among the indigenous people would encourage the “heathens” to embrace Christianity. Commenting on the effort to establish a public health department in India by the British colonial government in the mid-nineteenth century, Florence Nightingale observed that “it was not only a noble task but also a part of a mission to bring a higher civilization into India” (Cook, 1914). Even though Western medicine was regarded as an integral part of culture,

medical services were rarely extended to the masses without reservations.

Several studies have argued that medicine and medical services in the colonies evolved in response to political and economic needs of Western imperialism. They suggest that medicine played a critical role in the expansion of imperialism in the late nineteenth and early twentieth centuries (Arnold, 1988; Headrick, 1981). Medicine, as it was introduced to non-Western societies by imperial forces, was an instrument of political, economic, and cultural domination. With the expansion of European colonialism in Asia, Africa, and Latin America, the threat of tropical disease became a major obstacle to colonial rule. New medical sciences were developed to deal with diseases such as cholera, malaria, dysentery, and yellow fever for the protection of the European troops and administrators from diseases originating in the indigenous communities (Kavadi, 1999). Radhika Ramasubban, who has done an extensive analysis of the origin and the development of Western medicine in British India, suggests that the main concern of British colonial policy was to protect the health of the British army and the European civilian population living in India. As a result, colonial medical policy in India created medical “enclaves,” leading to the exclusion of local populations. Such policies were justified by the colonial administrators who contended that the Indians were “superstitious and backward” and would not accept modern medicine even if it were offered (Ramasubban, 1988).

In the larger context of colonial rule, medicine and medical services were important political and psychological tools that bolstered the colonial grip over local populations.

1. It became clear that the health of the European personnel, particularly members of the military, could not be protected by measures directed at them alone when there were epidemic diseases among the native populations (Turshen, 1984; Worboys, 1988).
2. The increased trade and political interactions with the colonies led to a heavy traffic of people and materials across the continents.

As a result, the increased vulnerability of Europe itself to epidemic diseases stemming from the tropics became a matter of concern (May, 1958).

3. The supply of raw materials for the industries in Europe and North America was dependent upon the productivity of the colonial labor force. Therefore, to sustain the capitalist economic development in the West, it was necessary to improve the productivity of the people in the colonies (Emmanuel, 1982).
4. The expansion of the market and future investments by the industrialized countries in these colonies were dependent upon the receptiveness of the masses to Western cultural and social values. Hence, the ability of Western medicine to eradicate diseases in these societies would “reduce the cultural autonomy of the agrarian people and make them amenable” to Western values and lifestyles (Brown, 1976).

Against the background of these recent interpretations of the role of medicine in colonial rule, we examine the impact of British colonial economic policies on the health of the colonial labor force in the plantation sector of Sri Lanka (formerly known as Ceylon) as a case study. The laissez-faire policy of the colonial government enabled the British planters to ignore even the most basic sanitary requirements such as latrines on the plantations in order to maximize profit. As a result, the plantations became breeding grounds for many parasitic and infectious diseases found on the island during the late nineteenth and early twentieth centuries. When the International Health Board (hereafter IHB) of the Rockefeller Foundation arrived in Sri Lanka in 1916 to set up a hookworm control campaign, there was an epidemic of hookworm infection on the plantations and the neighboring villages.

Historical Background

The British captured the Kandyan Kingdom of Sri Lanka in 1815, slaughtering thousands of natives and destroying scores of villages (Marshall, 1982\1846). Dr. Henry Marshall,

a senior medical officer of the 89th Regiment that led the war against the Kandyan Kingdom, wrote that “the incursions of our troops into the Kandyan territory. . . were calculated to fill the population with the most unfavorable opinions of our justice and humanity, and to confirm the worst prejudices against the European race.” As Marshall predicted, the bitterness of the war persisted among the Kandyan Sinhalese for a long time. When the British established plantation industries in central Sri Lanka during the mid-nineteenth century, the Kandyans refused to work on the estates. To fill this deficit, laborers were brought from the southern Indian state of Tamil Nadu for the year-round work in the plantation industry. Unlike in other British colonies, such as Mauritius and the West Indies, where the Indian labor had been employed since the early nineteenth century, the colonial government never directly participated in the recruitment of Indian estate labor for Sri Lanka. The authorities maintained that Sri Lanka was close enough to India to leave such recruitment to private economic enterprises (Kodikara, 1965). The estates’ agents, or *Kanganies*, recruited the laborers in India. The number of laborers recruited gradually increased with the expansion of the plantation industries: coffee in the years 1841–1880, tea in the years 1890–1910, and rubber in the first two decades of the twentieth century. By the turn of the century, about 100,000 workers and their families arrived annually in Sri Lanka (Heiser, 1936; Philips, 1955).

According to the contract, the planters provided living and hospital care for the workers (Chattopadhyaya, 1979). The workers lived in barrack-like “lines” that were constructed of temporary materials. Each family was given two small rooms and as many as 12 people lived in an 8 × 10 ft room. One of the unhealthiest aspects of the living conditions on the estates was that the lines were not provided with latrines (Rockefeller Archive Center, 1914b, hereafter RAC). The workers had no choice but to relieve themselves wherever they felt the inclination. As a result, the sanitary conditions on the estates were deplorable (RAC, 1914b). The lack of government regulations over the affairs of the

plantation industry made it easier for the planters to maximize their profit at the expense of the basic needs of their workers. In the extremely poor sanitary conditions on the plantations, immigrant workers and their families faced the threat of a wide range of diseases such as hookworm infection, malaria, smallpox, and cholera, which often became epidemics in many parts of the country. S. V. Balasingham, a Sri Lankan historian, describes the desperate conditions of the immigrant workers as follows: “The spread of epidemics, like cholera and smallpox in certain years in Ceylon has been traced to these immigrants and epidemics of either disease are reported to have carried away large numbers of the immigrants themselves.... There were reports in the Ceylon Times of starvation among these laborers and sale of children owing to the impossibility of maintaining them on the low wages of 6d a day” (Balasingham, 1968; Fig. 1).



Medicine and Colonialism in Sri Lanka, Fig. 1 A typical workers’ line in the Central Province (Courtesy of the Rockefeller Archive Center)



Medicine and Colonialism in Sri Lanka, Fig. 2 An example of latrines in the Dickoya estate. The materials used were jute bagging and jungle sticks. The tea factory

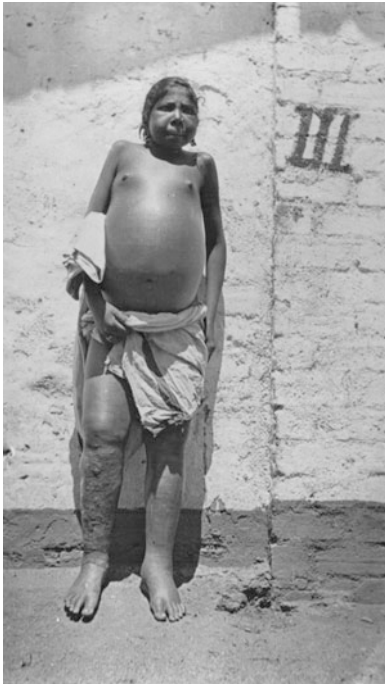
is seen behind the latrines (Courtesy of the Rockefeller Archive Center)

The Prevalence of Hookworm Disease

Hookworms are tiny, slender parasites from one-half to three-quarters of an inch in length. Although parasitic in the bowel, the worm does not gain entrance through the mouth but through the pores of the skin when it comes in contact with polluted soil. The hookworm infection causes undernutrition, anemia, and lassitude. The victims of hookworm infection sometimes die because the worms literally suck away the blood necessary for life. Usually, however, death occurs because – drained of blood – the sufferers are too weak to resist new infections (Cort, 1921; Fig. 2).

The hookworm infection (anchylostomiasis) first appeared in the administration report of the Principal Civil Medical Officer (hereafter PCMO) of Sri Lanka in 1888, when 31 cases were diagnosed at general hospitals in Colombo, Badulla, and Kurunegala (Sri Lanka National Archive, 1888, hereafter SLNA). This number increased rapidly, and by 1899 about 239 deaths from anchylostomiasis had been reported in the island. According to Allan Perry, PCMO, over 80 % of the reported cases were immigrant

workers, and the rest were people living in the neighboring villages of the plantation areas. “The greatest number of cases occurring in the planting districts. . . Yet other provinces show some cases, notably the Northern, which returned 57 cases for the year” (SLNA, 1899). Although the authorities were fully aware of the cause of the spread of the disease, they were reluctant to interfere with the private economic decisions of the planters (SLNA, 1916). Consequently, by 1916 the hookworm infection had reached epidemic proportions; more than 90 % of the population in the plantation districts was infected with the disease. Although the main cause of the spread of disease was the poor sanitary conditions in the plantation areas, the economic interest of the planters took precedence over the health of their workers (RAC, 1914). Even though a large number of the immigrant laborers arriving in Sri Lanka each year seldom lived more than “a couple of monsoons,” the planters were not concerned with the high death toll. According to K. M. de Silva, in the years 1841–1848, about 70,000 (10,000 per year) or 25 % of the immigrant workers died of various causes. These figures, according to de Silva, had been published by *The Colombo*



Medicine and Colonialism in Sri Lanka, Fig. 3 A severely infected woman on Balacaduva estate. She is at the last stage of the disease (Courtesy of the Rockefeller Archive Center)

Observer, a leading newspaper of the day, which argued that the death toll in Sri Lanka was much higher than that of Mauritius, where Indian laborers received relatively better treatment (de Silva, 1965). Particularly, with the proximity of Sri Lanka to South India and the large reserve of cheap labor there, the planters never felt any economic urgency to take the hookworm epidemic seriously. Moreover, the Kanganies who recruited laborers for the estates were always willing to bring as many laborers as the planters required. According to some observers, Kanganies who recruited laborers in India acted as leaders of each gang of up to 100 workers. In addition to their salaries for working as supervisors, the Kanganies received 2 % per day from each laborer's wage under their supervision. Further, they received a bonus when their workers turned up, and therefore they made every attempt to bring as many workers as possible to the plantations (Chattopadhyaya, 1979; Fig. 3).

Philanthropic Medicine

The Rockefeller Foundation initiated the hookworm control campaign in the early 1900s, when the disease was a major health problem in the southern United States (Fosdick, 1952). The public health program was started in the South for the purpose of integrating its agricultural territory into the more stable, industrial economy controlled by the capitalists in the North. John D. Rockefeller Sr. and his close advisors believed that the disease, illiteracy, and unemployment in the South were not only causing political and civil unrest but also contributing to the sluggish economy. By improving the health and education of the whole population, beyond racial boundaries, the Rockefeller Foundation expected to expand its industrial and commercial base in the South (Brown, 1979).

The political and economic interests of the Rockefeller philanthropists were certainly not limited to the United States. They clearly recognized the interrelationship between their own personal economic interests and those of the capitalist class and the global economy in general. Consequently, with the experience of controlling hookworm infection in the South, the International Health Board of the Rockefeller Foundation (hereafter the IHB) willingly extended its capital to other countries, particularly to the British Empire. Frederick T. Gates, who was one of the architects of the Rockefeller philanthropies, wrote to John D. Rockefeller Sr. in 1905 stating that the hookworm control campaign was one of the "special programs that has direct physical and economic benefits, and a means of creating and promoting influences" (Brown, 1976). The concept of health, for the Rockefeller philanthropists, was clearly an economic term embedded in the capitalistic pursuit of global economic and political domination. They had the foresight to understand that disease has no geographical or cultural boundaries. In relation to the hookworm control program in Sri Lanka, Dr. Victor Heiser, the director of the public health program of the IHB in the East, maintained that "disease never stays at home in its natural breeding place of filth, but is ever and again breaking into the precincts of its

more cleanly neighbors. . . . It should also have been evident to employers of colonial labor that human life had a direct monetary value. . . . even though it might vary greatly with age and race” (Heiser, 1936). The Rockefeller philanthropists believed that if health could be achieved in the British colonies, which included the largest share of the global market, Western industrial capitalists could not only expand their trade to those countries but also influence the national political affairs of those nations. In this context, they expected that medicine would help unify and integrate the emerging industrial economies and their social and cultural values with those of less developed agrarian societies and legitimize capitalist activities by diverting attention from structural and other environmental causes of disease (Brown, 1976).

When the IHB began the hookworm control campaign in Sri Lanka in 1916, the United States was already an emerging superpower with an established military presence in the East. Following the Spanish-American war in 1898, the United States was in control of the Philippine Islands (Wolff, 1961). While the US Army Board of Health was responsible for the overall public health activities of the islands, the Rockefeller Sanitary Commission was engaged in some philanthropic work in the field of tropical sanitation. Sri Lanka was a special interest case for the IHB in the East for specific reasons pertaining to the long-term objectives of the Rockefeller Foundation. Wickliffe Rose, the director of the IHB, pointed out that Sri Lanka was a key location in Asia where a successful public health program could attract a great deal of interest in the whole region (RAC, 1915). Among some of the specific reasons that he indicated for the choice of Sri Lanka were:

1. The government offered a favorable administrative framework.
2. The agricultural industry provided an effective economic medium.
3. The island delimited a large, but discrete, area.
4. The geographic location of Sri Lanka in the East might tend to help spread the new knowledge and its benefits (Philips, 1955).

By implementing a hookworm control program for a selected group of people in the country, the IHB expected to achieve high visibility and recognition in the international community. Furthermore, by eradicating hookworm infection among the workers in the plantation industry, the Health Board believed that it could help increase productivity (Brown, 1976). In his speech to the Planters’ Association in Kandy on May 12 1916, Dr. Howard, a project advisor of the hookworm control campaign in Sri Lanka, specifically mentioned the economic benefits of the hookworm campaign. “It is of immense importance to the planters and estate owners since their profit must be dependent upon the efficiency of the labor with which they operate. Further, not only would the efficiency rate of the treated laborers increase by 20–40 %, but also they were less likely to return to India necessitating the importation of others to replace them” (RAC, 1916).

The cultural and political aspects of the location of Sri Lanka were equally important for the Rockefeller Foundation. Sri Lanka, as the center of Theravada Buddhism in the East, was identified as an important cultural “laboratory” for a public health campaign of Western medicine, the success of which could be used by the Rockefeller Foundation as an example to highlight the benefits of Western culture (Jayawardena, 1988).

Organization of the Project

The project was begun in 1916 under the direction of an American doctor, John E. Snodgrass, who reported both to the IHB of the Rockefeller Foundation and to the PCMO of Sri Lanka. All the other subordinate staff working in the project was selected locally. The immediate objectives of the project were outlined as follows:

1. To reduce the cost of annual recruitment of new workers by reducing morbidity and mortality.
2. To cut down hospital expenses by reducing the rate of hospital occupancy.

3. To increase the rate of fertility among female workers and to produce a native-born permanent labor force by treating anemia.
4. To increase daily productivity by reducing the number of sick workers (RAC, 1916).

By the end of 1922, over 600,000 people had been treated. The rate of infection dropped dramatically, and hookworm related deaths in the island declined to their lowest level of 415 per million persons in 12 years. The reduced hospitalization among workers showed the planters the economic benefits of the campaign. Annual reports emphasized the increased productivity and the reduced absenteeism. "There have been indications that the health of many has improved since the treatment. There has been an increased capacity for work" (RAC, 1918). Reports were carefully worded to avoid any misunderstanding that could jeopardize the confidence in Western medicine or the work of the Rockefeller Foundation. For example, in the case of death following treatment, the locally recruited dispensers were accused. "Careless administration of treatment. . . may have caused one or two deaths in the hookworm campaign. There were mistakes and instances of irresponsibility on the part of some of the local staff, but all known emergencies were met by the doctors with an almost perfect record of medical success" (RAC, 1917). American doctors working in the field often interviewed plantation management to get their reaction to the increased productivity as a result of the treatment. One planter reported that "the whole labor force is healthier. . . there has been very little sickness lately and. . . one outcome of the treatment is the pending heavy increase in the birth rate. My coolies on the whole have great faith in the treatment" (RAC, 1918).

The increased productivity immediately after the treatment created a great deal of enthusiasm among planters as well as the Rockefeller field doctors. Almost every communiqué from the field doctors to the IHB officials clearly emphasized the fact that the laborers were healthier and working hard. But this enthusiasm was not translated into fundamental sanitary reforms on the plantations. Although the field doctors insisted

upon the establishment of latrines in workers' lines, it was beyond their power to impose such orders on planters. With the experience of reinfection under poor sanitary conditions in other countries, the field doctors made a number of appeals to the Planters' Association and colonial government for constructing latrines in the workers' lines. They recommended the following steps for permanent control of hookworm infection on the plantation:

1. The construction and improvement of latrines and line compounds in order to meet basic sanitary requirements.
2. The mass treatment of all employed laborers annually until the reinfection declined to a negligible level.
3. The establishment of quarantine camps in South India, where the plantation workers originated, to treat them before leaving for Sri Lanka (RAC, 1925).

The Rockefeller Foundation's hookworm control campaign on the plantation began with the understanding that the planters would take the appropriate measures to improve the sanitary conditions on the estates. However, these preventive measures required some spending which the planters did not want to undertake. As a result, the rate of reinfection continued to increase in the plantation areas. In one district alone (Matale), a year after the workers had been cured, the rate of reinfection was 88 % among a total of 3,000 persons examined (RAC, 1920a). The field doctors reluctantly admitted that the planters were unwilling to improve sanitary conditions, though they were happy to see that the laborers were being treated. In their annual reports, they recommended sanitary reforms as a fundamental requirement for the prevention of the disease. However, these cogent recommendations of the field doctors were not matched by sufficient will on the part of the IHB officials, whose mandate was to negotiate with the government and planters. For political reasons, financial contributions were approved so long as good will continued to prevail between these parties. For instance, in recommending

\$5,000 for a plantation company to provide treatment for their laborers, Dr. Jacocks, a senior representative of the IHB in Sri Lanka, wrote to the New York office, "I asked Dr. Rutherford [PCMO] for his opinion as to whether the granting of such a contribution by the Board at Government's request would help to 'heal the break' [original emphasis] between Government and the planters. He said that he thought it would, as it should be evident to planters that the aid could not have been granted without Government consent. He thought further that a more kindly reciprocal feeling between planters and Government would follow" (RAC, 1920b). Perhaps even in a more crucial ideological sense, presented with the choice of pressing for fundamental sanitary development or continuing medical treatments, the IHB officials consistently authorized the latter, which it favored due to its bias toward curative medicine. Instructing on how to spend the \$5,000 grant, Dr. Jacocks stated, "this sum to be used for post treatment as well as first treatment" (RAC, 1920b). Despite the apparent failure of the hookworm control campaign on the plantations, the IHB felt it had achieved its goal by demonstrating the relationship between the treatment for hookworm disease and increased productivity. Therefore, in 1922, the IHB decided to close its program on the plantations (Hewa, 1995).

While medicine and medical services were developed to overcome the threat of tropical diseases, these medical services were not extended to the people of the colonies until it was realized that the repeated outbreak of epidemics in the colonies would not spare the European troops and administrators. Moreover, the diseases in the colonies eventually found their way to Europe through trade. For example, the spread of cholera from India to Europe between the period of 1816 and the 1880s was a major concern that directly influenced the scientific research of John Snow, Louis Pasteur, and Robert Koch (May, 1958). While the health of the Europeans was always the first priority of colonial policy, the health of the indigenous people, as long as it did not threaten the economic and political interests of the empire, was ignored. Indian labor was exploited

extensively for the expansion of the empire in Asia, Africa, and the Pacific in the same manner as African slavery was used to build the colonial economy in America and the Caribbean.

As shown, the hookworm epidemic in Sri Lanka was the result of a colonial labor policy which compromised the basic sanitary requirements of the workers for the purpose of maximizing profit. Although there was nothing inherently evil in the medical services provided by the IHB in Sri Lanka or anywhere else for that matter, the predominant interests of the IHB – as epitomized by its partiality for curative medicine – effectively precluded the success of their campaign to cure disease at their source. This curative bias of the IHB official changed over time as they continued to work in Sri Lanka. This was evident in the subsequent Health Unit Program (Hewa, 2005) begun in the late 1920s that became the foundation of the primary care system developed in the last 75 years in Sri Lanka.

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Medicine in Africa

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Health and healing practices in sub-Saharan Africa have evolved over three millennia in constant interchange with those of other world regions. The medicine of Ancient Egypt shaped ideas of the civilizations around it, including the

medicine of classical Greek and Roman Antiquity. This complex in turn spread to African regions, through the influence of Islamic Medicine. Another dimension of Islam, “prophetic medicine,” brought notions of health and healing to Africa from Persia and Arabia (The term “Islamic medicine” encompasses the traditions of medical theory, practice and literature that have been developed in Islamic cultural contexts and expressed most commonly in the languages of Islam, principally Arabic, Persian, Turkish, and Urdu. There are two medical traditions that developed in Islamic contexts. One ultimately derives its authority, and many of its theoretical and practical components, from ancient Greek and Hellenist sources, called in this essay Islamic medicine; the other encompasses traditions associated with the Prophet Muhammad, or prophetic medicine). Christian faith healing, which spread first with early Christianity across North Africa and Ethiopia, later was part of European colonial expansion to sub-Saharan Africa. Post-Enlightenment scientific medicine, building upon ancient medicine, brought its ideas of public health and curative medicine. All these perspectives coexist in the early twenty-first century with African perspectives on health, sickness, and healing.

What then is African healing and medicine? Africa is of course a vast continent with a multitude of societies of great diversity, and we admit a certain hubris with the very idea of generalizing about it. We will focus our attention on the ethnolinguistic group known as Niger-Congo, within which we have ourselves had most of our experience (For Janzen, Central Africa (specifically, the Western southern savanna and Kongo coastal regions, the Great Lakes region, coastal Tanzania), and Southern Africa (Swaziland and Capetown); for Green, Swaziland, Mozambique, Southern Africa, East and West Africa). This group of societies is geographically widespread and numerically large, covering sub-Saharan Africa from the Wolof of Senegal to the Swahili of coastal East Africa, and down to Southern Africa. The Niger-Congo grouping relates the Bantu-speaking peoples of the Congo basin and southeastern Africa

historically and culturally to the dense population of West Africa. All of these societies share, in addition to historically related languages, “attitudes about God, religion, kinship, the nature of the world, and life” (Murphy, 1972, p. 179), and within them, health-related practices and beliefs.

Tools and Perspectives for the Historical Study of Changing Healing Traditions

Ecologically distinctive zones of the rainforest, savanna, and desert have shaped both health and adaptive responses by human communities. The modes of living – hunting and gathering, cultivation, herding, and then urban societies – also shaped the underlying determinants of health.

Hunters and gatherers, for example, such as the remaining Khoisan speakers of Southern Africa in the early twentieth century, practiced infanticide for population control and birth spacing of up to 4 years between children. They also picked up camp whenever diseases broke out, in order to reduce deaths in the settlement. Given their small population concentrations, contagious diseases did not have a chance to take hold and become endemic. The health of the band was promoted through spirit healing ceremonies led by leading healer-singers (Katz, 1982; Katz, Bieseke, & St Denis, 1997).

Both the West African and the Bantu-speaking civilizations, defined primarily by sedentary agriculture, have also been cattle herders and pastoral nomads throughout their histories. Where the tsetse fly has been absent – as across the Sahel, the eastern Sudan, in the lake region of East-Central Africa, and into moderate Southern Africa – pastoralism has brought with it a distinctive set of ideas about health, sickness, and medicine.

As livestock herding spread southward about six millennia ago, it skirted the rainforest area. This created at the center of the African continent a vast population without domestic large animals. As a result, this population is unable to digest animal milk – a condition known as lactose intolerance. The boundary between pastoralist and nonpastoralist societies has historically been

that between rainforest and wet savanna on the one hand and the dry savanna and the desert on the other. On the one hand, the pastoralists have had to manage their herds, concentrating on good breeding, learning the politics of being good neighbors (or superior raiders) on their annual transhumance treks to find seasonal pasture, and understanding the danger zones of the tsetse fly's habitat. On the other hand, the cultivators without large livestock have had to emphasize crop fertility, soil fallowing, irrigation and water management, and the importance of rainfall.

In West Africa, the domestication of plants and animals in sedentary settlements was well underway by 4000 BCE. Urban centers and stratified societies emerged in the West African and the Sudanic savanna by the early centuries of the first millennium AD, and trade routes linked West Africa with the Mediterranean and Europe. By the early second millennium AD the influences of Islam and Arabia were felt in the savanna, but pre-Islamic healing rituals or therapeutic practices were not fully supplanted.

The spread of food cultivation and sedentary social modes southward through and around the equatorial rainforest has come to be associated with the spread of the Bantu, Cushitic, and Nilotic cultures and languages. Perhaps as early as 1000 BCE the Bantu languages had begun to spread from the region that is now Cameroon and Nigeria. These languages ultimately came to be spoken throughout the whole of Central, Eastern, and Southern Africa, facilitating exchange of ideas and practices, including those related to healing. Food production and iron working spread rapidly through this area during the first millennium AD. The sedentarization of community life in sub-Saharan Africa and the domestication of food plants and livestock provided a moving threshold that also affected health and healing. With the transition to cultivation and larger, sedentary communities, new diseases appeared. There was sleeping sickness (endemic in the rainforests, a major threat to pastoralists), malaria (endemic in rainy forested areas), and smallpox (endemic once population concentrations emerged). Together with widespread environmental risks such as poisonous vipers, these

diseases offer examples of health threats that encouraged the creation of "medicines" directed at them. They also show the vocabulary of health-related terms and concepts in a common linguistic and cultural background.

Language history – along with archeology and the study of the distribution of cultural practices including uses of plants, animals, and other natural substances – offers one of the most promising avenues for the study of the history of African medicine and health related practices (Ehret, 1998; Janzen, 1992; Schoenbrun, 1998; Vansina, 1990). Analysis of the words and their meanings and uses by language family permits the determination of which concepts, practices, terms, and phrases are part of the institutional infrastructure of these varied adaptations. Language analysis assists in determining which are inventions along the way, and which are borrowed from elsewhere. Language history also allows the reasonable dating of the origin and spread of specialized institutions, practitioners, techniques, concepts and ideas, and materia medica (One of the best methods for reaching back through contemporary and recent African experience to find the faint images of ancient thought and practice is to follow the widespread vocabulary having to do with health, the nature of disease, and the ideas and techniques of healing. Sub-Saharan healing is not codified in written texts, but it is transmitted through rich oral instructions from generation to generation. These texts and their vocabulary are as persistent and more durable – in the tropics – than papyrus or parchment. Historical linguistics is based on the premise that core vocabulary in language remains relatively constant and can be traced by comparing languages with a historical affinity. Core vocabulary shows both lexical and phonetic change at a rate of about 20 % per millennium. Thus, if two languages are shown to have a 60 % common core vocabulary and related phonetic structure, they are about 2,000 year apart in their history. Newer techniques, ideas and related terms will show a different distribution, whose origins can sometimes be traced by examining the distribution and the phonetic transformations they have undergone. Phonetic changes occur in certain directions

within the basic human sound-making potential. This “historical linguistic” methodology permits scholars to study concepts at a depth of up to 5,000 year).

The common vocabulary of the Bantu expansion from about 1500 BCE includes terms for suffering (*-duaad-), healer (*-ganga-), medicinal plant (*-ti-), the power of words and will to affect health in social relationships (*-dog-), and song-dance ceremonies of trance and healing (*-goma-) are found throughout Equatorial, Central, East and Southern Africa (Janzen, 1992; Vansina, 1990) (A term headed by an asterisk (e.g., *-ganga-) indicates that it is a widespread cognate in either the proto-Bantu or proto-regional reconstructed core of verbal concepts). Such a constellation also characterizes medicine on the Guinea coast and West Africa. As this cultural complex moved eastward to the Great Lakes region, the basic term for healer became bifurcated and the root term for “big man” or chief (*-kumu-) came to be applied to diviner (*-mufuumu-), suggesting the importance of the diviner in social control (Schoenbrun, 1998).

Profound transformations were brought to African medicine by the mercantile trade of the sixteenth to the nineteenth centuries, and then by nineteenth and twentieth century European colonialism. Foreign trade, technology, ideologies, and social forms were often imposed by force. New ideas about health were part of this colonialism, ideas that discredited African medical systems. Missionaries and colonial regimes came to evangelize Africa. Just as Islamic crusaders had attacked “pagan” African forms of healing and religion, so Western Christian missions discredited the basis of knowledge as the overall approach to ritual healing. At a time when early positivist science was analyzing the causes of contagious diseases and public health campaigns were being waged to make Africa safe for “progress,” assumptions that social dynamics could cause sickness were dismissed as witchcraft. Since they had cures for diseases such as yaws, leprosy, and later malaria and dysentery, Christian missions and their hospitals contributed to the conversions of many Africans. Although Christianity gained widespread following in

sub-Saharan Africa, many of the marks of the African worldview of misfortune have been reincorporated or persisted quietly in private. In the postcolonial era – generally from 1960 on – the process continues of sorting out what indeed were precolonial health codes and realities and evaluating what in them is of importance and might be endorsed, revived, and further developed.

The latest economic and health crises lent an immediacy to these debates. African traditional medicine continues to be widespread, as biomedicine is expensive and often locally unavailable. The epidemic crisis of HIV/AIDS has revived the question of whether the African pharmacopoeia has something to offer. Such pressing issues have again raised questions about the fundamental character of African medicine and its ideas of health.

Interpreting Practical Applications of *Materia Medica*

Examples of pragmatic and empirical solutions to health threats include diagnoses and interventions for bone-setting, midwifery, and a host of specific interventions for such ailments as fever, rheumatism, intestinal disorders, parasites, lactation deficiency, earache, toothache, headache, epilepsy, menstrual disorders, and more. Most of the African pharmacopoeia under discussion here is derived from plants, but medicines from animal parts, sea shells, coral, soils and other substances of natural origin may also be used. Medicine may be drunk as herbal decoctions, or they may be ingested through inhalation, vaccination (dermal incisions), enemas, vaginal infusions, massage, bathing, or fumigation, in forms that include powders, porridges, soups, ointments, smoke, fumes, or eye drops (Bibeau et al., 1980).

These medications variously reflect the desert, savanna and rainforest ecologies and pastoral and farming ways of life. Following are two examples of pastoral knowledge of sleeping sickness and its vector the tsetse fly. The early nineteenth century Nguni king Mzila, as he was expanding his

territory in South-eastern Africa, concentrated his people in large settlements and had them garden close-in territories; then he sent his hunters out to kill all large wildlife in the savanna forests at a greater distance before allowing his herdsmen to take the cattle into those areas (Swynnerton, in Ford, 1979). The Turkana pastoral nomads of northern Kenya are well aware of the dangers posed by the sleeping sickness bearing tsetse fly to their cattle and themselves during the rainy season, especially in the lush grasses near streams. Therefore they send out young herders with the least valuable animals to graze in those sites to establish their safety from the tsetse before bringing in fertile cows. (Gray, 1997, based on fieldwork with the Turkana in Kenya).

Malaria is an endemic disease over much of Africa. It is usually that variety of malaria for which the *Anopheles* mosquito serves as vector. It became a problem for West and Equatorial African cultivators at the time they settled into sedentary communities and began to clear forests for crops. A genetic adaptation to the high death rates occurred soon after, in the form of the blood cell sickling that in its heterozygous form created immunity to malaria (although proving lethal in its homozygous form). Clearly no one was aware of the genetic structure of this adaptation to malaria. However, settlers preferred to build villages and towns on breezy hillsides rather than in the quiet thickets. Thus, before quinine and the late nineteenth century association of mosquitoes with malaria, breezy hilltops were the preferred settlement site, provided they were near sources of good water.

Smallpox too has been a scourge in sub-Saharan Africa since the advent of cultivation and large concentrations of people (Dawson, 1992, p. 90). The central placement of Ipoona, the god of smallpox, in the pantheon of Yoruba (and other West African) societies, suggests that it has a history of millennia rather than centuries. In addition to the sacrifices made to the angry god Ipoona, who could kill, a pattern of actions during smallpox epidemics suggests pragmatic public health consciousness as well. Examples include the separate burial of victims, the abstinence from

mourning in close proximity to the victims, and quarantining infected households or settlements. Most intriguingly, they refer to attempts to immunize those not yet infected by taking pus from the poxes of infected individuals and introducing it into scratches in their skin (See Green, 1999, pp. 69–70 for such evidence in southern Africa).

Immunization as seen in the case of smallpox may be part of a broader principle of confronting the evil of disease or threat. Several kinds of poisonous vipers have posed a serious problem in the lands of the Nyamwezi and Sukuma peoples of Western Tanzania. Organizations of snake handling experts actively promote the encounter with these poisonous vipers and other snakes through public dance performances in which they demonstrate that they can come to terms with the threat. The demonstration includes allowing the otherwise venomous snakes to bite them. However, the snake handlers have been inoculated with small doses of venom that they have milked from the vipers. This understanding of immunization is mainly available to those who have been appropriately initiated to the Snake Handling Order. These examples of immunization to smallpox and snake venom are part of the much wider notion of the need to incorporate or confront the threat in order to overcome it.

Curative plants are central to African medicine. Two examples illustrate the ways in which specific problems were, and are, approached with the curative powers of plants and techniques. Mirau, a herbalist of the Meru people studied by Finnish ethnographer Harjula (1980) who records many of the healer's herbal treatments as one-disease, one-plant related, practices a widespread treatment for intestinal microorganisms. Although this conveys a somewhat simplistic picture of African herbalism, it does permit a clear examination of Mirau's work from the outside. One of Mirau's 200 single-plant treatments is for children's diarrhea, a serious problem in many regions of the continent where infant mortality often reaches more than 100 per 1,000 births. Using the plant known locally as *mamiso* (*Bidens pilosa* L.), Mirau takes 15–20 flowers and boils them to obtain one dose, which is given twice daily as oral medicine. According to Watt

and Breyer-Brandwijk's (1962) massive compilation of East and Southern African medicinal and poisonous plants, this plant carries antibacterial substances against microorganisms, including five enteric pathogens. The same plant is reported in use against dysentery and colic in other regions of East and Southern Africa.

In another well-documented study from the national Zairian Research Institute (Bibeau et al., 1980), the work of six healers in Kinshasa was examined for effectiveness in 22 diabetes cases. Independent examination of blood sugar levels revealed an average glycine rate of 500 mg/108 ml of blood. After treatment, which lasted a week or longer, 17 of the cases experienced a decline of glycine levels to an average of 100 mg/108 ml of blood. Although a surprisingly large diversity of plants was used in preparation of the oral medications, several plants stand out for their repetition from healer to healer, including *Crossopteryx febrifuga* (Rubiaceae), *Nauclea latifolia* (Rubiaceae), *Anchonames difformis* (Arceae), and *Bridelia feruginea* (Euphorbiaceae), the latter of which is used in Ghana for diabetes therapy. Some of the Kinshasa treatments were accompanied by dietary proscriptions for salt, ripe mangoes, pepper, beer, manioc, and mushrooms.

Thus far these treatments have appeared to be of the empirical type that scientifically oriented Westerners would recognize. However, in classical African medical thought the added dimensions that Westerners might call "symbolic" or "social" are added without a conceptual break. In the next two examples of treatment with materia medica the fusion of the natural and the human dimension is evident; they deal with two types of bodily swelling.

Mama Mankomba of Mbemba village in the Luozi region of Lower Zaire was well known for her treatment for bodily swelling. She distinguished between two types of swelling, the first thought to be due to heart congestion, the second to poisoning, the result of anger growing out of animosity. Simple swelling was dealt with by an initial emetic from the drops of sap of the finger cactus (*diza kia nlembo*, *Euphorbia tirucalli* L.) with a soapy base to keep the poison from

harming the body. This was followed by a potion made from the roots of six savanna plants taken three times daily (*Nlolo*, *Annona arenaria* Thonn, *Annonaceae*; *Mumpala-mbaki*, *Crossopteryx febrifuga* (Afz. ex G. Don) Benth. = Rubiaceae; *Nkizu*, *Syzygium guineense* (Willd.) DC. = Myrtaceae; *Votila*, *Psorospermum febrifugum* Spachh. = Guteriferaceae; *Luvete*, *Hymenocardia acida* Tul. = Euphorbiaceae; *Kinsangula*, *Maprounea africana* Muell. Arg. = Euphorbiaceae). Dietary restrictions against sugar, salt, and pepper were also imposed. Poisoning cases received the same initial purge, but were followed by a second purge of the bark scrapings of only the kinsangula plant with salt and palm oil to provoke diarrhea and vomiting. Although Mama Mankomba treated the physical manifestations of anger illness, she refused to become involved with the deeper causes of anger which required conflict resolution and judicial action (Janzen, 1978).

The use of multiple plants and techniques not only introduces a degree of complexity from the botanical and chemotherapeutic compound involved, but also adds to these symbolic classifications, names, songs, and other ritual connotations and devices, and above all, the human dimension in health and disease. Studies of plant uses in circumstances where both chemotherapeutic and consciously exercised symbolic principles and human issues are at work need to be examined further (Figs. 1 and 2).

Divination: Differentiating What "Just Happens" from "Agency-Caused" Misfortune

As important as practical medicines is the pervasive concern that Kongo therapy managers spoke of as "something else going on" (Janzen, 1978). There is a shift from pragmatic to ritualized therapy that occurs because the misfortune or affliction is perceived to be fraught with anxiety and fear of pollution by both human and superhuman conflict (Janzen & Prins, 1981). This shift amounts to a purposeful amplification in practical care with affective symbols referring to the



Medicine in Africa, Fig. 1 Kongo healer-herbalist Kitembo of Balari commune in North Manianga stands in a forest clearing with a handful of leaves collected from wild plants, as is most of his pharmacopoeia. However, other Kongo healer-herbalists tend botanical gardens for their most frequently used herbaria (Photo by Janzen)

human dimension, to spirits, and to efforts to manipulate them. Usually only consecrated persons are considered capable of handling such powerful therapies as the purification of polluted persons and settings, making sacrifices to ancestors or neutralizing menacing spirits.

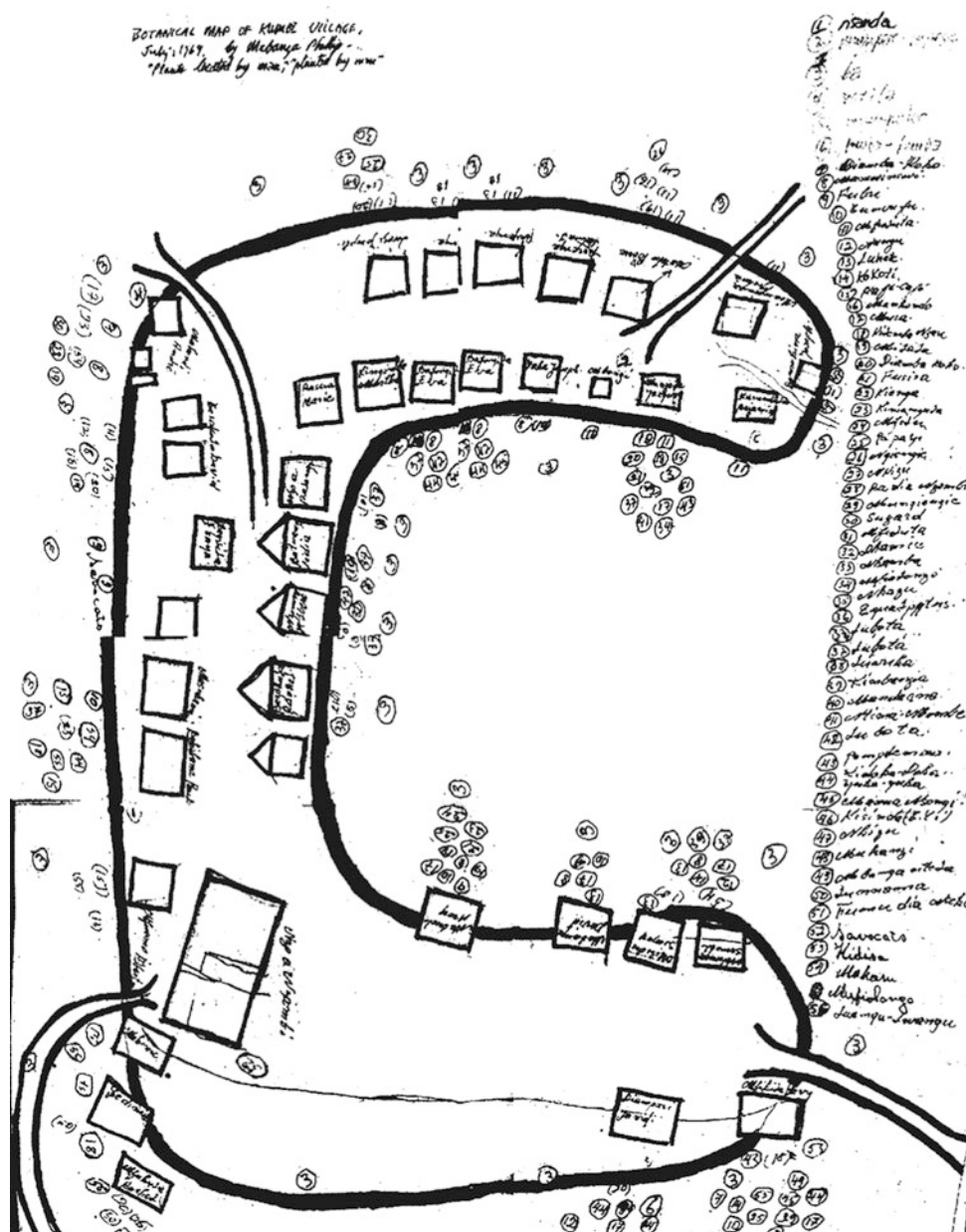
The pervasiveness of divination in treating African sickness and misfortune attests to the importance of causation, especially the suspected shift in cause from a mundane to a highly charged cause in the human or spirit realm. Usually consultation with a diviner is not undertaken until there is sufficient reason in the kin group of the sufferer to suspect causes other than natural ones. Such a precipitating factor may be the worsening turn of a sick person, a sudden and mysterious

death, the coincidence of a sickness with a conflict in the close social environment of the sufferer, or the paradoxical occurrence of a disease on only one side of a family. In such cases the clients are looking for answers to questions not only of “Why did it happen?” but “Why did it happen to us?” and possibly “Who caused it?” and “What should we do about it?”

Scientific explanations of health may not necessarily lay to rest these questions, which are of a different order from the ideas in natural causation. A community may know very well that the spirochete transmitted by the bite of an anopheles mosquito causes malaria in the blood of a human. But the diviner may shed light on the question of why some people are infected and not others, or why some died when all were infected. Divination may also clarify the human causes behind accidents or provide a pattern with which to explain them. Western medicine is often good at answering “why?” but not “why me?”

In the broad West Africa belt from Central Nigeria to Ghana, the prevailing mode of divination is known as Ifa. A cup bearing a set of usually 16 cowries or pods is thrown out into a tray. The combination of “ups” and “downs” is coded to indicate a set of verses, numbering in the thousands, which illuminate the life situation involved in the affair before the diviner. The tray or the cup usually bears the image of Eshu Elegba, the trickster, who is believed somehow to hold in his hands individuals’ and families’ fortunes. At least he attempts ceaselessly to surprise humans with contradictory and unintended turns of events, often for the worse. Thus he and his character of trickery, deceit, and surprise embody the essence of what divination seeks to illuminate (Pemberton, in Pelton, 1980, p. 136).

On the Southern Savanna, from the Atlantic coast southeastward to the Copper Belt, the Ngombo basket mode of divination is common. Its thorough integration into the societies suggests that the genre may be a thousand years old. Carved figurines and natural objects, representing human situations and predicaments, lie together in the basket. As the basket is shaken, one of the objects emerges at the basket’s rim between two lumps of clay, one red, and the other



Medicine in Africa, Fig. 2 A 1969 botanical survey map by Mabanza Philip of "plants planted by man" in Kumba village in North Manianga, Lower Congo, Democratic Republic of Congo. The map shows 56 varieties of shrubs and trees for food, medicinal, ritual, and other purposes. The *ba*, oil palm (3) part of the ancient West African domestic plant set, is used for cooking oil, palm wine, and raffia fiber. Others, such as *pai-pai* (25) and avocado (52) are much cherished edible plants. *Kienga* (22) and *lubota* (42) are potent medicinal plants; *lemba-lemba* (6) is a sedative and a symbolic plant of the

entrances; *mpese-mpese*, a poplar, used to outline chief's courtyards, here marks the men's lodge. *Kidiza* (53) is a cactus whose poisonous sap is used to catch fish and for emetics. The *nsanda* fig tree (*Ficus bubu*, sp. = *Moraceae*) (1), a harbinger of water, thus of a good village site, is said to be the first planted to determine the quality of the site. A botanical map such as this reveals the 2,000-year history of plant domestication and agriculture, just as the illustration of healer Kitembo with wild plants in his hand suggests the continuing history of foraging. Both modes of making a living are joined in Kongo culture and medicine



Medicine in Africa, Fig. 3 Divination by means of throwing “bones” in Swaziland (Photo by Green)

white. This “gateway” of white and red suggests the liminality of the threshold between the visible and the invisible spirit world. The diviner reads the case before him in the light of the emergent object or the constellation of objects in the basket (Turner, 1975, pp. 315–316).

In Southern Africa a common mode of divination is a bag of animal bones and perhaps sea-shells (brought or traded from coastal areas) which are shaken out and thrown onto a mat before the diviner and the client (Fig. 3). The bones, whose constellation represents issues in human life, relationships, and the world of spirits, may be combined with trances to indicate a complex hierarchy of causation behind the surface realities of a misfortune.

These and many other types of divination in sub-Saharan Africa are predicated on the assumption that sickness or other misfortunes may be caused by an untoward turn of events in the

human or related spirit world. The immediate cause or agent such as the sign or symptom of disease is thought to require interpretation in the light of ultimate natural, human or spirit agents. Thus, despite widespread acceptance of modern science, divination continues to be a common method for discerning the dividing line between that which “just happens” and the human or mystical factor that is seen as important in the pattern of misfortune.

Science or Magic? A History of Scholarly Debates About Etiology in African Medicine

Anthropologists and other scholars have debated the nature of African medicine and thought ever since David Livingstone published his debate with an Mbundu rain maker (Janzen, 1978, pp. 38–40), designed to show that the latter, although rational, was arguing with false premises. All participants in the anthropological debates accept empirically effective medicines, as mentioned earlier. The debate focuses on the nature of the other logic – the human and spirit logic – and the relationship between these and the empirical or “natural” realm of causes and cures. The arguments range along a spectrum from prioritizing the empirical treatments to charging that witchcraft overrules other causalities in African medical thought. A range of terms has been put forward to identify the several logics that work together in African healing thought, as for example naturalistic, personalistic, God-caused, or human-caused.

Many scholars of African medicine today would not be likely to use Foster’s global distinction between “personalistic” and “naturalistic” treatments (1976, p. 775), because it just does not fit well. Illnesses that “just happen” – we would say naturally – are attributed to God, a personalistic force. Nor would this dichotomy very readily do justice to impersonal ideas of pollution brought about by exposure to the dead, to certain diseases, and brushing one’s feet against polluting substances. Similarly, few would accept Murdock’s global survey of theories of illness, in which African societies, based

on the survey's reading of available ethnographies, demonstrated a prevalence of supernatural (including fate, ominous sensations, contagion, mystical retribution, soul loss, spirit aggression, sorcery, and witchcraft) over natural (including infection, stress, deterioration, and accident) etiologies (1980, p. 48). Nevertheless, British anthropologist Pool, who has studied Cameroonian societies (1994), has joined Murdock and scholars of other disciplines, missionaries, travelers, government administrators (pre- and postcolonial, foreign and African), doctors and health officials, and economic development professionals, who have simply taken these simplistic dichotomies and characterized African health beliefs as operating primarily, or solely, in the domain of "personalistic" or "supernatural" shaped witchcraft, sorcery and/or spirits.

Evans-Pritchard's classic on Azande ideas of misfortune (1937, p. 67) would seem to endorse their views. Yet Evans-Pritchard has been much misrepresented by his excerpt on the Azande granary's collapse being attributed to witchcraft rather than natural causes. A careful reading of Evans-Pritchard reveals that he describes a "hierarchy of resorts ranging from simple to serious, with recourse first to empirical treatments, then to magical interventions" (Janzen & Prins, 1981, pp. 188–189). Yet many scholars of African healing and religion, who have experienced attributions to witchcraft for events Westerners would say were caused by gravity, germs, or sheer coincidence, prioritize this explanation over one in which events merely occur because they occur (e.g., see Turner, on the Ndembu 1967, pp. 300–301).

A third group of anthropologists began to find evidence of empiricism and rational, logical thought in African ethnomedicine (Fortes, 1976; Horton, 1967; Morris, 1998; Yoder, 1982). Horton in particular sought parallels between African and Western thought, including in the domain of health and illness. Anthropological opinion has changed considerably since the 1970s, in part because of the involvement of anthropologists in applied research of infectious and sexually transmitted diseases (Green, 1999; Inhorn & Brown, 1990).

For example, recent research suggests that while magico-religious or supernatural ideas may often be associated with mental illness and certain other conditions, naturalistic etiologic notions rooted in empiricism are often found to underlie the infectious and contagious diseases that have always accounted for the greatest morbidity and mortality (Green, 1999). Diseases such as malaria, tuberculosis, schistosomiasis, cholera, amoebic dysentery, AIDS and other sexually transmitted diseases, typhoid, acute respiratory infections including pneumonia, yellow fever, leprosy, and dengue tend to be understood within a framework that may be called indigenous contagion theory. In this analytic framework, one becomes ill because of impersonal exposure. One comes into contact with something that anyone could come into contact with, not because an avenging spirit or an ill-intended person singles one out for misfortune in the form of sickness (Green).

A fourth and final group of scholars have sought to formulate the relationship between disparate types of logic and misfortune causation in African thought. Morris notes that Chewa medicine includes an "empirical herbalist tradition, based on a belief in the intrinsic efficacy of certain plant and animal substances." Yet it also includes "a cosmological tradition, which sees the human subject as a microcosm of the world and in which health was seen as restoring a balance or mix between certain vital 'humors' or principles, and a tradition that focused on 'communal rites of affliction,' and involved spirit healing" (Morris, 1998, p. 86). How do these multiple realms of African healing relate to each other?

The late Rwandan scholar and physician Pierre-Claver Rwangabo offers an insight into contemporary African thinking on the question. Even though not all aspects of the Rwandan medicine system are amenable to modern science, Rwangabo believes that it is a part of modern reality rather than a fossil. He divides the causal domains of Rwandan medicine into "physical" and "mystical" causes. Diseases range across a variety of types which may be attributed to either causal category or to both. Rwangabo's medical

training is evident in his listing of disease classes that include: parasitic diseases, microbial diseases, systemic diseases and bodily accidents, gynecological and obstetrical diseases, and psycho-mental and behavioral diseases. But under the latter group he identifies current psychopathologies that entail abnormal behavior as understood in traditional thought and diseases believed to be caused by broken prohibitions and beliefs about ancestors (*abazimu*) and other spirits (*ibitega, amahembe, nyabingi, amashitani, amajini*) which often are identified in relation to mental illnesses. "Poisoning," the result of human aggression, is a major aspect of the human source of misfortune. Misfortunes brought on by the breach of social rules also have a mystical though not necessarily mysterious causal character. Rwangabo's insight into the character of traditional medicine lies in the observation that most pathologies may have both a physical and a mystical dimension. This affects the way therapy will be arranged. The decision to seek physical or other therapy has to do with the context in which it occurs, its severity, the suspected human etiology, and response to treatment.

This emphasis on the context of the causal attribution makes all the difference in how sufferers, their therapy managers, diviners, healers and medical practitioners will treat illness. If the misfortune is considered to be ordinary and predictable, it will be seen along the lines of the material world. If catastrophic forces or circumstances have precipitated it, or if it seems to be the result of the chaos of underlying affairs in the human and mystical realm, it must be handled differently. Thus the same condition may need to be treated with different medicines. The first realm we might term "natural," the second "unnatural." But this dichotomy requires closer examination so as not simply to read into it influences of Western thinking.

In widespread sub-Saharan African parlance in the twentieth century, the natural realm is associated with God, or caused by God – the God of the created universe (Davis, 2000, pp. 94–95; Gilles, 1976, pp. 358–369; Janzen, 1978, pp. 44–49; Ngubane, 1977, pp. 22–24;

Orley, 1970, p. 137; Swantz, 1970; Turner, 1969, p. 52), not the God of a mechanistic Enlightenment world nor the God of puritanical retribution for human sin, as in the African Islamic or Christian view. Rather, God-caused misfortune is widely seen to be the created order of things such as the seasons and rhythms of birth and death in society and in the surrounding world. The death of an elderly person would be "in the created order," whereas the death of a child-bearing mother, for example, would be seen as "unnatural," or caused by some other human or spirit force. The unnatural source of misfortune – which may be manifested in an otherwise scientifically understood disease – may be attributed to human error or malicious motive, arising from the many inconsistencies inherent in human society, or the deceptive, antisocial nature of some individuals. This view of humanity often includes the ancestors or demigods who have a vested interest in the outcome of human affairs, especially in their clans and localities.

Paradigms in African Medical Thinking

Sub-Saharan African understandings of health, sickness and healing are often couched ideas about the nature of the world and life within it, ideas or images which offer powerful metaphors with which to make sense of suffering and uncertainty. These ideas are discernible in verbal concepts that have a deep history and broad geographical and cultural distribution and a continuing use in diagnosis, the formulation of the sickness experience, and in therapies (This is the most recent of a series of formulations of such broad ideas in sub-Saharan African medicine. The present essay is particularly informed by "sub-Saharan African Healing" (Janzen, 1997).

The first organizing idea defines an ordered structure of the body. Any disruption, negation, or distortion of this ideal suggests sickness, as expressed in a verbal cognate that extends from West to Equatorial Africa – *eela* or *ele* in Yoruba of Nigeria (Buckley, 1985); *beela* in Kongo of Western Zaire (Janzen, 1978, 1992). This notion often relates to a nonverbal code of three or more

colors and related substances used in medicine and ritual to situate the body within a wider cosmology. Chalk or kaolin from stream banks is used to represent purity and wholeness; camwood or other red is used to represent transition and danger. Charcoal or a substitute represents human chaos. White is associated with goodness and the legitimacy of the created order. Chalk is the most widespread of these colors used in healing and ritual. For example, chalk is smeared onto the face and body to represent the presence of ancestors, white beads are strung around the body or head to represent spirit possession, flour or another white powder is used to trace the outlines of sacred space, and white sap may allude to milk or semen as sources of life. Whiteness represents the realm of the water, the spirits, and the beyond. It usually stands for the clarity and goodness of the spiritual world where human life is rooted. Usually, the colors are used in combination. Redness, smeared on the face and body, dyed into cloth, or covering a ritual object, appears alongside whiteness to suggest the juxtaposition of “the white” with transition and danger. The combination suggests power that can build up the created order but can also destroy it. Hierarchies of spirits may appear represented in these two colors. Charcoal, the remains of fire, represents the chaos and destructiveness of human life left to itself. In association with white, this chaos and energy is balanced by the clarity, legitimacy, and order of spiritual truth. Turner wrote the classic study of this color code in sub-Saharan African ritual about the Ndembu of northern Zambia (1967, pp. 59–92).

In a second idea, balance or harmony is necessary to a state of health in the relationship between an individual and the people surrounding him or her, as well as between the human community and the natural and spiritual environment. The verbal concept *lunga* refers to a principle of health in the Zulu society of South Africa (Ngubane, 1977) and the Kongo society of Western Congo (Janzen, 1978) and to a type of healer in the Luba-influenced Tabwa culture of the western shores of Lake Tanganyika (Davis, 2000). In regions influenced by Galenic humoral theory

via Islamic medicine, balance may have the connotation of an equilibrium between the humors and between heat and cold. Balance between opposing humors or fluids leads to health, imbalance to disease.

The idea of balance or harmony often extends to relations with kinsmen, neighbors and others with whom people come into regular social contact. Social disharmony leads to resentment, anger, envy, evil-wishing, cursing, and gossip, and often finds expression in sorcery and witchcraft. Cases of illness or misfortune that seem particularly dramatic or ambiguous are commonly a cause for divination.

A third concept is that of “coolness” as grace and health, in contrast to the “heat” of conflict and ill-health (widely distributed in sub-Saharan Africa under the term **-pod-* in connection with cooling down, being cured). Conflict and anger are often associated with heat and fire that like energy out of control can cause great destruction, disease, and death (among the Ndembu of northern Zambia, Turner, 1969, pp. 27–31; among the Tabwa of eastern Congo, Davis, 2000, pp. 58–60). Medicines that extinguish the fire or cool the situation or sufferer are administered as an antidote to the dangerous condition. A balance between the extremes of fire and the cold of death are regarded as important for health and life (in the widespread *ngoma* ritual of healing, Janzen, 1992; among the Hemba of eastern Congo, Blakeley & Blakeley, 1994). The sub-Saharan African concept of the “cool” extends an aesthetic notion widely seen in the arts and in human relations into a definition of health.

Fourth, the widespread concept of “flow and blockage” is the closest to a classical African anatomy that inspires clear ideas about health and infuses numerous therapeutic practices. The prevalence of purgatives and emetics, fertility medicines, and herbal drinks in the African tool kit reflects this conceptual scheme (Janzen, 1978, p. 170). However, the physiological coordinates are usually linked to the wider world of a person’s relationships in society, if not to society itself as a body. In fact, an outside observer sees a clear homology between the physical realm of the

body and exchanges in society. Both are seen as needing to flow openly to thrive. Just as food and fluids need to be ingested for the physical body to be healthy, so the body social needs to be fed with reciprocal gifts and gestures of good will. Grudges, envy, and ill will in the social body are seen to cause blockage in the physical body (Taylor, 1992).

A fifth idea expresses purity, a ritual state in which the dimensions of the human world are in order; its opposite is a state in which these affairs are out of order, causing ritual pollution or sickness. Several Africanists have noted the importance of the antonymous concepts of pollution and purity and have noted practices related to these ideas in widely distributed Bantu-speaking societies (e.g., among the Kongo of Western Equatorial Africa, Janzen, 1982; the Lele of southern Congo, Douglas, 1966; among Nguni-societies of southern Africa, Hammond-Tooke, 1981; Ngubane, 1977; and in Mozambique and elsewhere, Green, 1999). Pollution commonly results from mystical contamination, which in turn is caused by death (including abortion) and women's reproductive processes (birth, menstrual blood, breast milk). The distinguishing feature in all of these examples seems to be an absence of an absence of spirits, witches or other malevolent humans as the cause of distress. Pollution is an impersonal condition that can be righted by purification rituals or curative interventions. In the course of years of applied ethnomedical research in Africa, Edward Green came to believe that purity and pollution concepts represent a traditional set of natural contrasts that may have served in the past as a foundation for ideas of health and disease prevention.

Finally, sixth, there are the related notions of contagion and protection, or immunization. That microorganisms can spread diseases is in fact a relatively old idea that goes back well before the theory of microbial vectors of disease. It is a widely held notion in African thinking about health, although that which is believed to spread and infect may include ill will, poison, malefic medicines, and a variety of forces which may cause harm. A well-known example of this idea is the case of precolonial Kenya, where smallpox-

infected communities were quarantined as a health measure and the healthy were immunized with a bit of fluid from the pustule of an infected individual (Dawson, 1992, p. 96).

In most societies where this theory is found, the agents of infection are described as worms or tiny insects, e.g., *kadoyo* among the Bemba (Zambia), *iciwane* among the Zulu (South Africa), *liciwane* among the Swazi (Swaziland), *atchi-koko* among the Macua (northern Mozambique), *khoma* among the Shona (central Mozambique), and *kokoro* among the Yoruba of Nigeria (Green, 1999; Foster, Osunwole, & Wahab, 1996). Sexually transmitted diseases are often thought to involve such infection agents.

Some scholars speak of African contagion as mystical, comparing it to pollution (cf. Murdock, 1980). Yet it is not so mystical when closely examined. People become ill as a result of contact with, or contamination by, a substance or essence considered dangerous because it is unclean or impure. Africans considered in an unclean or polluted state are often kept apart from other people, since they are considered contagious until ritually purified. In central Mozambique, people believe that several kinds of child diarrhea and/or dehydration are caused by contact with polluting essences (or by eating bad or spoiled food). One source of pollution that may appear mystical is unfaithful behavior on the part of a parent: if a mother or father commits adultery, he or she acquires a contaminating essence that makes the child sick. The immediate cause is physical contact with the child, or drinking "hot," "spoiled" or "contaminated" breast milk. This belief reinforces the importance of fidelity in marriage (Green, 1999, p. 13).

A third component of contagion theory, environmental danger, is based on the belief that elements in the physical environment can cause or spread illness. One expression of this is the notion that contagious illness can be carried in the air or wind. For example, the Bemba of Zambia believe that tuberculosis is an "illness in the air," spread by inhalation of unclean dust carried by the wind. The Bambara of Mali classify smallpox, measles, and other contagious illness as "wind illness," because only wind has sufficiently

widespread contact with the body to cause outbreaks (Imperato, 1974, p. 15). *Tifo temoya* (illness in the air) is a general Swazi term denoting illnesses that are contracted through inhalation. Colds, influenza, tuberculosis, severe headaches (probably malarial) and some types of contagious child diarrhea are examples (Green, 1999, pp. 189–90).

Recognition of this sort of contagious disease, along with sound preventive practices, can also be found in indigenous African veterinary practices. McCorkle and Mathias-Mundy (1992, pp. 67) have noted:

African herding strategies often reflect a highly sophisticated understanding of contagion and immune responses. For example, Fulani may move upwind of herds infected with hoof and mouth disease in order to avoid contagion; or they may move downwind so as to expose their animals to the disease, knowing that a mild case confers immunity.

Health in the Social Fabric: Shrine Communities and Cults of Affliction

The texture of society is extremely rich in sub-Saharan Africa. Social codes and the power of words are considered important to shaping health. A widespread verbal concept whose root is reconstructed as **-gidu-* refers to the role of social prohibitions, taboos, and the consequences of their violation. This is mentioned with reference to the restriction on eating or killing one's clan or individual totems and familiars. Other observers note that these prohibitions help individuals adhere to social codes in general, including health promoting restrictions on such things as overconsumption of alcohol, overeating, or health destroying excesses of any kind (Rwangabo, 1993).

Another aspect of the social dimension of health is bound up in the role of human agency in sickness or misfortune, in the action of anger or ill will in a relationship, and the action or gesture to harm the other, be it an injurious word, a blow to the head, or a bit of poison in the drink or food. The single root that most frequently refers to this "human cause" of misfortune is **-dog-* or **-dok-*

(part of the Proto-Bantu lexica of at least 3,000 years ago), modern derivations of which are found from Cameroon and the Kongo coast in the west (KiKongo: *kuloka*), Central Africa (Kinyarwanda: *kuroga*); to the Nguni-speakers in South Africa (Zulu: *kuthaka*).

In contemporary diagnoses of misfortune, victims will often identify a string of misfortunes and try to recall the exact words spoken by others prior to or in association with the events, drawing the logical inference that these utterances had caused, or could have led to, the bad luck. Words of warning or injurious words spoken in anger are especially suspect. Therefore, in divination, these moments are recalled so that the individuals or the relationships may be repaired. Without treating the root cause, the surface signs and symptoms cannot be permanently overcome.

There have been collective healing rites based on common afflictions or groups of devotees identified with gods or spirits considered to be the cause or medium of these afflictions. Such communities or orders have arisen and declined over time as particular constellations of afflictions have occurred. Often they have been a kind of barometer of the major dislocations and diseases in a region.

In West Africa, shrine communities and cult memberships were often associated with major shrines and cults to the earth, to the water, to nature, and to the sky, as well as to the rulers of local cities and states. Some shrines were addressed to specific conditions, such as twinship (as in the Ibeji of Yorubaland), or particular diseases, such as the very widespread shrine complex to the god of smallpox (variously Ipoona, Shapanna, Shapata). On the Guinea coast forms of gender-divided societies developed around the female Sande association and the male Poro association. These addressed many aspects of health and the public good such as instruction of youth, midwifery, social control, and hygiene. These shrine societies and cults of West Africa may well have been part of very early agrarian society, having become an integral feature of the cycles of celebrations and sacrifices.

Across Equatorial Africa this type of therapeutic ritual assembly often centers around



Medicine in Africa, Fig. 4 “Doing ngoma” in Guguleto Township, Capetown, South Africa, 1982. This composite shows the essential elements of a very widespread Central and Southern African therapeutic ritual. *Lower left*, two novices provide the drum rhythm; *upper left*, other novices sing-dance and “confess their dreams” to novices and

a few senior healers; *right*, a trained graduate of ngoma leads this particular event with her bold sure step and her colorful clothing and beadwork, which represents her well-developed sense of self in contrast to the novice-sufferers, who are entirely “white” (Photo by Janzen)

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particular issues as well, such as fertility, twinning, women’s reproductive issues, the health and well-being of infants and children (Devisch, 1993; Spring, 1978; Turner, 1968, 1975), debilitating chronic conditions, fortune and misfortune for men in hunting, mental illnesses, the survival of kin groups (Janzen, 1992; Nisula, 1999), and a range of social and environmental issues (Janzen, 1992; Van Dijk, 2000). Membership was usually made up of the afflicted and formerly afflicted, who underwent a therapeutic initiation with stages from sufferer-novice to healer-priest. These “drums of affliction,” as Turner (1968) dubbed them, are often associated with the voice of the ancestors and spirits which inhabit the celebrants and are expressed in the song-dances at the core of the ritual performances. Sometimes the mark of growth or healing in the

sufferer-novice is the creation of a personal song based on the ordeal of suffering, a dream/vision, or other moving experience. Such a song constitutes a unique set of powerful words, recalling the cognate *dok*, that offset and overcame the destructive forces of disintegration, misfortune, sickness and chaos of the previous period of the individual’s life. Where such a “drum of affliction” addresses community issues, the healing ritual may be directed to the community, and society becomes the body that is cured (Fig. 4).

These cults and shrines have related to Christianity and Islam for centuries. Sometimes the African institution has absorbed the outside idea or symbol, in other cases Christian and Islamic institutions have recreated the African forms and substance. Especially widespread in sub-Saharan Africa are the Independent African Churches,

many of which encourage healing, exorcisms, and various kinds of incorporating rites of purification, protection, and sanctification (Jonker, 2000; Sundkler, 1976). Prophet-founders play the role of ancestor-mediators, while prominent or talented members assume the diagnostic role of diviners.

Although orthodox Muslims frown on blending Islam with African indigenous religion, the interpenetration of Islam and African ritual healing is extremely common (among Hausas of Northern Nigeria, see Abdullah, 1992; Wall, 1988). *Jin* and *amasheitani* spirits widely cohabit the spirit worldviews of ngoma associations in Eastern and Central Africa. Muslims healers of the Swahili coast have long practiced ngoma as part of their medicine kit, along with reading the Koran; the purification symbolism of African healing merges with that of the ritual ablutions of Islam in connection with prayer. In northern Swahili towns such as Lamu, early twentieth century ngoma Maulidi was introduced for performance in the mosque; its songs celebrated the prophet Mohammed, much to the chagrin of fundamentalist Muslims.

New Health Crises and the Relegitimization of African Medicine

The financial crises of African societies, and the search for an infrastructure of health, have led planners to take a second look at African institutions such as cults of affliction and the education of healers. By 1998, findings from a survey by the World Health Organization's Regional Office for Africa showed that a national management or coordination body for traditional medicine activities existed in 17 of 30 countries surveyed. Twenty-two indicated that associations of traditional healers had been established, and ten said that a national directory existed. Four countries reported that a training program for healers existed (the actual number would surely be higher) and 17 countries had such programs for traditional birth attendants. Twenty countries indicated that institutions in their country were carrying out research related to traditional

medicine. Fifteen reported that there was local production of indigenous medicines, and 17 countries reported having botanical gardens or arboreta for cultivating medicinal plants (World Health Organization [WHO], 2000).

Research related to the medicinal value of plants in the African materia medica is important for several reasons related to public health (1) achieving community or national self-reliance in health by promoting locally available and already-accepted herbal medicines; (2) developing an indigenous pharmacological industry, based on local plants, that reduces national dependence on expensive, imported drugs; (3) promoting natural health care and reducing the iatrogenic effects of modern medicine; (4) finding out what traditional healers are using and, if medicines are found to be dangerous and highly toxic, trying to persuade healers to substitute safer plants or at least reduce dosages; or (5) finding an effective-seeming indigenous medicine for the symptoms of a high-priority illness such as child diarrhea, then finding ways to promote more widespread use of the medicine (Green, Jurg, & Djedje, 1994, p. 44).

Preliminary pharmacological research is showing that phytomedicines (medicines derived from plants) used by African healers may indeed be effective for diseases in three of the most severe current public health crises: schistosomiasis and childhood diarrhea.

Ndamba et al. (1994) analyzed the most commonly used plants used to treat schistosomiasis by 286 traditional healers in Zimbabwe, administering the crude extracts orally to hamsters infected with *S. haematobium cercariae*. It was found that plant extracts from *Abrus precatorius* (Leguminosae), *Pterocarpus angolensis* (Leguminosae) and *Ozoroa insignis* (Anacardiaceae) were lethal to adult schistosomes. In a study of HIV-positive Ugandans with Herpes zoster, herbal mixtures used by healers were found to be at least as effective as biomedical treatments, including the antiviral drug acyclovir, in treating symptoms (Homsy et al., 1999).

Recent phytochemical research has shown that the roots of *Mirabilis jalapa*, used in South

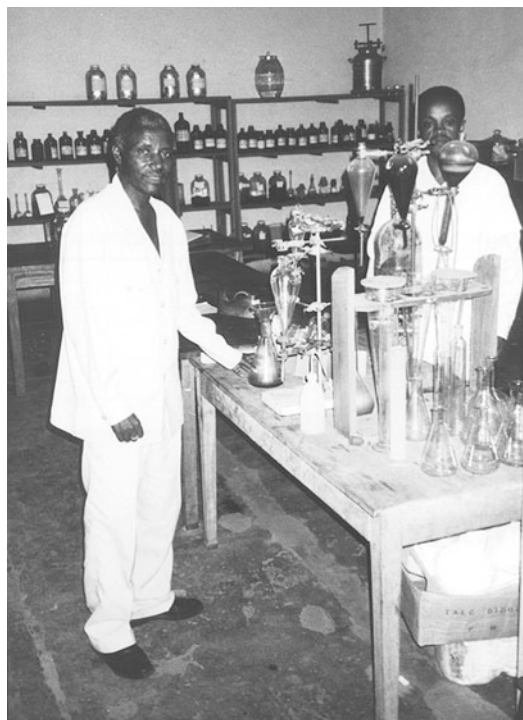
Africa as a purgative to treat some child diarrheas, in fact exhibit antibacterial activity against an impressive range of diarrhea-causing pathogens: *Staphylococcus aureus*, *Streptococcus pyogenes*, *Escherichia coli*, *Enterobacter sp.*, *Vibrio cholerae*, *Shigella flexneri* and *Salmonella typhi* (Chifundera et al., 1991).

At the World Health Organization Forum on Traditional Medicine in Health Systems held in Harare in 2000, the African Regional WHO office expressed keen interest in the mass production of phytomedicines for the treatment of malaria, AIDS, and other diseases identified as priority diseases by member states. It is a strategic objective of the WHO to develop a framework for the integration of traditional medicine into national health systems. The idea is to encourage local industry to invest in the local production of indigenous medicines and make them commercially viable. Governments were urged to create policies related to conservation, safety and toxicity, and regulation in order to assist a local production industry (Green, 2000) (Fig. 5).

Mass production, promotion, and distribution of African phytomedicines have begun. For example, Nigeria has developed medicines for ulcers, anemia, contraception, malaria and HIV, and it now holds patents for some of these in several countries. In late 2000, Nigeria became the first African nation to officially promote a plant medicine for the treatment of HIV/AIDS.

The ratio of traditional healers to the general population of various African countries seems to be in the range between 1:200 and 1:800, based on surveys and censuses (cf. Green, 1994, p. 19 for a review of studies). In Mozambique, a doctor theoretically serves about 10,000 people. In practice, coverage is even less. Most doctors live in larger cities, while most rural Africans are lucky if they live within 5–10 km of a clinic staffed by a minimally trained nurse, where medicines may or may not be available (Fig. 6).

It is widely accepted that at least 80 % of Africans rely on traditional healers for much or all of their health care. This had led some that work in public health to think that healers ought to play a role in curbing the spread of infectious disease. From a public health viewpoint, this



Medicine in Africa, Fig. 5 An example of African medicine given a modern scientific basis and commercialized. Dr. Byamungu Lufungula, left, French trained pharmacist, stands before instruments in his laboratory in Bukavu, Kivu, Eastern Congo. In 1994 his enterprise, SODIPHAR, employed 25 workers. Pharmacies in Goma, Bukavu, and Uvira sold about 20 products, all based on laboratory tested traditional medicines obtained in collaboration with herbalist healers. Byamungu is the author of *Les Plantes Médicinales, Les Rites Thérapeutiques, et Autres Connaissances en Médecine des Guérisseurs au Kivu*, 1982

would seem to make sense. Healers are found everywhere; they are culturally acceptable; they explain illness and misfortune in terms that are familiar. In the 1970s there were several collaborative programs involving traditional healers in areas such as child diarrheal disease and family planning (e.g., Good, 1987; Green, 1987, 1996; Warren, 1989) (Fig. 7).

With the explosion of HIV/AIDS in east and southern Africa, an even greater number of collaborative programs developed. In southern Africa, once they had participated in workshops on AIDS and sexually transmitted diseases (STDs), healers proved willing to promote

Medicine in Africa,

Fig. 6 Indigenous South African healers collaborating in public in AIDS prevention program, 1993 (Photo by Green)



Medicine in Africa,

Fig. 7 South African diviner-mediums (traditional healers) teaching each other biomedical ideas about HIV/AIDS, in a USAID-sponsored workshop in Tsitsikama, South Africa, 1993 (Photo by Green)



condoms and safe sex. Once it was accepted that standard STDs facilitate the transmission of HIV, it occurred to some that healers ought to be involved in STD treatment programs – at least through referrals to clinics – since patients with STDs so often consult healers. Moreover, avoiding AIDS by sticking to one partner usually made sense to healers because they already interpret locally recognized sexually transmitted illness as resulting (at one level at least) from violations of the codes that govern proper sexual behavior and exposure to essences believed to be polluting (reproductive fluids, death). They feel encouraged to learn that their own governments as well as the international community *also*

wish to warn people against having sex with “just anyone,” with too many people, with strangers, with prostitutes, or with someone other than one’s wife or husband. Finally, with drugs and hospitals in short supply, healers are already caring for a large proportion of those already infected with HIV. UNAIDS, the United Nations agency for coordinating HIV/AIDS programs, recently published an official “Best Practices” paper summarizing the role of healers in HIV/AIDS prevention and support programs, which concluded that they have made a substantial contribution (King, 2000), although the situation regarding HIV in Africa remains grim.

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Medicine in Ancient Egypt

Hedvig Györy

In pharaonic time people saw their everyday life as a mixture of rational facts and supernatural phenomena, and the healing texts and the relating archaeological artefacts reflect a similar double-sided medical attitude as well. According to their beliefs, each illness had two causes. One was of direct origin, caused by an invisible pathogenic material personified, such as a disease-demon, an evil spirit or an animal, or an object of the material world. The other was of indirect origin, caused by a god or goddess who was malevolent or who punished the patient, or by a curse invoked by individuals. This meant that the curing process had to be directed both to the physical and the divine world. One had to appease (*shṭp*) the appropriate god or exorcise the evil spirit or demon by religious or magical means and to fight the physical symptoms by the application of a remedy or physical treatment.

As the Egyptians themselves summarised, “Magic is effective together with medicine. Medicine is effective with magic” (Eb.2).

Sources

The study of ancient Egyptian medicine is based on various sources. The most complex are the ancient Egyptian texts from the pharaonic period, which instruct us not only about the scientific knowledge of the time but also about the way of thinking and the results physicians expected of their intervention. The medical anthropological study of human remains demonstrates the level of efficacy of ancient medications together with the general state of health of the population. There is also a good deal of analysis of the chemical-physical properties of pharmaceutical preparations that were used or applied in given cures.

In addition, scholars are able to look at religious, magical, historical, sepulchral, epistolary, and other types of texts written either by Egyptian or foreign people, archaeological and art historical finds or buildings, and (paleo)ethnographical parallels. All these sources are, however, not enough to provide a detailed medical overview of the complex of medicine in any period of ancient Egyptian history. The best-known period is the New Kingdom as most of the Egyptian medical literature known today relates to it. By contrast, the scientific analyses of the mummies are performed on mostly Late Period or Graeco-Roman mummies.

Healing Papyri and Ostraca

The healing texts, known from papyri (see Note 1) and ostraca (a potsherd used as a writing surface), can be divided into medical and medicomagical (=iatromagical) ones. Iatromagical spells are constructed the same way and contain exactly the same expressions such as in any other type of traditional magical spell, but the purpose stressed is medical – the annihilation or elimination of a disease-demon, the invisible enemy of the health of the patient. There are also prayers to various deities. The term medical papyri means those texts which deal with the physical reality of a disease. The mixture of medical and iatromagical texts is also common.

Medical spells can have several genres. Most of the extant medical papyri consist of prescriptions (*phrt*), which just name the disease to be treated or

say, “another one”, followed by a list of materials and key words for the preparation process. These were sometimes finished by an evaluation such as “proved a million times”. Texts relating to paediatrics and obstetrics often contain prognoses. Surgical case studies are documented in instruction form (*ss3w*), which contains both diagnosis and therapy, if needed.

The papyri are usually compilations of different “books”, often comprising groups of prescriptions. The original books seem to be arranged by the parts of the body the therapy had to be directed to, but the extant papyri often contain several books (or parts of them) mixed in with each other. Thus they were copied from various scrolls for practical guides to medication or for teaching or reference purposes. Only a few might be a copy of one original book, centred around one medical topic, such as curing methods (trauma in the Smith papyrus) or treatment of the same part of the body (such as the Kahun papyrus).

Many tracts must have been destroyed down through the centuries, but, according to ancient Egyptian traditions, the earliest medical book – an anatomy – already existed during the reign of Djer or Dewen, kings of the first Dynasty. If this is so, it must have been a list of anatomical expressions. Recipes are also attributed to Old Kingdom persons, such as the mother of Teti, sixth Dynasty (Eb.468), and spells against snakebite are listed among the Pyramid texts. In the tomb of Uash-Ptah we can read on the wall that he collapsed in front of Noferirkare, king of Upper and Lower Egypt. The pharaoh then sent for a physician who returned with a book to look up a possible way to save him, unfortunately without success. The known medical papyri originate beginning with the Middle Kingdom, and the last we hear about are mentioned by Clement of Alexandria (second half of the second century AD). He knew about six Egyptian handbooks devoted to specific aspects of medicine such as anatomy, illnesses, surgical instruments, drugs, eye diseases and gynaecology.

Human Remains: Mummies and Skeletons

Paleopathology is a relatively new branch of science. For a long time it relied entirely on bones. Thus, it meant not examining the

mummy, but during the autopsy everything was taken from the bones: wrapping, funeral goods, skin, soft tissues and muscles. The pioneer of its systematic application was Sir Marc Armand Ruffer, from the Cairo Medical School (1896–1917), who also changed to a scientific means of examination. He introduced regular X-ray examinations, which were first made for an Egyptian excavation in 1898, for Flinders Petrie. This is a non-invasive method to learn about possible diseases or fractures of the body, or to discover the cause of death. Even so, the destruction to artefacts and skeletons did not stop. Today’s methods are much more subtle and much less harmful. This is especially the case with computer tomography, which also helps in reconstructing a “living picture” of the examined person. The aim is now to get maximum data with no or minimum destruction. With very few samples (taken for instance by fibre-optic endoscopy) it is possible to determine the blood group, the DNS/DNA or the antigens of various infections. Scientific examinations resulted in finding severe infections from worms such as taenia (tapeworm), ascaris (roundworm), draconculiasis (guinea worm), strongyloides, trichinella or schistosoma. Bacterial and viral infections, such as tuberculosis, variola (smallpox) and mastoiditis (middle-ear inflammation) are also attested.

The arteries reveal the existence of arteriosclerosis; mummified lung tissues reveal sand pneumoconiosis, pulmonary tuberculosis or (probably lobar) pneumonia. The alterations and deformations of the bones demonstrate arthritis, periostitis, ostitis, osteomyelitis, osteoporosis, osteochondrom, multiple basal-cell naevus syndrome, pelvic contraction or vesico-vaginal fistule, and several types of tumours. Growth disturbances (indicated by Harris lines) together with various types of distortions of the backbones reveal spondylitis, scoliosis or Pott disease. Different types of innate distortions of the skull point to acrocephaly and hydrocephaly; other bones indicate achondroplasy, Klippel-Feil-Syndrom, talipes equinovarus or other disorders. The teeth are usually worn out and abraded, or else they have tartar or abscesses, if they are not missing. Caries are present mostly from the Ptolemaic

period. By the mummification of the inner organs it is also possible to examine the parts of the body, which show signs of anthracosis, silicosis, pneumonia, lung-emphysema; kidney hyperplasia, abscess, calculus, bladder stones; gallstones, cholecystitis; liver fibrosis; megacolon, prolapsus recti and several other diseases.

To what extent did the ancient Egyptian prosthetic medicine work for living persons? Some mummies are outfitted with prosthetic devices. In cases of the nose or stick legs, they were probably made for the afterlife, but some others might have been used. This is the case with a woman, probably in her 50s, in the Theban T95 tomb from the twenty-first Dynasty, who had an artificial wooden big toe.

Theoretical Background

Anatomy and Physiology

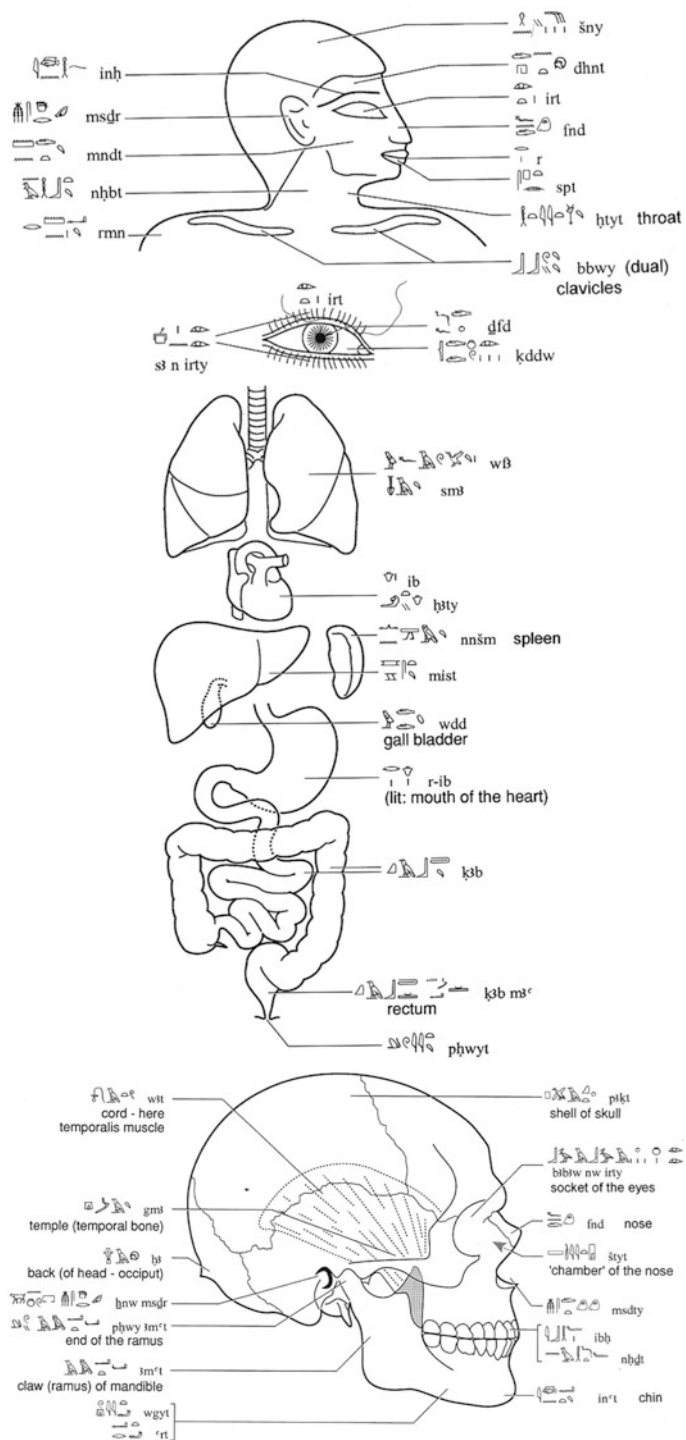
Ancient Egyptians had advanced anatomical and physiological knowledge. It must have been due to extended observation but also to the custom of mummification. This was a completely different science in the pharaonic period, and according to the data known today, persons executing it were never healers and had no connections to physicians. Characteristic to Egyptian culture, both fields of science had many specialised books, which were kept in libraries – available for every professional, which might mean a reciprocity of giving and receiving knowledge by embalmers and healers. Another opportunity for gaining similar experience might be from accidents or battles. For instance, the process of emptying the skull through the nostrils (a route applied often in modern brain surgery) by means of a long hook attests to a good knowledge of the anatomy of the head and brain. The exact description of the latter is given very vividly in the Smith papyrus (Sm.6). They obtained reliable information about the meninges, the cerebrospinal fluid, and twitches and pulsations, and they noticed a connection between the state of the brain and body control, although they did not develop it into a theory. A similar feature can be observed at the spinal cord, the dislocation of

which was connected to paralysis of the four limbs and incontinence (Sm.31), although the nervous system is not mentioned.

Their main concern was directed to the heart. Its position was described precisely, and some of its disorders, such as missed beats, were discussed. It was recognised as the centre of a circulatory system, where the various *mtw* – “canal” systems – met. They seem to have had two different schools for anatomical explanations (Eb.854, 856, Brl.163) concerning the numbers and roads of *mtw*. The *mtw* supplied the body with every substance it needed. They thought the blood vessels contained air in a healthy and blood in an ill state. Their vessels were thought to be hollow and have a mouth. The heart “spoke” through them, as they determined the pulse, and told the physicians at any part of the body about the general state of health of the patient. By this they recognised the peripheral pulses, but they were not aware of the circulatory system in a modern sense. All the fluids in the body, including air and blood, but also any type of body secretion, excretion and discharge flowed in a series of these interconnecting canals in the human body. The system was described based on everyday life: fluids and pathogens or even disease-demons were sailing there like Egyptian people were said to sail on the water of the Nile or its tributaries, with the Sun in the sky or on the river of the Afterworld. Thus *mtw* meant any blood vessel (veins and arteries), ducts or passages in the body, but they were also used as the technical term for muscles, tendons and nerves.

Ancient Egyptians sometimes used in the medical literature different words for a part of the body than were used in everyday life (for instance *wf3* for *sm3as* lung). For the names of body members see Fig. 1a–c. The vocabulary was rich for external parts, but relatively few names remained for the inner parts of the body. For instance, the kidney is not mentioned at all, though some hieroglyphs show such organs (lung and heart as *nfr*, heart as *ib*, intestins as *phr*), but with animal origins. They knew very little about their function. Regarding the respiratory system, they knew that the *t3wn'nh* (breath of life) entered through the nose, and then the

Medicine in Ancient Egypt, Fig. 1 Body members with their ancient Egyptian names (Source: Nunn 1996, Figs. 3.3a, b and 3.4)



heart and the lung gave it to the entire body (Eb.855a). There was another type of breath – the “breath of death” – which entered

the body through the left ear (Eb.854f). The concept of the digestive system was also simple; food and drink went to the stomach, and part of it left

through the anus. The details are unmentioned and, based on the treatments of the disturbances, they seem to not have been understood at all.

Pathology

Physicians often treated internal cases, where they could not see the alterations of the organs. They developed their concepts based on symptoms given by the patient and on exterior alterations of the body or of the given organ, experienced by palpation. Patients thought they had become ill because of an outside disease matter; namely the name of diseases was written in several cases by the figure of a god at the end. Among these “disease demons”, as they are called today, an enigmatic one is the *whdw*. The verb *whw* means “to suffer”. This pathogen afflicted many organs, causing suffering for the patient, and is a designation for all sorts of symptoms which changed their location. This meant that the *whdw* was wandering in the body (Eb.856). All the disease matters and demons entered the body from the outside world by natural or occasional openings. Thus, an important part of the cure and the prevention of morbidity was the physical and magical protection of the openings. A next step could be the cleaning of the *mtw*, the route of travelling of these elements. This theory is also the explanation of the frequent use of enema in treatments.

As the same treatment in a seemingly same case could end, however, with different results, they thought to seek for help in the divine world. This was important at each step of the treatment: from choosing the materia medica and the devices, preparing and administering the drug or performing the operation. This way they aided recovery not only by their medical knowledge but also by favouring the patients with psychological conditioning.

Medical Practice

Egypt was famous in the ancient world for its hygiene. Egyptians often cleaned themselves and their belongings. For this they used natron, ashes, or soda which are all good detergents and dissolve fatty matter. Probably it was also an important factor in the care of the sick. Another

aspect is drug administration which was often carried out at home, without professional help. This is what Homeros hints at, saying that everybody living in Egypt is a physician, for the whole population there originates from Paieon (*Odysseia* IV, 231–232).

Medical practice included the use of herbal remedies, but also surgery, various types of physical treatments, religious invocations and as an essential part, magical incantations. For the cure, healers had to handle problems concerning medical history, examination, diagnosis, prognosis, and various means of treatment if they were general practitioners or specialised in various fields of medicine.

Way of Examination

Medical practice was performed in a systematic way. According to the available clinical descriptions, before any treatment could be administered, a detailed history taking and questionnaire took place. The first course of action for the physician was to make a diagnosis, employing his powers of observation and experience to detect as many symptoms and to elicit as many signs as he could for determining the nature of the disease. He referred then to the medical papyri to determine the most appropriate course of treatment. Normally, this would take the form of a potion, unguent, ointment, balm, pill, poultice, enema, suppository or an eye lotion comprised from a concoction of natural ingredients.

The case study comprised several steps:

1. Interrogation of the patient
2. Detailed inspection of the face and skin, smell of the body, urine and faecal matter, palpation
3. Percussion of the body and diseased organs, functional testing
4. Diagnosis and verdict (“An ailment which I will treat”, “An ailment which I contend” or “An ailment not to be treated”)
5. Treatment

Treatment

Contrary to the statement of Herodotos (II.77), physicians seem not to have been concerned so

much with prevention of an illness, but rather with treatment of an ailment, using all the means at their disposal. And they had many. Unfortunately, we do not know details of them, as the texts are very limited. It is, however clear, that the physician gave patients medicaments, or he prescribed rest if needed (Kah 10). The duration of the treatment is often omitted, but it is sometimes specified by exact days (most frequently 4), or paraphrased (typical in the Smith papyrus: “until he recovers”, “until the period of his injury passes by” or “until you know that he has reached the decisive point”).

If medicine was prepared and administered according to the physician’s teachings, he was exempt from all blame if the treatment did not work. However, if he deviated from the traditional remedies and tried to increase his knowledge through experimentation, he risked losing his life if it failed (Diodoros I.82). These principles may have hindered changes in the medicine of Ancient Egypt.

Drug Therapy

Drug administration was the most popular method; drugs were either prepared by the physician himself or followed according to his instruction by an apprentice. Most of the medical texts describe a sole treatment. Medicaments contained a multiplicity of drugs simultaneously. The choice of selection seems to have been influenced by magical considerations. As a vehicle they usually used wine, beer, mothers’ milk, oil or grease (*mrht*) or honey; they used also active drugs in their own right; in addition to the most common, water. *mrht* came in many varieties, according to the plant or animal it was extracted from or made of. The measures were usually given in units or fractions expressed by the drawing of the components of the *wedjat* eye. The means of their utilisation is usually very short. It was a secret science. The chemical knowledge of the Egyptian physicians was so vast that some would attribute the origin of the word “chemistry” to “Kemet” the ancient name of Egypt.

The preparation process not only had its own rules, but also the administration – method, timing or dosage – was sometimes also specified.

Some of these were very complicated. Regulations adhered to the same guidelines physicians apply today. In some prescriptions even the dosage of the different drugs was adjusted to the patient’s age: “If it is a big child, he should swallow it like a draught, if he is still in swaddles, it should be rubbed by his nurse in milk and thereafter sucked on 4 days” (Eb.273).

Surgery

Surgery was considered in trauma and in a few cases of tumour and swelling. Based mostly on the Smith Papyrus, the simplest repertoire of surgical procedure is known, but these reveal a remarkably scientific manner and clean environment. There is, however, no mention of any sort of anaesthesia. Bandaging, stitching, bounding with oil and honey belonged to the usual wound managing. Infection of the wound was regarded to be a normal step of recovery. Evidence of operation is very sporadically attested on mummies. Fracture reduction was found a bit more frequently, and it was often successful, as were dislocations – also healed according to Kocher’s method.

Complementary Therapies

The ancient Egyptians practiced several other therapies. In the tomb of Anh-mahor (sixth Dynasty, Saqara) a sort of physiotherapy or reflexology might be inferred: the manipulating of fingers and toes were depicted. Chambers equipped with basins were found near Dendera temple, suggesting hydrotherapy in the sanatorium by the use of healing statues. Again they used the ultraviolet of the sunrays (heliotherapy) by exposing an anointed ill body in the sunshine. The treatment by mud and clay was also known (Eb.482).

Magical Practices

One of the most powerful tools in the healer’s armoury was magic. It was regularly used in conjunction with rational medical practices. Some materia medica seem to be chosen mainly on the magical character assigned to them, such as virgin’s urine, crocodile excrement, black pieces of bull hair, or tortoise bile.

Medicine in Ancient Egypt, Fig. 2 Small Horus stele amulet in the Museum of Fine Arts, Budapest



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The administration of the medicament, as with surgical intervention, was also accompanied by prayers and offerings or magical spells addressed to malign or angry deities. In addition, some objects sacred to certain gods or provided with supernatural properties or deemed as a reminder of a myth might give additional help in various other forms. They might be amulets, drawings, statuettes or tiny steles, or using an object as a model (e.g. crocodile statuette in Chester Beatty V. 4, 5–9) (Fig. 2).

If the medical treatments were deemed not to be working, the healer could call solely upon the divine world for destroying “the enemy”. Predominantly benign deities, in particular Isis,

Horus and Ra, were usually invoked. As expectations and environmental effects have measurable curative value, this was widely employed by ancient healers. Their emphasis on magic was an even more powerful psychological opportunity, the application of which improved therapeutic efficiency. In many cases, especially after attacks of animals such as snakes or scorpions, the spell casting activity of the healer-priest seemed to be decisive. It was thought to be the only treatment for a long while. After the publication of the Brooklyn Herpetological Papyrus, however, prescriptions became known which provided a very deep knowledge of snakes and the effects of their poisons.

Materia Medica

Pharmacology was a secret part of the physicians' studies and knowledge. There are a great variety of materials which cannot be identified, regarding the amount and quantity of usage, or time and way of gathering the raw material; these were guided by experience and theological concept. Physicians prepared the remedies themselves. They were made from natural ingredients, in raw or prefabricated conditions, such as:

- Small amounts of (toxic) *minerals*, like copper oxide, sulphate, antimony, zinc, lead, arsenic, malachite, natron, common salt, haematite, chalcedony
- Various parts of more than 200 *plants*, with about only a fifth identifiable with certainty. Among the common plants were fenugreek, sycamore, castor oil, acacia gum, carob, wormwood, juniper, Cyprus grass, cinnamon, date, lotus or sycamore fig. Vegetal components were collected not only in Egypt itself, but were also imported (such as the mineral lapis lazuli)
- *Animal* parts (meat, milk, fat, blood, skin, hair, bile, liver, brain matter, urine, or excrement)
- *Human* body products, such as milk, sweat or blood

Ancient Egyptian prescriptions do not say which elements were expected to exert pharmacological effect and which were used as a vehicle, or added for taste or general conditioning capability. Some constituents were used very extensively in most cases, but the texts often do not give the reasoning. The choice of the material changed during the history of ancient Egypt, which is well reflected by a comparison between New Kingdom and Roman time medical papyri, but it is impossible to follow the process because of our lack in knowledge of the time in between.

Instruments

As medical treatments consisted of rational and magical components, they required both medical devices and magical instruments.

Medical Devices

Healers required some objects for storing substances (such as special milk jugs, kohl pots, jars) or for preparing drugs, such as perforated plates for straining (*ṯh*), bowls for getting a homogenous mixture (*m ḥtwṯ*), pots for grinding (*nd*) and cooking (*ps*), small measures for volumes (the most convenient are *hnw*, approximately 450 ml and *ro*, approximately 14 ml) or sticks and spoons for the mixing procedures. For enema there were some sort of clysters; for fumigation there were burners. All the devices needed had to be packed in the house or sometimes in a bag to take to patients.

For the treatment of injuries we find "fire drill" which consisted of a stick and board used for starting fires by friction, as a cauterising tool, and various types of bandages. From the New Kingdom onwards, they used small metal knives as well as tools such as hooks, forceps, "disposable" lancets and blades fashioned from reed stems, spatulas and spoons.

In Kom Ombo, the Antonine (Roman) period inner decoration of the surrounding wall of the Sobek and Haroeris temple bears a table of surgical instruments, divided into four horizontal rows. The relief shows knife blades, a saw, spoons, spatulas, forceps, pincers, small bags, a small scale, specula and *wedjat* eye amulets. In the bottom register there are two round forms (possibly vases), a papyrus scroll, two packages for needles or small instruments, an oval object, needles and cleaning tools.

Magical Instruments

As magic and religion played a major role in treatment, magical instruments were also important. Amulets, models and other magical objects such as knots, magic wands, statuettes of gods and "concubine statuettes", bowls, representations of symbols and scenes or various inscriptions were generally used. Some of them had a specific aim; others had a wider range of applicability. As these practices changed continually, we can specify the time of their use. For instance magic wands was used almost exclusively during the twelfth to thirteenth Dynasties while the Horus-cippi, which repelled reptiles and cured

people who had been bitten, started to appear during the eighteenth Dynasty and stopped after the end of the Ptolemaic era.

Diseases

Degenerative diseases tend to afflict people the same way; other diseases are dependent on environmental factors. These were different in antiquity not only because of the thousands of years during which the virulence and geographical boundaries of many pathogens (and hosts) could have changed significantly but also because of alternating ethnical mixtures of people and changes of life patterns such as diet, way of life, quality of air or geographical factors. There are some which are already extinct. Thus the pathogens were less or more different, and they could cause slightly different symptoms. Examinations of the human remains reveal, however, that diseases usually resulted in the same conditions as they do today.

About 300 diseases are mentioned in ancient Egyptian texts. They are very hard to identify, because the prescriptions usually do not give any or enough description. Moreover, several diseases mentioned are only signs or symptoms (heat, cough, vomiting, obstruction, voiding of blood), which can occur in many diseases. Disease descriptions are also inaccurate for today's diagnoses. For instance the so-called "Asian disease", described very vividly in H.170, has been interpreted differently: bubonic plague (Goedicke), leprosy (Bardinet) or smallpox (Györy). Ancient Egyptian medicine paid detailed attention to the anus. Nevertheless, it is difficult to find a technical term for constipation or diarrhoea, though many remedies cleared the bowels and stopped evacuation (*wšš*). There is no doubt in the meaning of *gs-tp* – "half head", modern migraine (Eb.250, ChB V.4), and the probability is high in the identification of the passage Brl.67 as facial nerve paralysis (Bell's palsy). Due to the widespread nature of dental disease, halitosis (bad breath) must have been a common complaint. A prescription has been discovered to combat this condition.

Another difficulty in understanding ancient Egyptian medical texts is that a lot of words

have specific medical meanings, which are only rarely explained in a gloss. Some of them were not well understood even during pharaonic times. That is the reason we have glosses in the Ebers and Smith papyri. Thanks to them, we know much more about surgery and healing wounds than about any other medical cases. In the Smith papyrus, case 7 gives for instance a very plausible description of tetanus.

Prescriptions often speak about worms, as several disease terms are determined with the sign of a snake, the hieroglyphic sign also for worms. There seem to be only two, *ḥf3t* and *pnd*, with a sense of a specific worm. And there is no clue for the identification of these two. Several types of vermifuges were used against them, such as pomegranate or wormwood in medical texts or garlic, radish and onion in everyday life, but they are not specific. We have a nice description for the treatment of dracunculiasis (Eb.875), but the worm taken out over a painstaking month is not given a specific name. There is a possibility that the snakes for the emblem of Greco-Roman and modern medicine (caduceus) may be related to this procedure.

Ancient Egyptian representations could be a big help, because they were often accompanied by explications. The medical papyri are, however, not illustrated, and the reliefs on tombs give ambiguous information for medical interpretation. Servants are often represented as hump-backed. We do not know whether this represents poor posture or the result of a disease, such as Pott's disease, ankylosing spondylitis, porter's hump or a sort of fracture. The representations with gynaecomastia or elephantiasis are no better; they can be caused by several diseases, most often by schistosomiasis or filariasis. Similarly, the picture of the equine deformity of the foot of Rama can be the representation of either poliomyelitis contracted in childhood or a variety of clubfoot. The dilemma is the same with the mummy of pharaoh Siptah. The stela of Bak shows him with a high probability of having Simmer's fibrosis caused by schistosomiasis. The case of Seneb, who is sitting beside his wife on a statue from his tomb in Gisa, is a classic example for achondroplasiac dwarfism. But dwarfism was not considered a disease.

The Healers

Health was very important for ancient Egyptians. For many maladies, however, they needed special health care performed by specialised physicians who were remunerated for their services in barter and money-barter by the state or with gifts by private persons. They worked usually on their own, as pharmacists, nurses or midwives.

Herodotus (II, 84) attests in the fifth century BC that

The practice of medicine is so divided amongst them that each physician treats one disease and no more. There are plenty of physicians everywhere. Some are eye doctors, some deal with the head, others with the teeth or the belly, and some with hidden maladies. . .

A similar picture is reflected by the medical titles of the Old Kingdom and Late Period among the *swnw*, the ancient word for physician (from the root word “*swn*” meaning “to suffer pain”.) The hieroglyph contained the sign of an arrow, which might lead to a possible origin of the occupation such as removing arrows from the injured, or it might allude to Thoth, who not only gave written instructions but also cared for the wounded in battle.

Another type of physician were the priests of Sekhmet, the lion-headed goddess who dispensed disease especially at the end of the year, or cured it. They were called “the wab-priests of Sekhmet, who can dispel evil spirits”. They are thought to have been surgeons and might also be veterinarians. A third type of healer was the magician, called *s3w* (the protector). These three main categories of healers might function simultaneously for a given patient. All of them could perform the classical medical examination, including palpation. The main difference among them was their way of approaching the disease and consequently the treatment. All three functions could be united in one person as is the case with Hery-shef-nakht (Hatnub, twelfth Dynasty).

The magician healer used mostly magic, which did not exclude operations or medicaments prepared according to the medical prescriptions. His fields were probably centred around fertility and

severe illnesses hardly or not curable by physical treatments. They might also be specialised in some diseases; for instance, some healers of the first decades of twentieth century’s Egypt (AD) only took out maggots from the eye. Very specialised, the *hrp Srkt* (a sort of priest to the scorpion goddess Selket) dealt only with scorpion stings and snakebites by the recitation of spells and incantations. Surgeons used a “knife-treatment” operation for a wide range of cases, although the act was preceded and followed by religious acts such as offerings, prayers or incantations. The *swnw* were concerned with pragmatic medicine, but again with some divine help.

They adopted a rather elaborate hierarchy system for the health service, with titles such as:

- *swnw* – physician
- *hry-swnw* – one with authority over physicians
- *imy-r-swnw* – overseer of physicians
- *wr-swnw* – chief physician (possibly *smsw-swnw* – eldest physician in some cases)
- *shd-swnw* – inspector of physicians

During the Old Kingdom and Late Period there were many specialists in the different fields of medicine, such as the *swnw jrtj* (ophthalmologist), *swnwht* (physician of the abdomen; i.e. gastroenterologist), *nwr phwy* (shepherd of the anus; i.e. proctologist), who probably administered enemas; or *jryw-jbw* (dentist) and *jr-jryw-jbw* (great of those who are concerned with teeth), first given to Hesy-Re in the royal palace of the third Dynasty. Besides the palace, the army also had its own physicians, as well as some social groups such as the royal tomb builders, or miners. Some physicians held several specialised titles, such as Ir-en-akhty (First Intermediate Period), who was both court physician and their inspector, as well as proctologist, ophthalmologist, gastroenterologist and *3^{ce} mw m-h nw ntnnt* (interpreter of the liquids in the intestines(?)).

The ancient Egyptian physician was generally educated and trained by his father and relatives or within the temple schools and libraries, the so-called *pr-nh* (house of life). The most famous New Kingdom medical institutions were in the temples of Heliopolis and Sais. Pupils underwent

a formal apprenticeship under an acknowledged master. Training was so successful that Egyptian physicians became renowned throughout the ancient world for their skill. For instance, at the request of Hattushili, Ramses II despatched a physician to the Hettite court and later, at the request of Cyrus Amasis II, sent an Egyptian ophthalmologist to the Persian court. Many Greek people wandered to Egypt to learn from the Egyptians. Even Hippocrates highly esteemed their knowledge; he used the same method of reaching a diagnosis and deciding on a plan of action.

The title of *swnw* was held in high esteem in Egypt itself. More than 150 names of *swnw* have survived. Being an overseer of these was an important rank: Mereruka (son-in-law of pharaoh Teti, sixth Dynasty) was proud of being *jmy-r gswy dpt swnw pr* “3(overseer of the two sides of the boat of the physicians of the pharaoh). There is one story of a female physician: the mother of Akhet-hotep (fifth/sixth Dynasty) was their overseer – *jmj-r swnwt*. Moreover, two persons without known contemporary evidence of bearing this title – Imhotep, the royal chamberlain to Djoser (third Dynasty) and Amenhotep-son-of-Hapu, the royal scribe to Amenhotep III (eighteenth Dynasty) – were deified from the Late Period, the former one also identified with Asclepius by the Greeks (Fig. 3).

If one had to be ill in antiquity, ancient Egypt would be the preferred place. Although the basis of their medication was mainly empirical and aimed at the relief of symptoms, they thought to eliminate the cause of the disease by winning the gods’ benevolence. The medical knowledge of their physicians was without equal at that time; their formal, structured and logical approach to the patient is unchanged in modern medicine; and their techniques and treatments are often comparable to today’s medical profession.

Extra 1: The Most Important Medical Papyri

The earliest texts originate from the Middle Kingdom (Amenemhat III). The *Kahun papyrus* was found in the town of Illahun by Flinders



Medicine in Ancient Egypt, Fig. 3 Bronze statuette of Imhotep. Dyn. 26 (Source: 1. Nagay, Guide to the Egyptian Collection. Museum of Fine Arts, Budapest, 1999. p. 67)

Petrie in 1889, and is badly damaged (Griffith 1898; Stevens 1975). All the paragraphs are gynecological, but the first half is written in instruction form, while the second 17 paragraphs are prescriptions or pregnancy prognoses. The 17 *Ramesseum papyri* were found in a magician-healer’s tomb in the great temple of the Ramesseum, Thebes. They are also fragmentary and originate presumably from the thirteenth Dynasty. *Numbers 3 and 4* contain several prescriptions and also magical spells treating various parts of the body, though many deal with birth and babies or the eye. Scroll *number 5* is in the best state of preservation among them, and the writing suggests it to be the earliest copy. It collects cases concerning the *mtw* – that is the “canals” of the body – in this case usually muscles and tendons. The other Ramesseum scrolls are mostly magical.

The 4.5 m long *Edwin Smith papyrus* was purchased in Thebes in 1862 by its eponym, and published in 1932 by James Henry Breasted in two superb volumes. The recto gives an excellent insight into the surgical practice of ancient Egypt with the 48 trauma cases in instruction form. There are several corrections written in the paragraphs and explanations (glosses) appended behind them, which indicate that the original text was not understandable any more. Its language suggests a Middle Kingdom origin. It outlines procedures and techniques that are considered antecedents of modern surgical practice. The 48th case ended abruptly in the middle of a sentence. The verso was finished by another hand and consists of various medical paragraphs together with iatromagical incantations. The style of the writing dates the scroll approximately to 1550 BCE.

The longest medical papyrus is the *Ebers papyrus*, which was also bought by Edwin Smith in 1862. It was said to be taken from between the legs of a mummy in Assasif, Thebes. It measures some 20.23 m in length and 30 cm in height. A passage on the verso dates it to the ninth year of Amenhotep I. Georg Moritz Ebers published it in 1873. The recto contains 877 medical paragraphs of various topics arranged unsystematically in many books with some loose prescriptions and randomly placed glosses. The pages were numbered by the ancient compiler, who collected material from the ancient Egyptian medical literature – ophthalmology, obstetrics, contraception, dentistry, urinary and digestive system, psychiatry, etc. The “book of the stomach” (188–207) and the injury section (857–875) are in instruction form. It also contains two anatomical treatises (854–56) and a detail of a herbarium (251).

In 1901, a scroll of papyrus was presented at the Californian Phoebe Hearst expedition in Deir el-Ballas. The scroll, later named *Hearst Papyrus*, was written during the reign of Tuthmosis III and is a less systematically written compilation of several topics, probably a practicing physician’s formulary. It is concerned with diseases of the urinary system, blood, hair, bites, etc. More than a quarter of the paragraphs are similar or very

close parallels to the Ebers papyrus. The recto of *Chester Beatty VI* of the nineteenth Dynasty from Deir el-Medina consists of prescriptions for rectal ailments. The *Berlin Papyrus*, acquired by Giuseppe Passalacqua in Saqqara and sold to Friedrich Wilhelm IV of Prussia in 1827 for the Berlin Museum, bears a great similarity to the Ebers papyrus, and also contains an anatomical treatise (163). Beside the prescriptions for various illnesses there are also some birth prognoses. The paleography indicates that it is of the nineteenth Dynasty. Unknown is the origin of the badly damaged *Carlsberg Papyrus VIII* written by two different hands and dated to the nineteenth/twentieth Dynasties. Its language suggests a Middle Kingdom origin. The recto gives prescriptions for eye diseases and the verso prognoses for pregnancy.

The *Brooklyn Herpatological Papyrus* concentrates exclusively on snakebites and dates to the thirtieth Dynasty or Early Ptolemaic Period. It starts with a systematic description of the properties of 38 snakes and their bites (the first 13 were on the missing part of the papyrus), while the second section describes prescriptions to “drive out the poison” of snakes, scorpions and tarantulas and to “seal their mouths”. The *Fayum Medical Papyrus*, originating from the library of the Sobek temple of Crocodilopolis in the second half of the second century AD, is a compilation of prescriptions for various diseases. Although it is written in demotic and the structure is traditional, it is completely imbued with the Mediterranean medical praxis and drugs.

Extra 2: The Most Important Mixed and Pure Iatromagical Texts

The provenance of the *London Medical Papyrus* is unknown. It was given to the British Museum by the Royal Institute of London in 1860. It is a palimpsest in very poor condition dealing with various topics such as gynaecology, ophthalmology or proctology. The earlier work dates to the reign of Tutankhamun. Of its 61 paragraphs, 25 are prescriptions; the others are magical spells. Among the 19 *Chester Beatty Papyri* given by Sir

Alfred Chester Beatty to the British Museum, spells are often cast for unidentifiable diseases (VI verso, VIII, XV). Then again there are some systematic books – incantations against headache (V.) and scorpion stings (VII recto). The collection was found in a tomb at Deir el-Medina in 1928 and belonged to the archive of the family of the scribe Qen-her-khepeshef for over a century during the nineteenth Dynasty. The *Mother and Son Papyrus* in the Berlin Museum was auctioned from the Athanasi collection in 1843 as burial good from Memphis or Thebes. Written in two hands at the beginning of the eighteenth Dynasty, the papyrus contains 3 prescriptions for the newborn and 18 magical spells against children's illnesses or for delivery, mother's milk and the general safety of the child.

The *London-Leiden magical Papyrus*, which consists of a few prescriptions and many incantations for various ailments, was written in the third century AD. The two halves, sold first by Anastasi, the Swedish consul of Alexandria and acquired much later by the British Museum and the Dutch government, were discovered by the first publishers, Francis Ll. Griffith and Herbert Thompson. Although it is basically demotic, it also contains many Greek glosses, some coptic words and a few hieratic signs.

Typical pure magical texts were written against snakebites, and not only on papyri or ostraca but also carved on stone from the New Kingdom – mainly on *Horus-cippi*. Probably the most complete collections are the *Metternich stela* and the inscription of the *healing statue* of Hor-udja. These incantations often quote mythical events in connection with the child-god Horus or the goddess Isis. Other types of spells were cast over pain and aches in different parts of the body. The *Turin magical papyri* contains a large collection of these and snakebite spells.

See “► [Maps and Mapmaking in Egypt: Turin Papyrus Map](#).”

See Also

► [Mummies in Egypt](#)

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Medicine in Ancient Mesopotamia

Sema'am I. Salem

The art of medicine is as old as humanity itself. Diseases must have existed as soon as life was formed and early human beings tried to rid themselves of the pain and discomfort they caused. This art is not restricted to human beings alone; many animals even some plants have ways to combat sickness.

Early people probably practiced two completely different methods of medication: a practical method originating from the obvious, and another resulting from combating the unknown and the mysterious. When a thorn or a similar object penetrates the flesh, removing it relieves some pain and discomfort and is therefore a cure. Pressing one's finger or hand on a wound stops the bleeding and thus is a form of medication. On the other hand a cure for a mysterious or a supernatural illness, such as a high fever or epilepsy, is not as obvious and therefore requires a supernatural treatment. Not knowing the nature of such mysterious illnesses or how they entered the body of their victims, early humans accused demons and evil spirits, and called on magicians and exorcists to chase away the offending demons. Thus to combat diseases, the help of a benevolent god was invoked either directly by prayers and sacrifices, or through a medium, an expert in communicating with such a super power. This type of treatment survives today, practically unchanged into the twenty-first century, in many places.

Most of the almost 1000 medical tablets uncovered in Mesopotamia treat most diseases in this fashion: a disease is the invasion of the

body by an evil spirit or a harmful demon, and the cure is always described as a method to force the demon to leave the patient. This is accomplished either by a healing god, or by scaring, or disgusting the intruding demon. The evil spirit may become disgusted and forced to leave by feeding the patient repulsive materials, such as dirt or excrement. In Mesopotamia, the healing god was usually associated with a snake, the symbol of healing.

On one of the oldest Mesopotamian medical tablets, the Sumerians attribute numerous diseases to harmful demons and evil spirits and call upon their goddess for medical help. In their incantations, she is addressed by various names, such as Bau, Ninisinna, and Gula. An example of this kind of treatment is found on several tablets describing the disease that overwhelmed Tabi-utul-Enlil, the ruler of Nippur. He calls on various gods and goddesses, begging them to rid him of the evil demons that entered his body. There was no other cure mentioned.

An evil demon has come out of its (lair);
 It struck my neck and crushed my back,
 It bent my high stature like a poplar;
 Food became bitter and putrid,
 The malady dragged its course.
 My flesh was wasted, my hands were wan.
 All day the pursuer pursued me;
 At night he granted me no respite whatever.
 Then Tabi-utul-Enlil mentions how the diviner failed him and his gods deserted him.
 The disease of my joints baffled the exorcist,
 And my omens were obscure to the diviner,
 The exorcists could not interpret the character of my disease,
 And the limit of my malady, the diviner could not fix.
 He was baffled by his punishment, as he was a pious ruler, who performed his duties to gods and men.
 As though I had not set aside the portion for the god,
 And had not invoked the goddess on the meal,
 Had not bowed my face and bought my tribute;
 And had not taught my people fear and reverence.
 I thought that such things were pleasing to the gods.

Here, Tabi-utul-Enlil states that since he is such a pious man, he should not have gone through so much suffering. The good god should

have prevented the evil spirits from entering his body. But he never lost faith in his benevolent god. Finally, the good spirit appears, and cures all his ailments; a mighty storm drives all the demons out of his body.

He sent a mighty storm to the foundation of heaven,
To the depth of the Earth he drove it.
He drove the evil demon into the abyss.
He tore out the root of my disease like a plant.
Cured, Tabi-utul-Enlil praises his god, offers
sacrifices, and calls upon his subjects to have
faith, and never to despair.

This piece of Mesopotamian literature provides a clear insight into Mesopotamian view of diseases and cures. There is no difference between demon and disease; the two words were synonyms. And so were the words god and cure. Many historians see similarities between Tabip-utul-Enlil's story and that of the biblical Job.

Although magical cures were prevalent in ancient Mesopotamian society, there are indications that even in the early stages of Mesopotamian development, plants, and other substances were consumed for medical purposes and some specialized medicine existed. A clay tablet, written toward the end of the third millennium BCE was uncovered in Nippur and brought to the Museum of the University of Pennsylvania, where it was translated by Samuel Kramer and Martin Levey. Considered the oldest medical document of record, this tablet describes over a dozen remedies extracted from plants such as myrtle and thyme, and from trees such as willow, pear, fir, fig, and date. It also mentions extraction from milk, snakeskin, and turtle shell as well as table salt and potassium nitrate. This tablet has two drawbacks: it fails to mention the diseases for which these remedies were intended or the quantities to be used in the treatment. Another clay tablet that dates to the middle of eighteenth century BCE mentions aloe as a cure for "anything that ails you." An Egyptian papyrus written around 1500 BCE confirms the Mesopotamian claim; it states that aloe relieves skin afflictions, infections, and constipation.

Modern scientific studies have confirmed what Mesopotamians and Egyptians knew some

3500 years ago, that aloe has therapeutic powers; it heals burns, skin lesions, and frostbite; it reduces inflammation and enhances the immune response. If taken internally, certain components of aloe reduce stomach acids, relieve the pain of arthritis, and reduce blood sugar in diabetic patients.

The therapeutic effect of plants is also mentioned in one of the Sumerian creation stories. Uttu, the goddess of plantations, after being impregnated by her grandfather Enki (Lord-Earth), fulfilled her duty and created a variety of plants. Enki visited Uttu's plantations and, in an effort to determine their medical power, he ate some of them. The goddess Ninhursag (Queen-Mountain), enraged by what had happened, cursed Enki, who as a result, fell grievously ill. The Anunnki (Great Gods), troubled by Enki's illness, brought Ninhursag to Enlil (Air-God), their leader, who persuaded her to heal Enki. To perform that function, she placed the sick god close to her vulva and began to create a god (a specialist) for each of the diseases that afflicted him.

Ninhursag placed Enki at her vulva.

'My brother what hurts you?' – 'My tooth hurts me.'

I have caused Ninsutu to be born for you.

'My brother what hurts you?' – 'My mouth hurts me.'

I have caused Ninkasi to be born for you.

'My brother what hurts you?' – 'My rib hurts me.'

I have caused Ninti to be born for you.

The similarity between the creation of Ninti (Lady of the Life or Lady of the Rib) from the rib of Enki and the creation of the biblical Eve from the rib of Adam has been recognized since these verses were translated.

The therapeutic effect of plants was mentioned only rarely. The general public believed that demons and evil spirits caused all diseases, and magical cures were predominant. This led to devising and adopting various protective methods, such as hiding from the sight of evil demons, which in turn led to the use of masks and symbolic chains that protected loved ones from harmful contacts. Another way of hiding from evil spirits was by painting the patient in a variety

of colors, and this is might be the origin of tattoos. Changing the patient's name was another way of fooling the evil spirits, preventing them from finding him.

Other forms of protection against harmful demons included the administration of seven drops of a liquid, the assistance of a special person – a child, a virgin, a firstborn – and a variety of amulets such as odd-shaped stones, and threads spun from a virgin kid. Such charms were attached to the head, neck, or limbs of the patient, or tied about his bed or at the entrance of his dwelling.

These ancient protective devices may be viewed as the precursors of ornaments or signs used today, such as the statues of Buddha, crosses, and small boxes containing Quranic verses, usually worn around the neck, and also the signs of the cross painted above the doors of certain homes and statements such as “God bless our home,” hung on the wall.

In a society governed by demons, magic, and fetishes, individuals who possessed the power to pacify angry spirits and triumph over powerful evil forces became respected and admired. They were the priest-magicians-physicians, who rose to prominence, not only in Mesopotamia, but also in other societies. They called for the help of benevolent gods to frighten away evil spirits. In many instances they also foretold the future by observing the stars and other celestial phenomena, or by studying the liver of an animal or a fellow human being. They taught the people how to avoid forthcoming calamities. In modern religions, this function has been taken over by prophets, saints, and the clergy, who could intercede with God on behalf of people in need.

Mesopotamian society was host to such practices for some 2000 years, from the early Sumerian period until Hammurabi's rule. During that long period, magician-priests were the dominant factor in medical practices. But astrology also played an important role. The conjunction of the stars at the birth of a child was thought to determine his lot all through life as well as the time and manner of his death. This belief is still held by many people, and many prominent newspapers still publish a daily astrological column. This is

but one of many ancient myths still flourishing in our time.

Another magical concept came about from the belief that blood is responsible for all vital functions and for the continuation of life and must be provided with the proper nourishment. The liver was assumed to be the organ that receives the blood and was considered the seat of all life processes. Accordingly, when an animal was sacrificed, its liver was thoroughly examined for signs of destiny. Divinations were derived from its position, its form, and any irregularities it possessed. This concept passed unaltered from Sumerian medicine into Assyrio-Babylonian and then west into Canaanite, Hittite, and Etruscan medicine. In turn, the Etruscans passed it to the Romans. The Latin word for liver, *haruspex*, has its origin in the old Babylonian word for liver, *har*. Haruspicy, or divination using livers of animals of slain enemies, survived in Greece for several centuries after the advent of Christianity.

Various forms of magic were used to rid the patient of the invading demon. A magician-physician would wear a terrifying mask, cover himself with animal skin, and make wild noises, dance and jump, and rave until the patient laughed, a sign that the invading demon was frightened away. Did the ancient Mesopotamians discover the healing power of laughter? Another method to get rid of the demon was to set its image on fire. Often the image was shown bound, hand, and foot, its eyes pierced, and its tongues pulled out. Then the mutilated image was thrown into the fire.

Yet another method of extracting the demon from the body of the patient was to find a substitute: a lamp, a pig, or a bird. The chosen substitute was placed near the sick person, and then killed by tearing out its insides, enticing the demon to leave the patient and enter the body of the substitute. The animal was then offered to the gods as a sacrifice. Humans did not consume its meat. This notion of passing an unclean spirit from a person to an animal survived and spread west with Christianity as Jesus ordered the unclean spirit, Legion, to leave a mad man and enter a herd of swine (*New Jerusalem Bible*, Mark 5: 8–13). Based on the belief that the evil

spirit could enter a person and drive him insane, many people so afflicted were chained and put in dark caves, dungeons, or locked in a cellar, barn, or an attic to force the evil spirit to leave them. This method continued to be practiced in Europe and the Middle East well into the nineteenth century.

All medical treatments were based on the notion of forcing the evil spirits to leave the body of the patient, and all cures, regardless of their nature, were effective because they performed that function. In time the approach did change; scaring or disgusting the invading spirits gave way to pleasing and appeasing them. This was accomplished by treating the patient and therefore the evil spirits with delicious drugs, such as honey, milk, and sweet smelling herbs.

Based on their experience with irrigation and the effect of sweet water on the growth of vegetation, the Mesopotamians reasoned that water held healing powers. As this phenomenon was common and readily observable, many ancient civilizations reached similar conclusions, and sweet water became the medicine of choice, and the gods of healing in many civilizations were associated with sweet water. The Sumerian god Enki, whose abode was Apsu, the underground sweet water, was the god of healing, and so was the Babylonian god Ea, the god of the underground sweet water, and the wisest of all the gods. The Phoenician god of healing, Ashmun, was associated with the river and the pond that bears his name (the name has since been changed to al-Awwaly), and most of the Greek and Roman gods of the medical art were associated with sweet water. To wash away an ailment, the patient drank the water, sprinkled it over his head, or bathed in it. As a result many rivers, lakes, and pools became sacred and revered for their healing powers. Many still are.

When water was administered to relieve a patient from the clutches of demons, an incantation was usually chanted. One such incantation associated with the god Ea ritual reads:

With pure, clear water,
With bright, shining water,
Seven times and again seven times,

Sprinkle purify, cleanse!
May the evil Rabisyu depart!
May he step to one side!

The water was sprinkled seven times and again seven times because the number seven was considered sacred. The ancient use of sweet water as a healing commodity may have served as a prelude to Christian baptisms. Other rituals were later introduced. Among them was rubbing the patient with butter, milk, or oil while chanting the proper incantation.

During the golden age of Babylon, King Hammurabi put forth his code of law in which he detailed reward for various successful medical operations and describes penalties for failures. One such law reads, "If a physician performs a major operation on a nobleman with a bronze lancet and saves his life, or opens up the eye of a nobleman with a bronze lancet and saves the nobleman's eye, he shall receive ten shekels of silver." In Babylonian society there were three classes: nobility, commoners, and slaves. The eye of a commoner was worth half that of a nobleman's, and if a practitioner saved the eye of a slave, his reward was only two shekels.

To discourage imposters, Hammurabi put stiff penalties on failures. "If a surgeon shall make a severe wound with an operating knife and kill the patient, or shall open an abscess with an operating knife and destroy the eye, his hand shall be cut off." This was probably intended to prevent imposters from practicing medicine. Of course, penalties were less severe if the patient was a commoner or a slave. "If a physician shall make a severe wound with a bronze operating knife on the slave of a free man and kill him, he shall replace the slave with another slave. If he shall open an abscess with a bronze operating knife and destroy the eye, he shall pay half the value of the slave."

The fact that such legislation was needed in eighteenth century BCE proves that such operations were fairly common, and that the people of Babylon were enjoying the services of a class of able physicians. It also proves that empirical medicine was beginning to displace magic and exorcist medicine, but not to eliminate it. The two survived side by side for centuries, as they still do.

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Medicine in China

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The term Chinese medicine has a dual implication. It refers both to all medical systems prevalent in contemporary China and to traditional or indigenous medicine in its narrow sense (TCM for short). The former includes three medical systems: traditional, biomedical, or Western medicine as the Chinese call it, and integrated Chinese and western medicine.

Traditional Chinese medicine includes the experiences of fighting against disease, keeping fit, and seeking longevity. It was created by all nationalities of the Chinese people and is the synthesis of the medical systems of all ethnic groups. For historical reasons, TCM has been applied exclusively to the indigenous medical system created by the Han nationality. Logically, TCM should also include Tibetan, Mongolian, Korean, and Uyghur medicine and that of all other ethnic groups as well. Unfortunately, this interpretation would go against the common understanding of TCM. Hence, in this article we also use TCM in its narrow sense, referring to the Han-Chinese medical system only.

TCM has a history of at least three to four millennia. Archaeological findings reveal that the application of fire in the Paleolithic age not only brought warmth and cooked food, which was beneficial to health, but also resulted in the invention of ► [moxibustion](#) therapy. The Neolithic age also saw ancient Chinese people applying the stone knife and “needles” for treating some external diseases. These passed through a long process of evolution from stone to needles made of ► [bamboo](#), wood, porcelain, bronze, and ultimately metal. Shining gold and silver needles over 2,000-years old have been unearthed. The last kind of needle, in fact, is the basis for the invention of the unique channel system, though other factors may also have contributed (Cai, 2000). In terms of materia medica, legend has it that Shen Nong tasted and tried all kinds of plant herbs and other remedies from natural sources, beginning at the period of agriculture, about 7000–5000 BCE. People of other nationalities also discovered some effective remedies, such as wine from highland barley for stopping hemorrhages, which was used by Tibetan people, and Cistanche Salsa, Koumiss for nourishing the body, which the Mongolian people use (Cai, 2000).

Early in the Xia and Shang Dynasty (twenty-first to eleventh centuries BCE) some 3,000 years ago, some characters related to medicine were inscribed on bone and tortoise shells as oracles, including *yi* (medicine), *bing* (disease), and up to several hundred archaic characters relevant to the healing art. As early as the Zhou Dynasty (eleventh century BCE–475 BCE), medicine in the imperial court was divided into four departments: internal medicine, ulcerative (external) medicine, dietetic therapy, and veterinary medicine. TCM had already applied the four diagnostic methods – inspection, auscultation and olfaction, interrogation, and palpation (looking, listening and smelling, asking, and feeling) – by this period. Of these, palpation is the most worthy of mention. Chinese ancient physicians may have been the earliest to apply the art of pulse taking for medical purposes. In the *Shi Ji* (Historical Record), compiled by Sima Qian (b. 145 BCE), the Herodotus of China, in the Western Han

Dynasty (206 BCE-AD 24), it is recorded that the physician ► [Bian Que](#) of the Warring States Period (475 BCE-221 BCE) was the first one to apply pulse taking in clinical practice (Chen, 1957).

The most famous medical classics were compiled in the Pre-Qin period (before 221 BCE) and completed around the Han Dynasty (206 BCE-AD 220). Among them, the most important and extant ones are ► [Huangdi Neijing](#) (*Yellow Emperor's Inner Canon*), *Shennong ben cao jing* (*Divine Husbandry's Classic of Herbology*), *Nan Jing* (*Classic of Questioning*), *Shang han lun* (*On Diseases Caused by Cold Evil*), and *Jin gui yao lüe* (*Synopsis of Golden Chamber*). These lay the foundation for clinical science with definite treatment principles and diagnostics. Chunyu Yi of the Western Han (206 BCE-AD 24) Dynasty first formulated case records for the patients with a fixed pattern.

Chinese pharmacy reveals some outstanding achievements at this period. *Shennong's Classic of Herbology* presents many specific effective remedies. It sets up the theoretical basis of drug use, as well as describing collection, preservation, compounding, simple processing, and method of administration. Therapeutic effects of specific drugs, such as *rhei* for catharsis, coptis root for asthma, seaweed for goiter, mercury for scabies, and many others are mentioned (Anonymous, 1956). Their effectiveness has since been proved by modern techniques. The famous surgeon of the Later Han Dynasty (AD 25–220), Hua Tuo, first applied *mafei* powder as an anesthetic for some major operations, including abdominal surgery. As early as the third century AD, the *Mai jing* (*Classic of Sphygmology*), written by Wang Shuhe, recorded 24 kinds of pulse, touching the issues concerning heart rate, rhythmicity, condition of blood flow, texture of the artery, and the nature of blood itself such as viscosity and hemorrhology. Later, this Classic spread via Tibet and India to the Arabic countries, and it is not surprising to note that in the *Canon of Medicine* by Ibn Sīnā (980–1037), Arabic sphygmology has a lot of content in common with Wang Shuhe's. The *Classic of*

Sphygmology has been translated into several foreign languages.

From the second century AD, medical disciplines were professionalized. The following are worth mentioning: *Zhen jiu jia yi jing* (*A-B Classic of Acupuncture and ► Moxibustion*) by ► [Huangfu Mi](#), *Lei gong pao zhi lun* (*Master Lei on Drug Processing*) by Lei Xiao, and *Liu Juanzi gui yi fang* (*Liu Juanzi's Recipes Bequeathed from a Ghost*) by Gong Qingxuan, a textbook of surgery in the fifth century. Clinical medicine developed tremendously during the period of the third to tenth centuries. ► [Ge Hong](#) (265–341) was an expert in clinical medicine and a famous alchemist. His work, *Zou hou bei ji fang* (*Handbook of Prescription for Emergency*), contained discoveries on tsutsugamushi (mite-borne typhus) and smallpox, inventions for the treatment of hydrophobia by applying the brain tissue of the mad dog, and treatment of malaria by the juice squeezed from the artemisia herb, resulting in the extraction of a new effective anti-malaria remedy which is called artemisinin in modern biomedicine. Moreover, new medical techniques such as abdominal paracentesis, catheterization, first aid therapy for foreign bodies in the esophagus, and chiropractic were also introduced (Cai, 1984).

The Sui-Tang Dynasties (618–907) also saw several major medical issues. The *Tai Yi Shu* (Imperial Academy of Medicine) and the *Xin xiu ben cao* (*Newly Revised Materia Medica*) (659) are, respectively, recognized as the earliest medical university and pharmacopoeia. Several important medical works were compiled in this period, representing the improvement of medical science. Cao Yuanfang's *Zhu bing yuan hou lun* (*On Pathogenesis and Manifestations of All Diseases*) is the first elaboration on etiology, pathology, pathogenesis, and semiology in China. Sun Simiao's *Bei ji qian jin yao fang* (*Essential Recipes Worth a Thousand Gold*) contains a great thesaurus of valuable recipes for many diseases, some still in use today. Wang Tao's *Wai tai mi yao* (*Clandestine Essentials from an Imperial Library Curator*) records many effective recipes. During the Song Dynasty in the tenth to thirteenth centuries, a Jiaozheng Yishu Ju (Bureau for

Reviewing Medical Publications) and Huimin Heji Ju (Bureau of Compounding Remedies for Benevolence) were set up by the Imperial Court. What should be mentioned here is the casting of two life-sized bronze human models for acupuncture and moxibustion in the year 1026, on which the acupoints and channels were cast on their surfaces. This is not only a valuable and sophisticated work for appreciation, but also a skilled model for intuition education which greatly enhanced the development of the art of acupuncture and moxibustion.

During the Jin-Yuan Dynasties (1115–1360), four main academic medical schools appeared, namely the Schools of Cold-favoring, Spleen-Stomach Benefiting, Drastic Attack, and *Yin*-nourishing. Each had its own emphasis and advocacy, both theoretical and practical. This greatly advanced the academic development of Chinese medicine.

The academic standard of Chinese medicine was further elevated in the Ming-Qing Dynasty (1368–1910). A new school, the Wenbing Xuepai (Warm Disease School) evolved from the traditional Shanghan Xuepai (School of Disease of Exogenous Cold Evil). This new school was devoted to acute infections. It successfully tackled many infectious diseases such as B-encephalitis, acute viral hepatitis, influenza, and other viral diseases. Another outstanding contribution of Chinese medicine in this period was the invention of a human pox inoculation (variolation) from which Edward Jenner's smallpox vaccination drew its inspiration. Variolation should share the merit with vaccination in the global campaign to eradicate smallpox. The naturalist ► [Li Shizhen](#) (1518–1593) contributed his pharmacological knowledge to opening a new era in the history of Chinese materia medica. His rich knowledge on natural science aroused the interests of the evolutionist Charles Darwin, who indirectly cited many biological examples as evidence supporting his theory of evolution.

Beginning with the middle of the nineteenth century, Western medicine, so-called by the Chinese people since it was introduced by Western medical missionaries, came to China, resulting in the formation of three different academic factions

in the medical province: biomedical, traditional or indigenous, and integrative.

Through the ages, Chinese medicine applied and created a series of unique theoretical systems and practical techniques. The following is a brief introduction ([Needham, 2000](#)).

The philosophical concept of *yin-yang* is based on the observation of contradiction in nature. This was coordinated into a *yin-yang* theory for explaining the law of changes. In the medical circle, people made use of this idea to interpret the complex relationship between upper and lower, inner and outer, the body and nature and society. The equilibrium and harmony between these two aspects within the body is essential to and the base of the body's normal activities and functions. Conversely, once the harmony is broken, disorders of the body will develop, thus affecting normal physiological activities. Physiologically, *yin* refers to those tangible structures and *yang* to invisible functions. Thus blood itself belongs to *yin* while its circulation function falls under the category of *yang*. These, in TCM terms, fall under the categories of the so-called blood and *qi*. *Yin* and *yang* are mutually dependent. Without *qi*, blood will be stagnant and become a pathological entity, while *qi* attaches itself to the blood as its place to stay in. Without blood, *qi* will be "homeless." These ideas have direct bearing on the theory of treatment. Hence, *yin* and *yang* are mutually rooted, interdependent, and inversive.

Ancient philosophy states that the whole universe is constructed with five basic kinds of materials: wood, fire, earth, metal, and water. Each element has its own characteristics. As a microcosm, the human body, which is comparable to the universe, is also made up of these five elements. Like the universe, all the organs, tissues, functions, and systems can be compared with and assigned to one of the five categories. For instance, under the wood category, we have liver (*yin* viscera), gallbladder (*yang* viscera), eyes (sensory organ), sinews or tendons (tissue), sour (taste), wind (climatic factor), spring (season), anger (emotional state), and green (color). In the meantime, we have heart, small intestine, tongue, vessel, bitter, hot, summer, joy,

and red under the fire category; spleen, stomach, mouth, flesh, sweet, damp, long-summer (the last month of summer), anxiety, and yellow under the earth category; lung, large intestine, nose, hair, pungent, dry, autumn, sorrow, and white under the metal category; and kidney, urinary bladder, ear, bone, salty, cold, winter, apprehension, and black under the water category. The five categories have a dynamic rather than a static relationship, the order being wood, fire, earth, metal, water, and wood. Each category can also be conquered or restricted by another category, the order being wood (restricted by) metal, fire, water, earth, and wood. Hence we have the title Five Phases or *wuxing* with its theoretical system.

Both the *yin-yang* principle and the Five Phases theory are applied clinically for directing and interpreting physiology, pathology, diagnostics, treatment, or even prognosis, and they were proposed and completed some 2,000 years ago. The *yunqi* (activity of *qi*) or the *wu yun liu qi* (five activities and six climatic factors) theory or hypothesis investigates the influence of astronomical, atmospheric, and climatic factors on the human body and the occurrence of diseases. By five activities, it refers to the cyclic activities or movements of the five phases – wood, fire, earth, metal, and water – within the four seasons, while the six climatic factors refer to wind, cold, damp, dry, hot, and fire. This theory estimates the law of disease occurrence and yearly changes of weather with astronomy and the calendar as its parameters. In general, the yearly weather changes are wind in spring, hot in summer, damp in long-summer, autumn dry, and winter cold. Thus liver diseases are apt to occur in spring, heart diseases in summer, spleen diseases in late-summer, lung diseases in autumn, and kidney diseases in winter. The theory stressed the relations between weather and disease which, though a bit mechanical and controversial, has something to do with chrono-medicine. This theory reached its zenith a thousand years ago (Editorial Committee of Chinese Great Encyclopedia, 1992).

The theory of visceral manifestations deals with the physiology and pathophysiology of the five *yin* viscera: the heart, kidney, spleen, lung,

and liver; the *six yang* viscera: the small intestine, large intestine, stomach, bladder, gall bladder, and triple *jiao* (pancreas?); as well as the extraordinary viscera: the brain, marrow, bone, vessels, and uterus. The *yin* viscera function for the storage of essence and spirit of the body, while the *yang* viscera are responsible for the digestion, transformation, and transportation of residual materials. It is claimed that there exist mutually dependent inhibition relations among the *yin-yin*, *yin-yang*, and *yang-yang* viscera. Visceral manifestations also involve other body substances, including blood, saliva, mucus, sputum, body fluid, as well as body functions such as *qi*, spiritual forces, and genetic functions. The totality of the above-mentioned contents forms the visceral manifestations (Guangdong College of Chinese Medicine et al., 1972).

Visceral manifestations are closely tied to the theory of channels. Channels, the passages and tracts for the circulation of blood and *qi*, connect the outer with the inner part of the body and branch repeatedly to form a network spread over the whole body. Thus, through its connection, the whole body forms an organic whole. There are altogether 12 main or orthodox channels, each with its own underlying viscera, and eight extraordinary channels and collaterals and capillary networks. When channels are affected, their functions change accordingly, manifesting signs and symptoms by which a correct diagnosis can be made. Regulation of their functions through various stimulations, such as acupuncture, ► [moxibustion](#), massage, electricity, and percussing, yields therapeutic results (Guangdong College of Chinese Medicine et al., 1972).

TCM stresses the importance of recognition of etiological factors, which have a direct bearing on the treatment and prognosis of disease. Harmonious relationships among the *yin-yang* viscera themselves, and between the body and its environment, are crucial to the health of the body. All diseases occur on the basis of the disturbance or breaking down of this harmony. Diseases used to occur when the orthodox *qi* (body resistance) was defeated by the heteropathy (pathogenic evil). Orthodox *qi* is responsible for the body's resistance, preventing it from contracting a disease.

Pathogenic evils include exogenous (climatic), endogenous (emotional), and others (trauma, accidental insect or snake bites, injuries, dietetic, behavior, etc.). The relative force between body resistance and pathogenic factors determines the result of their struggle, either keeping healthy or falling ill. The aim of treatment is to support the body's resistance and remove pathogenic evils so as to keep one in good health.

There are four diagnostic methods. Inspection includes the spirit, complexion, form, and status of the patient. A tongue picture is also essential, including the texture of the tongue and its coating, the sense organs, and the condition of excreta. These provide much information about the condition of the internal viscera. Auscultation refers to hearing the patient's voice, including speaking, respiration, and smelling the odor from the patient's body and excreta. Interrogation refers to questioning the patient and other respondents about his present illness, past history, and family history. Palpation includes feeling the pulse and other parts of the body. It is sometimes said that TCM puts its main stress on pulse taking, or even relies solely on pulse taking. This is not true. TCM emphasizes that an overall diagnosis should have all four diagnostic methods interpreted comprehensively with equal importance, instead of relying on any single method (Guangdong College of Chinese Medicine et al., 1972).

The determination of syndrome manifestation (*bian zheng*) is the kernel of TCM clinical science. It is the process of analyzing the information and materials obtained from the four diagnostic methods, differentiating the causes, nature, location, stage of disease, and the reciprocal condition between the body and the pathogens. The result of this process is the identification of the type of syndrome manifestation, which is crucial to therapy. Long experience enables Chinese physicians to form an ensemble of methods, or determination of syndrome manifestations. There are many methods. The important ones are the *ba gang* (Eight Rubrics), applied for all kinds of diseases; the Triple *jiao* Method for warm infectious diseases, and the Six Channel method for diseases due to cold evil.

Among them, the Eight Rubrics method is the most important and universally applied one. Eight Rubrics denotes outer and inner (location of illness), cold and hot (nature of illness), depletion and repletion (reciprocal condition between the body resistance and pathogens), and yin and yang. Within the Eight Rubrics, the yin-yang is the key couple Rubric that dominates the other three. Furthermore, a timely, correct determination of syndrome manifestations, especially the Eight Rubrics, is the key to a reasonable and satisfactory therapy. The conception of Eight Rubrics has taken shape since the Han Dynasty (Cai, 2000).

The basic principle for treatment is the exploration of the root of disease, on which various therapeutic methods are based. The uniqueness of this is its flexibility, which varies with the analysis of the condition. Different treating measures may be given to the same disease because of different conditions manifested. Conversely, the same therapeutic measures may be administered for different diseases because of their common manifestations. The major principles include the regulation of yin-yang, supporting the body's resistance, and removing pathogenic factors. During the treatment, differentiation of the true nature and superficial manifestation, emergency and steadiness, severeness and mildness are of paramount importance (Guangdong College of Chinese Medicine et al., 1972).

Moreover, therapy and medication in TCM should be adjusted to the season, the place, and the different individual. First, changes of climate in different seasons exert definite effects on the body. During summer, the pores in the skin and neighboring tissues are open; in winter, they are contracted and closed. Hence, while treating cold disease due to wind and cold evils, therapy in the summer should not apply too many drugs of a pungent and warm nature, in order to avoid profuse sweating, or outer depletion would result. In winter, for the same cold disorders, pungent and warm drugs can be applied in substantial amounts, in order to expel the pathogens through perspiration without the risk of outer depletion. Since cold is very common in the north, for cases of external,

pathogenic disorders, one can use a heavy dose of pungent and warm drugs for dispersion of pathogens through perspiration. Applying the same principle to the southern part where weather is generally hot, only a light dose of pungent and warm drugs can be used, to avoid profuse perspiration. Thirdly, all patients vary in sex, age, and body constitution. Moreover, women have the added complications of child-bearing, menstruation, and vaginal discharge, while children have tender and delicate visceral systems. These conditions should be taken into account and carefully considered when prescribing. For instance, with a patient who is sensitive to cold with a constitution of cold tendency, cool or cold drugs should be used with caution, and vice versa for those of hot tendency.

As to concrete treating measures, basically there are eight therapeutic methods: diaphoresis, emesis, catharsis, mediation, warming, clearing, removing, and benefiting. All these methods are applied not only for drug therapy, but also for non-drug therapies such as acupuncture, ► [moxibustion](#), massage, and others (Guangdong College of Chinese Medicine et al., 1972).

In terms of Chinese materia medica, all the drugs applied are natural products, including those from the plant and animal kingdoms as well as minerals. Most of the pharmacological knowledge is derived from practice. Pharmacological theory is summarized, again on the basis of experience. The theory is also unique. It claims that the potential of the drug comes from its “nature,” composed of four *qi* and five flavors. The four *qi* are cool, cold, warm, and hot, while the five flavors refer to sour, salty, sweet, bitter, and pungent. The theory also includes channel tropisms, the functions of ascending, descending, floating, and sinking, as well as the toxicity of drugs. The nature of drugs is relevant to the condition of the disease as determined by diagnosis through differentiation of syndrome manifestations within the Eight Rubrics. Antagonistic therapy such as cool or cold drugs for heat disease, and warm or heat drugs for cold disease, is commonly used. Drugs with ascending nature are applied for heat disease of “collapsed”

nature, such as gastroptosis and the like, whereas drugs with descending nature are applied for disease of uprushing or adverse ascending flow of normal *qi*, such as hiccup, belching, vertigo, dizziness, and rushing up of liver fire. The channel tropism of drugs is directly related to the channel attribution of disease. For instance, the primordial stage of influenza falls under the category of Taiyang Channel disorders; hence, drugs of Taiyang Channel tropism are to be applied. Compatibility of drug compounding and toxicity of drugs are all highly stressed in Chinese pharmacy. Precautions when administering drugs are also unique. The breaking of necessary precautions would lead to failure of even a correct treatment. All the drugs are prepared in various forms, including decoction, powder, paste, pills, bolus, ointment, patent drug, and also modern drug forms like injection and aerosol. TCM also pays attention to the time of taking drugs, claiming that this has a direct bearing on the chrono-physiology of the body and on its therapeutic efficacy.

The ingredients for compounds of Chinese medical recipes are differentiated into the “king,” “ministers,” “assistants,” and “servants.” The aim of this compounding is to focus on the mutual synergic and detoxifying action among the ingredients. As a result, the effect is much more satisfactory than single drug administration, and the toxicity is much ameliorated or even eliminated.

Acupuncture and moxibustion are special treating techniques as well as health care measures in TCM. Acupuncture refers to the needling of specific loci, the acupoints for stimulation, to regulate the disharmonious state and arouse the resistance potential of the body. Moxibustion refers to the application of heat stimulation with a moxa roll or cone on the point or affected site instead of using a needle. As soon as the body is stimulated by these means, the afflicted *qi* and blood inside the channels and viscera are improved, activated, and regulated. Pathogens are expelled or eliminated, and normal physiological function is restored. The basic idea of acupuncture-moxibustion is also established on the same principles as

TCM, i.e., treatment based on the differentiation of syndrome manifestations, although it also has its own special demand such as manipulation techniques.

Massage and qigong exercise are also integral parts of TCM. The former is performed by specific manipulation techniques on acupoints or specific locations, while the latter is a self-care method in which the patient consciously controls his/her own mind, body, and the circulation of *qi* through controlling one's breathing movement. It is said that a proficient exerciser may even direct the flowing of *qi* in his/her own body at will.

TCM pays attention to disease prevention, or so-called "treating pre-illness" in the Chinese term. Various measures are proposed for this purpose, among them self-care massage, Daoyin, Taiji boxing, hygienic measures, and breathing exercises.

Since the basic conception of traditional Chinese medicine took its shape several thousand years ago, it applied concepts which are rather abstract and vague, not tangible or perceptible, let alone quantitatively estimated. To meet the needs of modern investigation and understanding, over the decades TCM workers have been encouraged to integrate and interpret their knowledge by modern scientific concepts, means, and techniques. A new school, the School of Integrated Traditional and Western Medicine, has thus emerged. This has become one of the modern trends in the development of China's medical science (Cai, 2000).

See Also

- [Acupuncture](#)
- [Bian Que](#)
- [Five Phases \(Wuxing\)](#)
- [Ge Hong](#)
- [Huangdi Neijing](#)
- [Ibn Sīnā \(Avicenna\)](#)
- [Li Shizhen](#)
- [Medical Texts in China](#)
- [Moxibustion](#)
- [Shanghan Lun](#)
- [Yinyang](#)

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Medicine in China: Forensic Medicine

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Forensic medicine refers to that part of medical science pertaining to legal and political affairs. In order to provide materials and evidence for trying and investigating cases, the discipline of forensic medicine deals with the issues of reconnoitering the scene, surveying the cadaver, and studying the material evidence, poisonous substances, and other relevant items.

Chinese medico-jurisprudence makes its appearance in the Warring States period (475–221 BCE). *Li Ji* (Record of Rituals) and

Lüshi Chun Qiu (Master Lü's Spring and Autumn Annals) both mention "investigating the wounds and trauma, inspecting and analyzing cases, reconnoitering and judging, and making decisions on lawsuits with justice." In 1975, some ► **bamboo** slips, later entitled "Qin Slips from Yunmeng," were unearthed from Yunmeng, Hubei Province in China. Within the slips, legal articles of the Qin Dynasty (221–207 BCE) and criminal cases were recorded. About 7 of the 22 cases involved forensic medical jurisprudence, in which killing, hanging to death, chopped-off heads, abortion due to trauma, and leprosy are included with records from the scene. Foot, hand, and knee prints, as well as blood and stools are mentioned. Circumstantial descriptions are given on the differentiation between homicide and suicide by hanging. All these demonstrate that achievements in legal medicine appeared as early as 2000–3000 years ago (Jia, 1980).

The earliest extant Chinese feudal code, *Tang Lü* (Law of the Tang Dynasty) was promulgated in 653 AD. This stipulates that when investigating fake illness, feigned death and injuries, false or incorrect reports will result in punishment in a grade next to that given to the swindler. For victims of illness, death, or injuries, a fake report would be given punishment equal to that of the sufferers themselves. Issues pertaining to autopsies of legal medical cases, including the severity of injury, fake illness, self-mutilation, administering abortion, disability, age, and critical diseases are also mentioned (Jia, 1984).

Medical jurisprudence developed a step forward in the Song Dynasty (960–1279). First, the officials responsible for the investigation of cases are stipulated in writing, saying "for examining cadavers *Canjun* (Adjuvant) at the provincial level and *Xian Wei* (district defendant) at the county level are responsible. In case *Xianwei* is absent, officials of *Bu* (appointee), *Cheng* (aide), and *Jian* (director) will be responsible in that order. The county governor himself should be responsible when all these staff members are absent." Regulations for responsibility and dereliction of duty, such as when those officials in charge are inaccessible, when there is a delayed presence at the scene, or when the wrong decision

for the cause of death is made are also stipulated. *Gemu* (Pattern Catalog), a compulsory regulation for the examiner, is mandated to avoid malpractice; this is claimed to be an important achievement in this field. This rigorous system for examination offers a firm basis for the advent of the prominent monograph on legal medicine, *Xi yuan ji lu* (*Collected Records of Washing Away the Wrong Cases*) and other similar works. Prior to these monographs, other works on legal medicine made their appearance, including *Nei shu lu* (*Record of Forgiveness*) and *Jian yan fa* (*Method for Examination*), which were unfortunately all lost. *Xi yuan ji lu* is an epitome of the achievement in the discipline of Chinese medical jurisprudence. Its merits include records on (Song, 1936 Rpi).

- The occurrence and distribution of cadaver speckle
- Conditions influencing the advent of putrefaction
- The relationship between the cadaver manifestations and the duration after its death
- Types of rope used for hanging
- The features of strangulation and how to differentiate those from self-hanging for suicide
- The difference between drowning and suffocation by compressing someone's nose and mouth
- The difference between fractures before and after death
- The determination of fatal wounds and
- Various methods for determining different causes of death

During the Yuan Dynasty (1271–1368), a formal pattern for examination of Confucian officials was announced. This is entitled *Jie an shi* (*Pattern for Winding Up a Case*). It deals with issues relating to medical jurisprudence, including examination of the cadaver, biopsies for wounds and illnesses, and material evidence. This monograph is the first to combine the three integral portions of medical jurisprudence into a whole.

The Chinese made a significant contribution to legal medicine. Important Chinese monographs

on legal medicine including *Xi yuan ji lu ping yuan lu* (*Reassuring the Wrong Cases*) and *Wu yuan lu* (*Free of Wrong Cases*) were translated into many foreign languages, including Korean, Japanese, French, German, Dutch, and English (Jia, 1984).

After 1911, performing autopsies became legal. When procurators and police officers are unable to ascertain the causes of death with a cadaver, an autopsy is performed by a medical practitioner rather than by the old-style *Wu Zuo* (cadaver examiner). This procedure is rigorously regulated.

The first Department of Forensic Medicine was established in the Medical College of Peiping University in 1930, while the First Institute of Forensic Medicine was established in Shanghai in 1932, and a *Medical Jurisprudence Monthly* was first published in China in 1934. A wealth of forensic medicine professionals has been cultivated, in order to increase public security and justice (Jia, 1984).

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Medicine in India: Āyurveda

Guy Mazars

Āyurveda or ‘the knowledge (*veda*) for longevity (*āyus*)’ is an ancient medical system whose main theories were already fixed more than 2,000 years ago. It has roots in the *Veda*, especially the *Atharvaveda* (Mazars, 1991; Zysk, 1996), and the conceptions of the ancient ayurvedic physicians have played a great role in the general

culture of India and have spread everywhere in Asian countries. With Buddhism, Āyurveda travelled to Sri Lanka, Nepal, Tibet, Central Asia and as far as Japan, and it reached Indonesia with the Hindu culture and civilization (Filliozat, 1934).

The legends related by the ancient Sanskrit medical texts make of this system a revealed ‘science’, annexed to the *Veda* sometimes as an ‘annexed member’ (*upāṅga*) of the *Atharvaveda*, sometimes as a ‘sub-veda’ (*upaveda*) of the *Rgveda*. Created by Brahman and transmitted to men by the successive interventions of Prajāpati, the Aśvins and Indra, this science is theoretically divided into eight branches:

1. General surgery (*śalya*)
2. Surgery of the head and the neck (*śālākya*)
3. Internal medicine (*kāyacikitsā*)
4. Toxicology (*agadatantra*)
5. Demonology (*bhūtavidyā*)
6. Obstetrics and paediatrics (*kaumārabhr̥tya*)
7. Tonic medicine (*rasāyana*)
8. Aphrodisiacs (*vājīkaraṇa*)

In fact, very few ancient texts follow this division which has been particularly in vogue among more recent authors. As regards their content, it represents in reality the fruit of the activity of medical observation and speculation in the course of the seven or eight centuries which preceded the Christian era. Unfortunately the documents going back to this period that are properly medical have disappeared, and they have been supplanted by more recent texts.

Source Texts

The classical doctrine of Āyurveda is already expounded in two famous treatises dating from the beginning of the Christian era, the *Carakasamhitā* or ‘Caraka’s Compendium’ (Sharma, 1981–1994) and the *Suśrutasaṃhitā* or ‘Suśruta’s Compendium’ (Bhisagratna, 1963), which are the oldest Sanskrit medical texts that have come down to us (Wujastyk, 1998).

Although these two works agree remarkably in their general teachings, they are too different for us to suppose that one may be an imitation of the other. But they manifestly rely on the same older doctrinal heritage. These two texts were the object, from a period even earlier than the tenth century, of very elaborate commentaries whose purpose was to clarify and add precision to their contents (Filliozat, 1964).

Later texts of great importance include the *Aṣṭāṅgaśāstrasamhitā* of ► **Vāgbhaṭa** (ca. AD 600), the *Mādhavanidāna* of Mādhavakara (ca. AD 700), the *Śārṅgadharasamhitā* of Śārṅgadhara (thirteenth or fourteenth century) (Murthy, 1984) and the *Bhāvaprakāśa* of Bhāvamiśra (sixteenth century). Vāgbhaṭa is the most celebrated author after ► **Caraka** and ► **Suśruta** (Hilgenberg & Kirfel, 1941). His identity has been the subject of unending discussion, and Indian critics hold that there was an ‘elder Vāgbhaṭa’ in addition to ‘Vāgbhaṭa’, grandson of the former and son of Siṃhagupta. In the *Mādhavanidāna* or ‘Aetiology According to Mādhava’, the author treats causes and symptoms of different diseases, by taking up in a systematic manner the data of Caraka, Suśruta and Vāgbhaṭa (Meulenbeld, 1974; Murthy, 1993). The *Mādhavanidāna* was the object of numerous commentaries, which proves that the treatise achieved considerable fame. Of considerable interest is the *Śārṅgadharasamhitā*. Śārṅgadhara is the first author to discuss several new elements, including diagnosis by pulse (Murthy, 1984). He also gives for the first time detailed information on many previously undocumented medical procedures, especially regarding the preparation of remedies. In fact, the main subject of the work is pharmaceuticals (Sharma, 1979). A whole section deals with pharmaceutical forms, giving exemplary formulations under each category, and adding new drugs and new techniques. Many recipes from Śārṅgadhara’s *Compendium* are still in use. There are also divergences between the nosological system of the *Mādhavanidāna* and the nosology described in the *Śārṅgadharasamhitā*. New names of diseases are mentioned in the texts. Syphilis is described

for the first time, under the name of *phiraṅgaroga*, in the *Bhāvaprakāśa* of Bhāvamiśra (sixteenth century). Alongside the great classical treatises and their commentaries there exists an abundant medical literature that comprises other general texts, specialised manuals and repertories of *materia medica* (Mazars, 1995b).

Philosophical Foundations of *Āyurveda*

The conceptual edifice of *Āyurveda* rests on ideas which are those of the *Sāṃkhya* philosophy, a system of thought having as its basis the analysis and classification of the constituents (*tattva*) of the world. It is not known in fact which of the two systems influenced the other. Some authors consider that ayurvedic doctrines are older than *Sāṃkhya* whose basic text is the *Sāṃkhyakārikā* or ‘Stanzas of *Sāṃkhya*’ (fourth century?). However that may be, according to ayurvedic treatises as well as according to *Sāṃkhya*, the human body is composed of the same basic elements (*bhūta*) that constitute the universe: earth (*pṛthivī*), water (*ap*), fire (*tejas*), air (*vāyu*) and void (*ākāśa*), represented, respectively, by the solid parts, the liquids, the body heat, the breath and the emptiness of the hollow organs (Filliozat, 1964). The combinations of the five basic elements form the differentiated substances of the body, the *dhātu*, seven in number: chyle or nutrient fluid (*rasa*), blood (*rakta*), flesh (*māṃsa*), fat (*medas*), bone (*asthi*), marrow (*majja*) and semen (*śukra*).

As it is described in the great treatises of Caraka and Suśruta, ayurvedic medicine distinguishes itself explicitly from empiricism, magic and religion. For, the conditions for the validity of the observations and reasoning which are at the root of diagnosis, prognosis and treatment interested the ayurvedic circles very early. Thus, the *Carakasamhitā* contains a teaching of logic intended to guide the future physician in his reasoning. Long passages and allusions appearing in various parts of the treatise constitute the exposition of this logic. The most systematic passages

are found in Chaps. IV and VIII of the section of the *Carakasamhitā* entitled *Vimānasthāna*. This logic, allied to the classical Indian logic, the Nyāya, acknowledges three methods of judgement (*pramāṇa*): the teaching of those who are accepted to be an authority (*āptopadeśa*), observation (*pratyakṣa*) and inference (*anumāna*) (Mazars, 1995b). There has been much discussion concerning the relationship between Āyurveda and the philosophical system of *Vaiśeṣika*, which has as its object the study of the special characteristics of things, their *viśeṣa*. The *Vaiśeṣikasūtra*, which constitutes the reference text of this school, dates from the early centuries of the Christian era, but its contents seem to show older interpolations.

Ayurvedic View of the Body

The anatomical nomenclature of Āyurveda is rich, but the notions covered by them are fairly rudimentary, especially as regards visceral anatomy. However, the value of opening corpses was known and the *Suśrutasamhitā* (Śārīrasthāna, V, 49–56) even describes a procedure of dissection closely resembling the procedure of *hydrotomy* suggested by Lacauchie in the nineteenth century (Lacauchie, 1853). As the conceptions of the brahmanical moral code were opposed to true methodical dissections of well-preserved cadavers (Zysk, 1983), anatomical knowledge remained scanty. Hence, errors and lacunae are numerous in the lists of organs furnished by the ancient medical texts. Osteology is fairly important in Indian anatomy (Hoernle, 1907), but it holds out little interest as regards the constitution of the medical doctrines.

The hollow organs or 'receptacles' were better known. The stomach is called the 'receptacle of the uncooked' while the intestines are the 'receptacle of the cooked'. The gall bladder is the 'receptacle of the bile', the bladder that of the urine and the uterus that of the embryo. In fact, among the organs, the best described are those on which surgical operations were performed: the rectum, the uterus and the bladder. Today limited to minor operations, such as

bone setting and to reductions of dislocations and fractures, ayurvedic surgery was once probably the most remarkable in Euro-Asiatic antiquity. The *Suśrutasamhitā* mention various operating techniques (incision, excision, scarification, puncturing, catheterisation, extraction, draining and stitching of wounds) as well as instruments and accessories. The *Suśrutasamhitā* also describes surgical operations which reveal the great daring of the surgeons of that period: the lowering of cataracts with a needle, grafts for repairing the nose and the earlobe, perineal lithotomy for extracting vesical calculi, resection of scrotal elephantiasis, Caesarean section, surgical removal of a dead foetus from the womb.

The *Carakasamhitā* and the *Suśrutasamhitā* even teach a very daring procedure for intestinal sutures which avoids the use of non-absorbable threads whose intolerance by the tissues had been recognised. This procedure consists in bringing the edges of the wound together and having them bitten by black ants. The bodies of the ants are then cut off from the head, whose mandibles serve as staples. It only remains thereafter to close up the abdomen by ordinary suture. This was the procedure in case of laparotomy for penetrating wounds of the abdomen and for intestinal occlusion. But instances of success must surely have been rare. One of the commentators on the passage quoted above observes moreover that the outcome of the operation was very uncertain. That was no doubt why the method is no longer taught in the later treatises.

The Indian surgeon had above all to know the 'vulnerable regions' (*marman*), injury to which is either fatal or particularly serious. The notion of *marman* goes back to a Vedic conception. The word is derived from the root *MR*, which means 'to die', and denotes above all a lethal point. The classical treatises, which carefully catalogue these bodily zones, describe them as seats of vital energy. They list 107 of them divided into five categories according to their location (flesh, pipes, ligaments, bones and joints) and into five categories according to the seriousness of the harm resulting from injuries to them. The details given by the texts enable us to locate them fairly easily. They are anatomical

reference points corresponding most often to big vessel-nerve bundles, tendons or important nerve ganglia, injuries to which are serious because of haemorrhage, paralyses or disabilities that they cause.

Representations of the Vital Functions

In the ayurvedic system, the totality of the transformations undergone by the seven organic substances (*dhātu*) is governed by the combined play and balance of wind, fire and water, present and active in the body in the form of three vital principles. Indeed, wind, the essential motive force of the Universe, is also that of the body in which it is represented by the 'vital breath' or *prāṇa*, which is localized mainly below the navel. 'Fire' is represented by a principle which collects in the form of 'bile' or *pitta*, which is localized between the heart and the navel. As regards water, it is found in the form of *kapha* or *śleṣman*, 'phlegm', a substance common to all the bodily serous fluids and secretions, which is localized in the chest. Each of these three principles acts by assuming five secondary forms which correspond to the different vital functions. Their action works towards a complex and autonomous process of balancing which maintains the organism alive (by the constant renewal of its constituents) and in good health. These Indian ideas are very close to the notion of *homeostasis*, already anticipated by Claude Bernard during the nineteenth century and which Walter Cannon (1871–1945) described as the totality of organic processes which act to maintain the stationary state of the organism, in its morphology and in its internal conditions, despite external disturbances.

Of the three principles, it is the organic wind, under its different forms, which is considered the most important vital element. According to the *Carakasamhitā* (Sūtrasthāna, XII, 8), it ensures by its action the ingestion, digestion and assimilation of food, the differentiation of the organic substances and their distribution, as well as the internal circulation of the fluids, respiration and movements, covering in this

way a number of aspects of functioning attributed today to the nervous systems. The seven *dhātu* contain a liquid principle which makes them alive and which is named *ojas*, i.e. to say 'strength'.

Psychological Conceptions

Psychological conceptions play a fundamental role in the teachings of *Āyurveda* (Rosu, 1978). The connection between the body and the mind is asserted in the most direct manner by the Sanskrit medical texts: 'The body is governed by the psyche and the psyche by the body' (*Carakasamhitā*, Śārīrasthāna, IV, 36).

It is interesting to note that, according to *Āyurveda*, the psyche represents the contribution of the previous existences of the incorporated soul. This is entirely in conformity with the Indian theory of *karman* (karma) which has become the central dogma of Hinduism. The word *karman*, derived from the root *KṚ*, 'to do', means 'action', but denotes also the results of the good and bad actions in the form of merit or demerit, the inexorable consequence of acts accomplished in previous lives. By affecting the *sūkṣmaśarīra* or 'subtle body', or in other words the psychic individual, the 'Self' (*ātman*), the permanent and unconscious substratum of the human being, *karman* obliges him indefinitely to undergo a new birth in a human or other form, determined by the quality of his past acts.

The observation of the relationship between the body and the mind has led Indian physicians to notions of personal temperament and physiognomy. Ayurvedic biotypology is based on two criteria, one constitutive and the other psychological. The first typology describes three kinds of temperaments based on the predominance of one of the three vital principles: the 'windy', the 'bilious', the 'phlegmatic'. The second typological system of *Āyurveda* categorises the individuals according to the properties (*guṇa*) of the mind. The ideal standard of behaviour is that which corresponds to a predominance of *sattva*, 'purity', according to the *Sāṃkhya* philosophy.

Diseases and Pathology

According to *Āyurveda*, diseases (*roga*, *vyādhi*) are of two kinds, exogenous and endogenous (Sharma, 1992). The former are caused by damage from outside (blows, injuries, bites, falls, burns, etc.). All the others represent an imbalance of the *dhātu* (*dhātvaiṣāmya*), or in other words disturbances in the normal balance of the elements which constitute the substance of the body and which animate it. 'Wind, bile and phlegm, in the normal state, enable a man to have a long life, with his faculties intact, endowed with vigour, good appearance, and health... But, if they become abnormal, they lead him to great adversity...' (*Carakasamhitā*, Sūtrasthāna, XII, 14).

That is why this triad of vital elements has been given the name of *tridoṣa*, the 'three vitiating factors'.

The conditions of perturbation of their functions are complex in most cases. The alteration of just one of these elements or just one of its secondary forms can unleash a disease by virtue of the disturbances resulting in the functioning of the others. Often two among them or even all three of them are simultaneously involved, in varying degrees, in the production of different ailments. Hence there are a very large number of pathogenic combinations. The perturbations of 'wind', 'bile' and 'phlegm' can in their turn affect the *dhātu*, the joints or the vascular system. The elements, the tissues and the organs interact, and imbalance of the ones leads to imbalance of the others. Some parallels have often been drawn between ayurvedic ideas and some of the data from Greek medicine. The text *Airs* of the Hippocratic Collection describes a pathology by the association of blood and 'wind', which brings to mind the theory of the *Suśrutasamhitā* relating to the pathogenic role of 'wind-blood'. Furthermore, there is a remarkable analogy between the doctrine of the *tridoṣa* and a theory described by Plato at the end of his *Timaeus* (Filliozat, 1964).

The perturbations in the functions of wind, bile and phlegm are themselves related to multiple causes called *nidāna* which are looked for mainly in the behaviour of the patient and his

food, having regard to external circumstances. Dietary deviations are often criticised.

Nosology is highly developed. It categorises the diseases sometimes according to their supposed origin and sometimes according to the nature of their symptoms. We also find them divided in another way, according to whether they affect the chyle, the blood, the flesh, the fat, the bones, the marrow or the semen.

Diagnosis and Prognosis

To identify an ailment, to know its stage of development as well as the part which should be ascribed to each *doṣa* in its production, the ayurvedic practitioner must undertake a minute examination not only of the body of the patient, but also of his mental state. The methods of examination must bring into play all five senses.

The practice of the examination of the pulse, common today in ayurvedic medicine, does not seem to have appeared before the twelfth century. The idea of examining the pulse might have been borrowed from China, but the technique attested in India is different and what one expects to learn out of this examination is not what the Chinese physicians look for. Indeed, by taking the pulse the Indian physician claims to recognise the disturbances in the equilibrium of the three vital principles, 'wind', 'bile' and 'phlegm' and in this way he diagnoses all the ailments. The interpretation of the various pulses is connected therefore to the ayurvedic theory of the *tridoṣa* (Kutumbiah, 1967).

The palpation is done by bringing the tips of the index finger, the middle finger and the ring finger close to each other and applying them on the radial artery of the right wrist for men, and the left wrist for women. The texts distinguish several types of pulse according to the amplitude of the pulsation (strong, weak or very weak pulse), the frequency (regular, rapid or slow pulse) and the temperature (hot or cold pulse), whose variations are presumed to reflect the activities of the three *doṣa*.

Questioning the patient and his family circle complements the various examinations. The

purpose of this questioning is not only for the physician to gain information about the circumstances in which the first symptoms appeared and the development of the ailment, but also about the personality of the patient, his activities, his food and his appetite, having regard to the season, the climate and, of course, the psychological context in which the sickness began, for Āyurveda cares for the whole human being, both his soul and body. According to these ideas, each patient should be treated holistically. Today, however, it is rare to find ayurvedic practitioners who will prepare remedies specific to particular patients. The *Carakasamhitā* indicates that the patient should also be questioned about his dreams.

In ancient times, the establishment of the prognosis concerning the curability or the incurability of a disease depended more often on the divining art than on medical science. Thus, one claimed to foretell the outcome of a disease according to the language, the clothes and the attitude of the messenger who came to fetch the doctor, or else according to the direction of the wind blowing at his arrival, or else according to the dreams of the patient. The anomalies that may be noticed in the sensations of the patient were generally regarded as bad signs. Other fatal indications could be drawn from the change in his complexion.

Preventive Medicine

Of all the ancient medicines, it is probably ayurvedic medicine which, from its origins, has accorded the greatest importance to hygiene, to diet, to physical exercises and to massage, both as means of prevention and as curative methods. The rules of hygiene and of diet were already extremely numerous and elaborate in the treatises of ► *Caraka* and ► *Suśruta* who devote several chapters to them. These rules take into account not only the climate, the season and the circumstances, but also the temperament of each individual.

In the chapters relating to prevention, the *Carakasamhitā* (Sūtrasthāna, VII, 31–34) emphasizes the benefits of physical exercise

(*dehavyāyāma*). It is said there that gymnastics makes the body light, increases its capacity for work, diminishes the *doṣa* and stimulates the ‘digestive fire’. But it must be practised with moderation.

The oldest Sanskrit texts lay stress on the importance of a well-balanced diet, both from the quantitative and the qualitative points of view. According to the *Carakasamhitā*, the quantity of food depends on the capacity of digestion (*agnibala*, literally ‘strength of the fire’), so much so that even foods considered as very easy to digest must not be consumed in excessive quantities. The medical texts systematically enumerate all varieties of edible products indicating their different properties, according to the temperament, behaviour and state of health of each individual, having regard also to the season, the time of the day, the quality and the quantity of the food taken. Thus, some foods recommended for cold and rainy weathers are strongly inadvisable during summer; a drink that is safe for a healthy individual carries the risk of complicating an already morbid condition, etc.

Āyurveda emphasizes also the benefits of tonics and stimulants, the *rasāyana*, and of aphrodisiacs, the *vājīkaraṇa*. The *vājīkaraṇa* are believed to increase the strength of those who are weakened and whose virility is low. These are most often preparations based on sesame, broad beans (*Phaseolus radiatus* L.), sweet potatoes (*Ipomea digitata* L.), sugarcane juice, long pepper (*Piper longum* L.), emblic myrobalan and milk, in combination with the testicles of goats, buffaloes or donkeys. The roots, bark, buds and fruits of the *aśvatha* tree (*Ficus religiosa* L.) are also used. As regards the *rasāyana*, they are elixirs which are expected to confer long life, health and youth. The *Carakasamhitā* gives very detailed instructions for their preparation. One of the most famous is the *Cyavana Prāśa* in the compounding of which more than 30 ingredients figure.

The choice of a therapy depends not only on the disease diagnosed, but also on the causes which are attributed to it in relation to the excessive activity or improper functioning of the three vital principles (wind, bile and phlegm),

the temperament and the environment of the patient. Ayurvedic treatments are therefore individualised and they give great importance to prescriptions of diet and hygiene.

‘Pañcakarma’ Therapy

Pañcakarma therapy is considered the method of treatment *par excellence* for restoring the normal balance of the three vital principles. Under this name are grouped ‘five procedures’ (*pañcakarman*): the administration of emetics (*vamana*), purgatives (*virecana*), enemas (*basti*), errhines (*nasya*) and bloodletting (*raktamokṣana*).

Vamana consists in orally evacuating the *doṣa* in excess by prescribing emetics in cases of ailments attributed to disorders of the ‘phlegm’. They are contraindicated in the case of consumptive disease, in case of weakness and for children, the aged and pregnant women.

Purgatives are administered for eliminating by the lower tract the impurities accumulated in the intestines. Purging is indicated in the case of diseases that result from an imbalance of the ‘bile’: fever, skin disease, digestive disorders, urinary disorders, eye diseases, etc. It is contraindicated for children and old people, as well as for pregnant women. Enemas are intended to purify the organism. The process owes its name to the bladder (*basti*) used for introducing various medicinal preparations into the body. Rectal injections are especially indicated in case of fever, diarrhoea, constipation, colic and flatulence.

Āyurveda recommends taking medicinal preparations through the nose (*nasya*) to rid the head and the neck of the problems which are located there. The prescriptions are powders and nasal drops whose choice, time of administration and dosage depend both on the condition diagnosed and the vital principle (wind, bile or phlegm) involved in its production.

Bloodletting is for ridding the organism of ‘polluted’ blood and for combating in this way various diseases for which blood is thought to be the seat, or the source, in particular diseases of the skin. Anaemia, pregnancy, fatigue and old age

constitute the major contraindications. Bloodletting can be carried out by means of lancets or by the application of leeches.

Besides these five ‘principal measures’ (*pradhānakarman*), *pañcakarma* therapy also includes preliminary measures (*pūrvakarman*). Patients are prepared by being oiled and sweated.

Drugs of Natural Origin

Most of the drugs recommended by Āyurveda are plant-based. In the course of the centuries, ayurvedic medicine has used more than 3,000 plant species of which a good 1,000 still enter, in various forms, into the composition of the remedies prescribed today. One notes also the use of a certain number of substances of animal or mineral origin. Among the animal products figure foods of animal origin, meats, fats, milks and derivatives, as well as blood, bones, nails and horns. The medical texts speak highly also of the beneficial effects of human urine and that of different animals. Goat’s urine, for example, is particularly recommended in cases of cough, breathlessness, icterus, anaemia or haemorrhoids. Horse’s urine, pungent, caustic and warm, is especially indicated in cases of perturbations of wind or phlegm. As regards human urine, it has been used in salves for treating certain eye affections. The mineral products of the ayurvedic pharmacopoeia comprise notably bitumen, arsenic, copper sulphate, gold, silver, lead and iron. The last mentioned was used very early, in the form of powder, in the treatment of anaemias.

All these natural substances have contributed to the manufacture of thousands of remedies often involving very complex formulas. This complexity of the compositions is explained simultaneously by ayurvedic pathology, by the complexity of the cases to be treated and by the concern for combining the different ingredients in such a way as to counterbalance, increase or prolong the effects of some by the properties of the others.

The forms of drug delivery are varied: powders, infusions, decoctions, macerations, electuaries, pills, liniments or ointments. Apart from

aqueous preparations, the usual vehicle is oil or clarified butter (*ghṛta* or ghee), but milk and honey are also used. As regards the methods of administration of these remedies, they depend on the nature of the medicine and/or the location of the disease. A certain number of preparations are administered orally, through the nose or through the rectum (enemas, suppositories). Others are reserved for external use.

In order to explain the properties of the different substances and their effects on the organism, Indian physicians of antiquity developed theories which apply as much to food as to plants and to the substances of animal or mineral origin in the pharmacopoeia. For that reason they were very early led to establish correspondences between the vital principles and the simplest perceptible properties of these substances such as their consistency, their odour, their colour and above all their savour (Mazars, 1995a; Meulenbeld, 1987).

According to *Āyurveda*, there are six basic savours: sweet, sour, salt, pungent, bitter and astringent. For a long time modern physiology only recognised four of them (sweet, sour, salt and bitter), but no one ever thought of verifying their primary character experimentally. In fact we know today that there is no basic savour. *Ayurvedic* medicine teaches that substances with a sweet, sour or salt savour calm the wind but irritate the phlegm. On the contrary, those which are pungent, bitter or astringent combat the harmful effects of the phlegm but excite the wind. As regards the activity of the bile, it is reduced by sweet, bitter or astringent substances and increased by sour, salt or pungent substances.

Of the six savours distinguished by *Āyurveda*, the sweet savour appears to be most important, for it has been thought to contribute to long life. But an excess of remedies or foods with sweet savour, by perturbing the 'phlegm', provokes obesity, promotes laziness, weakens the power of digestion and leads to all kinds of diseases.

Observing that some foods and remedies do not provoke the effects proclaimed by the theory of savours, the theoreticians of *Āyurveda* sought other explanations to account for the properties of all the substances. They were thus led to establish for each substance:

1. Its 'post-digestive' [*vipāka*, literally 'after cooking' (by the 'digestive fire')] effect, which flows from its savour.
2. Its 'quality' (*guṇa*). There are 20 *guṇa*, one opposing the other, as follows: heavy or light, dull or sharp, cold or hot, unctuous or not unctuous, smooth or rough, solid or liquid, soft or hard, stable or fluid, subtle or gross and non-slimy or slimy.
3. Its 'potency' (*vīrya*). Drugs are divided into two categories depending upon their potency: heating or cooling. Substances having 'hot' potency produce heat in the body. On the contrary, the substances having 'cold' potency have a cooling effect.

Finally, to explain the exceptions to these rules, the notion of *prabhāva* or 'specific action' was developed. These different conceptions conditioned the methods of choice, recommendation and preparation of foods and the medicines.

Āyurveda is the result of long medical observation, speculation and practice, and has exerted a great influence far beyond the frontiers of the Indian world. The underlying concepts of this system relating to health and disease are not devoid of interest. The examination of the data collected in the earliest Sanskrit medical texts shows that the physicians of ancient India visualised living beings in a way that we might qualify today as *systemic*. Humans (as well as animals) are considered an open system according to a concept fairly close to that developed by Ludwig von Bertalanffy (1901–1972), a system exchanging matter, energy and information continually with its environment (von Bertalanffy, 1968). *Ayurvedic* medical practice is also marked by systemic thought. Its overall objective is to maintain the normal balance of the vital principles responsible for the proper functioning of the organism or to re-establish this balance when it is disrupted. Thus, *Āyurveda* appears as a system which gives greater weight to prevention than to treatment, giving great importance to hygiene, food and environment whose decisive role in triggering certain diseases is being discovered today.

See Also

- [Medicine in China](#)
- [Nyāya](#)

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Medicine in Islam

Husain F. Nagamia

Preservation of life is mandated by the following verse of the Qur'ān: "The saving of one life is as if one has saved humanity."

From the earliest times in the history of Islam, medicine has played a vital role. The importance of seeking treatment was emphasized by the Prophet himself in his sayings, which are known as the Ḥadīth: "Allah never created a disease for which he did not create a cure. So seek treatment." "There is a cure for every malady (except old age). If the right treatment is administered, Allah willing the malady is cured."

All the religious scholars agree that a medical doctor is ordained to find a cure for a disease and if one is not found, he should continue to do research until it is found. Thus in Islam disease is not looked upon as a curse from God to be endured and suffered but as an affliction for which a cure has to be sought and administered, with patience and perseverance.

Ethics of Medicine in Islam: The Physician and the Patient

Very early in the history of Islamic civilization (second century after Hijra or the beginning of the Islamic calendar (The Islamic calendar began 16th July 622 marking the migration of the Prophet of Islam from Mecca to Medina)), Islamic medical ethical standards of practice were established set, and the relationship between a physician and patient was defined.

The physician was always held to the highest professional standards and ethics in treating his patient. One of the earliest treatises written on medical ethics was *Adab al-ṭabīb* (Practical Ethics of the Physician) by Ishāq Ibn Ali al-Ruhāwī, a ninth century physician practicing under the Islamic Caliphate. In this philosophical treatise Ruhāwī examines not only the relationships between a patient and a physician, but also a physician's personal standards of behaviour, conduct of daily activities, morality and even his relationship with God. A physician was expected not only to perform to the best of his capacity in treating his patient, but also to be a model citizen in his society.

In Islam certain rules have to be observed when administering treatment (Mohammed, 1980). With advances in medical sciences the ethics of a particular treatment have to be examined in light of Islamic tenets and beliefs *the Shariah*.

History of Medicine in Islam

Medicine as a science and art was cultivated during the development of the Islamic

civilization (Hamarneh, 1983). The advancements made were limited only by the development in the associated fields of physics, mathematics, chemistry, pharmacology, pharmacy, and philosophy. The Muslims gathered material together from extant sources added their own observations and compiled it into encyclopaedic works (Savage-Smith, 1994). Medical knowledge disseminated to all corners of the expanding Islamic empire.

The Early Era of Islamic Medicine and the School of Medicine at Jundishapur

Jundishapur or "Gondeshapur" was a city in Khuzistan founded by Shāpūr I (241–272 CE). In present day western Iran the site is marked by the ruins of Shahbad near the city of Ahwaz (Seyyed, 1976). The town was taken by Muslims during the caliphate of Hadrat Umar. At this time it already had a well-established hospital and medical school.

Many Syrians took refuge in the city when Antioch was captured by Shāpūr I. The closing of the Nestorian School of Edessa by Emperor Zeno in 489 CE led to the Nestorians' fleeing and seeking refuge in Jundishapur under the patronage of Shāpūr II. The Greek influence was already predominant in Jundishapur when the closing of the Athenian school in 529 CE by order of the Byzantine emperor Justinian drove many learned Greek physicians to this town. A university with a medical school and a hospital was established where Greco-Syriac medicine blossomed. To this was added medical knowledge from India brought by the physician vizier of Anushirwan called Burzuyah. On his return the latter brought back from India the "Fables of Bidpai", several Indian physicians and details of Indian medical texts. Thus at the time of the Islamic invasion the school of Jundishapur was well established and had become renowned as a medical centre of Greek, Syriac and Indian learning. After the advent of Islamic rule the university continued to thrive.

It is likely that the medical teaching at Jundishapur was modeled after the teaching at

Alexandria with some influence from Antioch. This hospital was to become the model on which all later Islamic medical schools and hospitals were to be built. The School thrived during the Ummayyid caliphate and medical and philosophical works of both Hippocrates and Galen were translated into Syriac. These were later to be translated into Arabic.

It was during the Abbasid Caliphate that Caliph al-Manṣūr, the founder of the city of Baghdad, invited the head of the Jundishapur School to treat him. This physician was Jurjīs Bukhtīshū^c, a Christian. He treated the Caliph successfully and was appointed to the court. He did not stay permanently in Baghdad, returning to Jundishapur before his death, but the migration to Baghdad had begun. His son, Jibrīl Bukhtīshū^c, established a practice in the city and became a prominent physician. By the second half of the second century after Hijra (eighth century CE) the fame of Baghdad began to rise. Many hospitals and medical centers were established and tremendous intellectual activity was recorded.

Resources for the Development of Islamic Medicine: The Bayt Al-Hikmah or "The House of Wisdom"

Al-Ma'mūn is usually credited with having made the translation of the Greek sciences systematic and institutionalized in the form of the Bayt al-Hikmah. This institution has been variously referred to as an academy, translation centre and library. Its principal activity was the translation of philosophical and scientific works from Greek/Syriac into Arabic.

Scholars have recently begun to doubt some of the assumptions and the interpretations that have been made about the nature and function of this institution. To start with, no date can be established for its foundation, so although the earliest reference to it is in the time of Hārūn al-Rashīd, it may have existed with the caliphs al-Manṣūr or al-Mahdī (r. 775–785). Regarding its function, there are references in the sources to translation activity, but these are about work from Persian to Arabic, and there is

nothing to suggest that there was any translation at the *Bayt al-Hikmah* from Greek into Arabic. Perhaps this can explain some of the confusion over its function. The main reason may be that by the time Ibn al-Nadīm was writing his biographical history the institution had assumed legendary qualities, which have continued to impress subsequent commentators (Attewell, 2002).

The most celebrated translator of Greek learning into Arabic is Ḥunain ibn Iṣḥāq (d. 873 or 877). Born in Hira, Ḥunain was the son of an apothecary. He soon translated the entire collection of Greek medical works, including Galen and Hippocrates. He was more scientific and interpreted the original text by cross-reference, annotation and citing glossaries. His original contributions included ten works on ophthalmology. He rose to the highest honor by being appointed the director of the House of Wisdom by Caliph al-Mutawakkil.

Yuḥannā ibn Masawayh (Mesuse senior) was an early director of the House of Wisdom. He wrote about gynecological problems.

The House of Wisdom had enormous effects on Islamic science, philosophy, art, architecture, agriculture and government. Some of the Islamic physicians had available to them much of the knowledge of ancient Greece, Syria, India and Persia and in turn they contributed their observations and originality.

Hospitals During the Islamic Era

The idea of a hospital as an institutional place for the caring of the sick has not been recorded in antiquity. There were sanatoria and "travel lodges" that were attached to temples where priests attended to the sick. Most of the therapy in these sanatoria consisted of prayers and sacrifices to the gods of healing.

A large number of hospitals were developed during the Islamic era. They were called *bīmāristān*. The early Caliphs adopted the idea of a hospital as a place where the sick could get attention. The first hospital is credited to Caliph al-Walid I (86–96 AH 705–715 CE). At first it

was considered no more than a leprosarium because it allowed the segregation of lepers from others. It did have on staff “salaried doctors” to attend the sick.

The first true Islamic hospital was built during the reign of Caliph Hārūn al-Rashīd (170–193 AH 786–809 CE). Having heard of the famous medical institution at Jundishapur the Caliph invited the son of the chief physician, Jibrīl Bukhtīshūʿ to come to Baghdad and head the new *bīmāristān*. It rapidly achieved fame and led to the development of other hospitals in Baghdad. It is claimed but not established that one of these, the “Audidi” hospital was built under the instructions of the Islamic physician ► *al-Rāzī*. At its inception it had 24 physicians on staff, including specialists such as physiologists, oculists, surgeons and bonesetters. When Djubair visited Baghdad in 580 AH/1184 CE he recorded that this hospital was “like a great castle” with water supplied from the river Tigris and all the appurtenances of royal palaces.

One of the largest hospitals ever built in the Islamic Empire was the Mansūri Hospital in Cairo. It was completed in 1248 CE. It had a total capacity of 8,000 people. The annual income from endowments alone was one million dirhams. Irrespective of race, religion and creed or citizenship (as specifically stated in the *waqf* documents, see below) nobody was ever turned away. There was no limit to the time the patient was treated as an inpatient. There were separate wards for men and women, and medicine, surgery. Fevers and eye diseases also had separate wards. It had its own pharmacy, library and lecture halls. It had a mosque for Muslim patients as well as a chapel for Christian patients.

The *waqf* (an inalienable religious endowment in Islam) specifically stated:

The hospital shall keep all patients, men and women until they are completely recovered. All costs are to be borne by the hospital whether the people come from afar or near, whether they are residents or foreigners, strong or weak, low or high, rich or poor, employed or unemployed, blind or sighted, physically or mentally ill, learned or illiterate. There are no conditions of consideration and payment; none is objected to or even indirectly hinted at for non-payment . . . (Ahmad, 1939)

Some of the hospitals, especially those established by princes, rulers and viziers, were luxurious; some were actual palaces that had been converted to hospitals. The annual income of Jibrīl Bukhtīshūʿ was 4.9 million dirhams (Rahman, 1989). His son, also a doctor, lived in a house in Baghdad that was air-conditioned by ice in summer and heated by charcoal in winter. For comparison, a resident, who was supposed to be on duty for 2 days and two nights a week, was paid 300 dirhams a month.

The Great Physicians of Islamic Medicine

The era of Islamic medicine produced some very famous and notable physicians. These physicians were not only responsible for getting all the existing information on medicine together, but also for adding to this knowledge by their own observations, experimentation and skills. Many of them were skilled in medical writing and produced encyclopaedic works which became standard texts and reference works for centuries. Some of these tenets form the basis of instruction of students of *ṭibb* and *ḥikmah*, traditional Islamic medicine still practised in India and Pakistan today, under the name ‘Unani or Tibbi’ medicine. For the sake of classification, the historic periods of the Islamic physicians can be divided into three parts (1) *the period of Islamic Renaissance*: This started from the beginning of Islamic era and ended with the end of the Abbasid dynasty; (2) *the period of Islamic Epoch*: when all sciences including medicine reached the pinnacle of development; and (3) *the period of decline*: during which the knowledge of Islamic medicine declined in the Islamic state but was translated into European languages and became the basis of further development and discoveries.

The Bukhtishu Family of Physicians

The oldest in this family was Jurjis Bukhtīshūʿ who was the Chief Physician at the Hospital in Jundishapur. He came from a Christian family and was summoned to the court of Caliph Maʾmūn (148 AH/765 CE) when the latter fell ill. It was his son Jibrīl Bukhtīshūʿ who was later

invited by Caliph Hārūn al-Rashīd to come to Baghdad to treat him (171 AH/787 CE). He was Chief until he died in 185 AH/801 CE.

Masawayh

Another family that migrated from Jundishapur to Baghdad was the family of Masawayh who went at the invitation of Caliph Hārūn al-Rashīd. One became a famous ophthalmologist. Most famous amongst his three sons who were physicians was Yuḥannā ibn Masawayh (Mesue Senior). He wrote prolifically; 42 works are attributed to him. He is known for having a sarcastic temperament but commanded great respect because of his medical expertise.

Ḥunayn ibn Ishāq

► [Ḥunayn ibn Ishāq](#), who was a student of Ibn Masawayh, became the greatest translator of Greek and Syriac medical texts during the third century AH/ninth century CE. He was responsible for masterly translations of Galen, Hippocrates and Aristotle into Arabic. He also improved the Arabic medical lexicon giving it a rich technical medical language to express medical terminology. He was himself a physician and wrote two original works on ophthalmology.

Al-Rāzī

The most famous physician of this time and perhaps of the entire early Islamic era is Muḥammad ibn Zakariyya ► [al-Rāzī](#) (born 251 AH/865 CE; died 312 AH/925 CE), called Rhazes by his Latinized name. He was born in Rayy in northern Persia not far from modern Tehran. Although not much is known about his early life or his medical education, his fame started with the establishment of a hospital in Baghdad of which he was the chief. The story of how he picked the site of the hospital when asked to select one has become one of the classical legends of Islamic medicine. He had pieces of meat hung in various quarters of the city and had them examined for putrefaction and recommended the site where the meat had decayed the least as the most suitable site. This made him one of the first physicians to infer indirectly that there was an element of bacterial putrefaction in the degradation of meat, and

suggested the environmental role that contaminated air plays in the spread of infection.

Al-Rāzī is known for numerous other original contributions to the art and science of medicine. He described the differences between smallpox and chickenpox and gave an in depth description of measles. He described allergy to roses in one of his classical cases. The Islamic historian and scientist ► [al-Bīrūnī](#) listed 56 medical works of al-Rāzī, the most famous being *al-Ḥāwī*, an encyclopaedia of medical knowledge based on his personal observations and experiences. A Copy preserved in the National Library of Medicine in Bethesda Maryland is described as the third oldest medical manuscript preserved in the world today.

Besides these and other original contributions of which many have been published, al-Rāzī devoted a lot of his time to teaching, bedside medicine and attending to the royalty and court. The impact of these publications on Islamic medicine was tremendous. His books became an invaluable addition to the armamentarium of a medical student of the time and remained standard texts until the appearance much later of texts by al-Majūsī (d. 994) and Ibn Sīnā, who authored such monumental works as *al-Qānūn fī l-ṭibb* (The Canon of Medicine).

Al Majusi

In the fourth century of Hijra, tenth century CE another Islamic physician gained prominence in Baghdad. His name was 'Alī ibn al-'Abbās al-Majūsī (d. 384 AH/994 CE). (Latinized Haly Abbas). He became the director of the Adudawlah Hospital. Al-Majūsī dedicated his medical work *Kitāb al-Malakī* (The Royal Book) to its founder. This book is very well systematized and organized. It is divided into two volumes, one covering theory and the other practical aspects. Each of these has ten chapters. The first volume deals with historical sources, anatomy, faculties, six primeval functions, classification and causation of disease, symptoms and diagnosis, urine, sputum, saliva and pulse as an aid to diagnosis, external or visible manifestations of disease and internal diseases like fever, headache, epilepsy and warning signs of death or recovery.

The second volume deals with hygiene, diet, cosmetics, therapy with simple drugs, therapy for fevers and diseases of organs. There is a chapter on surgery, orthopaedics, and finally treatment by compound medicaments.

About the second century AH/eight century CE a great centre of knowledge learning and culture had been developing in the western part of the Islamic empire. This was in Spain or “Andalusia” as the Arabs called it. Spain was invaded and conquered by the Muslims in 93 AH/714 CE. When the Ummayyad dynasty ended in Baghdad the last of Ummayyad princes escaped to Spain where they established the Western Caliphate. The rulers of this dynasty laid the foundation for the Muslim rule of Spain that was to last for seven centuries. During this time Cordoba, also called “Qurtuba”, became a great centre of international learning. A great library containing more than a million volumes was established.

Al-Zahrawi

Perhaps the most famous physician and surgeon of the era was Abū l-Qāsim al-Zahrāwī, known to the west as Albucasis (318 AH/930 CE to 403 AH/1013 CE). He gained great fame as a physician. He wrote a 30-volume compendium called *al-Taṣrīf*. The initial volumes dealt with general principles, elements and physiology of humours and the rest dealt with systematic treatment of diseases from head to foot. The last volume deals with all aspects of surgery. It was the first textbook of surgery with illustrations of instruments. He emphasized that knowledge of anatomy and physiology was essential prior to undertaking any surgery:

Before practicing surgery one should gain knowledge of anatomy and the function of organs so that he will understand their shape, connections and borders. He should become thoroughly familiar with nerves, muscles, bones arteries and veins. If one does not comprehend the anatomy and physiology one can commit a mistake which will result in the death of the patient. I have seen someone incise into a swelling in the neck thinking it was an abscess, when it was an aneurysm and the patient died on the spot.

He described operations on varicose veins, reduction of skull fractures, dental extractions, forceps delivery for a dead foetus to mention just a few. His work raised surgery to a high level.

Ibn Sina

However the greatest physician of the Islamic era was *Abū Alī al-Ḥusain ibn Abdallāh* ibn Sīnā, Avicenna or Ibn Sīnā. Some historians of medicine call him one of the greatest physicians that ever lived. That is because Ibn Sīnā was not only a physician, but also his knowledge and wisdom extended to many other branches of science and culture including philosophy, metaphysics, logic and religion.

Ibn Sīnā was indeed a prodigy. At the age of 10 he had memorized the whole Qurʾān. By age of 16 he had mastered all extant sciences that appealed to him including mathematics, geometry, Islamic law, logic, philosophy and metaphysics. By age 18 he taught himself all there was to learn at that time in medicine. Born in the city of *Būkhārā* in what is now central Asia in the year 370 AH/980 CE, he rapidly rose in ranks and became the vizier (prime minister) and court physician of the Samanid ruler Prince Nuh ibn-Mansūr. The Royal Library was opened to him and this enlarged his knowledge. He began writing his first book at age 21. In the short span of 30 years of writing he wrote over a 100 books of which 16 were on medicine. His magnum opus is *Qānūn fī l-ṭibb* (The Canon of Medicine). This voluminous compendium of medical knowledge rivaled one written earlier by ► *al-Rāzi* and al-Majūsī and indeed surpassed both of these in content and originality. It was composed of five volumes: general principles, simple drugs, systematic description of diseases from head to foot, general maladies and compound drugs. The Canon was translated into Latin by Gerard of Cremora and Andrea Alpago and remained the standard textbook of medicine in Louvain and Montpellier until the seventeenth century.

Ibn Nafis

Islamic physicians not only possessed excellent knowledge of anatomy, but also they added some challenging new concepts that were

revolutionary to the then understanding of anatomical concepts laid down by the “ancients”. The example that has now become well known is that of the discovery of the lesser or pulmonary circulation by Ibn Nafīs (d. 687 AH/1288 CE). The description he gave of pulmonary circulation challenged the fundamental concept held by Galen. In fact it suggested that there existed a pulmonary capillary bed where the blood was “purified” before being brought back to the heart by the pulmonary artery, thus predating the discovery of pulmonary capillaries long afterwards, made possible by the discovery of the microscope by Antony van Leeuwenhoek. Al-Zahrāwī emphasized that the knowledge of anatomy was a prerequisite for the surgeon.

Now this is the reason why there is no skillful operator in our day: the art of medicine is long and it is necessary for its exponent, before he exercises it, to be trained in anatomy as Galen has described it, so that he may be fully acquainted with the uses, forms, temperament of the limbs; also how they are jointed, and how they may be separated, that he should understand fully also the bones, tendons and muscles, their numbers and their attachments; and also the blood vessels both the arteries and the veins, with their relations.

The physiological concepts embodied in Islamic medicine were based on the Hippocratic and Galenic concepts of elements, natures and humours. In this theory harmony in the body prevails when all the humours are in proper balance and it is their imbalance that creates disease. Under this principle, disease is a state of imbalance of humours and needs the restoration of balance to bring the organism back to its normal healthy state. Islamic medicine also expounds the concept of elements and temperaments. The basic elements are earth, fire, air and water, and each of these is given a temperament: earth is dry and cold; water is humid and cold; fire is hot and dry; air is humid and hot. Each of the four essential body fluids – blood, phlegm, yellow bile and black bile – is assigned a respective temperament. Each dietary food, medicine or climatic environment can thus then modify or temper the humours of the body and it is an

interplay of these that can restore health from sickness or cause the sickness to worsen.

It was the fundamental belief of a Muslim physician that the organic body alone cannot manifest life, being innate and devoid of a life force. It was the instillation of a life force, *Ruh*, which gave it vibrancy and vitality of spirit. Thus without the *Ruh*, no function of the body is possible. It is the *Ruh* which descends from God to mix with the anatomic and physiologic body to make a complete human being. It is thus essential when treating a diseased state to take the Soul or ‘*Ruh*’ into consideration. Laying the foundation of Holistic Medicine.

Pharmacy, Pharmacognosy, Materia Medica and Therapeutics

One of the sciences that had an impetus on Islamic medicine was the development of pharmacy and pharmacognosy. Most Islamic physicians and scholars studied chemistry or alchemy. This study was furthered by the concomitant development of techniques to refine drugs, medications and extracts by processes of distillation, sublimation and crystallization. Pharmacists became commonplace in Islamic lands, and their proliferation ultimately required the institution of licensing.

Pharmacological drugs were classified into simple and compound drugs. The effects of these were detailed and documented. The earliest Islamic works on pharmacognosy, such as “Treatise on the Power of Drugs, Their Beneficial and Ill Effects” and “The Power of Simple Drugs” were written in the third and fourth century AH/ninth century CE. Most medical texts contained chapters on the use of both these types of remedies. Rāzī’s *al-Hāwī* mentions 829 drugs.

Materia medica and texts containing compendia of drugs and their effects appear frequently during the era of Islamic medicine. Notable amongst these is the contribution of Abu Bakr ibn Samghun of Cordoba, *The Comprehensive Book on Views of the Ancients as Well as the Moderns on Simple Drugs*. ► [Ibn Juljul](#) made a commentary on drugs and plants described by

Dioscordes and added a number of newer ones. Al-Zahrāwī's *al-Taṣrīf* mentioned earlier in reference to its surgical volume also had a section on plants and drugs. The second book of the *Canon* is devoted to the discussion of simple drugs and their powers and qualities. One of the most authoritative books on drugs was written by ► **al-Bīrūnī**, entitled *The Book on Drugs*, which contains a huge compendium of drugs, their actions and their equivalent names in several languages.

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Medicine in Japan

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When considering the Japanese history of medicine, it is important not to project our ideas about medicine today onto the past. Whereas modern medicine worldwide is based on the language and methods of natural science, the medicine of premodern Japan consisted of many different languages and practices. Moreover, the historical development of medicine in premodern Japan must not be thought of as following a linear development that inevitably ended in the adoption of Western medicine. It is, rather, the story of theories and practices that unfolded according to their own historical logic, often in competition with each other and without theoretical or practical consistency. The fact that the Japanese did adopt Western medical ideas and practices during the premodern period simply reflects the ways in which some Japanese medical ideas and practices developed.

Throughout the premodern period, which in the case of Japan spans all of history until the mid-nineteenth century, numerous medical theories and practices, many of which were mutually contradictory, coexisted. Until modern times, most people depended primarily on folk remedies to treat their ailments. These consisted mostly of shamanistic rituals whose remnants can be found today in a small number of Shinto shrines and Buddhist temples. Physicians with a textually based theoretical training were rare in rural areas, where most Japanese people lived as peasants or fishers. However because few documentary sources exist on which a history of folk

medicine could be based, historians have made the textual tradition the focus of their research. Hence it is also necessary to focus on this textual tradition here, but this is, of necessity, only a partial history.

Within these limits, the history of Japanese medicine can be divided into four periods: ancient, medieval, early modern, and modern. The ancient period spans from prehistory to the late twelfth century; the medieval period reaches from the beginning of the thirteenth century to the late sixteenth; and the early modern period encompasses the years from the late sixteenth until the mid nineteenth century. Because in many respects the history of Japanese medicine during the modern period parallels that of the Western world, this article deals primarily with the premodern period.

Prehistoric and Ancient Medicine

Based on skeletal remains, it is clear that the prehistoric inhabitants of the Japanese islands developed rudimentary medical practices. Some bone fractures, at least, were treated so that they healed cleanly. The earliest written records, which date from the early eighth century, recount the use of herbal remedies for some illnesses. However the same records also reflect the belief that most diseases were divine retribution for offending a deity or spirit; they were treated through exorcism, ritual ablution, and purification rituals. Some diseases, such as leprosy and tuberculosis, were also associated with ritual pollution, a belief which has found currency into modern times. Because this pollution was thought to be hereditary, these diseases often made it difficult for the persons who had them and members of their families to find marriage partners. When a disease reached epidemic proportion, it was thought to be caused by the more powerful deities that controlled forces of nature throughout the land, deities that the emperor or empress attempted to assuage with national purification rituals.

It is unclear when Chinese writing first reached Japan, but by the late fourth or early

fifth century scholars from the Korean peninsula were tutoring members of the imperial family in the Chinese classics. The real rise of literacy came with the Japanese adoption of Buddhism from the sixth century; it can be surmised that the advent of textually based medicine in Japan also dates from this time. By the seventh century, Buddhist monks from the continent were both practicing medicine and training Japanese monks to become practitioners themselves. Until the seventeenth century most trained medical practitioners retained the trappings, if not always the formal status, of Buddhist priests.

From the late seventh century the Japanese state adopted the legal codes of Tang China. These included provisions for government posts that specified the employment of various medical specialists, including internists, surgeons, acupuncturists, masseuses, exorcists, obstetricians, dentists, and pharmacologists. Although in China these posts were filled with scholars who passed required examinations, in Japan they soon became hereditary and remained so until the nineteenth century. This did not, however, preclude the adoption of new developments in medicine from the continent. Constant interaction with both Korea and China, where numerous Japanese Buddhist priests went to study, kept them informed of changing theories and practices, although the process of change was far slower than during more recent times.

Medicine during the Nara (710–794) and Heian (794–1185) periods remained the domain of court physicians and Buddhist priests. As in premodern Europe, internal medicine and surgery remained distinct practices. Internists had a high level of education and relatively high social status; surgeons, who mostly treated skin lesions, wounds, and fractures, had comparatively little theoretical training and low social status. These remained distinct until the late eighteenth century.

Internal medicine was based entirely on Chinese texts; the first Japanese medical text did not appear until the year 984. This was the *Ishimpō* (literally, Methods at the Heart of Medicine), which was written by the court physician Tanba Yasuyori (912–995) and remained an important

text among some schools of medicine until the nineteenth century. This 30-volume work contained information on internal medicine, pharmaceuticals, preventive practices, and other topics, and was based on over 80 Chinese texts written during the Sui (581–617) and Tang (618–907) dynasties.

Until the eighteenth century, anatomy envisioned the human body as containing five organs and six viscera, and physiology focused on their relationships with each other and the meridians found on the surface of the body. Visual observation of the internal organs played little role in the classical Chinese model of the human body, and organs including the brain, pancreas, thyroid, and adrenal glands played no role in the treatment of disease. Indeed, there was no word for the latter three organs, and visual depictions of human anatomy did not appear in the Japanese medical literature until the fourteenth century. Rather this model was conceptual, based on the Chinese notion of the five elements of fire, metal, water, wood, and earth. These were, respectively, associated with the heart, lungs, kidneys, liver, and spleen, and each organ was in turn associated with five colors, tastes, and seasons, the spleen being associated with the time of changes between seasons. Physicians interpreted diseases as resulting from imbalances within this system and treated them with herbal medicines, acupuncture, ► [moxibustion](#), massage, and restrictions on diet and behavior. Yet this model did not completely replace ideas of disease as being caused by spirit possession, and the literature of the Heian period abounds in examples of Buddhist priests attempting to cure maladies through exorcism, a common practice until modern times.

Because the diagnostic criteria and disease categories of premodern Japan were so different from those used today it is difficult to establish with any accuracy in modern terms the diseases from which people suffered at the time. Yet it is certain that the most common epidemic diseases of premodern Japan, beginning with the Nara and Heian periods and continuing through the nineteenth century, were smallpox, measles, influenza, and enteric infections. Tuberculosis,

malaria, and parasitic infections remained endemic during the premodern period. Despite a myth of cleanliness attributed to the Japanese, bathing and the regular washing of clothes were not common practices, making skin diseases common until modern times. In addition, kitchen areas frequently were far less than sanitary, and latrines and even graves were sometimes located close to water sources, contaminating them.

Although most medical folk beliefs are poorly documented, much is known concerning some popular beliefs related to what probably was tuberculosis. During the twelfth century, Chinese Daoist priests thought that a disease they called *zhuan shi* (*denshi* in Japanese), literally “transmission of the consumption bug,” was caused by minute worms. According to Daoist texts, this disease passed through a cycle of six phases with turning points on certain calendar days, when the worms metamorphosed from one phase to the next; in the sixth phase they were thought to be highly contagious. A popular belief in these worms took root in Japan from the Heian period as part of the *Kōshin* folk religion. They were considered a deity’s agents that reported a person’s sins on the days of *kōshin*, which occurred once every 60 days in the calendar cycle. If a person abstained from sleep on those nights, the worms would remain dormant; otherwise they would divulge their host’s sins to the deity, who punished people by causing consumption (*denshi*). At first, only the Heian-period aristocracy abstained from sleep on those nights, but the ritual spread throughout the country and was practiced in rural villages until the twentieth century.

Medieval Japanese Medicine

During the Kamakura period (1185–1333) warrior culture eclipsed the culture of the imperial court, but changes in medical theory and practice remained slow. The hereditary posts of court physicians remained in place, and the physicians who filled them were sometimes dispatched to treat the leaders of the military government in Kamakura. However these physicians had little opportunity to keep abreast of the changes in medicine that

occurred in China, and in most of Japan Buddhist priests dominated medical practice.

The most important medical text of the Kamakura period was the *Don'isho* (which is untranslatable), written by Fu-jiwara Shōzen (1266–1337) in 1302. This work was significant for its visual representation of human anatomy, the first in Japan. Like previous Japanese medical texts, the *Don'isho* was also a compilation of Chinese sources, except for the section on leprosy, which was based entirely on Buddhist thought. This reflected current Japanese ideas concerning this disease. From the Heian period, leprosy was called a karmic disease (*gōbyō*), the result of sins committed in past lives. As in medieval Europe, leprosy was common during the middle ages in Japan and had much the same stigma; persons who developed leprosy became outcasts, shunned by their families and communities alike, finding succor only in the care of Buddhist monasteries. The stigma attached to leprosy did not change even into modern times. (The plague, another representative disease of medieval Europe, did not reach Japan until the late nineteenth century and was never a significant cause of mortality.)

The Muromachi (1333–1468) and Warring States (1468–1600) periods witnessed considerable changes in the theory and practice of medicine. During the Muromachi period Buddhist monks became increasingly knowledgeable in Confucian thought, and were influenced by the rise of Neo-Confucianism during the Song dynasty (960–1279) in China. This new current in Confucian thought emphasized the role of *qi* (vital force; *ki* in Japanese) and *li* (principle; *ri* in Japanese) in the order of nature, states, and individuals alike. The ideas of Neo-Confucianism entered the mainstream of Chinese medicine in the theories of Li Dongyuan and Zhu Danxi, who were active during the Yuan dynasty (1279–1368). Li and Zhu understood disease according to interrelationships between an individual's vital energy, environment, and behavior. In therapeutics they placed a new emphasis on emetics, purgatives, and medicines that caused a person to sweat. The ideas of Li and Zhu became influential in Japan from the early sixteenth

century, primarily through the works of Tashiro Sanki (1465–1537), who studied medicine for 12 years in China. They then became established in the mainstream of Japanese medicine through the works of Manase Dōsan (1507–1574), who had studied under Sanki. Dōsan's descendants and followers remained highly influential, treating the warlords and hegemonies of the Warring States period. Following the establishment of the Tokugawa *bakufu* in 1603 Dōsan's medical theories and practices became government-sanctioned medical orthodoxy (*hondō*). As such they remained at the core of some schools of medicine until the end of the premodern period, and had virtually no competitors until the beginning of the eighteenth century.

Dōsan and his followers had a powerful influence on diagnostics, which they standardized. Later and competing schools of medical thought only supplemented the diagnostic procedures delineated by Dōsan, which remained standard until the advent of Western diagnostics during the nineteenth century. He based diagnosis on a four-step method. Visual observation focused on the patient's skin color, weight, strength, condition of the hair, and inspections of sputum, feces, and urine. Aural observation included listening for responses indicating pain when the patient was examined, for the type of cough, and for sounds in the chest. The physician questioned the patient concerning appetite, waste elimination, emotional disposition, and the circumstances preceding the illness. Finally there came pulse diagnosis, a technique without parallel in Western medicine, which analyzed the strength, speed, location, and other aspects of the pulse.

Endemic warfare during the Warring States period stimulated new approaches to surgery, with a widespread need for specialists who could treat battle wounds. The arrival of the Westerners in East Asia during the sixteenth century was soon followed by the spread of firearms, whose wounds called for new forms of treatment. This led to the adoption of Portuguese surgical practices during the second half of the century in what was called the *Nanbanryū* (Southern Barbarian School). At this time, however, the Japanese adoption of Western medicine remained limited to practical

measures for treating wounds, skin lesions, bone fractures, and dislocated joints, and contemporary European medical theory made little headway into Japanese medicine.

Early Modern Japanese Medicine

The defeat of the last major opponents to the hegemony of the warlord Tokugawa Ieyasu in 1600 marked the end of the Warring States period and the beginning of the Edo period (1600–1868), a time of peace and gradually increasing prosperity. The seventeenth century was a period of political, economic, and cultural stabilization and consolidation during which medical theories and practice changed little, dominated by the orthodoxy of Manase Dōsan and other established schools. A century of peace, however, ushered in a period of intellectual and cultural ferment that began during the last decade of the seventeenth century and continued into the nineteenth.

During the last half of the seventeenth century, Confucian scholars started to reject Neo-Confucian interpretations of the Chinese classics and focused instead on direct textual analysis. This trend appeared at the same time in medicine, with a number of physicians rejecting Song and Yuan dynasty interpretations of medical texts, emphasizing instead the direct reading of ancient Chinese medical works. Most of the leaders of this movement, which came to be called the School of Ancient Medicine (*Koihō*), lived in Kyoto, and included Gotō Konzan (1659–1733), Kagawa Shūan (1683–1755), Yoshimasu Tōdō (1702–1773), and Yamawaki Tōyō (1705–1762). Practitioners of the School of Ancient Medicine were by no means unified in their interpretations of either texts or phenomena, but most did emphasize practical methods to establish the validity of their ideas and methods. This was of momentous importance to the changes in Japanese medicine that followed during the rest of the premodern period.

Yamawaki Tōyō, a physician at the imperial court, was central to those changes. Tōyō

questioned traditional Chinese interpretations of human anatomy and attempted to replace them with a view based on a passage in the *Zhou li* (Rites of Zhou), one of the early Chinese classics, which described the body as containing nine organs. To verify his view, Tōyō conducted the first public dissection of a human body in Japan in 1754, and published the results in the *Zōshi* (Anatomical Record) in 1759. Although Tōyō's nine-organ theory did not gain currency, his method of examining the body through dissections did. Thereafter, physicians in various parts of the country performed dissections and advanced other anatomical theories, none of which, however, replaced the Chinese theory of five organs and six viscera.

In 1771 three physicians, Sugita Genpaku (1733–1817), Maeno Ryōtaku (1723–1803), and Nakagawa Jun'an (1739–1786), witnessed the dissection of an executed criminal's corpse in Edo (Tokyo). Discussing the results afterward, they concurred that they could not consider themselves medically qualified without a true understanding of the structure of human anatomy, and that such an understanding could be gained only by translating the Dutch anatomy text which Genpaku and Ryōtaku had brought to this dissection. In 1774 they published the *Kaitai shinsho* (New Book of Anatomy), their translation of the *Ontleedkundige Tafelen*, or "Illustrated Anatomy," by the German physician Johann Adam Kulmus (1689–1745). This both started the study of Dutch medicine (*Ranpō*) in Japan and opened the door to European ideas by making the Dutch language widely accessible; after finishing this translation Ryōtaku then compiled a Dutch-Japanese dictionary.

During the first half of the nineteenth century, growing numbers of Japanese physicians studied Dutch medicine under Dutch and German physicians who offered instruction in Nagasaki. Until after the Meiji Restoration in 1868, when Western medicine became mandated as the sole basis for medical practice, various schools of Chinese medicine coexisted with Western medicine in Japan, but the door to Western medicine and science had been opened because of indigenous Japanese developments that had taken place

during the eighteenth century, and in this respect the history of premodern medicine in Japan is unique in the world.

The spread of vaccination from the mid-nineteenth century marks the beginning of modern medical practice in Japan. By the 1850s, vaccination had become common in many parts of the country. However it was not until after the Meiji Restoration in 1868 that modern medical education became instituted. Tokyo University was established in 1877, with its Medical School one of the initial departments. Thereafter, numerous Japanese students traveled to Europe, and particularly to Germany, to study medicine. Some continued to work in Europe as researchers and several, including Kitasato Shibasaburō (1852–1931), who codiscovered the tetanus antitoxin and plague bacillus, became internationally renowned; he was nominated for the first Nobel Prize in medicine. By the late nineteenth century modern medical schools had been established throughout the country and medical practitioners were required to hold state licenses.

During the twentieth century Japanese physicians have remained on the cutting edge of medical research in many fields. Since World War II, national health insurance has made medical care available to the entire population, helping to make the average life span the longest in the world.

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Medicine in Korea

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“Oriental medicine” is the English name Koreans prefer for what is known in most of the rest of the world as Chinese medicine. Among themselves,

Medicine in Korea,

Fig. 1 A medicinal herb market in Seoul (Photo copyright Korea National Tourism organization)



Koreans call it “Korean medicine.” They believe their traditional medicine is as much Korean as it is Chinese, since for around 2,000 years they have adapted medical theories, practices, and even prescriptions from China to fit Korean needs (Cha et. al. 2007) (Fig. 1).

Koreans probably acquired elements of Chinese medical theory and practices for the first time a little over two millennia ago, after China’s Han dynasty established four outposts in and around the peninsula late in the second century BCE. Not long after the last of those outposts disappeared early in the fourth century, Buddhist monks from China and farther West began arriving and teaching not only their religion but also the more advanced civilization of China, including its medical theory and practice (Baker, 1994).

Exactly how much Koreans learned about Chinese medicine from those outposts and from those monks is not clear, since we have few written records from that period. The oldest extant history written by Koreans, the *Samguk Sagi* (History of the Three Kingdoms), dates back only to the twelfth century. However, statements in that book, as well as scattered references in Chinese and Japanese records from centuries earlier, indicate that Koreans were reading Chinese medical manuals and applying what they read in them during the Three Kingdoms period (300–668) as well as during the Silla period (Yeo et al. 2012, pp. 668–936).

The Kingdom of Goryeo (918–1392)

Substantially more information is available on medical theory and practice under the Goryeo, which followed Silla and ruled over the Korean peninsula for four and a half centuries. We know, for example, that Goryeo used Chinese-style civil service examinations to identify qualified candidates for government medical posts. Applicants for Goryeo medical posts were tested on their knowledge of the basic principles of internal medicine and pharmacology, as found in the same Chinese medical classics studied in China. They were also tested on their knowledge of external medicine (as defined in Oriental medicine), primarily acupuncture, moxibustion, and the treatment of wounds. That section included questions on material introduced in more recent medical texts, including at least two books from China’s Sui (581–618) dynasty.

Although China was the primary source of medical concepts and practices, Koreans had to adapt Chinese prescriptions to fit what was available on the Korean peninsula. For most of the Goryeo dynasty, Korea was blocked from direct land contact with China by hostile non-Chinese states in southern Manchuria. This forced Goryeo to develop *hyangyak*, Koreanized versions of Chinese prescriptions in which herbs, animal parts, and minerals found on the Korean peninsula replaced ingredients from China. The oldest

Korean medical text still extant, published in 1245, is called *Hyangyak Gugeupbang* (First Aid Prescriptions Using Native Ingredients). Not only did the prescriptions in this medical manual use ingredients available locally, but some of them were drawn from local folk medicine and therefore called for only one or two ingredients, in contrast to the multitude of ingredients in prescriptions which originated in China. This was just one of several medical manuals produced in the latter part of the Goryeo era which emphasized locally available ingredients as well as prescriptions of local origin (Kim, 1981, pp. 137–141).

The Joseon Dynasty (1392–1910)

The Joseon dynasty which followed Goryeo, influenced by recent developments in Chinese thought, embarked on a restructuring of Korean government and society along Neo-Confucian lines. That restructuring embraced medical institutions as well as medical practice.

The Neo-Confucian influence on medicine during the Joseon dynasty was seen in two areas: the creation of a national network of medical facilities and the certification of physicians through civil service examinations. The greatest concentration of physicians was in and around the capital city. The government established clinics inside Seoul to provide medical care for the royal family and top officials. It also opened medical clinics for commoners just outside the city walls so that those with infectious diseases would not have to enter the capital itself (Kim, 1981, pp. 196–199, 408–416).

In addition, the Joseon government established medical facilities in various regional centers, primarily to deal with outbreaks of epidemics among the general population as well as to collect materia medica from local areas. A Confucian scholar normally led the higher-level medical offices. Under him would be physicians who had passed the civil service medical examination.

Joseon Korea was a highly stratified society and privileged a distinguished ancestry and

knowledge of Confucian philosophy and literature ahead of technical expertise. Only those with a good family background and a passing grade on the Neo-Confucian civil service exams could be appointed to the highest posts, such as director of a major medical clinic. Consequently, the heads of central government medical agencies were usually Confucian scholars with more expertise in Chinese poetry and ancient Chinese history than in the details of medical practice.

Professional physicians ranked one step below Confucian scholars on the social ladder. There was a separate civil service examination for those who aspired to such a post. Though there was no legal requirement that those sitting for that examination be descended from a previous exam passer, the emphasis in the Joseon dynasty on hereditary status meant that a few families dominated the list of medical exam passers. For example, ten families produced almost 30 % of all officially certified physicians between 1498 and 1894 (we lack reliable records on medical officials for the first century of the Joseon dynasty) (Kim, 1999; Yi, 1997a).

Only physicians who sought an appointment to a civil service position were required to pass the medical examination. Until 1900, medical practitioners among the general population did not need any official certification of their medical expertise. Nor were they subject to government oversight. However, even among those with informal credentials, family background was still important. A popular saying during the Joseon dynasty warned villagers, “Do not accept medicine from a doctor who is not at least a third-generation physician.”

Joseon Korea was a patriarchy and restricted most government appointments, including medical appointments, to men. However, some women were employed as medical technicians because of the constraints of Confucian ethics. Uncomfortable with the idea of a male physician examining the body of a female patient, which would violate the Confucian directive calling for a rigid separation of the sexes among upper-class adults, King Taejong (r. 1400–1418) ordered that a few women be selected for training in acupuncture, moxibustion, and pulse measurement

(an important diagnostic tool). Male pharmaceutical specialists could prepare medicines for an upper-class woman who was ill, but they were not allowed to place the acupuncture needle or moxa on her skin nor could they place their male fingers on her veins to feel her pulse. After 1406, such tasks therefore were assigned to a small core of women medical practitioners at court (Heo, 1992, pp. 214–217).

Localized Chinese Medicine

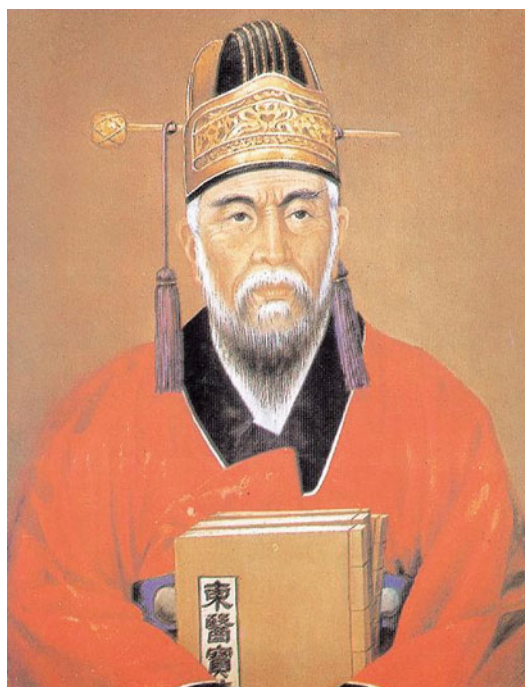
Official medicine in Joseon Korea was based primarily on the canonical texts of Chinese medicine (Bowman, 1915). Koreans supplemented the medical theory and clinical advice in those classical works with more recent Chinese publications as well as with Korean texts that provided local counterparts for the Chinese ingredients in Chinese prescriptions. Both trends are particularly evident during the reign of Joseon's fourth and greatest king, King Sejong (r. 1418–1450). Among the many volumes compiled and published under King Sejong's direction, two are particularly important for the history of Oriental medicine in Korea.

The first is the 85-volume *Hyangyak Jipseongbang* (*Great Collection of Native Korean Prescriptions*). Completed in 1433, this encyclopedic pharmaceutical guidebook identified 959 different diseases, arranged under 57 different categories. It described 703 different mineral, vegetable, or animal medicinal products available on the peninsula and told how to identify them, when to collect them, and what diseases they were effective against. Many of its prescriptions were extracted from Chinese medical manuals. However, whenever possible, it substituted native ingredients for expensive or rare Chinese ingredients (Kim, 1976, pp. 70–73). In addition, this work listed almost 1,500 ways acupuncture and moxibustion could be used, some based on local experience.

To ensure that his physicians had access to the best advice Chinese medicine had to offer, even if all the prescribed ingredients were not readily available, in 1445 King Sejong also had his

officials compile the *Uibang Yuchwi* (*Classified Collection of Medical Prescriptions*). Totalling 365 volumes, this massive reference work listed over 50,000 separate prescriptions, drawn from Chinese sources and arranged according to the symptoms they were believed to alleviate. It also included separate sections on treating childhood illnesses and mental disorders, on childbirth, on first-aid remedies, and on treating fractures (Kim, 1976, pp. 80–83).

Both the *Great Collection of Native Korean Prescriptions* and the *Classified Collection of Medical Prescriptions* were compiled for the use of physicians at court and were too large to be made available to the general public. However, in 1613, a more concise guide to medical theory and practice appeared. Koreans consider the 25-volume *Dongui Bogam* (*A Treasury of Eastern Medicine*) compiled by royal decree under the direction of Korea's most revered physician, Heo Jun (1539–1615), their greatest original contribution to the development



Medicine in Korea, Fig. 2 Heo Jun, the chief author of *A Treasury of Eastern Medicine* (Reprinted courtesy of the Association of Korean Oriental Medicine)

of Oriental medicine (Fig. 2). *A Treasury of Eastern Medicine* provided an encyclopedic overview of Oriental medicine from a Korean perspective (Heo, 2013; Kim, 2000). At only 25 volumes, it was more compact than either of King Sejong's two massive medical encyclopedias and therefore could be more easily distributed to government offices throughout the peninsula. Read by Confucian scholars as well as physicians, it shaped medical thought and practice in Korea for the rest of the Joseon dynasty and remains influential today. Its importance in global medical history was recognized in 2009 when UNESCO added *Dongui Bogam* to the Memory of the World Register (UNESCO, 2014).

A Treasury of Eastern Medicine opens with explanations of the basic concepts of Oriental medicine. Heo placed particular emphasis on *jeong* (Chinese *jing*), *ki* (C. *qi*), and *shin* (C. *shen*). Those three Sino-Korean terms are used in such a wide variety of contexts with such a wide range of meanings that it is difficult to find English equivalents for them. As Heo uses them, they refer roughly to essential bodily fluids, bodily energy, and refined bodily energy, respectively. All three terms refer to the fundamental cosmic energy that animates the universe. Within the human body, that vital energy takes three different forms, distinguished according to differences in visibility, tangibility, and density. Jeong is visible vitalizing energy, such as semen or blood. Ki is invisible but palpable vitalizing energy, discerned when a doctor feels the pulse of a patient to determine the state of his or her internal energy. Shin is ethereal vitalizing energy, so rarefied that it provides the physiological basis for consciousness. Heo places fostering and reinforcing that vitalizing energy at the core of his approach to Oriental medicine.

After introducing *jeong*, *ki*, and *shin*, Heo discusses various external windows into the state of vital energy within, including blood, phlegm, saliva, dreams, and the sound of the patient's voice. Only in his third chapter does he turn to the coagulation of vital energy into the five major governing organs (liver, heart, spleen, lungs, and kidneys) and the six supportive organs (gallbladder, stomach, large intestine, small

intestine, bladder, and triple burner). He follows that discussion of the inside of the human body with a discussion of the outside, from head to foot. Heo's lengthy discussion of the various components of the body and their functions is a departure from the way previous medical manuals had been written and had lasting influence of medical thought and practice in Korea, directing Oriental medicine in Korea down a distinctive path (Shin, 2010).

He complements this analysis of the basic components and processes of the body with a detailed analysis of the various ways those components can become dysfunctional and as a result damage the body's other components, preventing them from functioning the way they should. He also included a catalogue of the medicinal substances available in China and Korea, where they could be found, how to prepare them for human consumption, and when to prescribe them (Landis, 1898). His final chapters are a detailed description of when and how to use acupuncture and moxibustion.

The basic principles of both Heo's medical theory and his practical suggestions for health and healing were derived from the Oriental medicine of China. What made Heo's book different, and so influential, was the way he presented those theories and techniques. Earlier medical handbooks were primarily compilations of medical texts which did not evaluate the relative effectiveness of the various prescriptions and other medical strategies those texts recommended. Heo provided an interpretative framework for understanding which healing and health-enhancing techniques were likely to work better than others. He also provided evaluations of which medicines or procedures were likely to be the most effective in specific situations.

Despite the contributions of *The Treasury of Eastern Medicine*, medical problems increased rather than decreased over the next three centuries. The first serious new threat to Korean health was syphilis. Introduced onto the peninsula early in the sixteenth century, it became a major medical problem during the Japanese invasions at the end of that century. That deadly sexually transmitted disease was joined soon afterward by one

even more deadly because it spread from victim to victim through more casual contact. Sometime in the seventeenth century, a new virulent strain of measles appeared in Korea, taking the lives of thousands in periodic epidemics from the late seventeenth through the nineteenth centuries. The nineteenth century brought one more new biological brake on population growth. Cholera reached Korean shores in 1822, returning again several more times that century, each time killing tens of thousands (Magner, 1993; Miki, 1962).

The impact on population growth was striking. Instead of growing rapidly, as it had in the first part of the Joseon dynasty, the Korean population first stagnated and then began shrinking. The Korean government counted almost a million fewer Koreans in 1850 than it had found a half a century earlier. That 1800 figure itself was only a slight advance, of less than 100,000, over the census figures for 1750. Both epidemics and famines were taking their toll (Baker, 1990).

The response of Korea to this demographic decline was a popularization of Oriental medicine. *The Treasury of Eastern Medicine* was too large for distribution among the general population, so much smaller pamphlets dealing with prescriptions for specific diseases were printed and distributed to meet the growing popular demand for medical information. Such publications designed for the masses were not the only evidence of the popularization of Oriental medicine in the second half of the Joseon dynasty. The opening of Oriental medicine markets in four Korean cities, starting in the mid-seventeenth century, indicates that more and more Koreans were beginning to trust prescriptions more than the shamans and monks they had relied on in the past. By the middle of the eighteenth century, there was enough demand for Oriental medicine that a new occupation appeared in Korea – pharmacists. Koreans began to frequent private shops run by men skilled in diagnosing disease according to the categories of Oriental medicine who would then prepare prescriptions in accordance with their diagnosis (Kim, 1998, pp. 190–92).

This growing popularity of Oriental medicine among the general population stimulated not only

the greater use of indigenous materia medica but also the indigenization of medical theory. Near the end of the nineteenth century, an amateur physician supplemented the medical theory imported from China with some additional reflections on the relationship between differences in individual physical constitutions and differences in responses to medical treatment. Lee Je-ma (1838–1900) suggested that every human being could be assigned to one of four separate and distinct physiological categories, depending on which of four emotions (sorrow, anger, joy, and pleasure) dominated that individual's personality. He recommended that physicians determine which of those four constitutional types best described a patient before they treated him or her, since he believed that the same outward symptoms were manifestations of different internal malfunctions in different physiological types. The physiological category applied to a patient was determined by the emotion that patient tended to display to excess. Someone prone to sudden outbursts of anger, for example, would damage his liver and would therefore have a physiology different from someone who was too quick to indulge in sensual pleasure and would therefore have damaged lungs (Lee, 1996).

Lee's unique "Four Constitutions" approach to diagnosis and treatment has become increasingly popular in Korea in recent decades. However, before Koreans could create a Koreanized Oriental medicine based in part on Lee Je-ma's hypotheses, they first had to overcome a drastic fall in status for Oriental medicine in Korea at the end of the nineteenth century and the first half of the twentieth (Fig. 3).

In 1884, Christian missionaries from North America entered Korea carrying both Bibles and doctor's satchels. Within a decade, government legitimization of Oriental medicine through state civil service examinations had ended and a hospital practicing the new biomedicine from the West had opened in Seoul with support from the Korean government. Korea's rush to modernization threatened to leave behind Korea's traditional medicine.

Practitioners of Oriental medicine did not vanish from Seoul. There were so few physicians



Medicine in Korea, Fig. 3 Yi Je-ma (Reprinted courtesy of the Association of Korean Oriental Medicine)

trained in biomedicine on the Korean peninsula that the government found that it had to assign Oriental medicine doctors as medical officers for the modern army it began trying to build in 1896. Moreover, Oriental medicine physicians remained on the staff on the Royal Clinic and the Directorate of Medicine, since the royal family was still more comfortable with traditional medicine than with the new medicine from abroad. In addition, since most of the general population was also more comfortable with Oriental medicine than with biomedicine and also because there were very few Koreans trained in biomedicine, the Joseon government decided to include Oriental medicine in its plans for the modernization of its public health system. In 1899, it opened the Gwangjewon (Seoul Public Hospital) which it staffed primarily with specialists in Oriental medicine. The next year, the government inaugurated a licensing system for all practitioners of Oriental medicine on the peninsula. This was the first time in Korean history that medical specialists who operated outside of the civil service had received any official certification of their expertise (Shin, 1999; Son, 1999; Yeo, 1999 pp. 293–301).

Oriental Medicine in the Twentieth-Century Korea

In 1905, however, the Joseon dynasty lost most of its power to make its own decisions when the rising imperial power of Japan imposed Japanese advisors on the Korean government. Five years later, in 1910, the last vestiges of Korean autonomy ended when Japan turned Korea into a colony under direct Japanese control. The Japanese immediately embarked on a campaign to change Korea into a society more closely resembling modernizing Japan (Dimoia, 2013, pp 32–36; Yeo, 1999, pp. 305–307). That included changing traditional Korean medicine into the form of medicine Japan considered more compatible with the modern world, the biomedicine imported from the West. Oriental medicine had to wait until the Americans defeated the Japanese in 1945, and Korea recovered its autonomy, before it could regain anything close to the respectability it had enjoyed prior to Japanese colonial rule.

The end of Japanese colonial rule created two competing governments on the peninsula, with different policies toward Oriental medicine. The Communist government of North Korea redefined Oriental medicine as the traditional medicine of the Korean people and therefore worthy of government support. An Institute for the Study of Eastern Medicine was established within North Korea's National Medical Science Center in the 1950s, decades before a similar research center received government funding in South Korea. North Korea also incorporated Oriental medicine into the national public health system long before South Korea assigned Oriental medicine doctors to its rural health centers (Fig. 4).

In pro-Western South Korea, Oriental medicine had to overcome the assumption among South Korea's Westernized elite that Oriental medicine represented a past Korea needed to leave behind to win respect as a modern nation. A shortage of medical practitioners during the Korean War forced the government in 1952 to formally recognize Oriental medicine doctors as physicians. This paved the way for official

Medicine in Korea,

Fig. 4 Medicine cabinets used by Korean Oriental medicine specialists
(Copyright: Korea National Tourism Organization)



recognition of Oriental medicine clinics, as well as a state licensing examination for new Oriental medicine doctors (Yi, 1977, p. 316). Formal recognition, however, did not win Oriental medicine doctors the high status and high incomes biomedical physicians enjoyed. Given the traditional Korean respect for educational credentials, parity with biomedicine had to wait until there were respected medical schools for Oriental medicine in Korea.

The first college in independent South Korea dedicated to preparing doctors of Oriental medicine opened its doors in 1953. Four years later, it opened an attached Oriental medicine hospital. However, it ran into financial difficulties and was absorbed by Kyunghee University in 1965, which created an Oriental Medicine College within the Kyunghee University medical school. Kyunghee University quickly inaugurated a graduate program in Oriental medicine and in 1971 opened South Korea's first large Oriental medicine hospital as part of a newly opened Kyunghee University Medical Center. A year later, Won'gwang University, also privately run, opened South Korea's second medical school for Oriental medicine. Won'gwang University added its own affiliated Oriental medicine hospital in 1975 (Yi, 1997b pp. 317–319).

There are now 12 medical schools for Oriental medicine in South Korea, all but one of them

established by private universities. In 2009, Pusan National University became the first public university to provide formal training for physicians specializing in traditional medicine (Pusan National University School of Korean Medicine, 2014). There are also over 140 Oriental medicine hospitals, all privately run except for the one operated by Pusan National University, and over 7,000 Oriental medicine clinics. The growing respectability for Oriental medicine led the South Korean government to open the Korean Institute of Oriental Medicine in 1994 to coordinate research on the theory and practice of Oriental medicine (Introducing KIOM, 2013).

That growing respectability has also been reflected in changes in the 1990s in South Korea's laws regulating providers of medical care. Graduates of colleges of Oriental medicine are now allowed to fulfill their obligatory term of military service as medical officers in the South Korean military, just as graduates of other medical colleges have done since the establishment of the Republic of Korea in 1948. They may also be assigned to responsible positions in public health centers, something not permitted before the 1990s. In addition, in 1996 the law regulating pharmacists was changed to recognize those who had graduated from a pharmacology department of a college of Oriental medicine as certified specialists in Oriental pharmacology. In 1992, South Korea's

national medical insurance system recognized this increased respectability of Oriental medicine by adding coverage for a few basic prescriptions to the coverage established in 1987 for acupuncture, moxibustion, and vacuum cupping.

One way Oriental medicine has regained respectability in the last decade of the twentieth century is through modernization. Korean Oriental medicine has become more compatible with modern urban life by adopting such markers of modernization as standardization and mechanization.

Traditionally, an Oriental medicine physician or pharmacist would modify prescriptions to meet the particular needs of a particular patient. It is still possible to obtain individually tailored prescriptions in South Korea today, but it is also possible to walk into a drug store and purchase packages of Oriental medicine prescriptions in mass-produced pill, granular, or liquid form, no different in appearance from many medicines produced in the factories of Western pharmaceutical companies.

Similarly, patients who visit an Oriental medicine hospital for a physical examination might find that their blood pressure is checked the same way it would be checked in a biomedical clinic, although they may also have their pulse checked by a machine which will produce a result framed in terms of the traditional 27 measures of the pulse in Oriental medicine. In addition to an electrocardiogram evaluating how well their heart is functioning, they may encounter another mechanical device that will evaluate the flow of vital energy through their hands and feet.

Not only diagnosis but also treatment, particularly acupuncture, has been modernized as well. The traditional insertion of needles into specific points along the vital energy channels is still practiced, but now those needles sometimes are electrified to provide additional stimulus to vital energy. Lasers are also used to enhance the effectiveness of acupuncture needles. For the treatment of pain, sometimes bee venom is injected into an acupuncture point in a treatment called “medicinal acupuncture.” A new alternative is injecting herbal extracts into the body at acupuncture points (A New Era of Korean Traditional Medicine Treatment, 2010). Tapping is

another variant on traditional acupuncture. Tape is pasted over an acupuncture point, stretching the muscles and stimulating the vital energy flowing through that point.

Whether Oriental medicine in Korea is a unique Korean approach to health and healing or whether it is a Korean variant of traditional Chinese medicine, it is nonetheless seen by Koreans today as a legacy of their traditional culture worth preserving (No, 1971). Oriental medicine has not been supplanted by biomedicine in the twentieth-century Korea. On the contrary, Oriental medicine flourishes alongside biomedicine, in a complementary rather than an antagonistic relationship. Many Koreans remain convinced that, for certain medical problems, traditional remedies are more effective than those of biomedicine (Arirang, 2013).

That complementary relationship is revealed in the presence of family practice biomedical physicians staffing the emergency rooms of Oriental medicine hospitals. It also appears in the advice of a biomedical physician to a patient recovering from a stroke to visit an acupuncturist or in the advice of an Oriental medicine physician to a patient suffering from appendicitis to hurry to the emergency room of a biomedicine hospital. Such cooperation between doctors trained in biomedicine and doctors trained in traditional medicine has become more common. So has technological and pharmaceutical interchange, with Oriental medicine hospitals now using equipment such as CT scanners that originated with biomedicine and pharmacies offering clients a choice of medicines manufactured either according to biomedical formulae or according to formulae drawn from Oriental medicine (Han, 1997, pp. 113–116; VOAvideo, 2011).

For most Koreans today, biomedicine remains the medicine of choice for acute medical problems or for problems requiring surgery. However, Oriental medicine remains the medicine of choice for chronic pain, fatigue, or the ravages of old age (Han, 1997, pp. 108–110). If recent past history is any guide, it is likely that Oriental medicine will remain a viable and vital partner of biomedicine in Korea for decades, if not centuries, to come.

Extra 1

Some nationalists claim that needle-shaped bits of stone found in excavations of Neolithic villages on the Korean peninsula prove that Koreans rather than the Chinese invented acupuncture. Other nationalists cite references to mugwort and garlic in the ancient myth of Dan'gun as "proof" that what non-Koreans call Chinese medicine arose independently in Korea over four millennia ago. Few scholars outside Korea accept such claims (Kim, 1981, pp. 14–28).

Extra 2

Recently, one Korean claims to have greatly simplified acupuncture. Yu Tae-u, the founder of hand acupuncture, claims that he discovered in the 1970s that all the acupuncture points on the body have counterparts on the hand and that stimulation of those points on the hand is just as effective as stimulation of the corresponding points on the other parts of the body. Few mainstream doctors of Oriental medicine in Korea accept Yu's restriction of acupuncture to the hand, though hand acupuncture had become popular among the general population as a form of self-medication. It has also gained adherents in Japan and North America (Yu Tae-u, 1988).

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Medicine in Meso and South America

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Ancient America provides a unique case study for examining the independent development of medicinal practices and technologies in non-Western societal contexts (Majno, 1975). Initial European contacts with New World cultures of the early sixteenth century made clear that aboriginal medical systems and technologies embodied principles of a holistic – mental, somatic, spiritual, and supernatural – approach to healing (Classen, 1993; Guerra, 1971; Huber & Sandstrom, 2001; Lopez Austin, 1971). While the great centers of New World civilization provide our most complete record of medical practices and technologies, many localized native populations contributed to the extensive body of technical knowledge and expertise associated with herbal, chemical, surgical, extrasomatic, or ritual approaches to healing and public hygiene (Ankli, 2002; Gall, 1997; Kunow, 2003). From South American gold and other metal-based dental fillings, cranial ► **trephination**, postcranial surgery, and coca-based anesthetics, to Mesoamerican intramedullary nails, medicinal enemas, surgical sutures and cauterization, caesarean sections, topical anesthetics, poultices, and birth control, the list of ancient American medical practices and technologies is as impressive as it is extensive (Mendoza, 2003).

Because of the breadth and diversity of these practices in the Americas, we can only examine a

narrow sampling specific to ancient Mesoamerica and Peru. The following discussion will move from a consideration of basic Native American concepts pertaining to the causes of disease to the examination of specific case studies concerning the development and sophistication of Native American practices. The perspectives in question are drawn from contact era sixteenth-century accounts of the Aztec and Inca civilizations. One should bear in mind that the New World Inquisition inhibited and condemned the exercise of Native American medical practices. Through the entire duration of the colonial era (ca. AD 1521–1824) these practices were thought to be the work of sorcerers and other native practitioners in league with the Devil (Cobo, 1990). European colonials actively sought to destroy ancient medical works, along with pagan practices and practitioners, throughout the contact era. While early chroniclers attempted to document such practices, they openly disparaged them, and every effort was made to minimize their significance by comparison with European practices of the time by way of blatantly ethnocentric and racist assumptions about the mental life and intellectual contributions and potential of America's aboriginal inhabitants. In those few instances where a concerted scientific effort was made to collect information on the medical practices of such groups as the Aztec (Sahagun, 1932), the distribution or publication of such works was prohibited for centuries (Cruz, Byland, & Gates, 2000).

Much of our knowledge of contact era medical practices is derived from the detailed chronicles compiled to document the cultural history of the Aztec and Inca civilizations. For example, medical anthropologist Bernard Ortiz de Montellano (1990) has subdivided Aztec concepts pertaining to the causes and treatment of disease into three categories: supernatural or religious, magical, and natural or physical. He indicates that the Aztec held a holistic world view pertaining to the causes and cures of disease, and refers us to the work of Mexican ethnohistorian, Lopez Austin: "the origin of illness is complex, including and often intertwining two types of causes: those that we would call natural – excesses,

accidents, deficiencies, exposure to sudden temperature changes, contagions and the like – and those caused by the intervention of nonhuman beings or of human beings with more than normal powers. For example, a native could think that his rheumatic problems came from the supreme will of Tlalacahuan, from the punishment sent by the tlaloque for not having performed a certain rite, from direct attack by a being who inhabited a certain spring, and from prolonged chilling in cold water; the native would not consider it all as a confluence of diverse causes but as a complex" (Lopez Austin, 1974, pp. 216–217). This complex view required that the physician reconcile a variety of conceptual, spiritual, and physical dimensions in the course of diagnosis and treatment. Aztec doctors were required to balance herbal and other chemical treatments with interpretive models of causation ranging from the supernatural and magical to the natural, or a complex mix of both (Cichewicz & Thorpe, 1996). The supernatural and magical, encompassing astrological interpretations such as those prevalent in sixteenth-century Europe, were of the greatest interest to early contact-era European chroniclers (Majna, 1986).

Botanical Knowledge

While the botanical repertoire of New World peoples is discussed elsewhere within this encyclopedia, the relative significance of botanical specimens and knowledge to New World medical traditions necessitates brief consideration. It should be noted that recent research in this area makes clear the great contributions made by Native Americans (Lopez Austin, 1974; Lux, 2001; Schultes, 1994). The surviving Aztec herbal known as the *Codex Badianus* provides one of the most extensive listings of botanical specimens identified with the medication and treatment of a variety of ailments (Cruz et al., 2000). However, in his efforts to make the herbal, palatable to a European audience, Juan Badiano, the chronicler who prepared the document for submission to King Charles, modified it to

incorporate European medical beliefs regarding the role played by temperature in illness, diagnosis, and treatment.

The large body of medicinal knowledge identified with the Americas, and subsequently adopted by European-based medical systems, included such ancient Native American medicinal and hallucinogenic substances as coca (*Erythroxylon coca*), mescaline (*Lophophora williamsii*), nicotine (*Nicotiana tabacum*), quinine (*Quina cinchona*), psilocyben (*Psilocybe mexicana*), dopamine (*Carnegiea gigantea*), anodyne analgesics (*Solandra guerrerensis*), the ergot alkaloid D-lysergic acid (*Ipomoea violacea*), and genipen-based antibacterial agents (*Chlorophora tinctoria*). To this list may be added medications and related chemicals and supplements ranging from *N*-dimethylhistamine to atropine, serotonin, tryptamine, kaempferol, prosopine, pectin, and camphor – to name but a few. These served Aztec physicians in a variety of capacities. Ortiz de Montellano (1990) has documented the medicinal properties of many of the herbal and chemical treatments administered by Aztec physicians. Included in that listing are diuretics, laxatives, sedatives, soporifics, purgatives, astringents, hemostats, hallucinogens, anesthetics, emetics, oxytocics, diaphoretics, and anthelmintics. Furthermore, there were a variety of antibiotic or antiseptic treatments for treating wounds, medicating infections and fractures, and performing surgery. These included the herbal vasoconstrictor *comelina pallida*, maguey or agave sap, for its hemolytic, osmotic, and detergent effects, hot urine in lieu of other available sources of sterile water, and mixtures of salt and honey which have been determined to provide enhanced antiseptic functions.

Recent studies of the “hidden chemical wealth of plants” used by the Native American tribes of the Amazon rain forest provide but one more point of departure for gauging the range and extent of pre-Columbian medical traditions (Schultes, 1994). In his summary of the pharmacology of the Kofan and Witoto tribes of the Amazon Basin, ethnobotanist Richard Evans Schultes has observed that “the forest peoples’

acquaintance with plants is subtle as well as extensive. The Indians often distinguish “kinds” of a plant that appear indistinguishable, even to the experienced taxonomic botanist.” This taxonomic acuteness extends to the level of being able to distinguish chemovars, or the basic chemical constitution of a specific subvariety, by visual inspection alone. Despite an estimated 80,000 species of higher plants in the Amazon, fewer than 10 % have been “subjected to even superficial chemical analysis (Schultes).” Such a store of indigenous botanical knowledge recently prompted Schultes to ask “why not regard the Indians of the Amazon Basin as a kind of phytochemical rapid-assessment team already on the ground?”

Medical Specialists and Personnel

While it is clear from all accounts that herbal specialists existed in all regions of pre-Columbian America, the existence of a broader corps of trained medical specialists and personnel is less evenly documented. So intent were early contact-era European chroniclers on disparaging and discouraging pagan forms of medicine that much was done to reduce the role of medical specialists from Native American communities. In most instances, medical specialists ranging from herbalists to physicians were simply characterized as sorcerers or charlatans. Given the relatively impoverished state of European medicinal practices of the early sixteenth century, it is no wonder that most European chroniclers of Native American medical traditions expressed outright contempt for Native American physicians and their medical practices and traditions. Despite deliberate errors of omission and commission, surviving documents provide indications of the broad sophistication in Native American medicinal practices.

As for the documented existence of a scientific tradition with trained practitioners specialized in specific forms of surgical treatment, we are informed by archaeologist Burland (1967) that, in a region above Lima, Peru, there existed an

ethnic enclave known as the Yauyos with whom the Inca collaborated in the training of specialists in the art of cranial ► **trephination** or skull surgery. The patient was drugged, and pain was alleviated by way of the application of direct pressure to nerve endings in the affected area. In such instances, trephination was used only as a last resort, whereby the diseased or smashed bone was cut away from the skull. Other forms of surgery included the “removal of a torn spleen, cleaning out of ulcers, and the cleaning and after-care of wounds” (Burland). Professional alliances between the Inca and Yauyo allowed for the exchange of technical knowledge and technicians. Accounts of the work of Yauyo physicians indicate that they were highly trained and had developed a formal discipline based on a corp of specialists. Apparently, herbal specialists of highland Peru were organized into “local confraternities,” while medical specialists and physicians – *camasca* or *soncoyoc* – were sponsored by the Inca state and “highly trained within their own kind of collegiate discipline.” This latter point is of paramount significance in establishing the existence of a specialized corps of medical personnel, and as such, the makings of a formally constituted and state-sponsored scientific tradition specialized in the treatment and trephination of the human cranium.

According to medical historian Gordon Schendel (1968), technical distinctions were made between “old” and “new” school physicians. At European contact, old school physicians were thought of as more traditional and more adept at conveying medical and spiritual beliefs pertaining to the art of healing, whereas the physicians of the new school engaged specialized methods and medical procedures. Among the Aztec, medical specialists included the *tlana-tepat-ticitl* or healer who “cured with medicines which were digested or applied on the skin” (Guzman Peredo, 1985), the *texoxotlaticitl* or surgeon whose skills included bloodletting, and the *papiani-papamacani* or herbalist. Other terms utilized to identify Aztec medical specialists included *texoxtl*, or surgeons, and the *tlamatepatli* or medical interns of the *texoxtl*

surgeons. The *tecoani* were the bloodletters; the *temixiuitiani* were the midwives. The *papiani* were the pharmacologists or herbal pharmacists. The *panamacani* are identified with pharmacognosists, or those individuals specialized in the identification; collection, and dispensing of herbal remedies, a specialty not unlike that of the plant pharmacologists of the Amazon Basin. Schendel has also documented the existence of a variety of specialists and areas of medical specialization, including internists, psychiatrists or psychotherapists, anesthesiologists, dermatologists, dentists, obstetricians, gynecologists, orthopediatricians, ophthalmologists, urogenital surgeons, and other practitioners specialized in the administration of tonsillectomy and embryotomy. In all areas of medical endeavor, specialists were held accountable for their actions and practices by their peers, as well as by the community at large.

Other specialists included those who used chiropractic methods, whereby “these doctors, in the case of falls, usually strip the patient and rub his flesh; they make him lie face downwards and step on his back. I have seen this myself, and I have heard patients say that they felt better. . . the pity of it is that there are even Spanish men and women who believe them (Aztec physicians) and are manipulated to serve their needs and evil” (Cervantes de Salazar 1936, as cited in Guzman Peredo, 1985). Spanish Friar Bernardino de Sahagun commended the technical expertise of Aztec physicians and noted that they “had great knowledge of vegetables; moreover, they knew how to perform bloodletting and to reduce dislocated bones and fractures. They made incisions. They healed sores and the gout. They cut the fleshy excrescence in cases of ophthalmia (inflammation of the eyes).”

Surgical Practices

As our discussion of medical specializations makes clear, pre-Columbian medical practices, particularly those pertaining to surgical methods, were comprehensive and sophisticated in scope.

According to conquest period chronicles, “Aztec battle surgeons tended their wounded skillfully and healed them faster than did the Spanish surgeons ... [and] ... one area of clear Aztec superiority over the Spanish was the treatment of wounds. European wound treatment at that time consisted of cauterization with boiling oil and reciting of prayers while waiting for infection to develop the ‘laudable pus’ that was seen as a good sign” (as cited in Ortiz de Montellano, 1990). Medical historian Miguel Guzman Peredo (1985) cites Fray Bernardino de Sahagun: “Cuts and wounds on the nose after an accident had to be treated by suturing with hair from the head and by applying to the stitches and the wound white honey and salt. After this, if the nose fell off or if the treatment was a failure, an artificial nose took the place of the real one. Wounds on the lips had to be sutured with hair from the head, and afterwards melted juice from the maguey plant, called meulli, was poured on the wound; if, however, after the cure, an ugly blemish remained, an incision had to be made and the wound had to be burned and sutured again with hair and treated with melted meulli.” This citation makes clear the availability of prosthetic or cosmetic devices, the use of sutures, and the application of maguey or agave sap as an antibiotic ointment.

The Aztec also maintained a complex typology for mapping human anatomy and physiology. They identified specific body parts, organs, and their respective biological functions, and employed anatomical terms for the articular surfaces and attachments of limbs, as for instance in the use of the terms *acolli*, *moliztli*, *maquechtli*, and *tlanquaitl*, for the articulation of the shoulder, elbow, wrist, and knee, respectively. According to Guzman Peredo, “those physicians had more than elementary concepts of the different organic functions. They knew, for example, of the circulation of the blood. They even became aware of the throbbing at the tip of the heart; this they called *tetecuicaliztli*. The radial pulse was called *tlahuatl*.” Armed with such knowledge, the Aztec “used traction and counter traction to reduce fractures and sprains and splints to immobilize fractures” (Ortiz de Montellano, 1990). Perhaps one of the most significant medical

innovations concerns the use of the intramedullar nail. Bernardino de Sahagun (1932) noted that in instances where bone fractures failed to heal, “the bone is exposed; a very resinous stick is cut; it is inserted within the bone, bound within the incision, covered over with the medicine mentioned.” The intramedullar nail was not rediscovered by Western medicine until well into the twentieth century.

The most outstanding example of the empirical reliability and effectiveness of a pre-Columbian medical tradition centering on surgical applications was the use of cranial ► [trephination](#) or skull surgery (Mendoza, 2003). Examples of the practice have been documented from throughout South, Middle, and North America. An extensive review of this practice can be found elsewhere in the encyclopedia.

Our review of pre-Columbian medicinal practices raises many more questions than can be addressed in this essay. Clearly, the European predilection for accommodating only that which suited prevailing eurocentric modes of thought contributed to the uneven documentation of significant Native American medical innovations and practices. A selected recounting of significant innovations should take into account practices centered on (a) holistic concepts of health, (b) state-sponsored public health programs, (c) an extensive body of anatomical terminology, (d) the existence of confraternal medical associations and state-sponsored medical corps, and specific practices centered on medical innovations such as those pertaining to (e) cranial trephination, (f) prosthetic and cosmetic devices, (g) antibiotic and antiseptic ointments and medications, (h) intramedullar nails, (i) formal procedures for the maintenance of dental health and hygiene, (j) psycho- and logo-therapeutic, or image-based, psychological approaches, and not surprisingly, (k) the largest pharmacological repertoire of effective and affective herbal and chemical remedies ever documented in the ancient world. Ultimately, any assessment of pre-Columbian medical traditions and innovations will need to contend with the fact that scholars have only just begun to scratch the surface of this New World of lost science and tradition.

See Also

- [Ethnobotany](#)
- [Trephination](#)

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Medicine in Native North and South America

Åke Hultkrantz

“Medicine” is an ambiguous word in American Indian connections. The first European missionaries and settlers learned that in the aboriginal languages the word corresponding to medicine could also be translated as supernatural power. A “medicine man” could be a man who healed a human being, but also a kind of a miracle man who through his connections with the supernatural world of gods and spirits was able to prophesy the future, locate lost articles or persons, bring on rain, attract game animals, call on the spirits, escort the newly dead to the other world, and many other things. In short, he was, and still is, a mediator between humankind and the spiritual world. It is through his equipment of supernatural power that he can cure the sick. In this article medicine will be understood as the way of curing and as a medicament, except in the compound medicine man, which will retain its old composite meaning. The role of the medicine man in curing will be further elucidated below.

All medical measures depend upon the ideas of the character of the disease. Slight injuries and mild diseases are not interpreted so much in terms of supernatural agencies at work, but dangerous diseases – or diseases considered to be dangerous – are mostly referred to supernatural intervention. Ghosts, unknown spirits, disease demons, witches, or taboo infringements are

supposed to be responsible for cases of illness. The supernatural causation is a consequence of the fact that the basic harmony between humankind (or parts of humankind) and the sacred Universe has become upset. Prayers and propitiatory rituals may enclose all kinds of healing procedures but are more common where more grave diseases are concerned.

Whereas the supernatural element in curing is clearly present in the serious cases of disease and damage, natural knowledge plays a dominant role in the curing of ordinary wounds and diseases. Medicine men and women could relieve the pain and remove the diseases of this latter kind, but it was also common for old men and women to take care of them, at least in North America. These old people who had learned their medical arts during a long life and furthermore had particularly observed the traditional healing systems of the tribe, to a large extent used herbal medicines. They could, therefore, be called herbalists. It is not too much to say that herbs, for external or internal usage, were the most common medical cures in aboriginal America.

There were many different kinds of treatments. In Algonquian New England the colonists found that people who had been scalded had their sore skin washed with a strong decoction of tobacco, and thereafter a powder made from dried tobacco was sprinkled on to the wound. More to the south, in North Carolina, seeds of *Datura* were used for the same purpose. Bleeding was arrested with spiderwebs in large parts of North America. James Adair, who was a well-known trader among the Southeastern North American Indians in the latter part of the eighteenth century, reports that every Cherokee carried a variety of herbs and roots such as snake-root and wild plantain in his shot pouch as a remedy for the bites of poisonous snakes (Adair, 1775). The Indian chewed the root, swallowed a part of it, and applied another part to the wound. After some pain and contortions the man was relieved of the poison. Here we see how everybody was his/her own doctor.

From the same area the well-informed anthropologist Swanton (1928) reports that the Creek drank a cold decoction of "Devil's shoe-string,"

or catgut (*Tephrosia virginiana*), to relieve themselves of bladder trouble. They also boiled the roots of sassafras (*Sassafras officinalis*) into a hot drink to get rid of bowel and stomach ache. Sassafras seems to have been a health medicament wherever it occurred. Venereal diseases were also cured with herbal decoctions.

Herbalism was a subject in Aztec schools, and some herbalists were even examined in the priest schools, the *Calmecac*. They were known for their empirical approach to health. Ortiz de Montellano (1989) writes that "the efficacy of Aztec wound treatments has been validated, as well as their accurate knowledge of the physiological activities of plants. Their extensive ethnobotanical knowledge and accurate taxonomy indicates that herbals may have existed and were taught in school, although no genuine pre-Columbian herbal has survived." As the same author points out, it would, however, be wrong to postulate a distinction between empirical and supernatural knowledge among the Aztecs, for "good doctors also included those who used mixed therapies and psycho-religious techniques." In this respect the old Mexican doctors remind us of North American medicine men.

In South America herbalism is mainly thought of as a medical subfield of the medicine man. Herbalist specialists among the Araucanians might know up to 250 medicinal plants. Ackerknecht (1949), an authority on South American Indian medicine, has next to nothing to say about herbalism there. He points out, however, that such measures as massages, drugs, baths, bloodletting, diet and enemas do occur, and are "objectively effective." At the same time, the causation of such diseases, indeed, all diseases, is supernatural, he claims. Another expert, Métraux (1949), insists that "light and common ailments and the sicknesses introduced by the Whites often were regarded as natural and were treated with drugs rather than by shamanistic means." He admits, however, that most diseases were attributed to supernatural causes. It is obvious that these questions have not been satisfactorily investigated. Several works indicate that herbalism was very widespread in South America, but whether there were – and are – herbalists

who could be classed as inspirationally initiated medicine men is not clear.

A herbalist is, as seen in this article, a person who primarily deals with herbal medicine for internal or external usage. Secondly he or she also handles stimulant drugs, emetics, and, in some cases, surgical operations. In North America the *peyote* (*Lophophora williamsii*), a cactus growing in the vicinity of the Rio Grande, is supposed to cure all kinds of diseases when eaten, drunk, or smoked. Peyote is hallucinogenic but not narcotic; it is not habit-forming. A particular Peyote religion was formed at the end of the nineteenth century and spread over large areas of North America. The taking of peyote against disease occurs frequently in individual cases. In the cultic connections peyote is consumed because it gives supernatural blessings, including a medical cure. Peyote is powerful for many purposes, not just for medicine, although the medical reasons have been strongly supportive in the diffusion of the Peyote religion. It is very possible that other “herbs” have also had such a general effect because of their supernatural qualities. In South America narcotic beverages such as the *ayahuasca* prepared from the plant genus *Banisteriopsis* and the decoctions of *Datura arborea* are used in or after shamanic curing séances. Also here the drugs are active because of their spiritual force, and not because they have a specific medicinal content.

Some drugs have been favored since they have emetic qualities. In both North and South America poisonous or impure substances in the body are expelled from the mouth via emetics (and from the rectum via cathartics). The most well-known emetic is prepared from a particular holly, *Ilex vomitoria*, that grows in the southeastern part of North America. This drink, called “black drink” by the Whites because of its color, but “white drink” because of its supposed purifying qualities among the Indians of the Southeast, contains caffeine. Drunk in large quantities it provokes violent vomiting. This emetic was taken as a brew to produce purity before social and religious ceremonies – as ritual sweat baths in other areas – and in connection with diseases.

The disease belonged to the impurities that were removed through the black drink.

There are some reputed cases of surgery in the old days; however, amputation seems to have been scarce. Scarification occurred in many places in North America. Thus, according to Frank Speck, the northeastern Algonquians tried to relieve pain by creating an exit for it. Skull surgery, or trepanation, is mentioned from both Americas. Some scholars have tried to find rational reasons behind such operations – head injuries, unconsciousness, and so on. Since they were performed in pre-Columbian times it is impossible to get a definite answer. However, it seems more in conformity with American Indian thinking to presuppose an animistic model of explanation: the surgeons wanted to relieve the sick person from the spirit that plagued him. The most common method was, however, to put some herb or bark on the wound or over the aching area.

If there is much uncertainty concerning the ideas of etiology and the nature of the healers in herbalism, there is more certainty of the medicine men and their disease ideology. As stated above, the medicine men and women, or those medicine men and women who are doctors, function as such when through their own or other healers’ inspiration it can be stated that the disease is of supernatural origin. The medicine person was chosen by his/her guardian spirit to conquer the malign spiritual influence behind the disease. His or her healing is dependent upon the power with which he/she was entrusted in the course of his/her calling.

The supernatural aspect of religious causation can mean many things, for instance, that witches on account of their supernatural powers, or sorcerers because of their magical manipulations, upset the normal health of individuals. Or it can mean that transgression of tabooed places or actions, displeasing of the powers, or imbalance in the cosmic harmony cause the same result. Sometimes spirits and divinities introduce disease and wounds without any apparent reason. The immediate outcome of this supernatural line of action may be intrusion into a person’s body of objects or spirits (which could be the same thing

since objects may be inanimate manifestations of spirits, or instruments of spirits), and the loss of the soul which may be wandering around, or has been stolen by some witch or some spirit(s), usually the spirits of the dead. In the latter case the lost soul may be taken to the realm of the dead from which it is difficult for the medicine man to retrieve it and take it home. The soul entity that has been lost is usually a separable soul, mostly the free-soul, or the soul that sometimes distances itself from the body in dreams and trances. As long as the soul of vitality or, where it exists, the ego-soul remains with the body, the individual is alive; where all the souls (usually two souls, the free- and the body-soul) remain with the body the person is also alive. This is the general program, but many exceptions from this rule have been found among North and South American tribes.

There is a particular tendency among Native Americans to distinguish two definite systems of diseases behind the two causation theories. When the "intrusion" diagnosis is resorted to attention is directed to the body and its diseases. We can say that the patient's physical pain conducts the doctor. In "soul loss," however, it is the sick person's mental state that stands in focus. His intellectual power fades away, fever or absent-mindedness rule, he languishes away, loses his consciousness, and so on. Scholars have until fairly recently tried to show that intrusion was more common in America, and therefore is an older diagnosis, whereas soul loss has had a more spot-like distribution and is therefore a younger diagnosis. As will soon be seen, the latter diagnosis corresponds to more difficult healing procedures. However, the more field research has proceeded the more cases of soul loss have been discovered. The present distribution of diagnoses confirms the generalization made here. Of course, in some regions we find intrusion as the dominating complex, in others, soul loss. But the presence of both diagnoses – for different types of disease – seems to be the original pattern. In our days soul loss is missing in many places, but the memory of its application by capable medicine men some decades ago is living.

In some places, for instance among the Navajo, the decision of the nature of the disease

is left to particular diagnosticians who, in an inspirational state, are capable of finding out the roots of the disease. A serious disease to them is always referred to as being a break with the invisible world and its spirits; the diagnosis is never concentrated on the biological state of the individual, but on the acting spiritual forces. Among the Navajo the disease means that the afflicted person has fallen out with the balance and harmony of the Universe, so he has to be reintroduced by being identified with the supernatural powers in nocturnal rituals of up to nine nights. The officiant is a sacerdotal singer, not the diagnostician. The former could be termed a priest, the latter a shaman.

Shaman is a Tungusian word denoting those medicine men who perform their services in a trance or ecstasy. The word has since the eighteenth century become a technical term for medicine men who communicate with supernatural beings in states of trance. The Natives in America rarely have a term for differentiating shamans from ordinary medicine men; usually a shaman is said to be a stronger healer than others. Shamans occur, or have occurred, over most areas in America. The large majority of them, but far from all of them, handle diseases. When the recovery demands contacts with or intervention from supernatural powers, the shaman appears on the scene in order to meet these powers in a trance situation.

All medicine men, shamans included, receive their doctor's powers through inheritance, spiritual calling, or vision quest. In the question of inheritance it is often possible to see who is going to become a doctor; he or she has a nervous psychic constitution or is reminiscent of a deceased medicine man. In South America it is not uncommon for a doctor to transfer his profession to his own sons or nephews. The calling of the spirits is more or less attached to the inheritance idea since the guardian spirits of a shaman try to find his successor in the same family. In The American Great Basin, California, and Gran Chaco are areas where shamans are called by the spirits. Sometimes this calling follows very aggressive lines, for instance, among the Mapuche of Southern Chile. Vision quests are used in

the areas in eastern North America where ordinary individuals also seek guardian spirits in order to procure their powers and their protection. Shamanic spirits are stronger and more specialized in healing than other visionary spirits. The acquisition of spirits is connected with fasting and several days' staying out in the wilderness with the dangers of climate and wild animals. In South America the candidate smokes strong cigars and consumes *ayahuasca* wine in order to attain shamanic ecstasy. The novice also joins a medicine man school, or an experienced older shaman, in order to learn shamanic procedures and tricks.

The medicine man heals the patient partly through herbalism and partly through suction, blowing, massage, and wafting with feathers, to remove the disease object or disease spirit. In South America the medicine man may attain some degree of ecstasy by drinking *ayahuasca*, whereupon he blows thick clouds of tobacco into the patient's mouth. The disease object – an arrow, a dart – is sucked out by the medicine man and then regurgitated by him. In both Americas the medicine man often produces a little thing that he claims to have sucked out of the patient and that is supposed to have caused the disease.

In cases of soul loss the healing procedure is often more difficult and more dramatic. Let us, however, first of all state that the usual background of soul loss, the serious change of consciousness, in some places can be healed without too much difficulty on the part of the acting medicine man. Thus, sometimes the soul may be called back by the medicine man, or sought by him and his associates in the neighborhood of the camp or village. According to Karsten (1955), the Jivaro Indians at the sources of the Amazon River know no remedy for fever diseases but destroy their own villages and leave them, apparently in the belief that not soul loss, but attacks of disease demons have hit the patients. In North America, for instance among the Yuma, it happens that soul loss is cured through blowing and suction, a proof that the intrusion model of disease diagnosis has formed a general curing pattern here.

The most common cure of soul loss is that the medicine man – who in this case operates as shaman – sinks into a trance to transgress the boundary between this and the other world. In North America this entrance into ecstasy is mostly brought about through autosuggestion and drumming, and in South America narcotics such as tobacco and *ayahuasca* effect the same state. The shaman's soul, and in some cultures his guardian spirit (it also happens that he is transformed into his guardian spirit) then departs on the long road to the land of the dead. Sometimes he manages to catch up with the fleeing soul and can then return it to its owner. If however the soul of the sick patient has reached the land of the dead, the shaman has to risk his own life by seeking the fugitive soul in that realm and trying to persuade it to come back with him. In such cases the shaman has to fight violently with the mass of the departed who want to retain their newly arrived visitor. Usually the shaman wins the struggle and brings the patient's soul back home. He presses the soul against the patient's head or some other place, and after a short while the patient wakes up again. The shaman, who in most cases has been lying down as if he were dead during the soul journey, now also comes back to life.

Sometimes many shamans cooperate in a ritual drama in a so-called imitative shamanistic séance. An example of the latter is the voyage of shamans in a symbolical canoe to the land of the dead among the Puget Sound Coast Salish. The medicine men are equipped with boards which represent a canoe and paddles and act out the events of the voyage: the hardships on the journey, the battle with the dead, the release of the imprisoned soul, and its transporting home. Here it is not the question of a deep trance, but a dramatic performance in the inspired state of an actor.

Collective medical contributions are also given in some agricultural societies, such as the Pueblo societies in New Mexico and Arizona. They have curing organizations constituted of people who have once been ill and healed by the same organizations. Animal spirits, so-called Beast gods, are the patrons of the medical

societies among the Zuni Pueblo Indians. The societies are specialized in curing particular diseases, and use the methods adopted by medicine men healing patients suffering from “intrusion” diseases.

See Also

- [Ethnobotany](#)
- [Religion and Science in the Native Americas](#)

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Medicine in Oceania

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Accounts often portray indigenous or traditional medicine as a culture-bound set of knowledge and practice, rooted in superstition and indigenous religion, which will eventually be displaced by a more powerful scientific biomedicine (Strathern & Strathern, 1999). A study of traditional medicine in Oceania reveals that it is, in fact, a dynamic body of knowledge and practice which routinely incorporates new forms of medical knowledge, material, and practice which have been shown to be effective, and which, in the process, becomes progressively more useful. The extent of this incorporation is often missed because its practitioners soon come to regard innovations as part of tradition and because users often assume that since the medicine is dispensed by a traditional healer, it derives from some indigenous medical repertoire. This makes it difficult to reconstruct traditional medical knowledge.

It is, however, possible to reconstruct the trajectory of the incorporation and to identify the sources of new knowledge and the circumstances in which it occurred. In the Oceanic case, the late introduction of western illnesses and medical knowledge and the circumstances of their arrival have meant that scientific biomedicine became considered a useful adjunct to, rather than a

replacement for, traditional medicine and the two systems sit alongside one another as complementary elements of a healing system. However, what was once seen as a useful adjunct to traditional medicine may now be a threat to its continued existence, and the latter stages of this paper explore the nature of the threat to traditional medicine.

Some 5,500 years ago, people moved out of south China and, along two routes, into Oceania. Descendants of the original settlers moved steadily eastward, pausing only briefly while they developed the naval architecture and navigational knowledge to make the steadily longer voyages between ever more scattered easterly islands possible (Goetzfridt, 1992). They eventually settled the furthest reaches of the last uninhabited region on earth with voyages to Aotearoa (New Zealand), Rapa Nui (Easter Island), and Hawaii some 900 years ago.

The path, progress, and timing of the settlement of the Pacific have been confirmed by oral history and by steadily growing volumes of linguistic, archaeological (Kirch, 2002), anthropological (Kirch & Green, 2001), and, more recently, DNA evidence. Studies of voyaging and navigation techniques (Goetzfridt, 1992; Irwin, 1992; Lewis, 1972) and, more recently, a series of voyages in replica sailing vessels (Finney, 1988) have confirmed that the required journeys could have been made with available nautical knowledge and technology and have dispelled the earlier view (Sharp, 1957) that these were accidental or drift voyages. Findings of ongoing research in each of these fields confirm this theory of easterly settlement and typically refine dates or clarify processes. There are now accepted explanations for the presence of the few elements which led to consideration of the possibility that Oceania had been settled from South America.

On the surface at least, it should be possible to trace continuities in the knowledge and practices of the settlers. There was little which would have been expected to transform established knowledge and practice as the explorers moved from west to east. The settlers, who were agriculturalists, carried a limited range of cultigens and

technologies necessary to farm these. Beyond what is now New Guinea, they encountered no other peoples on their way eastward, and settlement occurred within a restricted range of terrestrial (Manner, Muller-Dombois, & Rapaport, 1999) and marine ecosystems within a relatively limited range of latitudes. Once settled, the Oceanic settler societies were only infrequently visited and then, typically, by Oceanic neighbors. This situation persisted until European explorers reached the region some 2,500 years later and limited the external influences on these Oceanic cultures. Despite thousands of years of separation, similarities are evident in the lexica of the Oceanic languages, and these have been recognized in the designation of an Austronesian language family (Pawley, 1999). There is also evidence of the passage of some cultural traits from west to east and explanations of why these might have taken various forms in different places (Kirch, 1989; Kirch & Green, 2001). Yet despite that, there is little evidence of the passage of a body of medical knowledge and practice from west to east.

That does not, however, mean that there was not a body of Oceanic medical knowledge and practice, but rather that it was not documented at contact, which had more to do with the worldviews of those who were in a position to record it. The earliest traders and missionaries typically dismissed the knowledge of indigenes as insignificant and as artifacts of a worldview which they sought to modify or replace. By the time better educated missionaries and settlers became interested in documenting indigenous knowledge, much of what had existed had been either lost, transformed by, or fused with the introduced worldviews with which it had collided. Introduced material and beliefs had found their way into traditional medicine, and in some cases, even the practitioners were unaware of the extent of these incursions.

It has, as a consequence, become difficult to reconstruct the autochthonous medical knowledges of Oceania. There are numerous studies of traditional practices in contemporary Pacific societies (Connell, 1980; Feinberg, 1979; Parsons, 1985; Whistler, 1985, 1992, 1996) but few

comprehensive reconstructions of pre-contact Pacific medical knowledge and practice. One exception is Samoa (Macpherson, 1985; Macpherson & Macpherson, 1990) which lies near the geographical center of Oceania. This case is significant because of Samoa's place in the settlement of Oceania and because it provides some insights into the dynamic nature of traditional knowledge.

Samoa was settled some 3,500 years ago, and a distinctive society developed over some 1,000 years before the bearers of this culture set out to settle the eastern reaches of Oceania. This case is culturally significant because Samoa lies at the boundary of eastern and western Polynesia, contains elements of western Polynesian culture, and is widely acknowledged as the birthplace of eastern Polynesian cultures. From the point of view of cultural reconstruction, Samoa is also significant. By the time European contact and settlement occurred in Samoa, there was more systematic interest in indigenous knowledge and practices, and a more comprehensive record, from authors with diverse personal and professional interests, provides a more reliable basis for historical reconstruction. This study is used here as the basis of an account of what might have existed in Oceanic societies.

Samoans referred to health as *soifua mālōlōina* which means "life rested" and refers to a form of biosocial equilibrium. It was also referred to as *la'oifua* or to be recovered from sickness, and in the language of chiefs, as *laumālie*. It embodies the idea of balance in relations between individuals, the social entities to which they belonged, the physical environment in which they lived, and the supernatural realm within which all humanity existed. An individual exists at the intersection of a number of related realms. These linkages were called *va* and had to be consciously maintained, *teu*, by individuals who wished to maintain good health. Such relationships were ideally balanced and reciprocal, or *fealod'i*, which implied mutual respect of rights and obligations which attached to related roles. This balance existed when norms of conduct for people in related roles were observed. Health was attained, and maintained, when a person attended

to his or her relations with others and with the spiritual agencies, *atua* and *aitu*, which controlled human activity. An ordered society is one in which relations between the realms were in a form of equilibrium and is known as one in which relationships are balanced *va fealoalod'i*.

Conversely, ill health occurred where people violated the norms and rules of social and spiritual relations. Ill health was the consequence of offenses against either social or supernatural agencies, and the causes of everything from physical trauma to mental illnesses were sought in these areas of social and supernatural relationships (Turner, 1983). These gods' influence was so pervasive, and their powers so extensive, that they were held to be the principal authors of all human illness. Gods generally created illnesses to punish people under their protection for a lack of appropriate respect or for acts of meanness to them. Various people, known as *taulāaitu* or *taula ole aitu*, or anchors of the spirits, acted as mediums and identified social and supernatural sources of an illness (Moyle, 1974). In the case of supernatural causation, the medium sought to identify the offended spirit or god, clarify the cause, and identify the appropriate form of conciliation.

In other cases, offended living persons could call on another class of gods, known as *taulā-aitu-va-alo-ma-fai-tu'i*, to make the offender ill. The resulting illness could take several forms, and the form gave some clues to the nature of the offense which, in turn, focused inquiries on people who might have committed it. Where social offense was suspected, a process of systematic inquiry led eventually to the offended person who had engaged in the sorcery which had created the illness and to the form of social activity which would lead to its removal. This consisted of incantations directed at the identified spiritual agencies (Moyle, 1974). Only when these causes were identified could the process of intervention commence, and only when this was completed and accepted could relationships be restored.

The focus of activity in each case involved the identification of the relationships which had been disturbed and the activity necessary to *teu le va* or

heal the relationship. In most illnesses, the human body was simply the site in which the offended parties had sought to demonstrate their displeasure. To complicate matters, the person who became ill was not always the one who had caused the offense, and so diagnostic inquiries had to extend to the conduct of those around the victim in case this person was a surrogate.

The level of agreement on an essentially social intervention process in the writings of a range of early observers of Samoan society was unexpected. Traditional models of physiology, etiology, and epidemiology, an extensive, and apparently thriving, body of plant-based medicines, and forms of massage are in use in contemporary Samoa (Macpherson & Macpherson, 1990). This paradox led to consideration of the possibility that those who documented it were led by their religious and social agenda to focus on these elements of practice and to overlook either accidentally or deliberately other elements of Samoan medical practice (Macpherson & Macpherson 1990). These missionaries were dependent on their supporters in Britain for the resources for the mission. Their records and tracts tended often to focus on areas of activity which showed the enormity of their task of conversion and which generated the most interest and most generous support on the part of British congregations. However, an examination of both religious and a number of secular authors' works suggested that there were only very rudimentary indigenous models of human anatomy and physiology and little in the way of biomedicine.

Early missionary authors, such as Dr. George Turner, who sought information on medicinal uses for Samoan plants, reported that relatively little medicinal use was made of the local flora and fauna (Turner, 1983). This was confirmed by other missionaries and surprised them as they were themselves regular users of herbs and simples. Comprehensive and well-regarded dictionaries compiled by early missionary linguists (Pratt, 1862) contained extensive lists of flora and fauna but few terms for medical implements or procedures and few annotations of medicinal plant uses. Relatively few indigenous terms or concepts relating to human physiology or biology

were discovered by these linguists. Early plant collections contained extensive notes on various practical uses of plants, but little evidence of medicinal uses (Powell, 1868). Comprehensive studies of Samoan material culture located no implements used in medicine (Hiroa, 1930).

This finding was remarkable, given that there is an extensive traditional knowledge and thriving traditional practice and that Samoans make regular use of both traditional knowledge and practitioners, and flora and fauna in their search for health (Macpherson, 1985; Macpherson & Macpherson, 1990; Whistler, 1996, 2000). The finding raised the issue of how missionaries and other settlers, who had so assiduously documented other areas of Samoan life, could have missed a body of traditional medicine.

One possibility canvassed was that the medicinal material and knowledge were, for various reasons, not revealed to early missionaries. Other forms of sacred knowledge, such as navigation, had been hidden from visitors to Oceania (Lewis, 1972). In this case, the missions had sought to undermine belief in Samoans' traditional gods and had ostracized those who had expressed continued support for them. The close association between the family and village gods and health and illness might then have been systematically hidden from missionary eyes by those who sought to retain their affiliation with the mission. This does not appear to be the case. Missionaries, who lived on mission stations with numbers of Samoans, were well placed to obtain this information but did not, and secular settlers who lived close to the Samoans (Pritchard, 1863–64, 1866) also found little evidence of an extensive indigenous medical knowledge and practice. They were able to obtain information on and document a range of other sacred practices and did so in the belief that their activity would be more successful where missionaries understood Samoan culture. Nor is it clear that Samoans were as completely dominated by missionary power as this explanation requires. At the turn of the nineteenth century, Samoans were reluctant to share medicinal knowledge, not out of fear of the missionaries, but out of suspicion that others might use it.

The German naval physician and pioneer ethnographer, Dr. Augustin Krämer, reported that Samoan healers would not share their knowledge with him because they believed he might expropriate it and incorporate it in his own medicine (Kramer, 1994, p. 134).

Another, and more likely, possibility is that Samoans living in relative isolation in the middle of the Pacific Ocean with few disease vectors suffered a relatively limited range of recurrent illnesses (Kramer, 1994). Those could be adequately explained by a paradigm which placed more emphasis on the social and supernatural causes of illness and rather less on the biological and physiological ones. This seems probable: Samoans lived in that archipelago for some 2,800 years until European contact occurred in the late eighteenth century. During that time, and after an epidemic which followed a visit by an Oceanic neighbor, Samoans prayed daily to deities to prevent sailing gods from landing and physically repulsed those who sought to land to prevent further epidemics (Stair, 1983; Turner, 1983). The presence and absence of illness could be explained by reference to humans' relationships within social, natural, and supernatural realms. In the circumstances, there was no need for a paradigm which systematically linked illness to biological vectors and or physiological processes.

This would also explain why in a relatively short period, between the early nineteenth century and the present, Samoans incorporated new medical ideas and practices which are now widely regarded as traditional. If this is indeed so, the Samoan case demonstrates that traditional Oceanic medicine is not static but dynamic and is constantly expanding as new materials and ideas become available and are incorporated into traditional medical knowledge and practice. The problem then becomes one of explaining the conditions under which an indigenous medical paradigm might expand and of identifying the factors which might influence the shape of the neo-traditional paradigm.

The commencement of contact between Samoans and people from beyond the archipelago provided a motive to rethink the preexisting

paradigm. Contact resulted in the immediate introduction of new diseases which struck indiscriminately at a population with little resistance or immunity to them (Macpherson & Macpherson, 1990, pp. 54–58). Ironically, the isolation which had produced the relative epidemiological stability before contact (Kramer, 1994) had prevented the Samoans from developing immunity and ensured that each of the illnesses introduced between 1830 and 1918 would have significant impacts on Samoan society (the 1918 influenza pandemic resulted in the death of some 23 % of the population of Western Samoa). Traditional etiological and epidemiological models could not explain the new forms and patterns of illness. This inadequacy led Samoans to seek new explanations for the new experiences.

The growing frequency of contact with visitors and settlers from beyond Samoa also provided opportunities to expand their models of illness. Settlers from Britain, Germany, the United States, Australia, and New Zealand, visitors from elsewhere in the Pacific, and indentured labor from Melanesia and later from China took up residence in increasing numbers just as the Samoans' new health problems were emerging. Bearers of new models provided the knowledge necessary to augment the Samoan explanations and, in some cases, new material and practices to expand their medical repertoire.

Some of this knowledge transfer was deliberate. The missions sought to undermine polytheistic Samoan religion by providing alternative explanations for illnesses. This involved, ironically, persuading Samoans to replace many gods who caused and healed their illnesses with a single one with similar powers. But not all missionary effort was driven by a religious agenda. The London Missionary Society, in an attempt to provide comprehensive theological education for Samoan missionaries, translated and published works on zoology and biology including, in 1886, a 330-page tome entitled *O le Tala i Tino o Tagata ma Mea Ola eseese: e iai fo'i o tala i manu ua ta'ua I le Tusi Pa'ia* which is, literally, an account of the bodies of people and various animals and of animals mentioned in the Bible (Powell, 1886). The manual was provided to

pastors who were encouraged to use the information to improve the quality of their teaching. The missions may not have fully appreciated the ways in which Samoans would use the explanations in these to supplement, rather than supplant, their own earlier ones. Some other manuals found even wider readerships.

But their efforts were duplicated by those concerned with public health. In 1912, George F. Cottle, the Health Officer at the US Naval Station at Tutuila, translated a health care manual for school children in American Samoa entitled *O le Tusi e a'oa'oina ai i le Tausiga o le Soifuaga o Tagata Samoa*, subtitled *Health Care for Samoans* (Cottle, 1912). A final, and influential, example was the comprehensive 1937 work by Miss E.A. Downs and Dr. H.B. Turbott entitled *Health for Samoans* (Downs & Turbott, 1937). It was subsequently translated by Drs. Ielu I'iga and Atimalala Mama as *Maloloina Mo Samoa* or *Health for Samoans*, in a text which contained side-by-side translations of the original material. The Samoan language version was widely distributed to upper school students, teachers, native medical practitioners (NMPs), nurses, and women's health committees in villages, and copies are still found often in the possession of healers and others. From the time that new health problems confronted the Samoans, they had access to a series of texts which opened up new ways of thinking about the human condition and managing illness.

Not all health knowledge transfer was deliberate. Some transfer was incidental and occurred as Samoans observed and availed themselves of the health practices of those who increasingly lived among them. Missionaries and others noted that Samoans were very interested in the visitors', often experimental, use of herbs and simples, particularly since they had access to the power of an omniscient and omnipotent god, to whom Samoans expected them to turn for remedies for their illnesses. Samoans regularly asked why mission personnel turned to these physical remedies when they had available the services of an omniscient and omnipotent god and seem to have been satisfied with their explanation that God had in his infinite wisdom provided all that

was required for their well-being in the world and that he had revealed the value of this or that plant or procedure to the faithful.

Some transfer was deliberate. Early in the twentieth century, the German administration and the US Naval Administration sought to reduce the costs of administering their Samoan possessions by training Samoan paramedics to minister to Samoans. Similar programs were later extended by the New Zealand Administration in Western Samoa. The training programs were based at hospitals, and graduates were given medical kits, texts, and basic equipment. The Samoans embraced the programs and villages often sent for training people who had shown a disposition for healing. These were often traditional healers, known as *fofo* or *foma'i samoa*, who on graduation returned to their former practice with an increased medical repertoire.

The availability of new knowledge led to the expansion of both explanations and treatments. For instance, the highly influential teachings of Christian missionaries taught that an omniscient and omnipotent god could and would bestow on faithful followers the ability to heal. The gift of healing, given to Jesus and later to his apostles and demonstrated in a series of acts in a sacred text, which rapidly became central to the Samoan worldview, was also available to the faithful and was, arguably, more powerful than other forms of human intervention. This led to the early incorporation of the belief that the most devout Christians might receive god-given healing powers and of such practices as prayer, singing, and fasting into Samoan healing.

From the mid-1800s, Samoan pastors became central in the missionary activity as the mission sought to convert the peoples of western Oceania. Samoan pastors trained in Samoa and served with distinction in western Polynesia and Melanesia. In the mission fields, they were often left to their own devices and became in many cases dependent on their congregations for food, shelter, and medicine. There, and particularly on high islands with abundant flora and fauna and often separated from support, they became familiar with a range of local medicinal plants and learned local

uses for plants. The Samoan pastors, duty bound to eradicate heathen practices, tended to ignore forms of intervention which invoked supernatural agency and to focus instead on plant-based medicine.

These practices and the associated plants were often repatriated at the end of their mission service and are now found so widely in Samoa that they are supposed to be indigenous. It is not unusual to come across gardens of introduced plants from Melanesia in Samoan villages and to find that their medicinal value and uses were originally acquired by missionary relatives who had served in those regions as much as a century earlier. This may explain why some Samoans assume that the plants and their medicinal uses are indigenous. This trend is evident in the steadily growing range of medicinal plants documented in Samoa. The ethnobotanist W.A. Whistler, for instance, noted that of 59 plants used in Samoan medicine, about 53 % were native, 30 % were Polynesian introductions, and 17 % were recent or European introductions (Whistler, 1992, p. 64) and that similar mixes were found in the Tongan islands to the south.

Despite white colonial administrators' attempts to prevent it, fraternization between the Samoan, Chinese, and Melanesian populations occurred during the first half of the twentieth century (Field, 1984; Shankman, 2001). Inter-marriage and cohabitation made the medical knowledge and practices of these groups available to Samoans with whom they lived. Melanians, who also came from high islands with similar flora and fauna, extended the Samoans' appreciation of medicinal uses of indigenous flora, and there are cases where the Melanesian origins of contemporary Samoan uses are marked linguistically and/or acknowledged by those who use them. However, it is also true that missions banned the use of certain Melanesian practices connected with sorcery, known as *fa'alauataua*. Medical concepts and practices also undoubtedly derived from Chinese medical models used by the 2,000 plus Chinese laborers who worked in Samoa, some of whom later married into and lived in Samoan society. Again, the Chinese origins of some contemporary medicinal ideas and

practices are marked linguistically and/or acknowledged by practitioners who use them. It is, however, impossible to establish the exact extent of these influences since only systematic questioning of those who know of the origins of their practices could determine this. In some cases, information on origins, which is not usually central to competent healing, has simply been lost in transmission.

The practice of incorporation continues. As Samoans have become more mobile, and despite increasing biosecurity measures at Samoa's borders, new plants are regularly introduced, established, and soon incorporated into traditional medicine. The dynamic nature of Samoan medicine is not always apparent to Samoans since most patients seek relief and do not routinely ask their healers about the origins of either the plants or practices in use. Contemporary practitioners do not always know the origins of knowledge and practices which were incorporated into traditional medicine two or more generations earlier. Occasionally, the source of plants is marked linguistically, as in '*ava fiti*', '*ava toga*', and '*ava niukini*' which distinguish varieties of *Piper methysticum* from Fiji, Tonga, and New Guinea, respectively, but this is often not so. However, systematic inquiry about exotic plants can yield interesting material on sources of exotic plants and ideas in use in traditional Samoan medicine where these are known. A Samoan rigger who had worked in Papua New Guinea in the 1970s and had hunted pigs with local tribesmen had brought to Samoa a plant used by hunters to relax cramped muscles. He had given the plant and instructions for its use to his mother's sister who had incorporated it into her repertoire. A Samoan Mormon missionary had brought back to Samoa a plant from New Mexico used as a nasal decongestant by native Americans which is now in use in her mother's sister's practice in Samoa.

Nor is the incorporation confined to plant materials. A number of traditional medicines are prepared in different strengths for babies, children, adolescents, and older adults, respectively. This practice, a healer explained, derived from the filariasis eradication program carried out in

Samoa in the 1960s on which she had served as a liaison person. She explained that the connection between body mass and dosage was obviously effective, and she had subsequently adopted a variant in her own practice.

The Samoan case offers evidence of two other forms of medical dynamism. Several studies have pointed to the declining use of certain plants where either the plants become scarce or other more efficacious materials and treatments became available (Macpherson & Macpherson, 1990; Whistler, 2000). The empirical evidence must be considered carefully, because of the difficulties of accurate sampling of the usage of plants in healers' repertoires which is compounded by the difficulties of doing longitudinal comparisons where plant names change over time. However, anthropological studies routinely reveal the dynamic nature of the process, and Whistler's ethnobotanical work is the best available for Samoa. Whistler, for instance, reports that of the 130 plants which have had medical usages reported for them, only some 84 are currently in use and that of the latter group, some are now used by only small numbers of healers. Other plants, however, have been found in an extended range of medicines. Significant numbers of the plants recorded by Kramer at the turn of the twentieth century are now used in a wider range of medicines. In these cases, new uses are sometimes the consequence of experimentation and, more commonly, of a growing awareness of alternative uses as a consequence of contact. Unusual uses of particular plants in some healer's repertoires were usually tracked to the presence of migrants from either Asia or elsewhere in the Pacific and, occasionally, to the practice of western-trained medical professionals who recommended readily available local plants as effective alternatives to more expensive imported medicines.

This search for new ideas and practices has not, however, led to the abandoning of preexisting models, which have, after all, served Samoans well over some 3,000 years of residence, but rather to their augmentation. The new illnesses, which were determined to be a distinct category of illnesses, and the property

of the visitors became known as *ma'i mai fafo*, sicknesses from outside, and included *ma'i papālagi*, the illnesses of Europeans; *ma'i saina*, the illnesses of Chinese; and *ma'i meauli*, the illnesses of Solomon Islanders. Their diagnosis and treatment required additional medicinal knowledge which was supposed to be possessed by those who had brought them. Just as Samoans were supposed to be familiar with the causes and management of *ma'i Samoa* or Samoan illnesses, the visitors were supposed to be familiar with the nature and management of these new illnesses. The people who brought the diseases were supposed, by the Samoans, to be well-versed in their management, and versions of visitors' explanations and management became incorporated into augmented Samoan models of illness and management. This meant that there was no obvious reason to establish empirically which, if any, of the available medical paradigms was more effective than another. This way of thinking about illness and its management opened the way for the coexistence of a set of complementary medical paradigms which continues today.

In these circumstances, there is no obvious reason why healers would not continue to expand traditional medicine or for patients to discontinue the use of traditional medicine since its use does not prevent them from using other forms of treatment where this may appear appropriate.

This case, outlined in greater detail elsewhere (Macpherson & Macpherson, 1990), shows that Pacific indigenous medical systems need not be unchanging, culture-bound, paradigms which depend solely on cultural and religious logics for their power. They can be dynamic systems in which both knowledge and practice are routinely augmented, as observation and experience of new models and practices suggest additional and more effective ways of approaching health. It also suggests that attempts to reconstruct truly indigenous medical knowledge and practice in such circumstances confront real problems. Because of the ways in which the sources of these ideas, materials, and practices are constantly expanding and because these are incorporated into traditional medicine without drama, it becomes difficult to tell which part of

today's traditional medicine was yesterday's introduction.

This traditional knowledge may be under threat. Throughout the islands, there is increasing support, from both aid donors and governments, for public health educational programs which are seen to improve health outcomes and reduce the cost of health service delivery to governments. These programs, mounted in school curricula and in the mass media, often confront head-on traditional beliefs and practices that are seen to obstruct the acceptance and use of cost-effective western biomedical procedures. These are particularly effective when they are delivered in schools which are increasingly regarded as the sources of modern knowledge and in the media by well-educated Pacific health professionals who have, presumably, made well-informed choices between traditional and modern knowledge and practice.

But this threat to traditional medicine may not be confined to the homelands. An increasing proportion of the Samoans, and indeed other Pacific populations, have been born and educated in expatriate enclaves around the Pacific rim where there are fewer active practitioners and in which the practice of traditional medicine is not as visible and as apparently normative as it is in the homelands. The overseas-born children of the migrants are often also less familiar with the language and culture in which the medicine is rooted which, in turn, limits their capacity to understand both the rationale of various central practices and of the epistemology which underpins the proof of its efficacy. So while migrant parents may continue to use the familiar medicine, their overseas-educated children, who have been educated to accept the power of western science and bio-medicine, may be more skeptical of, or simply less interested in, the healing potential of non-western medicines.

It is ironic that their lack of interest may be rooted in assumptions about the limited explanatory power of pre-modern knowledge and in their lack of awareness of the actually dynamic character of these traditional systems. This effect will be less pronounced in island populations that, for historical reasons, have limited opportunities to

emigrate and settle outside the homelands. But, with as many as 90 % of some Pacific island populations living in these expatriate enclaves and with the overseas-born and educated proportion of the population increasing steadily, there is a significant potential threat to the survival of these dynamic traditional bodies of knowledge and practice.

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Medicine in Sri Lanka: Traditional Medical Knowledge, Its History and Philosophy

Arjuna de Zoysa and C. D. Palitharathne

A Framework for Medical Histories

The study of Sri Lankan history recognizes four distinct periods (Bandaranayake, 1990) from pre-historic times (ca. 125000 B.C.E.) to a proto-historic era, when settled agriculture and Iron Age technology began. The historical period begins with the growth of advanced irrigation systems for food production and the surplus created by this results in the emergence of a flourishing civilization centered on cities such as Anuradhapura, Sigiriya, and Pollonnaruwa in the north central province. These city-centered civilizations spanned a period of one and a half millennia, from around 300 B.C.E. to 1250 A.D. (De Zoysa & Palitharatne, 1992). From 1250 A.D. onwards one sees a number of “centrifugal” tendencies, with fragmentation of centralized power to the periphery. With the arrival of the Portuguese (sixteenth century), a period of colonization by European powers followed and ended only after the Second World War. Modern Sri Lanka was heavily influenced by this colonial period (ed. note: see the article on Colonialism and Medicine in Sri Lanka).

From Proto-histories to Civilizational Periods

Living evidence of conditions in the pre- and proto-historic periods exists among the Veddha community, an indigenous people who retain most of their hunter-gatherer past even today (Spittel). The Veddhas possessed sufficient medical knowledge for their survival needs. They had knowledge of medicinal plants to treat wounds and used python fat for fractures. They practiced exorcism, which is still practiced today and

reputed to have great value in an appropriate socio-cultural context. There is however no evidence of any attempts to build a connected knowledge system out of these curative practices, and their life spans were short (Sagara, 1995).

With the coming of the city-centered civilizations (ca. 300 B.C.E.), there was rapid development in all fields of knowledge. Historical information of this period is derived from several sources (Bandaranayake, 1990; Uragoda, 1987):

1. Written material, which was recorded on Ola leaves. The *Mahavamsa* a collection of historical information, is such an example (Guruge, 1989);
2. Rock inscriptions at religious and archaeological sites;
3. Artifacts and buildings from archaeological sites.

A reasonable picture of what constituted medical knowledge in Sri Lanka during this time can be derived from these sources (De Zoysa & Palitharatne, 1992). By the end of the proto-historic period, curative medicines and practices were locally found and available, but it was probably not until the early historic period that Āyurveda and Siddhi (Classical Indian) and Unani (Classical Middle Eastern) systems were extensively used and integrated with local regional (*Deshiya Chikitsa*) practices or folk practices. Āyurveda forms the major practice of traditional medicine in Sri Lanka. The well-known texts on Āyurveda such as the *Carakasamhitā* and the *Suśrutasamhitā* were known and read in Sri Lanka from before the historical period. The *Arkaprakāśa* an early book on Āyurveda, supposedly written by a king, Ravana, is still available (Buddhadasa, 1960). The *Carakasamhitā* refers to a legendary conference on medicine held in the Himalayas (ca. 6000 B.C.E.), where a number of *Rishis* (meditating recluses), worked out the fundamentals of Āyurveda in consultation with divine beings. The *Rishis* are named, and one of them, Pulasthi, was from Sri Lanka, an emissary of Ravana who was supposed to have returned with the principles of medical knowledge to

Lanka (Buddhadasa, pp. 1–2). Āyurveda was probably first introduced to Sri Lanka during the time of king Ravana.

Āyurveda had the character of a well-connected knowledge system (De Zoysa & Palitharatne, 1992). There were for instance sections describing fields similar to surgery, toxicology and ear, nose and throat diseases. The *Suśrutasaṃhitā*, a book on surgery from India, describes 121 surgical instruments (Pilapitiya, 1982), many surgical practices using them, and dissections on dead bodies for surgical practice. Surgical procedures show knowledge of the infective power of microorganisms too small to be seen by the human eye. The underlying paradigms of Āyurveda were very different from biomedicine and form a powerful alternative to such a system.

During the city-centered historic period, extensive state sponsorship was given for medical practice and science. Some kings, such as Buddhadasa (fourth century), Aggabodhi (eighth century) and Parakrama Bahu (twelfth century), were actual practitioners and scholars of Āyurveda. The *Mahavamsa* records the existence of hospitals (Guruge, 1989), dispensaries and medical halls during this period, and archaeological excavations are supportive of these claims. Medical practice at this time was in line with Ayurvedic practices; as such it would have been comprehensive, covering both preventive and curative measures which extended even to the care of animals.

With the decline of the city-centered civilizations one sees the emergence of a number of regional centers of administration around the sea port cities such as Kotte, Jaffna and in the hill country Kandy. Although a large body of medical knowledge was preserved and passed down through generations, no notable achievements were recorded during this period (De Zoysa & Palitharatne, 1992).

The Colonial Period to Modern Times

Colonial conquests started with the Portuguese in 1505 and continued for nearly four and a half

centuries. This period saw also the rapid growth of modern science in Western Europe and its introduction to Sri Lanka by the conquering colonial powers, in particular the British.

Both the Portuguese and Dutch had a great respect for local medical knowledge and used it at times to treat even their own sick and wounded (Uragoda, 1987). The Portuguese are reputed to have used local knowledge to cure dysentery and snake poisoning among soldiers. They did however reject culture-bound practices such as exorcisms on religious grounds. The Dutch, who captured the coastal towns from the Portuguese in the seventeenth century, are credited with building many hospitals in Sri Lanka (Uragoda), where herbal medicines were used alongside drugs imported from Europe. Towards the latter part of the eighteenth century they even appointed “native” physicians proficient in Āyurveda in all their hospitals. During the Dutch period there was a brief renaissance in the study of traditional medicine. King Narendrasinghe (1707) translated a thirteenth century palm-leaf manuscript, the *Bhesajja Manjusa*, on medicine and was also responsible for compiling a *Vattoru Vedapotha*, a book of traditional medicinal prescriptions. Paul Hermann, a surgeon attached to the Colombo hospital, was interested in botany; he was at that time in contact with Linneaus and sent collections of local plants to him. It is said that Linneaus used these as part of his famous plant classification (Goonatilake, 1985).

The British colonial period in Sri Lanka started from 1796 and lasted 150 years. During this period the rapid industrialization of Europe and North America and its domination of the rest of the world took place. Not surprisingly, Western medical science was introduced and it established a dominant position in Sri Lanka. Āyurveda and traditional medicines were generally discouraged under British rule and the colonials learnt little from it. There were however notable exceptions. Sir Henry Blake, a British Governor in Sri Lanka, translated parts of the *Suśrutasaṃhitā* using Buddhist scholars; he claimed in a lecture delivered to the Royal Asiatic Society in 1905 that malaria was recognized as a

vector borne disease (Uragoda, 1987). This was never accepted in Europe, but it is difficult to envisage how an irrigation-based civilization flourished if it did not understand even the causative mechanisms of such a devastating disease like malaria. Another notable exception was the establishment of a College of Indigenous Medicines in 1929 with state sponsorship. These instances of support were however, very much the exception.

In spite of heavy state support for Western allopathic medicines and the marginalization of traditional practices, the latter survived and were used by a majority of people; even the urbanized middle classes, who were heavily “westernized” in outlook, continued to use them. What were the reasons which made these traditional systems of medical knowledge so resilient? We will in the following text investigate the worldviews behind the two knowledge systems of Āyurveda and allopathy (biomedicine). To do so, we will first touch on some developments in the philosophy of modern science.

A Philosophical Note

The term *incommensurable* first introduced by Kuhn (1970) and later developed by Feyerabend (1978) refers to the impossibility of comprehending a theory “A,” based on a paradigm “A,” by using concepts and terminology of a theory “B” based on a different paradigm “B.” By paradigm we mean,

On the one hand it stands for entire constellation of beliefs, values, techniques, and so on shared by the members of a given community. *On the other, it denotes one sort of element in that constellation, the concrete puzzle – solutions which, employed as models as models or examples, can replace explicit rules as a basis for the solution of the remaining puzzles of normal science.*

Numerous examples can be taken from the history of science itself as evidence for incommensurability between theories. Relativistic and Newtonian physics form two of the best-known examples. In Newtonian physics, mass, time, and energy are observer-independent entities,

existing in absolute space. In relativistic physics, they depend on the relationship between the observer and the observed, have no fixed value and lose all absolute meaning. In fact the concepts are so radically different that the use of the same words – “mass,” “time,” etc. – leads to confusion. A student used to years of reference to “Newtonian mass” finds it difficult to comprehend and adjust to “relativistic mass.” Perhaps it would be easier to make the gestalt switch if different terminology were used.

Werner Heisenberg (1952) provides a rather striking, but less well-known example of incommensurability. Heisenberg shows the almost total incommensurability between Newton’s and Goethe’s theories on color. Newton’s theory of color was mechanistic, precise and with later modifications proved to be useful for all kinds of practical purposes. Goethe’s theory of color was based on symmetry and complementarity. Its purpose was very different from Newton’s; it described a sensory world of color which was relevant and proved useful for aesthetic purposes.

Differing Worldviews

The worldviews or broad paradigms on which the two medical knowledge systems are based are different and incommensurable. The ontology of classical Western science takes for granted the existence of subatomic particles which form atoms, and these arrange themselves into chemical compounds growing in complexity to form organic molecules and hence life. In Vedantic philosophy, material form is described by five fundamental attributes, the Pañcamahābhūta. These attributes can be understood metaphorically by use of commonly encountered substances, such as Air (motion), Water (fluidity), Earthiness (solidity), Agni (fire), or energy in thermal form and Voidness (or emptiness). The above list of metaphors exhausts the discourse on materiality, and there can be no further additions to this particular classification. One can only go for an alternative form of classification which may contain as many as 12 properties. The substance-based element theories in modern

science are different. They refer to “elements” which exist “out-there” in material form. The discovery of additional elements to the original 92 is therefore expected. It is important to realize this difference; as the foundational base of Āyurveda is unchanging, its pharmacopoeia and curative techniques are dynamic. Health in the human body in turn is described as a balance between three metaphoric properties, known as the *tridoṣa*: *Vata*, *Pitta* and *Kapha*. The substance metaphors for these are often given as Air, Bile, and Phlegm. These metaphors should not be mistaken to mean the same as these actual substances. However, a *Kapha* imbalance would lead to a preponderance of phlegm in the body. These properties in turn are connected to conditions in the natural environment, age and disease. The knowledge system is thereby connected as a whole. A superficial understanding of this could lead to “fuzziness.” With the modern focus on quantitative exactness and reductionism many prejudicial viewpoints could result, if one views these ancient sciences with a simplistic lens. In understanding these concepts, language itself is an impediment, as they are difficult to translate. A proper understanding can only be derived by an appropriate gestalt switch from knowledge system “A” to knowledge system “B” (De Zoysa & Palitharatne, 1992).

Let us examine the paradigms underlying the theory of disease causation in the two systems.

In Āyurveda, there are four reasons for disease: *Aganthuka* (external factors such as injuries), *Sharirika* (Physical), *Manasika* (mental), and *Swabhavika* (natural, such as old age, hunger, thirst). Disease itself is defined as contact with *dukkha* (Pilapitiya, 1982). The meaning of *dukkha* is very comprehensive and includes unsatisfactory physical as well as mental states, both temporary and permanent. Negative emotions such as anger and jealousy are considered to be disease states. We can at once see why such a system has to deal with both physical and spiritual treatments. *Āyurveda* recognizes the existence of microorganisms, however, the main causative factor lies in an imbalance within the human body. Using such a theory, it would be easy to explain the occurrence of influenza

and to adopt preventive measures against it. Cold temperatures, moisture, food described as cooling, all enhance *Kapha*, leading to an imbalance, which makes the body susceptible to a viral invasion. Person “A” may contract it in autumn and not in summer and so forth. The virus after all presents itself constantly, but it is only sometimes and only some people who are affected. The *tridoṣa-vada* of balance and imbalance can be thought of as a comprehensive theory of resistance and susceptibility to disease. Its real benefits lie in disease prevention. There is also the recognition of *Kamma* (karma; ethical acts), either done in this life or in a previous life, which impact on disease. In fact if negative *Kammic* effects are dominant (*Kamma Roga*), special acts are specified to nullify these before or during medical treatment (Buddhadasa, 1960, pp. 63–64). In the *Carakasamhitā* there are diseases mentioned which cannot be cured by clinical means alone. It is said that people who think that one is born purely by the coming together of man and woman are supposed to have limited vision (Buddhadasa, p. 337). The worldviews between allopathy and Āyurveda are thereby fundamentally different.

In South Asian traditional systems, the emphasis is on health, not disease; the re-establishment of a diseased body to health is extensively dealt with. The cure in biomedicine might sometimes be worse than the disease. For example some chemotherapies and radiation treatments for cancers could be worse than the cancer itself and might lead to a disabled existence or death for the treated person. In South Asian medical processes such “cures” are no “cures” as they do not lead the patient’s body to health. Much could be learnt from the practice of Āyurveda, and a reasonable cross fertilization of knowledge systems could be beneficial to all.

Āyurvedic medical treatment is considered to be both a science (*Shashtra*) and a craft (*Shilpa*). The practitioner takes a personal interest in the patient and ethical norms are built into the very development of the *Shashtra*. For instance, animal experimentation is not allowed in Āyurvedic research.

On Validation

I will here use a particular example which brings the problem of validation into sharp relief. The double-blind test for the efficacy of drugs is a special case of a control widely used to determine the solely physical effects of drugs. In Āyurveda we find a category of herbal medicine known as *Khema*, in which a “wanted” physical component interacts with the “unwanted” psychological action. A *Khema* is always accompanied by an intricate story of its origin, and ritualistic preparations are used before administration. The patient is made to believe in these, and although the herbal medicine has a physical effect, its value is substantially enhanced by psychosomatic interactions. The two effects may not be separated out and studied, because in general their interaction is nonlinear, affecting the whole human body rather than the merely diseased parts of it. A double-blind test would be irrelevant in such a case (De Zoysa & Palitharatne, 1992). Validation of Ayurvedic efficacy should be taken as a whole treatment regime, and validation is a process, not a single medicine, which in any event is a *Sanyojanaya* (compound mixture) and not a chemically extracted active ingredient.

Quantification in classical systems is personalized. For instance Āyurveda gives three major measures – *Anguli*, *Anjali*, and *Matra* – with reference to the patient’s body size (Balasubramaniam, 2005). In the Western medical system measurement is with reference to abstract quantities. This difference means that any validation of classical medicines should be quantified accordingly.

The Future

Both Ayurvedic and Western medical practice claim to rest on a firm “scientific” basis. These claims are only partly true. The practice in a number of cases does not flow naturally from a theory based within a broad paradigm. In a Kuhnian sense, we cannot say that both are fully “mature sciences” flowing from broad generally accepted paradigms of theory to practice. There

are many practices and medicines, in both Western and Ayurvedic systems, which are used simply because they work. Some times ad hoc practices which do not deeply penetrate the respective knowledge systems are used. Vaccinations were used in Europe for smallpox long before any theory of immunity had been accepted as a specialist discipline. Smallpox inoculation is mentioned in the ancient Indian text, *Atharvaveda*, and was practiced in Ancient India by introducing “inoculated pustules of the previous year” to healthy persons (Pilapitiya, 1982). Again it is unlikely that Ayurvedic theory prompted such treatments. Treatment of many common ailments, such as back pain, is treated on a “try and see” basis in biomedicine, and often the patient knows what course of action would be best for him. Many other examples can be taken to show this disjointedness between theory and practice in both systems (De Zoysa & Palitharatne, 1992).

Western medical scientists interested in creative work have a fertile field in traditional systems of medical knowledge. They can learn much from the history of Western science itself, in particular from its major creative periods, to develop an openness and methodology for fruitful cross-fertilization of knowledge with traditional knowledge systems. A healthy respect for alternative knowledge systems would be a liberating force for science.

See Also

► [Medicine in India: Āyurveda](#)

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Medicine in Thailand

Viggo Brun

There exists in Thailand a medical tradition based on local disease concepts, the use of natural products and certain magical rituals which have been practiced by local doctors for centuries. This local wisdom has been passed on both orally and through manuscripts from teacher to pupil for generations. Traditional Thai medicine exists in two versions: a village variant, containing many regional and personal variations, and a court

variant influenced by Indian (Ayurvedic) medicine, which has been standardized to a certain extent.

Since around 1900 the official medical system in Thailand has however been solely based on biomedicine, and biomedicine is now widely accepted by the Thai public. But even without any official support, traditional Thai medicine has survived quite well in the rural areas, and in present-day Thailand, the public makes use of both traditions – predominantly the official cosmopolitan medicine, and, to a lesser extent, traditional medicine. Since the beginning of the 1990s the attitude of the state towards traditional medicine has changed, and the official policy is now to integrate traditional medicine into the public health system.

The Village Tradition

In villages all over Thailand one finds people referred to as traditional doctors (*moo phaen booraan*) who mainly use medicinal herbs (*samunphraj*) and other natural substances to cure diseases. The sum of knowledge and practices of these experts is labelled “traditional Thai medicine”. There is no traditional doctor who knows the entire body of traditional medical knowledge, and there are many local and individual variations of traditional Thai medicine within Thailand, both in the way plants and diseases are labelled, in the way disease terms are understood, in the way concrete cases of illness are diagnosed, and in the way plants and other materia medica are used in the curing process.

Traditional Thai medicine includes knowledge about the identification of plants (and minerals and animal components) and their curing properties, about diagnosis, cause and development of diseases, about prescriptions and about relevant incantations and ceremonies. The prescriptions, which exhibit the concrete relationship between diseases and the plant world, are – together with the incantations – considered to be the essential and most valuable part of the tradition and are surrounded with a certain amount of secrecy. The prescriptions contain

any number of ingredients, normally from five to ten, but sometimes less and often more, even comprising as many as 50 different ingredients. For each ingredient the prescription will ideally specify which part of the plant should be used – root, leaf, bark, fruit, etc. – and normally in what quantity. While much of the medical knowledge is transmitted orally, the prescriptions are written down. There are a vast number of medical manuscripts in Thailand, both in temple libraries and in the care of the herbalists, and almost all of these manuscripts are merely collections of prescriptions.

In order to access the information in the manuscripts as well as to copy them and write down the prescriptions, it was necessary to be able to read and write. In former times these skills were taught only in temples to boys, so the traditional doctors were exclusively male. Monks and former monks were central in the transmission of all written traditional knowledge, including medicine, and Buddhism has – as we shall see below – left a deep imprint on the way traditional medicine has been organized.

To a certain extent, the general public also possesses medical experience and knowledge which people use to talk about diseases, to choose between available curative alternatives, and for self-medication. There are a number of simple traditional remedies known to villagers, commonly referred to as “household remedies” (*jaaklaangbaan*).

The traditional doctors are often called to a career in medicine after they themselves have been sick. They will seek out a traditional doctor, get cured, and thereafter ask to be accepted as a student of that doctor and learn the prescription that cured them. After that they start treating people with this particular disease. If the treatment is successful, and if the new doctor feels he has a knack for traditional medicine, he seeks out more knowledge from other teachers, and thus gradually expands his curing range. Another path is to learn the trade from a practicing relative. Few traditional doctors become true generalists, though, and few become full-timers. For most of them, curing provides them with supplementary income, although a successful

traditional doctor will be respected and obtain higher social status.

Traditional Thai doctors neither perform surgery, except for lancing abscesses, nor do they undertake dissection. Thus they do not have a very precise or systematic knowledge of the human’s interior organs and how they function. A certain amount of anatomical knowledge is gathered from partitioning animals, and Buddhist scriptures do enumerate body components.

Some traditional doctors perform bone setting. The broken bones are pulled back into place – no painkiller! – and the area around the fracture stabilized with sticks of wood tied together, after which incantations are blown onto the fracture. Traditional bone setting may result in the bones growing together at unusual angles, so most people prefer to go to Western-style hospitals to be treated for fractures.

Massage and midwifery are separate branches of the local medical tradition. Traditional midwifery is fast disappearing, while Thai massage has become tremendously popular – also outside Thailand. A number of drawings of the human body in Wat Pho, the largest and oldest temple in Bangkok, pertain to Thai massage, indicating points on the exterior of the body on which applications of pressure have a therapeutic effect for specific ailments. Other drawings of the human body show lines (*sen*) connecting various points on the body. The meaning and practical application of these lines and how they connect up with the rest of traditional medical theory and practice are not clear. One homepage, http://www.bomi.info/books/thai_massage.htm, lists 12 books on Thai massage which have been published within the last decade – some accompanied by videos – mostly practical introduction written by people who operate clinics for Thai massage in various countries.

Traditional saunas, where steam from herb-steeped water is directed into a small, closed room, are also used. These steam baths are regarded as generally healthful but are also used specifically to cure certain skin or respiratory diseases.

In the countryside people used to rinse their mouths with water after eating, and they used

toothpicks and sometimes rubbed their gums with salt. Now most people use toothbrushes and toothpaste. Previously toothache was simply considered to be bad luck. When the pain became intolerable, the tooth was pulled out. Until recently there were peddlers appearing in the villages trying to convince people that their toothache was caused by small worms eating the teeth – they could miraculously produce such worms from the mouth of any bystander with toothache – and that their bottles of medicine would kill these worms. This medicine was very popular. The bottles they sold merely contained a simple plain painkiller.

Transmission

The medical tradition in Thailand is said to have been transmitted through a chain of teacher-pupil relationships which goes back to the tradition's original teacher, Jivaka Komarabhacca, the legendary physician of the Lord Buddha, and each practitioner pays respect to his teacher at annual rituals. On every occasion in which he uses the knowledge from the tradition, he should ceremonially invoke the whole chain of teachers – living and dead – to be present and thus infuse his actions with their sacred power. Medical knowledge is in principle restricted to those who have been ritually initiated into the tradition, and thus every potential doctor has to find a teacher who will accept him as a pupil and share his knowledge with the student. The teacher is important because the tradition consists of both oral and written information. The written manuals contain the essence of the tradition – the prescriptions – but the manuals contain almost no information about each particular disease or plant, beyond their names. All the background knowledge and detailed information which the manuals presuppose are transmitted orally. The student needs a teacher to give him this oral information and from whom he can observe the finer points of medical practice.

The ideal would be if the complete primordial knowledge was passed on verbatim through faithful repetition and copying. Still, time involves

change and decay, and it is recognized by everyone that losses, fragmentation, external additions and copying mistakes have occurred all along the transmission chain. Medical manuals are no longer complete and homogeneous, but fragmented and heterogeneous. The actual transmission of knowledge is no longer only faithful copying but also a continual process of selection and reorganization, and new knowledge may even be added to the tradition. The standard way of justifying additions is to present them as revelations, often referred to as *tamraa phii book* (manual told by the spirits). In other words, additions and innovations are permitted as long as they are received directly from the “other world”, i.e. as long as they are disguised as restoration, rediscovery or reestablishment of something original.

Traditional Pharmacy

There are probably several thousand plants (and ingredients from the mineral and animal kingdoms) in traditional Thai medical prescriptions, and these should – alone or in combinations – have a curing property of one kind or another. There are a number of herb stores in the larger towns where the traditional doctor can buy the ingredients he needs. Still it is convenient if he has the plants he uses most frequently ready at hand. Many traditional doctors therefore grow medicinal plants in their gardens and possess some botanical knowledge.

A number of monks also practice as traditional pharmacists or doctors. In Buddhist temples one can sometimes find extensive gardening of medicinal plants.

There are also a number of traditional pharmacists who produce homemade traditional medicines for sale at markets and fairs or through local stores. With the increasing popularity and growing demand, the traditional medicines – and herbal-based cosmetics – are now also being produced industrially by a number of firms. Thus people have easy access to ready-made traditional medicines, which are cheaper than the available biomedical medicines, and although it is widely

viewed that they may take a longer time to produce results, it is also claimed that they have fewer side effects than cosmopolitan medicines.

The Ministry of Public Health stipulates that traditional drugs should be approved before public sale, but this law is not strictly enforced.

Botanists and pharmacists in Thailand have published a large number of books on Thai plants and their claimed curative properties. There is also a “pharmdatabase”, <http://www.medplant.mahidol.ac.th/index.asp>, where one can search by plant name (English or Thai), genus, or biological activity.

Etiology

Many of the disease causes recognized by traditional Thai doctors are also causative factors in modern medicine. Some diseases are, for example, regarded as contagious and some as inherited; some as caused by changes in the climate and others by contact with external agents such as metal chains or washing powder, resulting in skin eruptions. Some are caused by insect or animal bites and others by spoiled food, or bad smells. There are natural causes for fracture, dislocation, contusion, burns, or wounds.

The close relationship between food and disease can be seen in the monastic rules (*Vinaya pitaka*) where medicines are classified as “non-substantial food”. Many of the most common medicinal plants are also ingredients in food. Food prohibitions are, moreover, integral to the treatment of many diseases. Such prohibitions might be against meat, frogs and fish with skin, seafood, pickled food, certain vegetables, eggs, liquor, or foods with certain tastes – all depending on the disease in question. There are also specific dietary rules for the post-natal period. Adding and withdrawing certain foods from the diet can also function as preventive measures.

A causative factor specific to the medical tradition of the court is “imbalance in the elements (*thaat*)”, i.e. imbalance between wind, water, earth, and fire. These are the elements of which our body (and indeed all matter) is composed.

In addition, traditional Thai medicine operates with other types of causes, which modern science summarily dismisses as superstition. These can be classified as spirits, black magic, and karma (past actions). If the diagnosis is that a patient in some way has offended and angered a spirit, who in retaliation has caused the offender to fall sick, then the curing process may consist of ritual offerings only.

There are cases characterized by sudden violent and abusive behaviour, which may be attributed to possession by an inferior, evil spirit. A specialist is then called upon who will talk to the spirit and ask it who it is, where it lives and what it wants. If the spirit does not want to leave the body after offerings have been given, it is mercilessly beaten out – the spirit apparently feeling all the pain, while the possessed person feels nothing.

Another type of mental disturbance may, after all other treatments have proved fruitless, be attributed to a superior, good spirit who wilfully has inflicted this kind of suffering on the patient to force her to become its medium. When the person accepts mediumship, the spirit immediately withdraws the ailment, and the person recovers.

Piercing or lancing pains in the joints, abdomen, or chest may, if unresponsive to treatment, be attributed to black magic. This means that an object – like a nail or a lump of skin – has been inserted into the patient’s body by a doctor using special incantations and acting on the instructions of an enemy of the patient. The only solution for the victim is to find a doctor who has even stronger incantations to counteract the original ones and can thus remove the object or even send it back to attack its owner. The Northern Thais say that the Karen and the Khamu hill tribes harbour powerful incantations, in Northeastern Thailand they may blame the Khmer for the black magic, and in Southern Thailand the Malays.

The Buddhist concept of karma may also be used as an ultimate causative factor, but normally only after all other explanations have failed. Using karma as the cause implies that the disease is a deserved and inescapable result of a previous

action by the patient. People do not favour this explanation, because it means that a cure is impossible and that a person simply must endure his or her fate. However, people confronted with the inevitable deterioration and malfunctioning of their bodies, such as the elderly and those with incurable diseases, use karma to indicate that they have accepted the inevitable. This resignation can also be a relief for relatives, who no longer need to feel obliged to search for new remedies and pay even more bills.

The recitation of holy words plays an important role in many contexts in Thailand, and there is a strong belief that recitation of holy stanzas (*weedmon khaathaa-aakhom*), if performed by the right persons, produces power and that this power is transferable. Incantations are an integral part of traditional medicine and are in many cases recited over or blown on to the medicines and the patients by the traditional doctor.

Magical practices are a central part of Thai culture and thus also of traditional Thai medicine. Still this must not overshadow the fact that traditional Thai medicine is basically a rational tradition based on experience. The traditional doctor will first seek a natural and rational explanation to a disease. Only if this does not work will he resort to other types of explanations and treatments. And if one accepts the premises of magic, such as the existence of spirits and other levels of existence, it too possesses its own rational logic.

Heterogeneity

A central feature of the Thai medical tradition is its heterogeneity: it generates many different answers to the same question. This is true at all levels of the tradition.

The names for one and the same plant may vary from locality to locality, and one and the same name may be used for different plants in different places (which is nothing peculiar to Thailand, of course).

The claimed medical properties of plants in isolation vary from informant to informant, and do not necessarily conform with the prescriptions

in which the plant actually occurs. When one, for example, asks, "What are the curative property/properties of plant P?" the first informant says, "It cures disease A", the second informant says, "It cures disease B", and when we check the prescriptions we have collected, we find that plant P does not occur in prescriptions against diseases A and B, but in prescriptions against diseases C and D.

The content of the local disease names varies according to the informant. Furthermore, disease names known by one expert may not be known by another even if they live in the same area. And finally actual diagnosis varies a lot.

One could speculate that a likely reason for this heterogeneity is a slow and erratic process of crystallizing experience, which again could be due to the lack of communication (i.e. competition) between the herbalists and the lack of records of the experiences of the individual herbalist. Furthermore, the lack of standardization of disease concepts and the lack of an explicit epistemological framework could well be factors which have hampered the crystallization process of the popular medical tradition and contributed to its continued heterogenic character.

But there exists another branch of the medical tradition in Thailand emanating from the royal court with an explicit and rather elaborate theoretical framework.

The Court Medical Tradition

At the Thai court royal physicians (*moo luang*), who held official positions within the Medical Department (*krom phaet*), were responsible for the well-being of the king and his court. The knowledge of the court medical tradition was kept within the court, and transferred in many cases through certain families. Rama III decided to make public parts of the traditional knowledge harboured within the court when he restored the Wat Pho (Wat Chetuphon) temple in central Bangkok from 1834 onwards – including medical knowledge, especially related to massage (stone inscriptions) and physical exercise (stone statues).

In 1870, during the reign of King Chulalongkorn (=Rama V, 1867–1910), a committee of royal physicians was appointed to collect and edit old medical manuals. The result of their work became known as *tamra luang*, the Royal (Medical) Treatise, and was kept in the library of the palace, available to court physicians only. When Siriraj Hospital was established in 1887, the patients could choose between cosmopolitan and traditional treatment, and likewise the curriculum at the Siriraj Medical School (1889) included instruction in both cosmopolitan and traditional Thai medicine. To standardize the teaching of traditional medicine, a printed version of the *tamra luang* was introduced as textbook at Siriraj Medical School with the title *tamraa phaetsaat songkhro*. Thus the court medical tradition went public, and became the official medical tradition until the teaching of traditional medicine was discontinued around 1906 (some say in 1913). Some 50 years later, in 1957, the Association of the School of Traditional Medicine was established at Wat Pho (Bangkok), and both the teaching and the officially supervised examinations there were based on reprints of the *tamra phaetsaat songkhro*. The Wat Pho school later established schools at a number of temples in major towns. Since 1957, in order to practice traditional medicine legally one has had to pass examinations from these schools, where courses in traditional pharmacy, midwifery, and general medical practice are offered. As an innovation women have been allowed to participate on equal footing with men.

In the court medical tradition we find a theoretical framework which is based on the four elements (earth, water, wind, and fire), the three humours (bile, wind, and mucus), and the ten tastes (hot, cool, mild, astringent, sweet, poisonous, bitter, oily, salt, and sour). The fact is, though, that the theoretical framework lacks internal coherence and consistency, and that its relationship to actual medical practice is weak: it is not readily applicable to diagnosis and treatment of concrete cases of diseases. One could say that the theoretical framework we find in the court tradition is divorced from practice and

functions only as a frame of reference, a model. This framework legitimates practice, but does not dictate it.

During the Aythaya period, the capital was a lively international trading port with many foreign communities from various Asian as well as European countries. A number of these foreigners were employed in the King's service. It is quite likely that these foreigners left an imprint on the court medical tradition, although it is not clear how and to what extent this actually happened. It is quite obvious, on the other hand, that there is an element of Sanskrit influence in the court tradition. A number of court medical manuscripts on which the *tamra luang* is based have Sanskrit names – although no one has yet been able to identify these names with titles of Sanskrit medical manuals in India – and many of the concepts and the disease names are borrowed from Sanskrit. Still, no comprehensive comparative studies on this matter have, to my knowledge, been undertaken, so it is difficult to ascertain the extent and exact nature of Ayurvedic influence on the court medical tradition in Thailand. Even now, there are separate institutions for Ayurvedic medicine, such as the Ayurvedic Society of Thailand (*samaakhom ajuraweed haeng pratheedthai*).

Many Thais regard the court medical tradition as more advanced than the village tradition, and thus accord it the status of *the* Thai medical tradition, considering the village tradition but a crude simplification with many local variations (cf. Somchintana, 1989, p. 280). This attitude is unfortunate because it glosses over the fact that even if the royal tradition has an explicit theoretical framework which the village tradition lacks, the medical practices of the two are still very similar.

Furthermore, there have not been any court physicians properly practicing traditional medicine for the last 100 years, so that the oral tradition that goes with the court medical tradition has been broken. Today there are therefore hardly any people who can explain the theories, concepts, organization, and the quite numerous unintelligible passages in the court medical manuals with authority.

Buddhism and Traditional Medicine

Buddhism is a crucial factor in Thai culture, but still there is no study of the influence of Buddhism and Buddhist medical lore on the Thai medical tradition.

In his study of the development of Buddhist medical knowledge within a broader Indian medical tradition, Kenneth Zysk points out that Buddhist monks at the time of the Buddha already acted as healers for their fellow *bhikkhus* (monks), and that “from around the mid-third century BCE monk-healers and the monasteries extended medical care to the population at large” (Zysk, 1991, p. 41). Portions of the medical knowledge and experience of the Buddhist *bhikkhus* were recorded in a chapter on medicines (*Bhesajjakhandhaka*) in the *Mahavagga* of the *Vinaya Pitaka*, the monastic rules, thereby giving rise to a Buddhist monastic medical tradition.

Medicines were part of the five requisites a monk could possess, and originally the monks were allowed only a very limited number of basic medicines. As time went by the list of medicines allowed was increased and became in principle open ended. Furthermore,

Medicines of the Buddhist monastic *materia medica* were considered to be foods but classified as nonsubstantial nourishment, allowing them to be consumed at any time. (Zysk, 1991, p. 73)

The medical knowledge in the *Vinaya* is organized in the form of case histories, where Buddha tells about the disease of a certain person and the remedies used to cure that person:

The section on medicines in the *Mahavagga* (of the *Vinaya Pitaka*)... is characterized by reference to actual cases, and functioned as a handbook and guide for the treatment of common afflictions... The medical importance of these Buddhist records, however, is their recounting of patients' medical problems and the corresponding treatments. The academic medical treatises of classical ayurveda offered no such case-by-case medical instruction... Between those two traditions [i.e. the Buddhist Pali records and the classical Indian medical treatises] many similarities, but also numerous differences, exist – significantly, the Buddhist emphasis on practical application devoid of the theoretical

considerations of disease etiology (italics added) that dominate the [non-Buddhist] medical books. This difference supports the view that codified Buddhist monastic medicine, with its emphasis on *materia medica* and case-based therapies, represents an early attempt to provide a manual of medical practice and in some sense legitimated the formalized collections of prescriptions... (Zysk, 1991, pp. 71–72)

As for knowledge of anatomy we find that:

In the *Mahasatipatthanasuttanta* of the Dighanikaya (in Sutta Pitaka), the four intents of contemplation (*cattaro satipatthana*) are detailed. The first of these was the human body (*kaya*) in all its parts, aspects, and impurities. The monk was to endeavor, through persistent contemplation, to realize the fundamental impermanence of his physical and mental constitution by meditating on the body:

And in addition, O monks, a monk contemplates this very body, up from the soles of the feet (and) down from the crown of the head, bound by skin (and) full of manifold impurities. “There is in this body (the following): hair of the head, hair of the body, nails, teeth, skin, flesh, sinews, bones, bone marrow, kidney, heart, liver, pleura, spleen, lungs, bowels, intestines, stomach, excrement, bile, phlegm, pus, blood, sweat, fat, tears, grease, saliva, mucus, serous fluid, and urine...” There is in this body “earth element, water element, fire element, and wind element.” (Zysk, 1991, p. 34)

This list includes anatomical parts, but does not give any further descriptive details, neither how they function and relate to each other nor how they relate to diseases. The four elements are mentioned, but only to underline that the body, like all other matter, is ultimately composed of these elements.

Buddhist medical knowledge encompasses concepts such as the four elements, the three humours, and the 32 constituents of the body, and shows a very practical attitude to the curing process, but it does not attempt to construct specifically medical theoretical frameworks. Thus when Zysk concludes that, “The medical doctrines codified in the monastic rules probably provided the literary model for the subsequent enchriridions of medical practice” (Zysk, 1991, p. 118), it is not difficult to agree that this has indeed also been the case for traditional Thai medicine.

Traditional and Cosmopolitan Medicine

If we look at patients' choices of curing methods in the countryside nowadays, we find, according to some statistics, that 95 % prefer cosmopolitan medicine as a first choice, while only a small minority chooses traditional medicine. Furthermore, traditional medicine is in many cases resorted to only after treatment with biomedicine has failed. This means that patients who no longer can afford modern treatment or people with terminal, incurable, or chronic diseases will resort to traditional medicine. But there are also certain illnesses where traditional medicine has a reputation of being more efficient than biomedicine. These include haemorrhoids, kidney stones, and diseases with "wind" as the prominent symptom. In addition, the simple fact that traditional doctors are local people who know their patients' social situation, speak the local dialect, talk in a way the patients understand, and have more time to listen may give them an advantage over the more sterile and impersonal relationships the patients have with the Western-trained physicians and hospitals.

From the patient's side, it is not an either-or situation. Many patients will choose both traditions. People who are sick often go to several doctors and several pharmacies at the same time, both biomedical and traditional, and thus follow parallel treatments. This may have the consequence that they stuff themselves with too many drugs, thus rendering it impossible to decide which medicine actually cured the disease.

While cosmopolitan-trained doctors are quite sceptical of the efficacy of traditional medicine, the reverse is not true. Traditional doctors recognize quite readily the qualities of cosmopolitan medicine, such as the surgical skills and the value of vaccination and antibiotics for example. They also in some cases refer patients to modern doctors and they may (re)sell certain Western drugs they find useful. Ideologically they also feel akin to biomedicine in that, as one traditional doctor put it,

Diseases are a terribly complicated business, so traditional doctors must use the same method

as the Western trained ones, namely the trial-and-error approach: If one prescription does not work, I will try another, and yet another, until I have found one that works, just like the pharmacists and the modern doctors.

But cosmopolitan medicine does indeed also take an interest in traditional pharmacopoeia, trying to identify and extract medically active chemical components from traditional medical herbs in the hopes of being able to design new drugs. Transnational – and Thai – pharmaceutical firms are involved in this search, and the Government Pharmaceutical Organization has in fact for years been producing herbal remedies for sale based on their own research.

Cosmopolitan medicine in Thailand is also adopting traditional Thai disease terms for modern diseases, thus eroding the traditional concepts and causing some confusion. Modern medicine has, for example, adopted the traditional term *mareng* for cancer, while the term originally was a vague disease term covering various skin diseases with itching eruptions. So it seems rather far-fetched to claim – as some traditional doctors do – that traditional prescriptions against certain skin diseases (*mareng*) also cure cancer (*mareng*) in general, simply because the names for the two diseases coincide. Also, some traditional doctors are claiming to have found or invented herbal medicines which can cure other "new" diseases, such as diabetes and AIDS, and herbal mixtures have also been used to cure heroin addicts.

Current Developments

Over the last decade or so, the Thai government has radically changed its policy towards traditional medicine. The general context for this change has been the new WHO policy to encourage governments to incorporate traditional medicine into their official medical systems. Furthermore, public expenses for medical care have continued to increase at an accelerating rate, and so has the bill for imported medicines and medical supplies. Thai politicians and bureaucrats also see the possibility for export of traditional Thai drugs, and that Thai medicine can

play an important role in transforming Thailand into Asia's health service centre.

There has also been a growing awareness of and pride in one's national heritage and local wisdom and knowledge, and "nature", "ecology", and "holistic approaches" have become very popular concepts and part of the current discourse on health. Some even feel that there is an incongruity between modern technology and the Thai way of life and indigenous culture. All these factors have contributed to strengthening the hand of traditional medicine and also in changing the attitude of the bureaucracy. One of the first official steps in this direction was the Seventh National Economic and Social Development Plan for 1992–1996, which stated that:

The promotion of people's health entails the efforts to develop traditional wisdom in health care, including Thai traditional medicine, herbal medicine and traditional massage, so as to integrate it into the modern health service system.

The Thai government has followed up on this plan, by adopting the goals of the plan in its official health policy and by establishing in 1993 the National Institute of Thai Traditional Medicine (NITTM) under the Ministry of Public Health. Its first director was the energetic and knowledgeable Dr. Phennapa Subcaroen. The basic aim of the NITTM is to integrate Thai Traditional Medicine (TTM) effectively into the National Health Service system. To achieve this aim, NITTM must, according to a brochure it has published, "systematize and standardize the body of TTM knowledge" and thus "gather knowledge, revise, verify, classify, and explain TTM knowledge" as well as "compare and explain the philosophies and basic theories of TTM and to produce textbooks on TTM".

Thus in order to revitalize traditional medicine and make it acceptable to the official medical system, the NITTM has deemed it necessary to create a new traditional medicine with a coherent medical theory, a consistent diagnosis and a consistent use of medical herbs, as well as a safe and efficient medical practice, or in other words, to replace heterogeneity with homogeneity. The result is no longer called "traditional Thai medicine" but simply "Thai medicine", "traditional"

having been dropped because it sounded too outdated.

This recreation of tradition is supposed to be done in cooperation with traditional doctors, NGOs, and other interested parties. But, according to Rancarati:

Not all health care workers, academics and traditional healers are content with official views of TTM. . . since they (particularly those in peripheral regions) feel that it is just another form of homogenization and domination of Central Thai culture within national boundaries. . . Standardized Ministry of Public Health TTM exams favour the Central Thai model, particularly by adopting Central Thai names and concepts related to medicinal herbs. (Rancarati, 2003, p. 209)

Another important step taken by the NITTM has been to protect Thai traditional medicine from being appropriated and exploited by foreigners. Thus the NITTM drafted the Traditional Thai Medicinal Wisdom Protection Bill which, after several years of discussion, was approved and came into effect in May 2000. This bill makes Thailand one of the first third world countries to regulate foreigners' access to all aspects of traditional medical knowledge. The law drew quite irate comments from the US embassy in Bangkok but was lauded by the local media. In a commentary in the *Bangkok Post* of 18 June 1997 for example, the editor Sanitsuda Ekachai praised this initiative to "defend our indigenous plants and age-old knowledge of their use from being hijacked by richer countries". She deplored the fact that rich countries with advanced biotechnology and sophisticated laboratories can use the genetic resources of developing countries free of charge, extract the effective chemicals, patent them and sell them back as expensive Western medicines. She also referred to the unfair global trade laws, and concluded, "The Traditional Medicine Bill is a small effort by Thailand to defend itself against such injustice. No one can rob us of this right".

The increased awareness about the value and potentials of traditional medicine in Thailand and the attempts to revitalize this tradition will hopefully contribute to a better and more self-reliant public health system, but it has also made traditional medicine a highly political issue.

Chinese Medicine

Chinese medicine is quite visible in Thailand, especially in the towns, where drugstores sell Chinese herbs and where acupuncture treatment is offered. Still, Chinese medicine remains quite a distinct tradition used mainly by the Sino-Thai population. Although the use of certain Chinese herbs and prescriptions – as well as massage theories – may have entered the Thai medical tradition over the centuries, no systematic study has been made to verify the extent of such influence. The popularity among the Chinese – be it in the Mainland, Taiwan, or parts of Southeast Asia – of using the horns, bones, or bile of certain animals as aphrodisiacs has contributed to the endangering of mammals like the rhinoceros, tiger, wild boar, bears, and certain snakes, among others.

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- This bibliography includes works on Thai traditional medicine defined narrowly, thus works on botany, pharmacy, medical practice in general as well as contemporary health problems and policy issues have not been included. I have also left out numerous studies on rituals and religion, many of which have a bearing on traditional medicine. Furthermore, the bibliography confines itself to Thailand and does not include relevant works from neighbouring countries, and it contains only works in Western languages, thus omitting a number of studies in the Thai language. For further bibliographic references to works on traditional medicine in Thailand, including works in Thai, see Shigeharu Tanabe, ed., *Religious Traditions Among Tai Ethnic Groups: A Selected Bibliography*. Ayutthaya (Thailand): Ayutthaya Historical Study Centre, 1991 (which contains special sections on Traditional Medicine).
- The bibliography below reveals that most studies in Western languages on traditional Thai medicine are articles on specific aspects of traditional medicine. There exist only a few more comprehensive studies: Golomb (1985) gives a broad anthropological view of medical practices in Southern Thailand; Bamber (1987) studies disease classification from a linguistic point of view; Brun and Schumacher (1987) concentrate on medical practice in Northern Thailand using the traditional doctors as informants; Mulholland (1987) studies traditional paediatrics based on manuscripts from the court tradition; and Somchintana (1989) studies the concepts and system of traditional court medicine in Bangkok from a cognitive anthropological point of view.
- There are but few works on the historical development of traditional medicine in Thailand for the simple reason that there is very little material in Thai which has survived from before around 1800. Scattered evidence can be found, but thorough and critical studies are extremely time-consuming and would not necessarily yield substantial results. Furthermore, detailed and critical comparative studies, both historical and contemporary, between the Thai medical tradition(s) and similar traditions in India, Sri Lanka, Burma, Cambodia, Laos, and China have yet to be undertaken. Thus how and to what degree these traditions have influenced each other is still an open question. What role Buddhism and the Buddhist *sangha* have played in the development of Thai traditional medicine awaits further studies. There is also a huge number of medical manuscripts which are in need of critical study which would also deepen our understanding of regional variations – just to mention some obvious areas of study which are needed to give us a better understanding of traditional Thai medicine.
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Medicine in the Ottoman Empire

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Medicine in the Muslim Middle East in the early modern period, like other traditional medical systems, was composed of several subsystems. Each promoted a unique etiology and practice and each enjoyed a different legitimacy. This was only to be expected in the Ottoman Empire, the most important political unit in the Middle East from 1300 until the end World War I (1918). As the Ottoman Empire stretched from central Europe to the Caucasus, from Morocco to the Arabian Peninsula, it was vast enough to contain different geographical zones and climates and diverse cultural heritages. The medical illnesses riddling a port city like North African Tunis and the medical steps to combat them were hardly the same as those of Baghdad in Iraq on the shores of the Tigris River or Sofia in the European hinterland.

Ottoman Medical Thinking (Based on: Shefer-Mossensohn, 2009)

In the early modern Ottoman context, there were three main etiologies all solidly present in the medical scene (based on Conrad, 1995): humoralism inherited from Antiquity, folklore based on custom, and religious medicines. During the long nineteenth century Ottoman medicine switched its focus to the knowledge and practices of European medicine. Indigenous Ottoman medicine was quite resilient and

continued to be practiced (with a revival in the last decades of the 1990s and 2000s), although it has been marginalized.

Popular medicine was sanctioned by custom and consensus from below. In the Ottoman case, this medical folklore was in itself of many varieties, partly because of the Ottoman past, partly because of the Ottoman present. The Ottomans inherited shamanistic medical traditions from central Asia which Turkish tribes immigrating to the Middle East and Asia Minor brought with them. The Ottomans blended their Turkish past with other traditions which they encountered in their expansions, ranging from Hellenic Anatolia and the Christian Balkans to the local folklore in the Arab provinces. All these pasts functioned in a concrete present, which in itself was made of several climate zones.

Mechanistic medicine, based on humoralism inherited from Greek Antiquity, is another medical tradition present in the Ottoman medical system. This tradition asserted its legitimacy by drawing on the scientific treatises of the sages of Antiquity, the patronage of a Muslim urban elite, and the dominant role it played in the intellectual and literary discourses of famous medical figures. This medicine based itself on the four elements: a physical and philosophical metatheory according to which everything in nature is a mixture of fire, earth, air, and water. Each element embodies two of the four qualities of hot, cold, dry, and moist. The human body was understood to correspond with this model, as it is a microcosm of nature. The body consists therefore of four humors, or fluids, the physiological building blocks of the body: blood (air), phlegm (water), black bile (earth), and yellow bile (fire). In the case of illness, which is a state of imbalance in the body, it was up to the humoralist physician to diagnose which of the four humors was in excess or deficient. The physician then proceeded to recommend a course of treatment, counteracting the offending humor by means of an opposite regimen. Excess in black bile, for example, known to be cold and dry, necessitates adding warmth and moisture artificially.

In Ottoman society, as well as in other early or premodern societies (Jewish, Christian, and

Muslim alike), humoralism filled the niche of “learned medicine” of its time. It enjoyed supremacy in urban communities, in the sultanic palaces and among the wider Ottoman elite. Chronicles and biographical dictionaries, two literary by-products of this social group, described ailments and explained death as stemming from changes in the humoral balance. This was also the medical system practiced in Ottoman hospitals, described in the section below.

Muslim religious medicine, the third medical tradition present in the Ottoman medical system, was similar in its contents to both popular and humoral medicines, but its legitimacy lay elsewhere. Instead of relying on custom or learned treatises, Muslim believers accept religious medicine as originating from (and therefore sanctioned by) the sayings of the Prophet Muhammad. One aspect of Muhammad’s prophetic charisma and a source for divine blessing is the healing powers attributed to him. Although too few to constitute a complete medical system, the sayings in which Muhammad gave his (positive or negative) opinion on medical practices were the basis upon which Muslim scholars built from the ninth century onwards. Hence this type of medicine is aptly known as “Prophetic medicine” (al-Ṭibb al-Nabawī in Arabic or Tıbb-ı Nebevî in Ottoman Turkish). Translations of Arabic treatises on the subject into Ottoman Turkish, in addition to the composition of original works in Turkish, bear evidence of the popularity of this branch of religious knowledge among Ottoman Muslims.

In addition to the different modes of legitimacy and theoretical and practical concepts of disease and health, each system had its own corps of specialist healers. Popular medicine was transmitted orally, whereas humoralism and Prophetic medicine were both grounded in written traditions. Moreover, humoralism and Prophetic medicine each had a unique written literary genre. Popular medicine emphasized techniques and results, not understanding bookish learning and accumulation of knowledge.

However, these medical subsystems were not independent of each other. None enjoyed

complete hegemony or was regarded by all as superior to others, absolutely true and exceptionally efficient. Instead of replacing each other, the different medical systems complemented one another. It was a situation of “not only/but also,” in contrast to the dichotomy of “either/or.” This background cultivated a relationship of competition between and completion of these three medical theories and practices. This reality brought about brutal competition among healers. If different types of healers offered the patients – their clients – more or less the same therapeutics, and none could boast superior success rates, healers could not single themselves out and justify the high level of financial rewards they expected. This was one recurring pattern in Ottoman medical history.

Ottomans ascribed much importance to preventive medicine (*hımāya*). At the same time, there were also many curative measures, and indeed there were multiple (and competing) means in the medical scene to treat all kinds of aches and ailments. Secondly, medical therapeutics had pronounced and far-reaching social aspects. Being embedded in the hierarchical Ottoman society, the realm of medicine too acknowledged social and financial differences. Ottoman medicines offered multiple methods for getting better and keeping one’s health; not unlike today, in reality they were not available to all. To many Ottomans, social and economic realities narrowed their medical options. Medicine was also a means for social demarcation and in turn helped to reinforce those status distinctions.

An integrative outlook at humans was another theme of Ottoman medicine: a “whole” person is situated in a “total” environment. Ideally all forces and elements in nature should interact in a balanced manner and be integrated into harmony. Such an ideal balance (*mīzān*) is hard to find and create, as it changes from person to person; it is even harder to maintain. Yet people are supposed to dedicate themselves to this multifaceted quest. The following section is concerned with the medical aspect of balance within the human body which corresponds with physical and mental health.

Ottoman Clinical Reality (based on Shefer-Mossensohn, 2009)

Traditionally, consuming rich and balanced food was extolled as a habit leading to good health. The Ottomans drew on several sources of inspiration to link food and health. It was a common thread in Turkish lore in central Asia. Food was a vital therapeutic tool in one medical theory and a practice common among Ottomans in the early modern period. In the humoralistic system, the recommended course of treatment was usually by diet, by means of counteracting the offending humor with an opposite regimen. Food and beverages were the first course of action, to be followed (only if they failed) by more invasive and violent measures. Humoralism promoted a hierarchy of treatments, from dietetics to medications and surgery. Food and beverages acted also as an insurance against illness, not only as curative agents. Ottomans believed that a strict regimen could guard one's body and soul against illness.

Many physicians in the imperial court were interested in dietetic medicine. In 1575, several treatises on medical culinary matters were loaned from the inner library at the palace (*İç Hazine*) to the Imperial Head Physician (*Hekim-başı*) who wanted to study them. Five years later they were still out, now given to the next head physician (The Library of Topkapı Palace (Topkapı Sarayı Müzesi Kütüphanesi [TSMK]), defter 8228). New treatises on medical dietetics were composed at the imperial court, like Zeyn al-Din al-Abidin's *The Advantages of Health*. This treatise still exists in multiple copies in various libraries in Turkey and around the world. It was printed in Cairo in 1872 together with another work by the same author on tea and pepper – all this attests to the author's prestige. Zeyn al-Din al-Abidin outlines different types of dishes and beverages according to their humoral attributes. The author explains how these attributes, combined with different cooking methods and the timing of a dish during a meal, affect one's inner balance.

Medication, like medical dietary, served both preventive and curative aspects of medical treatment. And medication, like diet, was a social

symbol as those of means could afford medication prepared of rarer and more expensive ingredients (although the outcome was not necessarily more effective medically). The affluent patients in the imperial palace, for example, received medication prepared from drugs like opium or hashish, pulverized gems (colored and clear), and precious metals. This possibility did not exist for the patients in the hospitals: such materials were certainly not on the lists of products bought for hospitals. On the open market, it was available only for those who could buy it at full price.

Middle Eastern pharmacology in the early modern period continued previous medieval Arabic pharmacies. The continuation is evident in two aspects. First, most drugs used were of plant origin, hence the uncertainty in certain cases whether the recipes are for condiments, for foods, or for medications. This was the theoretical reality as is evident from the pharmacological compendia of the time. Thanks to the survival of dozens of medical recipes from the imperial Ottoman palace, we have some clues to clinical reality which apparently was quite similar (although we do not know necessarily whether these prescriptions were actually prepared; and if they were, whether they were taken; and if taken, whether the patient followed the dosage and usage instructions). The range of products used by pharmacists was very wide. It included oils, fats, and dairy products (olive oil, butter, milk, and cheese products); pulses (like lentils, chickpeas, peas and beans); herbs, seeds, and nuts (cumin, coriander, mustard, cress, pistachio, and sesame were quite popular); sweets like honey, jujubes, peaches, plums, and palms; cooked foods; alcoholic drinks (wine and various beers); cosmetics (henna and hair dyes); and precious perfumes. Such commodities were stored in various vessels, boxes, and baskets made of glass, wood, or metal.

Second, early modern pharmacy continued previous forms of pharmacological literature. The literary models that existed in the Ottoman Empire evolved over hundreds of years. The Ottoman inherited these genres while adapting them. For example, many Ottoman physicians

now composed pharmaceutical manuals in Ottoman Turkish, not in Arabic. But like before, the various works were organized internally in a manner suitable for their use, whether as a quick reference for the doctor or pharmacist, for learned and through discussion, or a lexical interest. Some formed part of a larger medical encyclopedia, where one part was devoted to pharmaceuticals, and were not independent works. Each drug was analyzed according to its humoral characteristics and how it affected the body, i.e., whether it cooled, dried, heated, or wetted the body (not that there was necessarily unanimity among scholars about the typology of drugs).

Beside very modern methods like sprays, the Ottomans prepared most forms familiar to the modern patient, such as infusions, decoctions, pomades, pilules, syrups, pastilles, powders, emulsions, suppositories, and clysters (rectal or urethral). Medications were eaten, drunk, or swallowed, that is taken by mouth. There was also nasal medicine: fumes were inhaled and powders snuffed, sometimes with a blower used to open the nostrils. Baths, too, were used, so the patient would inhale the fumes from the drug more easily (the entire body was not necessarily immersed in the drug). Other medications were not ingested but rubbed on the outside, as in the case of ointments. Two forms seem to have been especially popular among Ottomans: syrup (*shurba* or *sharab* in Arabic or *şerbet* in Ottoman Turkish); the other was doughy paste (Ottoman *macun*; Arabic *ma'jūn*).

Narcotics were a special case of medication. Opium is singled out here because it was especially accepted as a healing substance among Ottomans. Opium served as a laxative, and purgatives were quite common in the pharmacological repertoire. Opium appeared, and in large quantities, on the lists of products purchased for the imperial kitchens. It was used also in other forms for patients in imperial palace of Topkapı. It was also bought for the imperial hospitals. But opium was not the prerogative of the upper echelon. It was used by Ottomans from all walks of society as a cure to all aches and pains, including those of children and even babies.

In humoral theory, curing by knife was the last option a physician should consider. Learned medical treatises reveal this hierarchy: surgery is indeed discussed in these books, but it is clear it was a peripheral option in the humoral medical arsenal. In the Ottoman context, this hierarchy within medical theory is revealed, for instance, in the paucity of texts focusing on surgery. Two main manuscripts survived from the early modern period: fifteenth century *Cerahiyyet-ül-Khaniyya* (*The Surgical Operation of the Khan*) by Şerefeddin 'Alī b. al-Haj Elias Sabuncuoğlu from Amasya in central Anatolia and seventeenth century Shams al-Din Itaki's *Tashrih-i abdan ve tarjuman-i kabala-yi falasufan* (*The Anatomy of the Body Parts and Expounding the Role of the Philosophers*) from Shirvan on the Ottoman-Safavid border who later on migrated to Istanbul.

Surgery as a learned genre may have been limited in comparison to other medical options, but surgical (that is medical intrusive) procedures were practiced regularly. Two procedures seem to be mentioned more than others: phlebotomy and cauterization.

Bloodletting (*hijāma*) was a popular medical practice in the Middle East well into the nineteenth century. Bloodletting involves the withdrawal of large quantities of blood from a patient. The humoral reasoning behind it was that the removal of blood should alleviate problems caused by excess or corruption of blood in the body. Before the discovery of the circulation of the blood in the seventeenth century, and even afterwards, there was a belief that blood could accumulate and get "spoiled" in the extremities of the body, hence the need to get rid of it (emetics and purgatives were intended to achieve similar aims on other humors). Bloodletting was a routine medical treatment for various aches and pains (head, eyes). It was a means of bringing a body into alertness as preventive medicine as well and became part of the lifestyle. The French traveler Jean Thevenot who toured the Ottoman Empire in the 1670s documented cases he saw of people bleeding themselves. However, the more common occurrence was to hire a professional.

Cauterization too, namely, burning a body extremity with fire (*dağ* in Ottoman Turkish,

meaning branding with a hot iron, or *‘ilāj bi-nār* in Arabic, literally “treatment by fire”), was very popular in the Muslim Middle East for medical (as well as for cosmetic) purposes. It was carried out by bringing white-hot iron to the designated spot in the body and removing it after a few seconds. The pain could be excruciating, and indeed the sources describe how several men of size were drafted in order to hold the patient’s limbs down and “glue” him. Cauterization was used as a treatment for a variety of ailments in all body parts, ranging from headaches to fistulas and hemorrhoids. Evidence from the 1970s attests it was still practiced in various areas of the Middle East as part of folk medicine (Karmi, 1985, p. 319).

A third surgical procedure that is usually ascribed to the Ottoman Empire is inoculation against smallpox, although in reality it was no more than a local indigenous practice in some Ottoman communities. We have evidence, for instance, from Edirne in Thrace (Wortley Montagu, 1965–1967) and Palestine (Davidovich & Greenberg, 2007). The Ottoman inoculation was very different, and more dangerous, than Edward Jenner’s (1749–1823) vaccination with cowpox which was eventually adopted. It was administered by older women specializing in folk medicine (Baxby, 2009).

Ottoman Hospitals (based on Shefer-Mossensohn, 2014)

After a period of almost complete halt in the foundation of large-scale hospitals in the later Islamic Middle Ages (from the Zangids onwards only a few new big hospitals were erected), the Ottomans renewed with gusto the tradition of imperially patronized hospitals and were associated with hospital foundation from the late fourteenth century. They established hospitals (referred to interchangeably as *bīmāristān*, *bīmārkhāne*, *tīmāristān*, *tīmārkhāne*, and *dār al-shifā’*) in the three capitals (Bursa, Edirne, and Istanbul), some princely seats in Anatolia, and various other provincial centers. To this list of Islamic hospitals, one

needs to add the many medical facilities of the many non-Muslim communities, some from pre-Ottoman times and some new.

On the one hand, the new Ottoman hospitals were physically bigger than the usual size of pre-Ottoman Muslim hospitals. They employed a larger staff that displayed wider medical capabilities and a higher level of medical professionalism. Yet the medical, administrative and architectural basis for this new hospital was clearly that of previous centuries. Like preceding Islamic hospitals, the Ottoman hospitals too were charitable institutions; their purpose was to heal sick patients (rather than to serve as hostels or hospices, caring for the dying or chronically ill), and they practiced only one medical tradition (humoral Galenism in its Islamic, first Arabic and now Ottoman form). The Ottomans, like in other aspects of their culture, drew on previous traditions and made them their own.

Relatively speaking, hospitals were marginal in the Ottoman medical scene. The number of hospitals and the beds that they offered could not meet the medical needs of the community. Hospitals also played only a minor role in the career of most Ottoman physicians. However, hospitals were not insignificant. The turnover in hospitals’ patient population and their accessible central locations enabled many to utilize their medical services, which were offered free of charge. Moreover, some hospitals functioned as internship sites for medical students, perhaps following previous Islamic traditions. Aside from physicians, each hospital offered employment to dozens of people in medical, administrative, and menial duties. Some hospitals also included musicians and story tellers on their payroll.

Whereas hospitals were founded in major cities all over the Ottoman Empire in the fifteenth and seventeenth centuries, this activity came to a halt in the eighteenth century. When it was resumed at the end of the eighteenth century, again the hospitals founded were of a different type. New hospitals in the eighteenth and nineteenth centuries were established against the background of reforms based on western models of modern society, culture, and state.

The Long Nineteenth Century: Modernization and Westernization (based on Shefer-Mossensohn, 2007)

Ottoman medical theory experienced a major turning point in the nineteenth century, as the Ottomans moved from Ottoman-humoral medicine to European medicine. The change was brought about under the aegis of the Ottoman imperial court and elite. In the Ottoman provinces, the local elite (for instance, in Egypt it was Mehmed Ali Paşa and his house) gave the cue. (For Egypt, see: Gallagher, 1990; Kuhnke, 1990; Sonbol, 1992; Fahmi, 1999, 2000; Kozma, 2011; Abugideiri, 2010). The new conceptualization of medicine, illness, and health emphasized biology and pathology over the holistic and human approach of previous centuries.

The ultimate aim was not necessarily to improve the well-being of citizens (citizenship was a new concept in the Middle East), but rather to improve state management. With health intentionally and successfully transforming into a mechanism of state control, medicine and disease in general and medical institutions in particular attracted much attention on the local and imperial levels during this period. The reforms in the medical realm did express the wish to protect public health: the nineteenth century saw for the first time formal programs to promote health by preventing disease and rendering medical care accessible. However, the goals and practices of public health brought about civic regulation and civic regeneration.

The Ottoman state now expanded its duties to cover all aspects of life, and that included medicine and health. New hospitals were founded (Shefer-Mossensohn, 2005) as well as new professional organizations and nonprofit organizations like the Ottoman Red Crescent Society. The state regulated midwifery and birth (Balsoy, 2012) and imposed quarantine measures (the first full quarantine apparatus in the Empire occurred in 1838). The state sent students to study medicine abroad and opened new medical schools within the empire. The inclusion of a chapter dealing specifically with health in the 1858

penal code is a symptom of the change. Governmental edicts dealing with health measures forced members of the public for the first time to take individual responsibility for the public space.

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Medicine in the Talmud

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Although whole books have been devoted to the study of talmudic medicine and quite a number of studies to specific related topics, only a small number of scholars in the field of medical history are aware of this rich corpus of knowledge. The core of the Talmud (the authoritative body of Jewish law and tradition), called *Mishnah* (divided into six tractates), was compiled between the second century BCE and the second century AD. Two extensive commentaries and glosses were added to the basic text. One is the so-called Jerusalem Talmud, which was completed in the fifth century AD. The Babylonian Talmud, which was much larger, was sealed in the sixth century. No medical texts from the ancient Hebrew-Jewish period have reached us, so the wealth of medical knowledge that is interspersed in the Talmud is the sole source of documentation in these matters. It should be made clear that these medical data are recorded by talmudic scholars in the midst and for the sake of legalistic discussions. In most cases few details are provided and only those that are relevant to the specific point under consideration.

The spectrum of medical knowledge covered in the Talmud is very wide. The field of anatomy (mainly of animals) is impressively represented,

particularly in the tractate *Hullin* which deals with dietary laws. The inspection of slaughtered animals is one of the remarkable institutions of Jewish law, as it related to public health. In order to decide whether an animal was acceptable for consumption (*kasher*) or not (*taref*), anatomy and pathology had to be mastered to a considerable degree. Two examples will be given here. The number of bones is considered in the context of uncleanness: it is ruled that everything contained in a tent (or room) in which there is a number of bones amounting to more than half of a corpse becomes unclean. The body is comprised of 248 bones (it says “members,” *evanim*), corresponding to the number of days of the lunar year, and 365 “sinews” (*gidim*) corresponding to the solar year [bab. Makkot 23b]. The Talmud mentions that once research was done on the corpse of a young female prostitute who had been executed by the (Roman?) authorities, and it was found that there were 251 bones. The Sages opined that the discrepancy was due to the fact that this was a young woman [bab. Bekhorot 45a]. Another opinion was that the number of bones may vary from 200 to 280 [Tosefta, Oholot 1: 7]. Osteology was not very exact, even in “academic” medicine. Galen speaks of “more than 200 bones” [De Form. Foet., Bk. 6]. Interestingly enough, ► *Ibn Sīnā* (*Avicenna*) and al-Zahrāwī (Abulcasis) both accepted the number 248, most probably in accordance with the lunar analogy and the macrocosmos/microcosmos similarity.

The second example is related to neuroanatomy. The case history featured a lamb which dragged its hind legs along, and the question was, “What kind of lesion does it have?” One sage said, “This is a case of sciatica” (Hebr. *shigrona*). Another replied, “Possibly this is a lesion of the spinal cord” (Hebr. *hut ha-shedrah*). The text then says, “They examined it (i.e., they performed an autopsy), and the second diagnosis was authenticated.” This shows a remarkable experimental approach. The sages decided that if an animal dragged its legs it would be said to have sciatica, and such an animal would be permitted for consumption [bab. Hullin 51a]. This is a very typical example of talmudic

casuistry. The sages not only allow, they even advocate thorough examination of the case, but the decision is based on the opinion of the majority and on the most frequent occurrences.

The Talmud, in both versions, is full of observations of medical and historical interest pertaining to internal medicine, gynecology and obstetrics, dermatology, neuropsychiatry, surgery, traumatology, and most other specialties (including otology, ophthalmology, and dentistry). Other fields such as dietetics, preventive medicine, forensic medicine, public health, and materia medica are also widely represented. Instead of listing a catalog of items, we shall give a number of examples that stand out for their detailed description and/or for their originality.

Commenting on the scriptural verse [Deut. 7: 15] which reads, “And the Lord will take away from thee all sickness...,” the Talmud asks the question, “What is sickness?” A number of answers are provided by the Sages in both versions of the Talmud [bab. Baba Mezia 107b; jer. Shabbat 14: 3]. In both versions we find three cardinal causes of diseases. One pertains to scientific medicine: the bile; one is related to popular medicine: the cold (or cold-and-warm); and one belongs to magic lore: the evil eye. Other agents that appear only in one version include: air (or wind); fever; abnormal or superfluous secretions; climatic factors (the *sharav* wind); obsession (one who is persuaded that he is sick), and carelessness (which is particularly stressed, thus enhancing the preventive aspects of medicine). Two other factors are mentioned elsewhere in the Talmud. One is blood (i.e., plethora): “At the head of all (causes of) diseases am I, the blood” [bab. Baba Bathra 58b]. The other is changes in one’s habitual way of life [ibid. 126a]. Another version mentions changes in one’s usual diet [bab. Kethubot 110b]. This particularly developed topic is characteristic of talmudic lore, as it includes popular beliefs, empirical notions, and scientific aspects. Humors (blood, bile), specific symptoms (fever), environmental causes (winds, cold), magical aspects (evil eye), psychic factors (obsession), and a heedless way of life (carelessness): these are part of a broad spectrum of the agents of sickness.

Gynecology and obstetrics are well represented in the talmudic corpus, particularly in the tractate *Niddah*. Menstruation (during, and 7 days after which a woman cannot be approached by her husband), vaginal bleeding, recognition and duration of pregnancy, as well as a wealth of details related to embryology, sterility, and abortion, are only examples of the topics considered by the Sages. We shall again select two items: cesarean section and embryotomy. Regarding cesarean section, it is stated [bab. Arakhin 7a], “If a woman dies during labor, the operation is performed even on the Sabbath day and the child is ripped out of the womb.” A decree of this kind was already extant in the early Roman *Lex Regia* of Numa Pompilius. More challenging is the question of whether cesarian section was performed on a *living* mother in talmudic times, a procedure that has not been documented in adjoining contemporaneous cultures. We read [Mishnah, Bekhorot 8: 3]: “A child born through the (abdominal) wall (Hebr. *yoze dofen*), and the one who comes (i.e., is born) after him, none of them are considered (legally) as being first-born.” It seems that it was acceptable in the times of the *Mishnah* (second century AD) that a woman gives birth by cesarean section, recover, and gives birth later to another child in the normal way. Such a possibility seemed quite strange to Maimonides [see his commentary ad loc.], who tried painstakingly to devise a case that would make sense. There has been a lively and prolonged discussion among historians of medicine and talmudic scholars regarding the definition of *yoze dofen*. Some think it could mean extrauterine pregnancy; others advocate abnormal birth through a perineal tear, or even through the anus. I am among those who think that this was a theoretical case based maybe on animal pathology [see ibid. Bekhorot 2: 8], but the question is still open to discussion.

Embryotomy is mentioned in the *Mishnah* as well: “In case a woman experiences difficulty in labor (her life being in danger), her fetus should be cut to pieces inside her womb and extracted limb by limb” [Mishnah, Oholot 7: 6]. It is clearly stated that the life of the mother has preference

over that of the fetus. However, once his head, or the majority of his body, is out of his mother's body, the fetus may no longer be harmed, for one life cannot be put aside for the sake of another.

Circumcision was, according to the biblical narrative, first performed by Abraham, and was henceforward to be performed on every male child at the age of 8 days [Gen. 17: 10–14]. The technical details of the surgical procedure are nowhere mentioned in the Bible; they are, however, discussed in the Talmud. What interests us here are some of the complications of the operation. It is stated that if two children of the same mother have died (from hemorrhage) as a result of circumcision, the third child should not be circumcised. It says further that if two children of one mother or one child each of two sisters dies, the third should not be circumcised.

The sages remark that there are families in which the blood is "loose," whereas in others it is "tied up". This is most probably the first historical description of hemophilia and of its genetic transmission [bab. Shabbat 134a and Yebamot 64b].

The operation that should be performed on a newborn baby which presents an imperforated anus is described in detail [Shabbat, *ibid.*]. It says that the membrane should be opened crosswise. This is noteworthy because a circular incision would indeed have been ineffective.

In accordance with Hippocratic medicine, the Talmudic sages considered that an 8-month baby could not be viable [bab. Shabbat 135a]. A baby was usually breast fed for 2 years. Therefore if a nursing mother lost her husband, she was not allowed to marry again until 2 years (at least 18 months) had elapsed, for fear that she might become pregnant again and her milk production could be stopped [bab. Yebamot 42ab]. In order to prevent a nursing mother from becoming pregnant (which could stop lactation), some sages advocated the use of a pessary (*mokh*) during intercourse. Others promoted withholding intercourse altogether during lactation, which was repeatedly urged in ancient medical lore. Wet nurses were hired in case the mother could not nurse her child. The wet nurse was supposed to tend this nursling exclusively; she could not even nurse her own

child [bab. Kethubot 60b]. The use of non-Jewish nurses was permitted. Some sources granted this permission without any condition [Tosefta, Niddah 2: 5]; others asked that the nurse be under the parents' close supervision [Mishnah, Avodah Zarah 2: 1]. Moreover the use of milk from animals, even from unclean beasts, was permitted, as the child was considered in deadly danger if he got no milk whatsoever.

Even a brief abstract of talmudic medicine cannot disregard the topic of public and personal hygiene. Dietetics is not exclusively centered on dietary laws. Several axiomatic statements, based on empiric and popular lore, are recorded. One should eat simply [bab. Shabbat 140b], slowly (carefully chewing food) [bab. Berakhot 54b], moderately [Shabbat 33a], and regularly. "Any change in one's usual diet is the beginning of bowel disease" [bab. Sanhedrin 101a]. Wine and meat are characteristic of a festive meal [bab. Pesachim 109a]. Excess of meat is considered harmful; the priests in the Temple suffered from bowel diseases, as they consumed too much meat (from the offerings). There was even a "specialist" for these diseases; his name was Ben Ahijah [Mishnah Shekalim 5: 1–2].

Fasts were instituted by the sages to commemorate great calamities such as the destruction of the Temple. The only fast that is of biblical foundation is the Day of Atonement (*Yom Kippur*). Fasts were also initiated in case of oncoming epidemics, wars, floods, or drought. Such fasts did not usually exceed 24 h [Mishnah, Ta'anit 3: 3–5].

Personal hygiene included cleanliness as reflected in the laws of purity. Women took a ritual bath after menstruation and observed an additional 7 days purification period. General hygiene is featured in a number of regulations on water supply, lavatories, bathing, care for the dying and burial, and the Sabbath rest.

Even after all this explanation, we can still ask the question: Is there actually a specifically talmudic medicine? I prefer the view that there is definitely a fascinating topic labeled "Medicine in the Talmud." These rich and multifaceted data should take their legitimate rank in the history of both medicine and culture.

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- treatments. Despite a history of opposition toward nonbiomedical forms of healing (Dole, 2004, 2006), traditional healing practices are still widely practiced and used within both urban and rural settings. As with any social practice, these healing practices change in relation to ongoing political, economic, historical, and social transformations.

The majority of traditional healing practices are closely related to Turkey's dominant religious orientation, Islam. Of these religious forms of healing, four general categories or types of healing can be identified. While there is a significant degree of regional, local, and individual variation, these categories reflect the most widespread practices and can be distinguished based upon their respective conceptualizations of therapeutic efficacy, of how each form of healing is understood as affecting a cure.

The first form of healing, *kurşun dökme*, roughly translates as “the pouring of lead” and consists of a lead pouring specialist (*kurşuncu*) who treats patients who have been struck by the *nazar*, or evil eye. The evil eye can manifest itself in a variety of forms – fever, sweating, “fright,” bad luck, pimples, skin rashes, and nightmares, to mention but a few (Çelik, 1974; Maloney, 1976). Although practiced exclusively by women, both men and women go to this specialist for treatment. Women and children (both male and female) are, however, the most frequent visitors. The primary ritual feature of the *kurşuncu* is the pouring of molten lead into a basin filled with water over which the patient, with a scarf or covering of some sort over her or his head, leans. While the lead is being poured, the *kurşuncu* recites prayers and commonly says, “It is not my hand, it is the hand of our mother Ayse Fatma.” After the lead has been poured – which creates a cloud of steam that passes over the patient's face – the *kurşuncu* removes the solidified piece of lead and reads it to divine the source of the evil eye. This is typically repeated three times.

Outside of this basic ritual formulation, there is remarkable variation, particularly in the many additional items that accompany the lead pouring and what the *kurşuncu* instructs the patient to do

Medicine in Turkey

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Turkey comprises a territory that has long been a crossroads for numerous empires, religions, and cultures. The medical and healing techniques that are practiced and utilized in contemporary Turkey reflect this diverse history. While cosmopolitan medicine has been practiced in Turkey for centuries and patients overwhelmingly prefer it when available, there exists a rich set of health care options for problems not defined as treatable within medical settings, in instances where one has no access to or cannot afford medical treatment, or, most commonly, alongside biomedical

with them. For instance, items such as onions, bread, salt, oil, coal, keys, soap, strainers, brooms, forks, and gold rings can be utilized within *kurşun dökme* rituals. After finishing the lead pouring, the patient can be given specific instruction about what should be done at home and what should be done with each item. Instructions can include such things as not talking with or kissing anyone, not telling anyone that their condition has improved, throwing the water where no one will walk, tossing the onion behind oneself without looking, feeding the bread to a dog or cat, burying the bread at a crossroads, and so forth.

Women who specialize in the pouring of lead commonly learn the practice from older female relatives. As children, they assist their elder relatives with the ritual, thus learning the ritual variations of each healer. In this regard, the relationship between female elder and daughter or granddaughter is central to the succession of healers. In addition to passing on the specifics of ritual practice, this relationship is significant in that the ability to heal is passed through the female line of a family. The actual passing on of the ability to heal is described as *el vermek* – to give one's hand. As compared to other forms of healing, this has perhaps shown relatively little historical change (Dole, 2002).

A second category of religious or ritual healing widely practiced is that of the *ocaklı*. The practices of the *ocaklı* are incredibly broad and overlap with *kurşun dökme*. This form of healing, however, is not defined so much by the ritual style of its healing, but its association with holy or sacred ancestors. The term *ocak*, the root of *ocaklı*, while having many connotations (furnace, hearth, fireplace, mine, political body, guild, fraternity), is associated here with the notion of "family line." To be *ocaklı* – literally, "with the *ocak*" – connotes someone having special powers to heal based upon their relationship to an ancestor. The *ocaklı* is thus usually linked to a particular tomb, that of his or her dead ancestor, which is generally located near his or her home village.

While different *ocaklı* may perform very different rituals, they all tend to be marked by a

considerable specialization in regard to the problems treated. There are respective *ocaklı* who, for instance, treat specifically warts, rashes, arthritis, shingles, and jaundice. In addition to these more localized ailments, some *ocaklı* were known for their ability to cure alcoholism, to miraculously induce fertility for those who were unable to conceive, and provide good fortune in general.

Although the ritual techniques of the *ocaklı* vary considerably, the recitation of Quranic verses appears to be consistently present. Many, as well, utilize particular verses from the Qur'an known as *şifa ayetler* (curative Quranic verses) that are recognized as being particularly effective in treating specific problems. While these verses are supposed to be effective no matter who reads them, the *ocaklı* is regarded popularly as having special powers in the realization of the verse's intent. Beyond this, there are some common but less ubiquitous ritual components to the practice of the *ocaklı*. Drawing or scratching (*çizmek*) on the skin is one such practice, particularly for skin related ailments.

As with the *kurşuncu*, the efficacy of the *ocaklı* is attributed to their inheritance of a special gift or power to heal from an ancestor to whom miraculous or extraordinary powers are accredited. Similar to the *kurşuncu* as well, the training of the *ocaklı* typically occurs through assisting an elder *ocaklı* as a child. Although like the *kurşuncu* the *ocaklı* is customarily elderly, unlike the *kurşuncu* both men and women can be *ocaklı*. Likewise, both men and women go to *ocaklı*. Similar to the *kurşuncu*, the practices of the *ocaklı* seem to have changed little over the years and there appears to be little difference between *ocaklı* practicing in rural and urban settings.

While the *ocaklı* may be popularly ascribed titles like *ana* (lit. "mother") or *dede* (lit. "grandfather"), mention should be made here of the distinct category of *dede* among Turkey's Alevi Muslim minority (comprising approximately 20–25 % of the total population). For the Alevi, *dede* is a title used to describe someone whose lineage can be traced back to Muḥammad through one of the Twelve Imams. While a given village, or group of villages, may be headed by a *dede* recognized as having spiritual and moral

authority, there are commonly many more *dede* who do not perform the customary judiciary, ritual, and religious functions of the *dede* who heads a village or group of villages. These individuals are *dedes* principally in name only. On occasion, however, particular *dedes* – in their association with their lineage, or *ocak* – are considered to have the ability to cure illness or fulfill wishes. While at times referred to as an *ocaklı*, they may also be described as a *dede*. The Alevi *dede*, however, is distinct from the *ocaklı* discussed earlier, although the latter may also be referred to as a *dede*. Among Turkey's Sunni Muslim majority, there is no figure that precisely resembles the *dede*, as it is understood among the Alevi. In terms of the more general category of *ocaklı*, however, there were few discernable differences in how the Alevi *ocaklı* and the Sunni *ocaklı* practiced.

The third form of healing, that of the *cinci hoca* or *üfürükçü*, treats a range of illnesses and problems which typically involve people being struck, harassed, or possessed by spirits (*cin*) or fairies (*peri*). Hence the title *cinci* (exorcist) *hoca* (teacher, or more specifically Muslim teacher or cleric). The *cinci hoca*, however, does not only treat those who have already been affected by *cin*. They may also work to control *cin*, and thus bring harm upon others. In this regard, such *cinci hoca* are considered practitioners of magic (*büyü*). Furthermore, their characteristic ritual blowing over either the patient while being prayed for or over the object being made serves as the basis for the title *üfürükçü*, itself a derivative of the verb *üfürmek*, to blow on someone or something. Although they address an incredible range of problems, the most common ones are epilepsy, nightmares/fright (*korku*), adultery, and a host of relationship problems.

Rather than an emphasis upon the inheritance of a sacred gift, such as with the *ocaklı* and the *kurşuncu*, the capacity of the *cinci hoca* to heal centers upon training and the learning of specific ritual formulas. Correspondingly, many *hocas* base their practice on such texts as *Gizli İlimler* (Secret Sciences), *Havasü'l-Havas*, and *Kenzü'l-Havas*. These books, which are readily available at many religious bookstores, contain extensive

lists of ritual prescriptions that are said to have been passed down from the distant past. A given treatment is typically the result of computations based on the Arabic equivalent of the letters of a patient's and that patient's mother's name, the patient's birth date, and the presenting illness, problem, or intention (*niyet*). Based upon these, the book then provides the appropriate ritual formula. This ritual formula can include not only the appropriate prayers to be recited a specific number of times and at specific times, but also instructions for the production of different ritual objects or talismans (*tılsım*).

The *muska* is by far the most recognizable object produced by the *hoca*. A *cinci hoca* may also be referred to as a *muskacı* – a writer of *muska*. The *muska* is a sheet of paper over which a Quranic verse, a ritual prescription, the patient's name, the patient's mother's name, and/or the object of the spell's intent has been written in Arabic. The paper is then folded, frequently into a triangle, and put into a pouch. This pouch can either be worn or placed on the body of the patient (e.g., around the neck, in one's pocket), or can be placed in prescribed locations to realize the desired effect. For example, there are numerous accounts of *muska* being placed under a bed so as to block the sexual drive of a person. Alternatively, the *muska* can be burned or soaked in water, after which the water is consumed (Eyuboğlu, 1987, 1998). Although there are instances of female *cinci hoca*, male *cinci hoca* are far more prevalent. Both women and men, however, visit the *cinci hoca*. The *cinci hoca* is a highly controversial figure and the target of considerable animosity (Dole, 2006).

In many a neighborhood mosque, or *cami*, the local imam may treat members of the community for various problems using some of the same practices as the *üfürükçü*. While any imam, or *cami hoca* as they are sometimes distinguished from the *cinci hoca*, would fervently disagree with being compared to the *cinci hoca*, many imams utilize similar rituals treatments for the ill, assign enormous importance to the *şifa ayetler*, and incorporate the ritualized blowing over the patient while reciting prayers. There are however drastic differences. The imam does

not utilize the astrological and numerological aspects of the *üfürükçü*'s practice. Outside of perhaps writing out the *şifa ayet* for the patient, the imam also does not utilize talismans such as the *muska*. Finally, the *camî hoca* tends to treat minor ailments and does not venture into the realm of magic and witchcraft. On theological grounds, imams categorically denounce the work of the *üfürükçü* as not part of Islam. The *camî hoca* is relatively rarely utilized and not typically conceived of as representing a specific tradition of healing.

The fourth, and far less prevalent tradition of healing, is that of the *evliya*. Although the meaning of the term is most closely approximated with the English concept "saint," one should be careful not to assume a homogeneity between Christian and Islamic notions of sainthood. Nonetheless, an *evliya*, as with a saint, is broadly definable as a person acknowledged as possessing extraordinary spiritual powers, which in turn connotes exceptional status. An *evliya* is commonly defined as a possessor of *keramet*, the God-given power to perform miracles. Unlike the *ocaklı*, the saint's power does not necessarily have to be the result of being a descendant of a holy person; they are the holy person from whom the *ocaklı* will be descended and to whom a *türbe*, or tomb, will most likely be dedicated. *Türbe* visitation is an extremely popular tradition in Turkey and commonly coincides with requests for cures (Olson, 1991, 1994). It could possibly be viewed as its own form of traditional medicine, although no designated healing practitioner is commonly associated with tomb visitation.

Although there are no specific passages in the Qur'an that authorize the recognition or veneration of saints, saint worship is nevertheless extremely popular. The existence of those recognized as living saints is however still rare. It should be noted that unlike Christian sainthood, particularly in Catholicism, there is no formal system of canonization when discussing the *evliya*. *Evliya* are, in many regards, "self made" (Faroghi, 1979, p. 658). As with the Christian saint, though, the principal task or duty of the *evliya* is to intercede with God on behalf of

petitioners or supplicants. While being able to heal is one of the commonly ascribed God-given powers of the *evliya*, they are not solely healers. Because the centrality of their efficacy revolves around an ability to perform miracles and speak directly with God, training is of little significance for the *evliya*'s authority. Though there is supposed to be only one *evliya* on earth at any given time, scattered throughout Turkey are nonetheless rumors of numerous saints appearing and disappearing.

Other than the principally religious based forms of healing discussed earlier, there are also prominent forms of healing for which there is limited scholarship. For instance, the use of herbal remedies is widespread in Turkey. In addition to frequently being self-prescribed, one can find individuals in both urban and rural areas who have received special training in mixing medicinal herbs. Additional healing specialists that were in the past particularly widespread in rural areas of Turkey are the *kemikçi* (bone-setter) and the traditional midwife (Önder, 2005).

The traditional healing practitioners described earlier constitute significant aspects of local health care systems, and people (from all backgrounds) seek their assistance for a variety of reasons. Most commonly, they are utilized alongside biomedical treatments. With the exception of perhaps the *evliya*, such practitioners are not leaders of religious groups or organizations. They are individuals who, like others, assume a variety of social positions – neighbor, greengrocer, butcher, relative – but have acquired a body of specialized knowledge that bestows upon them a certain degree of reverence.

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Medicine of Native North Americans

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American Indian men and women practiced the first medicine in the Americas, and Native North American medicine took many forms. Some of the Native medicine ways worked much like modern biomedicine, but other forms of traditional Indian medicine differed greatly. The Indian medicine practiced in various communities was different among the thousands of tribes, bands, and groups of American Indian people. Thus, no “generic” Indian medicine ever existed, but most Native American medicine was holistic and practiced by men and women who drew on medicinal plants, prayers, power songs, and experience to heal people. Indian doctors varied in their approaches to curing, but most addressed the physical, mental, and spiritual relationship of humans to the larger world. The differences between Native American and Western medicine are important considerations for health care

providers working with First Nations people who often think differently from non-Natives about disease, power, spirits, prayers, and the meaning of medicines.

Native North American Indians believe that medicine emerged with the creation of Indian people, and creative forces gave Native people the first medicine. Indian medicine took many forms, including spiritual medicine that entered the world in the form of positive and negative powers, forces, thoughts, and actions. For example, among some Indians, such as Navajos and Apaches, lightning is a positive force that can bring healing, but it is also a negative, harmful force. One Navajo woman once explained that she had suffered from a large sore on her thigh, which affected her entire body and brought her to the brink of death. A “hand trembler” diagnosed the young woman, explaining that she had become ill because a few days before her own birth, her mother had witnessed the awesome power of lightning that struck and killed an entire herd of sheep. The ill effects of the lightning manifested themselves in the girl and nearly killed her. A medicine man among the Diné (Navajos) performed a Lightning Way ceremony on the girl, and she lived to tell this story. Her sore disappeared, and she became *hozho* or whole, healthy once more.

Indian people brought medicine power with them from other places or “worlds” where they had once lived. In the creation stories of many tribes, the people moved about from one place to another, bringing with them both positive and negative power that they placed in the present world where it is still extant. Sometimes, they used this medicine power to recreate mountains, valleys, rivers, and lakes. As a result, the medicine power of former worlds can be found at certain places in the Americas. Members of some tribes still make pilgrimages to sacred places to pray and sing, make offerings, and hold ceremonies. Sometimes tribal members or medicine people go to these places to gather plants or collect soil for their medicine bundles, taking home with them a portion of the sacred earth that once had been brought here from former lands. Indian people know about these

places, their histories, and their uses through ancient stories and songs. Sometimes, medicine people repeat these stories and songs as part of contemporary ceremonies that link the people of today to the ancient ones. In a sense, medicine ceremonies link people with the ancient times, rituals, and medicine, all of which is part of the healing ways of Indian people.

Thus, creation in American Indian medicine is critical to an understanding about the way Native Americans perceive of and use medicine. In addition to bringing soil from other lands and creating sacred space, many Native people believe that at the beginning of time, creative forces set aside certain places on earth and put healing power at the site. Many believe the power is still there in caves, rivers, mountains, stone formations, and other natural occurring places. In the past medicine men and women – or Indian doctors – harnessed this power and usually used it to help and heal their people, although some people could use the power to harm or kill. This concept of power usage is common among American Indians today, and it can be compared to medical doctors and other health officials using their medical knowledge to heal patients or harm them, depending on how they use their talents, skills, and knowledge. The “laws” governing the use of medicine power among American Indian peoples vary considerably from tribe to tribe and region to region. But in general, Indian doctors, like Western doctors, are expected to use their power for the benefit of others, not to enhance themselves and their place in society.

No discussion of Indian medicine can discuss adequately the many aspects and ramifications of Indian medicine, because they vary considerably among tribes. However, a few shared concepts of Indian medicine exist in North America. First, people living within Native American communities – past and present – believe in unseen forces, powers, or strengths. The people believe that medicine power exists everywhere and within everything, animate, and inanimate. Thus, given the ability to access power, Indian doctors and others may draw medicine strength from rock formations, rivers, valleys, mountaintops, caves, trees, clouds, animals,

oceans, fire, and wind. Indian people believe in such power and doctors harness the power to cure disease and prevent illness. The general belief in unseen forces helped Native American people bridge the gap between Indian beliefs about disease causation and Western medicine when Native people first learned about microorganisms that caused disease. American Indians understood bacteria and viruses in terms of unseen enemies, like the ones they had learned about in oral traditions. During the 1940s and 1950s, Navajo nurse Annie Wauneka used traditional beliefs about invisible power to inform her people about the tuberculosis bacterium, a new unseen enemy that had entered their communities.

Second, Native Americans generally believe that all things in the universe are connected and influenced by all other things. Just as the moon influences the tides and the slant of the sun effects the changing seasons, so does the cosmos influence Indian medicine. Destruction of a river by a man-made dam can influence the health of Indian people, and the treatment of one person by another can also affect wellness within an entire community. Third, Indian people believe that their health and wellness depend on the continuance of prayers, songs, ceremonies, sacrifices, ritual acts, offerings, daily actions, and humor. Tribes often direct prayers for the benefit of the entire universe, not just their own people, because they are part of an enormous system. Every tribe has songs intended for the good of communities and individuals, and medicine people enjoy medicine songs given to them by unseen powers. Fourth, Indian doctors are respected within their own communities and among other Indian groups who know of the person's powers and use of medicine. In English, we refer to these men and women as priests, medicine people, Indian doctors, chiefs, shamans, and caciques. Fifth, all of these Indian doctors possess special medical knowledge and they can communicate with healing powers, summoning them for help during curing sessions and ceremonies. They often employ prayers, songs, stories, and material items such as feathers, tobacco, sage, sweet grass, pipes, and prayer sticks during their curing sessions. They have knowledge about these items

or instruments of health, and they know when and how to use them. Sixth, medicine people have a deep understanding of the “laws” governing their communities, and they often interact with patients in discussions to discover the root cause of physical and psychological afflictions. When shaman cannot engage in such discussions because of the patient’s condition or inability to communicate the problem, then the medicine people use their special ability to “see” deep within the person’s mind and body to find the cause of the health problem. Scholars and contemporary Indians often refer to these laws as rules, customs, and taboos. Seventh, most Indian people commonly believe that everything in heaven and earth has a soul or spirit, because everything is part of the creation and thus related to everything else. The Great Mystery, Great Spirit, Creative Force, or God made all things, and so all things are interrelated and have power, including medicinal power.

Most American Indian communities would agree that medicine is interdisciplinary and woven into their specific cultures in unique ways. The medicine ways of one tribe or group may not be the same as another group. For Indian cultures, medicine is integrated into many aspects of culture, including religion, psychology, economics, and government. Traditionally, Native people lived their medicine every day because they believed it to be alive. Some Native Americans still think this way. Harmony and balance became the objective of Indian medicine in most communities in order to prevent and cure disease. Indians tied Indian medicine closely with seen and unseen forces that existed inside humans and throughout the universe, so that medicine involved the relationship of people to plants, people, places, animals, celestial bodies, and other elements of the natural world. For Indian people “medicine” could bring order and structure to the cosmos and control the forces, powers, and strengths that could influence the health of individuals and communities. In other words, outward forces – beyond humans – influence sickness and death, but so did activities of the individual and community. For example, among the Ajumawe of northern California, the people

believe that only holy people or Indian doctors can ascend the heights of Akoyet or Mount Shasta, a sacred mountain that contains within its peak a basket holding all of the goodness of creation. If members of the tribe break this “law,” they place themselves, their families, unborn children, and communities in jeopardy of earthquakes, avalanches, fires, diseases, and death. Among the several tribes composing the Houdenosaunee, commonly called the Six Nations of the Iroquois, men desiring to cut a false facemask from a live tree must complete prescribed rituals before harming the tree. Otherwise, the health of the carver and others could be compromised. According to an Iglulik woman named Nanoraq from Baffin Bay, “The sickness is due to my own fault. I have not performed my duties well. My thoughts have been bad and my actions evil.” And Navajo people could become ill if they shook a tree imitating a bear or by stabbing a knife into a piece of meat. Both of these actions by Navajo people could bring on violent behavior and cause illness among their people. Pima shaman Juan Gregorio once explained that his people could become ill if they did not pray properly before killing an animal, did not handle eagle feathers correctly, or failed to be respectful to desert tortoises. Every American Indian community had “laws” given to them at the time of creation, and they had to obey these laws or suffer disease, natural calamities, or death. Bringing individuals and communities back into balance with the laws occupied some of the duties of medicine people.

Indian medicine helped control forces that could harm the people, and it invited the good strengths to provide the people with abundant harvests, favorable weather, game animals, long lives, and freedom from diseases. The medicine offered Indian people social order, healthy directions, and prevention from illness in an uncertain world. As a result, Native Americans elevated the place of medicine into the realm of the holy and sacred, and those who successfully practiced medicine earned a special place within every community. Different levels of Indian medicine developed with various names, depending on the group, tribe, and region. Some medicine people

danced, while others sang, created sacred art, diagnosed, offered herbal remedies, prayed, or helped conduct ceremonies. Indian people knew two larger forms of disease. Communal disease was caused by the transgressions of community members who did not obey the laws functioning within the tribes. Traveling disease included communicable diseases like measles, mumps, smallpox, chickenpox, influenza, and others, and was brought by newcomers. Indian doctors effectively controlled community disease, but they had a more difficult time addressing the new diseases that traveled from tribe to tribe, killing millions of Indian people after 1492.

Among the Indian tribes of North America, two larger categories or levels of Indian medicine existed and still exist today: common medicine and shamanistic medicine – both of which Indian doctors used to address community based diseases and traveling diseases. Within most Indian communities, family elders – particularly women – had a detailed grasp of herbal medicines. Among most Indian communities of the Eastern Woodlands, elders understood the medicinal qualities of sassafras root, which they used to make a tea and prevent and cure colds. The Eastern people along the Atlantic seaboard also used the fronds of the white cedar to make a tea that cured scurvy and relieved some of the painful symptoms of syphilis. Indian people across the West used creosote branches to create a tea to relieve sore throats, and they used the same remedy in larger doses to relieve constipation. Paiute-Shoshoni elder Dorothy Joseph once stated that as a child she never suffered from poison oak because each spring, her mother picked the new leaves of poison oak and had all her family consume a small number of the leaves, creating a temporary immunity. Indian families everywhere knew some of the uses of plants and how to prepare them properly. However, some of the elders knew botanical science far better than others, and they used their in-depth knowledge to help the people.

Very special individuals among all American Indian groups practiced another form of Indian medicine labeled “shamanistic” medicine. Shaman is a term derived from the Tungus people of

Siberia, and in the twentieth century, scholars have applied the term to Native Americans. All American Indian languages had words for different kinds of shamans, medicine people, or Indian doctors. Several different types of shamans exist today, just as they did in the past, although their numbers have been reduced over time. Shamans know herbal medicines as well as anyone within their communities, but they also know how to diagnose and cure their patients through spirit medicine. The people expect shamans to work for the good of the community and to help restore the balance within individuals, families, and communities. Most often, Native people pay for the services of a shaman, and sometimes a fee is negotiated before the healing takes place. In the past, families paid for the skills of shaman with trade items, food, furs, wampum belts, and other items. Today, this practice continues in some parts of North America, but more often, people pay Indian doctors in currency.

While most Indian people learned to appreciate and understand some aspects of medicine, Indian doctors had special knowledge of the Native medical field. Indian doctors became familiar with the unexplainable light and knowledge of unseen forces, and opened their minds to receive healing power. They usually gained such knowledge through prayers, songs, dreams, visions, and experiences that brought them into a new realm of understanding and power to heal the sick, control the weather, find lost objects, prophesize, interpret future events, and see into the minds and bodies of their people. Shaman received their power at sacred places away from human habitations, deep in the forests, within the depth of hot springs, in caves, and on mountains. They received power at these sites and converted the powers into energy to heal others. Each medicine person had his own power or powers. In the late nineteenth century, a spring and water bugs gave Wenatchi elder Texanap her power and song, which became so uncontrollable that as a young woman, Texanap could not walk. Her father, a powerful shaman, built five fires, set a post in the middle of the village, and sang. In a community ceremony, Texanap controlled her spirit power, used the pole to stand, and threw

her hair into each fire without it burning. In this way, she gained control of her medicine power, which she used to heal others.

The first shaman among the Iglulik came forward to help his people when they were starving because of the lack of game animals. According to oral tradition, he traveled to the bottom of the ocean to visit Arnaluk takanaluk, “the woman down there,” the controller of the animals. He spoke with her, pleaded his case, and asked for animals to visit his people again to save them from certain death. The mother of marine animals responded kindly to his request. The animals came to the people and gave of themselves so that the Iglulik could survive, and they did. This shaman used his power to bring the animals back to the people so they would not die. Indian doctors from other tribes also helped their people in other unique ways, including an Indian doctor among the Mojave of western Arizona and eastern California. He helped his people who were suffering from a tuberculosis epidemic in the late nineteenth century. He reported that even before his birth, he knew he was destined to be a shaman because he had traveled in dreams to the sacred mountain of Avekwame to meet the creator and power source, Kumastahmo. After tuberculosis arrived in the Mojave villages along the Colorado River, the Indian doctor dream-traveled to the mountain where he found Kumastahmo spitting up blood. The creator told the shaman to suck his chest, and so the Indian doctor did so, learning directly from the god how to become a “consumption doctor.”. This technique of sucking out poison, foreign objects, and negative power found within a patient’s body is a common technique among many shamans. The Mojave doctor reportedly could suck out the disease and destroy it in Mojave patients, and his story is a unique adaptation of a traditional medicine technique used on “traveling” or infectious disease.

Less well known are the smoke doctors who use tobacco smoke to find illnesses, and breath doctors who use their breath and labored breathing technique to open up air and blood blockages in the mind and body. Without surgery, the breath doctors enter the body, find blockages, and use

their breath to penetrate the body and remove the objects obstructing the flow of oxygen and blood. Some doctors also rely on dreams and trances that take them inside the body where they locate and destroy disease through thought energy. Such techniques of Indian doctoring may seem fanciful to people accustomed to or trained in Western medicine, and shortly after the arrival of non-Natives, some newcomers described Indian shamans as fakes, frauds, and “witchdoctors,” a representation that tied Indian medicine to Satan and the occult. For Indian people, however, many mysteries surrounded the methods used by their shaman who enjoyed sacred spiritual medical knowledge. However, most Native North Americans believed in the medical techniques of shamans and many still do today.

Wintu shaman Flora Jones of northern California died recently, but her work is well recorded by Indians and scholars alike. She earned a positive reputation as an Indian healer. She used many powerful spirits in her healing ceremonies, including star spirits, moon spirits, and mountain spirits. Other powers also came to her, but she had to order and structure them in order to travel to the site of the sickness and remove them. Like some other Indian doctors, Flora fell into a trance or altered state of consciousness, and spirits spoke through her to diagnose and establish a plan of curing. In severe cases, Flora conducted a Soul Dance, bringing greater power to and through her to help heal her patient. She had her own healing songs, procedures, and material items, which she used in her healing.

In their healing ceremonies, shamans often use a variety of material items to further their healing rituals, including feathers, plant pollens, pipes, tobacco, and other leaves, sand paintings, fans, prayer sticks, soils, crystals, and other items, depending on their power and instructions received from helping spirits. The power vested in these sacred objects also may speak to the shaman instructing the doctor to use particular herbal remedies or specific techniques, such as “roasting” the patient. In this form of treatment, doctors dug holes into the ground, built fires to heat the area, then covered the fire with soil and blankets so that the patients could be buried in the

warm pit with their heads above ground. The patient sat or lay down in the ground while the doctor sang and prayed, allowing the warmth of the earth to help the person with blood flow and reproductive problems. In addition to the warmth of the earth, the patient received the spiritual security of the earth wrapped around his body, and some patients felt a rebirth as they stepped out of the pit.

Some shamans worked their medicine in secular sites, while other took their patients to sacred places. In the early twentieth century, Serrano Martha Manuel stepped on spirit power set out by Cahuilla shaman Ignacio Ormego who had warned Martha and her cousin, Vincent Morongo, not to play in the area. Martha became violently ill and could not speak or walk; she ran a high temperature. Her family first took her to Dr. John Evans who placed Martha in a hospital in San Bernardino, California, but after a few days of not being able to diagnose her sickness, Martha's family took her by wagon to Palm Springs, California, where *pul amnahwet* or the highest-ranking Cahuilla shaman, Pedro Chino, doctored Martha. He lay the girl in the sun to help expose her illness. Chino used the power of the hot springs to diagnose Martha's problem, which took him considerable time. He found her sickness in her leg, which he sucked, drawing out a white worm that he showed to his family before destroying it. Martha's fever declined and she gained her ability to walk. She recovered fully, telling Chino and her family of Ormego's warning, and she also said that during her ordeal, she saw several tiny men dressed in black suits, all the same person, running about her leg. The family believes that Martha had seen her relative Pakuma or Santos Manuel, another powerful shaman who had died years before.

Among many Indian people of Southern California, Indian doctoring took place in the Big House or Ceremonial House, and this is still true in central and northern California where tribes have active Dance or Ceremonial Houses. Indian people throughout North America build special lodges for healing ceremonies, including the Medicine Lodge for the Sun or Thirst Dances, tipis for the peyote church, and pole and mat

longhouses for the Nez Perce, Yakama, Umatilla, and other tribes of the inland Northwest. Navajos use female hogans for their healing ceremonies, and the people of the Northwest Coast use cedar plank houses for healing ceremonies. Other tribes construct wickiups, log longhouses, kivas, earthen lodges, wigwams, brush shelters, and other dwellings, creating a man-made environment or sacred spaces for their medicine ceremonies and rituals. Nearly all tribes in North America also used sweat lodges to purify minds and bodies, a place to invite the spirits to visit, inform, and heal. Shamans used the lodges and special places as part of their medicine, drawing on various means to follow, find, and eliminate the sources of illness.

Generally, Indian doctors learned from others and pragmatically employed new plants, techniques, and ideas in dealing with the sick. When they found that new ways improved the health of their people, they often adapted and adopted the new medicine. After the Columbian encounter of 1492, Indian people throughout the Americas suffered high death rates because of the lack of natural immunities to contagious or "traveling" disease brought to the Native universe. Since Europeans could barely control diseases, American Indian shamans could not benefit greatly from the medical knowledge of the newcomers. However, contact with the newcomers helped medicine men and women understand more about infectious diseases and to fear the spread of epidemics. Indians in some parts of North America became more familiar with Western medicine after the United States and Canada established forts in Indian country where medical doctors first interacted with some Indian patients. Varying numbers of Indian people sought relief of their ailments from medical doctors. Some doctors, like Washington Matthews among the Navajo and James Walker among the Lakota, learned well from Indian people and their Indian doctors. Others denigrated Indian doctors, referring to them as quacks and charlatans. Still, by the late nineteenth century, Indian and non-Indian medicine began to converge, most often with Indians listening and learning about infectious disease causation and spread.

In 1879, the United States created its first off-reservation boarding school at Carlisle, Pennsylvania, where children became ill and died of infectious diseases, especially measles and tuberculosis (The horror of the Carlisle and other Indian schools is not dealt with in this article, but we urge the reader to read more. See Jessica Enoch, "Resisting the Script of Indian Education: Zitkala Ša and the Carlisle Indian School." *College English* 65.2 (2002): 117–142. See also Clifford E. Trafzer, Jean Keller, and Lorene Sisquoc, eds. *Boarding School Blues*. Lincoln: University of Nebraska Press, forthcoming 2006). As part of the curriculum at Carlisle and other Indian schools, students learned the cause and prevention of tuberculosis, particularly about the importance of isolating people known to have the disease. Through lectures, slide presentations, and pamphlets, students learned about diseases, and they took their knowledge home to share with their people. During the late nineteenth century and early twentieth century, Indians living on the reservations of Canada and the United States suffered greatly from tuberculosis, measles, influenza, smallpox, chickenpox, mumps, trachoma, accidental deaths, and a host of gastrointestinal diseases. These diseases also ravaged the Native populations of Mexico and the other countries of Latin America. In the United States, the Office of Indian affairs had a medical division that relied on a few medical doctors often contracted to conduct part time work with Indians. In Southern California during the 1880s and 1890s, for example, the Indian office hired one medical doctor to serve thousands of Indians from the Chumash villages surrounding the Santa Barbara region east to the Colorado River and south to the Mexican border. Neither the Congress nor the Indian Office funded Indian health, and in Canada, the federal government often contracted missionary doctors to serve Native populations. Thousands of Indians died as a result, in spite of the heroic efforts of traditional medicine men and women as well as some medical doctors.

National reforms focusing on Indians during the 1920s and 1930s led the United States and Canada to direct more money to Indian health

and the high mortality – including high infant mortality – caused by tuberculosis. Medical personnel also tackled trachoma, often resorting to radical grattage (scraping the eyes with a stuff brush) on Indian patients. Both countries hired more doctors, established more hospitals, and built sanatoria for Indian patients. Both countries also hired public health nurses who became the front line forces of Western medicine, treating Indian people on reservations, reserves, and remote regions of the Arctic. From the 1920s to the 1970s, field nurses traveled thousands of miles each year in automobiles, hydroplanes, dog sleds, wagons, horseback, and on foot to visit reservation populations. Like the teachers in boarding schools, they taught people to identify signs of tuberculosis. Nurses isolated Indian patients, drove Indians to hospitals, conducted clinics, informed mothers at "well baby clinics," directed Indians to X-ray screenings, and visited families on nearly all the reservations. Their efforts may have influenced the decline of Indian deaths caused by tuberculosis in the late 1930s and early 1940s, before the Indian offices began to use antibiotics in its treatment of tuberculosis.

The Office of Indian Affairs did not provide Indians in the United States with high quality medical care as stipulated by treaties and the laws of Congress. In 1954, the Public Health Service took over the duties of providing Indian medical care through the Indian Health Service. The change proved significant to Indians in the United States, as the Public Health Service provided far better care than the Indian Bureau. Still, Indian health lagged behind that provided to most Americans, Canadians, and Mexicans. In both rural and urban areas, Indian people continue to suffer high infant mortality rates and deaths caused by infectious diseases. However, after World War II, a new trend emerged within Indian communities as more Indians began dying of man-made degenerative diseases such as heart disease, cancer, kidney problems, and complications due to type 2 diabetes, alcoholism, and suicides. Although health services for Indians improved during the late twentieth century, few Indians received first-rate medical care, and most

still do not. However, the emergence of high stakes gaming among some tribes has made it possible for some Native Americans to buy their own health insurance and for tribes to partner with highly skilled physicians and the top medical institutions to offer tribal members better medical care. In 2003, Loma Linda University Medical Center, one of the nation's leading medical research institutions, launch a new American Indian health and wellness center and is currently working closely with the Chinook of Shoalwater Bay in Washington state, Shoshoni-Paiute of Fallon, Nevada, and Chemehuevis of the Twenty-Nine Palms Band. Although the Indian Health Service continues to play the significant role in Indian health today, the new partnerships of Indian nations with medical institutions and physicians shows great promise to improve the health of Native Americans throughout North America.

Today medicine among most Native Americans is a combination of traditional Indian medicine and Western medicine. While most Indians consult Western doctors and nurses and use hospitals, they continue to view disease, health, and medicine much like their ancestors. Shamans still perform healing ceremonies in many parts of Indian country and Indians still use common medicine taught to them by elders. Some Indians believe that the combination of Indian and Western medicine will lead to "new medicine" that relies on medical sciences and spirit medicine, particularly the power of prayer and material items taken from the earth.

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Medicine of the Australian Aboriginal People

Dayalan Devanesen and Patrick Maher

Australia is the only continent to have been occupied exclusively by nomadic hunters and gatherers until recent times. Carbon dating of skeletal remains proves that Australian Aboriginal history started some 40,000 years ago, long before Captain Cook landed on the eastern coast in 1770. This history is not completely lost. It is retained in the minds and memories of successive generations of Aboriginal people, passed on through a rich oral tradition of song, story, poetry and legend. According to Aboriginal belief all life forms, human, animal, plant and mineral are part of one vast unchanging network of relationships which can be traced to the great spirit ancestors of the Dreamtime.

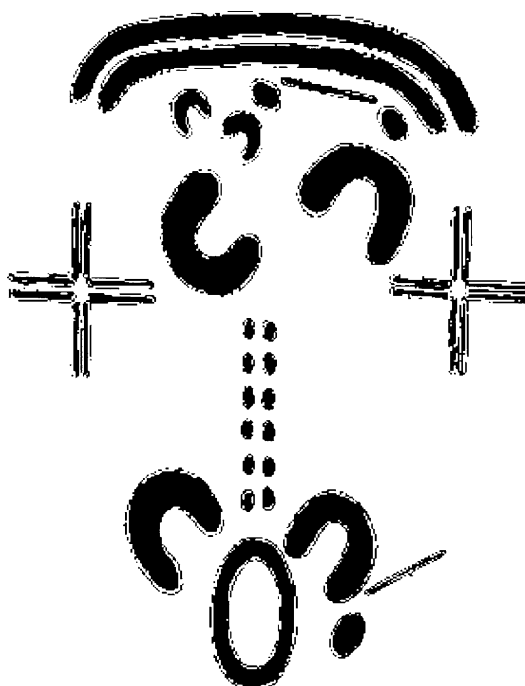
The Dreamtime continues as the "Dreaming" or *Jukurrpa* in the spiritual lives of Aboriginal people today. The events of the Dreamtime are enacted in ceremonies and dances and chanted

incessantly to the accompaniment of didgeridoo or clapsticks (Isaacs, 1980). The Dreaming is the source of the rich artistry, creativity and ingenuity of the Aboriginal people.

In Australia, Western health services have been superimposed on traditional Aboriginal systems of health care. However, these traditional systems have survived despite the dramatic influence of cultural contact, and Aboriginal medicine is still widely practised in the Northern Territory today (Tynan, 1979; Nathan & Japanangka, 1983; Reid, 1983; Soong, 1983; Devanesen, 1985; Maher, 1999). The Northern Territory occupies one-sixth of the Australian land mass. It has a population of just under 200,000 of which 28 % are Aboriginal. The vast majority of the Aborigines live in small remote communities scattered across the Territory.

Traditional Aboriginal medicine is a complex system closely linked to the culture and beliefs of the people, knowledge of their land and its flora and fauna. Its survival is explained by its “embeddedness” in the social fabric of Aboriginal culture. Reid (1983) has shown that, though Aborigines living at Yirrkala in the Northern Territory choose Western biomedicine to treat the majority of their sicknesses, they continue to explain the causes of these sicknesses through their traditional beliefs. This may be because the health beliefs continue to play a role in providing meaning to events and thereby helping people to cope with serious illness and death (Reid, 1983).

The Aboriginal approach to health care is a holistic one. It recognises the social, physical and spiritual dimensions of health and life. Their concept of health in many ways is close to the World Health Organisation definition of health: “a state of complete physical, mental and social well being and not merely the absence of disease or infirmity”. The Warlpiri Aboriginal tribe have described health as “life” or *Wankaru*. Their definition takes in a whole of life cycle. The front of their health centre at the Aboriginal settlement of Yuendumu is adorned with the painting in Fig. 1. It shows family life, food, shelter, warmth, water and exercise, all of which are essential for health (Devanesen, 1983).



Medicine of the Australian Aboriginal People,
Fig. 1 Health symbol for Yuendumu: Napangardi women's *Jukurrpa* or Dreamtime

M

Traditional Indigenous Health Systems

The traditional health beliefs of Aboriginal people are interconnected with many aspects of Aboriginal life such as the land, kinship obligations and religion (Tynan, 1979). The sociomedical system of health beliefs held by Aboriginal people places emphasises on social and spiritual dysfunction causing illness. This approach emphasises that “individual well-being is always contingent upon the effective discharge of obligations to society and the land itself” (Morgan, Slade, & Morgan, 1997, p. 598). A person's social responsibilities and obligations may take precedence over their own health because of the priority given to social relationships in this model.

Sorcery and supernatural intervention are part of the perceived reality of Aboriginal life (Waldock, 1984), and in Aboriginal society explanations in terms of sorcery are often used. The deaths of infants or the very old or

chronically ill are considered to be in the normal course of events, while deaths outside these groups may have a supernatural influence, especially if they are regarded as premature, unexpected and sudden (Reid & Mununggurr, 1977).

There are many beliefs associated with supernatural interventions and sorcery:

- Sorcery exists in many forms. Its effect is to manipulate and alter behaviour and cause morbidity and mortality.
- Sorcerers can be specialists or non-specialists.
- Distant groups have the most virulent sorcery and are the most feared.
- Many diseases come from dangerous, secret sacred sites. They are manifestations of the forces or power emanating from those sites.
- Unskilled or uninitiated people may release forces from a dangerous site by disturbing the site.
- Sorcery is carried out in secrecy.
- Retribution sorcery is directed serially at members of a family or lineage. Therefore, the serious illness or death of one member is followed by the illness and death of others.
- A traditional healer can apply counter measures to identify the cause and source of illness and death, but the healer should not interfere if it is the result of legitimate punishment (Biernoff, 1982).

The ill effects of sorcery will not necessarily be felt only by the “offender”, but may also be felt by his/her family and descendants. While the thought of sorcery is prominent in Aboriginal life, people do not live in constant fear of sorcery. Sorcery is usually an explanation that is applied retrospectively to explain deaths, serious illness or injury (Reid & Williams, 1984).

The concept of supernatural intervention and sorcery plays an important function as “it explains why one person and not another died or became ill at a certain time and not at another” (Reid & Mununggurr, 1977, p. 39). It provides the explanations of “why me” and “why now” which cannot be answered in terms of Western medical theory. It provides the answer to the ultimate cause of the event.

Many have acknowledged the cultural diversity, particularly in regard to health beliefs, between Aboriginal groups and communities (Reid, 1983; Elkin, 1994). We have therefore chosen to describe the features of the traditional indigenous medical system by particular reference to one tribe, the Warlpiri.

Traditional Health System of the Warlpiri Aborigines

The Warlpiri Aborigines comprise one of the largest tribes in the Northern Territory. They are scattered over many Aboriginal communities in the northwest of Central Australia. The main components of the Warlpiri health system are the *ngangkayikirili* or traditional healers, commonly referred to as *ngangkari* or *ngangkayi* (healing power), *Yawulyu* ceremonies; healing songs and herbal medicine. In addition there are laws governing behaviour that are aimed at preventing sickness.

Ngangkari

Traditional healers have a variety of roles, including providing strong spiritual and social support (Reid, 1983; Soong, 1983); determining the ultimate cause of a serious illness or injury (Nathan & Japanangka, 1983; Reid, 1983; Peile, 1997; Tynan, 1979); determining cause of deaths at an “inquest” (Nathan & Japanangka, 1983; Reid, 1983; Peile, 1997; Tynan, 1979); and employing counter sorcery to remove the evil influences causing illness (Reid, 1983; Tynan, 1979). They are believed to have many powers to undertake these roles and utilise numerous different healing techniques (see Table 1).

Professor Elkin (1994) referred to the traditional healers as Aboriginal men of high degree. The healers are kindred to Amerindian “men of power” and shamans. These healers are specially chosen and trained to remove the influence of sorcery and evil spirits and to restore the well being of the soul or spirit. Their role is extremely important because most serious illness is thought to be brought about by loss of a vital substance from the body (soul loss),

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Table 1 The powers and healing techniques of Aboriginal traditional healers

Powers/capabilities	Healing techniques
Have assistance from the spirit world to assist healing	Provide positive emotional support
Telepathy	Physical contact and touching
Divination	Massage
X-ray vision	Extraction of objects causing illness from a patient's body via sucking, rubbing or massage
Clairvoyance	
Telesthesia	Smoking used ritually (after initiation or death) or therapeutically for mothers and babies after childbirth
Control the weather	
Mind reading	Use of healing songs and chanting
Walk on fire	Counselling
Inserting healing objects into patient's body	Using objects with healing powers
Magically heal wounds including internal wounds	Dreaming
Travel at fast pace	Cleansing the patients' internal organ(s) while they asleep
Protect people against attack from spirits via counter sorcery	
Commune with spiritual beings including the dead	
Manipulate a patient's spirit	
Spirit travel	
Able to project their spirit into the body of patient	
Able to replace patient's blood with their own	
Able to communicate with the spirit world	

Sources: Nathan and Japanangka (1983), Reid (1983), Elkin (1994), Peile (1997), Cawte (1974), Taylor (1977), Tonkinson (1982), Toussaint (1989), Berndt (1964), Soong (1983), Brady (1995), Hunter (1993), and Eastwell (1973). From Maher (1999). Used with the permission of Blackwell Science Asia

introduction of a foreign and harmful substance into the body (spirit intrusion or possession) and violation of taboos or sorcery (singing). The traditional healers usually gain the power to

heal through inheritance or through special spiritual experiences. They possess a spirit called *mapanpa* which is associated with healing power. This is different from the spirit that every Warlpiri person has “like a shadow” (Tynan, 1979).

The traditional healer carries out a healing ritual which often includes sucking the sick person. After sucking, the healer usually spits out a wooden object called *yarda* which is covered in blood. The *yarda* represents the evil influence. Sometimes, the traditional healer massages the patient, manipulates the body or sings during the ritual. The traditional healer may diagnose the state of the spirit, e.g. *kurrunpa yulangu* (the spirit is sad). The traditional healers do not use herbal medicine in their practice.

Yawulyu Ceremonies and Healing Songs
Warlpiri women frequently perform *Yawulyu* ceremonies. These ceremonies improve the health of sick people but cannot remove the influence of sorcery. The ceremony consists of singing songs and painting designs on the sick person. These designs are derived from the power of the Dreamtime (see Fig. 2). Each ritual is carried out by the *kirda* (owners) or *kurdungurlu* (managers) of a particular “Dreaming”. Sometimes the songs and designs appear to the people in their dreams and are thought to be revealed by spirit creatures called *yinawuru* (Munn, 1973). During the ceremony the sick person may be massaged with fat and red ochre. These materials derive special potency from the songs. In some cases senior men and women sing songs without the ceremony to strengthen sick people. Songs are sometimes sung to ensure safe childbirth. The *Yawulyu* ceremonies and songs assist in providing strong family support for the sick person.

Herbal Medicine
Herbal medicine and knowledge of plants is not the domain of any particular group in the Warlpiri system. The whole family shares its knowledge and use. The Warlpiri have extensive knowledge of plants and have published their own book which lists several plants and their medicinal uses (Henshall et al., 1980).

Medicine of the Australian Aboriginal People, Fig. 2 *Yawulyu* designs on women – yam dreaming



Medicinal plants are mainly used symptomatically for coughs and colds, pains and aches. Some are used as dressings for wounds and sores. The main conditions that herbal remedies were used for reflect the types of sickness that Aborigines had before contact with Western society. They were joint and muscle pain, toothache and sore mouth, gastro-intestinal disorders, symptoms of colds and flu, e.g. fever, headache and ill-defined pain, congestion, cough, general malaise, sore throat, sores, boils, cuts, scabies, bites, stings, burns and major wounds, warts, allergy rash and itchy skin disorders, ringworm, other tinea form skin infections, eye disorders and fever.

Aboriginal expertise regarding plants has been acknowledged for many years. Webb (1969) has shown that many Aboriginal bush medicines contain biologically active compounds. Bitter Bark (*Alstonia constricta*), used to prepare a tonic, contains reserpine, a tranquilliser and antihypertensive. Plants used on sores and wounds contain proteolytic enzymes that help healing. *Spilanthes*, a native daisy used to treat toothache, has been shown to contain spilanthol – a local anaesthetic. Over half the world's supply of the drugs hyoscyne and scopolamine come from an Australian native tree *Duboisia*, which was used by Aborigines as an emu and fish poison (Pearn, 1981).

Herbal medicine was the first component of the Warlpiri health system to be eroded by the introduction of Western medicine. However, the movement of the Warlpiri people back to their traditional land has led to a renewal of interest in the use of herbal medicine.

A program by the Northern Territory Department of Health that commenced in 1973 to collect information regarding the Aboriginal use of plants has helped non-Aboriginal staff to appreciate the great knowledge and complexity of the Aboriginal health system (Devanesen & Henshall, 1982).

In 1995 staff at a remote health centre in the Northern Territory carried out a study to compare the effectiveness of wound healing by the use of a traditional remedy, *Bauhinia* root (*Lysiphyllum cunninghamii*) and a Western preparation in the treatment of boils, sores and scabies. The study concluded that the herbal medicine was as effective as the Western preparation. In addition the Aboriginal people felt more comfortable using the traditional remedies and felt a sense of pride in their own traditional knowledge and culture (McLean, Dow, Bathern, et al., 1996).

The Warlpiri Health System

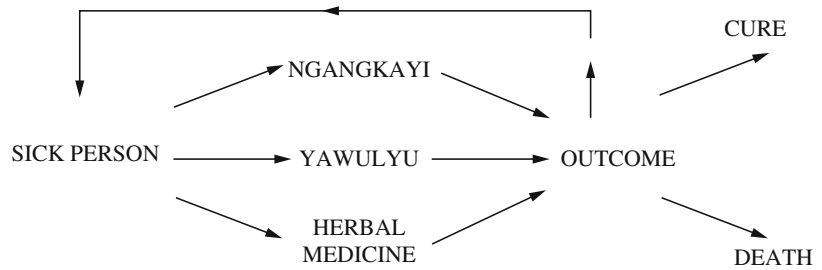
The Warlpiri health system can be represented as in Fig. 3.

When someone falls sick, one of the three main components of the health system is tried. If it does not work, another component is used or the same component tried again until there is a definite outcome.

Preventing Sickness

Reid (1982) gives a good description of prevention at the level of personal relationship and religious injunctions:

Medicine of the Australian Aboriginal People, Fig. 3 The Warlpiri health system (Adapted from Tynan, 1979)



Preventive measures can include avoiding foods prohibited during ceremonies or life crises, obeying ritual proscriptions, taking care not to abuse ones' land or trespass on territories of others, avoiding prohibited sacred sites or approaching them with ritual protection, observing debts and obligations to others, containing anger, violence or jealousy, exercising caution in interactions with strangers and taking steps to avoid sorcery or often conflict with others.

The methods of preventing illness link in directly with what are regarded as the ultimate causes of illness under the Aboriginal model of causation of illness. In summary, good health is associated with strict adherence to approved patterns of behaviour and avoidance of dangerous places, people and objects (Biernoff, 1982).

The Place of Western Medicine

Western medicine has been incorporated into this system at the same level as herbal medicine. By doing this, the Warlpiri are able to retain their belief in spirit causation of illness while using Western medicine for the relief of symptoms.

Changes are taking place in the illness-related beliefs of Aborigines in the Northern Territory. Reid's study at Yirrkala shows that this change is characterised by the "gradual addition of causes and elaboration of the existing causes within the aetiological domain". Reid lists three categories of causes (1) social and spiritual causes, e.g. sorcery or breaking the law; (2) causes other than social or spiritual, e.g. emotional state, old age, assault; and (3) emergent causes, e.g. alcohol, sin, smoking (Reid, 1983).

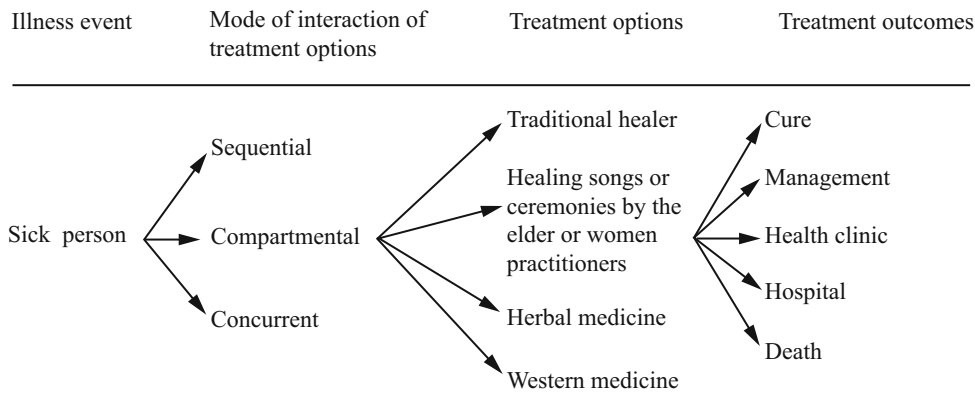
Aboriginal people use the strategy of domain separation to divide illness into Aboriginal and Western causes. This involves thinking in terms of separated cultural or social domains and deciding when to apply the rules of each domain (Harris, 1988). This strategy occurs not only in the area of health beliefs, but also in other areas to respond to cultural uncertainty, to reduce social complexity and stress and to deal with social dilemma (1988).

There are a variety of behavioural patterns of seeking medical assistance that traditional people use during illness:

- Sequential (use one practitioner then another kind, e.g. Western then traditional or vice versa)
- Compartmental (using traditional medicine for conditions which have established traditional explanations)
- Concurrent (concurrent use of traditional and Western forms of health care; Armstrong & Fitzgerald, 1996)

Aboriginal people use all these patterns (Reid, 1983; Peile, 1997; Tynan, 1979; Elliot, 1984; Tonkinson, 1982; Gray, 1979; Berndt, 1964). This model is best expressed in Fig. 4.

Generally combinations of traditional and Western medicines are used (Reid, 1983; Tynan, 1979). Western medicine may relieve symptoms and provide explanations to the mechanism of how something occurred while traditional explanations provide the reason why it occurred and are able to address the ultimate cause. In cases of supernatural intervention Western medicine is used to treat the symptoms and to hasten the cure, provided it does not conflict with



Medicine of the Australian Aboriginal People, Fig. 4 Model of Aboriginal behavioural patterns of seeking medical assistance (From Maher, 1999. Used with the permission of Blackwell Science Asia)

traditional beliefs, but it is not able to remove the cause of the illness (Tynan, 1979; Waldock, 1984). In contrast only Western medicine can affect emergent Western illnesses (Waldock, 1984; Scrimgeour, Rowse, & Lucas, 1997).

In spite of this attempt to incorporate Western medicine into the traditional system, there are areas of conflict. Western medicine is based upon particular Western explanatory models. Variation in the underlying beliefs, assumptions and general medical information has been implicated as the basis for the conscious rejection of Western health care by some Aborigines (Hamilton, 1974). It is well known that differences in underlying knowledge systems impede even willing compliance between culturally divergent groups. The lack of a common conceptual framework within which patient and practitioner can interact may result in decreased compliance and satisfaction (Maher, 1999).

Development of Traditional Practice in Health Services to Aboriginal People

There has been government support with recognition for traditional Aboriginal medicine since the 1970s. A report on Aboriginal health by the Australian Parliament recommended that:

Aboriginal cultural beliefs and practices which affect their health and their use of health services such as their fear of hospitalisation, their

attitudes to pain and surgery, the role of traditional healers and the differing needs and roles of Aboriginal men and women, be fully taken into account in the design and implementation of health care programs (Commonwealth of Australia, 1979).

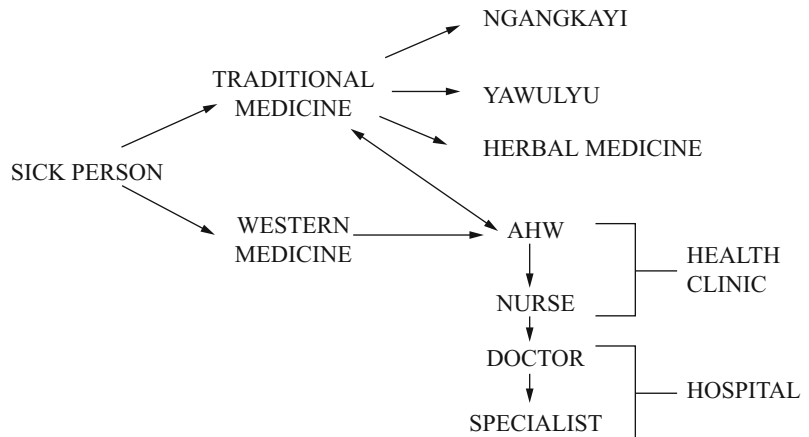
Bicultural Medicine

Two-way medicine is the term that has been coined by Aboriginal health workers (AHWs) to describe a bicultural approach to health care. It is based on the principle that “if you can use what is best in modern medicine together with what is best in traditional healing, the combination may be better than either one alone” (Werner, 1977). The Northern Territory Department of Health’s first policy on Aboriginal health stated that “traditional medicine is a complementary and vital part of Aboriginal health care, and its value is recognised and supported” (Northern Territory Department of Health, 1982). The Northern Territory Department of Health over the years has established several programs that recognise the traditional health system, Aboriginal values and beliefs.

Support for Traditional Healers/Ngangkari

Traditional healers were employed by the Northern Territory Department of Health at various rural health centres in Central Australia in the early 1970s. While this practice has ceased, rural health centres continue to recognise and

Medicine of the Australian Aboriginal People, Fig. 5 Aboriginal medicine and Western medicine



cooperate with traditional healers in the management of sick people, and some remote health centres run by Aboriginal Community Controlled Organisations have recommenced the employment of traditional healers. The healers often act also as consultants for determining culturally appropriate service delivery.

A meeting of Ngangkari was held near Uluru, Central Australia, in April 2000. Over 40 Ngangkari gathered together to discuss the production of an information manual about the work, history and traditions of Ngangkari (Mullins. Personal communication, 2000).

A recent proposal to establish an Aboriginal Healing Centre close to the Alice Springs Hospital is being examined. The centre would develop a place to promote spiritual health supported by a network of traditional Aboriginal healers.

Aboriginal Health Workers

There are over 300 AHWs in the Northern Territory today. The AHW training program is recognised as one of the main strategies for improving Aboriginal health. AHWs are selected by their own communities and trained in various Western medical skills. They have proved highly successful in treating common health problems in Aboriginal communities, such as diarrhoea, chest infections, trachoma, and ear and skin infections. They also act as mediators between Western and traditional medical systems.

Aboriginal health workers bridge the “cultural chasm” separating the traditional and Western

worldviews. They relate Western beliefs to an Aboriginal conceptual framework, making it possible for Aboriginal patients to understand what is being said and to assess the validity of the statements. They make it possible for the health centre teams to communicate with Aborigines in language and concepts that they understand. In most Aboriginal communities, the people’s point of entry into the Western health system is through the AHW who may refer them to a nurse or doctor or back to the traditional system as shown in Fig. 5.

The Bush Food Program

Aboriginal people often view food as their medicine. Many foods are known to strengthen the body against sickness or promote healing. Some prized foods such as the witchety grub (*Xyleutes*) are crushed and used for treatment of burns and wounds. The grubs are nutritious as well, with protein (15.1 %), fat (19.2 %), 100 mg thiamine and 5 mg vitamin C per 100 g (see Fig. 6).

In 1981, the Northern Territory Department of Health launched the Bush Food Program which sought to establish a durable record of traditional Aboriginal food practices and beliefs and develop a more relevant and acceptable style of nutrition education.

A publication on the nutritional composition of 42 Bush Foods collected through this Program has some interesting results (Brand et al., 1983). The green plum (*Terminalia ferdinandiana*) contains 3,150 mg/100 g of Vitamin C, making it the

**Medicine of the
Australian Aboriginal
People, Fig. 6** Witchety
grub (*Xyleutes*)



**Medicine of the
Australian Aboriginal
People, Fig. 7** Bush
banana (*Leichardtia
australis*)



richest source of Vitamin C in the world. The bush banana (*Leichardtia australis* and *L. leptophylla*; see Fig. 7) and the water lily root (*Nymphae macrospora*) contain very high proportions of protein, and the list goes on.

The Bush Foods Program has led to the stimulation of reciprocal learning processes between two cultures and the self-examination of attitudes and values.

The current health status of Aboriginal people is characterised by unacceptable levels of morbidity and mortality. Aboriginal life expectancy is 20 years less than other Australians; Western medicine has not solved many of the Aboriginal health problems.

Traditional medicine is part of Aboriginal culture. Its recognition can bolster the self-confidence of Aboriginal people and improve the delivery of health services to Aboriginal

communities. Two-way medicine needs to be supported and developed with ongoing research to evaluate the therapeutic value of traditional medicine. The increasing worldwide popularity and use of complementary and alternative medicine may assist in the development and sustainability of Aboriginal traditional medicine and healing in Australia.

Acknowledgements All references to the Warlpiri tribe are with the kind permission and consent of the Yuendumu Council.

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Medicine of Tibet

Robert William Prasaad Steiner and
Yangbum Gyal

How can we understand the practical applications of healthcare systems from different cultures? This chapter about the theory and practice of traditional Tibetan medicine (TTM) attempts to point to possible answers to that question.

Traditional Tibetan medicine approaches health from the perspectives of balance, synergy and integration of multi-dimensional aggregates that span body and mind, simultaneously and without distinction. The emphasis of TTM involves dealing directly with the nature of imbalances among the aggregates that result in the appearance of signs and symptoms of disease and illness. The approach includes dealing with issues of mind – including conflicting emotions and mental afflictions – as well as dealing with the external influences that adversely affect a person's specific constitution and condition. TTM avoids the schism of mind and body that is so prevalent in western medical care.

His Holiness Dalai Lama XIV offered a statement about the utility of TTM at the First International Congress of Tibetan Medicine in 1998 (Dalai Lama, 1999):

As an integrated system of health care, Tibetan medicine can offer allopathic medicine a different perspective on health. However, like other scientific systems, it must be understood in its own terms, as well as in the context of objective investigation. In practice it can also offer Western people another approach to achieving happiness through health and balance.

Dalai Lama states a position of cultural relativism – that opportunities are present to study culturally different traditions of healthcare that may benefit people in western cultures. This is possible if the native culture is understood and examined from its own premises, rather than maintaining an ethnocentric position. His Holiness also points to a priority of TTM – a primary goal of healthcare is to attain happiness. This goal is often not considered in western biomedical traditions of healthcare, where there is more emphasis on materialistic aspects of technological interventions to overcome disease.

The notion of disease can be viewed as a culturally bound concept – one that depends upon assumptions, motivations, and selective attention of the people in that tradition. Disease is a reified concept, based upon meaning and interpretations assigned to patterns of the subjective symptoms and experiences of illness and concurrent objective symptoms (Kleinman, 1981). One intention of this chapter is to examine the premises underlying the theory and practice of TTM, so that the engrained approaches of western biomedicine may become more accessible, understandable, and meaningful by comparison and contrast (Leslie & Young, 1992).

Anatomy and Physiology in Tibetan Medicine: Aggregates and Elements

Maintaining balance among the three aspects of bodily constituents (Tibetan: *Nyipa sum*) is the goal of Tibetan medicine (Dhonden, 1977, 1986, 2000). The three aggregates are complexes of

mind-body that include physical, personality, and spiritual aspects. The three aggregates are *rlüŋg*, *mKhris-pa*, and *Bad-kan*, often collectively translated as “humors” and translated as “wind,” “bile,” and “phlegm”. However, these terms do not accurately portray the unified and multi-dimensional nature of these aspects. Alternatively, the terms “*rlüŋg*, *mKhris-pa*, and *Bad-kan*” can be translated as “subtle energy, transforming energy, and supportive energy.” These alternative terms convey the qualities of functional interactions that are prominent within Tibetan medicine. The term “aggregates” will be used in the remainder of this chapter, in place of the more common translation as “humor.”

The aggregates of TTM are composed of elements. The elements that comprise the ordinary physical body in TTM are translated as space, air, fire, water, and earth (*nam mkha*, *rlüŋg*, *me*, *chu*, and *sa*). The five sensory consciousnesses (hearing, touch, sight, taste, and smell) each correspond to the same respective elements. Thus, each element is a metaphor, or “sphere of influence” (Porkert, 1974), representing the many dimensions of life experiences. For example, space represents formless potentiality (e.g., consciousness) and air is associated with subtle movements (e.g., conduction of impulses in the nervous system, circulation, respiration, or intuition). Fire represents active transformation (e.g., digestion of food into nutrients or intellectual discourse), while water represents cohesion and communication (e.g., empathy, lubrication, or feelings), and earth is manifest form (e.g., anatomic structure or physical sensations). Each element is associated with a sense organ and sensory perception, emotions, sacred images, and more (Tables 1, 2, and 3).

The elements combine to form the aggregates that represent a person’s constitution (Tibetan: *Rang bZhin*). Space and air together comprise *rlüŋg* (Sanskrit: *vata*). *RLüŋg* is traditionally considered the most important aggregate in Tibetan medicine, since movement is so basic to all vital functions. Consequently, *rlüŋg* conditions are highly prevalent. Fire is the primary element in *mKhris-pa* (Sanskrit: *pitta*) constitution, while water and earth combine to form *Bad-kan* (Sanskrit: *kapha*) (Lad, 1984).

Medicine of Tibet, Table 1 Five elements and their cellular, tissue, and physiological functions

Elements	Physiological functions
Earth	Muscle tissues, bones, nose, and sense of smell
Water	Blood, body fluids, tongue, and sense of taste
Fire	Body temperature, complexion, eyes, and sense of sight
Air	Respiration, skin, and sense of touch
Space	Body cavities, ears, and sense of hearing

Medicine of Tibet, Table 2 Relationship between the five elements, aggregates, and three poisons

Element	Three aggregates	Three poisons (mental and spiritual)
Earth and water	Phlegm (Tibetan: <i>Bad-kan</i>)	Delusion, ignorance
Fire	Bile (Tibetan: <i>mKhris-pa</i>)	Aversion, hatred
Air and space	Wind (Tibetan: <i>rlüŋg</i>)	Attachment, passion

Usually one aggregate predominates as a person’s constitution. The aggregates can also combine so that primary and secondary aspects are present. For example, primary *rlüŋg* and secondary *mKhris-pa* constitutions (and vice versa) allow for refined behavioral and medicinal prescriptions. When all aggregates are afflicted simultaneously, a condition known as *mug-po* is present. The Tibetan elements differ from the five-phase theory in the traditional Chinese medical model (Porkert, 1974).

An example of the explanatory model for aggregates in Tibetan physiology may be useful. When we eat, the nutrients go to the stomach where *Bad-kan* helps to mix them (lubrication function). Then the *mKhris-pa* will help to digest them (transformation activity), and the *rlüŋg* will help to separate the essential nutrients from the waste products (movement metaphor). The essences of the nutrients eventually form blood, and in a cascade of events, the essence of blood forms muscle tissue, the essence of muscle tissue forms fat, the essence of fat forms bones, the essence of bones forms marrow, and the essence

Medicine of Tibet, Table 3 Characteristics and functions of three aggregates

Aggregates	Characteristics	Functions
Wind (Tibetan: rlüng)	Rough, light, cold, subtle, hard, and mobile	Physical and mental activities, respiration, urination, defecation, development and delivery of the fetus, menstruation, spitting, burping, speech, clarity of the sense organs, sustain life by acting as a medium between mind and body
Bile (Tibetan: mKhris- pa)	Oily, sharp, hot, light, fetid, purgative, and fluid	Hunger, thirst, digestion and assimilation, promote bodily heat, gives luster to body complexion, provides courage and determination
Phlegm (Tibetan: Bad-kan)	Oily, cool, heavy, blunt, smooth, firm, and sticky	Firmness of the body, stability of mind, induces sleep, connects bodily joints, generates tolerance, and lubricates the body

of bone marrow forms the regenerative fluids. The qualities of the regenerative fluids are responsible for the radiant glow of good health (Sanskrit: *ojas*). When the three aggregates are balanced, then the seven bodily sustainers mentioned above are also balanced.

Functional relations are emphasized more than physical anatomy in Tibetan medicine (Rechung, 1976). From the spiritual perspectives of Tibetan Buddhism and in the context of TTM, the organs, their functions, and elements are each related to a particular wisdom portrayed in sacred iconography (Lauf, 1976, pp. 117–137). Each bodily structure is also associated with meditational deities and sacred sounds (*mantra*). Each element and aggregate is related to aspects of mind, sensory perceptions and emotions and modes of cognition. Body and mind, mundane,

and spiritual are fused within Tibetan medicine. Thus, health and disease are multi-dimensional, including spiritual dimensions.

Clinical Diagnosis in Tibetan Medicine

A Tibetan physician employs his own senses to examine the patient’s general balance of health. There are three main methods of diagnostic examinations in Tibetan medicine: questioning, observation, and palpation. Interactive and subjective clinical assessments are the essence of the diagnostic method. Objective technologies for clinical diagnosis are practically non-existent in TTM. There are modern clinical survey instruments to assess Ayurvedic constitution (Chopra, 1991; Sachs & Rapgay, 1995), but no psychometric studies are readily available to validate their clinical utility.

Diagnosis by Questioning

Questioning is based on a series of 29 items that help to identify the nature of the imbalance in constitution and condition (Clark, 1995). Questioning is analogous to taking a clinical history in western medicine, whereby signs, symptoms, patient perceptions, and meanings are elicited. For example, the cause of disease may lie in consumption of unwholesome foods or improper behaviors. Asking about specific signs and symptoms assists the physician in understanding the imbalances among the three aggregates (Finckh, 1988). When assessing constitution and condition, the qualities that the patient exhibits in responding to the questions are as important as the content of the answers.

Diagnosis by Observation: Urine and Tongue Diagnosis

The urine is examined to assess constitution, condition, and response to treatments. For constitutional assessments, the patient is instructed to refrain from eating spicy foods, drinking alcohol, performing unusual strenuous activity, and having sexual intercourse on the day before the examination. The physician examines the first early morning urine sample by stirring it in a

small bowl with a clean stick and then examining the color, vapor, odor, bubbles, sediments, and scum.

The color of urine is determined by the intake of food and drink, seasons, diseases, and imbalances. In general, a reddish color with a small volume of urine indicates a hot disorder, while whitish clear urine with a large volume indicates a cold disorder. For the patient with *rlung*, the urine is clear like water and it has many big bubbles that may last only a short time. The urine from a person with *mKhris-pa* constitution is a reddish-yellow color, with a very strong odor, and moderate-scant volume. The *Bad-kan* patient has urine that is clear in color, with little odor, large volume, and small bubbles that often last a long time. Repeat urine analyses are used to gauge the accuracy of diagnosis, the efficacy of the treatment and as a guide to refining the treatment.

The Tibetan doctor may view the patient's tongue to provide additional clinical information. For example, the *rlung* patient will probably have a red, dry, and rough tongue. The patient with *mKhris-pa* constitution will likely have a tongue with a thick yellow coating. The tongue of a *Bad-kan* patient is white, smooth, and wet. Tongue and pulse diagnosis may also prompt additional questioning to support or reject clinical assessments.

Diagnosis by Palpation: Pulse Diagnosis

Examination by touching includes palpation of the body parts to assess temperature, areas of tenderness, tightness, weakness, or abnormal growths. Pulse diagnosis is a key method for assessment (Dhonden, 1986; Dhonden & Topgay, 1980; Finckh, 1978; Steiner, 1987–1989). The physician interprets the waveforms of the patients' radial arteries to assess ongoing physiologic processes and relationships between body parts and aggregates. Patients are instructed not to engage in sexual intercourse on the day prior to the pulse reading, not to consume alcohol, eat excessively, or engage in strenuous activities. These recommendations are intended to normalize the three aggregates by minimizing extraordinary external influences.



Medicine of Tibet, Fig. 1 Positions of the physician's fingers for reading the pulses

The assessments of constitutional pulses are typically performed during the early morning, while the patient's stomach is empty.

The physician palpates the radial pulses on both wrists, while the patient is in a comfortable and quiet environment (Fig. 1). The left hand is slightly flexed, so that the wrist creases are clearly visible. A special pillow may be used to rest the wrists during this part of the examination. The doctor places the fingers of his right hand on the left radial pulse of the patient, so that the right index finger is proximal to the wrist crease, at a distance about as wide as the patient's distal thumb. The second and third fingers then fall naturally along the artery. The three palpating fingers generally do not touch one another unless the patient is small in stature. The patient's right radial artery pulses are palpated in a similar manner. The physician may examine the pulses on one wrist at a time, or he may examine both wrists simultaneously. The radial pulse is palpated with increasing pressures at each site proximal to the wrist crease.

Each of the physician's palpating fingers can assess the functional characteristics of specific physiologic systems from the observed and interpreted qualities of the pulses. It is again important to note that although the names for organ systems are used here, these terms are metaphors for the mind-body functions associated with the elements and aggregates. According to the text, the heart and small intestine are

Medicine of Tibet,

Fig. 2 A Tibetan physician reading the radial pulses



assessed at the first position on the male patient's left hand, the spleen/pancreas and stomach with the second palpating finger, and so on. Similarly, the pulses at the first position on the male patient's right radial artery correspond to the lungs and large intestine. Liver and gall bladder pulses are located at the second position, and right kidney and urinary bladder are at the third position.

The pulses of women are reversed at the first position only, so that the heart and small intestine are assessed at the first position on the woman's right hand and the pulse for lungs and large intestine is read on a woman's left radial pulse. The reason for the switch is due to slight differences between genders for the apex of entry for consciousness that enters the heart, although no physical differences in the anatomy of the hearts is present. This is consistent with teachings of Tibetan embryology.

There is a complex system for interpreting the qualities of the pulses at each of the 12 sites on the radial arteries. For example, floating, irregular or intermittent beat qualities may be present in the pulse in the presence of disorders of *rlüng*. This finding often indicates the presence of pain symptoms that may radiate or have a breaking quality in specific sites indicated by the pulse. *Rlüng* symptoms have a tendency to change or be fleeting. Protruding and rolling pulses in the proximal sites are often present in early pregnancy, a finding attributed to the excess blood from the fetus

(*Bad-kan* condition). Fast or jumping qualities indicates excess heat (*mKhris-pa*). Underlying patterns within the pulses can be discerned; this allows the physician to select various medicines in accord with their taste, potency, and site of action (Fig. 2).

Constitution Analysis and Treatment Methods

The first priority in Tibetan medicine is to restore harmony to each person in the context of his or her life experiences. Symptoms are a result of an imbalance caused by disturbances in circumstances such as diet, lifestyle, and seasonal and mental conditions. Treatment depends on the total situation rather than the individual symptom; therapy varies with constitution and condition. Two people with the same symptom may be given very different advice and treatment, if constitution and condition differ.

Tibetan medicine provides a systematic approach to treatment and prevention. There are four methods of intervention: diet, behavior modification, medicine, and physical therapies. The three constitutions (*rlüng*, *mKhris-pa*, and *Bad-kan*) each have patterns of symptoms, preferences, and tendencies that can be remedied with categorical therapies. If the illness is not serious, diet and behavioral advice may be sufficient; otherwise, prescriptive medicines may be needed.

However, the best use of medical treatment cannot provide good health through physical means alone; a healthy mind is needed as well (Rimpoche & Terhune, 1992, p. 21). Tibetan medicine gives priority to psychological and spiritual factors in its definition of health. It teaches that we can make peace with the disease once we know and understand it. The literature is rich with specific meditation techniques used to restore balance (Rimpoche, 1996; Sachs & Rapgay, 1995; Thondup, 1998; Tulku, 1979; and many others). Each constitution and typical treatments are discussed below.

Constitution and Conditions in Tibetan medicine: rlüng

The physical characteristics of rlüng constitution typically include an asthenic body (lacking strength or vigor), sensitivity to cold, and a talkative and lively personality. Rlüng people are easily aroused from sleep, tend to eat small amounts of food frequently, and work hard but sweat little. They are prone to worry and sorrow. Symptoms of excess rlüng tend to be worse during cold and windy climates, during summer, or during early morning and/or late afternoon. Aging tends to produce imbalances in rlüng, so that these conditions are more common among the elderly.

From the spiritual perspective, egocentric mind is the usual source for imbalances of rlüng. Relational issues about attachment, sometimes translated as passion, essentially characterize people with rlüng constitutions (Sachs & Rapgay, 1995). Ego, in this context, is the identifying with the false concept that each person is separate and independent from the world in which we live. In Tibetan medicine and culture, ego is viewed as a limitation to be overcome, rather than a psychological resource to be enhanced. Ego is synonymous with self-clinging habitual patterns of mind, and so it is viewed as an obscuration to the clarity of the self-liberated mind. Ethical motivations and meditative practices with an experienced teacher can be an aid to realizing and dissolving such barriers.

Diagnosis by observation of a person with excess rlüng shows a tongue that is rough and



Medicine of Tibet, Fig. 3 Wind tongue is dry, with a red tip



Medicine of Tibet, Fig. 4 Wind urine is clear with lots of large bubbles that do not last long

dry (Fig. 3). Pulse diagnosis shows qualities that are irregular, empty, or floating. Urine is clear and has many large or variable size bubbles that last only a short time (Fig. 4). Diagnosis by questioning may reveal symptoms that are worse with ingestion of foods with light or rough potency and symptoms that change quickly over time. Typically, symptoms worsen when the patient is hungry and they may be relieved with foods that are oily, hot, or heavy. Symptoms tend to have a breaking quality, particularly in the bones and joints and in the lower body. Nervous symptoms including anxiety are common in this group.

Patients with excess rlüng are typically instructed to rest – both physically and mentally.

Minimizing anxiety and worry is important, since this psychic discord is a basic manifestation of rlüng. They can be advised to stay in comfortable, quiet, dimly lit, warm places. Company with a few close friends is beneficial, as are small amounts of alcoholic drinks. Patients should avoid excessive indulging of strong coffee and black tea, cold or refrigerated food and drinks, smoking, unripe fruits and vegetables, bitter gourd, junk foods, pork, foods and drinks with bitter and astringent tastes. Patients are encouraged to eat sweets, protein and nutritional foods and drinks, oily and warm foods and drinks, warm milk, butter, wine, garlic, caraway, leek, onion, sesame, cauliflower, radish, nuts, pomegranate, strawberry, apple, nutmeg, flax seed, clove, star anise, cabbage, mushroom, mustard, sunflower seed, cinnamon, and soya bean.

Patients with rlüng disorders are asked to pay special attention to regulating their lifestyles (e.g., eating, sleeping, and excretory function), to find time for calm activities and socializing, and to exercise in ways that promote good overall circulation, using techniques such as hatha yoga exercises and pranayama (yogic breathing). External cautery, similar in principal to traditional Chinese or Mongolian ► [moxibustion](#) (the application of burning moxa or other combustible materials at the acupuncture points) may be used to heat the body. Figures 5 and 6 show some typical herbal ingredients used to diminish excessive rlüng.

Constitution and Conditions in Tibetan Medicine: mKhris-pa

People with mKhris-pa constitution may be very ambitious; they tend to be active and may try to control situations physically or through positions of power. They tend to be keen thinkers and may have extraordinary motor skills. Yet control and aggression are sources of suffering for them. Spiritually, people with mKhris-pa constitutions can be characterized by aggressive behaviors sometimes translated either as “hatred” or “aversion.” The attitudes and behavioral characteristics of mKhris-pa also rest upon a false sense of ego-clinging identity, just as was present among those with rlüng. However,



Medicine of Tibet, Fig. 5 Clove or *Eugenia caryophyllata*, an ingredient of Sem-De, a traditional herb medicine to reduce excessive rlüng

the varieties in constitution and condition allow for different manifestations of this basic ignorance.

Patients with mKhris-pa constitutions are typically medium size, muscular, with a yellowish tinge to the skin. They are frequently hungry and/or thirsty, sweat easily, and they like activities and challenges. They are prone to annoyances and anger. Symptoms of excess mKhris-pa tend to be worse during hot and dry climates, during autumn, or during midnight and midday hours. Imbalances in mKhris-pa tend to occur among middle age groups.

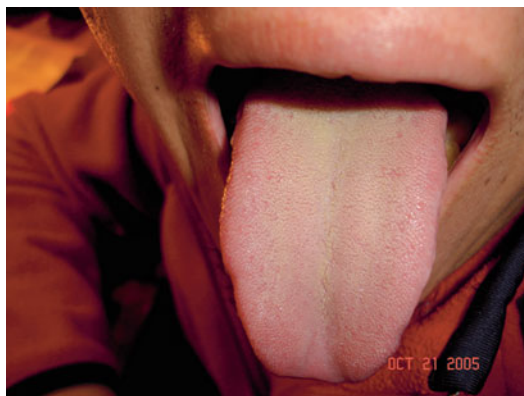
Diagnosis by observation of a person with excess mKhris-pa shows a tongue that is coated with a thick, yellowish substance (Fig. 7). Pulse



Medicine of Tibet, Fig. 6 Nutmeg or *Myristica fragrans*, an ingredient of Agar 8, a traditional herb medicine to reduce excessive rlüng

diagnosis shows qualities that are fast, strong, and jumping. Urine is yellowish-red, with a strong odor and small bubbles (Fig. 8). Diagnosis by questioning may reveal symptoms that are worse after eating, especially after foods with sharp or hot qualities. Symptoms may include a bitter taste in the mouth, a sense of heat or fever within the body and aches in the middle and upper parts of the body. Ingestion of cool foods may relieve the symptoms.

Therapy for mKhris-pa is directed to foods and medicines that are sweet, bitter and astringent in taste and cool, smooth and blunt in potency. Patients with an imbalance in mKhris-pa should eat beef, vegetables, butter, low fat cheese, cow's yogurt and buttermilk, and drink weak tea or spring water. A simple vegetarian diet is suitable, including legumes, potatoes, artichokes, bitter vegetables (e.g., dandelion), and turnips that may be seasoned with cumin, coriander, or fenugreek. Foods that are heating in nature should be avoided, including peanut butter, mustard and hot spices, garlic, ginger, onion, alcohol,



Medicine of Tibet, Fig. 7 Bile tongue with yellow coating



Medicine of Tibet, Fig. 8 Yellow, foul smelling urine for case with excess mKhris-pa (bile)

grilled meats (esp. lamb), oily and greasy foods, and soups made with bones.

Syrups and powders are traditional types of prescribed Tibetan medicines for mKhris-pa. Purgatives and strong laxatives are used to reduce the excessive amount of heat in the body. Behavior changes include the use of cold baths and showers, sitting in shaded places, walking by the sea and cooling scents such as sandalwood. Individuals suffering from a mKhris-pa disorder should avoid situations causing conflict and direct, excessive exposure to the sun. Physical activities that are relaxing are encouraged; an environment that is conducive to calmness is beneficial. External treatments may target the

Medicine of Tibet,

Fig. 9 Herbal remedy for excessive mKhris-pa (bile) is *Saussurea lappa*, an ingredient of Tik-Ta 8

**Medicine of Tibet,**

Fig. 10 Herbal remedy for excessive mKhris-pa (bile) is *Rosa sericea* Lindl., an ingredient of Tri-Nam



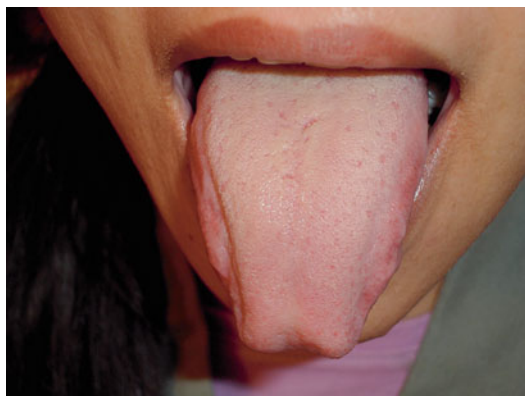
production of sweat and may also include blood-letting. Typical herbal ingredients for excess mKhris-pa are shown in Figs. 9 and 10.

Constitution and Conditions in Tibetan**Medicine: Bad-kan**

The physical characteristics of Bad-kan constitution are typically a large or tall body, someone who can endure hunger and thirst well, who shows a pleasant, easy going and friendly personality. People in this group tend to sleep soundly, eat too much and too quickly, and wear clothing that is insufficient to keep them warm. Excessive sleeping can worsen conditions. Bad-kan people tend to be slow, persistent, and methodical in

daily routines. Cultivation of good habits can be beneficial and enduring. Established routines are easily maintained, but changing habits can be difficult. Changing unhealthy habits may call for exertion that may initially make the person uncomfortable. This information is part of the prescription for health for this constitution. Babies and young children tend to have imbalances in Bad-kan.

The spiritual dilemma of people with Bad-kan constitutions can be characterized by ignorance, also known as delusion or confusion. Ignorance is one of the three poisons. It means not relating to self and others with a proper view. Ignorance has no relationship to intelligence, as we use the term



Medicine of Tibet, Fig. 11 Excessive Bad-kan (phlegm) tongue is wet and coated *white*

in western societies. As such, it cannot be remedied with more studies or acquisition of mundane knowledge. Spiritual insight is the key to resolving the dilemma of ignorance.

Diagnosis by observation of a person with excess Bad-kan shows a tongue that is moist, smooth, glistening with a thick gray lusterless coating (Fig. 10). Pulse diagnosis shows qualities that are slow, weak, sinking, or deep. Urine is usually clear, with little odor and few bubbles that last a long time (Fig. 11). Diagnosis by questioning shows that symptoms are worse after eating, especially after heavy foods, and relieved after warm or hot foods. Symptoms include a sense of discomfort, heaviness or coldness in the upper body or a sense of heaviness in the mind (Fig. 12).

Therapy is directed to foods and medicines that are pungent, sour and astringent in taste, with potencies of sharp, rough, and light. Patients should adopt a heating diet with respect to both the nature and the temperature of the food. For example, they are encouraged to consume a traditional diet to counter excess cold and retention of fluids, including: hot water, cooked foods, mutton, fish, barley, pomegranates, sheep cheese, yogurt, ginger, radish, honey, garlic, and wine. They should avoid cold drinks and raw foods such as salads, potatoes, tomatoes, eggplant, bell peppers, and sugar.

Patients with Bad-kan disorders may be instructed to keep warm and perform vigorous



Medicine of Tibet, Fig. 12 Excessive Bad-kan (phlegm) urine is clear with small bubbles that last a long time

exercise such as running or dancing. Swimming in cold water is not appropriate for Bad-kan conditions. Periodic emetics (e.g., induced vomiting) are recommended as part of a traditional health maintenance routine, since this reduces the excessive amount of cold and damp that tends to accumulate in the body. An environment that is conducive to heat producing activities is beneficial, including lots of exposure to warm sun and fires burning in the home. External treatments may target the cautery and other forms of heat. Traditional herbal remedies to reduce excessive Bad-kan are shown in Figs. 13, 14, 15, and 16.

Pharmacology in Tibetan Medicine

Natural herbal preparations are a large part of therapy in Tibetan medicine. The goal of herbal remedies is to restore balance among the constituents of the body-mind complex. The medicinal effects associated with Tibetan preparations are not due to the presence of a specific ingredient, as in western pharmaceuticals. Rather, the herbal combinations act on the body-mind aspects of the afflicted aggregates and elements to restore balance. Remedies act on the specific imbalance, while other ingredients support the aggregates

Medicine of Tibet,

Fig. 13 Pomegranate, an ingredient of Se-Dru 5, a traditional herb medicine to reduce excessive Bad-kan

**Medicine of Tibet,**

Fig. 14 Rhododendron, an ingredient of Dhe-Nyom, a traditional herb medicine to reduce excessive Bad-kan



that are not maligned during the period of the intervention, although they may be challenged during the dynamics of therapy and healing (Fig. 17).

Most of the ingredients in the Tibetan *materia medica* are herbs and plants. There are eight categories of natural substances used in preparing prescribed therapeutic remedies: precious metals and gems, stones, earth medicines, trees, resins, plants, herbs, and animal products (Clark, 1995; Clifford, 1990; Dash, 1976). The remedies can take ten forms: decoction, pills, powder, gruels, medicinal butters and calxes, concentrated extractions, medicinal wine, herbal medicine, and gems as medicine. Enemas, especially if

oily, mild, and soothing, are useful for rlüing imbalances. Purgatives reduce the heat in mKhris-pa conditions. Emetics reduce water and mucous associated with excessive Bad-kan.

Tibetan herbal pills are often complex, with 3–150 herbs per formula. Each herbal formula is prescribed to fit the manifestation of the disease and the evolving condition of the individual patient. The herbs are often sought from natural settings, often harvested from a great distance or requiring expertise in climbing or other skills to access the plants. The plants are gathered under specified circumstances, including time of day, phase of the moon, etc. Special mantras are often recited during collection of the herbs, during



Medicine of Tibet, Fig. 15 Saffron, an ingredient of Dhe-Nyom

preparation and after the pills are formed, to imbue the remedies with healing qualities.

The physician often starts with less potent preparations and advances to stronger forms if necessary. Typically, two to four formulas are prescribed for each day at specific times. Morning remedies commonly include those for Bad-kan disorders or digestive disorders. Afternoon remedies are typically used to treat mKhris-pa disorders. Remedies given in the late afternoon or evening are usually given to treat rlüng disorders. Herbal remedies are often modified at each visit (Figs. 18 and 19).

The substance in which a medicine is dispensed is called the medicine horse (*Men-Ta*) (Burang, 1974). Typical carrier agents include water, alcohol, sugar, treacle, or honey. According to tradition, sugar is the men-ta for dispelling mKhris-pa, treacle is the carrier for reducing rlüng, and honey is selected for overcoming Bad-kan. The compounded remedies are sometimes coated with resins, so that they pass through the stomach and into the intestine where



Medicine of Tibet, Fig. 16 A medical student gathering herbs

they are integrated into the body in accord with traditional concepts of physiology (Fig. 20).

The art and science of preparing TTMs is based on tastes and potencies. The tastes are associated with medicinal properties. Each taste is present as the result of interaction between two or more elements. Specific tastes can increase or decrease the activity of specific aggregates. The text says that sweet, sour, and salty tastes overcome (reduce) rlüng. Likewise, bitter, sweet, and astringent abate excessive mKhris-pa, and pungent, sour and salty tastes counter Bad-kan (Table 4). These same tastes also describe the medicinal properties of common foods and spices.

The properties of herbal remedies and traditional medicines can be determined by the refined sense perceptions of Tibetan doctors. The tastes and actions of therapeutic agents on specific parts of the tongue correspond with medicinal properties at specific parts of the body.

Medicine of Tibet,**Fig. 17** Medical students cleaning gathered herbs in Northern India**Medicine of Tibet,****Fig. 18** Modern methods for making TTM pills

For example, medicines with astringent tastes that influence the sides of the tongue may be useful for treating imbalances that adversely influence the gallbladder organ and associated dimensions, including some migraine headaches. Knowledge about tastes and medicinal actions of therapeutic agents is embodied in a cultural tradition of health care, known as microsystems of anatomic correspondence (Porkert, 1974).

Typically the Tibetan pharmacist is also a physician. Preparation of botanical medicines involves collection of specimens, drying,

cleaning, storage and preparation, detoxification and neutralization, and compounding. Various parts of plants are gathered at different seasons – fruits in the autumn, leaves during the summer, branches and barks during the spring, and roots during the winter. Mantras to invoke the Medicine Buddha and other deities are often recited during the time of collecting and during other stages in processing to imbue the remedies with additional potency (Fig. 21).

One fundamental difference between modern biomedical sciences and TTM is the notion about



Medicine of Tibet, Fig. 19 Packaging the pills

**Medicine of Tibet,
Fig. 20** Various forms of
modern Tibetan medicines



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the interdependent nature of reality. Interdependent realities include the participatory awareness of an observer in interactions with the relative world of appearances, including measurable phenomena. The perceiver, the object of perception, and the sensory faculties for perceptions are all interdependent. From this perspective, to exclude the observer from an investigation and analysis of phenomena is akin to

making an artificial reality. Experiential qualities of relationships are valued as much in TTM as are objective measures of form.

Indeed, one of the strengths of TTM is that mind and body, and mundane issues and spiritual aspirations, are each intimately linked with one another. The perspective of TTM and Tibetan Buddhism pose that the world we experience exists only in the context of our human presence

Medicine of Tibet, Table 4 Influence of tastes and qualities on the aggregates (Adapted and modified from Clifford, 1990, p. 120; Lad, 1984; and others)

Elements	Taste	Qualities	Food and spices	Aggregate increased	Aggregate decreased
Earth-water	Sweet	Cooling	Wheat, rice, peppermint	Bad-kan	Rlüng; mKhris-pa
Earth-fire	Sour	Heating	Yogurt, cheese, lemon, rose hips	mKhris-pa; Bad-kan	Bad-kan
Water-fire	Salty	Heating	Salt, kelp	mKhris-pa; Bad-kan	Rlüng
Water-wind	Bitter	Cooling	Dandelion, turmeric	Rlüng	mKhris-pa; Bad-kan
Fire-wind	Pungent	Heating	Onion, radish, ginger, garlic	mKhris-pa; rlüng	Bad-kan
Wind-earth	Astringent	Cooling	Unripe banana, persimmon, goldenseal	Rlüng	mKhris-pa; Bad-kan

Medicine of Tibet,

Fig. 21 Monastic community rituals for blessing TTM medicines



and interactions. In short, the world is an aspect of Mind. Questions posed by western health scientists tend to assume that the nature of reality is independent of the observer. This positivist view typically asks questions about form and status of external phenomena – the “what” of measurable components of nature. Thus, western sciences seem to be bound and limited by concept, form and reliance on objective measurements. TTM defers involvement of the inherent mind-body split of western science and medicine by defining mind as part – if not the source – of reality.

Thus, the very notion of disease and clinical reality as we know it in western biomedicine are challenged in TTM. TTM addresses the process-

oriented issues about “how” more than “what.” For example, “How might we live within this precious human birth in a manner that brings happiness to ourselves and all sentient beings?” is a basic motivation among practitioners of TTM. The focus is more on the dynamics of process and relationship, rather than on the parts to be measured. Yet form is not ignored in TTM – it is recognized as simply one mode of perception and relationship among many other possibilities. The dynamics of subtle anatomy and the interactions among the elements and aggregates are the core methods for identifying imbalances to be addressed through traditional methods of TTM.

Thus, a tension is acknowledged between biomedicine and TTM, where TTM focuses on processes for realizing subjective well being for all involved in life experiences, while modern biomedical care seems intent upon attaining disease-free states of objective health status for specific individuals. Yet, perhaps each health care system makes sense when viewed from its unique perspective. Each system is logically consistent within itself.

Does TTM offer any opportunities for new understandings of health and well being among people in western societies? That may depend upon the willingness of western scientists to overcome some engrained notions about the nature of reality and the nature of mind (e.g., of the observer-participants) in scientific investigations. Valid research methods to investigate culturally different health care systems may make use of hypothesis generation from the traditional perceptive, with psychometrically examined key measures that support the traditional view, complemented by known biomedical measures (Anderson, 1992; Steiner, 2003). Such methods for cross-cultural research, including hypothesis generation from the traditional perspective, may yield new insights about best practices in medical care.

Traditional Tibetan medicine offers an alternative view to health and healthcare, as well as a choice to western scientists. That choice is to consider complementing the focus of western sciences on measurable phenomena with an inward investigation about the nature of mind of the perceiver. In some Tibetan schools of mindfulness training, the inwardly directed investigations are initially analytic and conceptual in nature, but proceed to realizations about the nature of mind itself that are embodied within our human experience – but are not limited by ordinary dualistic conceptual thinking (Thondup, 1998; Wallace, 1996). That choice is available for any person who is willing to focus on the mindfulness of life experiences, as offered through the guidance of lineages and teachings of wisdom traditions from Tibet, including TTM. The study of TTM offers an opportunity to examine a participatory universe. In short, entering the path of health, healing and well being in accord with principles of TTM, is a choice.

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Medicine Wheels

Lawrence Tyler

The Indians of the North American Plains, because of their nomadic ways, were not dependent upon permanent settlements and structures. Aside from rings of stone left after *tipis* were moved there is little evidence of construction left by these tribes. The noted exceptions to this generalization are the formations known as “Medicine Wheels”. More than hundreds of these formations have been found in North America ranging through Saskatchewan, Alberta, Montana, North Dakota, Wyoming, and Northern Colorado. These sites are all located north to south, within a few hundred miles of the eastern

boundary of the Rocky Mountains, suggesting the migratory patterns of the Native American culture of this area. They are distinguished from *tipi* rings and camp sites by their size and by the spokes or arms which radiate from a central cairn. These formations are found in isolated locations, inappropriate to community dwelling. Always of native stone, these “wheels” usually consist of a central hub of stone, and/or an inner circle, from which other stone lines radiate out toward the horizon. They are not meticulously constructed but rather seem like a design that a few workers could put together in a matter of days. However, the dimensions are sometimes substantial. The Bighorn Wheel in Wyoming, for example, has a central hub about 12 ft across; with radiating spokes 90 ft in length.

The existence of many of these stone formations has been known for at least a century. The Bighorn Medicine Wheel was reported in the 1880s by explorers and prospectors; by radio carbon analysis it has been dated AD 1600–1700. The first archaeologists to investigate the Bighorn site asked local Native Americans about its use or origin but initially none of the tribes claimed responsibility for its existence or knowledge of its use. Gradually stories emerged, but there is always the question of whether the informants were creating the sort of responses that they thought anthropologists wanted to hear. In point of fact, none of the indigenous groups, such as Sioux, Cheyenne, and Arapaho, have folk legends and traditions which either explain or validate the role of Medicine Wheels in their traditional cultures.

Until the 1970s, the generic explanation for Medicine Wheels was that they must have been of “ceremonial” use, though no one was forthcoming with any detailed account of just what ceremony. The Sioux and Cheyenne are known for their Sundance ceremonies, for which special circular medicine lodges were built. Some observers have been tempted to point out the spatial similarities between the circular medicine lodges built around a living tree used as the center pole with roof and walls radiating from that center and the medicine wheels with central cairn and radiating spokes. The symbolic similarity

may be clear, but real intent and purpose remain unknown. So until the 1970s, Medicine Wheels were at most a curiosity of Plains Indian culture neither well known nor well explained. Then an integrative approach called archaeoastronomy, linking the previously separate disciplines of archaeology and astronomy, emerged as a new way of examining ancient phenomena. Basically its unifying theme is to examine megalithic and prehistoric formations for astronomical significance. One example of this is Gerald Hawkins' work documenting the astronomical alignments of Stonehenge in Salisbury, England. Soon practitioners of both astronomy and archeology were looking with renewed interest at ancient megaliths around the world, including Medicine Wheels.

The astronomer John Eddy is most closely associated with an archaeoastronomical interpretation of North American medicine wheels. He, in collaboration with an archeological team, studied several medicine wheels, including the Bighorn Wheel in Wyoming and the Moose Mountain Wheel (radio carbon dating, AD 100–500) in Saskatchewan. His findings suggested that many such formations could have been used as landmarks in the rolling plains of an otherwise undistinguished terrain. The simplest of these seem only to point to other stone formations, in the same way guideposts mark long trails across isolated lands.

However, for both the Bighorn and Moose Mountain wheels, Eddy notes solar and stellar alignments that could have been used for solstice calculation. Normally solstice observation is associated with agricultural societies, but nomadic groups such as Plains Indians also needed techniques for anticipating the severe weather changes of the northern plains. While such an interpretation is not conclusive, various studies are now suggesting that the Plains Indians were very careful observers of the evening sky as well as the land. The Medicine Wheels may be indicators of their ability to use markings on the earth to note celestial changes in the sky and the corresponding journey of the seasons; all useful information for high plains travelers. In any case Medicine Wheels could have been of both

ceremonial and astronomical utility since the world view of the plains tribes would have made no significant distinction between spiritual and stellar forms.

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Megalithic Monuments in Korea

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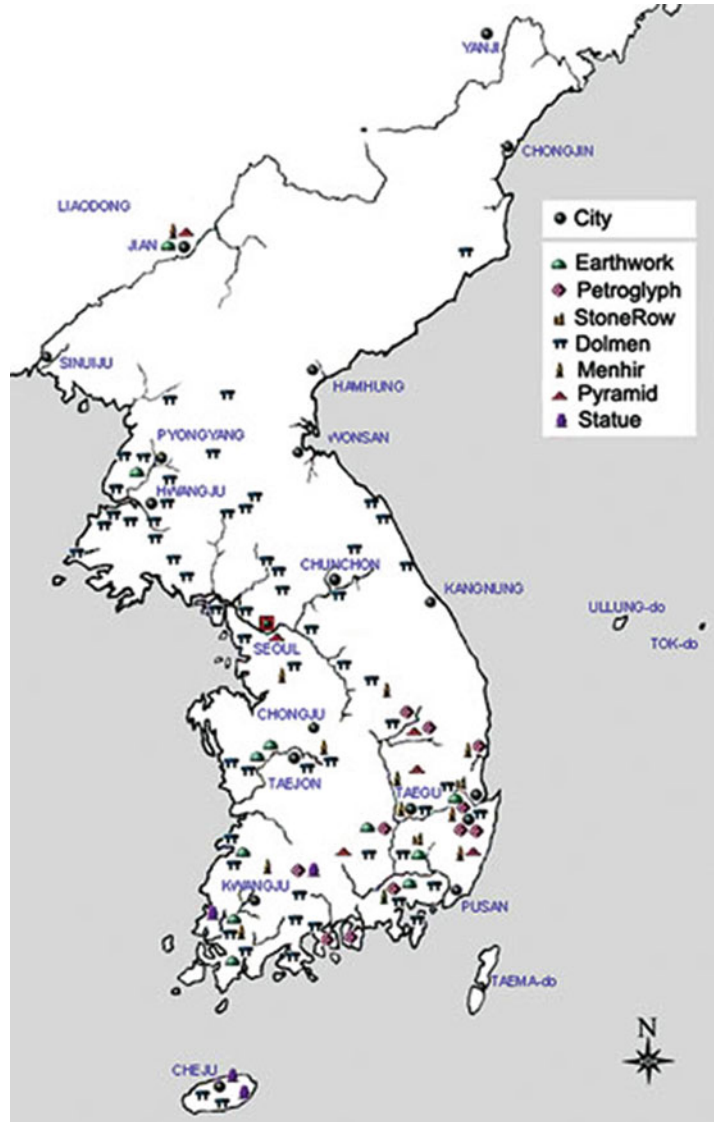
Megaliths in Korea are either single standing stone slabs (menhirs) or arrangements of standing stones with a large capstone on top (dolmens). Korea has not only the largest number of dolmens in Asia, but the most imposing ones as well. They range in time from about 1500 BCE to the early centuries AD.

Dolmens are found throughout the Korean peninsula but are far more common in areas where rice agriculture was practiced (Fig. 1). Calling these large constructions dolmens is terminology borrowed from Europe, where similar megalithic monuments are found, especially in Western Europe. In Korea, they are called *koindol*.

Dolmens are characterized by several standing stones propping up a capstone that covers and extends beyond the vertical stones. A single stone standing alone, without touching another stone, is called a menhir. Various typologies

Megalithic Monuments

in Korea, Fig. 1 This map of Korea is showing the ancient remains and the contemporary capital, main cities, rivers, and islands around the Korean peninsula. Icons of earthwork in the map mean mainly the enormous turf mounds (ancient royal tombs before A.D. 935)



of Korean dolmens have been proposed, sometimes dividing dolmens into as many as seven different types. The simplest division, and the most obvious, is between the table type, which stands above the ground usually on four upright stone slabs with a larger capstone balanced upon them, and the capstone-on-the-ground type, which covers a burial. The table type is more like the dolmens of Europe after which they are named, but it is clear that those that have only a large stone visible are a close relation. The table type is found mostly in the

northern part of the Korean peninsula as well as in Liaoning Province in China, and the other capstone on the ground type is found more in the southern part of the peninsula, although there is no clear demarcation line between the two.

The stone slabs holding up the capstone of the northern type can be as much as 2 m high, and the capstone usually weighs several tons. Most were probably burial chambers, although little has been left of their contents. Occasional sherds of red pottery, very rare polished stone daggers, and

tubular beads would place them in the Bronze Age. They appear to be related to cultures from the northeastern part of China that buried their dead in stone slab tombs. If so, then these are highly exaggerated slab graves. They tend to have been erected singly, on heights or in the middle of plains where they could be seen from afar. This meant that they were not difficult to locate, and very few of them escaped looting, in antiquity or later.

Southern style dolmens have a variety of types of graves underground beneath the capstone. They are hard to distinguish from erratic boulders and therefore have not been plundered at the same rate as the northern ones. Stone cists are the most common form of grave under the ground-level megalithic stone. Some of these burials were untouched and have yielded small red jars, polished stone daggers, and tubular bead necklaces, sometimes with a curved jade as a pendant. These curved jades are often known in the West by their Japanese named *magatama*, but in Korea, they are called *gogok*. Other graves found under dolmens include large jar burials, simple pit burials, and burials topped by a “paving” of small stones. They may have similar grave goods.

In the South, dolmens tend to be found in groups, often in lines. One may be larger or higher than the others, or they may seem to be equal in size. They may be spread along a stream when related to medium-sized habitation groups, but as part of larger villages or towns, they are often found in one or more rows.

Some dolmens have round pits in them that are known as cup-marks. These could be formed naturally by pebbles being scoured round and round in the rain, but some of them appear to have a pattern and may be deliberately made by a human agency. They have been related in Korea to various myths which associate the birth of important people with eggs.

Menhirs are usually found singly or in pairs. They have been likened to the wooden *changsun* that used to be carved in pairs, one male and one female, leading into Korean villages until the 1970s. Menhirs are less common than dolmens. It is said that there are several fields with seven

dolmens arranged in the shape of Ursa Major, or the Big Dipper. The *Chilsong*, the Seven Stars, are sacred to *mudang*, the women shamans of Korea.

Evidence that the southern style lasted into the Iron Age includes one with a cache of Chinese style daggers from the third century BCE. However, most dolmens seem to be associated with Bronze Age pottery and stone tools. It has been argued that rice agriculture brought social changes to Korea that are exemplified by the presence of dolmens. These large constructions would have required considerable labor, which would have had to be coordinated. Furthermore, they suggest permanent leaders, perhaps even chiefs, who had the ability to mobilize the labor of many people. Large villages and towns do not appear in Korea when the main crop consisted of millets; rather, they appear along with rice agriculture and larger settlements. The semilunar stone knife, sometimes found in dolmens and always associated with Mumun pottery and Red Burnished pottery, is argued to be a tool for harvesting rice. Nelson (1999) argues that rice agriculture appeared in Korea before dolmens and that dolmens are related to the increasingly complex social structure that became possible with the cultivation of rice.

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Metallurgy in Africa

S. Terry Childs

A condensed discussion of African metallurgy is difficult because of the large size of the continent and the 3,000 years over which it developed south of the Sahara desert. Furthermore, several metals were produced and used in Africa, and metal production involved many technological steps which were not necessarily used for each metal type (i.e., iron, copper, gold, and tin). Iron production, for example, involved mining iron ore and smelting it to a bloom, a nonmolten mass of metal intermixed with a waste product called slag. The bloom was then forged into objects by hammering, welding, and other processes. Some preindustrial societies made cast iron, a molten form of iron, but there is little evidence for this technology in Africa. Copper and copper alloys, on the other hand, were often made by reducing ore into molten metal and pouring it into molds, or by hammer forging solid copper. Gold was hammered out from its original nugget form, or melted and cast. Pellets of tin were removed from the slag output of tin smelting and were then melted into ingots. Moreover, not all societies used the same metals or mastered the same manufacturing steps for any given metal. Some cultures specialized in iron smelting, while others forged iron blooms into objects. In copper producing areas, some societies had craftsmen who cast molten copper into molds, others hammered out unrefined copper, and still others specialized in drawing out copper wire.

Much of the current knowledge about African metallurgy concerns iron production. There are several reasons for this. Iron has the clearest presence in the archaeological record, iron ore is virtually ubiquitous across Africa, and, for centuries, it was a subject of interest to Greek and Arab travelers and, later, European explorers, missionaries, and scholars. Copper smelting and casting, as well as the production and use of bronze (an alloy of copper and tin), brass

(an alloy of copper and zinc), and gold, have also received considerable attention. The more isolated occurrences of these technologies across Africa in the archaeological and ethnographic record, however, have resulted in less detailed reconstructions of their diverse histories and their significance to African cultures. Some tin production occurred in southern and western Africa, but this is the least studied indigenous metal and may have a relatively short history as compared to iron, copper, and gold.

The prehistory and history of African metallurgy come from several sources. Archaeological excavations often yield metal objects, and/or the physical remains of production centers (i.e., smelting furnaces containing slag, tuyères or blow pipes, and charcoal fuel; forging pits; casting crucibles; molds). Increasingly, archaeologists submit these remains to laboratory analysis to determine how an object was made, or the chemical and physical dynamics of an ancient metallurgical process, its environmental context, and its age by radiocarbon dating. Some scholars conduct collaborative research with village elders who still remember how to smelt and forge iron, or cast copper. Several projects have resulted in important films which underscore the complexity of many metallurgical operations, provide critical insights into poorly understood ancient practices in Africa and worldwide, and highlight the nontechnical aspects of production. Some researchers also perform experimental reconstructions of metallurgical processes to understand further the thermodynamics involved. A final source of information is the archival record of numerous visitors to Africa over the centuries. The reports from the early twentieth century first featured the nontechnical characteristics of African metallurgy, including esoteric knowledge, decorated furnaces, ritual, music, and taboos.

The following discussion begins with a brief overview of the prehistory of African metallurgy, then examines the technical diversity of metallurgical practices across Africa, and concludes with a look at its social and ideological components.

Although this review principally concerns Africa south of the Sahara desert, the earliest

evidence of metal production and use was in Egypt. Copper was first used there around 5000–4000 BCE and was being smelted by 3000 BCE. Iron objects were rare through the Middle Bronze Age, but became more frequent during the New Kingdom after about 1570 BCE. Iron smelting was practiced by the eighth century BCE.

Ancient Egyptian metallurgy had no influence on the rest of the continent except to the immediate south in Nubia and the later kingdom of Kush, both in modern Sudan. An Egyptian outpost was established in Nubia to smelt local copper ores in 2600 BCE, and Egyptians exploited Nubian gold from an early time. By the next millennium, Nubian craftsmen worked copper, bronze, silver, and gold. At Meroë (ca. 500 BCE to AD 300), the capital of the Kushite state, there were craftsmen of copper, bronze, gold, and iron. The earliest iron slag from the site dates to the fifth century BCE; domed, brick smelting furnaces, possibly of Roman influence, were used after about 200 BCE.

There is controversy over two interrelated aspects of the origins of metallurgy in sub-Saharan Africa (1) whether it was invented indigenously or introduced from elsewhere and (2) which metal – copper or iron – was smelted first. Researchers looking for a “natural” progression of pyrotechnological knowledge (i.e., simpler copper smelting to more complex iron smelting) to prove indigenous origins have been thwarted to date. Copper smelting only seems to have preceded iron smelting in Nubia and, during the early to mid first millennium BCE, along the southern Sahara in Niger and Mauritania. Current evidence shows that iron appeared first or at the same time as copper in the rest of sub-Saharan Africa. Other than at Meroë, the earliest indications of iron smelting are in Nigeria (ca. 900–800 BCE), Niger (ca. 500 BCE), Rwanda/Burundi (ca. 700–500 BCE), and Tanzania (ca. 300 BCE).

Many archaeologists believe that knowledge of iron smelting was brought from abroad, but they cannot agree on the route of introduction. Several routes have been proposed (1) Egypt to Meroë, then west and south, (2) from the Phoenician or Roman coast of North Africa across

the Sahara desert, and (3) via the Indian Ocean. The first has been ruled out because of the early evidence of iron smelting in West Africa. Little else can be resolved until issues over radiocarbon dating are settled, excavations are conducted in poorly explored regions, including the North African coast and Ethiopia, extensive historic linguistics are done, and the possibility that more than one route existed is carefully investigated. It is now recognized, however, that iron and copper were introduced to different regions of Africa at different times.

Iron working spread from the regions of early introduction in West Africa, Sudan, and East Africa to Southern Africa in 500–700 years. This rapid expansion was once thought to be linked to the movement of Bantu-speaking agriculturalists as they traveled south and east from their homeland in present-day Cameroon, over 3,000 years ago. Recent archaeological and historic linguistic evidence discredits this theory. Traces of early iron smelting have been found in modern Gabon and Congo, but not in northeastern Zaïre. Historic linguistics suggest that iron working in East Africa probably had northeastern, not western, origins. The earliest evidence of copper smelting to the south of Cameroon, on the other hand, occurs by the fourth century AD in copper-rich areas on the Congo coast and in northern Zambia/southeastern Zaïre at about the same time as iron working.

Intensified use of iron, copper, bronze, gold, and brass during the first and second millennia AD was connected to, but not the cause of, the rise of African states, urbanization, and the development of long distance trade routes in some regions. For example, the city of Jenne-Jeno in present-day Mali was well-developed by the third century AD. It did not begin to receive gold from across the Sahara desert until around the eighth to ninth centuries AD or brass (a known import based on the nonindigenous zinc present in the alloy) until the ninth to tenth centuries AD. Jenne-Jeno then became a major trade center in metals. In southern Africa, a long distance trade in gold developed between people living in modern Zimbabwe and those in coastal towns on the Indian Ocean by the tenth century, on the

back of an earlier trade in ivory and skins. A powerful state with its capital at Great Zimbabwe (AD 1275–1550) prospered, in large part, by taxing the gold mined and traded from this region. Bronze, a golden alloy of copper and tin, also was developed in the area around this time, but little is presently known about the technology and its local significance.

In many other parts of Africa at this time, relatively small quantities of iron and/or copper were produced, used, and traded locally. The diversity of mining, smelting, and forging techniques that developed over the last two millennia is extensive.

Metal ores, such as specular hematite, malachite, and galena, may have been mined many millennia ago in sub-Saharan Africa, but they were ground to powders for cosmetics. Once ores were mined for smelting, several techniques were developed depending on the type of ore exploited and the physical and technical constraints encountered.

A similar array of mining techniques was developed for copper, iron, gold, and tin across Africa. Some copper and gold ores differed from iron and tin ores in one critical way, however: they could be found in their native metallic state. Mining for native metals involved picking up workable nuggets, panning for and concentrating metal flakes in watery contexts, or digging shafts along seams of metal. This was often labor intensive, such as in ancient Zimbabwe where gold mining involved considerable digging, crushing the matrix rock, and then amassing the gold by panning.

African miners exploited the oxide minerals of copper, iron, and tin at or near the earth's surface for smelting. They dug narrow shafts until the ore was exhausted, the shaft was unsafe, or they reached water. Large open ditches were also excavated. Both techniques required metal tools and, in the latter case, fire-setting was also used to break up the rock. Often, the matrix rock had to be crushed to concentrate the ore. Cases also existed of panning to concentrate rich iron ores dispersed in sandy matrices. While many aspects of African metallurgy were performed and controlled by men, the labor of carrying the ore,

panning, and working in the narrow shafts was often done by women and, probably, children.

A facet of African metallurgy that has long intrigued scholars is the bewildering diversity of iron smelting furnaces over time and across space. At a very general level, three types of furnaces were built: pit or bowl furnaces lacking walls and operated by bellows and tuyères; shaft or walled furnaces with a pit beneath, also operated by bellows and tuyères; and tall furnaces (ca. 2.5–4 m), often without a pit, that used natural draft to stimulate combustion. Within each general type, there was enormous variation based on whether or not slag was tapped from the furnace during smelting, numbers of tuyères, bellows type, pit depth and diameter, height and shape of the furnace walls, building materials, decoration on the furnace walls, and presence/absence of interior furnace features.

Some scholars have theorized a chronological sequence for these general furnace types, from “primitive” pit furnaces in which wrought iron was made to shaft furnaces in which low grade steel was produced to natural draft furnaces. Regional and local variations would have then developed over time. Recent findings reveal that the earliest furnaces all had walled shafts, and that a heterogeneous bloom, varying from soft wrought iron to high grade steels, could be produced in each furnace type. It is now generally thought that furnace variation was a response to certain local constraints, such as ore types, but primarily to the different sociocultural contexts into which iron smelting was brought or developed.

Less is known about African copper smelting because it was practiced less widely and has been the subject of less research and ethnographic observation. Most copper smelting furnaces were the shaft type, but considerable variation existed based on whether the molten copper was tapped directly from the furnace into molds or was melted in crucibles within a furnace. Pit size, building materials, wall height and shape, number of tuyères, bellows type, mold sizes and shapes, and wall decoration also varied.

Gold was not smelted, but melted in crucibles over an open fire. There is little evidence of gold

extraction technologies in Africa except for occasional pieces of gold-encrusted crucibles from Zimbabwe and South Africa. Tin ore, like iron ore, had to be smelted or reduced in a furnace, but little is known about the processes used or when they were developed. An ethnographic account from Nigeria indicates that tin and iron ores were cosmelted and tin was removed from the slag. In South Africa, tin ore was smelted in tiny furnaces, pellets of tin were extracted from crushed slag, melted in crucibles, and cast in molds.

The fabrication techniques used to transform raw metal into objects were also diverse and varied by type of metal and region. Iron and steel, for instance, were always hammered into shape, but many types of hammers and anvils were used over the continent. Skill at welding together pieces of iron and/or steel and other joining techniques varied widely. Evidence that iron was drawn out into wire comes from East Africa and to the west in modern Angola, but the history of this technique is vague. Interestingly, no evidence of precolonial heat treatment of steel (i.e., quenching it in water) to harden and strengthen an object has been found.

Copper was manipulated in several ways: hammer forging solid metal into various forms; drawing out wire; casting molten copper into molds; and alloying copper with another metal, like tin to make bronze, and then casting the alloy (the ability to cast copper is improved by adding tin). Evidence to date suggests that a sophisticated lost-wax casting technology (intricate forms are made of wax and encased in clay; molten metal is poured into the mold which replaces the wax) was developed in West Africa by the ninth to tenth century AD. The site of Igbo Ukwu in Nigeria has yielded remarkable castings that were followed by later traditions at nearby Ife and Benin.

Igbo Ukwu also provides the earliest evidence of bronze which was used to make many lost-wax castings. Investigations into whether bronze alloying was an indigenous discovery in West Africa is ongoing. The only other region where bronze alloying developed was around present-day Zimbabwe, although little is known about the stimulus and dating of this technology.

It probably arose after the beginning of the maritime trade along the Indian Ocean, perhaps in the eleventh to twelfth centuries AD, and was used to make wire, beads, and simple two-sided mold castings. Brass, the alloy of copper and zinc, on the other hand, was used extensively for lost-wax casting in West Africa beginning around AD 1000, although the metal itself was imported into Africa from across the Sahara Desert and along the West and East African coasts.

There is no evidence of lost-wax casting outside West Africa, although casting traditions did exist. Open-faced or one-sided molds seem to have been used to cast copper into bar shapes as early as the seventh century AD in present-day Zambia. In the Zaïre-Zambia copper belt region, cross-shaped molds were made by the ninth to eleventh centuries AD in northern Zambia, but not until the fourteenth century in southeastern Zaïre. These ingots were then traded. Objects were made as the ingots or raw metal were hammer forged into sheet, rods, ribbon, and other shapes. Drawing copper into wire, a fabrication technique found in Central, Eastern, and Southern Africa, was used by the mid-second millennium. The history of its development and spread is unknown, although iron/steel draw plates for wire were found at Ingombe Ilede, Zambia, dating to the fourteenth to fifteenth centuries AD.

Gold objects tended to be produced by the same techniques as copper in a given region. Lost-wax casting of gold in West Africa, such as among the Asante of present-day Ghana, is particularly exquisite. Wire drawing of gold was also practiced in West Africa. At ancient Zimbabwe, gold was usually hammered to shape beads, wire, and sheet. Finally, there is no evidence that any objects were made of pure tin in Africa. Occasional ingots cast of tin are found in South Africa, presumably for used trade.

A critical part of African metallurgy that has not been discussed is the nontechnical – the social organization of labor, the use of space, and the esoteric knowledge, rituals, taboos, special clothing, and music involved. The innumerable processes of African iron and copper smelting, in particular, were complicated mixtures of technique, special knowledge, and ritual controlled

and designed by men to ensure success and circumvent danger and malevolence. This involved not only pleasing the ancestors, but countering the acts of sorcery that were perceived to be a threat to the process.

Central to this examination is the recognition that all social activity, including technology, must be explained and done so within a framework meaningful to the people involved. Questions concerning the sources of ore, how rocks become shiny metal, why some smelts are unsuccessful, and what slag is are answered in modern, Western societies by scientific principles of geology and engineering. In pre-colonial Africa, these questions were resolved through principles based largely on human physiology and social structure.

A compelling framework was offered recently to consider how many pre-colonial African societies explained metallurgical activities. This is based on two fundamental aspects of human experience – gender and age. Gender concerns the interaction of males and females through a life cycle, but focuses on one critical stage of life that is not shared. Women are capable of transformation and creation through their ability to give birth, a process that is interrupted by monthly periods of sterility and ends at menopause. The links between women, production, and reproduction are poignant. Male metal workers could only generate similar creative forces with which to transform rock into metal and then into objects by controlling and appropriating women's natural abilities through symbol, metaphor, and ritual.

The axis of age encompasses the relationships between youth and elders, as well as between the living and the dead. In many African cultures, the human life cycle involves the accumulation of wisdom and power through adulthood. Greatest power is acquired as an ancestor. Thus, elders have the expertise and knowledge to demand and exploit the labor of youth in most activities, including metallurgy; the ancestors have ultimate power over all significant activities of the living, particularly its reproduction. Integral to mining, smelting, and fabricating metal objects, therefore, was gaining and maintaining ancestral approval.

The cultural influences of gender and age were most obvious during iron and copper smelting – technologies of transformation and creation with many opportunities for failure. These influences were manifested in highly diverse ways. Often, smelting involved rituals and song that simulated significant times in the life of a productive woman, such as marriage, pregnancy, and birth. The Fipa of Tanzania, for example, adorned and treated a newly built iron smelting furnace as a bride who would have many children. The furnace was perceived as a “wife” to the iron smelters in many African cultures, such as the Phoka of Malawi. Furthermore, various parts of furnaces were often given the same names as female body parts, particularly those related to sexuality and birth. The Shona of Zimbabwe, the Chokwe of Angola, and others were more explicit and built their furnaces as women. They decorated the walls with breasts and scarification, denoting fertility, and the bloom sometimes came out between leg-like projections. Rituals also were used to consecrate new iron forges or tools which drew analogies between the anvil/hammer (the most important tool of a smith) and a second wife, such as among the Nyoro of Uganda, or a child, such as among the Ondulu of Angola.

Both age and gender strongly affected the roles played and choices made during metal working, including the significant influence of ancestral spirits, the technical and ritual expertise of elders, the work load of the youth, and the exclusion of women. Although women were often miners in cultures with labor shortages, all women, particularly pregnant or menstruating ones, were excluded from smelting operations. Prepubescent girls and postmenopausal women, however, sometimes participated in presmelting rituals or cooked and transported food to the smelters. Furthermore, strong taboos existed to prevent men from having sexual relations prior to a smelt. Such behavior represented infidelity to the furnace, and adultery was often thought to cause miscarriages in pregnant women. Furnaces were usually placed far away from villages to minimize this potential threat.

These rules of participation were designed to please the ancestors by preventing the presence of forces – uncontrolled fertility and temporary sterility – that might jeopardize a productive metallurgical operation. Young girls and postmenopausal women were not threatening because of their lack of fertility and active sexuality. The rules also served to separate metalworkers from the general public as people with special knowledge and capabilities. Many accomplished metalworkers became wealthy members of their societies, as well as important political figures.

Other forces influenced how a smelt proceeded and how failure was explained, including visible problems with the materials or technical steps used. In less obvious circumstances, however, a common explanation for failure was sorcery by jealous villagers or by competing metalworkers. Since iron, copper, bronze, brass, and gold workers were often relatively rich and powerful men, they sometimes became foci of envy. Actions to avert evil spells, therefore, involved meticulous attention to the preparation and placement of medicines in and around a furnace and, sometimes, a forge. Ethnographic and archaeological evidence reveal that the placement of medicines inside furnace pits has been practiced for two millennia. As a result of this integral part of the metallurgical process, metalworkers were often believed to be sorcerers and/or people with special powers. Particularly skilled metalworkers were regularly in demand by the general public for their abilities to heal and divine.

Two significant lessons – actually two sides of the same coin – may be learned from the study of African metallurgy (1) a technology can exhibit tremendous variation through time and across a continent and (2) a technology is a system that is at the same time technical, economic, social, ideological, and political. A technological system affects and is affected by the culture and society in which it operates such that a great diversity of associated behavior and knowledge may result over time and space. Unfortunately, all the complexity and variation of African metallurgy will never be fully appreciated and known, particularly as the elderly experts die with much of their precious knowledge untapped.

See Also

► Technology and Culture

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Metallurgy in Ancient Eastern Eurasia

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Background

Until recently, little evidence could be obtained to explain the emergence and spread of metal technology in the third and second millennia

BCE in the Eurasian Steppe where life was centered in kin-based with relatively independent agricultural or agropastoral communities. Archaeologists in central and eastern Eurasia have recently uncovered information about early metal use and production by residents of the steppe and the significance of this development in the area east of the Urals and west of the Yellow River. This is the area addressed in this entry.

Eurasia is a term given to the combined areas of Europe and Asia. Eurasia forms the largest landmass on the globe, or about 20,816,400 mile². Many geographers claim that this is one continent and therefore that Europe is merely a peninsula of Asia. But whatever one's conception of continent, the area extends from the Balkans to the Yellow Sea and links Europe and Asia. Lying between the 40th and 50th latitude of this enormous land belt is a steppe land with a fairly uniform terrain with an average altitude of between 500 and 1,000 m. Like the prairie across much of the midsection of the United States, this terrain is covered either by coarse grass or low woods. Only one mountain barrier with high forests, the Urals, crosses Eurasia in a north-south direction, giving rise to the nineteenth-century conception of two continents of Europe and Asia divided at the mountains. The Urals are, however, merely an interval, rather than an interruption, in the vast sweep of the Eurasian steppes.

Decades ago studies on the beginnings of metallurgy envisioned the setting in the centers of early civilizations, in Mesopotamia and Egypt in the West and China in the East, and early centers of production could be documented there, but not in between (Knauth, 1974; Moorey, 1985; Tylecote, 1992). Both the intellectual climate and the evidence available conceptualized the advent of metal use as a spontaneous occurrence in a single ancient society. But, given the discrepancy in start dates and distance between the Near East (beginning no later than the fifth millennium BCE) and the Far East (beginning at the earliest about 3000 BCE), there has been much speculation about what role, if any, Eurasia had in the process of transmission. Researchers asked

whether such a complex technology could be transmitted across the vast steppe to East Asia by the peoples of Eurasia or whether it was spontaneously generated in the Far East.

Sites investigated in Eurasia, that is, in the border provinces of present-day northern and western China, the Republic of the Altai, Kazakhstan, Mongolia, and Russia east of the Urals, in the past two decades document the production and use of metals as early as the late fourth and third millennia BCE (Chernykh, 1992, pp. 190–234, 2000; Frachetti, 2012; Grushin et al., 2009; Hanks, 2009; Hanks & Doonan, 2009; Houle, 2009; Linduff, 2003; Linduff, Rubin, & Shuyun, 2000; Pitman et al., 2013). Based on a synthesis of the current chronological and metallurgical information from the area, it is possible that the entire region, including north China, might be better understood as part of a larger sphere of interaction that produced metallurgical traditions that emerged during the late fourth to the second millennium BCE. Technological as well as typological differences found across the area may be explained by noting the availability of ores, use of artifacts, and social complexity and even the environment of the generative societies. It is clear that many regional traditions abound, but that movement of ideas as well as artifacts, and people, perhaps technicians more than whole groups, was likely and was a stimulus for the transfer and invention of the variety of technologies now known to have been employed in this vast area.

The Problem

At the eastern edge of the Asian continent, analysis of metallurgy has figured centrally, for its development was thought to signal the advent of societal complexity and especially “historic Chinese civilization.” In establishing ownership of the earliest bronze, priority was conventionally given to central China largely because it was where a high Bronze Age civilization eventually arose. The areas adjacent to ancient dynastic Chinese lands where early metallurgy was documented, even as distant as southern Siberia

and Mongolia, were seen as peripheral to it as independent centers of invention. The direction of exchange of people, ideas, artifacts, and/or technology in the area was a topic hotly debated in the past and is no better exemplified than by the dispute between Bernhard Karlgren (1945) and Max Loehr (1949a, 1949b) over bronze daggers and knives. They described the differences in the weapon and tool inventories of each area and agreed that there were two distinct traditions represented by diagnostic artifacts known from a limited number of excavations and from museum holdings. China was represented by straight-edged bronze knives; outward curving, hafted knives; and single-edged daggers with tangs decorated with conventional Chinese motifs, particularly *taotie* (animal mask) and dragon designs. The Eurasian (or Siberian) typology included socketed axes, curved knives with naturalistic images of animals on the pommels, and double-edged short swords, also often with recognizable animal designs on the handles (Fig. 1). The discussion was focused on issues of cultural primacy and the dating of the Siberian against the Chinese Bronze Age. Since no carbon dates were available then, the discussion rested on reasoning about typological sequencing. This debate has persisted in the literature for many decades.

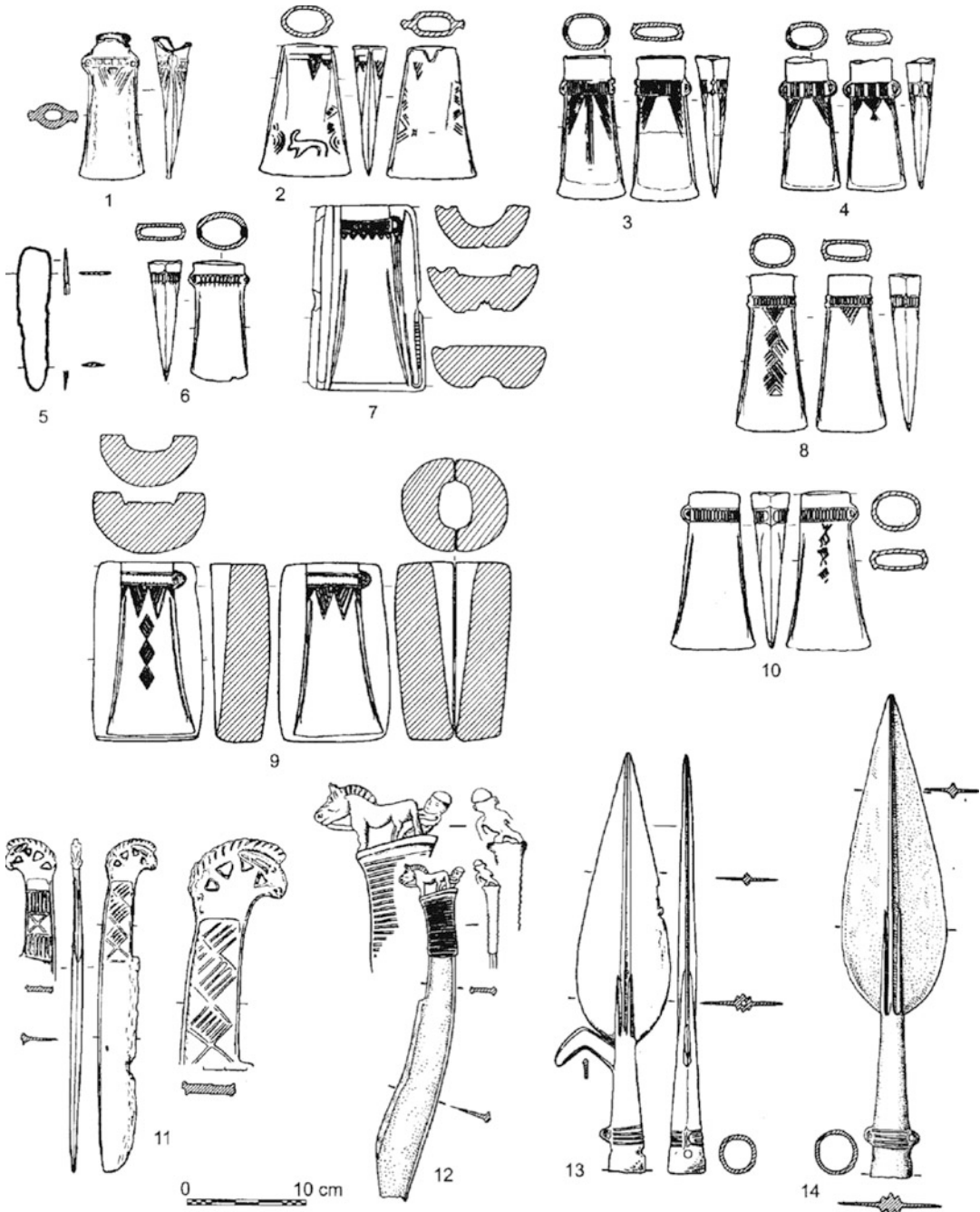
Study of the metal industry and proposals about who initiated the technology have been affected by mutual lack of information because of language barriers and especially by modern political borders and nationalistic sentiments. The Chinese and Russian studies, as well as the now-dated debate between Profs. Karlgren and Loehr, presented judgments about the direction of transmission for the technology that were based on comparisons of style of artifacts and on relative dating of each “host” culture. Their arguments, Karlgren as the champion of Chinese and Loehr of Siberian prototypes for certain artifacts and ultimately for the technology itself, were mounted at times when excavated, tested, and dated materials earlier than about 1250 BCE were lacking, so that only the fully developed phases of the second millennium BCE were studied.

Based on her own fieldwork and that of others in Russia and Kazakhstan, Legrand has reviewed the discussion, but not with an eye toward solving the debate over initial invention (2003, 2006). We now know that the “Karasuk” and “Andronovo” material does not represent the earliest use of bronze in either area and that the broadly defined dichotomous model developed by Karlgren and Loehr is far too simple to address the question of the emergence and spread of metallurgical technology, even in eastern Eurasia between the Altai Mountains and the Yellow River.

And, although archaeologists and metallurgists still debate the diffusionist and spontaneous generation models, new archaeological data, experimental work on production methods, the appearance of more C14 dates, and metallographic studies from both Russia and China permit a different way of thinking about the issue (Chernykh, 2000; Doonan & Hanks, 2009; Linduff, 2003; Pitman et al., 2013; Roberts, Thornton, & Piggott, 2009). After the breakup of the Soviet Union, both Kazakh and Mongolian Institutes of Archaeology have conducted their own investigations, and some of those results have been reported as well (Goriachev, 2003; Erdenebataar, 2003). These studies are the first in English to document carefully the earliest known use of bronze in each area.

In the current literature, there is another problem worth mentioning. Field archaeologists, whether trained in the Russian or Chinese intellectual tradition, for the most part have defined cultures according to pottery types and styles and discussed the transmission of technology accordingly by these “archaeological cultures.” The metallurgical scientists have looked at metallurgical traditions first and then connected them with cultures. The application of a single term to identify a “culture” such as the “Andronovo” in much of Eurasia generalizes to the point where its descriptive meaning is useless since it often ignores regional cultures and perhaps even very different traditions altogether (Korochkova & Stefanov, 2003).

For instance, bronze artifacts that follow the shape and style of ones called Andronovo or



Metallurgy in Ancient Eastern Eurasia, Fig. 1 Diagnostic types of copper and bronze object categories from the Seima-Turbino complexes (Asian centers) (From Linduff 2003, Fig. 1.10)

Seima-Turbino, such as trumpet-shaped earrings and socketed axes, have been excavated at a site called Huoshaogou, in Gansu Province in western China, and date from between 1900 and 1600

BCE (Linduff et al., 2000, pp. 15–19). Russian archaeologists might, on the basis of those objects, identify Huoshaogou as an Andronovo or Seima-Turbino culture site. On the other hand,

no Chinese archaeologist has labeled it thus, but rather consider it as part of a western extension of the “Yangshao” culture because the painted pottery found at Huoshaogou, they say, is a variant of the Yangshao diagnostic type known from the central Chinese heartland. Not only is the terminology of archaeological cultures true to neither “type” in this case, the application of these labels obscures the nature of the local setting. The site, its organization and use, shows that this community both produced metal artifacts and also imported metal items for burial. The issue here is not about to what “culture” they might belong, but how the local community was constituted and connected to traders, metalworkers, and each other. Clearly the site and its regional neighbors absorbed peoples and information from both their west and east, but are quite self-sufficient and distinct.

Or, similarly, there is no doubt that the Semireiche region in Kazakhstan is an important one for the development and transmission of metallurgical materials and technology throughout its immediate region as well as to its east, especially into what is now western China. Although several pottery traditions have been identified, there have been variously labeled Andronovo or Fedorovo, the distinctiveness of these subareas is argued for while recognizing how important large regional networks might have been to them (Frachetti, 2012; Goriachev, 2003; Linduff, *forthcoming*). Such a network has been determined with the excavation of a site where a massive mining effort was recently identified and dated in the late fourth or third millennium BCE at Kargaly (Chernykh, 2003). Kargaly is now known, for example, to have supplied large numbers of artifacts and raw materials to peoples living to the west of the Urals. Another such network probably connected patrons and metal manufacturers living in areas to the west and east of the great tin loads in the Altai Mountains (Chernykh, 1992). The territorial extent of these Eurasian trade networks is only beginning to be understood, but the amount of data now available allows us both to examine carefully local operations as well as to speculate on how individual societies might be connected to others.

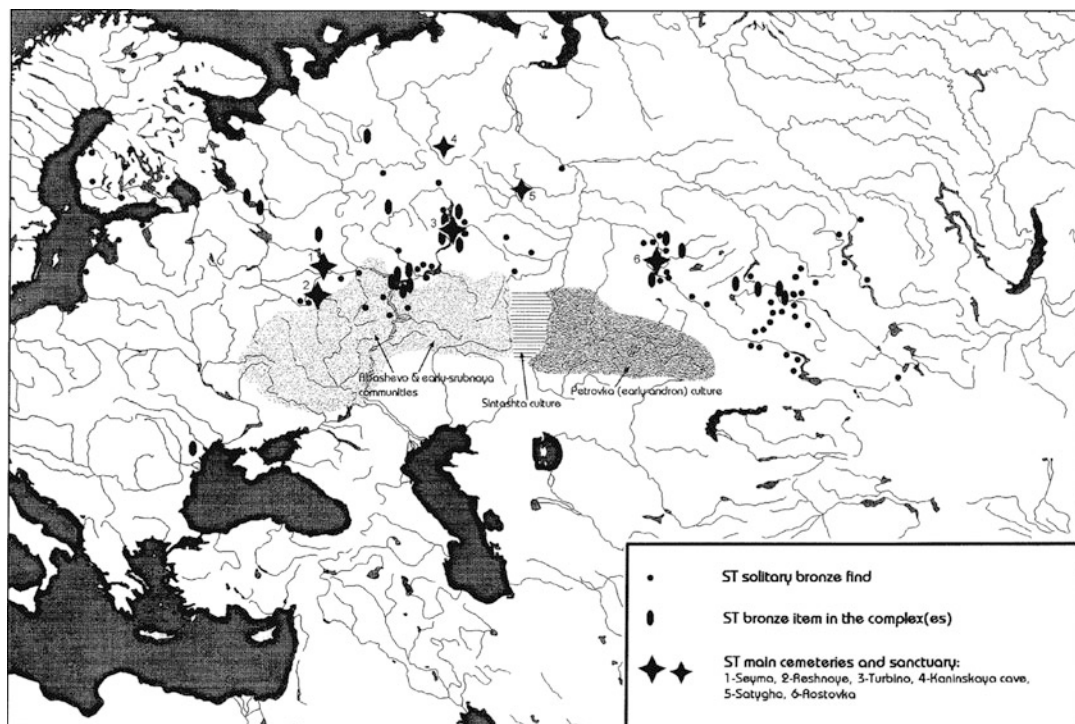
The Data from Southern Siberia, Kazakhstan, Mongolia, and the Altai

Debates and assessments of incipient metallurgy and its consequences in the ancient world now consider several crucial factors:

1. Knowledge of the presence of ores and the corollary existence or creation of trade networks
2. The presence of knowledgeable local and/or itinerant artisans who knew metals and their properties
3. A community able to support such workers, with a degree of social and/or ritual sophistication to create a demand for metal products
4. The ability to create temperature in furnaces high enough for smelting and refinement of ores and final castings

Many of the most sophisticated and earliest known metal-producing industries were apparently located in or near the more complex societies in the Near East where these products were used for many purposes ranging from utilitarian to luxury items for use in everyday activities to solemn rituals. The Eurasian metal period is on the whole later than that in western Asia.

The publication of Evgenii Chernykh’s texts and bibliographies on the early metallurgy in the USSR (Chernykh, 1992, 2000, 2003; Chernykh, Kuz’minykh, & Orlovskaya, 2003) and many reports on individual sites have provided data on excavated materials from the territories between the Near East and the current Chinese borders. In addition, more complete reports on copper- and bronze-using sites in Russia, especially those near the Ural Mountains, such as Arkaim and Sintashta–Petrovka (Gening, 1992; Zdanovich, 1997), have been published. Chernykh and his colleagues in Moscow have collected almost 2500 C14 dates from metal-using sites across Eurasia (Chernykh, Viola, & Orlovskaya, 2000). The map of the earliest known metal production from Chernykh’s essay (2003) shows quite clearly that metals were part of village life in Eurasia no later than the late fourth and third millennia BCE (Fig. 2).



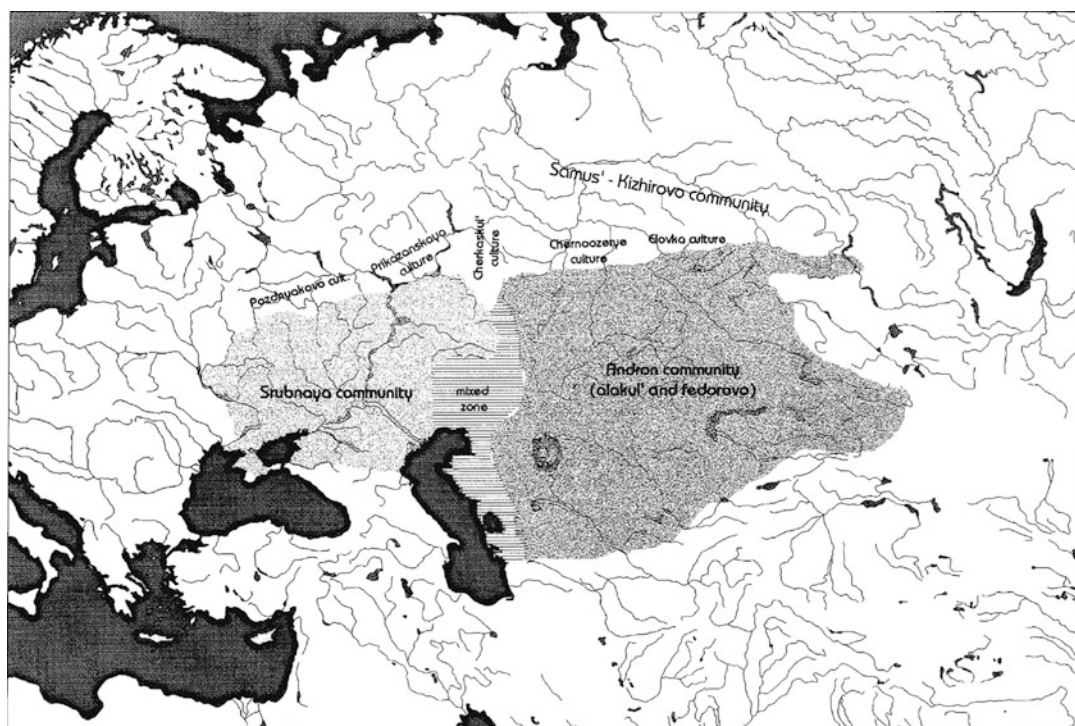
Metallurgy in Ancient Eastern Eurasia, Fig. 2 Borders of the Eurasian region and main archaeological cultures (The early/initial phase) (Linduff 2003)

Chernykh defined “metallurgical provinces” as large contiguous regions linked through shared utilization of morphologically defined ornaments, tools, and weapons; a common technology of metallurgical production; availability of or access to the same metallurgical resources often emerging into large trade networks; and comparable dating (Chernykh, 1992, pp. 7–16). These provinces cover distinct areas at different times and include discrete subareas of metallurgical knowledge and metalworking. What he calls the Eurasian metallurgical province (EMP) and its subcategory, called the Seima-Turbino chronological horizon, dated from the late fourth and third millennia BCE, or Late Bronze Age, are the most relevant here (Chernykh, 1992, p. 7; Fig. 3). Some artifacts, such as fishhooks, awls, rings, and bracelets, are ubiquitous in the Seima-Turbino contexts.

Although Kuz'mina challenged the method and details of dating this complex against the Andronovo (2003, pp. 37–84), there seems to be

little argument about the importance of the metallurgical development. The disagreements over the dating of each subarea complex depend at least in part on the methodology used to establish a chronology. Chernykh depends largely on C14 testing with calibration (Chernykh et al., 2000). Since carbon dates are never precise, Kuz'mina, for instance, proposes that the most reasonable dating can be derived from classification method using evolutionary-typological analysis (2003). Her system finds the Andronovo (and possibly the Fedorovo in Kazakhstan) and the Seima-Turbino synchronous in the seventeenth century BCE (2003). Many authors use a combination of both methods (Goriachev, 2003; Korochkova, 2003; Legrand, 2003).

More recently, however, regions called foci, or distinct centers of production, were also identified within the EMP (Chernykh, 1992). For example, the eastern region includes the Andronovo historico-cultural community and other archaeological cultures recognized



Metallurgy in Ancient Eastern Eurasia, Fig. 3 Borders of the Eurasian province and main archaeological cultures at the second phase (The period of stabilization) (Linduff 2003)

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previously by archaeologists in the southern Urals and central and northern and eastern Kazakhstan to the Altai and Tian Shan Mountains (Kuz'mina, 2003; Fig. 2.5). The significance of these regional centers is very evident in the study of subareas just east of the Ural Mountains (Korochkovo, 2003) and in eastern Kazakhstan (Goriachev, 2003) where small Andronovo/Fedorovo type metal objects have been excavated recently, and in western China where similar metal items have also been uncovered (Han & Sun, 2003; Mei, 2000, 2003). Although separated in many cases by large distances, analogies in the shapes and décor of these metal objects can and have been noted. In each case, however, regional peculiarities such as pottery types or décor and/or metallurgical traditions clearly mark important distinctions which Chernykh claims constitute subareas of a larger complex. For instance, unique types such as socketed axes with hatched triangles and rhombuses, forked-shank spearheads, and curved knives with animal (sheep

and horses) and human subjects on the pommel were made only in the eastern region in the Altai and Tian Shan. Because these items were used sparingly in burial and were unique in décor, they have been labeled “princely” artifacts (Chernykh, 1992, pp. 218–219). Currently available materials make clear these differences, while recognizing that there is an interchange throughout this region no later than the third and early second millennia BCE (Linduff, 2003).

Spectrographic analysis was carried out on all dated metal items from the Seima-Turbino area, and Chernykh attributes fundamental innovations in metallurgy and metalworking to this region at this time; his conclusions are based on analysis of the 422 metal objects and 30 casting molds excavated from burials. In the “eastern focus” area (i.e., up to the borders of present-day China), only two examples of arsenic–copper were found; all other examples were tin–bronze (all from Rudny Altai, Rostovka). The curved knives with horse figures on the hilts, for instance, are all

high-quality tin–bronze and were found by him only in the Altai. The vast quantity of tin ore in the Altai and clear evidence of tin mining no later than the early second millennium BCE in northern and eastern Kazakhstan (Stöllner, 2011) is given as the reason for such a concentration of tin–copper alloys in eastern and southern Siberia (Chernykh, 1992, pp. 224–226). By contrast, products typical of the western subarea were made from “pure” and arsenical copper and billon found in abundance in the Urals. And, although tin–copper and tin–arsenic–copper products were found throughout the EMP defined by Chernykh, only certain shapes such as ornately decorated Seima-Turbino socket axes were excavated in the western region, suggesting that the axes were supplied in a finished state (Chernykh, 1992, p. 224, 2003). Finally, Chernykh proposed that the Altai was the source of particular tool types and chemical compositions of tin–bronze and depictions of animals (Chernykh, 2000). In addition, jade and flint, bone tools, and protective armor are also exclusive to this area. The notion of an EMP can be extended to include Xinjiang and even probably Gansu and various of the northern provinces in present-day China, given the materials found and analyzed there in the past couple of decades (Han & Sun, 2000, 2003; Linduff, 1997; Linduff et al., 2000, pp. 1–29; Mei, 2000, 2003).

No one doubts that Xinjiang was a plausible point of transmission from Kazakhstan, but now we can broaden the geographic area of attention and think again about from where and how transfers might have taken place. Evidence from the region to the north and west periphery of the Chinese Yangshao and Longshan and subsequent dynastic settlements of the Central Plain during the third and second millennia BCE, more particularly, the area north of the eastern Altai Mountains during the Bronze Age, is now beginning to be available. Although contiguous to the Chinese sphere, developments there have not yet been entered centrally into the debate about the advent of eastern Eurasian or Chinese metallurgy. Recently though, metal artifacts of steppic, local, and/or hybrid models and aesthetics have been found in mortuary settings there, and much attention has been paid by Russian and Mongolian

archaeologists to categorizing their variants (Grushin et al., 2009; Kovalev, 2005; Kovalev & Erdenebaatar, 2009). But regardless of what “types” of artifacts have been located and to what archaeological culture they belonged, metallurgical technology was known and used there, at early dates (c. 2800–1500 BCE), suggesting that the transfer of technological ideas, people with technological knowledge, and/or metal artifacts in the region was possible and perhaps common across a broader region than Xinjiang.

In addition, evidence of production sites has been documented under the Great Bend of the Yellow River dating from the Miaodigou (c. 2500–2300 BCE) and Longshan phases (c. 2300–1900 BCE) (Linduff et al., 2000). In Shanxi at the site of Taosi, three copper items were found in dated contexts; at Zhoujiazhuang copper residue was found; and at Yujialing copper residue from the smelting process has been located – all dating from about 2300–1900 BCE or earlier. And, more recently, refined copper ores have been excavated in Shanxi in the Yuncheng Basin (on the slopes of Zhongtiao Mountain) that are dated from about 1900 to 1600 BCE (Dai Xiangming, personal communication, February 17, 2014), or dates comparable to those from Xinjiang and Gansu.

In this region, the team members have found mining pits/wells and mining tools dating to the same period. Copper residue (slag) was found at Yujialing with pottery sherds dated to between 2300 and 1800 BCE (Longshan period), and others coexisted with Erligang sherds (1900–1600 BCE). Recent carbon dates from the precise context in which the Yujialing slag belongs, but does not confirm if there was copper production earlier there, although the excavators believe it is possible or even probable since copper slag has been discovered in an ash pit at Zhoujiazhuang (near Xi’an) where dates are confirmed at between 2300 and 1900 BCE.

Moreover, at Shishulin (c. 1800–1600 BCE) and at Xiwubi (c. 1500–1350 BCE) in the same Yuncheng Basin, experimentation with metal production continued and has been documented throughout the period from c. 1800 to c. 1350 BCE. All of the finds were from ash pits, and in

the preliminary sample testing, these remains appear to be residue from smelting and refining copper ore, although copper ore was not found. Smelting and refining copper ore were possibly local activities, but so far this is still a hypothesis and more direct evidences, such as kilns or ovens, special containers, tools, large amounts of ore residue after smelting, workshop areas, and so on, are needed to confirm conclusively the existence of a local practice. The excavators remain open to the possibility that refining occurred at these sites or nearby (Dai Xiangming, personal communication, February 17, 2014).

This evidence provides dates and evidence for local processing of ores that challenge the earliest dates from Xinjiang through where most have thought the technology was transmitted. Even more surprising, brass (copper and zinc) items have been located in dated contexts in Jiangzhai near Xi'an to no later than the fourth millennium BCE (Fan Xiaopan, personal communication, July, 2013). Both the location and early dates for production, moreover, suggest that in Shanxi and Shaanxi, experimentation was perhaps earlier than in Xinjiang and, importantly, also suggest that we look at a broader area for contact and exchange of knowledge of the technology, no matter how it was used locally.

Moreover, knowledge of the metal-using sites in Mongolia creates a distribution in Eastern Asia and Eastern Eurasia that is wider than previously documented, and thereby implies that there were multiple routes of transmission of metallurgical knowledge throughout eastern Asia, including into present-day China. Both Mei (2009, pp. 219–223) and Linduff (1995, 2000) have proposed that the range of technology known in sites in western China suggests that experimentation commonly took place at the local level in the third and second millennia. Alternatively, such metal artifacts could have been both produced locally and imported. In Mongolia, although the materials have not been tested, the same pattern of selection appears to hold, at least with regard to type. Moreover, in the far northeast of present-day China, there may have been yet another point of transmission and that has been suggested by Shelach (2009).

The Data from the Northern Zone of China

Syntheses that investigate China usually view the archaeological landscape during the fourth millennium BCE as a mosaic of regional groups that interacted with each other (Chang, 1986). When dealing with the period of early metal use, however, most Chinese archaeologists have accepted a traditional model which regards the Central Plain of northern China as the dynamic center of social, political, and technological change and proposes that complex societies emerged in Asia through a process of political expansion and cultural diffusion from the Yellow River Basin (An, 1982). The elevated position of metal artifacts as well as the highly specialized and sophisticated multipiece mold technology developed to produce them in early Chinese society has led to the assumption/conclusion that the commencement of metallurgy in East Asia was to be found inside the early Chinese cultural, and/or even the political sphere. Now this conclusion has been reexamined because there is adequate information to show that metal artifacts were locally produced in enough volume to confirm their regular use all across the Northern Zone. Moreover, the types of objects found in this region as well as the component percentages of metals in the alloy correspond to metal types and alloying formulae found in the EMP, including both arsenic- and tin-bronzes (Sun & Han, 1997), and suggest that the advent of metallurgy in this region was not a separate occurrence.

Over the past two decades, articles about more than 70 sites that can be dated either by C14 and/or by archaeological context earlier than 1500 BCE have been published. These sites yielded metal artifacts and/or metal production materials such as crucibles or slag, and so forth. These sites date to the late fourth and third millennia BCE (Linduff, 1997, pp. 306–418; Linduff & Mei, 2012; Mei, 2000). The earliest metal-using communities are in Qijia/Siba sites in Gansu, with comparable sites in Xinjiang in the west, and others in Shandong, Liaoning, and Inner Mongolia in the east and north, and in the Central Plain in the lowest levels at Erlitou.

Because several levels of excavations are C14 dated and those dates have been matched up to ceramic types and styles, chronologies are more secure. An approximate chronological correspondence between the sites in the earlier eastern Eurasian Steppe and China is now clear and suggests that the emergence of metallurgy was supraregional (Linduff & Mei, 2012; Linduff et al., 2000).

Analysis of both the Chinese and Russian data, including metallic composition, casting technology, as well as types and uses in the period from about 3000 to 1500 BCE, has led to some surprising observations about the advent of metallurgy in eastern Asia (Barnard, 1993, pp. 3–48, 1987, pp. 3–37; Linduff, 1997, 1998, pp. 619–643). First, we can see that one of the most striking, as well as usual, additions to late Neolithic village life in northeastern Asia as far east as the Russian Far East was the use of metals. Sites where metals (including copper as well as alloyed metals) were first used and manufactured are located across a large area, showing that the growth of the industry did not solely, or even primarily, occur in the Central Plain. Moreover, preliminary observations on the process and patterns of the use of the technology are both shared and diverse (Siba versus Erlitou) (Sun et al., 2000).

Areas in China where metallurgical knowledge was in use emerged near ore sources of metals, especially copper in several combinations. For instance, arsenical bronzes produced in Gansu at Siba sites must have been manufactured by exploiting local arsenical copper resources still available in present-day Gansu. All areas developed a taste for items made from “pure” copper and copper alloys, and gold items have been found in the northeast and northwest China. Trumpet-shaped earrings, for instance, have been found all over eastern Eurasia and northern China and were made from copper, tin-bronze, as well as gold and silver according to the local preference. The lack of consistency in formulae suggests that knowledge was gained from several sources and not through local invention (Han & Sun, 2000, 2003; Mei, 2003).

In contexts where manufactured metal artifacts have been found in China, excavated villages have yielded evidence of both cultivated crops and domesticated animals, as well as the continued practice of hunting with improved arrowheads made of bronze, especially in the northeast. Chernykh’s fanciful speculation that the Seima-Turbino was formed through a fusion of metallurgists and warrior horse riders of the forest zones of the Altai and eastern Siberian taiga mobile hunters (1992) is suggested in the recent excavations of the village at Gorny (Chernykh, 1998), Kargaly (Chernykh, 1997, 2003), and many others including Arkaim and related sites (Zdanovich, 1997). Located close to vast resources of ores in the Urals, these excavations reveal that isolated groups of miners and metallurgists worked in specialized communities for many generations supplying patrons across western, and possibly eastern, Eurasia.

General Observations

The many shared traits discussed above suggest that there were “metallurgical networks” of some type, perhaps loosely connected. The region is linked through comparable artifact types, by closeness to ores, and by shared metallurgical technologies not easily transmitted without movement of craft workers or even groups of travelers. The consistently local character of pottery types and styles in subareas, as well as the appearance of metal items with affinities to cultural debris from Bronze Age southern Siberia, has suggested that there was movement into the area of western China, likely bronze-producing peoples of Andronovo background from eastern Kazakhstan and/or Transbaikalia (Ke, 1998; Linduff, 1998; Mei, 2000; Kuz'mina, 2000) and through southern Mongolia (see above; Linduff, forthcoming). Although animal sacrifice signified status and/or leadership in burial and metal items included tools, weapons, and personal ornaments associated with individuating societies in the region of Gansu (Linduff, 1997), metal items ultimately were used to identify only elite

members of a centralized political unit at Erlitou in the center of early dynastic China (Linduff, 2000). Kuz'mina suggested (2003) that the appearance of wheeled transport, metallurgy, and use and/or breeding of horses signal not only movement of ideas, technology, and perhaps peoples but also significant societal change, often to a more complex social order.

This change evidenced and discussed for the earlier to middle second millennium BCE was not a one-time affair. That was not the only period of interchange between the peoples of western China and points west. Continued stimulation, moving in both directions, can be witnessed in the later second and early first millennia BCE (Legrand, 2003). Nor are the border regions of present-day western China the limit of that exchange system. Both local pottery and early metal artifacts suggest that knowledge of metallurgical traditions and artifact types extended into northeastern China (Linduff et al., 2000) and into what is now the Russian Far East (Konkova, 2002).

Nevertheless, when considering the advent of metallurgy in the late fourth and third millennia BCE, all the criteria of the EMP defined by Chernykh are found in the “Chinese” contexts. If separated from modern nationalistic and centric views of ancient culture and considered as part of a larger metallurgical context, even the multipiece mold casting method developed in the late second millennium BCE at Erlitou, seen as a hallmark invention of early dynastic China, may be seen as a local technological variation within the easternmost Eurasian territory made for specialized ritual use.

Most recently the “culture”-based models are being inverted in favor of looking at places where technologies spread, as Potts suggests (2007, p. 6), enabling the production of distinctive, culturally local products and/or mixed assemblages of artifacts that might otherwise escape notice and not arouse any suspicion of intercultural contact and focus on the distinctiveness of ways of doing things, as opposed to end products, we may and do find another picture. This leads the discussion to identifying the difference between

“cultural patterning” at the level of local praxis and “technological style” as an external or formal extrinsic manifestation (Potts, 2007, p. 6), or language and word, as the linguist would say. This circumstance would certainly describe the ultimate response to the transmission of metallurgical knowledge in the center of dynastic China in the late second millennium BCE as has been suggested (Linduff, 2000).

Although one of the most persistent as well as unconvincing assumptions in the earlier literature is that “cultures” interacted, that somehow the Chinese interacted with “cultures” of Siberia, for instance. But dependent on the time and place of origin and use the introduction and production of metal artifacts may be thought of as products of “shared social fields” (Wolf, 1982, p. 76) or “technoscapes,” as Appadurai suggests for the modern world (1996, p. 33). In this sense, “social fields” would be inextricably involved with other groups in weblike connections in which technologies such as metallurgy were shared and modified by others caught up in the same process (Kohl, 2008, p. 496). This model shifts emphasis away from “cultural” interaction or meta-theorizing to sharing within “social fields” or “technoscapes” that, of course, require close examination of local contexts. This is a view proposed in different ways in several very recent studies (Hanks, 2009; Frachetti, 2012; Linduff, forthcoming) and one that is being tested and debated currently.

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Metallurgy in Arabia

Gerd Weisgerber

Geology

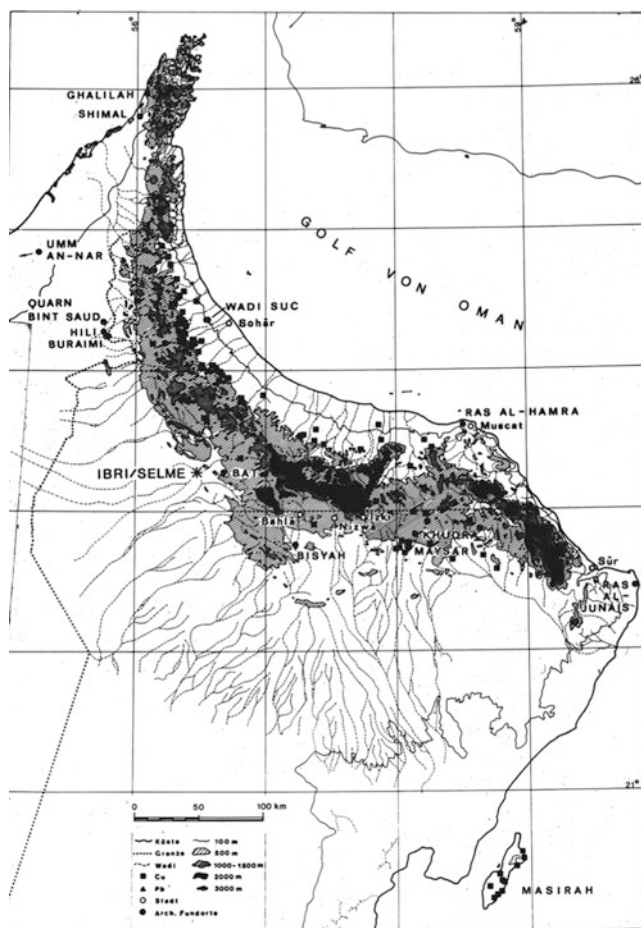
The Arabian Peninsula as a whole is rich in metalliferous ores and minerals, especially in gold, lead and silver, and copper. In the North there are the copper deposits of Feinan and Timna (Hauptmann, 2000; Weisgerber, 2006); the Yemen also has many. There are many ore bodies in the Hedjaz Mountain range in the west of Saudi Arabia that are nearly archaeologically unexplored. In the early 1980s three visits to ancient mining and smelting sites were undertaken (Hester, Hamilton, Rahbini, Eskoubi, & Khan, 1984).

So far only the copper deposits of Oman and their exploitation during the last 5,000 years have been studied (Fig. 1). There is not only the Early Bronze Age production of the third millennium connected with the Sumerian copper country of Magan, but also the Iron Age and the Early Islamic productions represent real industrial scale production.

Copper ores occur in two occurrences of ophiolite in the Oman mountains: in the Semail Nappe formation and on Masirah Island (Peters, 2000). Copper deposits are formed by irregular mineralization at the transition zone of peridotite to gabbro. Of the 44 locations studied until 1975 more than the half comprise shear zones with secondary copper minerals in gabbro and peridotite (Goettler, Firth, & Huston, 1976, p. 47; Hauptmann, Weisgerber, & Bachmann, 1988). Other copper deposits occur in ophiolitic pillow lavas. These stratified deposits sometimes are indicated by gossans, a rusty-red mineralization originating from the weathering of massive cupriferous sulphides (Coleman, Huston, El-Boushi, Al-Hinai, & Bailey, 1979, 1981; Hauptmann, 1985). In total the entire mountain

Metallurgy in Arabia,

Fig. 1 Copper deposits (*squares*) and important Bronze Age (third to second millennium BCE) find spots (*dots*) in Oman (scale 100 km)



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chains of Oman and those in the Masirah Island have more than 150 copper ore deposits (Goettler et al., 1976; Hauptmann et al.; Peters, 2000). They were newly discovered either by copper slags or by the red colour of their gossan (Fig. 2).

Except for a few big ones, most of the deposits in Oman are small. Small green showings indicate veins of the copper ore, e.g. malachite. They were mainly exploited during the Chalcolithic and the Bronze Age, between 3000 and 1300 BCE. During the Iron Age and probably during medieval times, the large deposits under the gossans were preferred, perhaps mainly in the enrichment zones.

Therefore most copper production sites show more than one period of production. But today no

site shows the whole spectrum of ruins – from mine to cemetery.

The Chalcolithic

There are some rare metal finds in the shell middens of the Neolithic found of Oman. But in the following Hafit period more metal occurs in the tombs. During this time copper production started. The oldest slags come from Batin in the Wadi Nam near Ibra (Fig. 3). They indicate local metal production (Yule & Weisgerber, 1996). In the new burial cairns all over the country metal finds are standard but beside the new metal finds flint tools still occur. In a not plundered tomb under the Umm un Nar fortress at Maysar-25

Metallurgy in Arabia,

Fig. 2 'Arja. The *red* gossan on *top* of the copper deposit results from the weathering and oxidizing of mainly chalcopyrite. This ore body recently has been completely removed by modern opencast mining



Metallurgy in Arabia,

Fig. 3 Batin in Wadi Nam near Ibra has the oldest slag. As is typical for the third millennium, the slag had to be crushed to expose and collect the copper drops and prills (scale 10 cm)



(Weisgerber, 1981, p. 198) there was an untouched burial with two metal needles (Fig. 4).

The Early Bronze Age

Sumer in Mesopotamia from 2500 to 1800 BCE received a large portion of its copper from a country called Magan. Business transactions were written on cuneiform clay tablets. Ships from Dilmun/Bahrain, Magan/Oman, and Meluhha/India at the time of king Sargon (about 2400 BCE) docked at Akkad were unloaded, reloaded, and prepared to start for the next several months' journey. For their exports the merchants intended to exchange, in addition to copper,

Afghani lapis lazuli, gold, cornelian, and exotic kinds of wood from India (Heimpel, 1987). From Magan came copper and black diorite. Usually the ships would make a stopover in the trade emporium at Dilmun/Bahrain, a well-known source of fresh water, which probably had full control over the seafaring in the Gulf (Bibby, 1970; Cleuziou, 2003; Potts et al. 1986, 1992, 2003; Weisgerber, 1983, 1986).

From Dilmun ships connected Magan for the first time probably at the small Island of Umm an-Nar off the coast of today's Abu Dhabi. Here the inhabitants of a small village had become extremely rich by transit trade, at least if one regards their large tombs with collective burials. They probably controlled the export of Magan's

Metallurgy in Arabia,

Fig. 4 Maysar-25, grave 1. Beside a typical Hafit vessel the grave contained two caramel coloured flint flakes, two copper needles, and beads

**Metallurgy in Arabia,**

Fig. 5 Nujum near Bidbid. These Bronze Age stone tools were lying around a trench mine



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copper. But the ships may have had stopovers also at other islands in the south (Carter, 2003). Bands of porters and caravans of donkeys brought the copper from the Oman mountain range to the island.

During the Early Bronze Age oxidic and carbonate ores were exploited. The Magan miners used stone hammers but had also metal chisels to break the rock. Good examples for mines of this time are the trench mines at Wadi Miadin and Nujum near Bidbid (Figs. 5 and 6). In addition to the local metal it seems that foreign copper was also in use (Prange, 2001; Weeks, 2003a).

The ores had to be reduced by charcoal with heat above 1,100 °C. Smelting happened in small free-standing pear-shaped and knee-high furnaces built of clay. In the walls these furnaces had holes for artificial ventilation probably by

bellows. The copper ores became reduced in the heat by the charcoal to metal (Figs. 7, 8, and 9). All remains such as fist-sized crushing stones, slag, ash- and fireplaces, holes beside them, fragments of furnaces and of crucibles, metal scrap, and an ingot hoard were excavated in the 4,000-year-old al Maysar-1 in the Wadi Samad south of the oasis village al-Maysar (Hauptmann, 1985; Weisgerber, 1981). The copper finds were made of local metal but not the ingots (Prange, 2001). Inside of one house stood a large anvil stone surrounded by several fireplaces (Fig. 10). Finally the fluid metal had to be poured in a flat hole in the ground, and after cooling the ingots got their typical planoconvex shape (Fig. 11).

The site of Maysar-1 produced more than copper. There were also a pottery kiln, manufactories for soft stone vessels (steatite, chlorite),

Metallurgy in Arabia,**Fig. 6** Wadi Miadin.

A most impressive several hundred metres long trench mine in the Wadi Ma'adin is a good example of shallow mining in the Bronze Age

**Metallurgy in Arabia,****Fig. 7** Maysar-1. Furnace

fragments with fragmentary holes indicate the use of bellows to increase the heat for smelting

**Metallurgy in Arabia,**

Fig. 8 Maysar-1. The mass of furnace fragments (*left*) in comparison with the few pottery sherds, both are the content of the same excavation square



Metallurgy in Arabia,

Fig. 9 Based on many fragments a pear-shaped smelting furnace could be reconstructed for the third millennium BCE. But in contrast to this artist's view the bellows most probably were simple skin bellows

**Metallurgy in Arabia,**

Fig. 10 Maysar-1, House 6. Fireplaces and an anvil stone indicate a workshop



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and evidence of agriculture. The oasis garden of Maysar-1 is the oldest preserved oasis in all Arabia. The dams to improve irrigation must also be mentioned (Hastings, Humphries, & Meadow, 1975; Weisgerber & Yule, 2003).

Building towers, organizing mining, smelting, and trading of copper depend on competent leaders and led finally to an elite which used seals (Fig. 12). Tower tombs are the monuments they built to house themselves after death.

In trade with Mesopotamia and the Indian subcontinent copper from Oman played a key role. But, Magan also became dependent on these contacts. When it lost the market both because of a competitor with higher technology resulting in a much cheaper copper

production at Alashia/Cyprus and when the Indian partner ceased to arrive because of their own internal political, social and cultural decline, then the end of the Magan civilization arrived.

The Middle and Late Bronze Age

Traces of second millennium smelting are rare. But they show that the same types of ore and smelting furnaces were used as before. The best information comes indirectly from the rich metal finds. Villages are nearly unknown (Cleuziou, 1981; Velde, 2003). But Wadi Suq tombs among Late Iron Age cemeteries indicate some



Metallurgy in Arabia, Fig. 11 Maysar-1, House 4, Locus 31. Between two fireplaces in a small depression a hoard of 6 kg of copper ingots was found in 1981. Only one ingot was complete

kind of occupation of the same oasis areas also during that period.

The rich community grave of Al Wasit (Wadi Jizzi) had 50 soft stone vessels and 16 swords and daggers and 42 spearheads. They probably are of local production as proved by the many tons of slag between the houses of today's village. But as most of the weapons are of pure Omani copper it is obvious that in those days tin for bronze was hardly available even for elites (Fig. 13) (al-Shanfari & Weisgerber, 1989, pl. 5; Prange, 2001; Weisgerber, 1991).

Some hundred years later the evidence had changed. In a thirteenth century warrior tomb at Nizwa the types of weapons correspond to those of that time elsewhere in the Near East, but now they are of bronze (al-Shanfari & Weisgerber,



Metallurgy in Arabia, Fig. 12 Impressions of a three-sided 4,000-years-old prism seal from the debris of house 4 of Maysar-1. The impressions show sheep, goat, dog, ibex, and scorpion, but most interesting is the humped bull in the middle (Indian zebu)

1989). Tin had become available again as demonstrated by some hundred bronze bangles of the Ibri/Selme hoard (Yule & Weisgerber, 2001).

The Iron Age

Beginning during the twelfth century BCE, large copper production restarts most probably with new kinds of ores possibly from the enrichment zone of the massive ore bodies (Prange, 2001; Weeks, 2003b; Weisgerber, 1988). The Cyprus multiple step chalcopryrite smelting technique which made Cyprus what amounted to a 'global copper player' in those days arrived in Oman (as it did also in the Alps). Cyprus lost its predominance and in Oman copper production continued or restarted on a large-scale. There is no large medieval smelting site without a predecessor of that period because both partly used the same ore bodies. The smelters are situated near the ore body but never as close as the later medieval ones. The smelting debris results in large tapped slag cakes of up to 10 kg. Only furnace fragments were found in Wadi Qatof (Fig. 14). We know no details about the Iron Age smelting processes.



Metallurgy in Arabia, Fig. 13 Al Wasit in the Wadi Jizzi. This collection of swords and daggers of copper were found in an extremely rich community tomb

Metallurgy in Arabia, Fig. 14 Wadi Qatof. On the rather low Iron Age slag heaps well-fired fragments of furnaces could be collected



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The largest and highest slag heap of that period is at Raki 2 near Yankul (Fig. 15). The site is located near the gossans of two large copper deposits, but they mainly used another ore location at Loch Bab. The large settlement site Raki 2 specialized in the production of copper from around 1200 until 800 BCE (Table 1). Slag cakes were used like stone slabs for constructing house walls. These often were built on top of slag piles (Weisgerber & Yule, 1999; Yule & Weisgerber, 1996) (Fig. 16). At Semdah or Lasail the Iron Age

slag heaps cover areas near the entrance to the sites. At Wadi Miadin a fortification building of that period controls the mining and smelting activities as does the fort of Qarn al Muallaq at 'Arja. Fortresses all over Oman controlled the new villages which had been created after the installation of a new subterranean system of water supply – the ► [qanat](#) or falaj system. The typical stone built hut tombs often survived near smelting sites, e.g. the largest cemeteries known with more than 100 hut tombs lay at the copper sites near Gebel Saleli and



Metallurgy in Arabia, Fig. 15 Raki 2 near Yankul. Here a more than 4-m high slag heap represents the highest Iron Age dump of smelting waste

Bilad al Maaidin, but they also occur at Mullaq. The tombs give a strong indication for a long lasting Iron Age copper production, although scanty habitation remains.

After the first half of the first millennium BCE copper production in Oman seems to have been interrupted for a while. For the Samad period only weak hints exist. But at ‘Arja there are indications of possible Sasanian occupation.

The Early Islamic Period

On first view nearly all smelting sites checked in Oman date to the Early Islamic period, because this was the latest metallurgically active period, and the ruins are therefore rather undisturbed (Weisgerber, 1993). This provides a great opportunity because in other parts of the world, like Central Europe and in the Mediterranean, hardly anything is known about mining and smelting techniques of that period.

Metallurgy in Arabia, Table 1 Generalized chronology

Chalcolithic	(Hafit Period)	3200–2500 BCE
Early Bronze Age	(Umm an-Nar Period)	2500–1800 BCE
Middle Bronze Age	(Wadi Suq Period)	1800–1300 BCE
Late Bronze Age/Early Iron Age	(Nizwa Period)	1300–1200 BCE
Iron Age	(Lizq/Rumeilah Period)	1200–300 BCE
Late Iron Age	(Samad Period)	300 BCE–AD 600
Early Islamic Period	AD 600–1100	
Middle Islamic Period	AD 1100–1500	
Late Islamic Period	Since AD 1500	

When the new mines at Lasail and ‘Arja in the Wadi Jizzi were reopened at the beginning of the 1980s insights into the old mines became possible (Fig. 17). At a depth of 65 m a gallery supported by wooden props was detected. Fragments of windlasses in that depth showed that the medieval mines were entered and ores were hauled up through vertical shafts; this was also true at ‘Arja.

Excavations in ‘Arja and Bayda yielded an interesting infrastructure (Costa & Wilkinson, 1987) – a relatively well-preserved battery of three roasting pits to burn the sulphur out of the ores and two smelting furnaces. The roasting pits consist of three or more chambers which apparently were used in turn (Weisgerber, 1987) (Figs. 18 and 19). Parallels can be found in the book by Georgius Agricola from 1556 (Agricola, 1950). The backs of furnaces stood up to 1.40 m in height and had an interior diameter of 0.60 m. They were operated probably with natural wind draught by means of clay nozzles (tuyères). At their front metal and slag were tapped into pits (Figs. 20 and 21). In front of many furnaces, which show traces of several repairs or reconstructions, up to 6,000 tons of slag may occur (Fig. 22), giving an idea of the thousands of tons of copper produced in medieval Oman (Hauptmann, 1985; Weisgerber, 1978a, 1980a, 1980b, 1981).

Metallurgy in Arabia,

Fig. 16 Raki 2, near Yankul. Ruins of a house on top of a stratified heap of crushed slag

**Metallurgy in Arabia,**

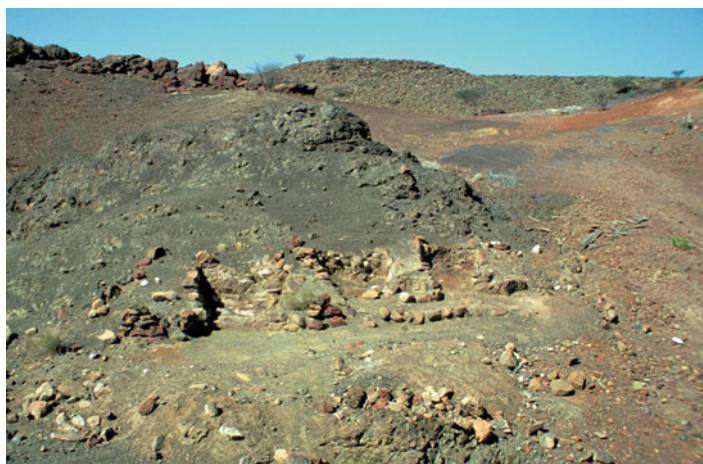
Fig. 17 'Arja-Bayda. In the 1990s the small gossan of Bayda became exploited by a large opencast mine. In the walls several medieval galleries can be seen



M

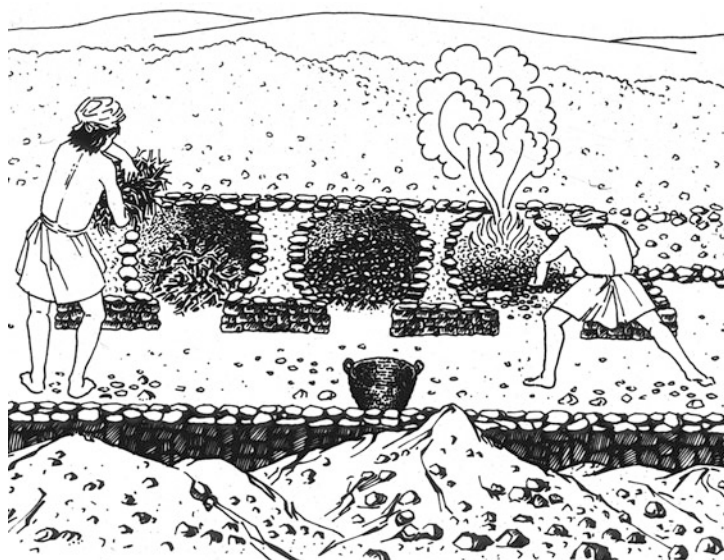
Metallurgy in Arabia,

Fig. 18 'Arja-Bayda. Battery of roasting installations. Three chambers are cut in the rock and framed by local stones



Metallurgy in Arabia,

Fig. 19 Artist's view of a three-chambered early medieval roasting installation



Metallurgy in Arabia,

Fig. 20 'Arja. Early medieval smelting furnace 'Arja 103 after excavation. Note the closed forefront above the opening which probably had to be opened and re-closed for each smelting process and the ramp to the right for going to the top of the furnace to fill in charcoal and ores



One may imagine that the long mining and smelting activities of the Early Islamic period over centuries led to a complete devastation of Oman's vegetation because millions and millions of trees were needed both in underground mining and in the roasting and smelting work on the ground (Eckstein, Liese, & Stieber, 1987).

The Middle and Late Islamic Period

In the area around the old well of 'Arja fields of slag cover the plain. There are no heaps or dumps but flat covers (Fig. 23). The complete slag pieces

have a diameter of about 25–30 cm. The bottom is concave, the sides curved. This slag of 13–16 kg was produced in a bowl furnace dug into the ground (Figs. 24 and 25). Copper smelting in bowl furnaces took place from the Middle Islamic times to the nineteenth century (Weisgerber, 1978b).

There is no mining activity which could be attributed to these periods. But all the Early Islamic slag heaps are marked by more or less circular depressions irregularly scattered in the dumps. Slag analyses confirm that they are high in copper (1–4 %; Goettler et al., 1976, p. 47). Remains of copper and copper-matte in the Early

Metallurgy in Arabia,

Fig. 21 Scheme of an early medieval smelting furnace

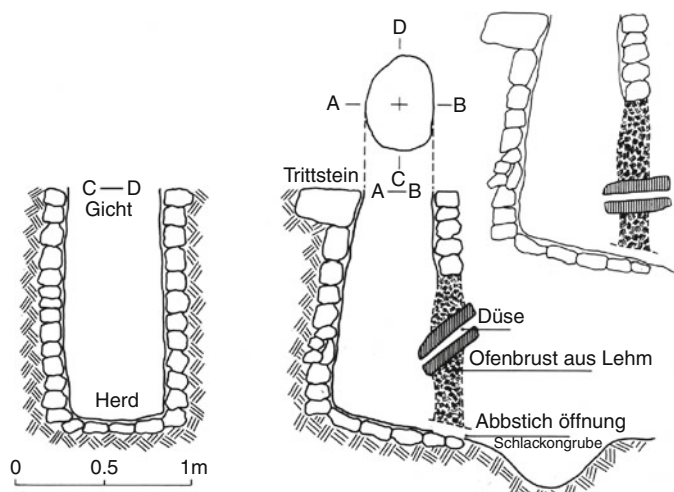
**Metallurgy in Arabia,**

Fig. 22 Tawi Raki. More than 60,000 tons of smelting remains at many production units prove that here an extremely successful mining venture had taken place. The slag heaps are clearly separated from each other. Individual smelting firms have their own smelting furnace and roaster. Between them a lot of houses can be seen



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Metallurgy in Arabia,

Fig. 23 'Arja. In the plain around Tawi 'Arja flat fields of bowl slag indicate the late and post-medieval production of copper



Metallurgy in Arabia,

Fig. 24 'Arja. At Tawi 'Arja some complete slag cakes helped to reconstruct the bowl furnace. To remove the copper ingot the lower edge of the slag had to be smashed away

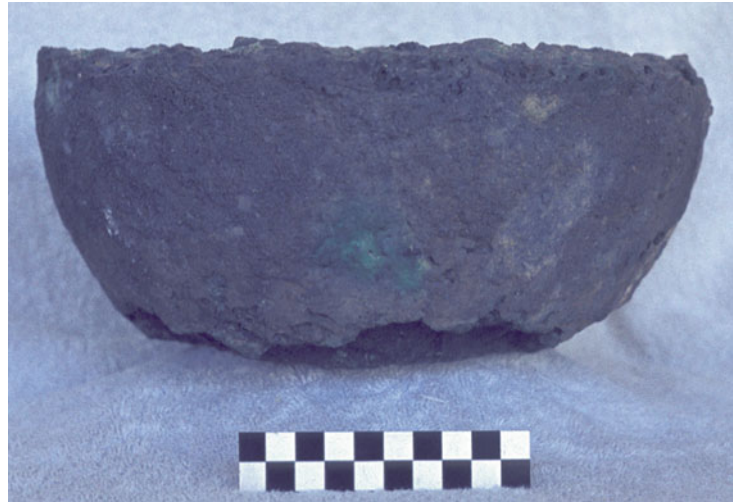
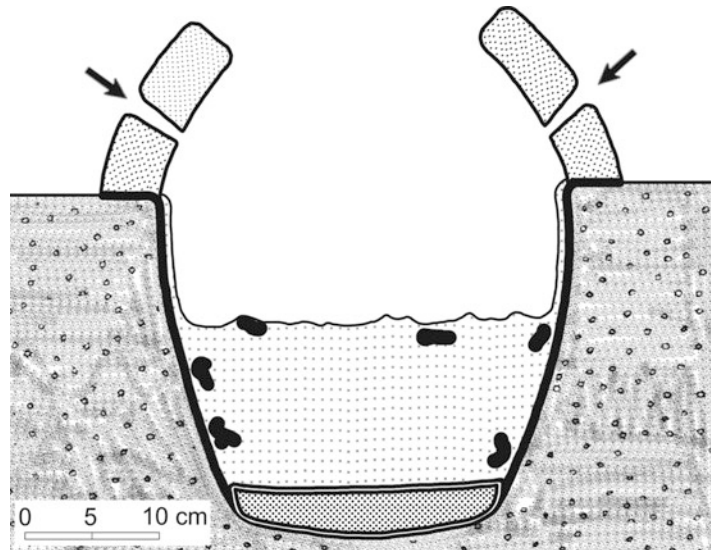
**Metallurgy in Arabia,**

Fig. 25 Scheme of a late medieval bowl furnace. The *upper* part is still unclear. The 4–5 cm wide holes for the air of skin bellows were found in specially formed wall fragments. Charcoal occurs in most bowl slag cakes. Only the copper ingot below has been reconstructed



Islamic slags were the target of this secondary digging work. And these were reduced in the bowl furnaces.

Recent Copper Production in the Sultanate of Oman

From 1983 to 2003 Oman is once again exporting copper to the world market. Modern mines have been opened at Lasail, 'Arja, and 'Arja-Bayda in the Wadi Jizzi west of the old

town of Sohar; a copper smelter has been constructed nearby. The mining and smelting work is connected with a new modern town, named 'Magan'. And it is this name which gives a hint to the 5,000-years long history of copper production in the Sultanate of Oman (Mobbs 2003).

See Also

► [Irrigation in the Islamic World](#)

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Metallurgy in China

Hua Jueming

The earliest metal relics ever found in China are two brass artifacts from the Yangshao Culture

Ruins in Jiangzai Village, Lingtong County, Shaanxi Province. They date as far back as 6,000 years ago, providing strong evidence that metallurgy germinated in China during that period. Considering that studies of possibly earlier metal relics are not done thoroughly enough, the problem of the origin of metallurgy in China has yet to be further explored.

By the latter part of the third millennium BCE, metallurgy had come into being in a number of regions, and many kinds of metal materials – red copper, primitive brass, tin bronze, and lead-tin bronze – were already used for small implements and ornaments.

The Xia Dynasty (twenty-first century to sixteenth century BCE) had evolved into the Bronze Age. In Erlitou Cultural Ruins, Yanshi County, Henan Province, remains of foundry workshops have been discovered where bronze sacrificial vessels, weapons, implements, and casting moulds have been excavated. Apparently, the making of articles was done with casting as the main means.

The earliest copper mining and smelting ruins known in China are located in Tongling (meaning copper ridge), Ruichang County, Jiangxi Province. Its mining can be traced back to the fourteenth century BCE. The shafts and drifts were supported by timber frames. Also excavated were ore-dressing troughs and wood winches for hoisting. Further study reveals that during Shang-Zhou Periods (Shang Dynasty: sixteenth century to eleventh century BCE; Western Zhou: eleventh century to 771 BCE; Eastern Zhou: 771–221 BCE) the mining of copper minerals had progressed to a rather large scale in the Liao River Valley and Yellow River Valley, especially in the middle and lower reaches of the Yangtze River. The smelting of copper was done in semicontinuous operation in shaft furnaces. By the late Western Zhou at the latest, copper sulfide minerals had been used to smelt copper.

The smelting technologies of lead and tin were mastered from the Shang Dynasty on. The lead vessels unearthed in Anyang have a purity of over 95 %. Tin ore deposits were scattered in the Northeast, Northwest, and South China regions, especially in Jiangxi, Guangxi, and Yunnan,

where tin reserves were very abundant. The early tin material must have come from these regions.

Alloying techniques improved greatly during the Shang Dynasty. The sacrificial vessels of imperial courts unearthed in Yin Ruins have a tin content of 18 % or more. The book *Kao Gong Ji* of the Warring States (475–221 BCE) recorded something about the alloy proportioning of *liu qi* (seven kinds of bronzes): *zhong* (bell), *ding* (cauldron), *fu* (hatchet), *ji* (halberd), *jian* (sword), *zu* (arrowhead), and *jing* (mirror). This indicates the craftsmen's clear understanding at that time that the mechanical performance of tin bronze varies with different contents of tin.

Shang-Zhou bronze culture was characterized by sacrificial vessels, complex in shape and delicate in design, which were mass-produced by casting. The key in achieving this characteristic without applying techniques such as the lost-wax process lays in the skillful use of composite pottery molds and various cast-joint technologies.

Beginning with the Spring and Autumn periods (771–475 BCE), it became in vogue to apply synthetically various shaping processes and decorating techniques: cast-joint, soldering, lost-wax process, forging, gilding, gold-plating, red-copper inlay, gold and silver inlay, engraving, etc. This significant change brought the manufacture of bronzes to a still higher level; the implements produced looked brighter and more colorful. As early as the late Neolithic Age, small-sized gold had already appeared. By the Warring States periods, there were more and more articles made from gold, and coins were first minted of silver. These may have been obtained by cupellation, a refining process in which metals are oxidized at high temperatures, and base metals are separated by absorption into the walls of a cupal, or porous cup made of bone ash. The production of mercury also reached a certain scale. It is recorded that a great amount of mercury used to preserve bodies from decay was found in the imperial grave of Emperor Qin.

It was far back in late Shang Dynasty that iron meteorites were used to be forged into blades and cast with bronze into weapons. This process was passed down all along to the end of Western

Zhou, perhaps providing impetus to the origin of certain iron smelting technologies.

Archaeological excavations have shown that artificial ironmaking may have begun in the late Western Zhou in China. It is worth noting that the smelting and casting of pig iron began only about 200 years later, i.e., the late Spring and Autumn periods. Only another 100 years had passed before pig iron was in wide use for casting production tools, especially for farming implements, thus marking the beginning of the Iron Ages in China.

Correspondingly, a series of outstanding inventions related to pig iron came springing up one after another. Two of the most important were the iron mold casting and cast iron toughening techniques. In these, pig iron castings were changed into white-heart malleable cast iron or black-heart malleable iron through decarbonizing heat treatment or graphitizing heat treatment, respectively. Others were the later ones of puddling iron (Western Han 206 BCE–AD 8) and Guan-steel (made by smelting pig iron and puddling iron together, about the end of Eastern Han AD 25–220). These revealed a technological course of development, which, though markedly different from that in ancient Europe, led to the same goal. This unique instance in the history of technology is interesting and thought provoking.

In China, many of the most important inventions in ancient metallurgy were made before the sixth century BCE. After the fruits in the preceding times were digested and imbibed in the Tang Dynasty (AD 618–907) and Song Dynasty (AD 960–1279), metallurgical technologies in China took shape, leading to further prosperity and greater achievements. For example, in the southern regions there was full scale mining and smelting of iron minerals and others such as copper, tin, lead, gold, silver, and mercury. There were also large and extra-large castings and bronze or iron structures, etc.

It must be mentioned that the making of white copper (copper nickel alloy) was already mastered as early as the fifth century, and that during the Han and Tang Dynasties and later, metallurgy in China had exchanges with and mutual impact

on the surrounding regions. Some examples are the westward spreading of iron-casting skills and the influences of Persian artistry on gold or silver wares in the Tang Dynasty.

In the Song Dynasty, wet metallurgy was put into large-scale practice to extract pure copper, annually yielding about 500 tons, which amounted to about one-third of the total copper produced in the whole country.

About 1620 in the Ming Dynasty, it was possible to smelt zinc, which was used in great amounts for minting coins. Antimony was smelted in the Ming Dynasty (AD 1368–1644), but it was not recognized at the time as a new kind of metal and thus was mistaken for tin.

Recently, some unexpected archaeological discoveries – such as the bronze culture of the ancient Kingdom Shu and the bronze groups of the late Shang in Xinggan, Jiangxi Province – indicate that there are still many mysteries in the metallurgy of ancient China which remain to be disclosed. Those disclosures would contribute greatly to academic studies.

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Metallurgy in Egypt

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Gold, silver, lead, and copper were among the metals exploited by Egyptians since the pre-Dynastic period (prior to ca. 3100 BCE). The main sources of these metals were the deposits in the ancient rocks of the Eastern Egyptian desert near the Red Sea and in the Sinai. Iron implements, although present in Egypt since the 26th Dynasty (ca. 665–525 BCE), did not become common before the Ptolemaic period (305 BCE–30 BCE), because Egypt did not have access to major sources of iron ore. The most common metals for daily use were copper and bronze (a copper-tin alloy).

With no written descriptions of the mining or metallurgical operations, we rely on vignettes of metalworking that appear in some funerary art as well as marks from actual tools for our understanding of the processes involved in procuring and using metallic resources. Although nuggets of relatively pure metals can sometimes be found, these must certainly have been used up very quickly, forcing the ancient Egyptians to develop techniques for exploiting deposits of metal ores. Mines might be either open shallow pits or underground tunnels following promising veins of ore.

The remains of ancient mine shafts and miners' stone tools, as well as heaps of waste, still indicate many of these sites. By the time of the New Kingdom (ca. 1550–1085 BCE), Egypt probably was relying more and more heavily on imports of copper, as well as tin and iron to meet its needs for metal implements.

It is likely that an initial extraction of the metal from the ore matrix took place in the vicinity of the mine itself since the ores usually contain approximately 10 % metal. Extraction of the metal involved either roasting (heating the ore with charcoal in the open air) or smelting in closed furnaces using either the addition of coke and silicate particles to absorb impurities and aid in reducing the oxides to metallic form or a forced air blast through the molten slag to oxidize the impurities and free the metal. To melt the metal requires a high temperature that can only be achieved through the use of blowpipes or bellows to feed oxygen to the charcoal fire. Many ancient peoples knew these technical processes. We should not forget, however, the geographical context in which trees, the main source of charcoal, were not plentiful. Large-scale building projects, such as pyramid construction, therefore, which require extensive metallurgical implements, must have placed many strains on the natural economy and demanded complex administrative planning for their completion.

Pure copper is relatively soft and so is nearly useless for many applications for which we would normally use metallic implements today. When hammered, it rapidly becomes harder but also more brittle. This hardening and brittleness may be removed through an annealing process (heating the metal above 500 °C and allowing it to cool again). Many early edged implements bear evidence of having been shaped through repeated hammering and annealing, ending with a final hammering to harden the cutting edge. Many metal implements were formed by casting (pouring molten metals into a pre-shaped stone or ceramic mold and allowing the metal to cool and harden) rather than by hammering.

For metallic objects not requiring solidity, the “lost wax” technique of casting used less of the precious metallic resources. In this process,

the object was first modeled in clay or some other heat-resistant medium. This model was then coated with a layer of wax of uniform thickness. The wax, in turn, was completely surrounded by yet another layer of fine-textured clay or plaster, leaving only a small opening into the wax-filled layer. The mold was then heated, melting the wax, which ran out through the drain provided. Through this same opening, molten metal was then poured into the mold and allowed to cool.

Special care must be taken in order to avoid formation of gas bubbles that might mar the finished product. The formation of gas bubbles is difficult to avoid when working with pure copper, since the molten metal readily absorbs gases which then produce bubbles that weaken the final product. If, however, a bit of tin is added to the copper, the results are significantly improved. Alloying copper with about 10 % tin also produces a considerably harder and more durable metal, bronze. Bronze, therefore, was widely used for tools and weapons from the time of the Middle Kingdom (ca. 2150–1780 BCE) until replaced by iron implements late in the New Kingdom period (after ca. 1000 BCE). Since tin is not found in commercial quantities in Egypt, it is not certain whether bronze was imported as a semifinished product or was produced in Egypt using imported tin.

Metal tools such as chisels, knives, axe heads, and adzes are common in funerary collections and are often portrayed in Egyptian art. Another major use of metal was in the production of weapons: daggers, swords, projectile points, and battle axes. Defensive armor, such as mail coats (made by riveting small bronze plates onto leather jerkins), became common during the New Kingdom period. Protective helmets also appear to be a relatively late innovation, although some tomb paintings from the Ramesside period (ca. 1290–1225 BCE) show foreign mercenaries equipped with protective headgear. A third important use of copper (and later, bronze) was in the production of domestic articles such as cauldrons, ewers, basins, and ladles. Mirrors of polished metal were used throughout the Dynastic period. Excavators have also found pins, tweezers, and razors.

The gold deposits of the eastern Egyptian desert and Nubia were the largest in the ancient

world, so perhaps the techniques for extracting gold and its alloys, as well as methods for working them, were discoveries of the inhabitants of the Nile valley. We cannot be certain, of course, for such knowledge was handed down from father to son and from master to apprentice without being recorded.

Sheets of metal, whether gold, silver, copper, or bronze, could be worked by a variety of techniques to produce decorative effects. Making metallic jewelry relied on several techniques. Repoussé is worked from the back of the metal sheet so that the design stands out on the front in raised relief. Chasing is relief worked from the front of the sheet by hammering down the background while leaving the desired figures raised in the foreground. Engraving, also worked from the front of the piece, means cutting a groove into the metal during which a portion of the metal is actually removed. Tracing, which leaves a similar effect, does not remove any metal from the piece. Sheets of gold could also be hammered thin to produce gold leaf.

Sometimes it is desirable to join together pieces of worked metal to form an object. The ancient Egyptians knew how to use a variety of soldering techniques effectively. In soldering, a metal or alloy with a melting point lower than that of the metal pieces to be joined is allowed to flow along the seam. On cooling, the two metal parts are joined together. Since the ancients rarely worked with pure gold or other metals, the choice of suitable solder was very important. For example, gold and copper melt at very nearly the same temperature (1,083 °C and 1,063 °C, respectively). If 10 parts by weight of copper is added to 90 parts of gold, however, the mixture's melting point is only 940 °C. Thus, if one were working with relatively pure gold, a gold-copper alloy might prove a suitable solder to use. A somewhat similar technique, sweating, involved coating the edges of the pieces with the solder, bringing the edges together and heating until the joining compound melted, without adding further solder. Sweating often makes a neater join than does soldering.

There has been considerable debate about whether the ancient Egyptians knew how to

draw wire. There exist, both physically and in funerary art, numerous examples of what seem to be beads strung on fine wires. It is not clear, however, whether these were truly wires or merely thin strips cut from a sheet of metal using a chisel, for example. Friction with the beads during the construction of the jewelry might be the true cause for such strips to appear rounded like modern wire.

Jewelry was an important adornment of both gods and humans. We have, in tomb decorations, numerous scenes of jewelry making, as well as many illustrations of jewelry in use. In ancient Egypt, people wore jewelry for a variety of purposes. Perhaps the most important was as amulets to protect the wearer from evil forces that the Egyptians perceived to surround human life on every side. Gold itself was considered magical, identified by some with the flesh of the gods since gold, among the metals known to the ancient Egyptians, was least susceptible to tarnishing and change. Precious stones were also used, along with natural objects such as the claws or teeth of a ferocious creature (who may have been considered to embody the powers of the god). Jewels could also be used, perhaps as an extension of their magical power, to enhance the sexual attractiveness of the wearer. In addition, they could, as today, serve as symbols of status and wealth. We have reports of Pharaohs giving golden collars or other gold ornaments to their favorites as a mark of distinction. Jewelry was also essential to the burial customs of the Egyptians. Finally, jewelry could indicate the power to carry out royal prerogatives delegated by the Pharaoh. The man who held the king's signet ring or royal seal, for example, carried enormous responsibilities, both politically and religiously.

Jewelry involving precious metals or semiprecious stones seems to have been manufactured in relatively few centers of culture and political power. Since gold was mainly the possession of royalty, it seems probable that jewelers who supplied the royal household with golden ornaments enjoyed considerable social and economic status. Three overseers of goldsmiths had tombs at Thebes, as did two goldsmiths, indicating a high social status. Of course, the workers who actually

carried out the designs of the jewelers must have had a lower social status, but they were not of the lowest social class. Skilled workmen in metals would always have been in demand, and this demand would translate into at least a modest level of social prestige and influence.

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Metallurgy in Meso and North America

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Native American metallurgical technologies held great attraction for sixteenth century European

empires seeking to stake claims in the American New World. While the technical feats and mastery of Native American metalworks have only recently generated systematic scientific inquiries (Benson, 1979; Lechtman, 1979, 1984, 1991; Lechtman, Erlij, & Barry, 1982), the attraction of Mesoamerican and Andean precious metals has resulted in the plundering of massive quantities of these metals – often in the form of jewelry and other materials – from ancient centers where they served both ceremonial and funerary functions. Precious metals craftsmanship was an ongoing enterprise at the time of the Spanish conquest of the Inca state in 1532; heirloom items, ritual caches, and funerary offerings fed the raging smelters of European outposts in the New World for the duration of the colonial period. The crafted booty delivered to Fernando Pizarro by the Inca nobility, as ransom for the Inca Emperor Atahualpa, occupied nine forges for 4 months in 1533; this, in order to smelt the over 26,000 lb of silver and 13,420 lb of gold jewelry and other reliquary collected as tribute at that time. For the Spaniards, gold and silver were the fuel that propelled the expansion of the Holy Roman Empire; while for the Inca, gold, and silver symbolized the sweat of the sun and the tears of the moon, and thereby, the cosmologically ordained male and female principles, respectively.

Much of the precious metal processed by early European colonists in the New World was smelted from intricate works of art crafted into jewelry sewn into elaborate blankets, capes, shawls, and other clothing, as well as worked into ritual and funerary art and furnishings, weapons of war, and medical and agricultural tools (Easby, 1974). Ancient and large-scale metallurgical workshops and industrial centers are known from the *patios de Indios* (native workshops) of Colombia, and from such ancient centers as Atzacapotzalco, Mexico, where craft guilds were a significant aspect of the economic and social landscape.

The growing international black market in antiquities has both hastened the looting of ancient sites containing pre-Columbian metal craft, and has, by extension, spurred the

collection and preservation of these works as priceless relics of a bygone age. When one takes into account the fact that individual tombs from sites such as Batan Grande, Peru, contained as many as 200 gold objects, much of which consisted of tall – 30 cm – gold beakers, it is no wonder that much of this legacy has already been destroyed. Other funerary chambers, like that of Tomb 107 at Monte Alban, Oaxaca, Mexico, contained a veritable treasure trove of over 500 precious metal and stone objects recovered by Mexican archaeologists in the 1930s. Other archaeologically documented precious metals caches have been recovered from Zaachila, Oaxaca, and Coclé, Panama. Where bronze craftsmanship is concerned, individual tombs have produced upward of 500 kg of such metals worked from alloys of tin and arsenic-bronze. Given the notoriety of such discoveries among grave robbers and the general public, it should be of no surprise that looters persist in destroying ancient sites in search of treasures.

The recent discovery and subsequent excavation of the tomb of the warrior-priest of the ancient ceremonial center of Moche, Peru – which contained a collection of dynastic relics and funerary items of gold, silver, and alloys of copper and tin – was initially brought to the attention of the scientific community as a result of looting. Despite such destruction, archaeologists and other investigators continue to document the technical achievements of Native American metallurgists of Peru, Mesoamerica, Central, and North America (Shimada, Epstein, & Craig, 1983).

In 1921, Swedish ethnographer, Erland Nordenskiöld began research into technical secrets made apparent through metallurgical analysis of ancient metal objects from South America (Linné, 1957). Nordenskiöld ascertained that pre-Columbian metalworks were far more technically sophisticated than imagined at that time. He made a number of observations concerning metallurgical problems, including those pertaining to the metallurgical composition of *tumbaga* (a complex alloy of copper and gold, or copper, gold, and silver), soldering with silver, and the welding of copper.

The technical analyses completed by Nordenskiöld were a precursor to the sophisticated analyses now undertaken by archaeologists, and metallurgists, using a variety of techniques ranging from replicative experiments – where the objects themselves are reproduced with known ancient methods and technologies under controlled conditions – to physical and chemical tests to ascertain the composition and construction of the alloys employed in the creation of pre-Columbian metal objects (Lechtman, 1991; Meeks, La Niece, & Estévez, 2002; Shimada, 1988).

The body of ancient technical secrets relevant to the manufacture of pre-Columbian metal objects has grown considerably since the first European observations of Native American metallurgical techniques in the sixteenth century.

The Old Copper culture, which flourished from 3000 BCE to 1000 BCE along the shores of Lake Superior in North America, is credited with having introduced the earliest known metal-working tradition in the Americas. This tradition was the basis for later developments in the use of copper and related metals by Hopewellian and Mississippian peoples of the first-millennium CE. Old Copper culture sites have produced evidence of significant early metallurgical techniques, including cold hammering, hammer welding, annealing, and the production of socketed metal tools, conical points, knives, axes, chisels, awls, harpoon heads, and a variety of projectile point types derived from prototypes of stone, horn, shell, and bone. To this list we can add sheet metal, intricate sheet metal cut-outs, repoussé decoration, crimping, riveting, the gold sheathing of copper, gold and copper beads, and the hammer-welding of silver and copper, or “copper and meteoric iron to produce bimetallic objects” (Easby, 1966, 1974). This demonstrates an early, independent, and regional tradition in the art and science of metal craft.

The lost-wax, or *cire perdue*, casting process was first employed in the region of Colombia by 100 BCE, but quickly spread into Ecuador, and lower Central America (Panama and Costa Rica), and was subsequently adopted in Peru and Mesoamerica by AD 800 (Hosler, 1986). Ultimately,

according to historian Easby (1966), lost-wax casting achieved “its highest development in the Oaxacan area of Mexico, where during the fifteenth and sixteenth centuries AD Mixtec master craftsmen produced little hollow castings that are unrivaled for delicacy, realism and precision.”

Where Mesoamerica is concerned, the North American tradition of cold hammering and annealing, and that of South America, consisting of cold hammering, annealing, and casting, inspired the initial development of three distinct Mesoamerican metallurgical traditions. These traditions include those that emerged in the areas of upper Central America or southern Mesoamerica (including southern Mexico, Guatemala, Honduras, and El Salvador); the Pacific coastal lowlands including the Tarascan culture area, and the Mexican Gulf Coast lowlands and Yucatan Peninsula which encompassed the ancient Huastec, Totonac, and Maya cultures. Archaeologist Hosler (1986) argues that the relatively late adoption of metallurgy in Mesoamerica – after AD 700 – serves to explain the largely elite character of the Mesoamerican metallurgical tradition. While both South and North American metalcraft evolved from a utilitarian foundation centered on the manufacture of agricultural implements and other tools, trade and exchange in precious metals ultimately inspired the Mesoamerican metallurgical tradition. Hence, the wholesale and widespread adoption and exchange of metallic axe monies, tokens, and precious-metal objects.

While recent studies have yet to establish definitively the earliest dates identified with the origins of bronze metallurgy, Lechtman (1986) argues that arsenic bronze was in use in northern Peru by the fourth-century AD. Tin-bronze originated in highland Bolivia by AD 700, and, by the Inca era (ca. AD 1450) spread throughout the areas identified with the modern states of Peru, Bolivia, Chile, and Argentina. Finally, metallic money – in the form of copper axe blades and tokens – appeared in Ecuador by AD 1000 and quickly spread throughout South, Central, and Middle America.

The holistic nature, independent development, and antiquity of Native American metals

craftsmanship are only now beginning to be clarified (Meeks et al., 2002). Metallurgical technologies that were developed by pre-Columbian craftsmen are far too numerous to discuss in any detail in this essay. However, a partial listing should provide some idea of the significance of this legacy. Those identified to date include (a) the *cire perdue* or lost wax casting process, (b) surface metallurgy, depletion gilding, acid pickling, and tumbaga, (c) the application of organic reagents and binding emulsions, (d) arsenic, copper-arsenic, and tin-bronze casting, (e) copper-arsenic, tin, and bismuth alloys, (f) silver chloride coatings, (g) gilt copper sheeting, gold and silver sheathing, sheet metal processing and fabrication, mechanical crimping, gold-leaf treatments, hammer-welding, and the raising of sheet metal vessels, (h) silver/silver-copper/spot solder and soldering, (i) copper soldering, brazing, and spot welding, (j) electrochemical replacement plating, (k) complex annealing, cold-hammer and anvil, binary and ternary alloy processing, and ground and hammered meteoric iron implements, (l) charcoal-fed ore reduction and air-blast smelting/refining furnaces, (m) iron ore or hematite flux, and the reduction of sulfide ores, (n) open cast, multicomponent, and vented casting molds, and powdered carbon casting emulsions such as that of the Aztec *tecualtl* (charcoal water), (o) mechanical and metallurgical joints including metal nails, rivets, staples, ribbon clips, strip clips, lacing, long sockets, short tabs, tab-and-slot and other metal fasteners, (p) repoussé and other embossed sheet metal applications, including cinnabar cloisonné, (q) solid-state diffusion bonding, sweat welding, fusion gilding or Sheffield plating, and cladding, (r) slush casting, (s) multicomponent sheet metal miniatures, (t) color surface and powder metallurgy, (u) technologies for the manufacture of thin cast rods, wire coils, strip wire, wire-work surfacing and filigree, metal sequins, quad metal mosaics, architectural cramps, agricultural blades and implements, socketed chisels and related tools; and copper and bronze axe blades, metallic monies and tokens, (v) arsenic and tin-bronze implements including fish hooks, eyed needles,

pins, depilatory tweezers, and surgical instruments such as *tumi* knives and blades, (w) the standardization of metal ingots and tools, (x) platinum plating, ore processing, and the sintering of refractory metals such as platinum, and finally, (y) a variety of prospecting methods, including shallow shaft mining, the strip mining of exposed deposits, and the placer mining of alluvial gold and platinum. According to Lechtman, the tumbaga alloys alone “constitute the most significant contribution of the New World to the repertoire of alloy systems developed among ancient societies.” It should be noted that the processing of platinum (which has a melting temperature of 3,000 °F), was a feat accomplished by ancient Ecuadorian metallurgists by way of the “mixing of grains of platinum with gold dust” through a powder process identified with the “sintering of refractory metals” (Easby, 1966; Meeks et al., 2002).

Electrochemical replacement plating and depletion gilding, developed by the Moche of Peru nearly 2,000 years ago, allowed ancient Native Americans to plate precious metals on to semiprecious metals to a thickness of less than 1 µm. This electrochemical replacement process was not rediscovered until the twentieth century CE. Recent studies indicate that electrochemical replacement plating and depletion gilding or silvering “both involve sophisticated chemistry, and pre-Columbian surface metallurgy is surely as much chemistry as it is metallurgy” (Lechtman, 1986). As Easby says, “the tale persists that the egotistical Benvenuto Cellini spent months trying to ascertain how an ancient Mexican craftsmen had fashioned a silver fish with gold scales and finally conceded that he was baffled.” Unfortunately, as is the case with so many other aboriginal New World technological innovations, the very presence of such metallurgical traditions as that of the lost-wax casting process and tin and arsenic-copper bronze alloys was once taken to indicate that such technologies were introduced or diffused from the Old World.

Recent archaeological investigations underscore the paucity of information pertaining to metallurgy currently at our disposal, as well as the abundance of ancient archaeological

materials that have yet to be studied in any systematic fashion (Lechtman, 1986). Unfortunately, the relatively recent and highly specialized nature of publications pertaining to pre-Columbian metallurgy have led some scholars to suppose that even the most ingenious ancient Native American technologies were little more than isolated or accidental instances of technical insight and ingenuity. Such scholarly perspectives are clearly artifacts borne of the relative scarcity of and limited access to information. As the body of studies grows, it is becoming clear that innovations in metallurgy, such as depletion gilding and electrochemical replacement plating, were far more ancient and widespread than once thought.

While the wholesale destruction of the pre-Columbian world has closed an important window on the cosmology and beliefs of its metallurgists, we can nevertheless advance interpretations as to the social and ritual significance of metals based on contact-period and ethnographic accounts.

Both Inca and Aztec craftsmen, and Native Americans more generally, identified precious metals – gold and silver – with the male and female principles. The alloying of copper and gold, or, copper, gold, and silver, which produced a red, pink, or golden metal known as *tumbaga*, was in turn identified with the menstrual flow and ambered moon. Among the contemporary metals craftsmen of west Africa, smelters are designed to symbolize the female sexual organs, while the metals themselves are thought symbolic of the male principle embodied in semen and other bodily fluids. The cosmological message inherent in the metal itself, when combined with the supernatural and religious icons and images, must surely have served to enhance the power and prestige of the bearer, while at the same time providing clear indications of that individual’s identification with supernatural and cosmic forces. The use of metals in personal adornment and ritual attire served to convey the associations of the bearer with universal principles, within which gender ultimately served as a distinguishing characteristic of the individual, and thereby, the cosmos.

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Metallurgy in Northern South American Indigenous Societies: Pre-Columbian Goldwork and Social Change

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Goldwork played an important role in the development of northern South American chiefdoms, particularly in Columbia. Thus, the history of goldwork is also the history of social change among indigenous societies. Although relations between social organization and goldwork are little known, new research has provided valuable information especially during the last years. It is now known that just the presence of goldwork is no indication of social complexity. How spectacular and well crafted goldwork is does not help to measure social complexity either. In all northern South American regions, first evidence of social differentiation (*not* political centralization) is reported early in the sequence, sometimes in the absence of evidence of goldwork. In most cases, goldwork was introduced at a relatively late date, long after social differences developed. But there are chronological differences, both in the introduction of goldwork and the development of complex societies. In the San Agustín Region, goldwork is dated around 0 AD in the Upper Magdalena Region. It is somewhat earlier in the Calima region and much later in the Sierra Nevada de Santa Marta and the Eastern Highlands. The range is from around 400 to 1000 AD in the Sierra Nevada de Santa Marta and from 1000 to 1200 AD in the Eastern Highlands. Evidence of social differences, on the other hand, is much earlier in all regions. Nonetheless, despite differences in chronology, and the contrast in some of the most conspicuous evidence of monumentality, early chiefdoms with political centralization are associated in many regions with an important investment of energy in mortuary practices and spectacular goldwork. Late indigenous society's goldwork was much less impressive.

There is evidence regarding the highly individualistic nature of the early elites. Objects that are found in their burials are frequently unlike anything else excavated in the same region. Early burial goods from Sierra Nevada de Santa Marta, Calima and the Upper Magdalena are not only different from materials found in domestic contexts but also from those found at other elite burials. Frequently, elite objects are inspired in foreign iconography. The San Agustín statuary incorporated lowland representations; in Calima, goldwork was similar to Upper Magdalena statuary. Neguanje offerings have been compared to Lower Central American and Quimbaya goods. Early Muisca goldwork was similar to the Quimbaya goldwork. Nonetheless, long distance trade of luxury items during the periods of chiefly development seems to be limited. The Calima goldwork imitated the statuary of San Agustín, but elite objects from San Agustín are yet to be found in the Calima region. Likewise, the La Badea burial in Dosquebradas includes gold ornaments similar to those found in the Calima region during the Yotoco Period, but they are not identical. The Neguanje burial includes goldwork similar to what has been called Classic Quimbaya, as well as pottery that has been compared to that of la Guajira and stone adornments comparable to those of Lower Central America. But these goods are not identical to anything else found in other burials and they seem to have been locally crafted. In the Muisca territory early evidence of goldwork was probably inspired in the so-called Classic Quimbaya style. However, we are not talking about imports, but instead of locally produced goods. This is not to argue against the fact that during the early period of chiefly emergence some objects were traded, sometimes over long distances, for this was certainly the case. It just means that copy and imitation were practiced more often than trade. Whether this means common cultural identity or not is not known. What is clear is that local conditions seem of importance to explain when and how goldwork was adopted and consumed.

The role that imitating crafts from abroad played in early chiefdoms was probably related to the role of leaders as intermediaries with the

outsiders. Helms (1981) has proposed this on numerous occasions. If Reichel-Dolmatoff (1988) is right about the iconography of many Columbian gold objects, it seems reasonable to argue that shamanistic icons played an important role as the basis of leader's legitimacy. The fact that most of the early goldwork in all four regions was locally crafted contradicts the idea that emerging elites concentrated on long distance trade. Instead goldwork would have functioned in highly competitive systems, within the context of basically local changes in demography, settlement patterns and economic conditions. As most elite objects were locally crafted, and undoubtedly are of extraordinary elaborate craftsmanship, it seems reasonable to argue that the production of elite objects was of importance for early chiefs, whether they or attached craftsmen were in charge of such production. Thus far, the direct evidence of such craftsmanship is scant. Besides isolated objects, like an Ilama metallurgy tool kit and the fact that an early workshop for goldworking was found in San Agustín associated to a mound and elite burial, no other workshops have been found. At any rate, production of gold adornments seems to have been very limited precisely because these were elite objects, limited to few individuals. The only way in which such early craftsmen had a "market" was because of the fact that prominent leaders passed away and elite goods went with them.

The contrast with late chiefdoms is evident in all four regions. What were previously materials associated with the elites (i.e., gold or luxurious stones) were later extensively used by the populace. Most frequently, gold adornments did not find their way to burials because they were inherited and accumulated by the living. In the case of the Muisca, the use of gold was not limited to the elite and neither was it among the Tairona. The fact that nose rings are so frequently represented in Sonso pottery suggests that this might have been the case in the Calima region too. This information is consistent with the idea of increasing craft specialization. Despite the fact that certain objects were consumed only by the elite, a characteristic of late chiefdoms in the Sierra Nevada de Santa Marta, Eastern Highlands, Calima, and the Upper Magdalena was

that production became specialized and oriented toward the supply of a larger number of consumers. Late Muisca, Tairona, and Calima pottery becomes so standardized that the existence of centers dedicated to their production is suggested. In the Muisca territory, sites dedicated to the production of large quantities of pots, gold offerings, and spindle-whorls have been reported. In the Valle de la Plata region, it is only during the last pre-Columbian period that a distribution network from a single producing center of pottery prevailed. And this was probably not just the case with ceramics. In the Sierra Nevada de Santa Marta ethnohistorical information documents the existence of villages specializing in the production of stone adornments and goldwork.

Another common trait in late chiefdoms is that most of the labor force was not used for the construction of monuments, but rather for the construction of earthworks dedicated to the production of food. Terraces for agriculture, irrigation, and drainage systems become usual traits in the Sierra Nevada. In Calima, the landscape is transformed as never before by agricultural practices. In the Eastern Highlands, mounds and terraces are also related to agriculture for the times prior to the arrival of the Spaniards. Archaeological surveys in the Upper Magdalena and the Muisca territory suggest settlement was not oriented toward the exploitation of the best soils during the period of early chiefdom emergence. Conversely, in the case of the Muisca, it seems that the sixteenth century large villages and seats of chiefly power were located on some of the best soils in the region.

There are few documents where the production of ornaments is described in detail for northern South America. According to one source from the Magdalena Valley the leaders themselves were goldworkers (Martínez, 1989). Nonetheless, in the Muisca territory production was in the hands of specialists attached to their service. In this territory it even seems that the position of goldsmith was inherited (Langebaek, 1996, p. 130). In all regions, the production of gold objects in late periods was directed toward supplying a large portion of the population, whether it was a matter of producing adornments, as was the case among

the Tairona, or offerings, as it is reported among the Muisca. In all cases, it seems that a larger demand relates to processes of population growth. Available research does not allow comparisons between the production of late chiefdom metal ornaments and that of earlier chiefdoms. The often small, mostly *tumbaga* (an alloy of gold and copper) ornaments that seem to constitute a large proportion of production in late chiefdoms are certainly not very attractive to museums, and they are often disregarded. But given that access to such goods was in most cases open to the populace, there is every reason to believe production was considerable.

Another feature of late Columbian chiefdoms was the increase in external relations that were at least partially controlled by the elites. The traditional view is that early elites depended on long distance exchange networks and that somehow they collapsed before the Spanish conquest. However, early goldwork was not only locally produced in all areas but in many cases it was highly individualistic, and probably made for specific individuals. Thus it is difficult to speculate about extensive trade networks and even less about their demise. In contrast, sixteenth century sources depict active trade routes (Kurella, 1994; Langebaek, 1987, 1996). Such trade involved the long distance exchange of luxuries (Boomert, 1987; Szaszdi, 1983; Whitehead, 1990), as well as the exchange of raw materials and crafts. In the case of long distance trade, goods such as sea-shells, stone beads, and even some gold ornaments from the coast found their way to the Eastern Highlands. Crafts such as pottery circulated across ethnic frontiers, but this usually involved short distances within ethnic boundaries.

Goldwork played an important role in the development of northern South American chiefdoms. Gold objects are ideal means of communication. Therefore, its use depends upon a social context that determines the way in which it was used, its value, and, undoubtedly, its meaning too. As archaeologists learn more about pre-Columbian goldwork they have become aware of the complex ways in which ideological and economic factors came into play among goldworking indigenous societies.

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Metallurgy in Pre-Columbian South America

Gray Graffam

Numerous pre-Hispanic artifacts of gold and silver craftsmanship testify to the exquisite skill of ancient Andean peoples in their production of metallic art. Prior to European arrival, ancient metallurgists prevailed in working gold, in winning silver and copper metal from a variety of rich

ores, and in creating various sophisticated alloys. Ancient artisans triumphed in working these materials in ingenious ways to improve their performance and appearance, and in joining them to form complex composite pieces. A tremendous wealth of exquisitely crafted metal ornaments and metallic art was created through native talent. Today, the skill of pre-Hispanic Andean peoples in winning and working metals is revealed by early historical sources, archeological research, and the remaining portion of metal objects that avoided the Conquistador's torch. Some of the finest examples come from the Moche and Chimu regions of northern Peru; they include funerary masks, breastplates, diadems, and crowns, some of which are inlaid with decorative stones of turquoise and chrysocolla.

Early historical sources are clear in their portrayal of native Andean peoples as skilled metallurgists. Among the first chroniclers, Cieza de Leon described the successful native process of smelting silver, using wind-blown furnaces (*huayras*). Historical records for Potosi are also clear in stating that it was through the work of native metallurgists that the silver wealth was first tapped. For nearly three decades, from 1545 to 1572, all silver production was the result of skilled Andean natives, who used thousands of wind-blown *huayra* furnaces to smelt the rich silver-lead ores. Such furnaces were still employed by Andean natives in the seventeenth century, at which time they were recorded by people familiar with Old World metallurgy, and similar devices have been employed well into the twentieth century.

Archeological research today includes the discovery and study of metallurgical sites. Work at the site of Batan Grande in northern Peru reveals a centuries-long sequence of copper-bronze production, ending with Inca-period efforts just prior to the Spanish Conquest. Detailed research by such scholars as Izumi Shimada and John Merkel reveals the sophisticated nature of the smelting procedure, and reconstructs the various steps used in the metallurgical process. In addition, recent related efforts by Heather Lechtman focus on the source of the ores used in the production of the

copper-arsenic alloys, arguing for a highland-coastal exchange. With regard to detailed archeological investigations of sites where metal was crafted, rather than smelted, the research on metal craftsmanship at Chan Chan is an important contribution, which examines the activities carried out by metal smiths within a particular district of that pre-Incaic city. Also of note are investigations into the pre-Hispanic smelting facilities and processes in the South Andes. To date, the earliest metallurgical (copper) slags in this latter region come from the Wankarani site in highland Bolivia; they date between 250 and 1200 BCE. Of particular note, research at the Ramaditas site in northern Chile reveals a highly skilled, natural draft technology operating in the Atacama region by 100–50 BCE, where pre-Hispanic metallurgists were capable of achieving a good separation of copper metal from slag during production. These studies lend weight to the idea of a highly effective metal smelting technology in place in the South Andes during the first millennium BCE.

In general, it is thought that gold working preceded copper smelting, gold being found in a natural metallic state in association with certain minerals. The earliest known gold-working kit and beaten gold work in the Andes date to approximately 1500 BCE from Waywaka, Peru. The first working of native copper would also be theoretically of a similarly early date.

The most extensive body of research on ancient Andean metallurgy deals with analyses of the metal artifacts themselves. Included here are laboratory studies on gilding, joining of metals, alloying, and the other techniques of artistry and design. When the Spanish began melting metal objects shortly after the Conquest, they noted with dismay that not all “golden” objects were in fact pure gold. Many specimens appeared to be gold on the surface, but were actually copper alloy in the core, which meant that they had little of their anticipated content of precious metal. Modern laboratory studies have succeeded in replicating the ancient techniques employed in gilding, as well as the casting, welding, and forming of exceptionally well-crafted objects (Lechtman, Erlij, & Barry, 1982; Tushingham,

Franklin, & Toogood, 1979). Andean craftsmen were adept in altering the appearance of an alloy, sometimes within the same piece, as in the case of Vicus nose ornaments. In some cases, their illusions seemed to accomplish the impossible, where different metals appeared to be welded together. These ancient metal smiths exercised superb control over their artistic medium, in which the color of the metal was as important a factor as the iconography that the piece intended to convey.

As one shifts from the North Andes to the South Andes, there is a shift in the metallic art from complex and fully modeled pieces to artifacts of decorated sheet metal. In Bolivia, northern Chile, and northwestern Argentina, metallic art most often takes the form of objects made from flat metal. Discs, diadems, bracelets, rings, and pendants are common forms, all executed from hammered sheet. Casting is also known, but seems to be used primarily in the manufacture of axes and mace heads, i.e., nondecorative objects that required more substantial weight. The tradition of working sheet metal has a long antiquity, extending back three millennia.

Today, Andean natives remain active in working metal and crafting pieces of native art. Like their counterparts in the American Southwest, they melt coins for metal, rather than smelt ores as formerly done. The end product is most often geared toward tourist consumption, which means that it is generally of a form that is readily marketable. Still, there is a folk practice that persists among the native Andean peoples, one which has an extremely long history.

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Metallurgy in Southeast Asia

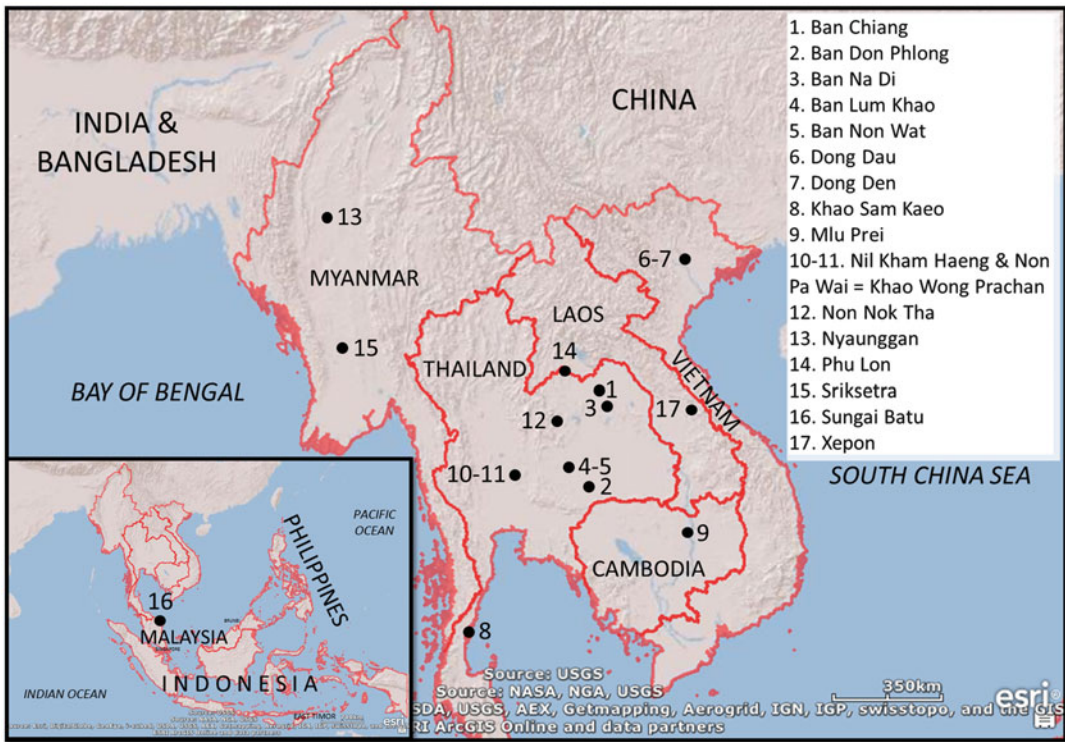
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Situated at the eastern terminus of the mighty Himalayan range, Southeast Asia's early metal technologies are intimately related to similar

developments in neighboring Eurasian populations – namely, in present-day China and India (Fig. 1). This chapter will summarize past and current academic thinking on how regional base metal (copper, tin, lead, iron) production, exchange, and consumption was initiated and evolved from the début of the Mainland Southeast Asian (MSEA) Bronze Age through to the Historical era, c. 500 AD. The Island Southeast Asian Metal Age will be briefly treated at the end due to the significant time gap in its appearance.

The Bronze Age

In the previous paragraph, I specifically avoided giving an absolute date for the MSEA Bronze Age as therein lies a controversy that has spanned almost five decades and has yet to be unanimously settled. Due to the complex mid-twentieth century political situation in MSEA, the first “modern” archaeological investigations did not take place until the mid-1960s and were concentrated in northeast Thailand (Fig. 1). The two cemetery/habitation sites in question, Ban Chiang and Non Nok Tha, furnished metal and metal-founding paraphernalia (crucibles and moulds) in contexts with claimed thermoluminescence and radiocarbon dates to the mid-fourth millennium BC (e.g., Bayard, 1972; Gorman & Charoenwongsa, 1976; Solheim, 1968). These dates were, at the time, earlier than those for the earliest metallurgy in China and were also published during the ascendancy of the New Archaeology movement, which then had a substantial focus on multicentric origins for major agricultural and technological developments. The inevitable result of this confluence of interests was the proposition that Thailand was a center for the independent invention of copper-base metallurgy, rather than having adopted and/or adapted foreign technologies (reviewed in White, 2008, p. 91). This was punchy stuff and chimed well with those advocating Southeast Asian agency after decades of colonialism, but was soon disputed by general and regional archaeologists on methodological and data-scarcity grounds



Metallurgy in Southeast Asia, Fig. 1 Major regions and sites mentioned in the text

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(e.g., Higham, 1975; Muhly, 1981). The notion of an independent origin for regional metallurgy was dealt a decisive blow by a drastic revision of Ban Chiang's Bronze Age layers to the early-second millennium BC (White, 1986) and the complete dismissal of Non Nok Tha's compromised radiocarbon chronology (Spriggs, 1996–1997). Nevertheless, it is the universally academically rejected 3600 BC “independent origin” interpretation that can still be found in regional tourist guidebooks.

Notwithstanding MSEA's vast geographical size and ecological diversity, which imply that we should not necessarily expect unified and constrained regional chronological horizons, extensive fieldwork, laboratory, rhetorical, and theoretical efforts to resolve an absolute Bronze Age date continued throughout the 1990s and 2000s to the present day. The issue at stake is more than mere scholarly rectitude but concerns competing visions of Southeast Asia's cultural trajectory and the respective roles of local

agency, foreign influence, and transformative technologies in evolving regional social stratification and political complexity. Space constraints dictate that I run the risk of *reductiones ad absurdum* the two principal positions, which I label the “long” and “short” chronologies for succinctness:

- The “long” chronology's chief advocate, Joyce White, places the Neolithic/Bronze Age transition c. 2000 BC (White, 2008) and sees the appearance of copper-base metallurgy in northeast Thailand (Ban Chiang) as the result of migrant metalworkers, or those trained by them, importing a complete and competent technological tradition from southwestern China, and potentially as far as the Altai Range of western Mongolia (White & Hamilton, 2009). In White's view the earliest MSEA copper-base metallurgy has a limited cultural impact and is not associated with increased sociopolitical complexity.

The same parties also dispute the dating of MSEA's Neolithic to the tune of at least one millennium (Higham, Guangmao, & Qiang, 2011; Rispoli, 2007).

- The “short” chronology’s principal advocates, Charles Higham and Roberto Ciarla, place the Neolithic/Bronze Age transition c. 1100–1000 BC, based upon radiometric dates for Bronze Age and terminal Neolithic sites across MSEA, as well as having re-dated the Ban Chiang sequence using stratified animal and human bone samples (Higham et al., 2011; Higham, Higham, & Kijngam, 2011). Their detailed assessment of literature on the Chinese Bronze Age suggests to them a technological transmission route via south-eastern China – though they do not entirely dismiss a southwesterly derivation as per White – and that the mechanism was “trade and exchange” (i.e., diffusion) rather than the long-range movement of experienced metalworkers. In the “short” chronologists’ view, the earliest MSEA metallurgy has, especially at the extensively excavated northeastern Thai cemetery and habitation site of Ban Non Wat, a huge cultural impact, with copper/bronze being used to enhance the social status of incipient political élites (Higham & Higham, 2009).

My current position, based upon the data deployed by White, Higham, and Ciarla and noting the huge knowledge gaps in the potential transitory regions of northern Laos, Myanmar, and Vietnam, is that the balance of probabilities tilts sharply towards the “short” rather than the “long” chronology. White’s (2008) c. 2000 BC transition Ban Chiang chronology presents a very large anomaly compared to the rest of Southeast Asian Bronze Age dataset, but her suggestion of a southwestern Chinese transmission route is certainly worthy of further investigation, not least as there may have been multiple routes responsible for the appearance of metallurgy in different parts of MSEA.

Aside from the strict question of dating, the metallurgical data themselves are of paramount importance. However, a comprehensive typology

of Bronze Age (or Iron Age) MSEA copper-base artifacts has yet to be produced so, while various common forms of axe/adzes, bangles, rings, bells, and vessels may be recognized (e.g., Rispoli, Ciarla, & Pigott, 2013, Fig. 13), detailed techno-stylistic comparisons remain problematic. Likewise, while many excavated MSEA Bronze Age cemetery and habitation sites (e.g., Cambodia, Mlu Prei; Myanmar, Nyaunggan; Thailand, Ban Chiang, Ban Lum Khao, Ban Na Di, Ban Non Wat, Non Nok Tha, Non Pa Wai; Vietnam, Dong Den, Dong Dau; see Fig. 1) have furnished some evidence for secondary copper/bronze production in the form of bivalve molds, shallow-spouted crucibles, and/or hearth remains; only in a few cases (e.g., Cawte 2011; Higham & Kijngam, 1984; Vernon, 1996–1997, 1997) have these been subjected to detailed scientific study. Useful comparisons, though difficult, have been made in the highlighting of similarities with various Chinese traditions (e.g., Ciarla, 2007b; Higham, Higham, Ciarla et al., 2011; Pigott & Ciarla, 2007; White & Hamilton, 2009), as well as the striking volumetric and thermal history dissimilarity between crucibles used in MSEA secondary (refining, alloying, and melting) and primary (smelting) copper/bronze production processes (Pryce et al., 2011). Metallurgical data were certainly taken into account by the “long” and “short” model advocates discussed above, but as a predominantly extractive archaeometallurgist, I will concentrate on primary production sites and exchange networks for the remainder of this section.

The study of MSEA primary metal production (mining and smelting) sites was initiated by the Thailand Archaeometallurgy Project in the early 1980s, which focused on two such loci, Phu Lon and the Khao Wong Prachan Valley, in northeastern and central Thailand, respectively (Fig. 1, Natapintu, 1988; Pigott, Weiss, & Natapintu, 1997). The Phu Lon complex, although it lies on the banks of the River Mekong, a major potential communication route for the transmission of metal technologies, did not produce any reliable Bronze Age dates and will be discussed in the following Iron Age section. However, the site of Non Pa Wai, in the Khao Wong Prachan Valley,

Metallurgy in Southeast

Asia, Fig. 2 A low-tin bronze axe with a non-local lead isotope signature excavated from a Bronze Age grave at Non Pa Wai (lh image courtesy of the Thailand Archaeometallurgy Project)



consists of a Neolithic cemetery (c. 1800–1100 BC), overlaid by a Bronze Age (c. 1100–500 BC) cemetery and possible habitation with copper founding and limited smelting evidence, followed by a very substantial Iron Age copper smelting/founding deposit (c. 500 BC to 200 AD, Rispoli et al., 2013, Fig. 4). These dates form part of the “short” chronology argument, but the technically competent copper-base founding evidence at Non Pa Wai c. 1100 BC could support the idea of experienced migrant metalworkers, an important element of the “long” chronologists’ model (White & Hamilton, 2009).

However, detailed laboratory study of predominantly Iron Age Non Pa Wai slag, mineral, and crucible samples suggests that the copper smelting technique was rudimentary, inefficient, and potentially experimental for in excess of a millennium (c. 1100 BC to 200 AD) and that they were not, as the “long” model would advocate, experienced in the complete copper/bronze production process (Pryce, Pigott, Martín-Torres, & Rehren, 2010). By this I mean the slags’ high chemical and microstructural variability indicates that neither smelting recipes nor operating parameters were fixed, as would be expected when metalworkers were trying out new ideas or working haphazardly. It has recently been argued that some samples once thought to be intrusive in Bronze Age layers can indeed be dated to the Bronze Age (Rispoli et al., 2013).

These samples could not be distinguished at the time of the laboratory study (Pryce et al., 2010). Indeed, geochemical analyses by the Southeast Asian Lead Isotope Project of a Bronze Age axe from Non Pa Wai (Fig. 2) indicate that it was not produced from local copper, and its very low tin content (c. 1 wt%) probably resulted from its constituent metal having been diluted by several alloying cycles (Pryce, Brauns et al., 2011; Pryce, Pollard, Martín-Torres, Pigott, & Pernicka, 2011). This also seems to have been the case at Ban Non Wat, where the very earliest copper-base artifacts (“Bronze Age 1,” c. 1050–1000 BC) have a low tin content and do not match any known Southeast Asian source, whereas two unalloyed copper adze/axes and one chisel from “Bronze Age 2” (c. 1000–900 BC) burials are highly consistent with the Non Pa Wai isotopic production signature and provide a solid cross-date for early Thai copper smelting (Pryce, 2011; Pryce et al., 2014). Even putting the dating issue to one side, the laboratory identification of probable imports during the initial MSEA Bronze Age is arguably closer to the “short” model of “trade and exchange” of metal objects stimulating local primary production, rather than the migrant metalworkers importing a complete and competent metallurgical package, from whichever direction (for MSEA see Pryce et al., 2010; for Eurasia see Roberts, Thornton, & Pigott, 2009, p. 1013).

It should be noted that MSEA Bronze Age metal artifacts are few in number and even fewer from sites with reliable chronological sequences. Of this limited subset, only 17 have actually been subjected to detailed technical analysis, of which six artifacts can have their raw materials attributed with reasonable confidence to a known source: the three Ban Non Wat BA2 artifacts that match the Khao Wong Prachan mentioned above, two bronze bangles, and one bronze spearhead from Upper Early Period (“Bronze Age,” Higham, Higham, Ciarla et al. 2011) Ban Chiang that are consistent with a major copper smelting center at Xepon in Laos (Fig. 1), which has so far only produced Iron Age stratified dates (see below, Pryce, Baron et al., 2014, Table 1). The small but growing collection of high-quality data for Bronze Age MSEA metallurgy, alongside fieldwork efforts to fill in the enormous lacunae in Laos and Myanmar (e.g., Pryce et al., 2013; Pryce et al., 2014), means our understanding of the region’s very earliest copper-base metal technologies is likely to improve significantly and rapidly in coming years, but I think the direction of travel is already clear – a late second millennium BC partial transmission of knowledge and objects via one or more southerly Chinese traditions.

No MSEA Bronze Age tin production centers have yet been identified, so contemporary regional bronzes with Non Pa Wai or Xepon copper signatures may represent the import of unalloyed tin from long-distance, potentially Chinese, sources. MSEA Bronze Age bronzes typically contain low levels of lead, which probably is derived from the copper and/or tin ore minerals rather than a deliberate addition of lead metal. Correspondingly, no contemporary regional lead production centers have yet been identified despite the abundance of potential sources (for Thailand see Sitthithaworn, E. (Cartographer), 1990).

The Iron Age

Conventionally defined by the appearance of iron and/or steel artifacts in archaeological contexts,

though usually heralding a period of major shifts in sociopolitical complexity, the beginning of the MSEA Iron Age is dated to the fifth to fourth century BC. Before I enter into a discussion of regional iron/steel production and exchange, for which we have relatively few data, the cultural implications of the Iron Age transition can be highlighted by looking at what happens to copper/bronze consumption. Quite simply, it rockets. Gone are the days when iron/steel, as a superior alloy, was thought to displace copper/bronze. Rather, the use of copper/bronze during the MSEA Iron Age is concentrated on the decorative and ideational sphere (bells, bowls, drums, figurines, finger and toe rings, bangles, belts and ear discs), whereas utilitarian objects (adze/axes, knives, digging stick tips, ploughshares, and spearheads) are produced in iron/steel. In some instances, bimetallic objects combine the mechanical and aesthetic qualities of the two. The drastic rise in copper/bronze consumption is best seen in MSEA Iron Age cemeteries, where human burials are frequently found with literally dozens of bangles on each arm (e.g., Fig. 3). It would be impractical to wear so many bangles in life, so, as a funerary assemblage, we must remember that any social differentiation thus signaled in an individual’s death was communicated by their survivors. Nevertheless, the firm impression is given of copper/bronze being used to emphasize the personal and/or group status of a much wider proportion of the MSEA Iron Age population than was seen in the Bronze Age social aggrandisers very restricted consumption (Higham & Higham, 2009; Higham, Higham, Ciarla et al. 2011).

Supply naturally following demand, Non Pa Wai’s vast Iron Age 1 and 2 (c. 500 BC to 200 AD, Rispoli et al., 2013) copper smelting deposit is up to 3 m thick over 5 ha and evidences substantial though inefficient production. Archaeometallurgists often discuss what is meant by production efficiency as a process may be optimized for fuel, mineral, or labor expenditure. Here I mean there was lots of copper left in the slag, as prills and unreacted minerals. Three kilometers away at Iron Age 2 (c. 200 BC to 200 AD, Rispoli et al., 2013), Nil Kham Haeng,



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Metallurgy in Southeast Asia, Fig. 3 (Left and detail) Burial 14 and (centre) Burial 69 with copper-base belts, arm bangles, finger, and toe rings at Noen-U-Loke (Courtesy of Charles Higham), (right) Burial 82 with

copper-base belt and bangles (right forearm) at Ban Non Jak (Courtesy of Charles Higham, Nigel Chang, Dougald O'Reilly, and Louise Shewan)

a meticulously crushed industrial deposit up to 6 m deep over 4 ha, is a testimony to intensive high-labor mineral-efficient primary copper production (Pryce et al., 2010) and is replicated at numerous sites of different sizes in the environs of the Khao Wong Prachan Valley: including the Khao Sai On Mineral District, Promatin Tai, and Tha Kae (Ciarla, 2007a; Pryce et al., 2011; Rispoli et al., 2013). Likewise, 400 km north, at the aforementioned Phu Lon complex, Iron Age primary copper production of a similarly motivated ethos is indicated by the mining out of half a mountain, to the point at which it collapsed, and the fine crushing of all materials to extract the maximum possible metal (Pigott, 1984; Pigott & Natapintu, 1988; Pigott & Weisgerber, 1998; Pryce, Brauns et al., 2011). Furthermore, archaeologists working at a modern copper/gold mine,

Xepon in central Laos, have identified a prehistoric copper production complex stretching over several kilometers of the Annamite mountain range, which also corresponds to a pass connecting the Mekong River Basin with coastal Vietnam (Fig. 1, Pryce, Brauns et al., 2011; Sayavongkhamdy, Chang, Viengkeo, & Cawte, 2009). Excavation has to date provided only for Iron Age (c. 200 BC to c. 200 AD) radiocarbon dates, but the absence of glass ornaments in some contexts (a typical Iron Age find class) and the lead isotope cross-dates with early Ban Chiang bronzes suggest strongly that Bronze Age production loci remain undiscovered on the vast mining concession. A detailed laboratory study is in planning, but preliminary analyses reconstruct a complete copper production sequence: mining, smelting, refining, and

Metallurgy in Southeast

Asia, Fig. 4 Copper processing crucibles from (top, Courtesy of Roberto Ciarla) Non Pa Wai (Bronze/Iron Age) and (bottom, Courtesy of Nigel Chang) Puen Baolo, Xepon



alloying using a broadly similar crucible type to that seen at Non Pa Wai and/or a furnace arrangement (Fig. 4, Wątroba, 2012).

In addition to the primary production data, exchange patterns identified by the Southeast Asian Lead Isotope Project and a Japanese team led by Professor Yoshimitsu Hirao (e.g., 2013) evidence a major shift in MSEA copper/bronze consumption behavior during the Iron Age. Not only are copper-base artifacts much more common on Iron Age sites – hence the regional sample population being 500+ as opposed to 17 for the Bronze Age – approximately half of the studied finds are made from leaded bronze or, less frequently, leaded copper. The addition of lead to copper or bronze reduces the liquidus (melting point), making it easier to cast larger objects with more decorative detail, which is exactly what MSEA Iron Age metalworkers needed to produce

the drums, bowls, and bells for which copper/bronze was then predominantly used. However, despite the presence of numerous MSEA lead deposits, and even the identification of premodern lead mines in west-central (Glover & Sukawasana, 1990) and northern Thailand (Pigott, 1984), none has yet produced a date for Iron Age exploitation (Pryce 2012). Of the handful that have been characterized by lead isotope analysis (LIA), none match the archaeological artifact LIA database, so the sources of lead used during the MSEA Iron Age are currently unknown. Moreover, once copper or bronze is alloyed with lead metal, the latter's lead isotope signature completely overwhelms the signature of the trace lead derived from the copper and/or tin ores. At present we have no idea of the sources for any raw materials for about 50 % of the MSEA Iron Age copper/bronze database. Indeed, the situation looks even

worse once one taken into account the non-lead alloys – the other c. 50 % – whose trace lead signature can theoretically, and sometimes in practice, indicate the geological region from which the copper was produced. Although LIA characterization of the three known MSEA Iron Age primary copper producing areas, the Khao Wong Prachan Valley, Phu Lon, and Xepon, has furnished very distinct signatures (Pryce, Brauns et al., 2011), only a tiny number of MSEA Iron Age finished artifacts can be reasonably attributed to those sources (Pryce, Baron et al., 2014). So what is going on? Do we just give up?

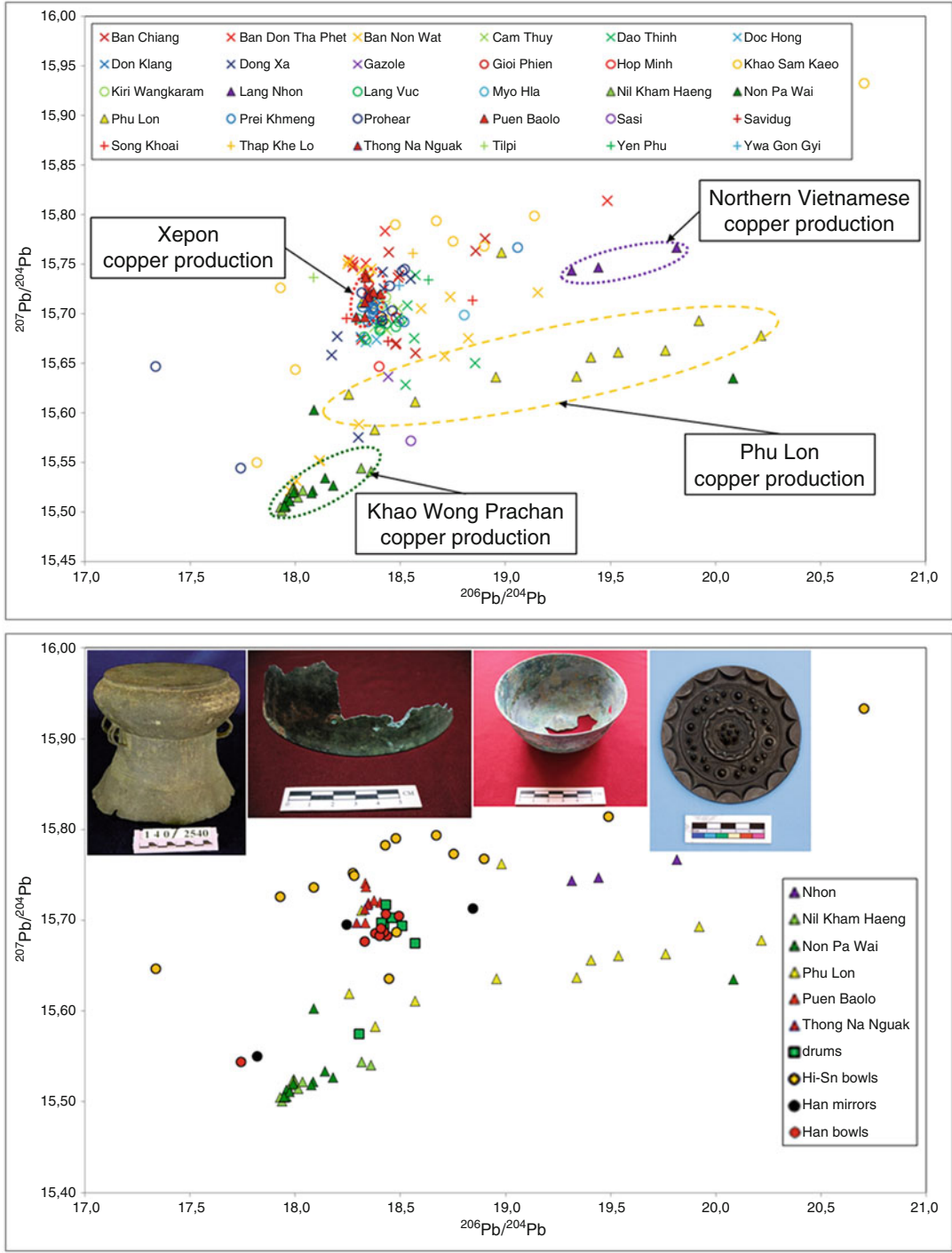
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Although MSEA's substantial mineral wealth (Smith 2012) undoubtedly means prehistoric primary metal production centers remain to be found, the near absence of matches between regional production and consumption signatures warrants more explanatory effort:

- First, a substantial proportion of the MSEA Iron Age nonferrous-based metal database consists of objects that are, at least stylistically, “exotic,” meaning they may well have come from outside of MSEA. Correspondingly, many of these objects, and in particular the “Indian” wrought high-tin bronze bowls and the Han Chinese leaded bronze bowls and leaded high-tin bronze mirrors, produce the most strikingly different isotopic data (Fig. 4, Pryce, Baron et al. 2014). What this patterning evidences, and is corroborated by studies of ceramics and glass (e.g., Bellina, Epinal, & Favereau, 2012; Dussubieux & Gratuze, 2010), is that as opposed to the relatively low intensity long-distance interactions of the MSEA Bronze Age, from the fourth to fifth c. BC, some regional populations were participating in highly active cultural exchange spheres linking maritime, littoral, and continental groups from the Pacific to the Mediterranean (Bellina and Glover 2004; Sherratt 2006), which foreign stimulus contributed to rapid changes in MSEA sociopolitical complexity (Fig. 5).
- Second, nonferrous metal exchange studies are highly susceptible to mixing, alloying, and

recycling processes. The admixture of copper metal from two different sources, e.g., the Khao Wong Prachan and Xepon, will produce a cumulative lead isotope signature directly proportional to the trace lead content of the constituent metals – i.e., Xepon lead has c. 2,000 ppm Pb as opposed to c. 200 ppm in the Khao Wong Prachan, so mixing 1 kg of Xepon copper with 1 kg of Khao Wong Prachan copper will produce 2 kg of copper whose signature will still plot close to that of Xepon. Those 2 kg of copper might then be alloyed with 300 g of tin to produce a 15 wt% Sn bronze. The trace lead content of tin ores is typically much less than that of copper ores, whose isotopic signature will thus predominate, but high-Pb tin ores do exist, and over numerous alloying cycles, the constituent tin can cause the bronze signature to drift, sometimes indicating that metal circulated for centuries between production and deposition (Bray and Pollard 2012). As mentioned above, the alloying of lead completely obliterates the copper signature. Finally, whereas some MSEA Bronze Age copper-base artifacts seem to have gone directly from the original production site to a grave without further thermal treatment, the dearth of Iron Age matches suggests copper-base metals, in ingot, scrap, and finished form, were circulated, reused, and reprocessed several times before deposition. The clustering of MSEA Iron Age data into recycling “pools” suggests that the more practical scale of metals provenancing is that of regional secondary production workshops, or foundries, which seem to have circulated materials within a geographically and/or culturally delimited sphere of end users. The metal's movement may be explained by commercial and/or social exchange factors but in either case evidence of a dynamism of social interaction that we do not see in the MSEA Bronze Age.

As for the production and exchange of tin, despite the medieval and recent historical fame of the Southeast Asian Tin Belt (e.g., Bronson, 1992; Penhallurick, 1986; Tibbetts, 1978), the metal is methodologically difficult to study due to the



Metallurgy in Southeast Asia, Fig. 5 (Top) $^{206}\text{Pb}/^{204}\text{Pb}$ / $^{207}\text{Pb}/^{204}\text{Pb}$ lead isotope data bi-plot for all SEALIP samples, showing poor correlation between production and consumption signatures and (bottom) $^{206}\text{Pb}/^{204}\text{Pb}$ / $^{207}\text{Pb}/^{204}\text{Pb}$ lead isotope data bi-plot for “exotic samples,” from left to right: leaded bronze drum from Khao Sam Kaeo (c. 400–200 BC); high-tin bronze bowl from Prohear (c. 100 BC); leaded bronze Han bowl from Cẩm Thủy (c. 2000 BP); leaded high-tin bronze Western Han mirror from Khao Sam Kaeo (Reproduced from Pryce, Baron et al. 2014)

typical nature of its original extraction (placer mining) and it being rarely found by archaeologists in non-alloyed form (Haustein et al. 2010). To date, only one site has produced any evidence for regional Iron Age tin production, the fourth to second c. BC proto-city state and river port of Khao Sam Kaeo on the Gulf of Siam coast of the upper Thai-Malay Peninsula (Fig. 1). Found during excavation and survey in 2007 and 2008, one slagged crucible fragment and one slag fragment were analyzed and discovered to contain microstructural pseudomorphs from a cassiterite cementation reaction, that is, tin oxide minerals were charged into a crucible containing molten copper or low-tin bronze, with the resulting high-tin bronze alloy then being poured into one of the hundreds of nipples molds discovered on site to produce a, presumably, relatively high added-value ingot (Murillo-Barroso, Pryce, Bellina, & Martín-Torres, 2010; Pryce, Murillo-Barroso, Biggs, Martín-Torres, & Bellina, *in press*). Much work remains to be done on this potentially very important commodity in late first millennium BC exchange networks, as indeed it does for gold and silver, both of which appear in MSEA contexts from the fifth to fourth century BC but for which no primary production sites are known and typological data are scarce due to looting and collecting (Pryce, Bellina, & Bennett, 2008; Reinecke, Laychour, & Sonetra, 2009; Schlosser et al., 2012).

Finally, I shall attempt to put the iron into Iron Age and outline its historical importance. As per the major agricultural and technological advances of Neolithic and Bronze Age transitions, regional archaeologists usually want to know the where, when, how, and why of iron/steel metallurgy's first appearance and subsequent development, as this can furnish evidence for the long-range social interactions that may have stimulated MSEA sociocultural economic change from the mid-first millennium BC. Unfortunately, due to a number of factors particular to iron/steel, providing answers for some of these questions is appreciably harder to do than for copper/bronze:

- First, although iron's critical role in agriculture, industry, and warfare is widely

recognized, it is, like lead, generally not considered to be a "prestige" metal, like copper, gold, silver, or even tin, and, as a result, regional ferrous archaeometallurgy has long been underdeveloped.

- Second, even when the will exists, iron research is complicated in a tropical region where iron/steel artifacts are frequently so badly preserved that their form and purpose for the original consumers can often only be hazarded. Thus, at present, no comprehensive typology exists for detailed techno-stylistic comparisons of MSEA Iron Age iron/steel artifacts (as per those in copper/bronze), though localized efforts have been made (e.g., Dizon 1990; Hognan & Rutnin, 1989; Pigott & Marder, 1984; Pryce et al. 2008; Sukawasana, 1991).
- Third, iron/steel exchange research is hampered by the provenance methodology being only recently developed, highly destructive, expensive, and laborious, though again preliminary studies have been successfully attempted in the region (Bennett, 1982; Biggs, Martín-Torres, Bellina, & Pryce, 2013) and are now proving especially fruitful in Angkorian period research (Hendrickson et al., 2014).
- Fourth, although nearly every MSEA Iron Age habitation site furnishes smithing slags as evidence of secondary iron/steel production (Pryce & Natapintu, 2009), only three contemporary primary (mining/smelting) production sites have thus far been identified: third to first century BC Ban Don Phlong in northeast Thailand (Fig. 1, Nitta, 1997), first to second century AD Sriksetra in central Myanmar (Fig. 1, Hudson, 2012), and early/mid-first millennium AD Sungai Batu in northeast peninsular Malaysia (Fig. 1, Chia & Mokhtar, 2011), substantially hobbling comparisons of regional technological styles.

So much for the dataset's weaknesses, what interpretations can currently be drawn and how do they help us understand the MSEA Iron Age? Given the relatively late, mid-first millennium BC, date for the appearance of iron in regional

archaeological contexts and the proximity of established iron making and using cultures to the west and north, it is probable that technological transmissions from one or both of these regions can account for MSEA iron/steel metallurgy, as opposed to independent development. Of the two possible foreign sources, India has often been preferred due to the *début* of the Iron Age, and the first appearance of MSEA iron/steel, coinciding with the first evidence for sustained contact across or around the Bay of Bengal (Bellina, 2007; cf. Bellwood, 2007; Glover, 1990; Rispoli et al., 2013). India is also reputed for its bloomery or direct iron smelting traditions (e.g., Tripathi, 2008), which is the solid-state process seen at the three known MSEA Iron Age primary production sites (Chia & Mokhtar, 2011; Hudson 2012; Nitta, 1997), whereas China is famed for its precocious development of blast or indirect iron smelting technology (Bronson 1999; Needham & Gwei-Djen, 1974; Wagner, 1993). However, it is now better understood that blast smelting was prerogative of the Chinese state and its organizational power, with bloomery smelting practiced in the hinterland (Yasuyuki, 2009). It is thus quite possible that upper MSEA, especially northern Vietnam, was subjected to Chinese ferrous technological influence, while that of India predominated in lower MSEA. Though based on a small and sometimes poorly contextualized assemblage from peninsular Thailand (Khao Sam Kaeo and environs; see Fig. 1), the most recent study of regional prehistoric iron came to the same open-ended conclusion (Biggs et al., 2013). No smelting slag was identified at any of the sites, only smithing slags, but metallographic analyses of iron/steel artifacts indicated a range of smithing traditions, potentially corresponding to contemporary Chinese or Indian techniques though not of the same level of technical competence. Complementary chemical analyses of slag inclusions within the metal matrix also suggested a wide spectrum of raw material sources, none of which can be identified at present as the necessary geochemical production database does not exist (Biggs et al., 2013). Suffice to say, much more research needs to be done on prehistoric

MSEA iron/steel, but of the Iron Age package of which ferrous metallurgy was part, the conclusion is clear: the availability of cheaper and more effective tools, alongside animal traction (buffalo), transformed the region's agricultural and industrial capacity, whereas the abundance of iron/steel weapons suggests the metal's martial potential was well understood and employed by the upper echelons of an increasingly ranked society to consolidate economic and political power. A catalytic and transformative technology indeed and one for which a recent wave of historical period iron-based research in Cambodia, Laos, Myanmar, and Thailand is furnishing a growing literature (Hendrickson, Hua, & Pryce, 2013; Hudson, 2006; Larp, 2008; Pryce, 2013; Pryce, Chiemsisouraj, Zeitoun, & Forestier, 2011; Pryce et al., *in press*; Suchitta, 1992).

The Islands, Gold and Silver

Despite an earlier prehistory in which very extensive seafaring accounts for both initial human colonization and various phases of neolithisation, Island Southeast Asia (ISEA) appears to have been ametallic until c. 200 BC (Bellwood, 2007). Then, when metals do appear, they all appear at once: copper/bronze, iron/steel, gold, and silver. As such, the period c. 200 BC to 500 AD in ISEA has been termed the "Metal Age" as opposed to the "Iron Age" that overlaps in MSEA. Notwithstanding the difference in nomenclature, the transmission mechanisms responsible for initiating these multi-metallic chronological phases are doubtless related, namely, a substantial increase in the activity of numerous interlinked cultural interaction spheres (e.g., Bellina et al., 2014; Calò, 2009; Calò et al., 2014). To date, very little prehistoric archaeometallurgical research has been conducted in ISEA, which is unfortunate given that the region was known to be a substantial producer of iron/steel and gold in historical period (Bronson, 1992; Bronson & Charoenwongsa, 1994) and even today hosts some of the world's largest copper/gold mines. As such, no Metal Age primary metal

production sites are currently known, though there is some evidence for localized foundry traditions, perhaps stimulated by MSEA imports (Calò, 2009; Calo et al., 2014). ISEA metal provenance studies have only just commenced, but copper/bronze, gold, and silver artifacts are providing tantalizing hints of contacts with the Indian subcontinent, southern China/northern MSEA, and central/southern MSEA (Calo et al., 2014; Pryce, Baron et al., 2014; Schlosser et al., 2012). Once again, much more research is needed, which, when one considers the size of some of the countries in question, i.e., Indonesia, is both daunting and exhilarating in equal measure.

Summary

Steady progress has been made on the early metallurgy of Southeast Asia since research commenced afresh in the mid-1960s. Extensive and robust data suggest that the Mainland Southeast Asian Bronze Age was initiated in the eleventh to tenth century BC by the import of copper-base metals and founding techniques from a proximal interaction front along the southern Chinese border. Although the phenomenon may not have been universal across MSEA, based heavily on evidence from Ban Non Wat in northeastern Thailand, copper-base metal consumption appears to have been appropriated by emergent political élites to enhance their social status. This demand was met locally within a very short period of time (perhaps a couple of generations) by primary copper production activity in the Khao Wong Prachan Valley in central Thailand.

The MSEA Iron Age commenced in the fifth to fourth century BC and was marked metallurgically by the appearance of gold and silver ornaments and a transition to iron/steel for tools and weapons, whereas copper/bronze continued to be used for ornamental and decorative applications. Notably, the demand for copper/bronze mushrooms in an environment of increasing social stratification, which was partly met through exotic imports and partly by the huge intensification of copper production in and around the Khao

Wong Prachan Valley, alongside Phu Lon in northern Thailand and Xepon in central Laos. MSEA's iron production technologies are thought to have a foreign source but arguments for China versus India are currently inconclusive due to the dearth of sites and studies, and both regions may have contributed in any event. So far the only evidence for MSEA tin production comes from Khao Sam Kaeo in peninsular Thailand, but no lead mining or smelting site has yet furnished a prehistoric date.

The Island Southeast Asian Metal Age is dated from second century BC to fifth century AD and is marked by the (seemingly) simultaneous appearance of copper/bronze, iron/steel, gold, and silver artifacts. These objects were, at least for the outset, almost certainly imports from China, India, and MSEA, as a result of much increased long-distance interaction activity. No primary production sites are currently known but local founding traditions have been identified. For both MSEA and ISEA, the vast geographical areas, often covered by thick vegetation, imply that a huge amount of work remains to be done before we have anything like a comprehensive understanding of the region's industrial history. Nevertheless, the convergence of being an ancient communication hub with exceptional mineral wealth and diverse human ecological adaptations suggests that future research will reveal a rich vein of metallurgy running through Southeast Asia's historical trajectory.

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Metallurgy in Southern South America

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The Andes represent the largest source of mineral wealth in the Americas and the birthplace of New World metallurgy. Metallurgical exploitation of these resources occurred for millennia prior to colonial contact, as testified by numerous artifacts of gold, silver, and bronze. Prior to the arrival of Spanish conquistadors in 1532 AD, indigenous South Americans smelted silver ores, hammered gold sheets, and annealed copper alloy sheets, independently of technologies that, by then, were highly developed in the Old World. Despite this extensive history, we know astonishingly little about the development of metallurgical techniques through time.

Today we learn about ancient metallurgy primarily through three sources of information. The first is the collection and analysis of artifacts recovered from archaeological excavations. However, looting of archaeological sites is pervasive and as a result the archaeological record is incomplete (Jones & King, 2002). This means that the archaeologist often works with either a small fraction of the original material, or with artifacts that have been removed from their original context. Moreover, looters frequently “restored” looted artifacts, severely limiting what information can be drawn from their appearance (Shimada & Griffin, 2005). The second source of information comes from historical and

ethnographical data collected at the time of conquest. For recordkeeping purposes, Spanish conquistadors documented the looting of Inca palaces and exploitation of Inca mines (Lechtman, 1976). Useful as these archives are, they tell us little about those peoples who preceded the Inca. Moreover, the Spanish were primarily concerned with the acquisition of gold and to a lesser extent silver. They make little mention of copper and copper alloys, even though these represent the foundation of Andean metallurgy. The third method is that of archaeometry. Archaeometry is the application of scientific methods to archaeological sites or artifacts. In the Andes, the most common archaeometric analysis employed is a compositional chemical analysis (Lechtman, 1999, 2002). Recently, scientists have also utilized geochemical analysis of lake sediments to track atmospheric pollution from smelting. This method was used to establish the onset of smelting at the town of Potosí in the highlands of southern Bolivia (Abbott & Wolfe, 2003). This method provides an independent record of the timing and intensity of smelting for the region. However, as with the previous approaches, it has its limitations. It cannot answer which group specifically was smelting or how it was used or valued by ancient South Americans, and is restricted to regions, which contain continuous sedimentary environments suitable for analysis (i.e., lakes, swamps, bogs, etc.). Despite the limitations of each of these methods, by studying them in concert, it has become apparent that indigenous South Americans possessed extensive knowledge in acquiring metals from various ores and also in combining and working metals into elaborate artifacts. Here, we review the major findings related to the procurement and smelting of nonferrous ore bodies in the southern Andes and the manufacture and use of various alloys as tools and objects of adornment within indigenous South American culture.

Smelting

Nonferrous metal ores have been smelted in South America for approximately 2,500 years. The

earliest evidence to date for smelting activity in southern South America comes in the form of copper slag from the Wankarani site in the highlands of Bolivia dating between 900 and 700 BCE (Ponce, 1970). Slag, also known in the Andes as *scoria*, is the waste or by-product of smelting. Often this is all that remains for the archaeologist to find as an indication of metallurgical activity (Van Buren & Mills, 2005). Very little research has been conducted on the metallurgy at Wankarani and to date little is known about what type of metal artifacts were being produced and how the control of metal resources was governed.

To the southwest, additional evidence for early smelting comes from recent research at the Ramaditas site in the Guatacondo Valley of northern Chile (Graffam, Rivera, & Carevic, 1994, 1996). Here, excavations have revealed evidence that copper smelting and sheet metal working (*repoussé*) began near the first century BCE. This finding confirmed that not only does metallurgy date back in excess of 2,000 years in northern Chile, but that this activity was often carried out independent of the presence of a large formalized state or Empire (Graffam et al., 1994, 1996). Northern Chile contains abundant ores of copper and the exceptionally arid environment allows excellent preservation of artifacts. This makes Chile an ideal locality to conduct future metallurgical research.

On the *altiplano* of southern Bolivia, a silver deposit known as Cerro Rico de Potosí was once the world's richest silver mine. Legend attributes the discovery of silver at Potosí to the penultimate Inca ruler, Huayna Capac, in the mid-fifteenth Century AD. However, this date was recently challenged by the discovery of much earlier metal pollution in a nearby lake that can only be explained by local smelting activity (Abbott & Wolfe, 2003). During smelting, trace metals are released into the atmosphere and are subsequently deposited into the lake environment through precipitation and dry atmospheric deposition. As soils, algae, and sediments accumulate at the bottom of the lake, they preserve these atmospherically derived metals. Natural archives, i.e., lake sediments, are sensitive enough to pick up even preindustrial

emissions (see Renberg, Persson, & Emteryd, 1994). Lake sediment cores (tubes of sediment recovered vertically from the bottom of a lake) were collected from a high alpine lake downwind of Cerro Rico de Potosí. Geochemical analysis of the sediments revealed a long history of smelting activity beginning shortly after 1000 AD, 400 years prior to the supposed discovery of silver! The use of this method to track metallurgical activity has only just begun and research is currently underway to understand the chronology of smelting throughout the Andes.

The final source of information on indigenous smelting at Potosí comes from a combination of historical archives and ethnoarchaeological research. Given its richness, Potosí was the central focus of colonial mining for years after conquest. As a result of this attention, a written chronicle of smelting techniques in use at Potosí exists. For example, between 1545 and 1572 AD, Inca silversmiths under colonial rule using indigenous furnaces conducted all silver production. Three different types of furnaces were recorded by the Spanish during this time as they worked Potosí and the nearby mine of Porco. The first type of furnace was simply a pit dug into the ground that reduced ores rich in silver. The second type was a small, and sometimes portable, reduction furnace called a *huayara*. These charcoal-fired, wind-drafted furnaces were lined with clay and were often placed on mountaintops to take advantage of strong winds. As such, they were prone to destruction by any number of natural forces (e.g. landslides, earthquakes) and to date none have been recognized in the archaeological record. Recently, however, a *huayara* has been found still in use today in Bolivia (Van Buren & Mills, 2005). This is an important discovery, which promises to contribute a great deal toward the understanding of ancient smelting techniques and their remains in the archaeological record. The third type of furnace was a *tocochimpu*, which was normally used to refine silver in combination with argentiferous galena or *soroche* (lead sulphide). Cieza de León was one of the first Spanish chroniclers to describe the use of *soroche* at Potosí and documented its use as a flux to enable extraction of silver from even

low-grade ores. Future research combining historical archives, archaeological and ethnoarchaeological research is sure to illuminate lingering questions regarding the spatial and temporal homogeneity of smelting technology in the southern Andes.

Despite these advances in the smelting of ores, direct analysis of the metal artifacts themselves is the most common analytical approach. The most frequent analysis performed is that of a compositional analysis which determines the relative proportions of the metals which make up an artifact. This has shown that the vast majority of Andean artifacts are composed of alloys. Alloys, rather than pure metals, are pervasive in both Old and New World metallurgy for three reasons. First, occurrences of pure copper, silver, and gold do not commonly occur in any large quantity. Second, alloys have the benefit of often being harder than objects made of native metal, as is the case with silver and gold (Lechtman, 1996). Third, by combining one or more metals, the melting temperature of those metals is lowered, which facilitates the smelting of ores. This is important as all pre-Columbian metallurgy was done without the use of bellows and had to rely on natural drafts to aerate furnaces.

The most common alloys found in southern South America have been those of arsenic-copper (arsenic bronze), tin-copper (tin bronze) and ternary alloys of copper, arsenic and nickel. There is also evidence that the Inca alloyed bismuth in bronzes recovered from the site of Machu Picchu (Gordon & Rutledge, 1984). Alloys composed of copper-gold (a binary alloy sometimes referred to as tumbaga) and copper-silver-gold (a ternary alloy) have also been found, though not in the same quantity as copper alloys (King, 2000). The precious metal artifacts that are found normally occur as items of personal adornment (e.g., discs, bracelets, rings, and pendants) associated with individuals of high social status, and as religious or ceremonial items (Olsen Bruhns, 1994). Because of the extensive looting which has taken place in Peru, both recently and during colonial times, few precious metals remain and our understanding of them remains comparatively sparse. Here we focus our discussion on

the appearance and distribution of copper alloys as they represent the backbone of Andean metallurgy. We then highlight two examples in which indigenous South Americans altered the appearance of copper-gold and copper-silver alloys to give them the appearance of precious metal.

Bronze Alloys

Arsenic bronze was the earliest alloy to be utilized in both northwest Argentina and southern Peru. In northwest Argentina, arsenic bronze was in use by 400 AD and its use continued until colonial conquest. This bronze alloy was used both for tools (axes, chisels, and wedges) and finer domestic items (awls, needles, bracelets, and tweezers) (Fester, 1962; González, 1979). In southern Peru the earliest evidence for arsenic bronze metallurgy occurs at the site of Pikillacta in the Lucre Valley circa 600 AD (Lechtman, 1997). This occurs during the influence of the pre-Inca Empire known as the Wari, which controlled the area from approximately 600–1000 AD (McEwan, 2005). These arsenic bronze artifacts are normally represented by domestic items or tools (Lechtman, 1997). Naturally occurring alloys of copper and arsenic are readily available in the high Andes of central/southern Peru and would have been accessible to native South Americans. Therefore, arsenic bronze metallurgy characterized the time period between 400 and 1000 AD in southern Peru and northwest Argentina.

In contrast, in Bolivia there is a paucity of both natural alloys and artifacts made of arsenic bronze. Rather, tin bronze and copper-arsenic-nickel alloys seem to have been the metals utilized. The earliest occurrence of this alloy in Bolivia is found on the Bolivian *altiplano* around 600 AD (Lechtman, 2002). Tin bronze was favored for ornamental rings, while copper-arsenic-nickel appears to have been preferred for needles, nails, and chisels (Lechtman). The tin for tin bronze appears to have been obtained from the rich “tin belt” of the *altiplano*, where it primarily occurs in the mineral cassiterite (tin oxide). No source has yet been found for the copper-arsenic-nickel alloys. Therefore, tin-based bronze metallurgy in

northern Bolivia appears to have begun around 600 AD. This is broadly contemporaneous with the widespread use of arsenic bronze metallurgy in nearby southern Peru and northwest Argentina. Future research is needed to understand what, if any, interaction was occurring between Bolivia and southern Peru at this time of florescence of the copper industry.

Traveling north and forward 200 years to 800 AD, the site of Batán Grande represents early arsenic bronze metallurgy along the north coast of Peru. Previously undocumented in the New World, Batán Grande is a prehistoric metallurgical center situated in the La Leche Valley (Shimada, Epstein, & Craig, 1982, 1983). Smelting here began circa 800 AD and continued until just prior to the Spanish conquest. Though small quantities of copper ore are locally available, arsenic bearing minerals are not. However, the highlands of northern Peru are rich in arsenic bearing minerals; this fact has led Lechtman (1991) to argue that highland miners might have provided coastal smelters with the necessary arsenic. The mechanism for this highland-coastal exchange, be it social, economic, or otherwise, has yet to be adequately explained.

Batán Grande was also the site of a large-scale cosmelting operation heretofore undocumented (Lechtman, 1999). During cosmelting, a mix of both the sulfides (the primary ore minerals) and oxides (the secondary or the weathered alteration product of sulfides) were charged into the furnace. This mixing need not be deliberate and yielded clean, coherent copper-arsenic alloy ingots (Lechtman & Klein, 1999). Cosmelting represents a dramatic improvement in smelting operations while eliminating noxious arsenic fumes that might otherwise have been generated.

Moving forward to the mid-fifteenth century AD, the Inca Empire implemented the use of tin bronze for domestic and household metal items throughout Peru, Bolivia, northwest Argentina, and northern Chile. This widespread occurrence of tin bronze associated with the Inca Empire has been dubbed the so-called “Tin Horizon” (Costin et al., 1989; Lechtman, 1996; Lechtman & Klein, 1999; Owen, 1986). The tin would have been prepared as sheet stock and then could be

dissipated through the Empire where it was added to local alloys of arsenic bronze or simply added to local copper to form tin bronze (Costin et al., 1989; Lechtman, 1976). Adding tin to existing bronze technology improves the workability of the metal and increases the hardness of the finished product (Costin et al., 1989). The Inca represent the culmination of metallurgical development in native South American history until the conquest of the Spanish in 1532.

In summary, two loci of bronze based metallurgy can be distinguished for the southern Andes. This appears to be a direct result of differences in local resources (arsenic-copper deposits in southern Peru and northwest Argentina versus tin-copper deposits in northern Bolivia). The situation changes with the establishment of the Inca Empire, after which tin bronze becomes the domestic metal of choice throughout the Andes.

Precious Metals

Although artifacts made of bronze alloys are the most commonly found during archaeological excavation, gold and silver remained the most prized metals during Inca and pre-Inca times as well (Costin et al., 1989). For the Inca, gold was endowed with spiritual and symbolic meaning and was believed to be the rain of the sun, while silver was the rain of the moon (Jones & King, 2002). However, artifacts composed purely of silver or gold are extremely rare. Considerably more common are alloys containing a mixture of copper and gold or silver. After the Spanish conquistadors took control of Peru, they began to melt down what they believed to be golden objects. To their surprise, they discovered that these “golden objects” were in fact composed of copper alloys and had only very thin surfaces of gold. This was because locally available resources, combined with sophisticated alloying techniques were used to produce golden surfaces on alloys containing small percentages of precious metals (Lechtman, Erlij, & Barry, 1982).

Experimental archaeology has been especially important here in determining how Andean

cultures manipulated alloys to accentuate desired qualities. Two of the best examples of native abilities were the processes of electrochemical replacement plating and depletion gilding. In electrochemical replacement a copper alloy is given an extremely thin and even surface coating of silver or gold. To accomplish this, silver and gold were dissolved in an acidic or corrosive solution (Lechtman et al., 1982). A copper artifact was dipped into this solution, and a chemical reaction would occur that resulted in a very thin and even “plate” or surface coating of silver or gold. In addition, the specific color of the object could be altered simply by varying the relative amount of silver or gold in solution (Lechtman et al.). Depletion gilding was used on alloys of copper-silver-gold. Here, naturally-occurring chemicals are used to separate the gold from the silver, leaving a surface of the desired precious metal. These are just two of the techniques in which native South Americans manipulated the appearance of metal artifacts in order to achieve a surface of silver or gold. These technologies appear to have been developed by the Moche (100–800 AD) on the north coast of Peru and remained a northern phenomenon until the rise of the Inca Empire in the mid-fifteenth century. At this time the Inca Empire relocated the northern metallurgists to Cuzco to serve at the Inca capital. Further research is needed to document fully the full range of both Inca and pre-Inca alloying techniques.

In short, a wide variety of metallurgical techniques were used by Andean cultures, and considerable skill was demonstrated in the manipulation of nonferrous ores. By integrating the fields of archaeology, ethnohistory, and geology a great deal can still be learned about these cultures’ use of metals.

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Metallurgy in Tanzania

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Introduction

Compared to professional research on Stone Age technology, which started in the mid-1910s, professional archaeometallurgical research in Tanzania started relatively late, in the 1970s, with the works of P. Schmidt, D. Avery, and T. Childs in the western Lake Victoria region (Childs, 1986; Schmidt & Avery, 1978). Observations and reporting on the iron production process by travelers, explorers, and missionaries started long before the 1970s (Brock & Brock, 1963; Greig, 1937; Lechaptois, 1913; Wise, 1958; Wychaert, 1914). Some of these early writers witnessed the process of producing iron especially in Ufipa, southwestern Tanzania, before the ore smelting process was halted in the 1950s mainly because of external factors (cf. Mapunda, 2010). The delayed start of professional research in archaeometallurgy in Tanzania as well as other East African countries can be attributed to the dearth of trained experts from this part of the continent.

The 1960s witnessed the emergence of anthropologists and ethnographers interested in and who wrote on iron production (Wembah-Rashid, 1969; Willis, 1966, 1968). Foreign nationals dominated the early period of professional archaeometallurgical research (1970s to mid-1990s). Interests in training national archaeologists matured with the establishment of the Archaeology Unit (now the Department of Archaeology and Heritage) at the University of Dar es Salaam in 1985. Today, along with foreign archaeometallurgists, there are two local archaeometallurgists in Tanzania, the authors of this entry. Archaeometallurgical research in Tanzania has concentrated mainly on iron. This is

because iron production dominated indigenous technologies in the country. Although copper deposits have been noted in some areas west of the country, no record of exploitation of the same scale is known so far.

Professional research into iron production in Tanzania has focused on various themes including origin and chronology, technology (e.g., furnaces, tuyère ports, and tuyères), and culture (rituals, symbolism, and taboos) of producing iron and steel.

Origin and Chronology

One of the key questions for early archaeometallurgical research has been finding out whether iron production was introduced or independently invented in sub-Saharan Africa. Tanzania is no exception. On the basis of the available research evidence in Tanzania, it is extremely difficult to declare that iron production in Tanzania was introduced from elsewhere outside Africa. The technology of Early Iron Age (EIA) Tanzania is so different from the known European and Asian evidence, which makes it reasonable to suggest that the technology of iron production in Tanzania has an independent origin in sub-Saharan Africa (cf. Schmidt & Avery, 1983, p. 432). The absence of a three-stage process of iron production in Eurasia also strengthens the proposition of independent invention of iron technology in sub-Saharan Africa. In terms of chronology, the metallurgy of Tanzania is conveniently divided into two phases, namely, EIA and Later Iron Age (LIA). For the purpose of this entry, the first phase approximately covers the period between 500 BC and 1500 AD (Chami, 1994; Haaland, 1993, 1994/1995; Mapunda & Burg, 1991; Schmidt & Childs, 1985; Schmidt, 1988), while the LIA covers *ca.* the period between 1500 AD and 1950 (cf. De Rosemond, 1943; Lyaya, 2011). From the oldest to the youngest, the archaeological sites with EIA iron technology in Tanzania include (i) Rugomora Mahe, KM2 and KM3 in the Kagera Region; (ii) Limbo in the Coast Region; (iii) Dakawa in the Morogoro Region; (iv) Ntuhia in the Mbinga, Ruvuma Region; (v)

Usambara mountains; and (vi) Magubike in the Iringa Region. There are many LIA archaeological sites in Tanzania in almost every region, although more research is needed to declare this position. The technology of iron production spread widely during this period possibly because it was vital for socioeconomic and cultural activities than in any other time before (Mapunda, 1995; Lyaya, 2013).

Process of Iron Production

Generally speaking, the process of iron and steel production in sub-Saharan Africa either followed a two-stage or three-stage process. The process of iron production especially in the southern highlands of Tanzania followed a three-stage process including ore smelting, iron refining, and iron smithing (primary and secondary smithing) stages. It means that not all iron-producing societies followed the three-stage process; most of the iron-producing societies in Tanzania and elsewhere in sub-Saharan Africa followed a two-stage (ore smelting and smithing) process. So far the three-stage process has been verified ethnoarchaeologically and archaeometallurgically in Unyika (Brock & Brock, 1965) and Ufipa (Greig, 1937) in the southern highlands of Tanzania. The two-stage process is popular in much of Tanzania and in many other places across the globe. In extension, the three-stage process was practiced in Zambia, Malawi, Democratic Republic of Congo (DRC), NW Mozambique, and Tanzania (Chaplin, 1961; Davison & Mosley, 1988; Killick, 1990; Mapunda, 2010; van der Merwe & Avery, 1987).

In terms of the end products, the second stage of the three-stage process, locally referred to as the *vintengwe* process, aimed at producing carbon-rich steel through carburization of the end product (soft iron) of the ore smelting stage (locally referred to as the *malungu* process). The end products of the first stage of the two-stage process were either soft iron (bloom) or steel, while the end product of the three-stage process was the soft iron from the ore smelting stage and carbon-rich steel from the second *vintengwe*

stage. The ore smelting and iron refining stages used furnaces, and the smithing stage used smithing hearths. The difference between the two processes can be discussed in relation to the nature of the iron ore, because the *malungu* furnaces utilized low-grade iron ore, but the relatively small and short ore smelting furnaces utilized iron-rich ores (Mapunda, 2010; van der Merwe & Avery, 1987).

Furnaces

The ore smelting and iron refining furnaces can be described in relation to variable criteria such as (i) building material, (ii) height, (iii) presence or absence of slag-pit provision, (iv) furnace morphology, (v) decoration, and (vi) presence or absence of a peep hole. The majority of EIA furnaces were built using bricks or clay rolls, but with the exception of the Barongo furnaces that were termite slab-made, almost every LIA furnace was built using wet clay. The general change of the building material can be associated with efficiency of the furnaces in terms of the effect of air in smelting the metal, possibly because expansion and contraction due to heating and cooling loosens the fireclay cement between the bricks and clay rolls, which in turn allows air to be drawn in and gas to escape at low levels (cf. Tylecote et al. 1971). The furnaces in the EIA period were completely bowl furnaces, although it is difficult to completely verify this position on account of the fragmentary nature of the furnace remains (Sutton, 1985). Some of the EIA furnaces have been referred to as shaft-bowl furnaces (Schmidt & Avery, 1983). Generally speaking, the bowl and shaft-bowl furnaces had slag-pit provision wherein liquid slag accumulated at the bottom of the furnace.

There is a group of furnaces especially during the LIA period that were clearly shaft furnaces: short shaft furnaces about 1 m and tall shaft furnaces about 1.5–3 m. Most of the shaft furnaces had no slag-pit provision; the liquid slag was tapped out of the furnace through tuyères [a nozzle through which an air blast is delivered to a forge or blast furnace] or through special

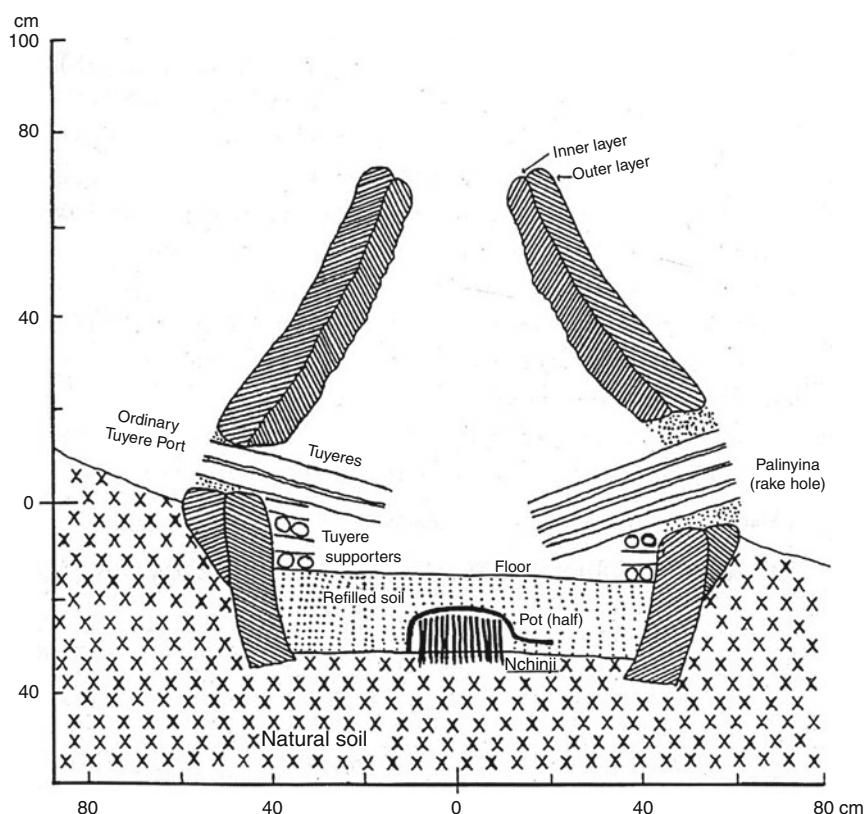
holes dug below the tuyère level. The shaft furnaces are greatly variable in terms of morphology, which includes truncated and globular, almost cylindrical, conical, and olpe-shaped furnaces (Figs. 1, 2, 3, and 4).

It should be noted that for the sake of stability and maintenance of the reduction temperature in the furnace, almost all the shapes were designed such that the furnaces were wider at the base diameter and tapered toward the top (see Fig. 1). Some furnaces were decorated, for example, with breasts and wood punches, while others were undecorated (e.g., Kapinga, 1990; Mapunda, 2010, p. 114; Sutton, 1985). Most of the smelting furnaces had peep holes for monitoring progress in them, but some smelters used short tuyères (*kikolombi*) for this purpose.

Tuyères and Tuyère Ports

Generally, the iron production furnaces had about two to ten tuyère ports, where the smelting furnaces of Umatengo, southern Tanzania, had the minimum number of two tuyère ports (Kapinga, 1990) and the *malungu* furnaces of Ufipa and Unyiha represent the maximum number of tuyère ports, 10 (Mapunda, 2010). Generally speaking, the number of tuyère ports relates to the mode of draft a particular iron production process employed. Low numbers, say 2–5, were associated with forced draft whereas high numbers with natural draft. Often, tuyère ports of the former mode housed a single tuyère each, although cases of twin tuyères have also been reported, for example, among the Matengo of southern Tanzania (cf. Kapinga, 1990; Lyaya, 2013). The smelting furnaces with eight (*katukutu*) to ten tuyère ports (*malungu*) housed multiple tuyères and were natural-draft furnaces. The mode of draft bears some relationship to the height and size of the furnaces. For example, the internal base diameter (IBD) of a furnace with two or three tuyère ports is ca. 40–60 cm, while the internal base diameter (IBD) for the *malungu* is ca. 130–160 cm.

The individual or multiple tuyères were placed horizontally, one beside another or one on top of



Metallurgy in Tanzania, Fig. 1 Globular ore smelting furnace (Adopted from Mapunda, 2010, p. 131)

another. While the main function of tuyères was to supply air into the furnace (for examples, see Childs, 1996; Schmidt, 2006), in Ufipa, tuyères were also used for slag tapping (cf. Mapunda, 1995, 2010). Tuyères used for such a purpose would be placed in such a way that they were sloping downwards outwardly, while those used for air supply alone were inwardly inclined (Mapunda, 2010, p. 154). In terms of length, the longest tuyères from Ufipa (Fig. 5) measure *ca.* 40–50 cm, and the shortest tuyères from Iringa (Fig. 6) measure *ca.* 10–15 cm.

Morphologically, tuyères are either flared proximally or having the same diameter tip to tip. The former shape is associated with forced air supply and hence could be used for smelting, refining, or smithing, while the latter is associated with natural-draft combustion system and is therefore not associated with the post-smelting process of smithing.

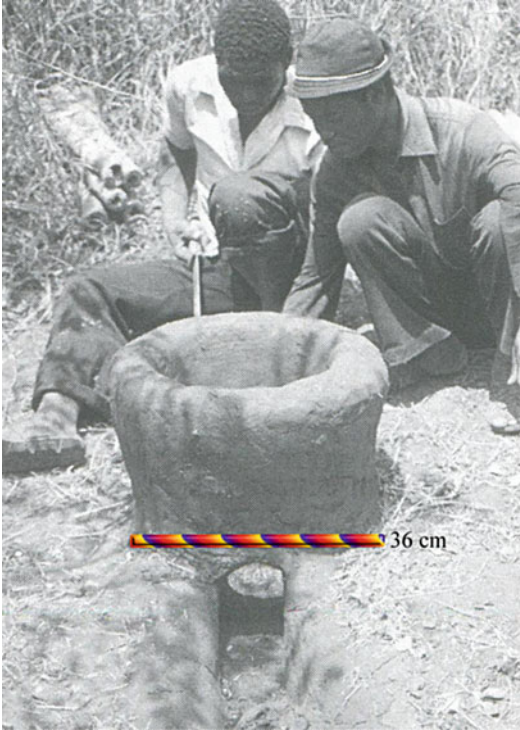
Rituals, Symbolism, and Taboos

The process of iron production in Africa was fully associated with ritualistic symbolism and taboos, and Tanzania is no exception (cf. Lyaya, 2011; Mapunda, 2013; Schmidt & Mapunda, 1997; Schmidt, 1997). Metaphorically, the ore smelting process was equated to the human (re)production system. The furnace was regarded as a pregnant woman, and that is why some smelting furnaces in the southern highlands of Tanzania were decorated with breasts (Kapinga, 1990; Sutton, 1985). The furnace “rake hole” was considered as the “mother door” in Ufipa (Mapunda, 2010), and for this reason, the metal produced was regarded as the child. Because of the importance attached to a childbirth event and the risks involved, no wonder that the process was accompanied with ritualistic medicines and symbolism to guarantee a safe child delivery. Similarly, the

process of iron production used ritualistic medicines to symbolically ensure successful production of the metal. Most of the plant and animal species used for the ritualistic medicines in the iron production process had similar sociocultural uses in societies including curing or protection

against witchcraft, diseases caused by witchcraft and spirit possession, epidemics threatening the community, venereal diseases that reduce fertility, and symbols of fertility (Mapunda, 2010, 2013; van der Merwe & Avery, 1987). It therefore follows that the use of such medicines in iron production was related to the belief of the smelters that because these medicines worked efficiently in child conception, pregnancy, and delivery, they could have worked effectively to ensure successful bloom production (Lyaya, 2012, 2013; Mapunda, 2011, 2013).

Most of the iron production ritualistic medicines have been found buried at the bottom of smelting furnace floors. Some of the medicines were covered with ritual pots, which were sometimes perforated to supply breathing throughout the furnace (Kapinga, 1990). The use of smelting medicine was critical for the smelters; smelting could not be conducted without it (Barndon, 2004a; van der Merwe & Avery, 1987). The smelting magic functioned to increase the seriousness of the performers (rewards or punishment) and to increase confidence to cope with the unknown. The legacy of iron production medicine is evident in some iron-producing societies for they use the smelting sites for ritualistic healing, because people believe that the smelting medicines were strong and eternal (Mapunda, 2010, p. 160). Others in the southern highlands of Tanzania collect and keep smelting memorabilia in their houses.

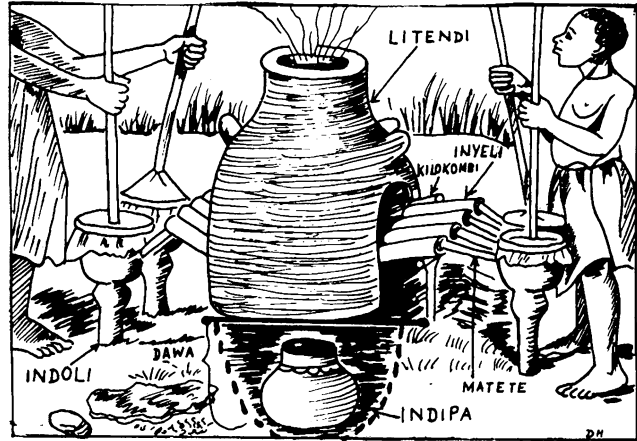


Metallurgy in Tanzania, Fig. 2 Cylindrical *Kitengwe* iron refining furnace (Adopted from Barndon, 2004b)

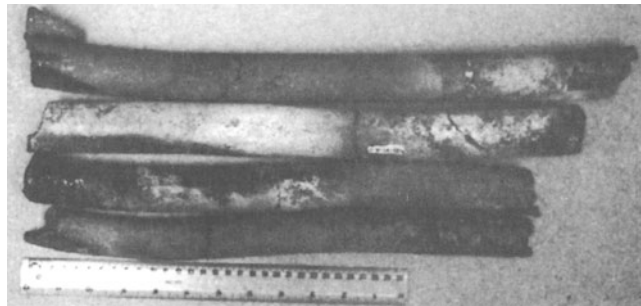
Metallurgy in Tanzania, Fig. 3 Conical ore smelting furnace from Ufipa (Adopted from Lyaya, 2013)



Metallurgy in Tanzania,
Fig. 4 Olpe-shaped ore
smelting furnace (Adopted
from Kapinga, 1990)



Metallurgy in Tanzania,
Fig. 5 Longest tuyères
from Ufipa (see Mapunda,
2010, p. 126)



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Metallurgy in Tanzania,
Fig. 6 Shortest tuyères
from Kalenga (see Lyaya,
2013)



The process of ore smelting in Tanzania was governed by serious taboos, including the following. First, among most communities, smelters were not allowed to take showers for the entire smelting season! Second, they were required to maintain celibacy during the entire period. Third, in most iron-producing societies, women especially those menstruating were not allowed to

come close to the smelting site or any smelting raw materials. For the same reason, in some cases, women already in menopause were allowed to come close to the smelting sites. Fourth, the smelting activities were isolated from the general public eye and especially from the strangers. Lastly, smelters were required to stay peacefully at the smelting camp. If one of

these taboos was violated, then there was a big chance that the smelt would fail. Anyone who was identified to have violated the taboos was punished including chasing them from the smelting exercise (for details, see Bandon 2001, 2004b); Mapunda, 2002, 2011, 2013; Schmidt & Mapunda, 1997)!

Conclusion

We have noted that archaeometallurgical research in Tanzania started relatively late when compared with other archaeological themes such as Stone Age technologies, human evolution, pottery ware and traditions, and coastal archaeology. Nonetheless, expansion of research in this subject both spatially and thematically has been comparatively impressive. Almost 50 % of the country is sufficiently surveyed through staff and postgraduate research or undergraduate field schools program and its archaeometallurgical information is confidently known. Efforts continue to cover the remaining area so as to gain a comprehensive understanding of the metallurgical history of the entire country within the next 10 years. Thematically, research interests have covered issues related to technological variations (both stylistic and spatial), origins, composition, symbolism, bio-metallurgy, metallography, and elemental analysis.

There are efforts to train more practicing local archaeometallurgists. Various archaeometallurgical courses have been introduced in both undergraduate and MA levels for students interested in metallurgy. These have proven to be quite interesting to students. For example, since the establishment of an MA (archaeology) degree program in 2003–2004, with an average of six students every year, a total of seven students have conducted their dissertation research on archaeometallurgy. We continue encouraging and supporting colleagues from outside Tanzania to work both collaboratively or independently in this subject matter for the interest of global science. In terms of future research directions, we see it that a purposive employment of archaeometry methods to the study of the

archaeometallurgy of Tanzania is vital, in order to improve our understanding of the archaeometallurgy of Tanzania. In line with this there is a need to establish a BSc and MSc in archaeological science programmes at the University of Dar es Salaam.

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Metallurgy in the Near East

Haskel J. Greenfield

The Near East represents one of the earliest centers for the development of metallurgical technology and is crucial to the investigation of issues related to the development of metallurgy (Muhly, 1988; Tylecote, 1986, 1987, 1992; Wertheim & Muhly, 1980). Metallurgy appears very early, with the recovery of cold-hammered copper artifacts from the Late Pre-Pottery Neolithic. With the development of smelting techniques, copper metallurgy spreads fairly quickly and widely during the Chalcolithic. Metallurgy spread ever more rapidly when it was discovered that the properties of copper could be improved by alloying copper with other metals such as arsenic, lead, or tin, to produce bronze. Bronze tools begin to be found in



Metallurgy in the Near East, Fig. 1 Cut mark on bone from site of Atlit Yam, sample 164 (Photo by Haskel J. Greenfield)

the Early Bronze Age (EBA). By the Middle Bronze Age, the use of bronze becomes more frequent (Maddin, Muhly, & Stech, 1999; Mellaart, 1976; Moorey, 1998; Redman, 1978). However, it is impossible to document the introduction and spread of metallurgy into a region by simply using the frequency of metal finds. Metals, such as bronze and copper, are notoriously unstable. They decompose under most depositional conditions and/or are reused.

The objective of my research has been to investigate this issue from the perspective of Zooarchaeology, or the analysis of animal bones from archaeological contexts. Slicing cut or butchering marks on bones can be used to identifying the nature of the raw materials which were used in the butchering of animals (Fig. 1). By distinguishing whether metal or stone tools make cut marks on animal bones, an independent measure of the relative importance of the different raw materials used for butchering or cutting of meat can be generated. The spread of metallurgy, as a result, can then be quantitatively monitored both across time and space within a region, and even within a single settlement.

Method

The method for distinguishing between stone and metal cut marks is based on experimental

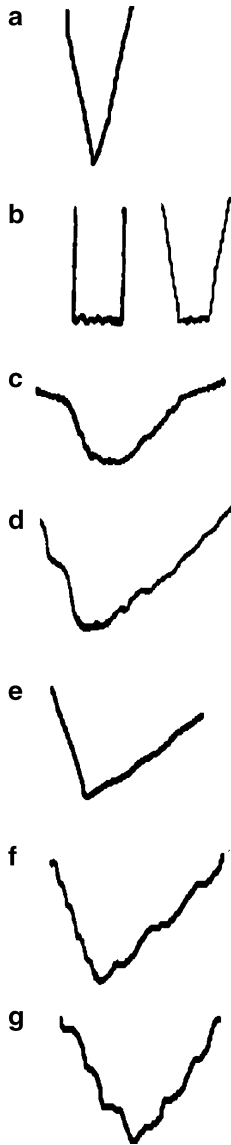
research conducted by the author and others and is discussed at length elsewhere. It will be only briefly summarized here (Greenfield, 1999, 2000a, 2002a, c, 2006; Olsen, 1989). In order to identify bones with butchering marks on them, each bone fragment was individually examined. Most of the butchering marks were readily identifiable to the naked eye. A low power magnifying glass was used to survey each bone in order to enhance the potential for discovering butchering marks. Even though microscopic examination of the entire surface of each bone may have located a higher number of butchering marks, it was not deemed to be a realistic in terms of sample size, time, and finances.

Butchering marks are often relatively easy to distinguish in this period from tooth and other marks in later prehistoric bone assemblages. The nature of the activity leaves a relatively clear signature for even the naked eye – a relatively short straight incision in the bone. Many bones with potential cut marks were rejected when subjected to microscopic examination since they were deemed to be caused by nonbutchering sources. Once butchering marks were identified, the cut mark was examined under a light optical microscope and a tentative identification of the nature of the raw material of the implement was made – stone or metal.

Subsequently, a silicone mold of the incision was made in order to further study the mark in a scanning electron microscope. Each mold was subjected to further examination by the author and another assistant in the lab at the University of Manitoba. In this way, each mold was separately and repeatedly examined to determine whether a stone or metal blade had been used during butchering. This ensured a level of accuracy and repeatability of results rarely encountered in such analyses.

Several simple diagnostic criteria can be used to distinguish metal from stone tools. Metal tools have the following patterns (Fig. 2):

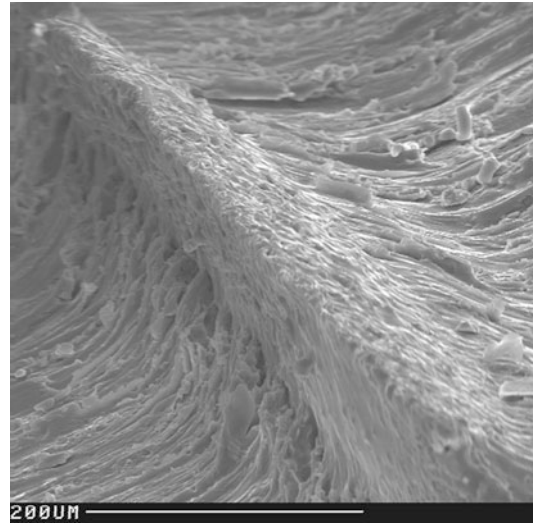
1. Metal knife blades sharp V-shaped or (Fig. 3) hard cornered L-shaped grooves (Fig. 4) that meet at a distinct apex at the bottom of the groove (Fig. 2a, b).



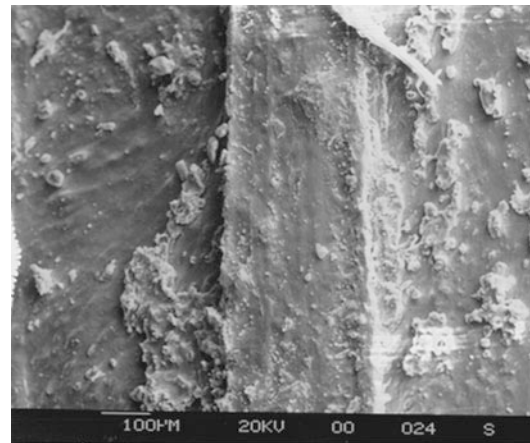
Metallurgy in the Near East, Fig. 2 Profiles of cut marks made by stone and metal blades

2. Metal tools make more uniform patterns on the bone, often removing material in the groove more effectively. They leave either no striations or striations of a more uniform depth and spacing than when stone tools are used (Fig. 5).

In general, metal knives produce a cleaner and more even slicing cut (except for serrated-edge blades – Fig. 2c).



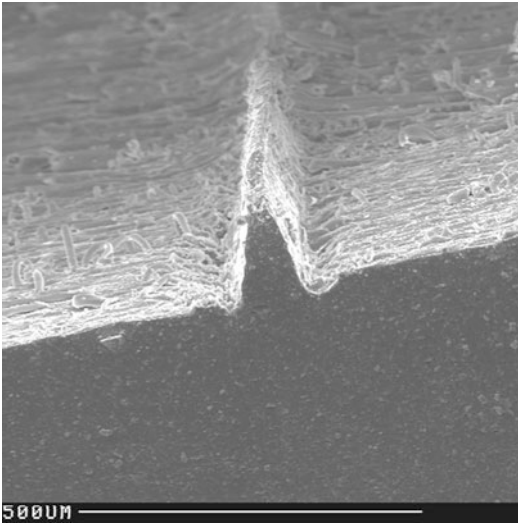
Metallurgy in the Near East, Fig. 3 Inverse mold of flat-sided metal knife (metal 9c) cut mark



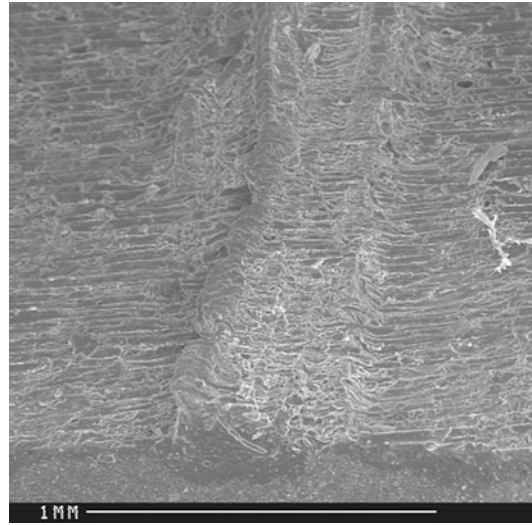
Metallurgy in the Near East, Fig. 4 Inverse mold of dulled metal knife (an236) cut mark

By contrast, chipped stone tools have different diagnostics, which can be summarized as follows:

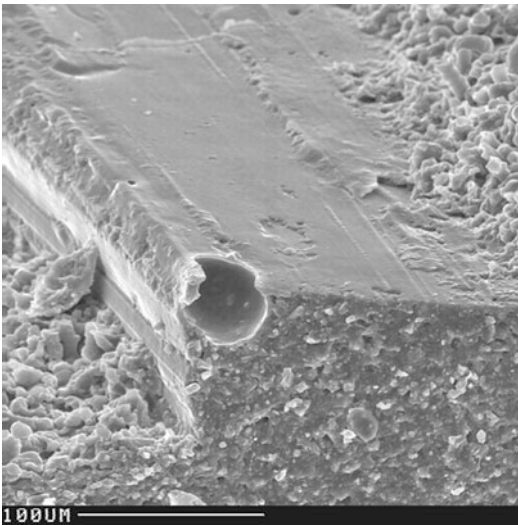
1. Chipped tools (blades or flakes) create a groove with one side rising steeply and smoothly and the other side rising more gradually (Figs. 6 and 1e), except for scrapers (Fig. 1d).



Metallurgy in the Near East, Fig. 5 Inverse mold of flat metal blade (metal 4c)



Metallurgy in the Near East, Fig. 7 Inverse mold of unifacially worked stone blade (stone 6a) cut mark



Metallurgy in the Near East, Fig. 6 Inverse mold of unretouched stone blade (stone 125a) cut mark

2. The gradually rising side will have one or more striae that run parallel to the apex of the cut, depending on whether it is retouched or not (Fig. 7).
3. Retouched tools may have lateral striations on both sides of the apex, depending on whether they are unifacially or bifacially retouched (Fig. 1f, g).

4. Stone tools produce a shallower, less even cut mark.

In sum, the type of raw material used in making a butchering implement can be distinguished on the basis of its profile. In this illustration, typical profiles for different types of metal or stone butchering implements are presented.

Data

In order to investigate the origins of metallurgy in an area, sites from before and after the assumed starting point must be included in the analysis. Data from Israel were chosen since this is an area with early metallurgy (Levy, 1998; Levy and Shalev, 1989; Mazar, 1990; Shalev, 1994; Shugar, 1999) and is one of the few areas of the Ancient Near East where many animal bone collections are easily accessible for analysis. At this point in time, data from over seventeen zooarchaeological collections have already been analyzed from sites excavated in Israel and the present Palestinian Authority areas (Greenfield, 2004a, b; Greenfield, Gallili, & Horwitz, 2006; Seidel et al., 2006).

Data from the Proto-Neolithic through the Middle Bronze Age are included in the study. In this way, it is possible to monitor the possible introduction of metallurgy even the Chalcolithic, when the first metallurgy has been proposed to exist. Most of the sites fall into the PrePottery Neolithic, Pottery Neolithic, and EBA. The other periods are more poorly represented. Over the next few years, more sites will be added to the database.

Results

A total of 857 bones with useable butchering related cut marks have been identified (to date) from the above sites. The data can mostly be analyzed from the perspective of time, although there are some inferences that can be made with regard to spatial divisions with the data (Fig. 8).



Metallurgy in the Near East, Fig. 8 Map of sites used in analysis

Temporal Distribution of Butchered Remains

In the Proto, PrePottery, and Pottery Neolithic assemblages, there is no evidence for metal cut marks on bones (Fig. 9 and Table 1). This is not unexpected, but is important to demonstrate. A few metal cut marks were found at (Jericho in the PPNB sample), but these have been deemed to be from intrusive or improperly labeled specimens.

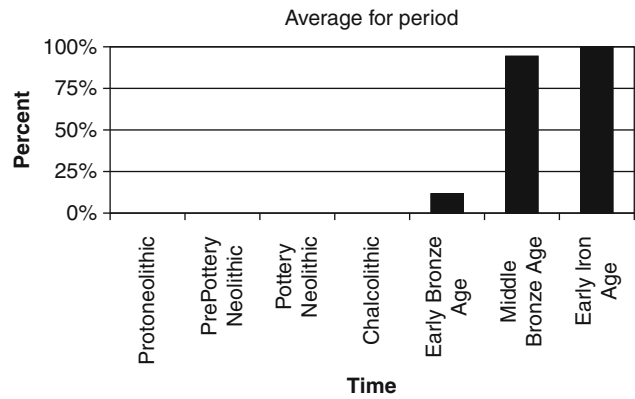
This pattern of stone tool dominance continues during the Chalcolithic. While the sample size of sites is much smaller than in the previous periods ($n = 1$, Gilat), there are a substantial number of cut marks from the site.

During the EBA, the pattern begins to change. Metal cut marks begin to appear. The data from Jericho indicate that both stone and metal cut marks were found in the assemblage in substantial numbers. During the EBA, metal tool marks are present in 41 % of the bones of Jericho.

But the frequencies of metal cut marks in other Early Bronze (EB) sites is different from that seen above for Jericho. At sites, such as Afridar near Ashkelon, 89 % of the cut marks belong to stone tools and the remainder are metal tool marks. At the nearby EB site of Ashkelon Marina, the similarly low percentages of metal cut marks are found. Only one out of the seven bones with identifiable cut marks had a metal cut mark on it (14.28 %). At Be'erotayim, all of the bones were butchered with stone tools. The situation is less clear at the EB sites of Dalit and Tel Kinrot. While the data are evenly split, the frequencies of cut marks are so small that they have no statistical reliability and should not be given any weight in the analysis. They are presented here merely to demonstrate that metal appears across a wide range of sites during the Early Bronze Age.

Only one site with a Middle Bronze Age (MBA) sample has been analyzed so far (Jericho). The frequency of metal tool marks rises dramatically in the MBA at Jericho to 94 % of the total (85.19 % in the tell deposits and to 95.19 % in the tomb deposits). This indicates the nature of the dramatic change between the two periods. The pattern for the MBA continues in later periods. Metal tools made almost all of the cut marks.

Metallurgy in the Near East, Fig. 9 Histogram of percentage of metal cut mark frequency over time (average per period)



Metallurgy in the Near East, Table 1 Distribution of cut marks by period and site

Period	Subperiod	Site	Stone no.	%	Metal no.	%
Protoneolithic		Jericho	4	100.00	0	0.00
PrePottery Neolithic	PPNA	Jericho	17	100.00	0	0.00
PrePottery Neolithic	PPNB	Jericho	15	88.24	2	11.76
PrePottery Neolithic	PPNC	Atlit yam	117	100.00	0	0.00
PrePottery Neolithic	PPNB	Yiftahel	4	100.00	0	0.00
Pottery Neolithic		Jericho	1	100.00	0	0.00
Pottery Neolithic		Lod	23	100.00	0	0.00
Pottery Neolithic		Neve Yam	10	100.00	0	0.00
Pottery Neolithic		Tel Dan	10	100.00	0	0.00
Pottery Neolithic		Tel Hereiz	12	100.00	0	0.00
Chalcolithic		Gilat	34	100.00	0	0.00
Early Bronze Age/EB I		Afridar (1963)	10	100.00	0	0.00
Early Bronze Age		Arad	86	91.49	8	8.51
Early Bronze Age		Jericho	10	58.82	7	41.18
Early Bronze Age		Dalit 2	1	100.00	0	0.00
Early Bronze Age		Dalit 78	0	0.00	1	100.00
Early Bronze Age		Tel Kinrot	1	100.00	0	0.00
Early Bronze Age	EB I	Ashkelon Marina	6	85.71	1	14.29
Early Bronze Age	EB I	Afridar	8	88.89	1	11.11
Early Bronze Age	EB I/EB IV	Rujm Be'erotayim	6	100.00	0	0.00
Middle Bronze Age total	Tell and tomb	Jericho	13	6.07	201	93.93
Early Iron Age	Eleventh century BCE	Ashkelon tell	0	0.00	6	100.00

Raw Material by Geographical Region

Some spatial interpretations of the data can be made, but the data are very incomplete. There is evidence for early use of metal for butchering during the MBA from a variety of sites, ranging

from the southern (Afridar and Ashkelon) and central coastal regions (Dalit), through the northern Negev (Arad) to the Jordan Valley (Jericho) see below. Other regions of the Country, such as the Central Negev, do not show any use of metal. It is difficult, at present, to discuss spatial trends

Metallurgy in the Near East, Table 2 Distribution of cut marks by taxon and period (NISP) – Jericho

Period (revised)	Domestication	Taxon	Metal	Stone	Grand total
Protonedithic	Wild	Gazella sp.	0	4	4
PPNA	Wild	Gazella sp.	0	14	14
		Sus scrofafer.	0	1	1
		Vulpes vulpes	0	1	1
		Bos primigenius	0	1	1
PPNB	Domestic	Bos taurus	1	1	2
	Wild	Gazella sp.	0	9	9
		Sus scrofafer.	0	1	1
		Bos primigenius	1	4	5
Pottery Neolithic	Domestic	Ovis	0	1	1
Early middle BA	Wild	Gazella sp.	0	1	1
EBA	Domestic	Bos taurus	3	4	7
		Ovis	2	3	5
		Ovis/Capra	2	2	4
	Wild	Ovis orientalis	0	1	1
MBA	Domestic	Equus caballus	2	1	3
		Ovis	0	1	1
		Ovis/Capra	17	2	19
		Sus scrofa dom	1	0	1
		Sus scrofafer.	2	0	2
	Wild	Dama mesopotamica	1	0	1
MBA tomb	Domestic	Bos taurus	3	1	4
		Capra	14	0	14
		Capra hircus	9	0	9
		Equus asinus	4	0	4
		Ovis	105	6	111
		Ovis aries	19	1	20
		Ovis aries?	2	0	2
Grand total		Ovis/Capra	22	1	23
			210	61	271

within any single site since the data are not yet processed from this perspective.

Raw Material by Taxon

While there is no perceived pattern of which taxa were butchered with the various types of raw material, the EB metal cut marks are concentrated on domestic and wild cattle remains. This is visible in the data from Jericho, with its large frequencies (Table 2). In the periods with metallurgy (EBA and MBA), both domestic and wild taxa are butchered with both metal and stone tools. This pattern can also be seen in the data from EB Afridar (Table 3).

Comparison with Other Sources of Data

In Israel and the PA areas, the origins of metallurgy have also been investigated through the analysis of lithics. Steve Rosen (1997) demonstrated that the first stage in the adoption of metallurgy did not involve the wholesale replacement of flint tools (as is commonly assumed). Functional chipped stone tool types gradually disappear between the end of the Chalcolithic and Iron Age. Some types disappear because of changes in subsistence (arrowheads), while others are replaced with metal types that had a corresponding function (axes). Some stone tool types disappear quickly (at or prior to the beginning of the Bronze Age – arrowheads),

Metallurgy in the Near East, Table 3 Distribution of cut mark by taxon (NISP) based on light optical microscope – Afridar

Domestication	Taxon	Metal no.	%	Stone no.	%	Grand total no.
Domestic	<i>Bos taurus</i>	1	12.50	7	87.50	8
	<i>Bos taurus?</i>	0	0.00	1	100.00	1
	<i>Capra hircus</i>	0	0.00	2	100.00	2
	<i>Ovis aries</i>	0	0.00	4	100.00	4
	<i>Sus scrofa dom.</i>	0	0.00	1	100.00	1
	<i>Ovis/Capra</i>	0	0.00	4	100.00	4
Wild	<i>Alcelaphus buselaphus</i>	0	0.00	1	100.00	1
	<i>Bos primigenius</i>	1	100.00	0	0.00	1
?	Large mammal	1	50.00	1	50.00	2
	Medium mammal	1	100.00	0	0.00	1
Grand total		4	16.00	21	84.00	25

others disappear gradually through the Bronze Age (axes), and some continue to be used into the Iron Age (sickles). To explain the continued use of stone (in the face of increasingly available metal tools) into later periods, Rosen has suggested that until a clear improvement in efficiency emerges, the economy would perpetuate the use of the traditional material.

While the data from the region is admittedly very small, geographically unrepresented, and was collected for the most part haphazardly by archaeologists in the field, they still represent the only available data. Even so, they can be used to represent changes in the region over time. Eventually, more information will be added to the database and process across space may be investigated.

Problems that plague the analysis are that it is hard to obtain a statistically significant pattern from small sample sizes and it is always possible that some material from multiperiod sites (e.g. Jericho) that is found in one or another stratum is either residual or intrusive, especially when the objects are small (such as animal bones). As a result, it is always possible that when you have a very small database, the effect of possible intrusions becomes statistically greater. It will only be from relatively large samples that we can have enough reliable data to draw definitive conclusions. Nonetheless, the data allows us to draw some tentative conclusions.

The evidence indicates the evolution of a butchering technology that changes over time. It was

exclusively reliant upon stone tools from the Pre-Neolithic levels (represented at Jericho), through the various sites represented by PrePottery and Pottery Neolithic, and into the Chalcolithic periods. Most tools were probably unmodified flakes, haphazardly made, or blades. In contrast, the data from the EBA and MBA indicate a gradual, followed by a substantial shift in butchering technology from stone to metal. Stone butchering technology continues to play an important role in the EBA, but it is barely present in the MBA. This is not surprising given the differences in the nature of metallurgy between these two periods. Only copper or occasionally natural arsenical alloys (i.e., arsenical bronze) are in use until the very end of EB III, when tin makes its appearance. The evidence from the cut marks provides independent supports such a shift in metal technology. A functional butchering bronze metallurgy is entirely or almost nonexistent in the EB and this is evident by the lower use of metal tools in the butchering process.

It is apparent that there are some spatial differences in the availability of metal. While most sites have little or no metal cut marks during the EBA, major centers such as Jericho have substantial quantities. This may reflect the beginning of differential access to valued resources over time.

The data presented above are important for increasing our understanding of the spread and rate of adoption of a functional metallurgical butchering technology. It would appear to be adopted in spurts, similar to the process described

for the abandonment of stone tools (Rosen, 1997). These patterns appear to be more common than previously thought. Comparable data from other regions show striking similarities (as in the central Balkans and in southern Turkey; see Greenfield, 1999, 2000a, b, 2002b).

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Metallurgy of Ancient Indian Iron and Steel

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Early ideas about the Aryan migration theory and the introduction of iron into India from the West have now been proved to be incorrect. For example, Pleiner (1971) proposed that so-called Aryans had no iron production until the second half of the first millennium B.C.E., and that there was no iron export to the West from the area of the Aryans, whom he assumed to be “the Sanskrit speaking people.” However, there are firm dates for the advent of iron in the Indian subcontinent before this period. The independent origin of iron has been convincingly argued by Chakrabarti (1992). Agrawal and Kharakwal (2002) have compiled radiocarbon dates of excavated iron manufacturing sites in the Indian subcontinent. The earliest available date, 3050–90 BP, is from Raja-Nala-Ka-Tila in Uttar Pradesh (Tiwari, 2003).

The primacy of iron technology in the Indian subcontinent is well established and there are

several published books on the state of ancient Indian iron technology (Balasubramaniam, 2002; Biswas, 1996; Chakrabarti, 1992; Neogi, 1914; Tripathi, 2001). The metallurgy of iron and steel in ancient India is the topic of this article, which includes the working of iron, the extraction of iron and salient features of ancient Indian iron. Some objects illustrating the skill of the Indian blacksmiths are provided. The Delhi Iron Pillar (Fig. 1) illustrates the pride of Indian blacksmithy skills.

Metal Extraction

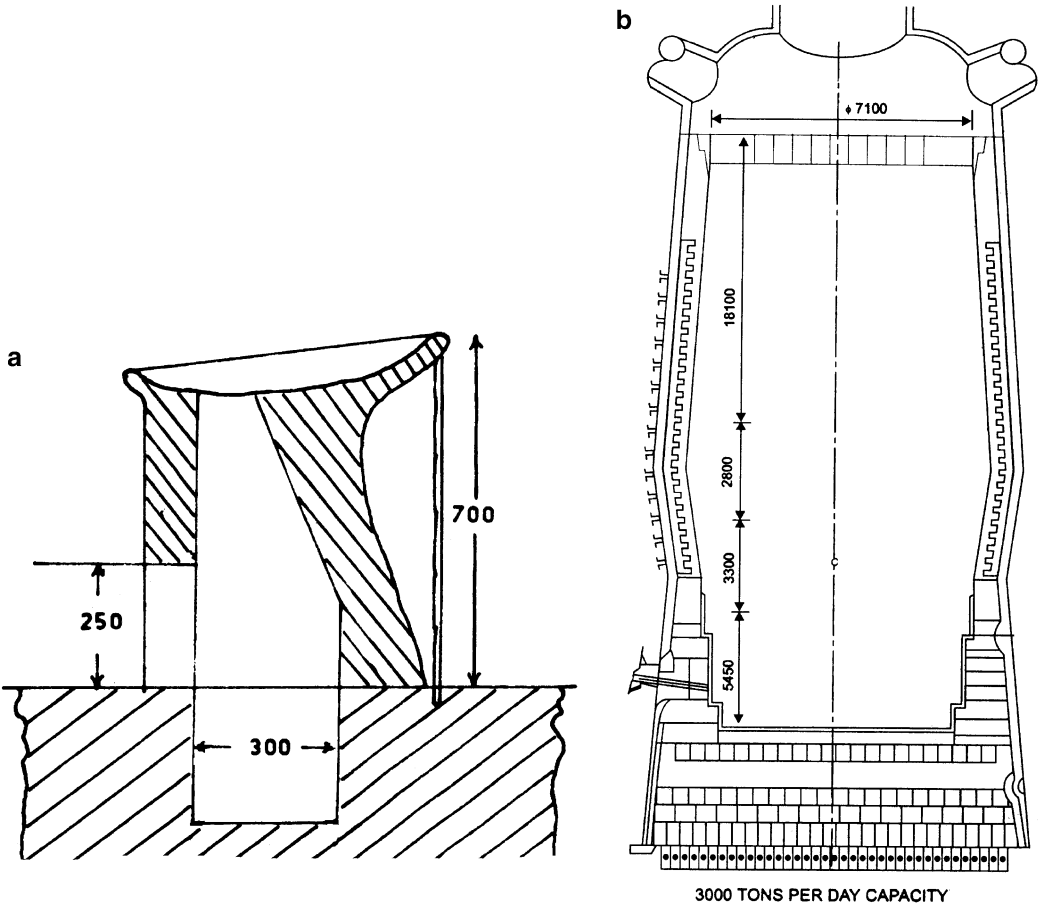
The direct reduction method of iron extraction was used for a fairly long period in India's history. Iron lumps were the starting material for the fabrication of most objects.

Iron melts at 1,540 °C and the ancient Indian furnaces were incapable of attaining this high a temperature. The various aspects of construction and operation of ancient Indian iron furnaces (called bloomery furnaces because the end product was an iron bloom) have been discussed in the literature (see Tripathi, 2001). The ore for extracting iron was carefully collected by the ironsmiths. Interestingly, specific ore was collected depending on the end application. Preheating facilitated breaking of the ores, and the fine dust was separated by washing or by wind. The preheated iron ore and charcoal were charged in alternating layers, the furnace ignited and slowly heated to the reduction temperature (1,000–1,200 °C). Different designs of iron extraction furnaces have been described in the literature. Their heights ranged between 5 and 20 ft. A typical ancient Indian bloomery furnace is schematically compared with a modern blast furnace in Fig. 2.

Bellows placed at the bottom of the furnaces were operated at a controlled rate. The iron ore had to be reduced in order to obtain the iron. Iron ore is essentially oxide of iron and it is reduced by the carbon monoxide (CO) that is produced by the burning of charcoal in the bloomery furnace (or coking coal in a modern blast furnace). The other unwanted oxides, like silicon dioxide (SiO₂), which is commonly found in iron ores, have to be removed and this was possible by the

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Fig. 1 Delhi Iron Pillar located in the Quwwat-ul-Islam mosque in the Qutub Complex at New Delhi



Metallurgy of Ancient Indian Iron and Steel, Fig. 2 Comparison of **a** modern and **b** ancient furnaces for extracting iron from ore

creation of a liquid slag called iron silicate or fayalite FeSiO_4 or $2\text{FeO} \cdot \text{SiO}_2$. While some of the liquid slag flowed out of the bloomery furnace during the reduction of iron ore to iron, some of the liquid slag still remained when the hot iron lumps were taken out of the furnace. Therefore, the hot lumps that were extracted from the bloomery furnace at the end of the heat (typically lasting for about 6–8 h) were immediately hammered. In this process, most of the entrapped liquid fayalitic slag flowed out of the solid reduced iron mass. However, it was not possible to remove all the entrapped liquid slags and ancient irons produced by the direct reduction process will always contain entrapped inclusions. The inclusions are essentially composed of fayalite, some iron oxides (for example, wüstite FeO) and glassy phases (due to calcium silicon phosphates). As a result of entrapped slag particles and iron oxides in the structure, the specific gravity of ancient irons is lower than that for the purest form of iron (Fe).

The slag present in ancient irons is generally microscopic in nature with a few in larger sizes. As the solid-state reduction resulted in a fine distribution of slag particles, it was difficult to completely hammer the slag out of the metallic matrix. The resulting sponge iron always contained some amount of entrapped slag inclusions and unreduced FeO . These are not of uniform size and also not strictly uniform in composition.

Viewing the production of iron lumps from a powder metallurgical viewpoint, the ancient Indians produced iron “pre-forms” directly from iron ore which implied that the powder production, powder consolidation, and sintering processes were combined into one operation (Dube, 1990). (Sintering is a process in which fine solids are combined into a porous mass that can then be added to the blast furnace. These include iron ore fines, pollution control dust, coke breeze, water treatment plant sludge, and flux.)

The end product of the extraction process was a lump of iron that was subsequently used for a wide variety of applications, either directly or after further heat treatments. One important heat treatment that was successfully conducted was controlled carburization of iron in specially

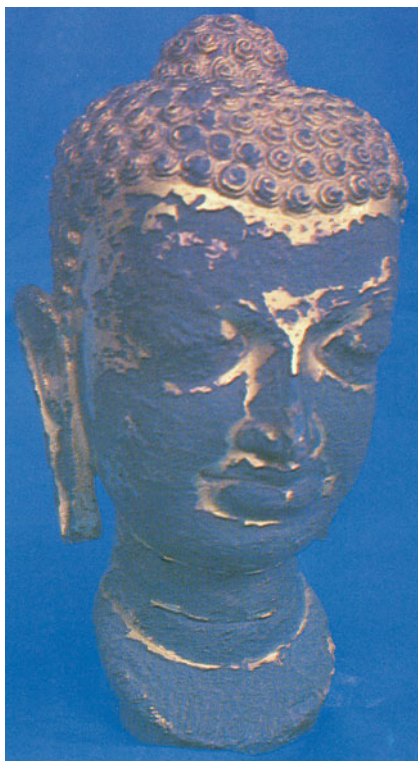
designed crucibles. The carbon content of steel (i.e., an alloy of iron and carbon) was carefully controlled by subsequent decarburization treatments. It is important to control the carbon content in steel because the mechanical properties of steel are critically dependent on the carbon content. As a rule of thumb, the higher the carbon content, the higher the strength of steel.

The relatively small iron lumps produced in the bloomery furnace were the starting materials for the manufacture of large iron objects. The lumps were also used, after suitable heat treatments, for manufacturing agricultural (hoes, spades, sickles, and weeding forks), household (knives, ladles, spoons, sieves, saucepans, cauldrons, bowls, dishes, saucers, and tripods), building (nails, clamps, staples, sheets, door handles, and spikes), tools (anvils, hammers, scissors, saws, chains, and smithy tools), and warfare (swords, javelins, armor, helmets, and shield bases) items. A marvelous example of a forge-welded object is the gilded Buddha head from the Gupta period (320–600 A.D.) (Fig. 3).

With the advent of the carburization of iron, a special type of high carbon steel was produced in India from as early as the fourth century B.C.E. This steel was known as *wootz steel* and it was much prized by warriors because tough swords could be wrought from wootz steel (Srinivasan & Ranganathan, 2004). There were several applications for wootz steel, like the manufacture of tough swords (see Fig. 4), helmets (see Fig. 5), and armor (see Fig. 6).

Classification

Ancient Indians were masters in the production of iron and steel. The method of production of wrought iron directly from the ore by the process of direct reduction continued for a fairly long time, up to the end of the eighteenth century A.D. The Indians knew fairly early about the beneficial aspect of carburizing iron to increase its strength. The earliest evidence for carburization of iron dates to about 800 B.C.E. (Ghosh & Chattopadhyaya, 1982). The second urbanization



Metallurgy of Ancient Indian Iron and Steel, Fig. 3 Gilded wrought iron Buddha image of the sixth Century A.D., now in Lucknow State Museum



Metallurgy of Ancient Indian Iron and Steel, Fig. 4 Typical watered blade manufactured from wootz steel

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of India (i.e., settlements along the Ganga) was strongly influenced by the steeling of iron.

Three principal varieties of iron were recognized based on the carbon content. Each of these was further subdivided into other varieties depending on the composition and properties (Prakash, 1991). Sanskrit literary sources (for example, *Rasa Ratna Samuchchaya* dated to the eighth to twelfth century A.D.) classify iron into three basic categories: wrought iron (*Kanta Loha*), carbon steel (*Tikshna Loha*), and cast iron (*Munda Loha*). *Rasendrashār Samgraha* also mentions these three classifications and states that “*munda* is ten times better than iron rust, *tikshna* hundred times better than *munda*, and *kanta* million times better than *tikshna* iron.” These three basic categories were further classified according to the carbon content, heat treatment, and end use. *Munda* was again subdivided into three varieties: *mridu*, which easily melts and does not break and is

glossy; *kuntha*, which expands with difficulty when struck with a hammer; and *kadāra*, which breaks when struck with a hammer and has a black fracture surface. Six varieties of *tikshna* were provided: *khara*, *sāra*, *hrinnāla*, *tārābatta*, *bājira*, and *kālaauha* (black metal). One variety is rough and free from hair-like lines and has a quicksilver-like fracture surface, while another variety breaks with difficulty and presents a sharp edge. Five different varieties of *kanta* were recognized: *bhrāmaka*, *chumbaka*, *karshaka*, *drāvaka*, and *romakāntā*. The variety of iron which makes all kinds of iron move about was called *bhrāmaka*; that which kisses iron was called *chumbaka*; that which attracts iron was called *karshaka*; that which at once melts iron was called *drāvaka* and *romakāntā* was the kind which, when broken, shoots forth hair-like filaments.

The ancient Indian iron furnaces were capable of producing iron of consistent (low) carbon

content-containing entrapped slag inclusions (Tripathi, 2001). Iron meant for corrosion-resistant applications contained higher phosphorous (P) contents. Therefore, it is reasonable to

conclude that the ancient Indian metallurgists possessed the art of manufacturing iron and steel according to the desired application and corrosion-resistant steel was one among them. The excellent corrosion resistance of ancient Indian iron can be attributed to its relatively high phosphorus contents. This is due to the absence of CaO (calcium oxide, i.e., limestone) in the charge of the bloomery furnace.

Microstructures

In materials engineering, the close correlation between structure and properties is well known. Structure indicates arrangement of the material. When one views the arrangement of electrons, neutrons, and protons, we call it atomic structure. On a microscopic scale, in the order of micrometers, the grain structure of engineering materials is understood. Finally, the macrostructure refers to observations made in the range millimeters. Structure affects the properties of engineering materials.

The microstructures of ancient irons are highly heterogeneous; the iron normally possesses nonuniform grain structures.

In the unetched condition, the specimens generally reveal slag inclusions irregularly distributed in the microstructure. The end product of the bloomery furnace was a lump of direct reduced iron, which contained phosphorous as the major



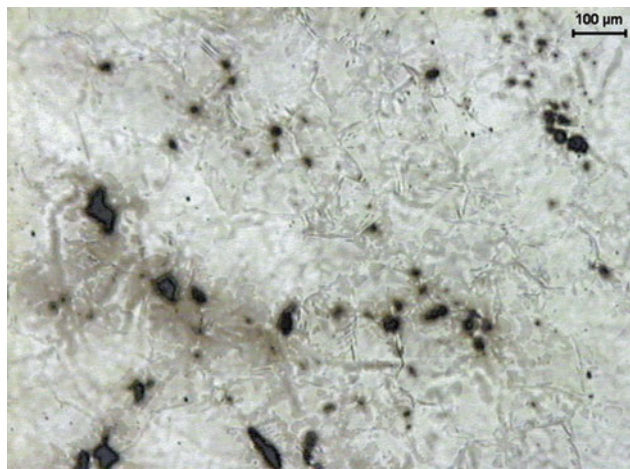
Metallurgy of Ancient Indian Iron and Steel, Fig. 5 A typical medieval Indian helmet fabricated out of wootz steel



Metallurgy of Ancient Indian Iron and Steel, Fig. 6 Typical medieval Indian body protection gear wrought out of wootz steel

Metallurgy of Ancient Indian Iron and Steel,

Fig. 7 Microstructure of Gupta period (320–600 A.D.) iron revealed using Oberhoffer etchant. The regions depleted in P appear darker in contrast. The dark structures are entrapped slag inclusions



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Fig. 8 The massive forge-welded iron cannon called *Rajagopala* located at Thanjavur



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alloying element. The end product of the ancient Indian direct process of extracting iron can be called phosphoric iron. The end product of modern blast furnaces is pig iron, in which carbon is the major alloying element. In contrast to macrosegregation of P in pig iron, microsegregation of P is realized in ancient phosphoric irons. Figure 7 shows an optical metallograph obtained after polishing an ancient Indian iron sample to a mirror-like finish and etching it with Oberhoffer etchant. The particular etchant reveals the distribution of P in the microstructure. The dark areas in Fig. 7 are the regions where the P content is less, while the bright areas are indicative of higher P contents. Notice that

P is depleted from the grain boundaries and from the regions surrounding the entrapped slag particles. There are several fascinating insights that can be obtained from the study of microstructures but this is beyond the scope of this article.

The forge-welding method of manufacturing iron objects continued for a long time. Indians did not quickly adopt the cast iron technology that was becoming popular in Europe from the beginning of the sixteenth century. They continued with their traditional method of forge welding to manufacture large objects like cannons. One typical example of a massive cannon manufactured by forge welding is seen in Fig. 8. This cannon was fabricated in the early part of the seventeenth

century and is located at Thanjavur. There are several other massive forge-welded cannons from the medieval period (Balasubramaniam, 2007).

Death of Indian Iron

Indian metal crafts flourished until the end of the Mughal period (1526–1705). After the establishment of the British Empire, restrictions were imposed by them in the form of production taxes and bans on export. It was natural that this industry should die. This disappearance of the ancient technology during the eighteenth to nineteenth centuries was aggravated by the discovery of new scientific principles and development of new industrial process of metal production in Europe.

The direct reduction process of iron making declined after the advent of the processes for making liquid steel in large-scale in the middle of the nineteenth century. The iron and steel trade from India declined and the ancient method of extraction and processing became extinct by the beginning of the twentieth century.

The British in India made attempts to work on iron ores on a large-scale by modern methods. Several iron and steel works were set up in the country. For example, the Bengal Iron Company was established at Barakar in 1874. It employed 821 people in 1891 and produced 12,000 ton of pig iron (Jaggi, 1989). However, these iron works depended on the availability of charcoal and this necessarily meant the destruction of forests and depletion of charcoal supplies. Another factor was also at play. By the end of the century, indigenous iron ceased to be produced because of the import of iron.

Another factor in iron's decline is the fact that certain essential steps were not shared by the master smiths with anybody except their favored apprentices. Traditional artisan communities in India never reveal full details to outsiders and when the communities disappeared, so did the methods. Other factors include the use of the same age-old furnaces, processes, and blowers (*bhathi*) by many tribes. This shows that these process secrets were

well guarded and any change in the process or equipment was considered a bad omen. Probably this is one of the reasons for the loss of metal technology like wootz steel manufacture.

In the twentieth century, the condition had become so bad that the memory of ancient glory remained only in the form of stories narrated by old men. After independence in 1947 India had to borrow the modern technology from western countries to set up steel plants. The situation is now changing with India again rising to the challenge and hoping to be one of the largest producers of iron and steel in the twenty-first century.

The wishful thinking of Neogi in 1914 is worth recollecting.

We hope we have been able to give a trustworthy account of the process of the manufacture of Indian steel, which was an object of envy of all nations but successfully imitated by none and which supplied the materials of many a true blade of warriors both in the East and the West. It is sad to reflect that an ancient indigenous industry which attracted merchants from Persia, as narrated by Dr Voysey, barely a hundred years ago, is on the point of extinction; but as even the darkest cloud is not without a silver lining, a distinct ray of hope is visible in the not very distant horizon presaging that India will yet regain her lost iron industry under modern scientific conditions together with other attendant industries depending upon iron.

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Metallurgy: Early Metallurgy in Mesopotamia

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The development of metallurgy in ancient Mesopotamia and the surrounding regions of the Ancient Near East to the end of the Neo-Babylonian period (ca. 539 BCE) represented a largely unprecedented achievement that strongly influenced the evolution of technology in much of the ancient Old World. Although the alluvial plain of the Tigris and the Euphrates was lacking in the mineral resources and fuel required to extract metals, the rise of urban centers and long-distance trade networks allowed this region to benefit from raw materials and expertise gathered over a wide area from the Aegean Sea to the Indus River valley. This technology required an investment in labor and materials that reached beyond the constraints of earlier industries and enabled advancements in many fields including agriculture, transportation, armament production and the

visual arts. Although much has been learned from archaeological exploration, the study of ancient texts, and the application of scientific analysis to the study of ancient materials, many aspects remain to be elucidated in a field for which the following can serve only as an introduction.

The Nature of Metals

Cuneiform texts do not reveal any evidence that Mesopotamian craftsmen sought to develop a theoretical understanding of the nature of metals and their alloys. Nevertheless, the artifacts they produced bear witness to a considerable practical knowledge accumulated from centuries of experience manipulating the raw materials at their disposal. A brief consideration of metallic microstructure provides some insight into the medium with which they were working. The atoms of each metal species are arranged in one of fourteen possible crystal lattice configurations that can be visualized as closely packed spheres arrayed within larger crystals known as grains. Metals of the face-centered cubic configuration which include gold, silver, copper, and lead – all of which were used in the ancient world – are malleable at least in part because their compact geometry limits the friction encountered in slippage between atomic planes when stress, such as hammering, is applied. When the planes begin to interlock with continued working, heating the metal in a process known as annealing enables the atoms to reorder themselves thus restoring plasticity.

Impurities introduced naturally or by intentional alloying affect both grain size and composition and may result in the precipitation of immiscible inclusions at the grain boundaries. These discontinuities within the crystalline structure can increase an alloy's hardness and brittleness which are useful for certain utilitarian purposes but may render the metal unfit for forming by hammering. At the same time, alloying lowers the melting point of the more refractory constituent – a useful quality when casting and producing solders with melting points lower than those of the surfaces being joined.

When buried in the seasonally damp and salted soils of the Ancient Near East, metals, with the exception of gold, will begin to return to an oxidized state similar to the ore minerals from which they were extracted. As a result, the structure and appearance of many of the metal artifacts recovered from this region have been altered in some way since their original manufacture. Over time, corrosion as well as the precipitation of alloy components can cause embrittlement. Corrosion usually proceeds inward along the grain boundaries producing metallic salts that deposit on the surface and often cause internal fractures due to the expanded volume of oxidation products relative to that of the original metal. Nevertheless, careful cleaning and x-radiography can reveal surface details preserved within corrosion layers and a considerable amount of evidence about an object's manufacture, and subsequent history can be gleaned by analyzing cross sections prepared from small samples taken from artifacts.

Copper and Its Alloys

While valid in broad terms, the tripartite division of human civilization into the Stone (ca. 7000–3000 BCE), Bronze (3000–1200 BCE), and Iron Ages (1200 BCE–present) proposed in the early nineteenth century CE has been extensively refined. It is now known that lithic, metal, and even ceramic-based tools and technologies coexisted in the Ancient Near East both earlier and later than it would indicate. The earliest extant metal objects are beads and small tools such as pins, hooks, and awls made of relatively soft native copper – i.e., geological deposits of metallic copper discovered near the earth's surface – which have been recovered from eighth millennium BCE contexts at sites in Anatolia, Iran, and northern Mesopotamia. While knowledge of smelting during the following millennium is implied by the presence of a lead bracelet in level 1 of Yarim Tepe in Iran, it is not until the first half of the fourth millennium BCE that clear evidence from Levantine sites – such as the impressive hoard of 416 copper



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 1 Objects from the hoard found at Nahal Mishmar. Copper alloy. Levant, first half of the fourth millennium BCE (Israel Museum, Jerusalem) (Roaf, 1990, Photo: David Harris)

alloy objects discovered at Nahal Mishmar (Fig. 1) – indicates that the extraction of metal from ores was occurring on a significant scale.

Experimentation in the annealing and melting of native copper alloys as well as the accidental reduction of copper oxide pigments during the firing of decorated pottery may have prompted initial experimentation into the smelting of metal from copper ores. Early smelting furnaces, such as the late fourth millennium BCE example excavated at Timna in the southern Negev, consisted of a bowl or pit cut into the ground that was packed with dressed ore and charcoal – the latter providing both heat and carbon which combined with and removed oxygen. High temperatures were attained by drafts of forced air supplied by bellows inserted into the fire whose tips were protected from burning by refractory ceramic cones known as *tuyères*. At around 1,083 °C – the melting point of pure copper – molten metal would puddle at the bottom of the furnace, while the lighter, siliceous impurities of the ore, known as the *gangue*, would separate out with the aid of a flux forming a layer of slag. Since both slag and *tuyères* were discarded in situ, they provide evidence of metallurgical activity at particular sites even in the absence of metal artifacts which were often hoarded and recycled.

Much of the initial smelting took place in the mountainous regions surrounding Mesopotamia that possessed mineral resources as well as extensive forests for producing charcoal. After an initial extraction, further refining could be achieved by repeated smelting in crucible furnaces at or near the workshops where artifacts were produced. Copper mines in the highlands of Iran, accessible by overland routes, appear to have been an early source of metal for the urban centers that arose in southern Mesopotamia – the heartland of ancient Sumer – during the period which is named after the important city of Uruk (ca. 3800–3200 BCE). With the expansion of seaborne trade fostered by the city-states of the Early Dynastic period (ca. 3000–2350 BCE), ore sources in Oman, which has been identified with the Magan of ancient texts, as well as the eastern lands of Aratta and Meluhha, both of which most likely received partially refined copper from various sources in Iran and Central Asia, increased in importance. The island of Dilmun – modern Bahrain – was well situated near the southern end of the Persian Gulf to serve as a mediator in this maritime copper trade particularly in the late third and early second millennia BCE. To the west, the copper mines in Anatolia supplied copper to production centers in the Levant and northern Mesopotamia from an early period and provided the raw materials for an indigenous tradition of sophisticated copper metallurgy exemplified by the late third millennium BCE objects found at the central plateau sites of Alaca Höyük and Horoztepe (Fig. 2). With the rise of important trading cities on the Levantine coast in the mid-second millennium BCE, the importation of Cypriote copper to the region also increased.

While bronze, an alloy of copper and tin, is attested in texts and objects dated to the beginning of the Early Dynastic period, modern analysis has indicated that for many centuries the copper used in Mesopotamia actually contained low concentrations of arsenic, nickel, and other elements (often referred to as arsenical copper) and that the use of tin only gradually increased toward a standard concentration of around 10 % as that of arsenic decreased. Arsenical copper has often been



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 2 Bull Standard. Copper alloy and electrum. Height, 48 cm. Alaca Höyük, Anatolia. Late third millennium BCE (Ankara Museum of Anatolian Civilizations, Turkey, 11850) (Aruz & Wallenfels, 2003, Photo: Bruce White)

viewed as bronze's inferior precursor – a soft alloy that was unfit for most practical purposes. However, ancient metalworkers appear to have been aware that this alloy could be effectively worked hardened by hammering and cast more easily than pure copper, making it a useful alloy.

It has been suggested that the progression from native copper to bronze alloys reflected the nature of the ore deposits being exploited (Tylecote: 7–9). In many copper ore bodies, the layer closest to the surface and most easily exploitable consists of copper carbonates and oxides as well as native copper. Below lie two copper sulfide deposits which must be oxidized by “roasting” in an open fire before smelting. Of these, the uppermost layer, which is enriched by copper washing down with groundwater from above, contains the highest

concentration of impurities including arsenic, nickel, and antimony. As these arsenic-containing deposits gradually became depleted by ancient miners, it is possible that the need for a new alloying metal promoted the use of tin. However, recent archaeological work indicates that the actual situation may have been less straightforward, as complex ores containing different mixes of impurities were cosmelted from an early period. In addition, the possibility that arsenic in some form was intentionally added remains a matter of debate.

Tin is not usually found as a natural impurity in copper ores and tin deposits are relatively rare. While evidence of tin mining in eastern Anatolia indicates that this area may have been a source of this metal at least in the Early Bronze Age, the primary source of this metal appears to have been the Badakhshan region of Afghanistan where oxidized tin is associated with alluvial deposits of weathered granite. Afghanistan is also thought to have been a primary source of the lapis lazuli, gold, and semiprecious stones that played an important role in Sumerian art of the mid-third millennium BCE. This is seen most impressively in the finds from the Royal Tombs of Ur (Figs. 3 and 4), when bronze alloys increasingly were used. Like these prized materials, tin may have been traded initially as a precious commodity used in the production of highly valued objects. Early in the succeeding millennium, however, cuneiform texts indicate that large quantities of tin – presumably obtained in the East – were being transported up the Euphrates to the ancient city Mari from where they were distributed to other urban centers. During approximately the same period, merchants from Ashur, the historic and spiritual capital of the land of Assyria in northern Mesopotamia, established a merchant community (*karum*) at Kanesh in central Anatolia where tin and textiles were exchanged for locally obtained precious metals.

Gold and Silver

While gold and silver objects have been recovered from early contexts in northern



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 3 Statue of Queen Napir-Asu. Copper alloys. Susa, Iran. Middle-Elamite period, fourteenth century BCE. Height, 129 cm (Musée du Louvre, Paris, Sb 2731). (Harper et al., 1992, Photo: Photo Studio, The Metropolitan Museum of Art)

Mesopotamia and Anatolia, it is not until the third millennium BCE that significant numbers of precious metal objects were being produced across the entire region. Gold, found in many of the lands encircling Mesopotamia, was retrieved from alluvial deposits in nugget form or gleaned from quartz veins by grinding and separation in water. Native gold usually contains some silver and copper, or these metals could be intentionally added to achieve desired working properties and/or color. Natural or artificially produced gold alloys with high silver contents, such as the inlays in a copper alloy standard from Alaca Höyük (Fig. 2), as well as the jewelry and ingots found by Schliemann in Early Bronze Age levels at Troy, are known as electrum. Alternately, gold could be refined by the preferential oxidation and



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 4 Queen Puabi's Headdress. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B 16692-3, 17709-12) (Zettler & Horne, 1998, Photo: The University of Archaeology and Anthropology)

removal of the baser elements from the parent metal. This process, known as cementation, is alluded to in textual evidence dated to the first half of the second millennium BCE and may have been practiced even earlier. A recent study of a dagger from Ur suggests that a similar process of surface enrichment known as depletion gilding, which was independently developed in the pre-Columbian New World, was practiced by Sumerian metalworkers in the mid-third millennium BCE (La Niece, 1999).

Although some smelting of silver ores may have occurred, most ancient silver appears to have been obtained by cupellation from argentiferous lead ores mined in the mountains of Turkey and Iran – two regions that displayed an early expertise in silversmithing. In this process, the ore was heated in porous bone cups, or cupels,



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 5 Spouted cup. Gold. Height, 12.4 cm. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (The Trustees of the British Museum, London, BM 121346) (Aruz & Wallenfels, 2003, Photo: The Trustees of the British Museum)

that absorbed oxidized lead, leaving behind silver droplets that were collected and melted together. The earliest archaeological evidence of this technology in the region has been found at the site of the Late Uruk city of Habuba Kabira which was located on the Euphrates River in what is now the country of Syria.

Metalworking Techniques

Forming objects by hammering and annealing, first attested in the earliest copper artifacts, remained an important manufacturing technique throughout the history of the Ancient Near East. Worked sheet was used to make simple tools, vessels (Figs. 5, 6, and 7), and relief decoration (Fig. 8). Vessels were formed by sinking or raising which involved hammering in concentric circles on the inside or outside surface, respectively, of the container being formed sometimes with the aid of a form. Decorative reliefs and friezes were formed by repoussé in which figures were raised against a flat background plane by light hammering from the reverse. After forming, fine linear details were added by lightly tapping metal tracers with various shaped heads on the surface which displaced the metal forming lines and



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 6 Bowl. Gold. Length, 13.12 cm. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B17693) (Zettler & Horne, 1998, Photo: The University of Pennsylvania Museum of Archeology and Anthropology)



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 7 Tumblers. Silver. Height, 16.5–17.4 cm. Ur, southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 (University of Pennsylvania Museum of Archeology and Anthropology, Philadelphia, B17072a-d) (Zettler & Horne, 1998, Photo: The University of Pennsylvania Museum of Archaeology and Anthropology)

decorative patterns as seen in the figural decoration on a silver vase dedicated by Enmetena, a ruler of the city-state of Lagash, to the god Ningirsu around 2400 BCE (Fig. 9). A masterful example of all these combined techniques is also provided by in a cylindrical silver container attributed to western Central Asia of the late third–early second millennium whose surfaces virtually erupt with lions, bulls, and wolves in extraordinarily high relief (Fig. 10).

Worked metal sections were joined to produce some of the earliest known metal sculptures in the round. The ability of ancient silversmiths to produce sensitively modeled, naturalistic figures on a small scale through the careful combination of separately formed components is demonstrated by an anthropomorphic kneeling bull attributed stylistically to the Proto-Elamite culture (3000–2800 BCE) of western Iran (Fig. 11). Worked sheet was also used to create large free-standing figures with a minimal use of metal. The bull statues that originally adorned the façade of the Early Dynastic IIIB (2400–2250 BCE) Ninhursaga temple at Tell al-Ubaid featured bodies consisting of worked copper alloy plates that were nailed onto carved wooden cores. Before its cladding, the wood was coated with a pliable bitumen layer in order to support the metal during its final chasing (Fig. 12).

Various casting methods also were employed according to the type of object being produced. Open-faced molds may have been used to produce flat tools such as the sickles found in a hoard of mid-second millennium farming implements from Tell Sifr in southern Mesopotamia (Fig. 13). Bivalve molds were used to cast solid objects of simple shape. Reusable molds – which varied in complexity from the late third millennium BCE stone mold for casting trinkets and jewelry such as the example found at Sippar (Fig. 14) to a Neo-Assyrian multipart metal mold for simultaneously casting several arrowheads – were used to mass produce identical castings. Such easily portable molds, which may have been owned by itinerant craftsmen, enabled the widespread diffusion of cultural forms and metalworking expertise.

It was the technique of lost-wax casting, however, that provided Mesopotamian craftsmen with their greatest opportunity to display their metallurgical and artistic skills. First attested by the intriguing “standards” and “scepters” of the Nahal Mishmar hoard, this technique was sufficiently advanced by the Akkadian period (ca. 2350–2100 BCE) to facilitate the production of the earliest large scale metal sculptures known from the ancient world including the head of a ruler and the lower half of a male figure on an



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 8 Details of two door decorations from the Balawat Gate. Copper alloy. Height, each 27 cm. Balawat, northern Mesopotamia. Neo-Assyrian period, ninth century BCE

(The Trustees of the British Museum, London BM 124662 and 124661) (Curtis, 1988, Photo: The Trustees of the British Museum)



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 9 Votive vase of Entemena, ruler of Lagash. Silver on copper alloy base. Height, 35 cm. Southern Mesopotamia, ca. 2400 BC (Musée du Louvre, Paris) (Roaf, 1990, Photo: Service Photographique de la Réunion des Musées Nationaux, Paris)



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 10 Cylindrical box and lid with lions, bulls, and wolves in relief. Silver. Height, 23.1 cm. Western Central Asia, late third–early second millennium BCE (The Metropolitan Museum of Art, New York; Lent by Shelby White and Leon Levy L.1999.74.1). (Aruz & Wallenfels, 2003, Photo: Photo Studio, The Metropolitan Museum of Art)



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 11 Keeling bull holding a vessel. Silver. Height, 16.3 cm. Iran. Proto-Elamite period, ca. 3000-2800 BCE (The Metropolitan Museum of Art, New York, Purchase, Joseph Pulitzer Bequest 1966, 66.173) (Aruz & Wallenfels, 2003, Photo: Photo Studio, The Metropolitan Museum of Art)

inscribed base, both dated to the Akkadian period and found in northern Iraq (Figs. 15 and 16) (see [Extra: Head of a Ruler](#)). Lost-wax casting begins with the sculpting of a model in wax or other thermoplastic material that is covered – or invested – with clay and fired, causing the wax to melt out through channels provided in the investment. During casting, these channels provide access for the molten metal to enter the mold and egress for gases evolved that could impede its flow. In order to reduce the amount of metal required as well as the risk of casting flaws, the model can be fashioned over a core of refractory clay that is held in place by metal supports inserted through the investment and into the core before the removal of the wax. After casting, the investment



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 12 Standing bull from temple. Copper alloy, wood, and bitumen. Height, 71.2 cm. Tell al Ubaid, Mesopotamia. Early Dynastic IIIb period, ca. 2400–2250 BCE (The University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B15886) (Aruz & Wallenfels, 2003, Photo: The University of Pennsylvania Museum of Archaeology and Anthropology)



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 13 Farming implements from Tell Sifr in southern Mesopotamia. Early second millennium BCE Copper alloy (The Trustees of the British Museum, London) (Moorey, 1971, Photo: The Trustees of the British Museum)

is broken away, and the core supports are removed down to the surrounding surface.

Bronze – often with the addition of minor amounts of lead – is an excellent casting alloy, as tin can lower the melting point of copper by as much as 200 °C and inhibit the oxidation of copper which can lead to casting flaws. Since the use of tin is so advantageous, its absence in many of the copper alloy sculptures produced



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 14 Mold form for jewelry, seals, and amulets. Stone. Height, 9 cm. Sippar, Mesopotamia. Late third millennium BCE (The Trustees of the British Museum, London, BM 91902) (Aruz & Wallenfels, 2003, Photo: The Trustees of the British Museum)



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 15 Head of a Ruler found at Nineveh. Copper alloy. Height, 36 cm. Mesopotamia. Akkadian period, ca. 2300–2159 BCE (Iraq Museum, Baghdad, IM 11331) (Oates, 1986, Photo: Directorate-General of Antiquities, Baghdad)

before the Iron Age has often been attributed to disruptions in the tin trade. That other factors may have influenced the composition of the metals



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 16 Nude, belted figure found at Bassetki. Copper alloy. Diameter of base, 67 cm. Mesopotamia. Akkadian period, ca. 2300–2159 BCE (Iraq Museum, Baghdad, IM 77823) (Oates, 1986, Photo: Directorate-General of Antiquities, Baghdad)

used, however, is suggested by the sculpture of the Middle Elamite Queen Napir-Asu (ca. fourteenth century BCE) that was excavated in Iran at the site of the ancient city of Susa. The outer shell of this life-sized metal sculpture was cast by the lost wax method over a ceramic core using copper containing only 1 % tin (Meyers, 2000). For reasons that remain unknown, the ceramic core was subsequently removed, and the void was filled with a bronze alloy containing 11 % tin (Fig. 3). That the more intractable alloy was used for casting the outer shell even when tin appears to have been on hand may be due to the fact that a considerable amount of work was required to remove and/or patch casting imperfections and to add surface details and inscriptions with tracers after casting. Before the advent of hardened iron alloys that could engrave or cut into copper, this work may have been easier to execute on relatively pure copper rather than on bronze.

Although some casting of precious metals occurred, the rarity of gold and silver dictated that they be used more economically in sheet form to create vessels, jewelry, and small figures. The numerous elements of gold sheet used



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 17 Great Lyre from the King's Grave, gold, silver, lapis lazuli, shell, bitumen, and wood. Height of head, 35.6 cm. Ur, southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B17694) (Aruz & Wallenfels, 2003, Photo: The University of Pennsylvania Museum of Archaeology and Anthropology)

in the elaborate headdress of Queen Puabi found at Ur undoubtedly created a striking visual and aural impression when worn (Fig. 4). Silver and gold also were also beaten into foil or very thin leaf that was used in the embellishment of baser materials in objects destined for elite or sacred use such as the lyres and rearing goat statues also found at Ur (Figs. 17 and 18). Grooves for mechanically locking metal foils in place found on copper alloy sculptures – including that of Queen Napir-Asu – indicate that metal surfaces could also be partially or fully gilt.



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 18 Rearing goat with flowering plant. Gold, silver, lapis lazuli, copper alloy, shell, red limestone, and bitumen. Height 42.6 cm. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, 30-12-702) (Aruz & Wallenfels, 2003, Photo: The University of Pennsylvania Museum of Archaeology and Anthropology)

In addition to mechanical joints involving nails, rivets, crimping, and casting onto existing metal surfaces, metallurgical joints were made using solders of various compositions. The use of soft (i.e., lead/tin) solders, which melt at low temperatures and are difficult to control, was mainly relegated to joints in copper alloy objects that would not be readily visible. Metallurgical joints on precious metal objects were made either by carefully heating metal surfaces until they fused – a technique known as “sweating” – or by using hard solders containing copper which has a lower melting point than either silver or gold. Ancient metalworkers were very skillful at exploiting minor differences in the melting



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 19 Necklace with pendants. Gold. Length, 43 cm. Dilbert, southern Mesopotamia. Nineteenth–eighteenth century BCE (The Metropolitan Museum of Art, New York, Fletcher Fund, 1947 (47.1a-h). (Harper 1984, Photo: Photo Studio, The Metropolitan Museum of Art)

temperatures of these hard solders when constructing complex objects. For example, the 17 sections of the Proto Elamite kneeling bull noted above were joined using silver solders containing increasing amounts of copper – and consequently lower melting points – as the figure was assembled, thus ensuring that previously made joints would not fail each time the appropriate amount of heat was applied. Elements in gold jewelry also could be affixed in place using a colloidal hard solder consisting of an organic binder such as animal glue mixed with ground copper salts. When heated, the combustion of the glue provided a locally reduced atmosphere that aided the diffusion of copper ions into the adjacent gold to produce a strong and virtually invisible joint that was ideal for affixing tiny gold grains in granulation work as well as other joints in complex jewelry constructions (Fig. 19).

The Advent of Iron

While iron oxide pigments as well as meteoric iron had been used for centuries in the creation of paintings and objects, the use of iron alloys did



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 20 Helmet. Iron. Height, 30.8 cm. Nimrud, northern Mesopotamia. Neo-Assyrian period, eighth century BCE (The Trustees of the British Museum, London, BM 22496) (Curtis, 1988, Photo: The Trustees of the British Museum)

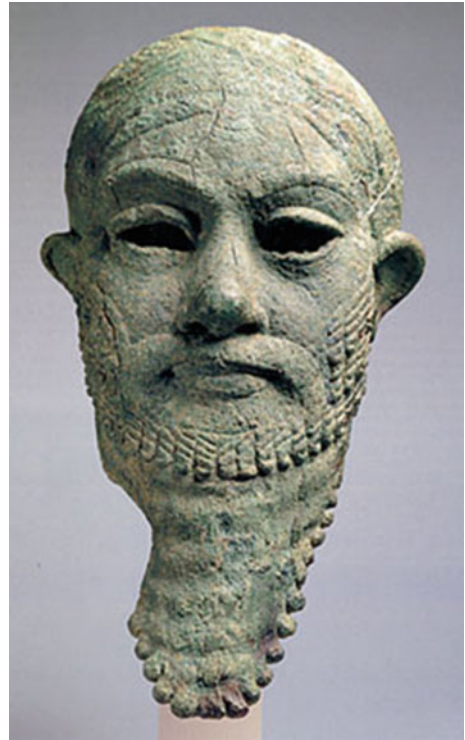
not become widespread until the early first millennium BCE, following a long development that has been difficult to trace as much of the original evidence has been lost to oxidation. It is possible that experimentation with iron-rich *gangue* separated from copper ores may have led to the discovery that iron ores could be processed to provide a workable metal. Due to a melting point (i.e., almost 500 °C. above that of copper) that exceeded the capability of early Mesopotamian pyrotechnology, iron could not be directly separated from its slag nor melted for casting. In fact, in the ancient world only Chinese metalworkers developed the technology for casting iron. Instead, iron ore was reduced in a solid state reaction at about 800 °C in a reducing fire. The mass obtained from the furnace – known as the bloom – required repeated heating, folding, and hammering to squeeze out the siliceous slag and provide a metal that could be shaped by hot forging.



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 21 Multipiece sword. Iron. Length, 50.1 cm. Luristan, Iran. 750-650 BCE (The Metropolitan Museum of Art, New York, H. Dunscombe Colt Gift, 1961 61.62) (Muscarella, 1988, Photo: Photo Studio, The Metropolitan Museum of Art)

Wrought iron objects are relatively soft, and it was only with the development of carburization, in which carbon is introduced at the surface to form the iron-carbon alloy known as steel, and quenching, which preserves crystalline phases and structures normally found at high temperatures, that useful cutting edges harder than bronze could be produced. The skill with which these operations were carried out progressed unevenly across the region presumably offering temporary advantage to those groups who were more advanced. Although this technology was not completely mastered in early Mesopotamia, the relative abundance of iron ore deposits allowed for a dramatic increase in the use of this metal in the production of tools, weapons, and armor from the Neo-Assyrian period onwards (Fig. 20).

While forging largely limited the use of iron to the production of utilitarian objects such as tools and weapons, by the eighth century BCE, skillful



Metallurgy: Early Metallurgy in Mesopotamia, Fig. 22 Head of a Ruler. Copper alloy. Height 34.3 cm. Mesopotamia. Akkadian period (?), late third millennium (The Metropolitan Museum of Art, New York, Rogers Fund, 1947 47.100.80 (Aruz & Wallenfels, 2003, Photo: Bruce White)

smiths in the Luristan region of southeastern Iran were already able to fashion complex shapes such as the multipiece sword now in New York (Fig. 21).

The Legacy of Mesopotamian Metallurgy

As outlined above, many of the metalworking techniques used up to modern times were developed in the Ancient Near East. In addition, the long distance trade spurred by the demand for metal ores and finished artifacts resulted in the widespread dissemination of technical knowledge and artistic styles across the entire Mediterranean region. Recent archaeological discoveries such as the Early Bronze Age copper manufactory at Khirbat Hamra Ifdan in the southern Levant as well as the continued examination

Metallurgy: Early Metallurgy in Mesopotamia,

Fig. 23 Horizontal computed tomography cross section through the *Head of a Ruler* showing core supports (Photo: The Metropolitan Museum of Art, New York)



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and analysis of artifacts will undoubtedly broaden and revise our understanding of the interaction of culture and technology during this crucial period.

Extra: Head of a Ruler

Based on its style, purported Iranian provenance as well as the perceived ethnicity of its facial features and hair treatment, the *Head of a Ruler* now in The Metropolitan Museum of Art in New York has been attributed most often to the Elamite cultural sphere of the late third millennium BCE (Fig. 22). Whether or not it is a true portrait, this cast copper sculpture possesses a strikingly life-like presence that is enhanced by specific features such as the broad nose, deeply set eyes, and prominent ears. The eye sockets, which are now empty, were probably inlaid with shell or stone. A tang projecting

from the plate across the bottom of the neck indicates that this head was attached to a body or other mount that may have been made of another material.

Long thought to be virtually solid, radiographic cross sections recently obtained by computed tomography revealed that this head contained a core and may be among the earliest examples known of life-sized hollow casting. In addition to locating the position of core supports, this examination found internal porosity associated with the casting flaw on the right side of the beard as well as voids around the ears which may indicate that they were made separately and joined to the wax model of the head before casting (Fig. 23). If such is the case, then this head bears some similarity in technique to an Akkadian period copper head found at Nineveh that is now in the Iraq National Museum in Baghdad (see main text Fig. 14 and Strommenger, 1986).

See Also

► Beads

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Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy

Mark T. Lycett and Noah Thomas

Despite the long pre-Columbian tradition of metallurgical technology in West Mexico, there is no evidence for the development of metallurgy

in the US Southwest prior to Spanish colonization. Metal bearing minerals are widespread in the region and were used as pigments and ornamentation prior to Spanish contact (see Extra). Discussions of the largely untapped potential of mineral wealth are ubiquitous in Spanish colonial descriptions of New Mexico from the sixteenth through the nineteenth centuries. Documentary sources suggest that iron, copper, and other metals of every day necessity were relatively scarce in this colony. Small amounts of manufactured metals appear in assemblages from Franciscan missions and other Pueblo settlements occupied during this period. Despite the importance and widespread use of these metals, there is little evidence of mining or processing of local ores, and it has generally been assumed that all metal in colonial period New Mexico was imported from New Spain. While this supposition may be true for much of the material recovered in colonial period assemblages, strong evidence of metal production has been found in a few Hispanic contexts and from the missions of San Pedro and San Marcos. While some of these processes were spectacularly unsuccessful, copper metallurgy appears to have been the predominant focus of this technology. Archaeological and metallurgical analyses suggest a number of important patterns in the organization and development of these processes. Spatial segregation of technological processes and activities is coupled with a diversity of ore bodies, metals, and products, and shifts in the use of facilities and processes. These create a complex mosaic of emergent experimentation in novel and hybrid technologies shaped by the requirements of colonial tribute demands, locally available resources, indigenous knowledge and practices, and frontier exchange relationships.

The colony of New Mexico was established in 1598, at the height of Spanish silver production in the New World. The mines in New Spain had produced unprecedented wealth for the Spanish crown and had begun to influence European economic systems through the easy availability of silver currency allowing for the development of early capitalism. The profitability of the mines in New Spain was in a large part due to the

availability of cheap labor, primarily composed of both coerced and paid Native American workers. In addition to mining activities, Native West Mexican smiths were sought after for their traditional metalworking skills. The incorporation of indigenous individuals within the industry also allowed for the development of technologies better suited to the dry, wood scarce environment of northern New Spain than European water powered and charcoal fueled smelting practices, through the incorporation of indigenous traditional materials and technologies. To facilitate production along these lines, Spanish administrators often uprooted whole indigenous communities through forced relocations in order to obtain closer proximities of labor, ore and fuel sources.

In contrast to Western Mexico, the organization of early colonial metallurgy is very poorly documented in New Mexico, with strong evidence of metal production from a very few contexts. Recent excavations on the early to mid-seventeenth century industrial terrace at the Mission of San Pedro, known alternately as Paa-ko Pueblo, have recovered extensive evidence suggesting that the Pueblo occupants of this village experimented with a range of metallurgy technologies including the reduction of copper oxide and lead sulfide ores to produce copper and lead metals, the refining of silver through cupellation (Cupellation is the recovery of precious metals in a cupel by exposure to a blast of hot air that oxidizes the unwanted base metals, such as lead, which are partly absorbed. A cupel is a small container in which precious metals are refined, especially in which gold and silver are separated from base metals during assaying), the manufacture of sheet and cast copper artifacts, and the forging of iron artifacts.

Located at the head of the San Pedro Valley, one of three major drainage systems on the eastern slope of the Sandia Mountains, this site lay outside of any of the major settlement clusters or “provinces” identified by Spanish colonists. It was a small scale, intermittently occupied, and partially incorporated community. Although the village was part of the mission system, it never had a resident friar or a permanent Spanish presence. The situation of a metallurgical facility within



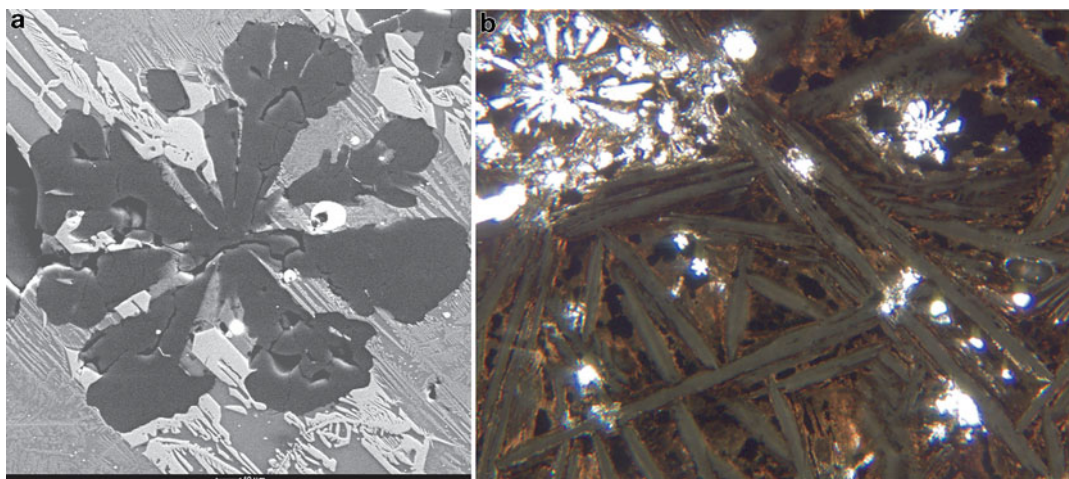
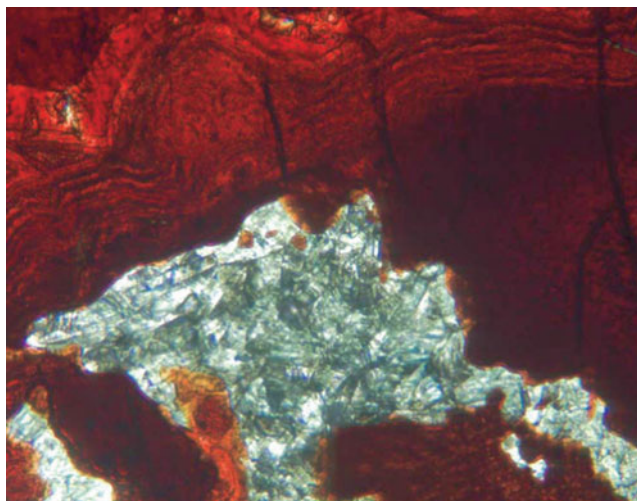
Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy, Fig. 1 View from Mission San Pedro looking east towards local ore deposits in the Cerrillos Hills and the Ortiz Mtns (Photo by Noah Thomas)

this remote community may have allowed some colonists to engage in a valued form of production outside of the scrutiny of colonial administration while still maintaining access to mineral sources, fuel, and a subject labor force (Fig. 1). Nevertheless, the evidence at Paa-ko points toward a strong Pueblo involvement in the design as well as the implementation of these technologies.

At this site, a terraced hill slope covering more than 200 m² was repeatedly used for metal production with numerous superimposed and interdigitated facilities produced through periodic episodes of use, maintenance, and reconstruction over a number of years (Fig. 2). The specific functions of these facilities may have included copper smelting, copper ore roasting, charcoal preparation, and iron forging. Both Spanish and Puebloan construction techniques

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy,

Fig. 4 Petrographic section in plain polarized light of gossan containing malachite, cuprite, and banded iron hydroxides. This is the main ore type found at the facility. Magnification 100× (Photo by Noah Thomas)



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy, Fig. 5 (a, b) SEM-BSE compositional image and petrographic section in plain polarized light of slag from the facility exhibiting high temperature

quartz and iron silicate minerals associated with temperatures in the range of 1,200–1,400 °C (Photo by Noah Thomas)

especially a rust-colored outcrop of iron ore) ores producing a copper-iron alloy (Figs. 4, 5a, b, and 6). Lower temperature smelts were conducted as well, producing a copper metal with copper sulfide inclusions (Fig. 7). Both alloys have been found in association with finished copper artifacts and copper sheet scrap suggesting the inclusion of both alloys within the overall production process of the facility (Fig. 8).

The variation in smelting regimes may represent the experimental and improvisational nature

of the technology employed at the facility suggesting a process by which practitioners developed techniques appropriate for local materials. The development of extractive metallurgy at Paa-ko employed both the knowledge of high temperature and high reducing metallurgy technologies, such as those applied to iron smelting, as well as knowledge of lower temperature processes more appropriate for copper extraction.

The focus on copper production apparent from the volume of copper slag and

**Metallurgy: Pueblo
Indian Adaptations of
Spanish Metallurgy,**

Fig. 6 Metallographic section of copper-iron alloy produced at the facility. Magnification 200× (Photo by Noah Thomas)

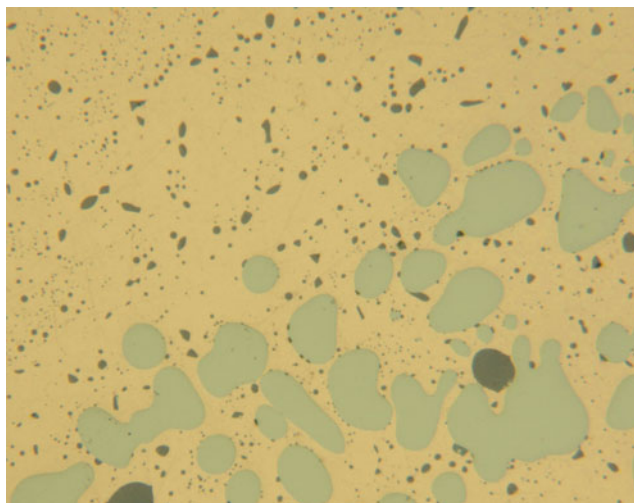
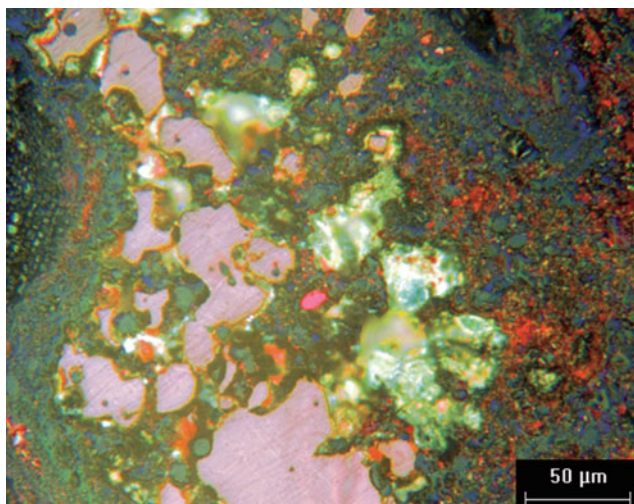
**Metallurgy: Pueblo
Indian Adaptations of
Spanish Metallurgy,**

Fig. 7 Metallographic section of the low temperature product of relatively pure copper in association with cuprite and charcoal. Magnification 50× (Photo by Noah Thomas)



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predominance of copper artifacts and scrap recovered from the facility is unusual given that the focus of Spanish colonial metallurgy in the New World was on silver extraction. Copper production as an industry in New Spain was relatively small and was focused in West Mexico, under the technological control of indigenous Tarascan smiths up until the turn of the seventeenth century. Yet, copper played a significant role in the global exchange of metals. The growth of the copper industry in Europe can be directly tied to the development of colonial exchange at the frontier of colonial expansion. Central Europe became a center for production in this system

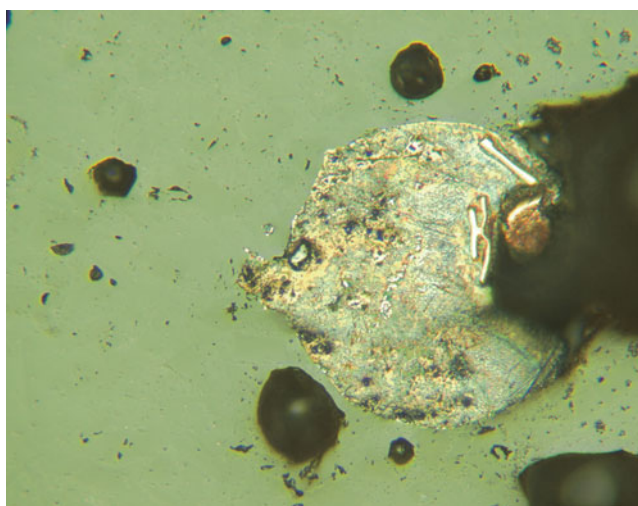
during the fifteenth and early sixteenth centuries, using copper left over from the *Saigerprozess*, the extraction of silver from copper metal with the addition of lead, to produce items for trade such as copper and brass kettles, knives, and ornaments.

A possibility that may explain the predominance of copper metallurgy at Paa-ko may be the adaptation of this global model to local silver ores and colonial exchange relationships in the New Mexico colony. The materials recovered from the facility such as lead slag, galena, and litharge fragments containing copper and lead prills (A prill is the button of metal from an

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy, Fig. 8 Copper-iron alloy ingots from high temperature smelt (Photo by Noah Thomas)



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy, Fig. 9 Polished section in plain polarized light of litharge recovered from the facility at Mission San Pedro containing copper and lead metal. Magnification 100× (Photo by Noah Thomas)



assay), suggest that one of the technologies present at the facility included a process of silver refining utilizing cupellation, involving both lead and copper metal (Fig. 9).

The evidence from Mission San Pedro may represent a participation within two colonial systems of value: one centered on the production of silver and the generation of wealth within models of European commerce, and one centered on the colonial trade and exchange relationships of frontier communities. The most common form of manufactured copper in these

samples is sheet copper, occurring as both manufacturing debris and finished artifacts (Fig. 10). Sheet copper commonly occurs in other mission assemblages, although there is no evidence of copper production or its by-products from most of these sites. Copper, as distinct from silver, was a metal of relatively little value in the exchange networks of colonial New Spain, but copper ornaments were a novelty in colonial New Mexico, circulating in partially overlapping systems of value defined by both colonizer and colonized. Metallurgical

**Metallurgy: Pueblo
Indian Adaptations of
Spanish Metallurgy,**

Fig. 10 Cache of copper
sheet scrap and finished
artifacts recovered from the
facility at Mission San
Pedro (Photo by Noah
Thomas)



practices may have been simultaneously understood as forms of commercial production, disciplinary instruments of Spanish church and state, and an idiom of Christian and indigenous identity formation through personal adornment.

Metal has been recovered from the seventeenth century missions at the sites of Abo Mission and Quarai, in the Salinas district, from San Marcos, San Lazaro, and San Cristobal in the Galisteo Basins, and from the Zuni site of Hawikuh and the Hopi site of Awatovi. Much of the metal recovered from these sites is poorly documented or is so sparse that it is impossible to develop an overall sense of how metals were used by the Pueblo population. The excavations at Pecos Pueblo are an exception. Over 344 metal objects were recovered from this excavation, providing for an adequate data set in which to compare the information gleaned from the historical documents.

The metal assemblage from Pecos is dominated by copper sheet scrap both as sheet fragments and as rolls. As Kidder notes, “more than half of the collection consists of small, irregularly shaped scraps of thin sheet metal, varying from the size of a fingernail to that of the palm of one’s hand. Their edges are sometimes cut as with a sharp instrument, sometimes roughly torn” (Kidder, 1932, p. 308). The high frequency of this material suggests that copper metal was being worked by the Pueblo inhabitants of this Mission. Kidder suggests that the scrap represented the reduction of copper kettles

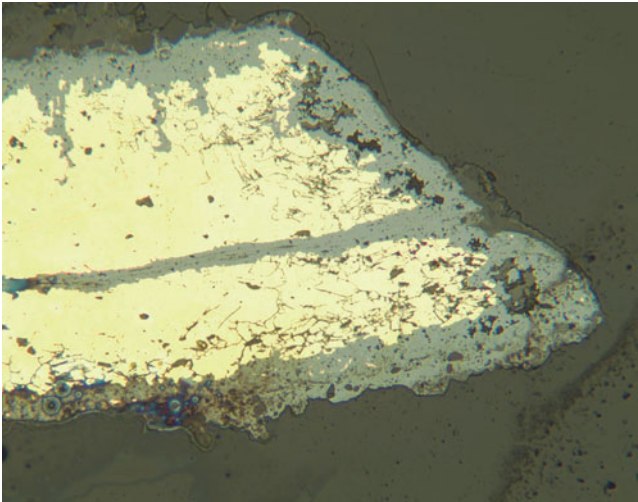
much like that which occurred in Northeastern Native American historic sites. This may in fact be the case, as the historical documents suggest that a large volume of copper material was coming into the colony as copper alloy vessels (see Note) (Fig. 11).

The frequencies of artifact types listed historically and recovered archaeologically suggest a pattern of Puebloan use of metal artifacts in the seventeenth century that stresses clothing and adornment (Fig. 12). In addition to this, the predominance of copper sheet scrap suggests that European copper goods were eventually highly modified to produce other artifacts that perhaps were perceived to have a higher value. At least 8 of the 16 crosses recovered from Pecos were made from sheet copper suggesting a relationship between the working of copper sheet through the reduction of domestic artifacts, and the production of objects of adornment.

The emergence of novel forms of production in colonial settings is an historical process marked by experimentation, adaptation, and variation. Evidence of this process at sites like Paa-ko (San Pedro) and Pecos indicates involvement with European metallurgical technologies included production of a variety of metals through a variety of techniques, recycling of existing materials, and the working or finishing of metals from both sources. The participation of Puebloan communities in Spanish metallurgy suggests that indigenous knowledge, indigenous materials, and indigenous exchange networks

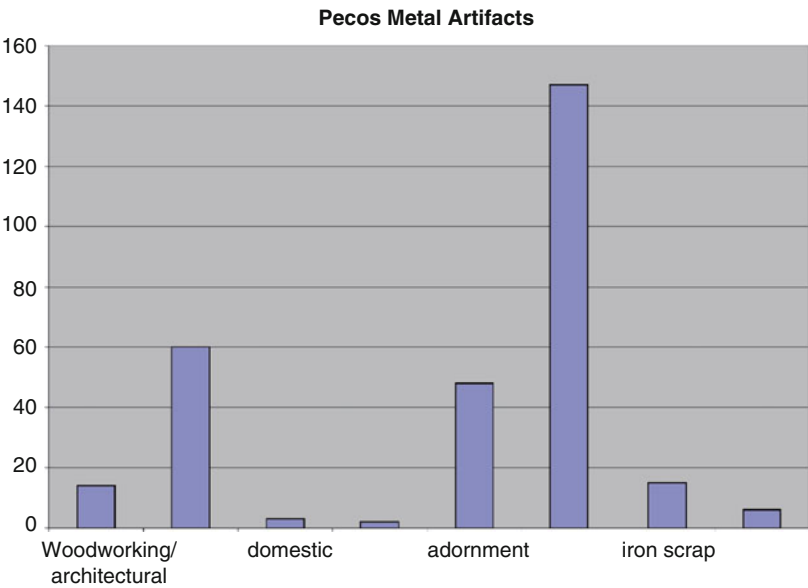
Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy,

Fig. 11 Polished section of a reworked brass sheet fragment recovered from the facility at Mission San Pedro. Magnification 50× (Photo by Noah Thomas)



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy,

Fig. 12 Metal artifacts recovered from the excavations at Pecos Pueblo. Artifacts listed by function



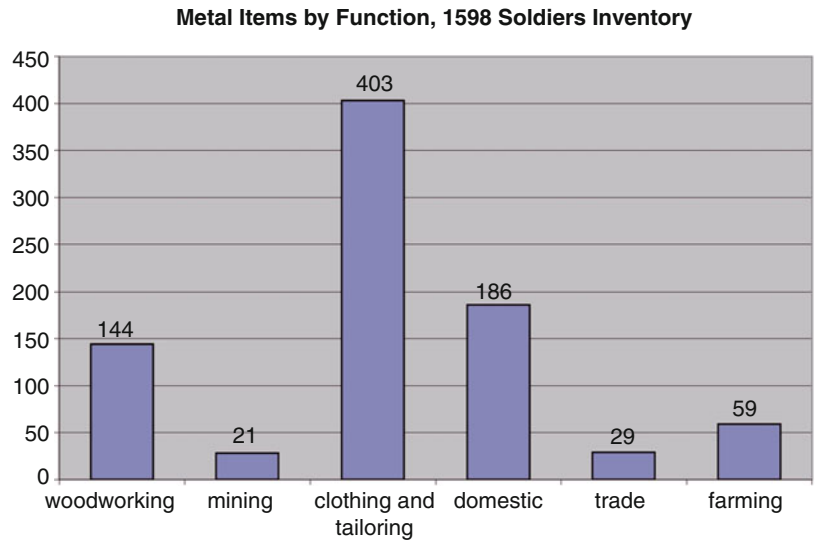
may be at least as important as indigenous labor in the implementation of new technologies.

Extra 1: Pre-Colonial Metal Use in the Southwest

Despite the presence and time depth of metallurgical technology in West Mexico, little evidence exists for the transference of techniques of metallurgy to the US Southwest prior to Spanish colonization. Trade in metal objects of West

Mexican origin existed by the tenth century, and possibly earlier, based on the presence of copper bells in sites from Chaco Canyon, the Hohokam region of southern Arizona, and the Mogollon mountain region. Trade in bells to the US Southwest follows the chronological patterning of technological style of West Mexican bell types. Based on this chronology, two phases have been recognized by Vargas. Phase I consists of trade in non alloyed copper bells 800–1250 AD, and Phase II consists of trade in stylistic forms associated with alloyed copper bells from 1250 to

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy, Fig. 13 Metal items listed in the Salazar inspection of the Oñate colonizing force of 1597. Items grouped by function



1520 AD. As Vargas (1995) notes, this trade appears to have been highly restricted and/or infrequent. In both phases distribution is centered on the Hohokam region of southern Arizona. As of yet, no solid evidence exists for the smelting of copper or the production of copper objects within the region during the precolonial period.

Despite the fact that metallurgy appears not to have been practiced, metal bearing minerals are prevalent within the region and were extensively used prior to Spanish contact. Both copper and lead bearing minerals were used as pigments, as objects of adornment, and as components in the indigenous pyrotechnology of lead glazed ceramics. The development of lead glaze in the Puebloan world began in the fourteenth century and continued to be practiced through the early colonial period up until the Pueblo revolt of 1680.

Extra 2: Historical Data on the Introduction of Metals and Metallurgy

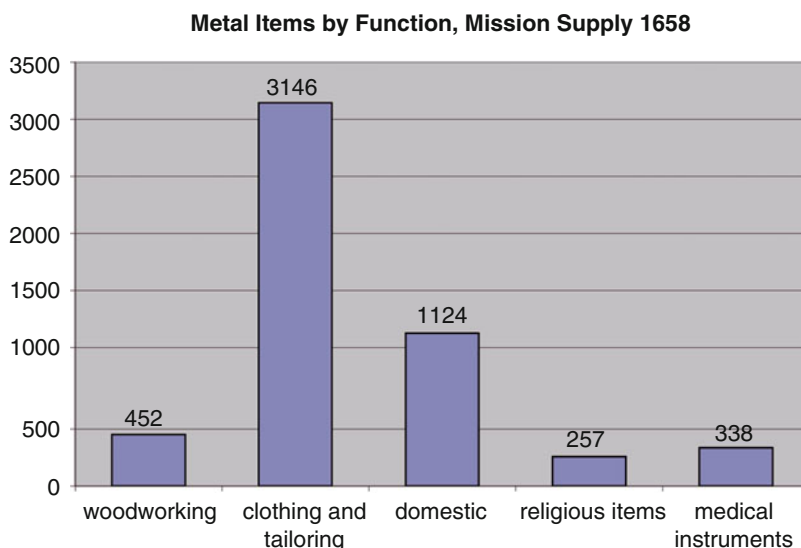
The historical record suggests that a wide variety of metals came into New Mexico with the initial colonization of the late sixteenth and early seventeenth centuries. Iron, lead, and mercury were brought in as raw materials for the mining industry and the production of tools and lead shot.

Other metals and alloys entered the colony as finished tools, religious articles and ornaments. Though iron was probably the most predominant of metals imported, copper and copper alloys appeared in large quantities primarily in the form of domestic items. Tin, pewter, silver, and gilded items are mentioned both within the inventory of items brought in the initial colonization of 1598 and in the requested items of the mission supply caravan as well.

Excluding iron goods needed for horseshoeing, when comparing the lists of items brought in the initial colonization with the mission supply lists of the 1650s, the most prevalent metal items are tools related to clothing and tailoring activities (Figs. 13 and 14). These include items such as needles, thimbles, awls, pins and scissors. These items were also the predominant trade good brought in the initial colonization. Their high frequencies may be due to their ease of transport, the low cost per quantity as an item of trade, and/or their general perceived utility across ethnic boundaries.

The second most prevalent item by function is domestic implements. This category most likely represents the largest category outside of horseshoeing equipment in terms of volume and weight and is dominated by copper alloy items. Copper kettles, boilers, *ollas* (a pot or jar having a wide mouth), and *comals* (large flat griddles on

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy, Fig. 14 Metal items listed in the mission supply list of 1,658. Items grouped by function



which tortillas are cooked) are mentioned specifically. In the mission supply list of 1,658, 37 and 20 lb bronze *ollas* and 25 lb copper kettles are requested. These probably refer to both European and Mexican manufactured items. Brass and bronze alloys were most likely produced in Europe, while copper vessels may have been produced in traditional copper working communities in West Mexico. Much of the copper produced in New Spain in the sixteenth century was done so within these communities.

In the colony of New Mexico, as a remote and isolated enclave, access to European and West Mexican goods and smithing expertise was limited, yet maintenance of metal goods must have been a concern and required individuals with requisite experience. The inventory of tools for the forging and smelting of metals brought in the initial colonization suggests that this knowledge and expertise resided primarily with individuals in the mining industry. Though mission centers were established as institutions for the socialization of Native American individuals, mission supply lists do not carry requests for metallurgical tool kits. Therefore it is more probable that the transference of the technology, at least in the initial colonization of the seventeenth century, occurred through the mining industry among coerced Native American laborers.

See Also

► [Knowledge Systems: Local Knowledge](#)

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Meteorology in China

Li Di

Chinese meteorology, here referring to the traditional meteorology which was used in China, has many unique characteristics. Although China began to adopt Western meteorological knowledge as it was introduced in the seventeenth century, Chinese traditional meteorology lasted 250 years. Chinese meteorology can be described from four aspects.

Knowledge About Meteorological Phenomena

The Chinese recognized some meteorological phenomena 3,000 years ago. In the inscriptions on bones or tortoise shells of the Shang Dynasty (ca. sixteenth to eleventh century BCE), there were some words meaning rain, frost, snow, thunder, lightning, rainbow, etc. The Chinese identified the relationship between the rain and rainbow; they knew if there was a rainbow in the western sky in the morning, it would rain soon. The Book of Songs declared, “White dew is frost.” In this case, frost must have been frozen dew. Two thousand years ago, the Chinese also recognized the six segments of a snowflake.

► **Wang Chong** (AD 27–97) was one of the first to record meteorological phenomena. He said that the rain came from the ground, not from the sky, meaning that the rain came from the vapor rising from the ground. He also said that clouds and fog are omens of rain, there is dew in the summer but frost in the winter, and rain when it is hot but snow when cold. He understood that rain, dew, frost, and snow were formed of vapor from the ground at different temperatures.

The ancient Chinese had exact knowledge about rainbows, too. Kong Yingda (AD 574–648) who lived in the early time of the Tang Dynasty, pointed out that the rainbow was created by the sun’s shining on the waterdrops.

Sun Wanxian and ► **Shen Guo** (AD 1030–1094), who lived in the Northern Song Dynasty, studied the rainbow too, and agreed with Kong Yingda. Sun Yanxian said that the rainbow was the reflection of the sun in the rain, created when the sun shines on the rain.

They also had a good deal of knowledge about the wind and the clouds. In the fourth century, it was recognized that the trade wind had 24 fans. ► **Li Chunfeng** (seventh century) recorded the wind as having 10 grades according to its strength and 24 types according to its direction. Shen Guo once recorded a land tornado in his book. “There is a tornado coming from the south-east in Enzhou and Wucheng. It looked like a huge sheep horn, and carried all the big trees. Quickly it disappeared in the sky.” Sima Qian (b. 145 BCE) divided clouds into three types according to their height from the ground. Eighteen pictures of clouds were drawn in the fourteenth century according to weather conditions. Later the number reached 32.

Weather Forecasting

Many methods of weather forecasting were used in ancient China. The first is forecasting according to the air humidity. In the second century, the Chinese recognized the relationship between the sound of a musical instrument and the weather. Later, Wang Chong pointed out that it would rain as the strings of a *zheng* (an instrument in some ways similar to the zither) became slack. No later than the eighth century the Chinese recognized that many waterdrops appearing on a solid body with good heat-conductivity, or high temperature and great humidity, were all omens of the rain.

The second method is forecasting the weather according to optical phenomena such as rainbows, rosy clouds, and halos. Some records written in the nineteenth century proved that the natives of Fuzhou could predict a heavy rain and a great wind, even a typhoon on the sea, according to the position and height of the rainbow. In the eleventh century, Kong Pingzhong pointed out that the morning glow is the omen of

a rain, while the evening glow is the omen of a sunny day. Lou Yuanli, who lived in the Yuan Dynasty, stated that the solar halo was the omen of a rain, and the lunar halo of a wind. He also pointed out that the direction of a wind was the direction of the gap of the lunar halo.

The third method is forecasting according to the movement and patterns of clouds and fog. Clouds and fog are the bases of some weather phenomena such as rain and snow, so their height, patterns, and direction can be used to forecast the weather. Since the Tang Dynasty, there have been many such forecasts. Huang Zifa, who lived in the Tang Dynasty, once forecasted, “if there is some cloud moving against the wind, it will rain.”

The fourth method is the forecast according to sounds and lightning. There were many weather-related proverbs in ancient China. “If there is lightning in the southern sky, it will rain; if in the northern sky, it will not.” (Lou Yuanli). “If the lightning is irregular, it will rain hard.” “No rain, but thunder, go by boat, come by feet,” meaning it would not rain for some days.

The fifth method is according to the activities of animals. Some animals are sensitive to weather changes. The ancient Chinese could forecast the weather according to their activities. ► [Wang Chong](#) said, “If it is going to rain, ants migrate, earthworms come from their holes.” There was a proverb in the Tang Dynasty that said that if ants blocked up their holes, it would rain. Also ancient Chinese recognized that if birds’ wings moved hard as they fly, it would rain.

Meteorological Survey and Instruments

The ancient Chinese conducted many meteorological surveys and invented many surveying instruments.

Wind and Surveying Instruments

Two thousand years ago, the Chinese used a surveying flag and Xiangfeng bird to judge the direction of the wind. A Xiangfeng bird was made of copper slices fixed on the top of a high pole. It could be revolved by the wind, and its head was always along the direction of the wind.

At first, Xiangfeng birds were used in meteorological observatories; later they were used in the government and private houses. Even now, some Xiangfeng birds can be found on the tops of some towers. Li Chunfeng recorded the method to measure the direction and speed of the wind using a chicken feather, i.e., to measure according to the moving direction and dip angle of the feather. In 1716, the Qing Government set up a meteorological network to survey the direction of the wind using surveying flags, which was the primary form of the modern meteorological network. However, the Chinese also began to use western wind surveying instruments at that time.

Precipitation and the Chinese Precipitation Gauge

Because precipitation was very important to agriculture and people’s lives, in the Eastern Han Dynasty (AD 25–220) the court ordered that every noble government should report precipitation in the period from the beginning of the spring to the beginning of the autumn. ► [Qin Jiushao](#) recorded a kind of precipitation gauge – Tianchi Basin, which was widely used in 1247. The Western precipitation gauge and distiller were recorded in Chinese books of the eighteenth century.

Humidity and the Surveying Method

In the Western Han Dynasty, the Chinese invented a method to measure the air humidity by hanging a lump of earth and a bar of charcoal (or a feather). When the air was dry, the bar of charcoal (or the feather) was light; when the air was humid, it was heavy, but the earth had little change in its weight. By hanging a lump of earth and a bar of charcoal (or a feather) on the two ends of a staff separately and fixing a lifting string on the middle point, making the staff horizontal in the dry air, a humidometer was made. When the air became humid, the end which had the charcoal fell down. Huang Lüzhuang (AD 1626–?) invented a humidometer to indicate the air humidity by a moving needle. Later, Ferdinand Verbist (AD 1623–1688), a Belgian missionary, invented another one.

Atmospheric Temperature and Pressure

The Chinese paid much attention to atmospheric temperature. Wang Chong once pointed out that the atmospheric temperature changed during a day and affected rain and snow directly. Until recent centuries, the Chinese had not invented a thermograph. In the nineteenth century, Zou Boqi (AD 1819–1869) recorded a barometer for the first time.

Achievements in Phenology

Phenology is the process of discovering meteorological laws by the regular activities of some animals and the regular changes of some plants. The Chinese began their study in phenology a long time ago; some records of phenological phenomena written 3,000 years ago have been found. In *Xiaxiaozheng* (Lesser Annuary of the Xia Dynasty), there were some records of the turn of the months. The knowledge of the 24 divisions of the solar year in the traditional Chinese calendar was gained in the Spring and Autumn Period (770–476 BCE) and the Warring States Period (475–221 BCE). Every day marking the 24 divisions has relationships with agricultural activities. The Chinese usually arranged their agricultural work and other activities according to the 24 divisions of the solar year.

There are many records of phenological phenomena written during the period of the Western Han Dynasty to the Song and Yuan Dynasties (ca. second century BCE to fourteenth century AD). Lu Zuqian (AD 1137–1181), who lived in Northern Song Dynasty, observed the phenological phenomena in Jinhua, Zhejiang province for 19 months and made many records, including the blossoming of 24 kinds of flowers such as winter sweet, peach, plum, lotus, and chrysanthemum, and the first appearance of the spring warblers and the autumn insects.

No later than the Spring and Autumn Period the Chinese recognized that migrants' activities changed with the seasons. ► [Shen Guo](#) recorded in his book that the natives of Hebei called the frost "information frost," because they knew there would be a frost when the wild white geese came.

There are many Chinese records of meteorological phenomena, and they are still used today.

See Also

- [Li Chunfeng](#)
- [Qin Jiushao](#)
- [Shen Guo](#)
- [Surveying](#)
- [Wang Chong](#)

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Meteorology in India

A. S. Ramanathan

From the beginning, people tried to understand their surroundings and make use of their beneficial aspects. Their first action in this direction was to produce food, making use of the available water in the rivers and rainfall in the region. Though initially extreme phenomena like heavy rains, winds, cold and hot spells, droughts, and floods appeared incomprehensible and hostile, early humans gradually sorted out their seasonal character and planned their agricultural

operations accordingly. Thus began in a crude way the development of weather science all over the world.

In India, the development of this science commenced in the early R̥gvedic period. That the heat of the sun lifts the water to the atmosphere which after some time comes down as rain was recognized by the Vedic seers at a very early stage. In order to explain the occurrence of rain during a restricted period of about 2 months in their region in extreme northwest India, they imagined that water was absorbed by the sun's rays in the vast ocean areas in the south during the winter season and the humid air carried northward by the sun's rays. When the sun attains its extreme northward position and starts retracing its path, the humid air gets deflected near the foot of the Himalayas and brings rain from the east to their region. These moist easterlies replace the westerlies that were present in the region before the arrival of the monsoon rains. Whenever there was drought, they performed rituals to invoke the rain god. They believed that in nature there is a feed of a substance called soma from above into the atmosphere, which aids the occurrence of rainfall. Therefore they fed into the ritual fire some substances like wild dates and some special types of grass which produced smoke and were believed to be effective in aiding rainfall.

The post-Vedic scholars developed the subject further, mainly working on the pregnancy concept of rainfall. They looked for symptoms in the winter season for the commencement of pregnancy and identified the characteristics of winter disturbances in their region as indicating the same. Working along these lines, they were able to observe weather very carefully during the premonsoon months and were able to define the course of events which go toward the nourishment of rain embryos and the delivery of good summer rainfall at the right time after 195 days. Any departure from the defined meteorological conditions during the growth period, such as too much rainfall or snowfall, unfavorable winds, and temperature, was said to affect the quantity of rainfall delivered during the rainfall period. They also believed that hail would occur if the

rain fetuses stayed too long in the atmosphere. The moon's position with respect to the sun and the stars was believed to influence the formation of rain embryos. The moon was conceived as a replica of soma in the heavens, and soma was capable of fertilizing the atmosphere.

Based on such concepts and extensive observations, the post-Vedic scholars developed several rules of long range rainfall forecasting. If they were successful, it was certainly due to their capacity to observe day-to-day weather and individual weather elements, like clouds, temperature conditions, wind, rain, lightning, and thunder. They were extremely clever in mentally working out correlations based on observed data. For short- and medium-range forecasting they framed many rules of thumb based on winds, clouds, temperature, lightning, thunder, moisture in the atmosphere, behavior of people, animals, birds, snakes, worms, insects, trees, and plants, as well as visual impressions of the sun, moon, stars, and sky. They were so thorough with local weather that their capacity to forecast in the short- and medium-range was as high as that of any modern forecaster who does the same with sophisticated equipment and maps.

Measurement of rainfall in India dates back to the fourth century B.C.E. A standard rain gauge was constructed around the third century B.C.E., and this system of measurement was prevalent in North India for a very long time (third century B.C.E. to sixth century A.D.).

Well before the birth of Christ, the Arab dhows sailed across the Indian Ocean for trade purposes. Hippalus, a Greek pilot of the first century, sailed across the Arabian Sea for the first time. A handbook for merchants called *Periplus* was written by a Greek around A.D. 50. Subsequently, Arab geographers wrote many books giving details of Indian Ocean voyages. Sidi Ali's *Mohit*, written around A.D. 1554, not only gives a map of the Indian Ocean area, but also mentions the occurrence of monsoons at 50 distinct places.

With the arrival of more voyagers from the west in the Indian Ocean, a steady effort for systematically observing the wind, weather, and weather systems of the Indian Ocean

commenced. In his first voyage from Melinda to Calicut in 1499, Vasco da Gama made use of the monsoon winds and reached his destination in just 3 weeks. William Dampier published many observations of Indian Ocean weather and weather systems in his travel accounts. He was a sixteenth-century buccaneer who lived and worked with some of the rowdiest pirates in history. But he was also an astute observer of nature in general and weather in particular. In his *Discourse on Winds and Breezes, Storms and Currents*, he deals with general wind systems throughout the world and their seasonal changes, which include the Southeast trades of the South Indian Ocean and Northeast and Southwest monsoons of the North Indian Ocean. During the seventeenth and eighteenth centuries, the military and trade activities of the European powers in the Indian Ocean waters increased.

Matthew Maury in his *Physical Geography of the Seas* (1874) explained the formation of monsoon winds as resulting from the heat of the plains and deserts of the Asian region. The following ideas about the mechanism of the Southwest monsoon and its rainfall were generally agreed upon by the meteorologists of the nineteenth century.

The plains of North India get very hot during the summer, and the air over that region ascends and becomes light. As a result, air over the sea areas, where the pressure is high both in the neighborhood of the equator and south of it, moves toward the region of low pressure of the land. The Southeast tradewinds, while moving northward and crossing the equator, become Southwest winds, owing to the rotation of the earth. Again, these Southwest winds do not blow directly into the region of low pressure, but go around it in an anticlockwise direction. If one stands with one's back to the wind, the pressure to the left is lower than to the right in the northern hemisphere. In the southern hemisphere, the relation is reversed. The copious precipitation of the west coast is due to the high mountains which run along the coast. The higher the mountains, the heavier the precipitation. The monsoon is sustained by the latent heat released during the precipitation, which adds more heat to the

atmosphere, and therefore further rarefaction takes place. Strong winds blow into the region of heavy rainfall, since air from the neighboring regions rushes to occupy the space created by ascending air.

Meanwhile, more knowledge was added to the science of cyclones in the Indian Ocean. Henry Piddington made a monumental contribution to the science of storms. He was the first to coin the term "cyclone", which gained world usage later. In a series of papers he gave detailed accounts of many Indian Ocean cyclones. His bestseller at that time was the *Horn Book of Storms for the India and China Seas*, which was followed by another book called *Horn Book for the Law of Storms*, in which he explained the use of transparent horn cards provided in his book for finding out the center of cyclones.

Many Indian meteorologists, led by Desai, Rao, Koteswaram, and Majumdar, worked on various aspects of the formation of cyclones. They investigated the role of the upper tropospheric flow patterns in the intensification, movement, and dissipation of tropical disturbances in the Indian Ocean. The availability of aircraft winds and satellite pictures enabled the meteorologists, such as Raman and Srinivasan, to study the low-level convergence and associated winds around the calm eye region of the cyclone, upper-level divergence, and the relation of the direction of movement to the upper-level winds. They also studied the influence of sea surface temperature on the formation of the cyclone.

As regards the Southwest monsoon, the upper air observations of wind and temperature and also the newly formulated dynamical concepts enabled the meteorologists to understand many synoptic aspects of the monsoon. Many meteorologists studied the role of the easterly jet stream and the Tibetan high, the northward shift of the westerly jet stream, the advance of the intertropical convergence zone to northern India, and the extension of equatorial westerlies. Koteswaram and Flohn (1960) made important contributions in this field.

Today meteorology in India is a highly developed subject, both from the research and service point of view.

See Also

► [Navigation in India: Sea and Inland Navigation](#)

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Meteorology in the Islamic World

William J. Mcpeak

Medieval Islamic conceptions of nature and physical phenomena were partially based upon a translated accumulation of Greek thought. Among the Greek philosophers who had conjectured upon the phenomena of the atmosphere, the most famous was Aristotle (384–322 BCE), whose geoscience treatise in four books

called *Meteorologica* dealt not only with atmospheric phenomena but also with the general terrestrial aspect (including geological, hydrological, and oceanographical ideas) of his systematic cosmology.

Some of the questions pondered were meteorological: whether the Milky Way and comets were of terrestrial or celestial origin, hail forming theories, the origin of wind, the relation of thunder and lightning, and optical theories of the rainbow and the halo.

With the ninth century came a stabilization of the long political turmoil after the Islamic conquests. Also, with the rise of the Abbasid Caliphate at Persian Baghdad, that civilization and India significantly influenced the seminal culture of the new Islamic empire. With the founding of a translation center within Caliph al-Ma'mūn's (813–833) *Bayt al-Hikma* (House of Wisdom) at Baghdad, the next three quarters of a century would be very important for Islamic thought.

The *Meteorologica* would have been included among the Aristotelian translations. Evidently the first translation of the work into Arabic from the original Greek or Syriac of about 820 was that by the Jewish Arabic scholar Yaḥyā ibn-al-Biṭrīq (fl. ca. 820). Abū Naṣr al-Fārābī (ca. 870–950) had, following the Persian mathematician ► [al-Kindī](#) (ca. 801–ca. 866), adopted the Aristotelian classification of knowledge with study of nature under physics. In addition, the general scheme of Islamic knowledge defined philosophical science with seven subdisciplines of natural sciences, with meteorology as one of those. Though virtually lost, al-Fārābī's many large commentaries on Plato and Aristotle included the *Meteorologica* in his *Kitāb Iḥṣā' al-'ulūm*. But he only discussed the traditional conception of the four elements of matter – earth, air, fire, and water – in noting the contents of the work.

Four particularly outstanding Islamic thinkers accentuate the tenth through the twelfth centuries. The great Afghani polymathic scholar Abū Rayḥān ► [al-Bīrūnī](#) (973–1048) wrote copiously, though again many works are known only by name. A rare linguist, who knew not only Arabic

and Persian but also Turkish, Sanskrit, Hebrew, and Syriac, he steered clear of formal Aristotelian commentary, showing an observationally rich interest in the geosciences. His *Tahdīd Nihāyāt al-amākin li-taṣṣīḥ masāfāt al-masākin* (Determination of the Coordinates of Cities) discussed fossils, physical geology, geography, and the ancient geodetic problem of finding the circumference of the earth. His *Kitāb al-taḥīm li-awā'il ṣinā'at al-tanjīm* (The Book of Instruction in the Art of Astrology) also contained much on the sublunar world, including weather and climate over the known globe. Of the more conventional meteorological fare, he accepted basic ancient atmospheric ideas, including a variant view of the Milky Way as atmospheric smoky vapors screening the stars. The three most recognizable Islamic contributors to meteorology were: the Alexandrian mathematician/astronomer Ibn al-Haytham (Alhazen 965–1039), the Arab-speaking Persian physician Ibn Sīnā (Avicenna 980–1037), and the Spanish Moorish physician/jurist Ibn Rushd (Averroës 1126–1198).

The commentaries of these great philosophers reflected the high end of Arabic evolution toward the dictates of observation based on the logic of both critical deductive and inductive reasoning. Ibn al-Haytham, particularly noted for his seminal experimentally based inductive reasoning, was the first outstanding medieval Arabic theorist of physical optics with important applications to meteorological phenomena. His prolific output included some 20 science treatises, including his great optical treatise *Kitāb al-manāẓir* (Book of Optics).

Among the optical discussions, the treatise contained his extensive experiments and findings on reflection and refraction, and his experiments on the rainbow mechanism, a phenomenon all the vogue as a physical problem in the Middle Ages. His rainbow findings were also reported in his *Qaws quzaḥ wa'l-hāla* (On the Rainbow and the Halo), a work not in the *Optics* nor available other than as a manuscript. Ibn al-Haytham's innovative experimental method entailed a laboratory to study the phenomena of the earth, such as chemical compounds, as well as his optical studies.

Aristotle had considered the rainbow a reflection phenomenon from clouds of uniform drops acting as a continuum surface like a convex mirror. Ibn al-Haytham, researching reflection of light from plane and curved mirrors, reasoned that the phenomenon was a case of reflection similar to a spherical concave mirror. He simulated the rainbow colors by transmitting sunlight through glass spheres of water, spherical concave mirrors representative of clouds, with the cloud still acting as a continuum. Unfortunately, he also decided that refraction had nothing to do with the phenomenon, considering the same mechanism for the lunar halo and solar corona. He also employed his ideas of reflection in dealing with a terrestrial Milky Way in one of his treatises, *al-Majarra* (On the Milky Way).

Ibn al-Haytham has been considered the first thinker to realize the refractive, i.e., light bending properties, of the atmosphere. The phenomenon had been continually hinted at since ancient times in the discrepancies found in observing celestial objects because of near horizon distortion of position and size. He wrote a short treatise, *Mas'ala fī Ikhtilāf al-naẓar* (A Question Relating to Parallax). And, in his *Fī ma'rifat irtifā' al-ashkhāṣ al-qā'ima wa-a' midat al-jibāl wa irtifā' 'al-ghuyūm* (Determination of the Height of Erect Objects and the Altitudes of Mountains and of the Height of Clouds), he was evidently the first medieval thinker to use knowledge of refraction in theorizing by a convoluted geometry that the atmosphere was much lower than the ancients had estimated. His near contemporary Cordoban Ibn Mu'ādh (ca. 989–1079) should also be mentioned in regard to atmospheric height for his singular hypothesis in his treatise – mistakenly attributed to Ibn al-Haytham – “On the Dawn” (evidently known only by the Latin translation by Gerard of Cremona *Liber de crepusculis*), also called “On Twilight and the Rising of Clouds.” Sunlight before sunrise and after sunset are also phenomena of refraction, and Ibn Mu'ādh estimated the angle of depression of the sun at dawn and evening twilights, arriving at the fairly accurate value of 18° by which the height of atmospheric moisture (believed responsible for

twilights) and thus atmospheric height could be determined.

Ibn Sīnā and Ibn Rushd represented concerted Arabic commentary as it moved from the eleventh to the twelfth century. Though more noted for his varied contributions to medicine, Ibn Sīnā contributed to physical science in 20 volumes of general thought, *Kitāb al-ḥāṣil*. He also wrote on the seasons and climate in the *Kitāb al-Anwāʾ* (Book of Meteorological Qualities). Ibn Sīnā's meteorological significance centers on the rainbow mechanism and the medieval fascination with the origin of the Milky Way. Departing from Aristotle's cloud continuum and Ibn al-Haytham's spherical mirror analogy, he reasoned that the rainbow was the result of reflection from the total amalgamation of water drops – this being the key discovered later – supposedly released by clouds as they dissolved into rain. His observational prowess is seen in his explanation. The idea came to him by watching the diffraction of sunlight by water drops created by the watering of a garden in a bathhouse. He thought the Milky Way celestial in origin, voicing yet one more assent to a physical concept important to both meteorology and astronomy as an eventual point of redefinition of the ancient boundaries of celestial and terrestrial phenomena. Yet, as with thinkers to follow and into the late eighteenth century, the fact that the Milky Way was an expanse of stars and not a by-product of those stars, escaped him as well. Ibn Rushd also held a celestial opinion of the Milky Way, one more both analytical and worthy of further discussion.

Contrary to a later conception of Ibn Rushd as slavishly Aristotelian, we can say that his jurist's logic followed the exact Aristotelian order of nature as a model of systematic formulation. Ibn Rushd wrote both short introductions and extended larger commentaries, such as *Al-aṭār al-ʿalwiyya*, which included textual discussion, arguments about the opinions of other commentators, and his own analysis.

The Milky Way was a more bothersome challenge. Ibn Rushd decided that Aristotle's theory was untenable since it depended on the reality of

hot and dry exhalations which had not been proved. He also reasoned by the phenomenon of parallax (the apparent change in position of relatively close objects with change in position or view of an observer) that if the Milky Way were terrestrial (below the sphere of the moon) and thus relatively close, it would have a backdrop of different stars depending on where it was observed. In proving this, Ibn Rushd spent time observing and recording the positions of the Milky Way with respect to the stars in the constellation of Aquila from different locations. He found no change. He also noted that because the Milky Way was a constant phenomenon, whereas the exhalation was an ever changing one, the Milky Way appeared to be in the celestial sphere. But ultimately he kept the phenomenon terrestrial, calling it an atmospheric refracted image of light from a conglomerate of small stars seen from the perspective of earth.

Among later commentators was Abū'l-Faraj (Aboul-farag d. 1286), the Nestorian bishop, who wrote a theory in 1279 of the Milky Way phenomenon in relation to fixed stars and constellations. He leaned toward considering the Milky Way as wholly consisting of stars and having nothing to do with terrestrial nature.

Islam's commentary also turned to its first generation of philosophers. Optical interests seemed to die with Ibn al-Haytham, until Qutb al-Dīn ► [al-Shīrāzī](#) (1236–1311) and his student Kamāl al-Dīn (d. 1320) pursued a more critical look at his optics in *Tanqīḥ al-manāẓir* (Revision of Optics), which also delved into rainbow and halo theory. In analyzing Ibn al-Haytham, Kamāl al-Dīn initially looked to Ibn Sīnā's rainbow as a water drop reflection phenomenon, leading him to consider the water drops as analogous to transparent spheres of water. This was the breakthrough conclusion, allowing him to reason that two refractions took place, one on and one in a cloud drop in the rainbow optics. Kamāl al-Dīn used a better conceptual physics and geometry to explain the rainbow than Ibn al-Haytham had used.

The cultural devastation of the Mongol invasion of the thirteenth century punctuated the end

of the Islamic golden age. Nonetheless, it left its intellectual legacy in North Africa and passed to Spain, where cosmopolitan Toledo served as a clearinghouse of translation for both Christian and Islamic scholars.

See Also

- [al-Bīrūnī](#)
- [al-Kindī](#)
- [Al-Ma'mūn](#)
- [Al-Shīrāzī](#)
- [Astronomy in the Islamic World](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn Rushd \(Averroës\)](#)
- [Ibn Sīnā \(Avicenna\)](#)
- [Optics in the Islamic World](#)

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Military Technology

William J. Mcpeak

The term military technology is broad, and, as a subject restricted to non-Western cultures, potentially laden with analytical complexity. In fact, the constraints of a survey make it necessary to view the more technical innovations of the larger cultures rather than the myriad of variations on pointed weapons fashioned by essentially all peoples. Stimulated by environment and nature, the gamut of world cultures have used artistic and functional inventiveness in weaponry. Non-Western ancient military technology provided significant origins for Western military technology as well.

The first most significant line in the military technology progression was metallurgy of copper in the transitional period between the Neolithic and true Bronze Ages, approximately between 4500 BCE (perhaps 5000 BCE) and 3500 BCE in the Near East arc from Mesopotamia to Egypt. Copper's cold malleability enabled the earliest metalworkers to beat, rather than fire it from the ore as with harder metals. In doing so, they could fashion a metal version of basic wood, bone, and stone pointed weapons: arrow tips, spears, and particularly, swords. This was followed by smelting (melting metal to separate out impurities) and founding (melting the purer metal for casting and molding). By about 3000 BCE the general use of copper and experiment with its alloys (bronze with tin and brass with zinc) ushered in the Bronze Age to southwestern Asia over five centuries before general use. This was an essentially Near Eastern phenomenon, probably disseminated to India, Anatolia, and surrounding areas after this.

As far as we know today, the first great civilization of humanity was that of Sumer in southern Lower Mesopotamia after 4000 BCE. Among so many accomplishments handed down to subsequent Mesopotamian civilizations and the west,

one especially important one was worked copper alloys and probably bronze swords. Mesopotamian cast copper mace heads, the first technical use of metal, date from 2500 BCE. About the same time Sumerian smiths were casting socketed axe heads. In the north, Semitic peoples to be called Akkadians, from which the Assyrian and Babylonian cultures developed, assimilated Sumerian technology. Before 2000 BCE non-Semitic, Indo-European invaders from central Asia began various waves of infiltration from Asia through Asia Minor into Mesopotamia and on to India. All would leave their military mark. Among these were the Hittites from the northwest and later the Hurrians from the northeast and the Caucasus – the one moving into Lower, the latter into Upper Mesopotamia.

The Hittites overran most of Asia Minor (Anatolia) after 2000 BCE and about 1500 BCE invaded Babylonia long enough to raze Babylon. Anatolia, a high plateau fringed by mountain ranges, was rich in mineral resources, among these gold and silver, but most importantly iron. The Hittites probably ushered in the early Iron Age by their use of this much harder metal in their weapons. In the general extent of southwestern Asia the Iron Age did not arrive until about 1000 BCE, although a few Mesopotamian objects of perhaps smelted iron have been dated before 2200 BCE, and some Egyptian work has been conjectured as even older. Iron was much superior to bronze in edged and projectile weapons and required higher temperature metallurgical processes of smelting iron ore and founding the crude metal. Although it was thought in some quarters of the last century that Egypt was the cradle of iron work, development of its metallurgy may have been contemporary with that of Asia Minor, considering abundant Egyptian iron resources. The use of iron also brought more effective defensive hardware, i.e., in armor and in horse trappings and the chariot.

The horse and the two-wheeled chariot were Hittite innovations to western Asian warfare. The horse brought mobility to tactical maneuvering on the battlefield for the specialized soldiers called cavalry. The chariot was introduced during the eighteenth century BCE and likely by the

Indo-European Aryans (Indo-Iranian, also metalworkers – perhaps early iron weapon users) who invaded Iran from the northeast at that time and influenced the Hittites and evidently held sway over the Hurrians. The chariot provided a further tactical edge, allowing a soldier or two soldiers to act in concert in inflicting multiple casualties at one time. As specialized warriors, the charioteers introduced military class rule to Near Eastern civilizations. With the added innovations of scythe-like blades on its wheels, the chariot also added the mass fear psychological factor to warfare. The Hittites took northern Syria in their clash with Egypt about 1400 BCE, the latter having adopted the horse and chariot after their temporary defeat by the chariot tactics of the Hyksos, Amorite peoples who invaded Palestine about 1700 BCE. These latter also contributed large fortification technology to the general mud wall military architecture pool of the Near East which started with the high curtain walls of ancient Jericho (8000 BCE), the first example of specialist military architecture.

By the middle of the fourteenth century BCE the Assyrians were able to take the military ascendancy in Upper Mesopotamia and eventually all of Mesopotamia by the late eleventh century BCE, to become a great empire. By the eighth century BCE the Assyrian army had reached an apex of coherency, a blueprint for the Persian army. Made up of both professional and militia soldiers, the Assyrian army equipped all troops with finely tempered iron weapons. They employed cavalry and chariots, archers (using the composite recurved or reinforced bow, found in the Middle East to 3000 BCE), and slingers, who used the simplest, oldest missile weapon. Adding to their siege tactics, sappers (essentially meaning diggers at that time) were used in approaches to mud-walled defenses, as were battering rams and wheeled platforms, equipped with shielding defenses against arrows, for rolling against such walls. By the sixth century BCE the Persians had become heir to the Assyrian Empire and to the diverse military technology of the Near East. It remained dominant for 200 years until the informal transition of east to west finally came face to face with the challenge

of Greece under Alexander the Great in the middle of the fourth century BCE.

In the Far East, Chinese civilization as far back at 2000 BCE was characterized by a value placed on functional technology. The integration of the wall into Chinese cultural architecture was given a profound military expression in the Great Wall, which was started in 214 BCE by the first emperor Shi Huangdi as a linking of earlier rampart walls. It was meant to keep out the north/northwestern invaders who would plague China for centuries. The crenellated, brick-faced wall still stands, stretching some 4,000 miles and 30 ft (9 m) high, with regular spaced square watchtowers 40 ft (12 m) high with a 9–12 ft (3–4 m) passageway through them. Along with their own cultural variations on basic weapons, the Chinese designed light hunting crossbows by the fifth century BCE and were using them in combat by the second century BCE.

The use of iron metallurgy continued to be the prime advance in military technology. Iron ore is plentiful all over the world. Variations of alloying iron with carbon in smelting processes, which included the introduction of air blasting to fan the fire (the forge) to high temperatures, meant that steel (iron with a small proportion of carbon) and its hardening were probably fairly contemporaneous with iron working (from 1000 BCE). Although dating is indeterminate, the great deposits of iron in Central Africa and the proximity of the Egyptian influence point to limited iron and steel forging. Indian weapons of iron were prevalent by 500 BCE. In fact, tempered steel was produced fairly early in India. Bars, rods, and plates of raw steel were exported throughout the Near and Middle East. Indian steel was used in the founding of blades of “watered steel” (the process of folding malleable steel over and over then beating it out). These light, high tensile strength curved (Damascus) blades enabled the effective long sweeping offensive draw cut, used by both the infantry and cavalry of western and central Asia down through the last century.

The development of the relatively simple smelting methods of steel and steel weaponry was disseminated eastward to southeast Asia via

Indian colonization. Iron weaponry and working began independently in China about 500 BCE and smelting of crude steel was fairly contemporaneous (about 400 BCE). By the Middle Ages the effectiveness of the Mongolian steel saber, influenced by Middle Eastern contacts, was supplanting the straight Chinese sword. Japanese iron weaponry, with Chinese influence, began about 200 BCE, although the earliest relics date between the second and eighth centuries BCE. The best of the distinctive long, slightly curved samurai steel blades date from the twelfth century and progress to the fine temper-lined watered blades of later centuries. All these areas applied iron and steel technology to military accoutrements and armor. The work of the Near and Middle East, China, and Japan was particularly artistic as the Middle Ages progressed.

Although the steel sword would remain the principal weapon of the great non-Western cultures, the destructive potential of ► [gunpowder](#) technology into the High Middle Ages was to affect the larger non-Western cultures as it did the West. The use of incendiaries was already ancient, most noticeably in China. The so-called “Greek fire,” the generic term for a variety of mixtures based on naphtha (a petroleum distillate) added to sulfur, pitch, turpentine, tars, and oils (in modern interpretation, probably a suspension of metallic sodium, lithium, or potassium in a petroleum base), was perhaps in crude use by the fifth century BCE. It is noted as being used by the Boeotian Greeks at the siege of Delium in 424 BCE during the Peloponnesian War.

The historiographic origin of gunpowder, that is black powder, is still controversial. The gunpowder recipe itself is of uncertain origin, but its basic constituents are now generally first attributed to ninth century Chinese alchemists. It might also be the independent product of Islamic lands, most like Moorish Spain by the mid-twelfth century. From there it perhaps moved to India where there may have been independent knowledge and use of the chemical ingredients from the late eleventh century. It was known in northern Europe by the early thirteenth century. The argument for an intermediary disseminator, the Eurasian Steppe lands, the

European/Asian crossroad, to Islam and Europe, particularly by the thirteenth century Mongols is also plausible.

Explosive application of gunpowder in a weapon has also been controversial. Some theorists of Chinese primacy (Chinese toy rocket experiments for fireworks evolved early) date bamboo-tube hand guns or cannons and rockets for arrows and spears from AD 900–950. Various types of incendiary arrows, slings, and javelins, as well as incendiary and exploding bombs, grenades, and fire-balls are also attributed to the Chinese by the eleventh century. The historical point of military effectiveness of such devices remains uncertain. Widespread military use in China did not appear until the Song-Jin dynastic wars of the twelfth and thirteenth centuries. By the thirteenth century bomb technology with iron casings and large size was used by Chinese and Mongolian antagonists in land siege warfare. There is also evidence of time delay fusing using flintstone abraded against steel wheels to set off multiple mines in fourteenth century China. Rockets were introduced to Europeans during the Mongol western invasions at the Battle of Legnica in 1241. There is also evidence of rockets in India in the eighteenth century.

Gunpowder weapons applications appeared about the middle of the thirteenth century in Muslim North Africa and Moorish Spain as crude iron and iron-reinforced wooden bucket mortars for flinging stones in fortifications warfare. Also, Moors were using effective rockets on Spanish soil by 1249. Thereafter some evidence shows that the evolution of mortars, cannons, and finally handheld firearms progressed with most tactical efficiency in Europe, although some historians date Chinese cannons of significant size and metal composition from as early as the tenth century. Non-Western applications were innovative in their own right. By the middle of the fourteenth century, cannons mounted on walls or on mobile carriages and cradles had replaced most of the traditional engines of war in both Europe and the Near East. And Eastern projectiles ranged from stone balls to huge arrows with sheet-metal fins.

The growing threat to Eastern Europe, the Adriatic, and the Aegean by the ascendancy of the Ottoman Turks through the fourteenth century was furthered by their pursuing the use of artillery to challenge the weakening Byzantium Empire. A parallel was the thirteenth century Mongol challenge and conquest of China, with cavalry, siege tactics, and ► [gunpowder](#) technology. By the fifteenth century the Turks were casting – sometimes with the guidance of European renegades – huge bronze mortars and cannons, such as those used in the final siege and fall of Constantinople in 1453.

The Turks also turned to the Western matchlock arquebus, the first gunpowder longarm, which was the single most important transitional pivot from medieval to modern warfare. The Ottoman domination over the Arab world influenced firearm dissemination to Arabia and North Africa where, unlike the more angular stock of Turkish and Persian guns, styles reflected Arab and Kabyle preferences.

The influence of the West on the Asian Pacific was initially felt in trade and subsequently in acquaintance with western gunpowder technology. Perhaps the most interesting case involved the Japanese, who quickly adapted the matchlock arquebus which the ubiquitous Portuguese traders, already established in China, brought in 1542. The Japanese matchlock was an austere but highly stylish weapon, smaller in size and caliber than western matchlocks with a spring design firing mechanism, which soon joined the traditional feudal weapon array and went on to change the tactical maneuvering of the civil warfare of the sixteenth century.

The Korean civilization provides an interesting development in Asian and world naval warfare at this point in military technological history. Located on a strategic peninsula, the Korean people endured centuries of piratical incursions from the Japanese islands on one hand and politically complex dynastic invasions' from the Chinese mainland on the other. A sophisticated native culture, including science and technology (particularly, shipbuilding), was able to grow from the tenth century. Until 1592 peace and cultural advances continued. Then the

Japanese general Toyotomi Hideyoshi unified Japan, calling for the invasion of China through Korea, which refused his passage. Although they had cannon, the Koreans did not have the matchlock longarms of the 200,000 Japanese invaders. The ensuing incursion was successful until 1593 when the Korean admiral Yisunsin invented what must be the first ironclad ship, evidently thin iron plating over a high, flattened oval-shaped ship of 16 oars with circumference cannon ports. Burn and board-proof, a fleet of these “tortoise boats” was sent against and defeated a Japanese armada in Chinha Bay. This triumph provided the impetus to drive the Japanese out.

The Chinese perpetuated their own hand cannon, large wall artillery technology, and ship-board cannon well into the nineteenth century. They adapted to the Portuguese style of longarm lock but designed their own pistol grip-like stock. Both features influenced the far away Malaysian peninsula gun style which itself influenced the intermediate region of the Gulf of Tonkin. On the under side of Asia, Indian matchlocks showed significant regional variations from both the Portuguese and Arabic initial introduction. Three basic subcontinent Indian matchlocks were joined by very stylized weapons from Ceylon (Sri Lanka). By the early seventeenth century the Ceylonese exceeded the Portuguese in the manufacture of musket size matchlocks, one type with a unique bifurcated scroll butt. The Burmese side of the Malaysian peninsula essentially used Indian matchlocks with local decorations.

Although more isolated non-Western peoples continued to use the matchlock (indeed, the Japanese did until the early nineteenth century), most succumbed to trade and import and adapted to the progression of firearms manufacturing and, just as significantly, ordinance technology in keeping with the single-minded exigencies of superiority in warfare. These latter factors inevitably and irrevocably set the new course of non-Western military technology as a dependent reflection of the West, a reflection all the more thought provoking in the modern shadows of nuclear and chemical weaponry.

See Also

► [Gunpowder](#)

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Military Technology in Ancient Egypt

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Weapons and warfare were a part of ancient Egyptian life from the Prehistoric periods through Dynastic times. While examples of actual weapons, chariots, fortifications, and ships are relatively rare, Ancient Egyptian art and archaeology provide us with many depictions and descriptions of these objects. This information helps us to identify and reconstruct some of the technologies of the Late Prehistoric and Pharaonic periods (3500–332 BCE).

Weapons

The Ancient Egyptians used a large a variety of weapons in the Predynastic and Dynastic periods.

Many of the early types continued to be used throughout the Pharaonic period. Generally, weapon innovation in Egypt tended to lag behind neighboring states and groups in Southwest Asia due to social, technological, geographical, and political factors (Spalinger, 2005, p. 15). Whereas individual craftsmen produced weapons until the Late Neolithic period, by the Early Dynastic period specialized royal workshops were producing larger volumes of weapons (Gilbert, 2004, pp. 71–72; Gnirs, 2001, p. 405). At the beginning of the New Kingdom, new weapons were introduced into Egypt from Western Asia, and a period of innovative design started, during which Egyptian craftsmen perfected designs for the chariot and composite bow (Shaw, 1991, pp. 59, 68–69; Spalinger, p. 1).

Most scholars categorize Egyptian weapons by their range: short-, medium-, and long-range (Schulman, 1995, p. 290). Weapons can also be grouped according to their function: e.g., specialized weapons, tool-weapons, etc. (Gilbert, 2004, p. 33). Both methods are useful, and they provide different perspectives on the way weapons were used in Egypt.

Short-range or close-combat weapons were the mace, club, ax, stabbing spear/lance, dagger, sword; medium-range weapons were throwing stones, throw-stick/boomerang, throwing spear/javelin. Long-range weapons were the sling and bow and arrow. Specialized weapons were the mace and sword; weapon-tools were the spear, ax, club, boomerang, sling, and bow and arrow. Tool-weapons were knives, hammers, etc. (Gilbert, 2004, p. 33).

The primary materials for the production of weapons were stone, copper or copper alloy, wood, and leather, but bone and ivory were also used (Hoffmeier, 2001, p. 406). Use of chert/flint in tools and weapons dates to the Paleolithic period and continues through the Dynastic period, for specific weapons, like spear and arrow heads, because it was abundant in Egypt and fairly easy to work (Gilbert, 2004, pp. 33, 71–72; Hoffmeier, p. 406; Nicholson & Shaw, 2000, pp. 28–29). Copper was used for weapons by the end of the Neolithic period, and continued to be used after bronze became more

widely used in the Middle Kingdom. (More copper objects were found in Tutankhamun's tomb than bronze ones; Nicholson & Shaw, pp. 153–154.)

Natural, unworked stones were probably one of the earliest weapons (along with sticks). Stones could be thrown or used as hand-held weapons (Newberry, 1893: Pl. 14). Slings were an inexpensive and easily made weapon, and could propel a stone to a greater speed and attain a superior range than a thrown stone (Hoffmeier, 2001, p. 410). While there is no evidence in early Egypt for slings, they are used in later periods (Gilbert, 2004, p. 70).

Maces were made from a shaped stone with a hole drilled through its middle for the handle. Many examples of disc-, oval-, and pear-shaped maces have been found in mortuary or temple contexts. Hard stone mace-heads in early Egypt were a status symbol. Maces are represented in the art of all periods, but their numbers decline after the early Dynastic period (Gilbert, 2004, pp. 35–41; Shaw, 1991, p. 31; Shaw, pp. 31–32; *MH* 2, Pl. 102).

Although primarily used as hunting weapons in the Predynastic and Dynastic periods, sticks were also used by warriors and soldiers (Capart, 1904: Pl. 1; Gilbert, 2004, pp. 69–70). Staffs and clubs were probably among the earliest weapons, and they are used throughout the Pharaonic period (Capart: Pl. 1).

Axes were some of the oldest and most common weapons in ancient Egypt (Shaw, 1991, pp. 34–37). Stone axes (probably all hand-held) date to the Paleolithic period (Hoffmeier, 2001, p. 407). Flint axes were produced in the Neolithic period, but the earliest evidence of an ax with a handle is perhaps the one on the Hunter's Palette, which dates to the end of the Late Predynastic period (3500–3300 BCE; Gilbert, 2004, p. 63). Starting in the Mid-Predynastic period copper axes appear in Lower Egypt and subsequently appear throughout the country. Early axes are of plain form, some with holes and others with lugs for attaching to a handle, and most examples seem to be from the Early Dynastic period (3032–2707 BCE; Gilbert, pp. 63–68). In the Old and Middle Kingdoms semi-circular and

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Table 1 Ancient Egyptian chronology

Late Predynastic period (3200–3032 BCE): Dynasty 0
Dynastic or Pharaonic period (3032–332 BCE): Dynasties 1–30
Early Dynastic period (3032–2707 BCE): Dynasties 1 and 2
Old Kingdom (2707–2216 BCE): Dynasties 3–8
First Intermediate period (2216–2046 BCE): Dynasties 9 to early 11
Middle Kingdom (2046–1794 BCE): Dynasties late 11–14
Second Intermediate period (1794–1550 BCE): Dynasties 15–17
New Kingdom (1550–1070 BCE): Dynasties 18–20
Third Intermediate period (1070–664 BCE): Dynasties 21–25
Late period (664–332 BCE): Dynasties 26–30
Greco-Roman period (332 BCE–395 AD)
Ptolemaic period (332–30 BCE)
Roman period (30 BCE–395 AD)

rounded ax blades are shown used by Egyptian troops in siege scenes (Arnold & Settgest, 1965, Fig. 2). These ax heads would have been attached to the haft with leather bindings (Shaw, pp. 34–37). A “scaloped” or three-“tanged” ax head was also used in the Middle Kingdom (2046–1794 BCE; Blackman, 1914: Pl. 3). At about the same time, in Syria and Palestine axes with “duck-billed” blades and socketed heads were used and show up as copies or imports in Egypt (Gnirs, 2001, p. 405; Hoffmeier, p. 407; Spalinger, 2005, p. 15). Later, in Western Asia and New Kingdom Egypt, longer, narrower ax blades that were more suitable for piercing shields or helmets appear and were possibly developed as a response to the introduction of armor (Shaw, pp. 34–37) (Table 1).

Examples of large-chipped stone spearheads dating to the Paleolithic period have been found in Egypt (Hoffmeier, 2001, p. 407). One of the earliest representations of a spearman is on the Hunter’s Palette (Gilbert, 2004, p. 58). Flint spearheads continued to be used in the Old and Middle Kingdoms, even though copper spearheads appear in the Late Predynastic period (Gilbert, p. 59). Bronze, socketed spearheads appear in the New Kingdom (Shaw, 1991, p. 37). Spears could be

used as an offensive or defensive weapon, but the javelin was primarily an offensive weapon. The lance or long spear was used as a thrusting weapon and was used in the Predynastic and Dynastic periods (Gilbert, pp. 60–61; Hoffmeier, p. 407).

Bifacially flaked flint daggers and knives were used in the Neolithic period and Predynastic periods. Copper daggers appear in the Middle Predynastic period and continue in use throughout the Dynastic period. Daggers were provided with wood, bone, or ivory handles (Gilbert, 2004, p. 42; Shaw, 1991, p. 37). As the use of bronze expanded in the New Kingdom, a longer dagger or short-stabbing sword was developed (Hoffmeier, 2001, p. 407). By the Ramesside period (1292–1070 BCE), mercenaries in the Egyptian army employed longer, double-edged, pointed swords. The sickle-sword or *Khepesh* first appeared in Mesopotamia, and the Egyptian varieties that appeared in the New Kingdom were modeled on the West Asian types and may have been used more like an ax than a sword (Hoffmeier, p. 408; Spalinger, 2005, p. 15).

The bow and arrow were used in all periods, starting as early as the Late Paleolithic period (Gilbert, 2004, pp. 44–45). Until the New Kingdom most bows were made from a single piece of indigenous wood, which could be used to construct both the simple and double-curved/convex types of “self”-bows (Western & McLeod, 1995, pp. 77–79). These early bows did not have a nock for the bowstring, but instead the string would have been wound around the ends several times (Hoffmeier, 2001, pp. 408–409). Self-bows continued to be used in the New Kingdom, and 14 examples were discovered in the tomb of Tutankhamun (McLeod, 1982, pp. 1–2).

Influences from Western Asia led to the adoption of the composite bow in Egypt. Because of its construction – a laminated sandwich of wood between horn and sinew – the composite bow was more elastic and therefore had greater range and penetrating power than self-bows (Shaw, 1991, pp. 37, 66). There were recurved and triangular types of composite bows (Shaw, pp. 42, 66).

Arrows were composed of three elements: the point or arrowhead, the shaft, and the fletching. Arrow points were made from stone, ivory, bone,

and wood in all periods and copper and copper alloys in later periods (Gilbert, 2004, p. 46; Hoffmeier, 2001, p. 409). Arrowheads were made in a variety of shapes, depending on use (Gnirs, 2001, p. 405). Arrows with copper alloy points did not become common until mid- to late Dynasty 12 (ca. 1875–1794 BCE; Spalinger, 2005, p. 15), and it was afterwards that the use of flint points declined (Gilbert, pp. 48–54). However, 20 arrows with flint transverse points were discovered in Tutankhamun's tomb (Gilbert, pp. 48–54). Reeds and wood were used for arrow shafts. The nocks could be cut in the reed or in anock-piece made from wood, bone, or ivory fitted into posterior end of the shaft (McLeod, 1982, pp. 4–5). Fore shafts were attached to the anterior part of the shaft and could be made from the same materials as the nock-piece; the fore shaft was often sharpened to serve as the point. If arrowheads were used they could be attached to the shaft with mastic (Gilbert, p. 49). Two, or more commonly, three, or four vanes of feathers were added to provide stability to the arrow in flight (Western & McLeod, 1995, pp. 77–79). Depictions of quivers were rare until the Middle Kingdom, and prior to that time archers usually carried arrows in their hands (Blackman, 1915: Pl. 8 – both methods depicted here; Capart, 1904: Pl. 1). (It is possible that the quiver was introduced into Egypt from Western Asia, since the Egyptian word for quiver is derived from a Semitic word; Spalinger, p. 15.) In the New Kingdom quivers were still carried but were designed to attach to the sides of chariots as well (Shaw, 1991, pp. 66–67).

Shields are the only type of defensive equipment depicted in early Egyptian art (except perhaps the parry stick; Gilbert, 2004, pp. 43–44). In the New Kingdom new types of shields, helmets, and body armor appear, possibly as a reaction to the introduction of new powerful offensive weapons, like the composite bow and sword, and the increasing use of copper alloy for missile and hand weapons (Davies, 1930: Pls. 16, 22, 23, and 24; Gnirs, 2001, p. 405). The shields found in Tutankhamun's tomb were made from wood, leather, and other animal hides. In the New Kingdom copper or copper

alloy shields or shield parts may have been used. Leather scale armor was used, as were leather tunics with attached copper alloy scales (Hoffmeier, 2001, p. 410).

Chariots

Whether the Hyksos introduced the chariot into Egypt or if it came from Southwest Asia by some other means, its first mention in an Egyptian context does not occur until the beginning of the New Kingdom (1550 BCE; Spalinger, 2005, pp. 8–14, 18–23). The adoption of the chariot was rather rapid, since many of the technologies and conditions required for its construction and use already existed in Egypt in the late third and early second millennium BCE. For example, horses and the wheel are attested prior to Dynasty 18 (Gnirs, 2001, p. 402; Shaw, 1991, p. 65). However, the first steps in the development of the chariot occur elsewhere in the Middle East (Hoffmeier, 2001, p. 410; Littauer & Crouwel, 2000; Schulman, 1980, pp. 117–118). While the Hyksos may have employed chariots, there is no mention of their using them, nor has any evidence of chariots been discovered at Tell ed-Dab'a (Hoffmeier, p. 410). There may be a reference to a chariot or chariot team on the Kamose stela, but the first clear text reference is found in the autobiography of Ahmose Son of Ibana, a career sailor who fought under the early kings of Dynasty 18: Ahmose, Amenhotep I, and Thutmose I (Lichtheim, 1976, pp. 12–14). Fragmentary battle scenes depicting teams of chariot horses and chariots were discovered in the ruins of King Ahmose's funerary structure at Abydos (Harvey, 2001, pp. 52–55).

The expense of chariot building and maintenance meant that its use was limited to the royalty and nobility (Gnirs, 2001, p. 403; Schulman, 1995, pp. 295–297), so from the very start, the chariot was a status symbol, which besides being used in a military context was also employed in domestic activities like hunting and inspecting estates (Davies, 1903: Pl. 17; Davies, 1905: Pl. 13; Davies & Gardiner, 1936: Pls. 50, 68).

There are few surviving examples of chariots or parts of chariots, but fortunately the Egyptians often portrayed them in paintings or relief sculptures on tomb or temple walls. Actual vehicles or vehicle fragments include the chariot from Yuya and Tuya's tomb, the Florence chariot, the six examples from Tutankhamun's tomb, the body of a chariot of Thutmose IV, and the Amenhotep III hub fragment (Carter & Mace, 1927, pp. 54, 60; Carter & Newberry, 1904, pp. 24–38; Davis, 1907: Pl. 32; Hansen, 1994, p. 52). In art, chariots are shown in domestic contexts (e.g., Ahkenaten and Nefertiti visiting a temple), being constructed (e.g., in the tomb of Puimre), or in military contexts (e.g., Ramses II fighting the Hittites at Kadesh). In battle scenes, there is often a two-man crew represented, a driver, who also often holds a shield, and an archer.

The chariot was a mobile platform for archers, usually operating at a distance from the enemy. It also performed some of the duties that were later assigned to cavalry, such as screening infantry and out-flanking and pursuing the enemy. Use was limited by terrain: rivers could be difficult to ford and rough ground presented obstacles. Therefore chariot use was restricted to relatively flat ground, and because they were light and unarmored they could be easily damaged (Davies & Davies, 1933: Pl. 7 – bearers easily carry parts of a chariot). Egyptian accounts of the battle of Kadesh relate that the Hittites deployed 2,300 chariots, but Schulman believes this is an exaggeration (Schulman, 1980, p. 132). Nonetheless, the *Annals* of Thutmose III record that 924 chariots were captured at Megiddo (Gnirs, 2001, p. 402).

Chariots were primarily composed of parts made from a variety of woods and leather, although other materials like metal fittings, textiles, glue, bone, and ivory were also used (Shaw, 1991, p. 64). Chariot workshop scenes became a popular subject for New Kingdom tombs; they show workers making wheels, bodies and other components of chariots (Davies & Davies, 1933: Pls. 7, 10, 11, and 12). Local and imported woods were used for many parts, some of which, like rails, drive poles, and yokes, required steam bending, a technique the Egyptians possessed

prior to the New Kingdom (Nicholson & Shaw, 2000, p. 357; Shaw, 2001, pp. 63–64). Leather was also used liberally in chariot construction, for floors, harnesses, and tires (Nicholson & Shaw, p. 309; Scheel, 1989, p. 47; Hoffmeier, 2001, p. 410; Carter & Mace, 1927, p. 56; Shaw, p. 63), and for binding and protecting the more vulnerable components of the chariot (Davies & Davies, p. 12).

The first Egyptian chariots had wheels with four spokes (Davies, 1923: Pl. 23, bottom). A larger, stronger wheel was probably required as the chariot became bigger in order to accommodate a two-man crew (driver and warrior). Therefore, an eight-spoke wheel was briefly used, but this was abandoned in favor of the six-spoke wheel, which was found sufficiently strong to bear the weight of the crew (Carter & Mace, 1927, pp. 57, 58; Carter & Newberry, 1904: Pls. 10–11). The hub or nave was the most complex component of the wheel and was composed of morticed halves, together with the six V-shaped spoke segments, and tenoned wheel flanges (used to extend the hub along the axle to prevent wobbling; Hansen, 1994, p. 52; Carter & Mace, p. 57).

Fashioned from a single piece of wood, Egyptian chariot axles were long (2–2.3 m) to provide great stability and maneuverability. There were no bearings, but the axle could be fitted with greased leather sleeves to minimize friction and wear from the wheel (Hansen, 1994, p. 54). The placement of the axle at the rear of the vehicle helped to distribute the crew's weight between horses and wheels, and absorb some of the shock of the ride (Carter & Mace, 1927, p. 56) (Fig. 1).

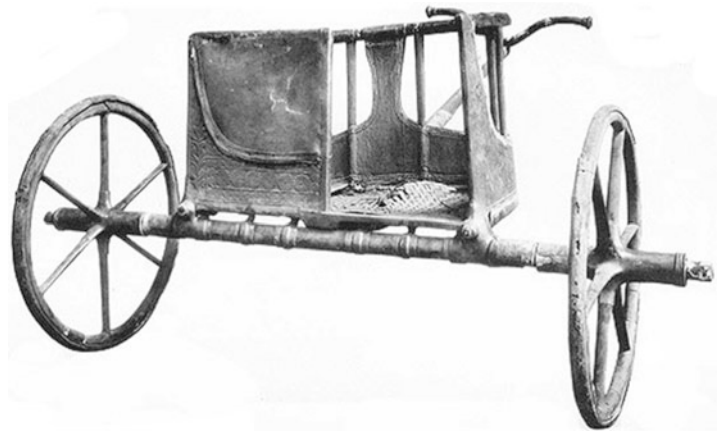
The body of an Egyptian chariot was small and light, being composed of a bent wood support frame and rails, with side panels of linen and leather. Most chariot bodies were open in the back. Portions of the body were attached or stabilized by leather lashings to the floor, pole, and axle (Hansen, 1994, p. 59).

Bow cases, arrow quivers, and javelin cases would have been attached to the sides of the chariot, but only paintings or relief carvings of these survive (Fig. 2).

Chariot warriors are occasionally shown wearing helmets and leather (?) armor, but most

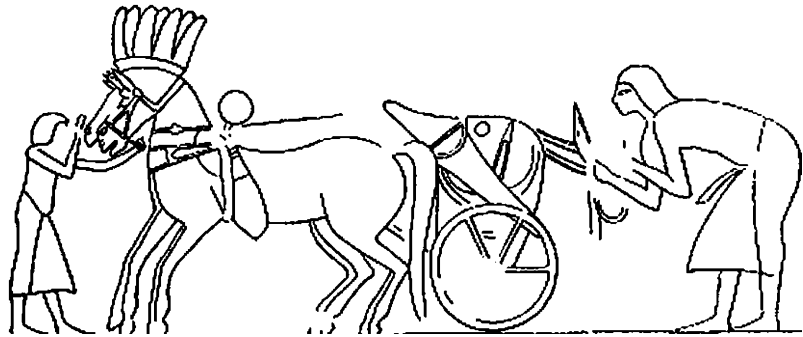
Military Technology in Ancient Egypt,

Fig. 1 The chariot found in the tomb of Yuya and Tuya (Newberry, 1893: Pl. 32)



Military Technology in Ancient Egypt, Fig. 2

A bow case mounted on the side of a chariot (Newberry, 1894: Pl. 12)



commonly, the crew and horses were nearly unprotected. Perhaps its mobility and speed were effective in keeping the chariot crew and team safe. Representations of chariot teams on tomb or temple walls provide much of our information about leather harnesses and bridles. Though metal bits were used, none have been found with surviving chariots (Carter & Mace, 1927, p. 59), but examples from excavations indicate metal bits were standard equipment (Spalinger, 2005, p. 19).

Horses became an important commodity in Egypt at the same time the chariot was introduced. Most of Egypt's horses were captured in battle, imported, or obtained as tribute (Schulman, 1995, pp. 295–297; Shaw, 1991, p. 65; Spalinger, 2005, p. 19).

Fortifications/Siege

Evidence for fortifications, assaults on fortified places, and sieges first appeared in Ancient

Egypt during the Predynastic period. Some of the large, decorated cosmetic palettes, or fragments of palettes that were found at Hierakonpolis and elsewhere, are decorated with scenes that occasionally include fortifications. For example, on a fragment of the “Bull Palette” is a relief carving of a fortified enclosure, represented in plan by a wall with buttresses. Similar scenes are found on the Narmer Palette and the so-called “Libyan Palette.” From this time forward, depictions and descriptions of defensive architecture and assaults on fortified places became popular subjects in Egyptian art and literature. Monumental mud-brick structures were constructed during the early Dynastic period at Hierakonpolis (Kasekhemwy “Fort”) and Abydos (Shunet el-Zebib), and while these buildings had a funerary purpose, they are our earliest archaeological evidence that the Egyptians were capable of building large-scale fortifications at this time (Figs. 3, 4, 5, 6, and 7).



Military Technology in Ancient Egypt, Fig. 3 “Bull Palette” fragment (Capart, 1904, p. 235, Fig. 166)

Scaling ladders and towers start to be represented in some of the tomb decorations of the Old Kingdom, as seen in the Dynasty 5 (2504–2347 BCE) rock cut tomb of Inti at Deshasheh (Petrie, 1898: Pl. 4) (Fig. 8).

Beneath the scaling ladder two Egyptian soldiers and their commander are prying blocks or bricks from the wall. In the Dynasty 6 (2347–2216 BCE) tomb of Kaemheset at Saqqara a large ladder with two wheels at the bottom is shown propped against the wall of a city during an Egyptian assault (Quibell & Hayter, 1927: Frontispiece). Egyptian soldiers armed with axes and pickaxes are shown, attempting to create a breach or undermine the fortifications.

A number of fragments of a siege survive from the mortuary temple of the Dynasty 11 King Mentuhotep II (2046–1995 BCE) at Deir el Bahri and from the Theban tomb of Intef (TT#386), who commanded the army under Mentuhotep (Arnold & Settgest, 1965, pp. 50–51 and Fig. 2). A mobile siege tower is shown in the battle scenes from Intef’s tomb, and like the ladder portrayed in Kaemheset’s tomb it also has wheels.



Military Technology in Ancient Egypt, Fig. 4 Bull palette detail (Capart, 1904, p. 235, Fig. 166)



Military Technology in Ancient Egypt, Fig. 5 Narmer palette and detail of bottom (Capart, 1904, p. 237, Fig. 168)

From Dynasties 11 and 12 are depictions of assaults on fortifications from the tombs of high officials at Beni Hasan (Newberry, 1893, p. 85, Pl. 14 – tombs of Khnumhotep I (#14) and Amenemhat (#2); Newberry: Pls. 5, 15 – tombs of Baket III (#15) and Khety (#17)) (Fig. 9).



Military Technology in Ancient Egypt, Fig. 6 Narmer palette, detail of bottom (Capart, 1904, p. 237, Fig. 168)



Military Technology in Ancient Egypt, Fig. 7 “Libyan Palette” (Capart, 1904, p. 229, Fig. 160)

Either the fortified structures depicted in these tombs were constructed on mounds, or the lower portions of their walls were protected by a glacis (a cleared bank sloping down from a castle's walls. It makes a clear line of fire in which attackers have nowhere to hide). The glacis would have reinforced the walls, made it difficult for sappers to undermine them, and prevented siege towers from approaching. The tops of the walls were crenelated and had towers that protruded outward. From the protection of a shelter the attackers used a kind of lance-like weapon to create a breach in the upper parts of the walls or to clear the parapet of defenders.

As Egyptian influence grew in Palestine and Nubia during the Middle Kingdom, Egyptian

kings constructed forts along these frontiers to protect trade and communication routes (Shaw, 1991, pp. 16–23). In the region of the Second Cataract several forts and fortified towns were constructed or expanded; the most elaborate ones were at Mirgissa, Buhen, and Aniba. The forts had elaborate defenses, including massive brick walls, buttresses, towers, counterscarps, glacis, and ditches. Their plans were similar to one another, with regularly laid out streets, lined with buildings for government officials and garrison troops (Emery, Smith, & Millard, 1979: Pls. 2–4).

The kings of the New Kingdom maintained many of the older frontier forts and built new ones in the region south of the Second Cataract.

Depictions of battles and assaults on fortified towns are displayed on the walls of later New Kingdom temples. Textual references to sieges include the account of Ahmose Son of Ibana about the fall of Avaris, the Hyksos capital in Egypt's eastern Delta, and Sharuhenn, a Hyksos stronghold near present-day Gaza City. These cities only fell to the Egyptians after several campaigns and sieges (Lichtheim, 1976, p. 12–14), leading Redford to suggest that Egyptian siegecraft was not very sophisticated at this time (Redford, 1992, p. 138–139). However, it is possible that the Egyptians revisited these cities several times, during several campaigning seasons, rather than conducting a single lengthy siege (Redford, p. 129).

Thutmose III spent several campaign seasons in Palestine, Syria, and Mitanni. For the first time in Egyptian accounts the *Annals* of Thutmose III describe a siege wall at Megiddo, presumably constructed to prevent any of the populace from escaping and to protect the Egyptians from sorties and from an enemy relief force (Redford, 2000, pp. 31–33).

There are several temple relief scenes from the reign of Ramses III that depict assaults on fortified towns in great detail but show no real advances in either fortification or siege technologies (MH II, PL.90; MH II, PL.87; MH II, PL.94 and 95 (photo); MH II, PL.88 and 89 (photo)). The fortified “Eastern High Gate” of Ramses III's mortuary temple at Medinet Habu resembles

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Fig. 8 Siege scene from the tomb chapel of Inti at Deshasheh, Dyn. 6 (Petrie, 1898: Pl. 4)



Military Technology in Ancient Egypt, Fig. 9 Assault on a fort from the tomb of Amenemhat (#2) at Beni Hasan (Davies, 1903: Pl. 14)

some of the Syrian fortifications that are depicted in some of the relief scenes of sieges from Dynasties 19 and 20 (*MH* VIII, PL.591; *MH* II, PL.87).

Following the New Kingdom, Egyptian control of Nubia and Syria-Palestine began to wane as did royal authority inside Egypt. The unsettled conditions of the Third Intermediate period (1069–664 BCE) were witness to the construction of additional fortified towns and cities throughout Egypt. The Kushite King Piye (r. ca. 746–715 BCE) recorded the events of his campaigns in Egypt on the Gebel Barkal Stele, including descriptions of fortified sites in Middle

Egypt and the Delta, some of which were besieged and assaulted by his forces (Lichtheim, 1980, pp. 66–84). At the siege of Memphis, one of his commanders suggested building a ramp or causeway across inundated land to bring Piye's troops before the walls of the city. Though there is no previous record of ramps being used in sieges, there are examples that survive in architectural contexts (as on the inside face of the first pylon at Karnak). In addition, in Papyrus Anastasi I, which dates to the late New Kingdom, a military officer is given the task of estimating the volume of materials (brick, reeds, and beams)

needed to construct a ramp of specific dimensions (Gardiner, 1911, pp. 16–17, 31–33). Rather than construct a causeway or build siege towers, Piye used ships to ferry his troops right up to the walls of the city where they successfully overwhelmed its defenses (Lichtheim, pp. 75–76). Piye's forces also may have used siege engines called "hurler" and "wooden servant" at Hermopolis, but their exact functions remain unknown (Lichtheim, pp. 71–73; Schulman, 1995, pp. 298–299). A generation later the Assyrians assaulted Memphis and captured it using siege techniques similar to those used earlier by the Egyptians.

Navy

Although boats have been depicted in Egyptian art since Predynastic times (Berger, 1992, pp. 107–120), it is difficult to ascertain their specific military uses until later periods. The earliest boats were reed craft, but local and imported woods were used in boat construction from at least the Old Kingdom (2707–2216 BCE). In a military context it seems that boats were primarily used to transport troops and materials (Lichtheim, 1976, pp. 12–14). The earliest surviving representation of a conflict on water is carved into the ivory handle of the Gebel el-Arak knife, which dates to the Naqada II period (ca. 3500–3300 BCE; Shaw, 1991, pp. 59–63). Examples of large-wooden boats were discovered in 1991 in 14 boat graves near the Shunet el-Zebib at Abydos (University of Pennsylvania; Pierce and Kosty, 2000: <http://www.upennmuseum.com/pressreleases/forum.pl?msg=43>).

Scenes of boat building are often included on the walls of Old Kingdom tombs, such as the Dynasty 6 tomb of Mereruka at Saqqara (The Sakkarah Expedition, 1938: Pl. 152). Two large, wooden boats dating to Dynasty 4 (2639–2504 BCE) and belonging to the funerary equipment of King Khufu were discovered beside the Great Pyramid at Giza, and the Palermo stone describes a 52-m boat that was built during the reign of Khufu's father Sneferu (r. ca. 2639–2604 BCE; Wilkinson, 2000, pp. 141–144). One of the Khufu

boats has been restored at Giza. Instead of a keel it has a central shelf and two side shelves that provide stability. The planks of the sides are joined to one another by pegs, ropes that run through a system of holes on the inside of the planks, and by hook scarves (Landström, 1970, p. 28).

Six boats were discovered near the pyramid of Sesostri III at Dashur. One of the boats has planks that are joined only by pegs and by dovetailed fasteners (Landström, 1970, p. 90). Hogging-trusses were also used in lieu of a keel to strengthen river craft and sea going ships alike (Landström, pp. 64, 12–23).

Ships are often shown in the funerary art of the Middle Kingdom, including model wooden boats, and it is in a scene from the early Middle Kingdom tomb of Inyotef at Thebes that archers are depicted firing from boats or barges. Prior to the emergence of the chariotry, it seems that the elite mobile arm was the navy (Spalinger, 2005, p. 5). At the end of Dynasty 17 and the beginning of Dynasty 18 Egyptian naval activities against the Hyksos are described on the Kamose stele, and in Ahmose Son of Ibana's tomb biography (Goedicke, 1995, pp. 103–104; Lichtheim, 1976, pp. 12–14).

The Sea Peoples attacked Egypt during the reigns of Rameses II (r. ca. 1279–1213 BCE), Merneptah (r. ca. 1213–1203 BCE), and Rameses III (r. ca. 1183–1152 BCE). The sea and land battles that Ramses III fought against these invaders are described and depicted on the walls of his mortuary temple at Medinet Habu. They provide the first glimpse of a pitched sea battle in Egyptian art. Ships seemed to be specifically constructed for warfare; the Egyptian examples have fighting platforms at prow and stern, and lion-headed protrusions at the prow, which have been described as both battering rams and figure-heads. Sailors and marines fought ship-to-ship, using swords, slings (?) and bows and arrows, during the melee phase of the battle (*MH I*, PL.40).

As previously described, at the beginning of Dynasty 25 the forces of King Piye used ships as assault craft to overwhelm the defenses of Memphis (Lichtheim, 1980, pp. 75–76).

As Egyptian maritime contacts widened during the mid-first millennium BCE Egyptian naval technology was influenced by other powers in the Eastern Mediterranean, and in order to compete, Dynasty 26 kings built Phoenician/Greek type war galleys (Shaw, 1991, pp. 59–63).

See Also

- [Leather Work in Ancient Egypt](#)
- [Woodworking in Egypt](#)

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Military Technology in the Andes

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Much of our knowledge of military technology in the Andes comes from historical accounts of Inka warriors and battles. Though archaeological attention to military life, and more broadly warfare, in the Andes has been sporadic over the last century, fieldwork in the last decade has contributed important information on the strategies of fortification, weaponry, and the changes in these things through time. In this entry focus is paid to developments in the Central and South Central Andes (Table 1).

For very early time periods, it can be challenging to distinguish clearly between tools and weapons. Just as in other parts of the world, spears and other projectiles might be used for hunting and for military ends. In some ways, the use of the word “military” for the Late Archaic (3000–1800 BC) and some of the Formative Period (ca. 1800–200 BC) in the Andes is problematic because we have no good evidence for the existence of militaries for much of this time. However, there are some early indications of social conflict. These conflicts might be viewed as the roots of what later became a more complex and organized military culture.

A controversial find of slingstone piles regularly spaced along a beach at Ostra Base Camp, an Archaic site near the Santa Valley, has been interpreted as the earliest evidence of defense (Topic, 1989). Technologies related to battles at this time were not elaborate. Current evidence indicates that no defensive architecture was built. But people were using slings, as evidenced by the slingstone piles, or were hand-throwing stones, during conflicts. These conflicts were probably small-scale raids between communities that were quite mobile. There were no specialized warriors. Some Archaic period burials show

Military Technology in the Andes, Table 1 Table of the Central Andean relative chronology with date ranges and major developments

Period	Date range	Major cultural developments
Late Archaic	3000–1800 BC	Caral
Initial Period	1800–900 BC	Manchay, Kotosh
Early Horizon	900–200 BC	Chavín, Pukara
Early Intermediate Period	200 BC–AD 500	Moche, Lima, Nasca, Early Tiwanaku
Middle Horizon	AD 500–1000	Wari, Tiwanaku
Late Intermediate Period	AD 1000–1475	Chimú, Chancay, Yschma, Huarco, Lake Titicaca Kingdoms
Late Horizon	AD 1475–1532	Inka Empire

trauma indicating the use of other weapons, most likely spears (Arkush & Tung, 2013). But during the Archaic there was probably no specialized “military” technology of which to speak.

The lack of specialized military weaponry changes sometime in the early Formative Period (specifically the Initial Period, ca. 1800–900 BC), although there are only hints of this change. One of the earliest representations related to military aspects of life is seen on stone carvings at the site of Cerro Sechín in the Casma Valley. Individuals who may have been warriors are depicted with clubs. Accompanying these representations are dismembered bodies. The use of clubs associated with images of the dead (possible enemies) suggests that people were engaged sometimes in close-range combat. Representations of shields on the colorful friezes at the site of Garagay in the Rimac Valley also suggest that more specialized weaponry arises during this period.

At this time, however, there are no unambiguous signs of fortifications. The innovation of formal defensive architecture does not emerge until the latter half of the Formative Period, ca. 900–200 BC (also called the Early Horizon). For the first time in the Andes, Andean peoples built defensive architecture, most of it in naturally defensible locations such as hilltops or mountain ridges.

These early fortifications (ca. 800–400 BC) might have started out simply as platforms and other structures built on high ground. But, based on recent efforts to date these fortifications more securely, there appears to be an elaboration of such structures as war intensifies. The construction of massive perimeter walls with features

characteristic of military architecture such as parapets, bastions, ditches, and baffled entries becomes widespread between 400 BC and AD 100. This architectural technology changed the nature of military engagements. Enough people could be mobilized to build such architecture, and enough people would need to be mobilized to attach such locales. It is at this time, perhaps, that the first armies emerge.

Slings, especially in the hands of defenders behind massive perimeter walls, standing on parapets, would have been very effective weapons. Slingstone piles, as well as dispersed slingstones, are common at these fortifications (Brown Vega & Craig, 2011; Topic & Topic, 1987). Still it merits mentioning that these fortifications are interpreted by some to be ceremonial places, and slingstones are often ignored or simply reported as ecofacts. The sites are viewed to be the locales of ritual battles, if any at all, that do not constitute “real” war (Arkush & Stanish, 2005). One of the more compelling interpretations of these sites has been offered for the well-known site of Chankillo in the Casma Valley. Chankillo is argued to be a fortified temple – a place of both real ceremony and real war (Ghezzi, 2006).

During this time there appears to have been relatively little innovation in weaponry technology. Slingstones were used clearly as military weapons as were spear-throwers and small shields. These weapons are all depicted in figurines excavated from Chankillo. The figurines suggest that specialized warriors existed at this time.

After the Formative Period, in the Early Intermediate Period (ca. 200 BC–AD 500), architecture and weaponry changed, though not in

substantial ways. Clubs and maces, however, appear to be much more pervasive, indicating an intensification of hand-to-hand combat. Representations of warriors with clubs and handshields are very common among the Moche and Recuay societies (Lau, 2004). Much work focused on the Moche society has identified highly ritualized battles related to warrior sacrifice (Verano, 2001). There are clear iconographic representations of individuals with clubs, maces, shields, and knives.

During the Middle Horizon (ca. AD 500–1000), there has been relatively little discussion of military culture, despite the development in this period of two complex and expansionist states: Wari and Tiwanaku. One notable development in the way of weaponry, however, is the appearance of the bow and arrow. There are depictions of warriors with bows and arrows on Wari ceremonial vessels (Ochatoma Paravicino & Cabrera Romero, 2002). In some coastal valleys earlier fortifications are reused and augmented during the Middle Horizon (Brown Vega, Craig, & Asencios Lindo, 2011). But more detailed work is lacking here to illustrate how military strategies may have been enacted at these larger fortifications.

Perhaps in terms of military strategy, what we see fairly clearly in the Middle Horizon is an example of diplomacy. In the Moquegua Valley, a frontier zone of the Wari and Tiwanaku states, both polities appear to have been involved in diplomatic negotiations despite being in direct competition with one another (Moseley et al., 2005). While there may be evidence of defensive posturing at the site of Cerro Baúl, there is no evidence in Moquegua or anywhere else in the Andes that Wari and Tiwanaku engaged in conflict with each other.

During the Late Intermediate Period (ca. AD 1000–1476), despite the existence of widespread conflict, little innovation is noted in military technologies. Many ancient fortifications were reused and, in some cases, augmented with additional walls and defenses. Slings were clearly in use as evidenced by the slingstones noted at fortifications of this period. In some coastal areas, sling pouches of maguey fiber slings might have been made larger to accommodate larger projectiles.

Interestingly, there does not appear to have been a heavy use of spears. Generally, chipped stone technologies such as spearpoints are not as common as in earlier periods, though spearpoints made of metal may be more common.

There are indications, however, that war had changed by the Late Intermediate Period. There is good evidence for massacres during the time along the coast (Verano, 2007). As a military strategy, fear and terror may have been implemented by this time period. It should be noted that Late Intermediate Period fortifications, just like earlier ones, had few to no internal water sources (Arkush, 2011). Many scholars argue that such places would have been used as relatively short-term refuges and could not have withstood lengthy sieges. This suggests that though military armies existed at this time, military strategies did not entail lengthy attacks of fortifications.

Strategies appear to change in the Late Horizon (ca. AD 1476–1532) when the Inka Empire dominated the Andean region. Historical documents indicate the Inka laid siege to the Huarco polity of the Cañete Valley and the Chimú Empire capital at Chan Chan in the Moche Valley. The Huarco polity had several fortifications and was able to withstand Inka incursions for several years before finally being conquered (Marcus, 1987). Up to this point in time, fortifications may have been very effective. But against persistent armies backed by a powerful polity such as the Inka state, fortifications may not have been enough.

Archaeologically, important data on fortifications comes from the frontiers of the empire in modern-day Ecuador, Northwest Argentina, and Bolivia. The Inka invested heavily in fortifying the far reaches of their territory. Around the modern-day city of Quito, numerous local and Inka fortifications have been identified (Connell, Gifford, González, & Carpenter, 2003). Inka fortifications, and those of local people resisting Inka conquest, are also documented for Bolivia and Northwest Argentina (Malpass, Alconini, & Mujica, 2010; Nielsen, 2009).

Slings, spears, and shields were common weapons used by the Inka military. Apparently a new weapon appeared during Inka times: the *macana* (Ravines, 1992). It was a double-edged

broadsword that does not appear to have antecedents. Depictions of armies and battles appear in Felipe Guaman Poma de Ayala's early chronicle of the conquest period *Nuevo Crónica y Buen Gobierno* (*The First New Chronicle and Good Government*), providing limited insight into strategies that may have been used in military campaigns (Bram, 1941; Rawls, 1979).

While there were clearly military specialists, the Inka Empire also collected labor tribute (*mit'a*), which entailed mandatory military service by males. There may have been relatively few changes in weaponry or fortifications, but strategies, leadership, and organizational structure within military ranks were much more complex in the Andes at the height of the Inka Empire.

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Millet in China

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Milletts comprise an informal (not a taxonomic category) group of about a dozen small-grained

Millet in China,
Fig. 1 Foxtail millet
 (*Setaria italica* ssp. *italica*)



grass crops common mainly to Africa and Asia. Two millets formed the foundation of North Chinese agricultural developments. One is foxtail millet (*Setaria italica* ssp. *italica*; Fig. 1) and the other is broomcorn (proso or common millet, *Panicum miliaceum*; Fig. 2). Both are in the subfamily Panicoideae, tribe Paniceae, of the Poaceae (grass family). A third East Asian millet, Japanese or barnyard millet (*Echinochloa utilis*), does not appear in the archaeological record of China until quite late. Japanese millet, as the name indicates, was domesticated in Japan (Crawford, 1983, 2011). Two other plants grown in East Asia today, Job's tears (*Coix lacryma-jobi*) and sorghum (*Sorghum bicolor*), are considered by some to be millets. *Coix* is native to China but little is known about its history. Sorghum is not indigenous to East Asia and reports of its presence in the Neolithic archaeological record are incorrect (Liu, Crawford, Lee et al., 2012). The culture-historical importance of foxtail and broomcorn millet in China is symbolized by the legendary Houji of the Xia Dynasty (2070–1600 BC). “Houji” translates as “Lord of Millets.”



Millet in China, Fig. 2 Broomcorn or proso millet (*Panicum Miliaceum*)

Modern Production

About six million metric tons each of foxtail millet is produced in the world today (CGIAR, 2014a). Statistics for annual broomcorn millet production are not as clear but production may

be about five million metric tons per year. Foxtail and broomcorn millet are important food plants in China, usually grown in rural areas for local use where other crops are grown for sale. Both

millets mature between 60 and 90 days after planting and do well where growing seasons and growing degree days are short. Both millets have low water requirements. Broomcorn millet grows farther north and at higher elevations than foxtail millet (CGIAR, 2014c). Foxtail millet grows mainly in poor and marginal soils, while broomcorn millet can grow in a variety of soils (CGIAR, 2014b, c).

Millet Botany

Broomcorn millet was an important early crop in western Eurasia as well as in East Asia. Genetic research has attempted to sort out whether this millet was domesticated separately in each of the regions or whether it diffused from one region to the other. In fact, broomcorn millet consists of two genotypes, geographically split between east and west with an approximate boundary in north-western China (Hunt, Campana, Lawes et al., 2011). However, the archaeological and genetic data so far do not clarify whether there were several domestications or a single domestication of broomcorn millet. The specific ancestry of broomcorn millet is also unclear. It is a tetraploid that is not known in the wild; its greatest genetic diversity is in the Loess Plateau of North China, evidencing a long history there (Hu, Wang, Lu, et al., 2009). A weedy form with brittle or shattering fruit is recognized (*Panicum miliaceum* subsp. *rudernale*), but it may be feral broomcorn millet. The wild ancestor of foxtail millet is *Setaria italica* subspecies *viridis*, or green foxtail grass.

A glutinous or waxy (sticky) type of broomcorn millet is common in East Asia and is mentioned in Chinese records about 2000 years ago (Sakamoto, 1996). Foxtail millet also has a sticky variety that originated in East Asia and has many molecular types indicating separate origins of each. Sticky grains (including sticky rice) evolved through a selection process that appears specific to East and Southeast Asia where they are used to make alcohol, cakes, and dumplings, as well as being eaten as a grain. The nonsticky types are mainly boiled and eaten whole.

Millet Domestication

The earliest evidence for Paniceae exploitation in China is from the Late Glacial Maximum occupation at Shizitan locality 14 that dates between 23000 and 19500 BP (Liu, Bestel, Shi, et al., 2013). Starch grains extracted from grinding stone surfaces include those from Paniceae grasses. Some of the Paniceae starch grains bear a specific resemblance to green foxtail grass, the ancestor of foxtail millet. A few starch grains are larger than those of wild-type Paniceae but Liu et al. (2013) are not comfortable with their being from a domesticated millet because grinding appears to increase the size of starch grains. It may be that the size variation documented in these early Paniceae starch grains is linked to factors other than domestication. While none of the starch grains from Shizitan locality 14 have characteristics of domesticated millets, other researchers report domesticated millet starch grains in contexts dated to 11,000 years ago (Yang, Wan, Perry et al., 2012). Starch grains extracted from pottery fragments and stone tools recovered from the Nanzhuangtou and Donghulin sites indicated that starch grains of both wild and domesticated foxtail millet occur in contexts dated to 11000 BP. The relative proportion of domesticated to wild-type starch grains increases between 13 % and 16 % by 9500 BP (Yang et al., 2012). Research at Shizitan 9 on starch grains that overlap in time with those from Nanzhuangtou and Donghulin failed to identify starch from domesticated grasses or even from *Panicum* or *Setaria* (Liu, Ge, Bestel et al., 2011). Considering the doubt that the large starch grains are only related to domestication and that genus and species identifications of these starch grains are somewhat equivocal, more research on what lies behind this variation and what these starch grains represent seems required.

Grass caryopses (seeds) provide a better opportunity than do starch grains for genus and species identifications as well as to assess domestication status. Seeds of modern domesticated broomcorn and foxtail millet are easily distinguished from their wild relatives (Tsubakisaka,

1988). The oldest charred Paniceae seeds in China have been recovered from Shizitan locality 9 (Bestel, Crawford, Liu et al., 2014). At least 8 of the 24 charred seeds from the site are Paniceae grasses and at least three of these specimens appear to be from the genus *Setaria*. The specimens all conform to the wild morphotypes, being dorsally compressed. Domesticated foxtail and broomcorn millet seeds are relatively spherical compared to their wild relatives' seeds. This study confirms that Paniceae grasses, including *Setaria*, were being exploited during the late Upper Paleolithic of North China. Research on the charred seed specimens does not yet confirm that domesticated millets were being grown between 11,000 and 9,500 years ago. However, Upper Paleolithic peoples were collecting Paniceae grasses, and probably *Setaria*. So far there is no evidence of *Panicum* being used at the time.

The controversial study of plant remains from the Cishan site in North China proposes that broomcorn millet was indeed in use by 10000 BP (Lu, Zhang, Liu et al., 2009). The Cishan site was originally excavated in the early 1980s (Tong, 1984). Numerous storage pits, houses, and other domestic remains were reported. The pits apparently contained large quantities of millet but a detailed analysis of the remains had to wait until relatively recently. New samples collected from the exposed profiles of pits from the earlier excavations did, in fact, contain millet remains. The remains are not seeds, but chaff. A detailed analysis of the cell structure of the chaff and the analysis of biomolecular markers (e.g., the presence of high levels of miliacin) indicate that the remains are predominately broomcorn millet. Two radiocarbon dates reported in the 1980s placed the site at circa 8000 BP. A new series of radiocarbon dates taken directly from the chaff provided a range of dates from 10500 to 7600 BP. Most archaeologists reject the new dates because such a range of dates from a single pit are at odds with the pit structure and its formation. The well-preserved pit contents likely represent a short period of use, not several millennia of deposition. Nevertheless,

the research clarifies that broomcorn millet was an important resource at Cishan at least during the period ca. 7500–7000 BP.

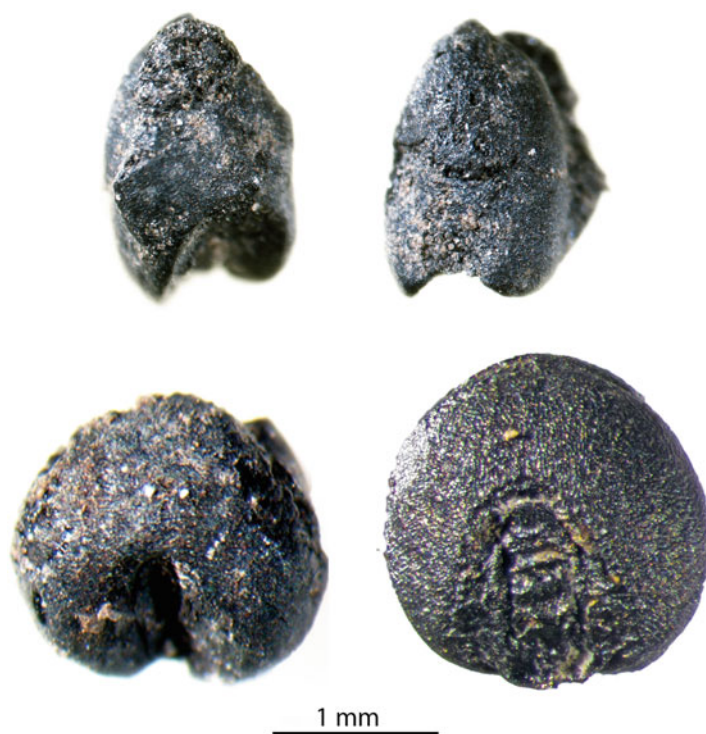
The earliest confirmed reports of charred broomcorn millet remains are from three sites: Yuezhuang, Xinglonggou, and Dadiwan (Zhao, 2004; Crawford, Chen, & Wang, 2006; Barton, Newsome, Chen et al., 2009; Zhao, 2011; Crawford, Chen, Luan et al., 2013). Broomcorn millet is rare but present in phase 1 at the Dadiwan site (7900–7200 BP). More substantial samples are from Yuezhuang and Xinglonggou where most of the millet specimens are broomcorn millet but a few are foxtail millet. A direct (AMS) radiocarbon date on rice from Yuezhuang is 8060–7750 cal. BP (2 sigma), while an AMS date on broomcorn millet is 7880–7710 BP (2 sigma). A mean value of AMS dates on millet from Xinglonggou is 7670–7610 BP. The broomcorn millet grains from the Yuezhuang and Xinglonggou sites are not dorsally compressed but are slightly spheroidal compared to wild Paniceae seeds. A comparison with relatively recent archaeological specimens from Japan indicates that the Yuezhuang and Xinglonggou specimens are smaller and not as spheroidal (Fig. 3) (Crawford et al., 2013). Thus, the morphology of these early broomcorn millet specimens lies between that of wild *Panicum* and modern or recent archaeological specimens of broomcorn millet. A detailed description of the foxtail millet grains from Xinglonggou is not available, but the specimens from Yuezhuang are similar to modern reference specimens and late prehistoric specimens in Japan (Fig. 4). Isotopic studies confirmed that as much as 25 % of the diet in the Huang He (Yellow River) basin ca. 8000 BP was from millet and within a millennium, during Yangshao times, millet contributed significantly more, perhaps as much as 75–85%, to the human diet (Hu, Wang, Luan et al., 2008).

Millet Noodles

In 2005 well-preserved noodles dating to 4000 BP were reported from the Lajia site in

Millet in China,

Fig. 3 Archaeological broomcorn millet: charred grains recovered from the Yuezhuang site dating to about 8000 BP (*top*) and the Sakushu-Kotoni River site, Hokkaido, Japan, dating to about 1200 BP. The older grains are not as large or spheroidal as the more recent grains indicating that they are at an early stage of domestication



northwestern China (Lu, Yang, Ye et al., 2005). The remains were sealed in an upside-down earthenware bowl in which starch and phytolith specimens of broomcorn millet were also found. The researchers concluded that the noodles were made from this millet. The suitability of millet to make noodles has been questioned (Ge, Liu, Chen, & Jin, 2011). A mixture of millet and wheat flour results in good quality noodles but no wheat starch or phytoliths were recovered from the bowl. The experiment apparently did not include sticky (glutinous) millet so it still might be possible to produce noodles if sticky millet was used. Nevertheless, the experiments showed that grinding millet grains and cooking the flour to make a noodle meal renders most of the starch grains unidentifiable. Before the Lajia noodle analysis, the noodles apparently disintegrated so the sediment in close association to the original noodles was sampled rather than the noodles themselves. The starch grains are arguably not from the noodles. Millet phytoliths were also recovered from the bowl but these

phytoliths are from chaff, and chaff is not used for noodle production. Researchers do not dispute that millet was grown and eaten at Lajia. We may not know with any confidence from what the noodles were made.

Distribution Expands

Between 4000 and 1000 years ago, the millets became widespread in the archaeological record of East Asia. By 1000 BP millets had spread into Hokkaido, Japan, where they were growing along with wheat, barley, and a variety of other dry crops (Crawford & Yoshizaki, 1987). Before that, they had diffused to Korea by 5400 BP because millet remains have been recovered from the Tongsomdong site and the grains have been directly radiocarbon dated (Crawford & Lee, 2003). Potentially earlier fox-tail and broomcorn millet evidence has been found at the Munamri site but archaeologists are still assessing the age of the sample.

Millet in China,

Fig. 4 Archaeological foxtail millet: charred grains showing dorsal (R) and ventral (L) views recovered from the Yuezhuang site (bottom) and the Sakushu-Kotoni River site, Hokkaido, Japan (top). These examples illustrate the relatively similar shapes and sizes of the grains despite being separated in time by about 7000 years



However, the current opinion is that they are Middle Neolithic and at least as old as those from Tongsamdong (Lee, 2014).

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Mining in Ancient Egypt and Nubia

Dietrich Klemm and Rosemarie Klemm

After an early period around 4000 BCE, during which gold nuggets were collected in some Pleistocene wadi (a valley, ravine or channel that is dry except in the rainy season) grounds and perhaps some native copper was also collected in superficial altered copper sulphide-containing quartz veins, real metal mining started in Egypt from around 3000 BCE. Until that time tools and weapons in early Egyptian culture were generally based on stone tools such as flint knives, arrow- and spearheads, scrapers and axes and hammers of hard stone. The few predynastic copper artefacts, like small tools and fishing hooks, may have been made from such copper sheets in altered copper sulphide-containing quartz veins but also from scanty imports.

It is not clear whether copper or gold mining started first in Egypt; most probably both started contemporaneously.

Copper Mining in Ancient Egypt

Figure 1 shows the positions of the various copper production sites mentioned in the text. Pre- to early-dynastic (ca. 3200–2600 BCE) gold mining has been reported from only a few sites in the Egyptian Eastern Desert, such as Wadi El-Urf near Ras Gharib, Abu Mureiwat near Safaga, Bokari and Higalig in the Central Eastern Desert



Mining in Ancient Egypt and Nubia, Fig. 1 Topographic map of Egypt and border countries with position of copper mines worked during ancient times (black stars)

(Klemm & Klemm, 1994). But only in Higalig do remains of early waste dumps with malachite-stained granitic rocks give some hint to copper mining during those early times.

Convincing arguments for Old Kingdom copper mining were found in Buhen south of Wadi Halfa at the western bank of the river Nile, where copper furnaces of the fourth and fifth dynasty were excavated (Emery, 1963). But the nearest

copper mine in that region is Um Fahm some 80 km south and 30 km inside the eastern Desert (Figs. 2 and 3). In Quban, at the mouth of Wadi Allaqi, copper slags from the Middle Kingdom were discovered (Emery & Kirwan, 1936). The next copper mine is Abu Seyal, again about 80 km away in a tributary of Wadi Allaqi. Unfortunately this site is archaeologically very poorly known, but it seems that copper mining here dates



Mining in Ancient Egypt and Nubia, Fig. 2 Copper bearing shear zone of Um Fahm in northern Sudan. Note the *green* coloured remains of malachite in the ancient mine

back at least until Middle Kingdom times. Also very poorly archaeologically studied is the copper mine of Umm Semiuky in the Southern Eastern Desert of Egypt. The site was covered up during careless early twentieth century copper mining with modern shafts, which also destroyed possible underground operations. Thus, no clear information concerning ancient exploitation of this site is available.

In the Central Eastern Desert of Egypt, in Umm Soleimat (Fig. 4), Old Kingdom to Middle Kingdom copper mining has been detected (Klemm & Klemm, 1994). Middle Kingdom copper mining settlement with small furnaces in Wadi Dara (Northern Eastern Desert of Egypt) was confirmed (Castel & Mathieu, 1992).

Mining techniques did not vary significantly during the various ancient periods. They started

with open cast trenches, following the direction of the copper-containing quartz veins within which the primary copper ores were chalcopyrite (CuFeS_2) occasionally digenite (Cu_2S) and a few others. These copper minerals were leached by water and, whether directly in the quartz vein itself or in the joint systems of the host, rocks re-precipitated as copper carbonates, mainly as malachite ($\text{Cu}_2[(\text{OH})_2/\text{CO}_3]$) or, very rarely, as azurite $\text{Cu}_3[\text{OH}/\text{CO}_3]_2$. Only these carbonates were usable for the ancient metallurgists.

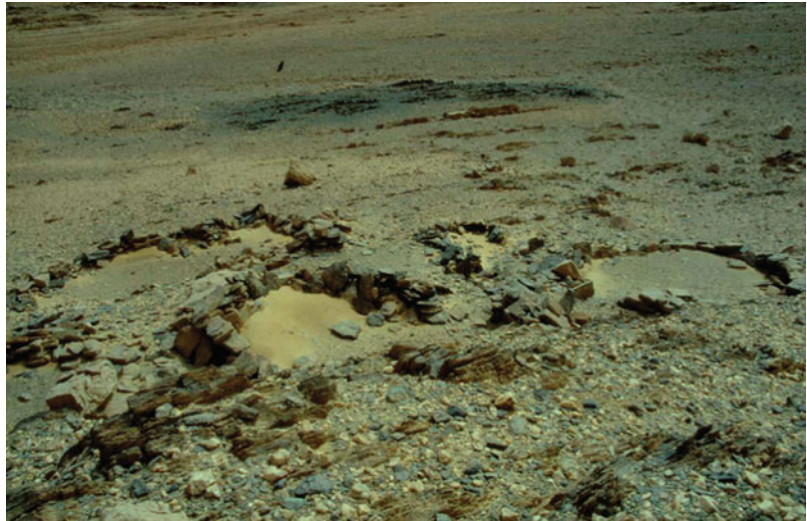
Mining tools for metal mining were until the New Kingdom exclusively of stone. After that bronze chisels, and from Ptolemaic times on, iron and steel were used in metal mining. They mined not only the copper carbonate containing quartz ore, but also the malachite filled joint systems in close vicinity to the veins within the host rocks.

Because of the necessary superficial alteration of the primary copper sulphide minerals, the depth of the trenches reached a maximum about 20–25 m, but they could be deepened when it turned out that the vein might be even richer, e.g., gold bearing.

Apart from imports from Cyprus, mainly during the New Kingdom, the main sources of copper in ancient Egypt from at least the Old Kingdom but probably also from pre-dynastic times on, was the Sinai (Lucas & Harris, 1962). In Magharah (southwest of the Sinai Peninsula about 16 km from the turquoise mining site of Serabit el-Khadim) copper mining dates back at least until the third dynasty. In the nearby Wadi Nasb, various inscriptions give evidence of copper mining from the 12th until the 20th dynasties. Predynastic copper production was reported (El Gayar & Rothenberg, 1995) from Wadi Ahmar, west of Bir Nasb with slags and remains of ancient smelters. Quite a number of other sites was reported (Lucas & Harris, 1962) with heaps of copper slag also close to Serabit el-Khadim. The most important copper mining site is Timna, which today is in Israel, not far north of Eilat. The work of Rothenberg et al. (1988, 1990) gave intensive insight not only to the special mining techniques of this site but also to smelting procedures. According to Rothenberg (1988), copper

Mining in Ancient Egypt and Nubia,

Fig. 3 Remains of an ancient workers' settlement in Um Fahm (northern Sudan). The two house types indicate cooperation of Nubian (*round huts*) and Egyptian (*rectangular huts*) miners at this site



Mining in Ancient Egypt and Nubia, Fig. 4 Copper-gold mining site of Umm Soleimat in the Central eastern Desert of Egypt. Note the *green remains of malachite in the host rock*

workings at this site probably started during the second part of the fourth millennium BCE. In contrast to the Eastern Desert of Egypt, where the copper mineralizations are from hydrothermal quartz vein systems, the Timna ore occurs exclusively as malachite impregnation pockets in sandstone.

Gold Mining in Ancient Egypt

In addition to copper mining, more than 250 gold production sites in the Eastern Desert of Egypt and the Nubian Desert of Northeast Sudan were located (Klemm & Klemm, 1994; Klemm, Klemm & Murr, 2001).

Gold Production in Predynastic and Earlydynastic Times

Discoveries of gold artefacts, dating back as far as predynastic times (about 3500 BCE) demonstrate that gold production must have taken place in Ancient Egypt (Kroeper & Wildung, 1994). Statistical analysis of the geological environments around pre- and early dynastic mining sites indicate unambiguously that the earliest prospectors



Mining in Ancient Egypt and Nubia,
Fig. 5 Predynastic gold mine of Hagalig in the southern Central Eastern Desert of Egypt. Note the smooth host rock walls of the extracted gold containing quartz vein due to the use of the calabash type two-handed stone hammers (Fig. 6)

concentrated their mining activities on well-selected geological targets of gold-enriched quartz veins, mainly in granodioritic rims of Neoproterozoic granitic intrusions, belonging to the so-called older and younger granites of the Eastern Desert. Furthermore, discoveries of the oldest mining tools are connected to mining sites associated with superficially altered quartz vein systems, which originally contained a variable copper-sulphide mineralization that is almost completely leached out and which has been re-deposited as typical green malachite within the host rock's joint system. This green staining guided early prospectors not only to copper but also to the auriferous quartz veins.

Gold mining in Ancient Egypt started in pre- and earlydynastic times with open pits and moderate underground activities (Fig. 5). During this early period, the gold-bearing quartz veins were crushed in situ to a fine powder fraction by huge calabash-shaped stone hammers of 6–10 kg weight, which must have been held with both hands (Fig. 6). In this way the gold slivers within the quartz were liberated for later processing. This mining method formed conspicuous smooth surfaces, both at the walls and the stopes (a step-like part of the mine where minerals are being extracted) of the underground operations.

Gold Production in Old and Middle Kingdom Times

During the Old (2700–2160 BCE) and Middle Kingdom (2119–1794 BCE) the previously described prospecting method of searching for malachite staining in the host rocks continued, but in addition hematite-enriched quartz veins (in places with barite) became important for exploration and, in the case of gold discovery, for subsequent mining targets.

Old Kingdom gold mining techniques continued with in situ crushing of the gold-bearing quartz vein systems, but two new basic types of stone hammers were developed: an oval stone axe of 2–5 kg weight (Fig. 7) with a chiselled notch for a forked wooden stick and a more or less cylindrical one-handed stone hammer with a ergonomically formed handle (Fig. 8). With these new mining implements, a more effective exploitation of the auriferous quartz veins was established.

During the Middle Kingdom this tool inventory continued, but additional stone mortars were introduced, allowing for the lumpy quartz ore to be crushed first to about pea-sized grains and then to a powder fraction. Again, no archaeological evidence for further gold recovery treatments during this period has been discovered, but the remark of the nomarch (provincial ruler) Ameni, who is quoted in his Beni Hassan tomb as having

Mining in Ancient Egypt and Nubia,

Fig. 6 Calabash type andesitic stone hammers from Hagalig, Eastern Desert of Egypt, of 6–10 kg weight with which the gold bearing quartz veins and vein near host rocks were smashed down to powder size



Mining in Ancient Egypt and Nubia,

Fig. 7 Andesitic stone axes with grooved notches for a forked wooden stick from Bokari mining area in the Central Eastern Desert of Egypt used mainly in Old Kingdom gold mining sites



said “I forced their (Nubian) chiefs to wash the gold” (Newberry, 1893) gives a clear hint that hydro-metallurgical concentration processes were well established during these periods.

In Fig. 9, a few gold mining sites for both pre- and early dynastic times and Old and Middle Kingdom periods are shown. However, quite a few of the early mining sites might have been so intensively overlaid by later operations that today no older surface remains are still visible.

Gold Production in New Kingdom Times

From the New Kingdom (1550–1070 BCE) onwards, gold mining operations concentrated

more in the central Eastern Desert, predominantly south of the Qena-Safaga road, and were also spread over the eastern portion of the Red Sea hills (Fig. 10). Because of the conquest of Nubia, exploitation of the Wadi Allaqi area and sites deep into Northeast Sudan (Fig. 11) also became possible. Moreover, gold prospecting targets were significantly enlarged. Quartz vein systems free of hematite and green copper aureoles were also successfully prospected. More detailed studies of the quartz vein systems exploited during the New Kingdom indicate the profound knowledge of the ancient prospectors. They were clearly aware of the general structural control of gold-bearing veins. Furthermore, because of the systematic exploration of remote



Mining in Ancient Egypt and Nubia, Fig. 8 One-handed stone hammer from El Sid mine/Central Eastern Desert with a chiselled, ergonomically formed handle used in Old and Middle Kingdom gold mining sites

desert regions during the New Kingdom, granitic-granodioritic areas in the southern and eastern parts of the Eastern Desert became new and important prospecting and mining targets. These were extended to the Wadi Allaqi and even to Northeast Sudan.

Intensive gold prospecting and processing were extended to include wadi-working operations, where gold-bearing quartz samples were systematically picked from the coarse grained fractions of the wadi sediments. At these sites, the employment of hundreds of workers was possible, in contrast to the limited number of miners in underground workings. This led to an enormous increase in gold production, documented by an increase of known gold artefacts.

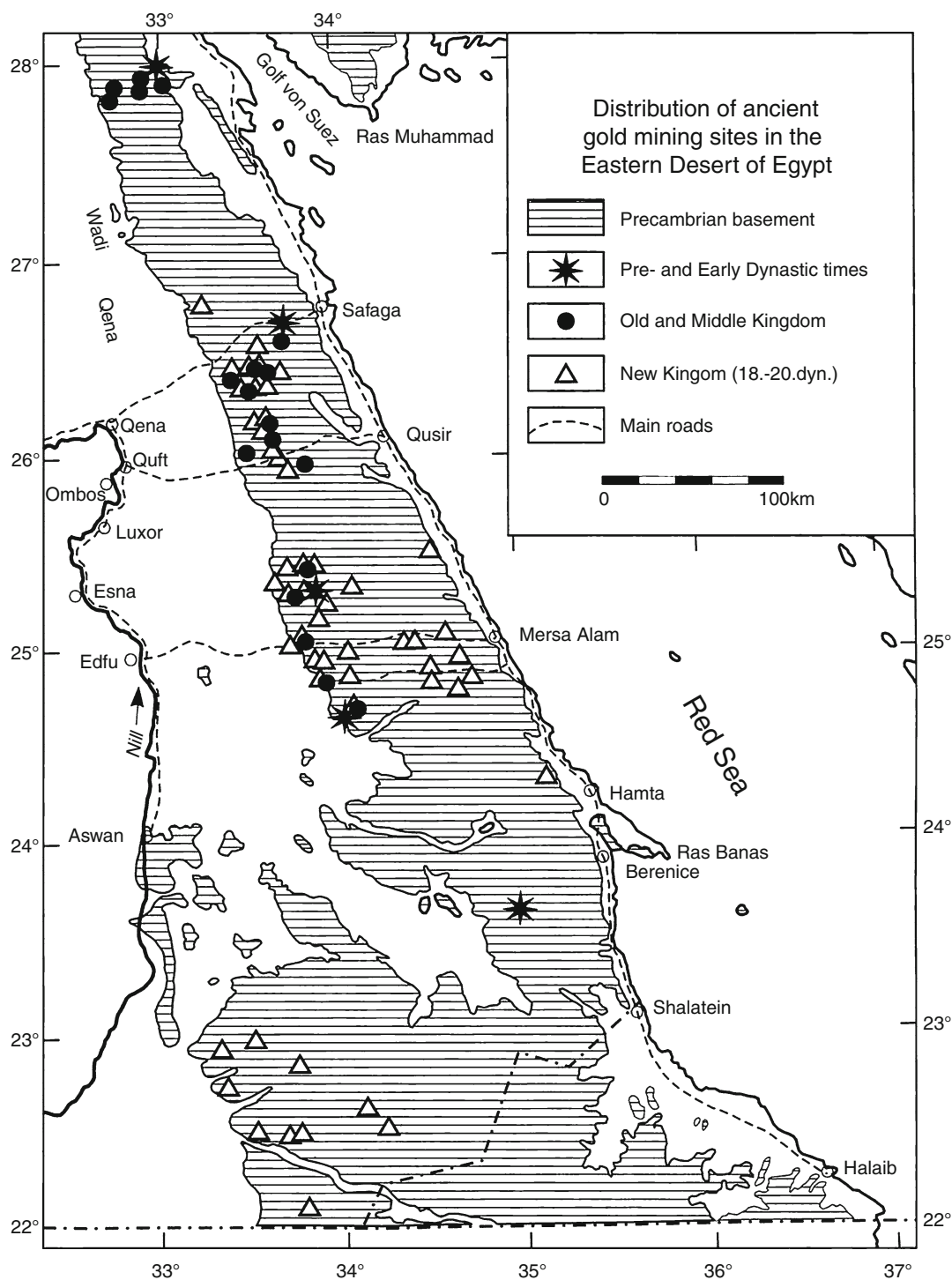
A radically new milling technique also had a strong impact on gold production at the onset of the New Kingdom. Millstones up to 80 cm long and 30–50 cm wide, with a flat and oval-shaped grinding plane, and differently sized sets of

millstones used with one or both hands (Fig. 12) were introduced. These stone mills are similar to the flour mills commonly used in the Nile valley since very early times (Roubet, 1989). The introduction of these flour milling techniques into the gold ore processing industry indicate that only from the New Kingdom onwards were the majority of miners Egyptians from the Nile valley. This assumption is also confirmed by the predominant occurrence of typical New Kingdom pottery remains within mining sites in the Egyptian Eastern Desert, and also in Nubia.

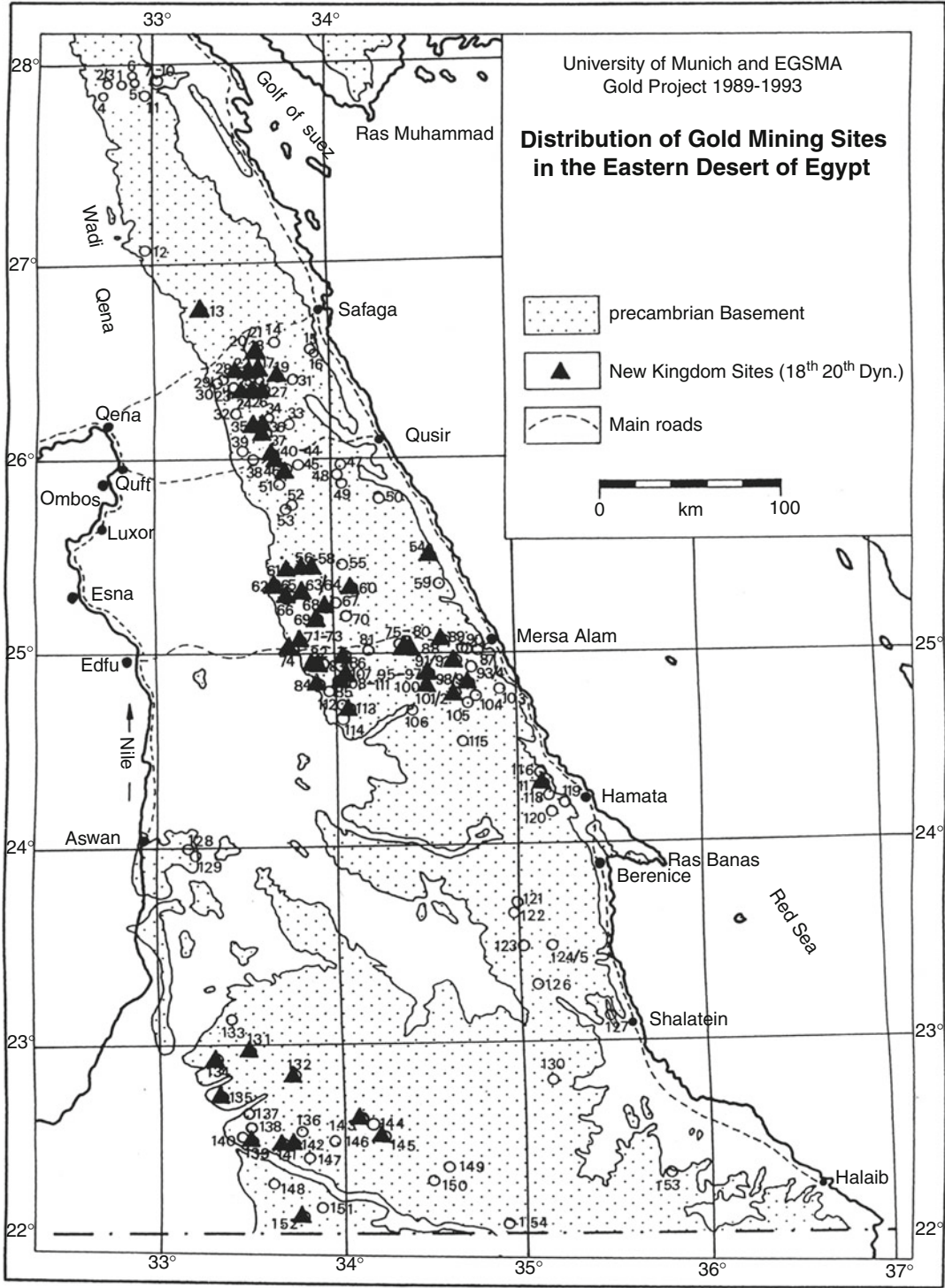
Before milling, the initial lumpy ore was crushed down to about bean-sized particles with a double-sided stone anvil of about 30×30 cm and a rounded stone pestle of 0.5–2 kg weight. The separation of barren and gold-bearing quartz fragments exclusively by eye was perfected by the workers, as small and uncommon remaining mine dump heaps in the wadi grounds today contain only milky white and translucent barren quartz gravels (Fig. 13).

Separation of gold from the fine-milled quartz powder fraction was managed by washing as attested by preserved tailing dumps. At first view these tailings appear as mostly pink to reddish heaps of quartz sand, analogous to normal desert sand. Investigation with a simple hand lens, however, reveals both sharp-edged quartz grains which are artificial products as well as remaining gold concentrations of about 3–5 g/t. This rather high residual gold content unfortunately caused the destruction of many ancient gold production sites at the beginning of the twentieth century, when modern gold production started with cyanide leaching of the old tailings, thus destroying most of the preserved and untouched original archaeological sites (Schweinfurth, 1904).

At quite a few of the New Kingdom gold production sites, inclined gold washing tables constructed of stone fragments, consolidated by primitive clay/sand mortar and with a surface covered by a layer of the same material, can be observed. The lengths of these washing tables varies between 2.2 and 4 m, and they are 40–60 cm wide and 80–100 cm high, corresponding with an inclination angle of $15\text{--}20^\circ$ (like Fig. 14, but in general much more ruined).

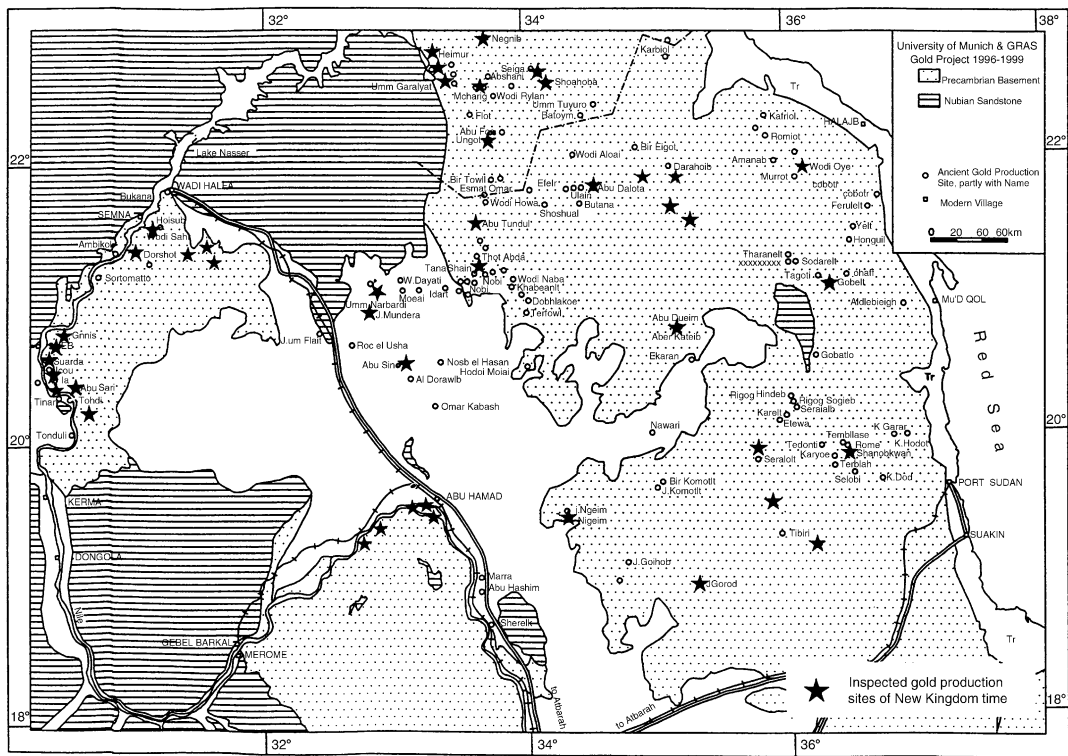


Mining in Ancient Egypt and Nubia, Fig. 9 Map of the gold mining sites in the Eastern Desert with the positions of both Pre- and Early dynastic times and Old and Middle Kingdom periods (After Klemm et al., 2001)



Mining in Ancient Egypt and Nubia,
Fig. 10 Distribution of the New Kingdom gold production sites in the Egyptian Eastern Desert. Note the wide

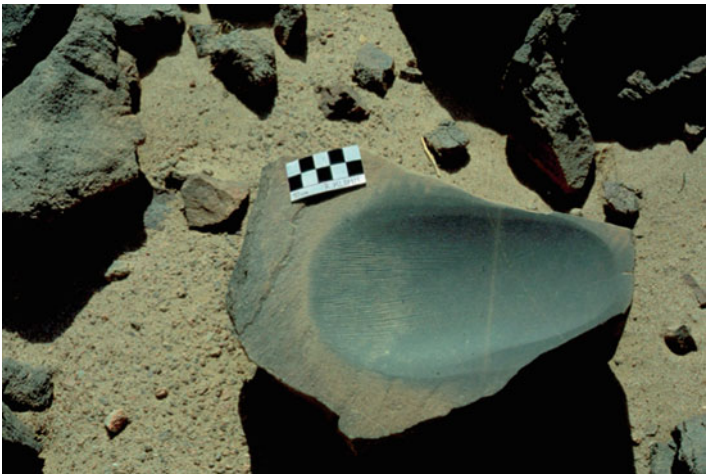
activities all over the Desert regions especially within the very southernmost parts around Wadi Allaqi



Mining in Ancient Egypt and Nubia, Fig. 11 Distribution of the New Kingdom gold production sites in Northeast Sudan. Note the concentration of

the sites along the river Nile, but also the widely scattered localities all over the vast distances of the Nubian Desert

Mining in Ancient Egypt and Nubia, Fig. 12 New Kingdom millstones with a flat and oval-shaped grinding plane and differently sized sets of millstones used with one or both hands. These stone mills are similar to the flour mills commonly used in the Nile valley since very early times



The question remains, however, as to how the planar surface of the inclined table was prepared, to separate the fine-grained gold particles liberated by the grinding process from the quartz ore. No direct archaeological evidence exists for this

important step in ancient gold recovery. Because of the lack of any archaeological relics it might be assumed that the covers of these inclined tables were of organic materials. Two possibilities are likely – either a wooden grid or simply



Mining in Ancient Egypt and Nubia,
Fig. 13 Remaining New Kingdom waste dump heaps
 from wadi workings at Umm Garaiyat, Wadi Allaqi,

southern Eastern Desert, Egypt. Note that parts of the
 wadi ground became flooded later, destroying most of
 the ancient works

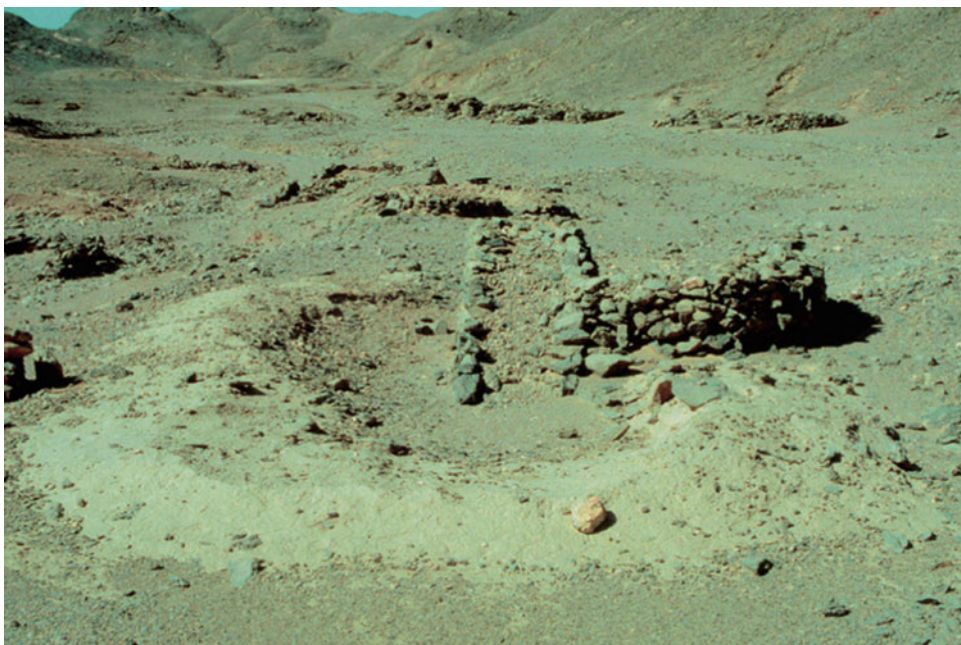
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sheepskins, as both were commonly used in the more recent past for separation of gold slivers and quartz sand fractions. The sheepskin hypothesis is supported by the supposition that sheep were available at the mining sites as food, and further, both the lanolin grease and the washed fibres of the sheepskins would have trapped the sharp-edged gold particles whereas the barren quartz particles were carried off with the water suspension. The legend of the Golden Fleece, therefore, may have been of Egyptian origin and of far greater antiquity than the voyage of the Argonauts. Finally, burning the pelts containing the gold particles yields a raw gold product, but obviously no witness to this last possible step of the gold recovery procedure remains.

In the early New Kingdom, approximately between the reigns of Thutmose I (1504–1492 BCE) and Amenophis IV (1351–1334 BCE), Nubia was conquered and incorporated into the Egyptian New Kingdom Empire. Most probably the name Nubia is taken from “nub”, the ancient Egyptian word for gold. Along the river Nile in Nubia, panning techniques most probably

increased gold production in the New Kingdom (Vercoutter, 1959). As mentioned above, the Middle Kingdom nomarch Ameni forced the chiefs of the Nubians to perform gold washing. As alluvial river gold is still panned today in parts of Nubia, especially in the area around Shamkhiya, some 30 km west of Abu Hamed, this or a similar technique may have been known during Pharaonic times. Inscriptions on dedication lists at New Kingdom Egyptian temples like Medinet Habu, where “gold of the water” is registered (Hölscher, 1957), support gold extraction from alluvial (wadi and river sediments) sources (Fig. 15).

The well-organized housing areas of the various gold-working sites of the New Kingdom are constructed mainly of three to four roomed houses, with dry stone walls about 30 cm wide and up to 1.5 m high and, in many cases, with a front terrace (Fig. 16). The lack of any protective enclosing walls indicates that during this period the Eastern Desert of Egypt was peaceful and under the direct control of Pharaonic Egypt. In Nubia, starting from Wadi Allaqi, this peaceful



Mining in Ancient Egypt and Nubia, Fig. 14 Two inclined Arab period washing tables perpendicular to each other with a rim of light tailing from Heimur/Wadi

Allaqi. This type of washing table has been archaeologically assigned to be in use from the New Kingdom on, but they might have been in use even earlier

situation became changed at places. At Umm Garaiyat the New Kingdom settlement is protected by a large enclosure wall, and at other sites the New Kingdom settlements are hidden inside wadis, such as at Duweishat and Abu Sari. Other New Kingdom gold production sites further to the south, like Sai Island, Shamkhiya, Tanta and Mograt Island seem to have been operated only within strongly fortified settlements.

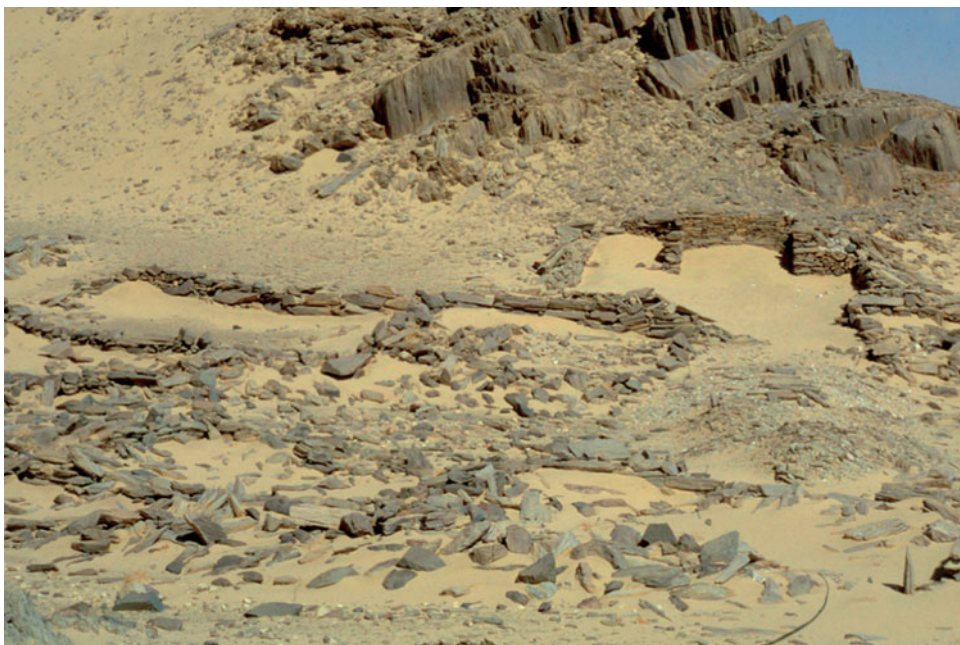
This latter assumption is based on the observation that almost all of the more southerly New Kingdom gold production sites today are only indirectly recognizable, as the typical New Kingdom stone mills and crusher stones are mainly incorporated into the walls of far later medieval fortifications of the Christian kingdom of Makuria. The most probable interpretation is that these fortifications are nothing less than rebuilt earlier defensive installations from New Kingdom times. This assumption is supported by a site called Ras el-Gazira at the westernmost part of Mograt Island (near Abu Hamed in Sudan),

where a relatively untouched New Kingdom gold production site is directly protected by an impressive stone fortification with an extended field of rock palisades towards the open eastern plain of the island. Here, as at the other sites, mostly only scanty ceramic remains are detectable as surface inventory, but a detailed archaeological excavation is urgently required.

Mining technique improved significantly in New Kingdom times, mainly with the introduction of bronze chisels, which allowed a much more selective separation of the gold-bearing quartz generations of a multiphase quartz vein from the barren parts of the host rocks. The miners selectively followed the most promising ore shoots, which resulted locally in a somewhat chaotic pattern of underground operations. Fortunately, in most mines supporting pillars ensured the safety of the ancient miners. During the New Kingdom no sophisticated ventilation of the underground operations was developed, limiting the maximum depth of operations to about



Mining in Ancient Egypt and Nubia, Fig. 15 Nubians bringing gold in pockets and ring ingots. Wall painting remains in the tomb of Huy, viceroy of Kush (Nubia) under Tutankhamun, end of Eighteenth Dynasty, New Kingdom



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Mining in Ancient Egypt and Nubia, Fig. 16 Remains of a many-roomed stone house from the New Kingdom settlement of Abu Sari gold mining site, Sudan

30 m, the maximum depth for maintaining a sufficient oxygen level by normal circulation for men and burning oil lamps.

In Figs. 10 and 11 the distribution of the many New Kingdom gold production sites in Egypt and NE Sudan shows the very extensive gold production operations carried out during these times. It should be emphasised that in Nubia these activities were restricted only to the rather limited period between the reign of Thutmosis III and Amenophis III. From the government of Amenophis IV onwards, throughout the Ramesside (about 1300–1100 BCE) period, no archaeological evidence for Pharaonic gold mining within the Nubian Desert, south of Wadi Allaqi has been detected. In the Egyptian Eastern Desert, primary New Kingdom gold production started early in the 18th Dynasty and collapsed completely by the end of the Ramesside period; it seems to have been suspended throughout the entire Late Period, until early Ptolemaic times.

Gold Production in Ptolemaic (Greek) Times

It is very likely that in Ptolemaic and also in Roman times essentially no new prospecting strategies were developed and that only the ancient New Kingdom Pharaonic mining sites were reorganized and partly mined out. The mining was again limited by underground shaft termination at a final ventilation depth, approximately 30 m below surface. Only those mines which were located close to the desert roads (Murray, 1925) were further exploited or re-established in Ptolemaic and Roman times (Fig. 17). Based on Agatharchides, reported by Diodor III, 12, gold mining took place in the southern part of Egypt, close to the “border of Ethiopia”. In spite of justified doubts about the authenticity of Agatharchides’ description (Woelk, 1966) it is generally accepted that gold mining took place in the Wadi Allaqi district during Ptolemaic times, although the exact area is not mentioned literally. Recent investigations (Klemm et al., 2001) within the Wadi Allaqi area,

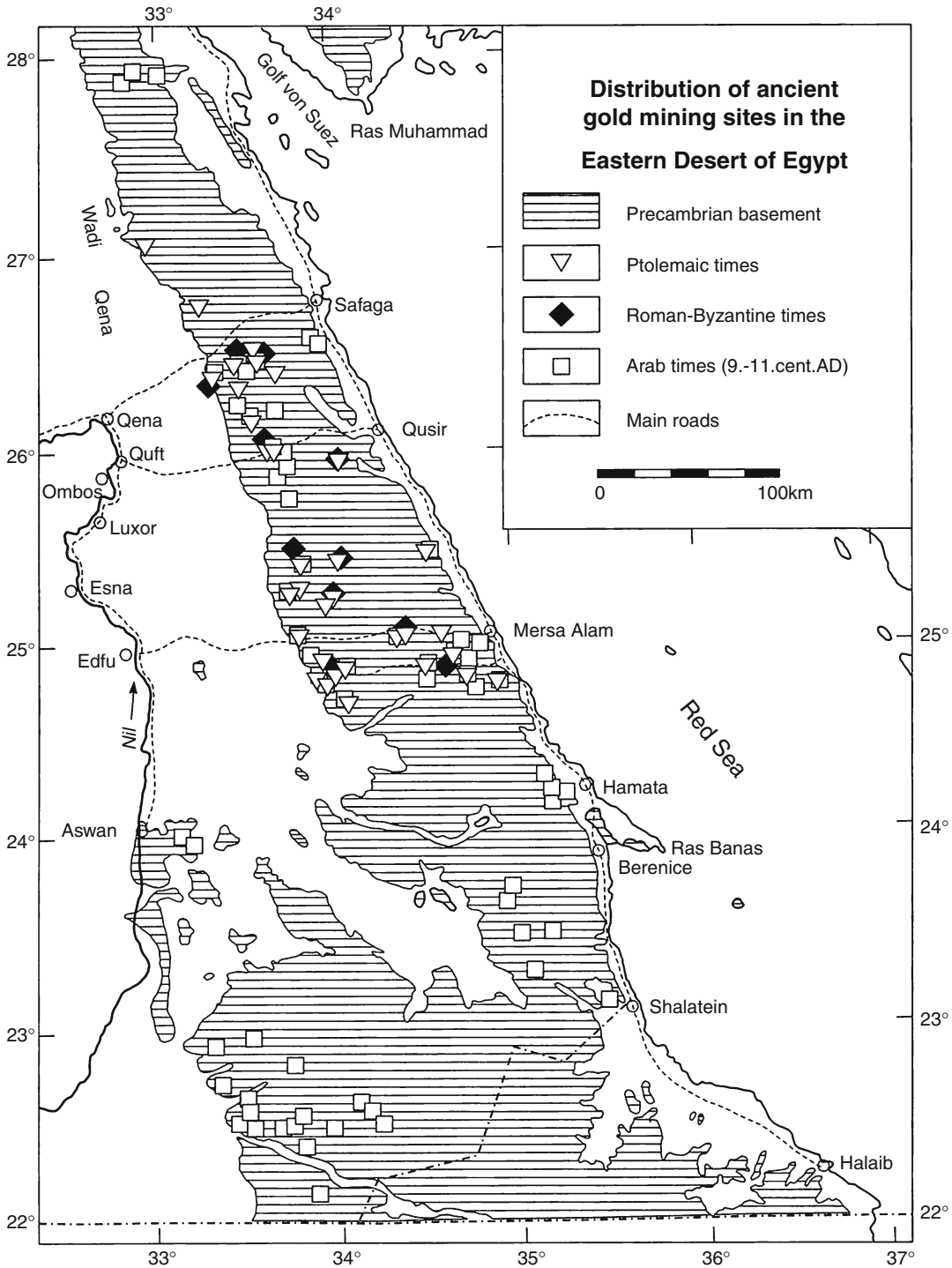
contrasting Castiglioni, Castiglioni and Vercoutter (1995), did not confirm any Ptolemaic mining site, and it is most doubtful whether during that period any gold mining activity was feasible in this area, because of the aggressive desert tribes dominating the entire southern Eastern Desert and reaching deep into what is now Northeast Sudan (Updegraff, 1982).

A dramatic improvement in milling technique and ore processing was introduced by the Ptolemaists. They used concave-shaped millstones of 70–80 cm length and 30–40 cm width, with parallel incised, about 1 mm deep grooves on the milling plane. Semi-circular two-lugged millstones of 5–10 kg weight were moved by hand over the grinding plane, milling the pea-sized crushed quartz into a powder fraction and setting free the fine gold slivers (Fig. 18). With this swinging milling method the whole process was about five times more effective than earlier methods. For crushing, the old anvil and pestle system remained, but with an enlarged size of the crusher stone.

Most probably this new design of a concave-shaped milling stone is not an original Greek invention. It may have been derived from the Minoan island of Crete, where this mill type has been excavated in the Minoan cities of Gournia and Festos. Based on the Greek mining experience, Ptolemaic underground mining in Egyptian gold mines became significantly improved. Thus, in gently dipping gold quartz vein workings, dome-shaped mine ceilings allowed the reduction of supporting pillars to distances of 4–6 m, which increased the minable output.

Another important improvement was the adaptation of circular concentration washing plants from the Laurion mining district in Attica, as described in detail by Conophagos (1980). It became possible to process primary gold-bearing sulphidic ores with pyrite, chalcopyrite, galena, sphalerite and arsenopyrite, hitherto not extractable. Remains of such concentration plants (Fig. 19) are well preserved at Daghabag, Bokari and, in spite of recent destruction, also at Barramiya.

The reasons for the reduced Ptolemaic gold mining activities in only the Central Eastern



Mining in Ancient Egypt and Nubia,
Fig. 17 Distribution of Ptolemaic, Roman-Byzantine
gold production sites in the Eastern Desert of Egypt.
Note that only in the central parts of the Eastern Desert

during Ptolemaic times did gold production activities take place. Note further the sparse Roman-Byzantine sites (After Klemm et al., 2001)

Desert of Egypt are not reported in historical documents, but we know from Roman sources that large parts of the Eastern Desert and Nubia were difficult to subdue because of the

aggressive attitudes of the local nomadic tribes (Sidebotham, 1991), who the Romans called Blemmyes. The Bisharin tribes inhabiting this region today are regarded as their descendants, and still habitually carry dangerous swords and daggers.



Mining in Ancient Egypt and Nubia, Fig. 18 Concave-shaped Ptolemaic gold mill with a two-handled milling stone, together producing a swinging milling technique and thereby increasing the fineness of the quartz ore powder fraction. Gidami gold mining site, Eastern Desert, Egypt

Gold Production During Kushitic Times in Nubia

In Nubia quite a few New Kingdom gold mining sites became reworked later, reusing the older tools, especially the stone mills. At these sites one can observe that the typical, rather flat New Kingdom oval, trough-shaped stone mills bear a distinct deeper secondary concavity, indicating a different and later type of handling of the milling technique.

The most probable age for renewed mining of these sites was during the strong Kushitic Kingdom (about 800–400 BCE). Unfortunately, at these sites only local Nubian ceramics, hard to assign to a distinct period, have been found and more detailed excavations are needed to yield a better chronology. The relatively few sites where this reworked millstone variety, dating to the Kushitic period, was identified, might not have been the only gold source of this time, because washing of gold took place in Nubia at least since Middle Kingdom times.

Mining in Ancient Egypt and Nubia,

Fig. 19 Remains of a circular heavy mineral concentrator from Daghabag gold mine, Eastern Desert, Egypt, introduced during Ptolemaic times into Egyptian gold ore processing, but originally designed in the Laurion district, Attica, Greece



Mining in Ancient Egypt and Nubia,

Fig. 20 Cylindrical stone mills for gold milling (quern) from Hashai, Sudan. A Celtic invention, they were imported by the Romans into Egypt and were still used as gold mills in early Arab times



Gold Production in Roman and Byzantine Times

During Roman and Byzantine times, gold production decreased dramatically because of continuous attacks by the desert tribes of the Blemmyes. The Roman presence in the Eastern Desert was restricted exclusively to well-protected desert roads, with fortifications spaced at about a day's walk. It became economically ineffective to protect the many gold mining sites scattered all over the desert. Only a few highly productive sites close to protected roads remained operable during Roman times. In spite of the highly evolved Roman prospecting experience, the gold mining activities in the Eastern Desert dropped nearly to zero in contrast to other regions of the Roman Empire.

The final improvement in the effectiveness of gold processing was the import of the Roman quern technology (Childe, 1943), originally a Celtic invention (Cauuet, 1991). This type of a round mill, of 30–45 cm in diameter, consists of a basal stone with a disc-shaped hollow in which a round convex upper turning stone was fitted that had a central axial hole and a lateral one for the handle stick (Fig. 20). The quern produced an even finer powder fraction with an improved gold recovery in about a third of the time required by the earlier method. The crushing stones are of characteristic small size (about 15 × 15 cm) and

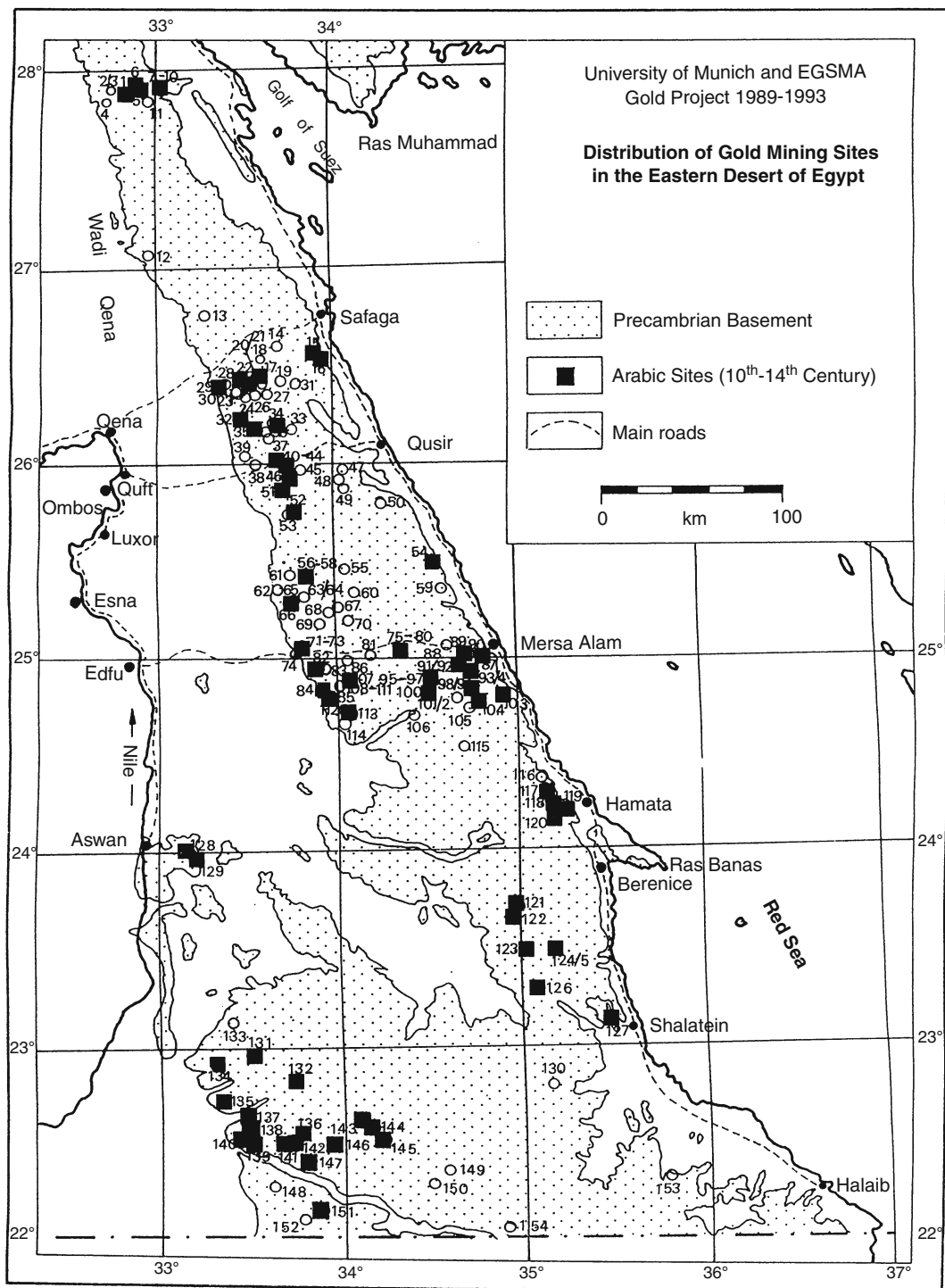
were used as both hammers and anvils. The same tools remained in use until Arab times and querns are still used today within rural areas as flourmills.

For Byzantine times, only very poor archaeological evidence for gold mining exists. Even for the settlement at Bir Umm el-Fawakhir which was inhabited during Byzantine times, and despite the assumption of Meyer and Heidorn (1998), we could find no unequivocal proof for gold ore dressing during an extended survey.

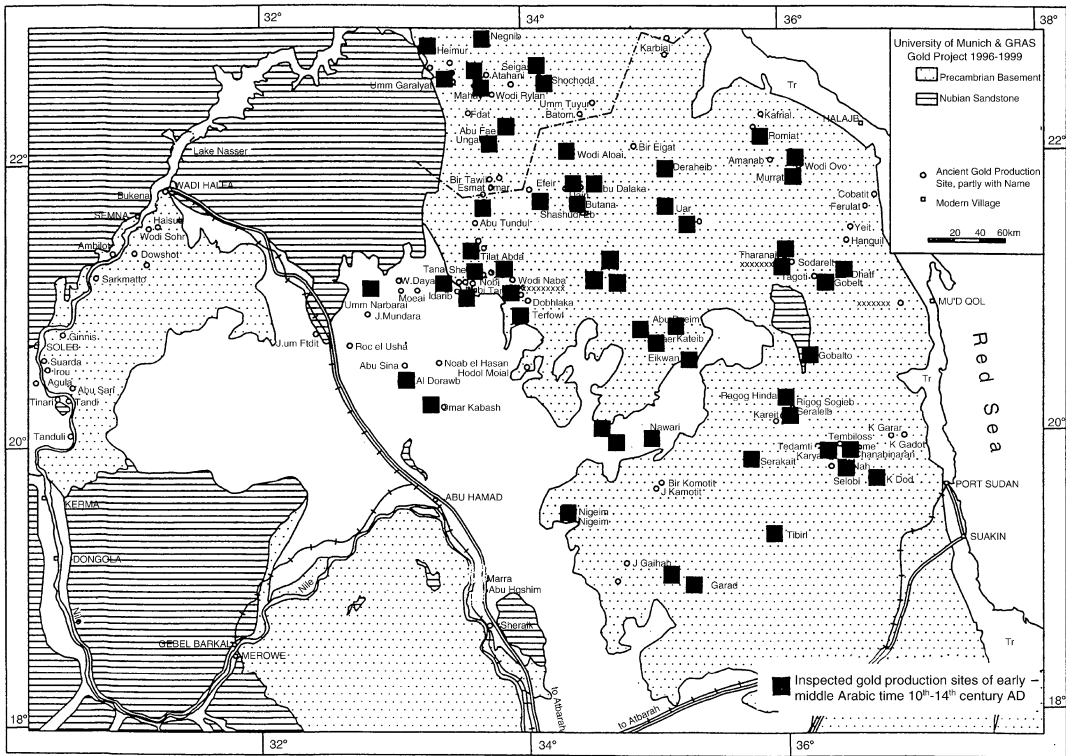
The Bedouin tribes, dominating the entire Eastern Desert of Egypt and the Nubian Desert, traditionally were not interested in mining. This is the same today (Hasan, 1967), as they refuse any digging in the ground, including even simple agriculture in sufficiently watered wadi grounds.

Gold Production in Arab Times

For the early Arab times no field evidence for primary underground gold prospecting has been detected and only existing ancient mining sites became reactivated all over the entire Eastern Desert. In contrast, in Northeast Sudan away from areas close to the River Nile, extensive wadi working operations in secondary gold deposits were started at many new sites. It seems that the mining activities during this period became more concentrated in the southern parts



Mining in Ancient Egypt and Nubia, Fig. 21 Distribution of the gold production sites in the Egyptian Eastern Desert during early Arab times. Note the extension to the very south of the desert region



Mining in Ancient Egypt and Nubia, Fig. 22 Distribution of the gold production sites in the northeastern Sudan (Nubian Desert) during early Arab times. Note that the Arab gold workings never reached the river Nile regions

of the Egyptian Eastern Desert including the Wadi Allaqi and especially in the Northeast Sudan. The abundant wadi works in secondary gold deposits formed part of huge fortified settlements, and inclined washing tables surrounded by tailings can be found. According to Floyer (1893), the peak of the early Arab mining activities took place from the tenth to eleventh centuries AD, beginning under A. Ibn Tulun (about 990 AD) until the Fatimitic time in Egypt (Fig. 21), and until about 1350 AD in Northeast Sudan (Fig. 22). The rich and highly specialized ceramic finds at these sites indicate different ethnic populations.

We do not know why the Arab gold operations became paralyzed around 1350 AD. Most probably, the productive wadi grounds were worked out and the few underground mines reached their lowest ventilation levels. Around this time also

the Christian Kingdoms in Nubia collapsed and their population converted to Islam. Whether this religio-political step has any connection to the cessation of gold production in the Nubian Desert must be left for further investigations.

Nevertheless, it might be taken into consideration that the conversion to Islam opened to the Arabs the possibility of immigration by systematic intermarriage with the local Nubian population. Their concomitant access to the fertile lands around the Nile valley offered a much better livelihood than the increasingly exhausted gold production sites of the unfavourable Nubian Desert.

See Also

► [Fishing in Ancient Egypt](#)

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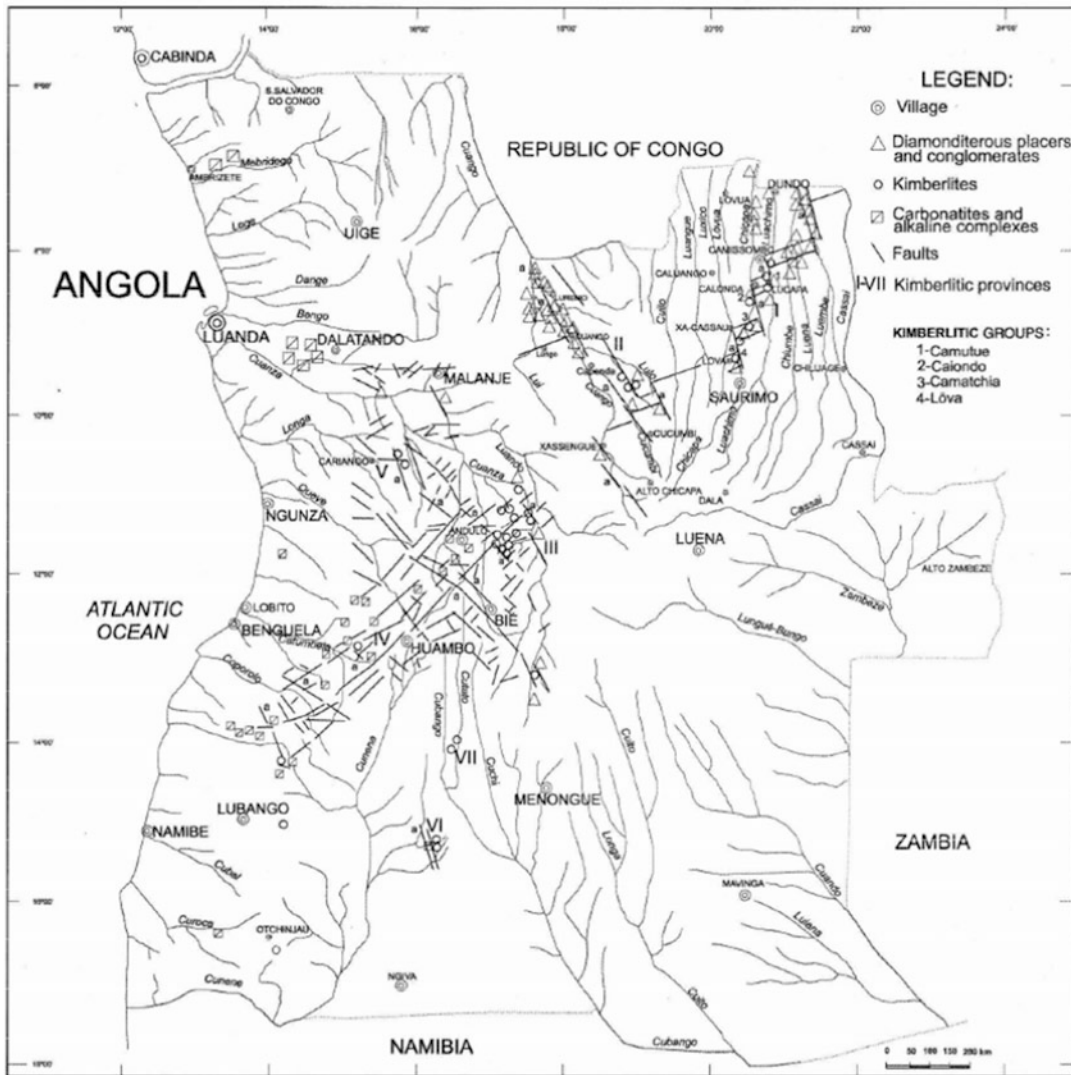
Mining in Angola

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The Extent of Diamond Mining

Angola has vast mineral resources: gold, platinum, nickel, chrome, iron, copper, manganese, kaolin, gypsum, quartz, zinc, phosphates, granite, marble, uranium, lead, wolfram, tin, fluorite, sulfur, feldspar, mica, asphalt, and talc. While rough indications of the location of mineral resources are easily available, only 31 % of the country has been accurately geologically mapped (Ministry of Geology, Mines and Industry, 2010). The mineral industry in Angola today includes metals (copper), industrial minerals (cement, diamonds, and gypsum; granite, marble, and salt), and mineral fuels (petroleum) (Bermúdez-Lugo, 2011; Coakley, 2003).

Commercial oil exploration in Angola only began in the 1950s; the first offshore Cabinda field, Malongo, started to produce in 1968, before independence. Today, Angola is the biggest



Mining in Angola, Fig. 1 Mineral map of Angola (Source: Pereira, Rodrigues, & Bernardo, 2003, p. 200)

deepwater offshore oil producer and exporter in Africa, with the fields located in the Northern provinces. According to the World Bank, oil production represented 46 % of the Angolan GDP and 96 % of its exports in 2012. Diamond production is today the second main mineral industry. It was the major mineral industry of the colonial period, located since the 1920s in the northeastern province of Lunda. By the 1950s, iron had also acquired a noteworthy importance in the provinces of Malanje, Bié, Huambo, and Huíla. In the latter, the Cassinga mine was one of

the most important nationwide. Iron ore production reached an average of 5.7 million tons per year between 1970 and 1974, most of it being shipped to Japan, West Germany, and Britain.

Other minerals have been economically less significant and have not been fully exploited, both in the colonial era and after independence in 1975. Though attempts, especially in the 1980s, were made to revitalize the production of varied minerals, oil and diamonds have the most important economic focus, associated with the political evolutions of the last three decades (Fig. 1).

Two types of diamond digging are found: industrial open pit mines on the volcanic pipes (known as kimberlite) and alluvial mining, of diamonds that are washed out from the pipes. Kimberlite diamond mining is the most profitable type for large-scale mining, and, to date, more than 600 such pipes have been discovered in Angola.

The Colonial Launching

Diamonds were not traded in the region before its colonization by the Portuguese. The early commercial activity of the population in the region with the Portuguese was the trade of guns that the Tchokwe, the Lunda people, made with iron. Precolonial foundries were associated with the political power of the blacksmith Kings.

The district of Lunda was created in 1895 as a result of the establishment of a border separating the Lunda Empire (and the diamond rich region) by the Berlin Conference. Projects for the military occupation of the interior that followed mainly concerned agricultural exploitation but the possibilities were not disregarded of finding minerals such as gold or copper.

According to the records, diamonds had already been found in the Tchikapa river basin in 1906. Diamond exploration, however, only started after the discovery by the *Société Internationale Forestière et Minière du Congo* (Forminière) of seven diamonds in 1912 in the Mussalala River, an eastern margin tributary of the Chiumbe River, not very far from the modern border between Angola and the Democratic Republic of Congo. The Angolan Mining Research Company (PEMA – *Companhia de Pesquisas Mineiras de Angola*) was founded that same year. Diamang, a Portuguese public firm with De Beers capital and with the participation of other European firms, was constituted in 1917 as the viability and economic importance of diamond exploitation was realized. Diamond exploration began in the following year and the first open cast mines were opened in 1919: Cavuco, Camimanga, Cassanguidi, and Luacohe. A vast concession area was demarcated in 1926 (*Zona Única de Prospeção*) giving the company

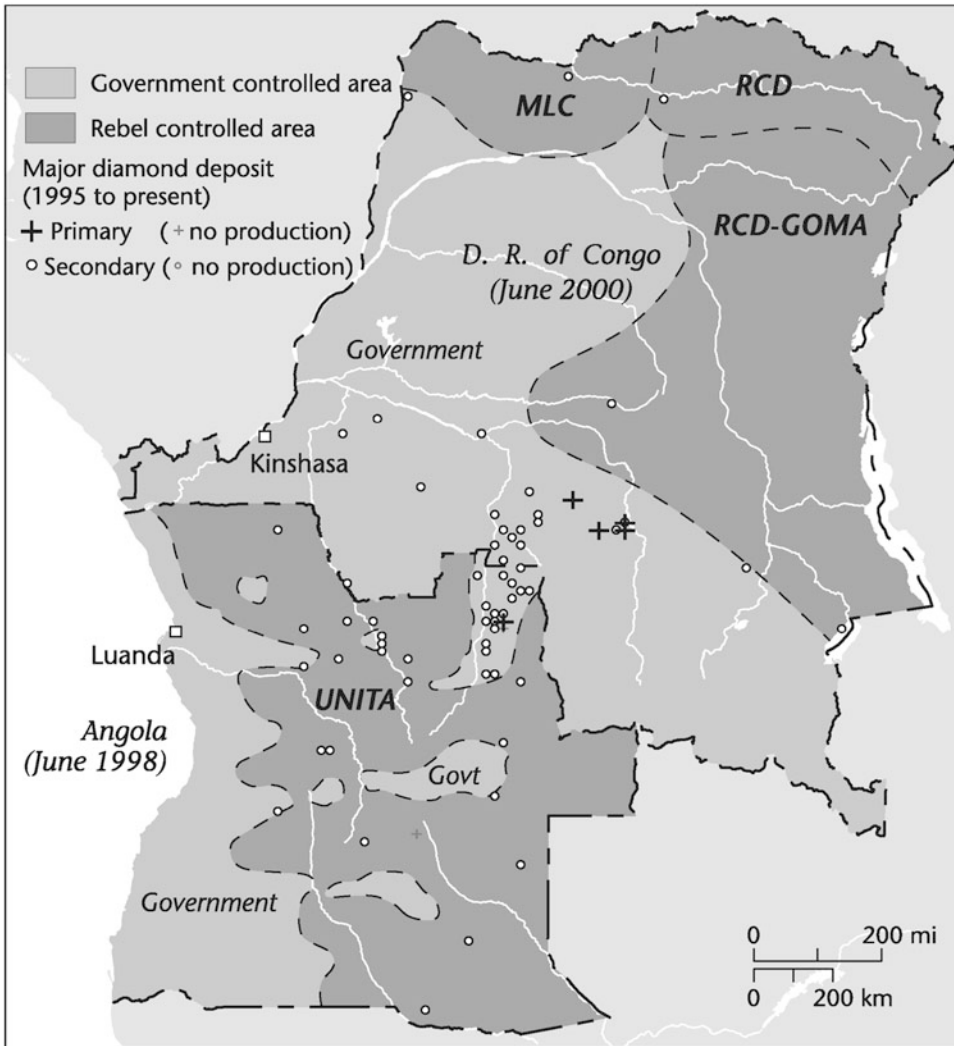
all rights for prospection and production. The first kimberlite, the Camafuca-Camazambo, was discovered as recently as 1952.

During the colonial period, forced labor was responsible for the initial impetus of diamond exploration in Angola. This type of working scheme was then transformed into contract work as international pressure and nationalist movements became more active, but hard work and poor conditions continued for the workers in the Diamang encampments. However, in the main cities and other concession areas of the Diamang, this work represented an opportunity to many because of the salaries it provided (Cleveland, 2008a, 2008b, 2009). Diamang organized not only the technical aspects of the production of diamonds but also labor and settlement in the region, which led to particular features of urbanization in the region (Udelsmann Rodrigues & Tavares, 2012). Several cities and villages, all designed and organized by the company, absorbed masses of migrants working for the firm, both expatriates and locals. In 1971, diamond production reached its colonial record of 2.4 million carats.

The Wartime Scramble

At independence, Diamang was replaced by Endiama (*Empresa Nacional de Diamantes de Angola, E.P.*), a public capital company instituted in 1981 by a committee of the National Defense and Security Council to work as a concessionary of the mining rights in the diamond area. The civil war that followed independence deeply affected formal industrial mining, particularly in the 1990s, forcing almost all firms to suspend their activity in face of the militarization of the diamond business. The resource-related war involved both oil and diamonds but had more impact in the mining fields. The linkages between war and resources placed oil and diamonds in the center of the conflict that lasted for three decades (Cilliers, 2001; Le Billon, Jedrzej, & Wood, 2001; Fig. 2).

Garimpo (illegal artisanal mining) was a scattered activity during the colonial period because of Diamang's surveillance. During the



Mining in Angola, Fig. 2 Diamond locations and government control (Source: Le Billon, 2008, p. 360)

civil war, artisanal mining gradually involved more people in direct (digging, buying) and indirect (trade, services, transportation) activities. It became the UNITA guerrillas' income source (Dietrich, 2000b, 2000c; Malaquias, 2001a, 2001b, 2007; Sherman, 2000). Moreover, employment opportunities were scarce both in Angola where the war was playing out and in the neighboring Democratic Republic of Congo. This attracted an important number of *garimpeiros* to the Lundas, transforming artisanal mining into a cross-border enterprise (De Boek, 1998, 1999, 2001; Dietrich, 2000d).

The main areas of agglomeration of artisanal mining were located in the Lunda Norte, particularly in the vast Cuango River area. The complex organization of the network of diggers and traders had important international extensions, as well as complex schemes of profit distribution among all those involved, that still subsist in part.

In 1998, the United Nations' sanctions against UNITA for its "blood diamonds" or conflict diamonds and the Kimberley Process that followed them contributed to increased control mechanisms regarding the extraction, certification, and export of diamonds, but only after the end of the

Mining in Angola,
Fig. 3 Artisanal mining in
 Lunda Sul, 2011



war in 2002. The Kimberley Process Certificate Scheme (KPCS) is a late 2002 industry-wide effort to prevent commerce in rough diamonds by insurgent groups.

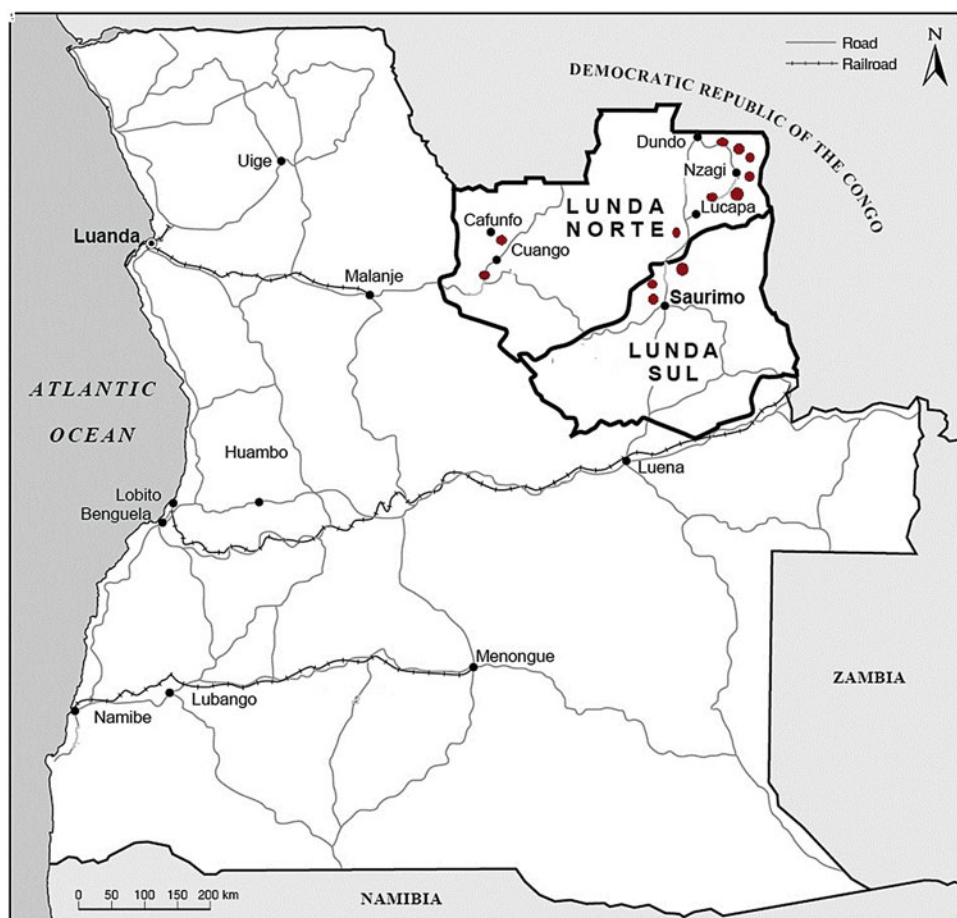
The Postwar Primacy of Industrial Mining

The legacies of war made diamond mining today highly surveyed and politically sensitive and imprinted specific perceptions about diamonds locally (Pearce, 2004). The current system, built from the Kimberley process, is based on two certification mechanisms controlled by SODIAM (*Sociedade de Comercialização de Diamantes*) that is the Endiama subsidiary responsible for marketing Angolan diamonds and ASCORP (Angola Selling Corporation), which is responsible for issuing licenses to sub-buyers.

The number of immigrants that came to the region since the boom of wartime *garimpo* is impossible to count. However, reports of the evictions of illegal migrants point to over a 100,000 successively repatriated since 2004, when 28,000 illegal persons were repatriated from Kwanza Sul, Malange, Lunda Norte, and Lunda Sul provinces, most coming from DRC

and West Africa (OCHA, 2004). Angolan efforts to expel illegal and foreign *garimpeiros* began with Operation Brilhante in 2004 and have continued at a similar pace every year since. The latest was Operation Crisis that began in May 2009, expelling about 18,000 illegal *garimpeiros* in 37 days from Lunda Norte alone (OCHA; Smillie, 2009). The government has been criticized for transgressing the immigrants' human rights and suspicions have arisen that *garimpo* have moved to hidden locations (Udelsmann Rodrigues & Tavares, 2012). According to SODIAM, official exports from the artisanal sector are significant and smuggled production is still a major concern. Despite the expulsion of many illegal miners, it is estimated that there are still approximately 200,000 active in Angola (Fig. 3).

Garimpo has persisted through colonial times, the civil war systems and the current government control, supported by the large-scale mines. The estimated diamond output of the *garimpo* sector today is still high, at 30 % of the Angolan diamond production by value each year (Smillie, 2009). The mining law already regulated artisanal mining but, since 2011, detailed regulations have been published, particularly regarding artisanal mining (Lei 31/11).



Mining in Angola, Fig. 4 Location of postwar industrial mining (Source: author)

Both formal and informal mining are traditionally more intensive in Lunda Norte but recently both types of mining started to expand to Lunda Sul and even to other provinces such as Bié as the “ribbon” of diamonds extends up to the Congo in the Coluezi area.

As industrial mining recovered after the war, more control over artisanal mining was established. In 2003, formal diamond mining in the Lundas accounted for 80 % of the provincial GDP and 50 % of the country’s total GDP, while it created 6,120 jobs in the region (Golder Associates, 2006). In 2008, industrial-scale diamond operations accounted for about 92 % of the country’s total diamond production by volume and for about 82 % of total diamond production by value (Soto-Viruet, 2010). In 2011, Angola’s

economy grew by 3.4 %, with increases driven by industries other than oil. Diamonds accounted for about 1.8 % of exports in that year, representing 6.7 % of world diamond production by volume and about 8 % of world diamond production by value (Bermúdez-Lugo, 2011).

Formal mining firms today are still concentrated in the Lunda Norte but expansion to the Lunda Sul – where in fact the biggest mine, Catoca, is located – and to other provinces is underway.

Catoca is the fourth largest diamond mine in world, a 66 ha kimberlite pipe. It was discovered in 1985 but the civil war in Angola hampered its early development which only fully began in 1997. By 2000, Catoca produced two million carats per year, and in 2007, it increased to 6.7

million carats. In 2009, it represented 78 % of the total industrial production in the country at over nine million carats (Catoca Annual Report, 2009), and in 2011, 7.8 million (Catoca Annual Report, 2011). Today, the company employs over 2,000 workers and has expanded the village associated with the mine. The Camafuca pipe of 160 ha was the first kimberlite discovered in Angola in 1947. It is one of the world's largest kimberlites but mining there started only in 2007, also as a consequence of the civil war. The Camatchia-Camagico mine in Luó is situated on two adjacent kimberlite pipes upon a total surface area of 28 ha. Mining also started recently, in 2007 (Read & Janse, 2009; Fig. 4).

Mining has direct effects in Angola, both economic and social. National diamond mining policy foresees returning 10 % of diamond taxes to the Lundas, contributing to the local development budget. Recent reports show, however, that this policy appears to have had a little effect (Gordon, 2005), despite the major companies frequently publicizing their results in this area. For instance, both Catoca and Sociedade de Desenvolvimento Mineiro (SDM) deliver dividends to shareholders and have projects in the areas of health, education, agriculture, and electricity and water, beyond the tax contribution. The inherited perception from the colonial times that companies should be responsible for the welfare of the population is still significant today while, at the same time, concerns regarding the type of government and the possibilities for corporate social responsibility remain central to the discussions about Angolan development (Wiig & Kolstad, 2012). The foundation Brilhante, managed by the national ENDIAMA, that congregates Angolan mining firms and has been operating since 2004 in the area of social responsibility, is an example of such state-led programs.

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Mining in Botswana

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Introduction

Botswana has maintained one of the world's highest economic growth rates since it attained political independence in 1966. It has transformed itself from being one of the poorest countries in the world to a middle-income country, with a per capita GDP of \$16,800 World Bank (2010).

The Economy

The leading drivers to this impressive economic growth are mining, commerce, and government services.

History of the Mining Sector

Botswana's mining history has been episodic. Table 1 shows the dates and locations of where the main minerals were discovered. Figure 1 shows the location of these mines.

Predating the discovery of diamonds, modern mining towns in Botswana began over a century ago when gold was discovered in Francistown. During the 1950s and early 1960s, mining activities entailed gold, manganese, and asbestos production. However, the scale of operations was small relative to the present. The discovery of diamonds by De Beers at Orapa in 1967 marked a turning point. The diamond fields, extending over 112 ha, proved to be one of the largest known diamond-bearing kimberlite (a type of igneous rock that sometimes contains diamonds) pipes in the world. Further exploration led to the discovery of smaller diamond pipes at Letlhakane mine, situated about 30 km southeast of Orapa.

Production at Orapa, under the Debswana Diamond Company, began in 1977. In 1975, other kimberlite pipes of larger size and superior quality were discovered at Jwaneng, 125 km west of Gaborone, that began production in 1982. The youngest diamond mine is the Damtshaa mine which became operational in December 2002.

Open cast copper mining started in 1974 at Selibe Phikwe but has now switched to pit mining

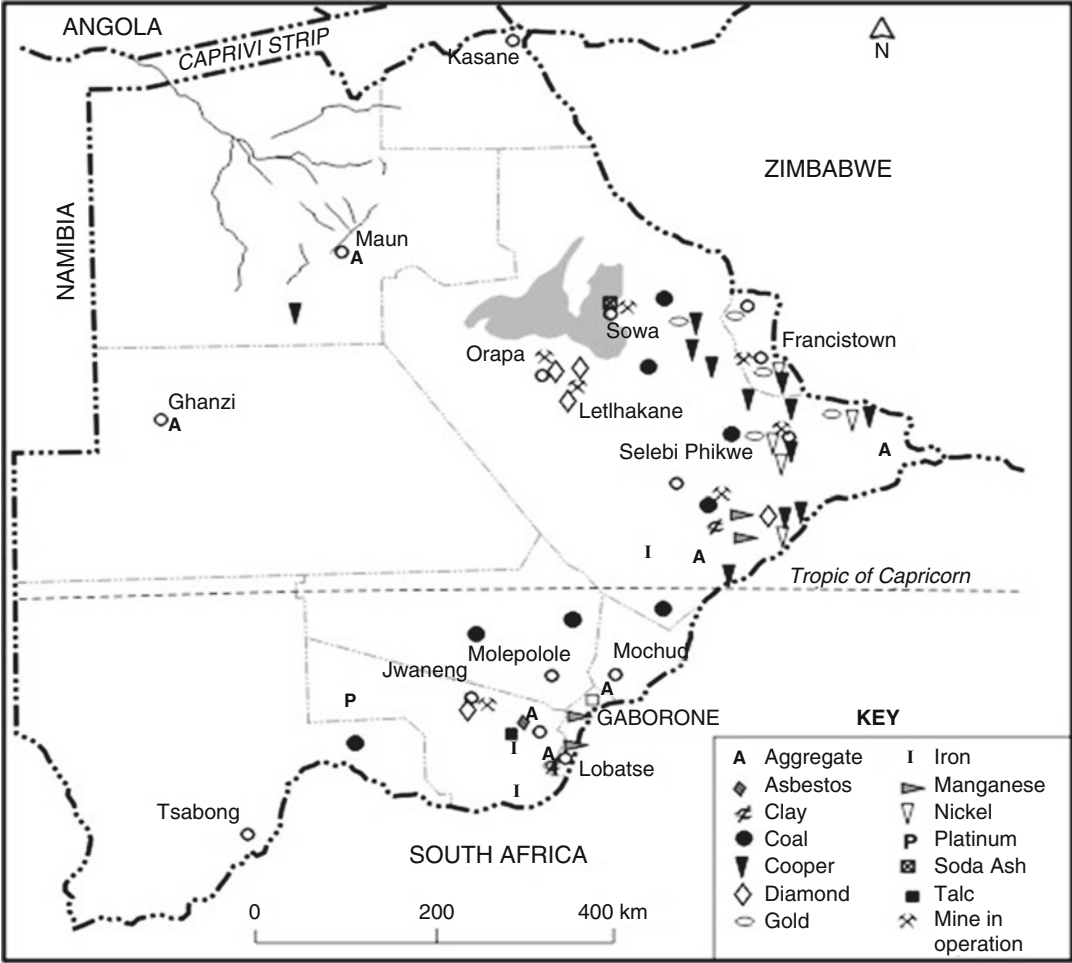
at deeper levels. The hitch has been that the prices of copper nickel have fluctuated a great deal since the 1970s causing the mine to operate at a loss. This was exacerbated by labor unrest that culminated in a major strike in 1975. Other problems plaguing Selibe Phikwe mine included its relatively remote location, high transport costs, its distance from the seat of government in Gaborone, and lack of financial and commercial-industrial services (Silitshena & McLeod, 1998). Selibe Phikwe was in danger of becoming a ghost town due to the unprofitable operation of the mine and the company's accumulation of financial debt. The government intervened to ensure that the mine remained open. Since 1988, it developed an industrial site to encourage businesses to set up light manufacturing industries and established the Selibe Phikwe Regional Development Programme (SPRDP), in order to promote non-mining economic activities in the town and surrounding areas. The program is, however, facing a number of economic and implementation problems Botswana Govt (2012).

Known coal reserves in Botswana have been estimated at 202 billion tonnes. The main coal mine is at Morupule near Palapye. It was built to provide coal for the power plant at Selibe Phikwe's copper nickel mine. Coal mining takes place underground through highly mechanized processes. Current developments at Mmamabula, by Jindal Steel and Power Limited, are in response to the increasing demand for coal for energy, the diversification of the national export portfolio, and the extraction of by-products such as gas, tar, and explosives. Production of soda ash and salt started in 1991 near Sowa Pan. The soda

Mining in Botswana, Table 1 Discovery dates and location of mines

Name of mining town	Location by district	Mineral	Year discovered	Population
Francistown	Northeast	Gold	1866	100,079
Orapa	Central	Diamond	1967	9,544
Letlhakane	Central	Diamond	1975	20,841
Selibe Phikwe	Central	Copper nickel	1966	49,742
Jwaneng	Southern	Diamond	1975	18,063
Sowa	Central	Soda ash	1991	3,599
Morupule (Palapye)	Central	Coal	1973	36,211

Source: Department of Mines; Central Statistics Office 2011



Mining in Botswana, Fig. 1 Geographical distribution of the mines

ash and salt occur as brine under the pan surface. The extracted liquid is pumped into evaporation ponds to crystallize before harvesting.

Botswana has a limited small-scale mining industry and needs to introduce structures to support the sector (Matshediso, 2005). The Mineral Policy does not address issues relevant to the small-scale mining sector. Botswana have frequently criticized government for not facilitating their entry into the multibillion Pula (P2.85 = \$1.0) mining industry. Citizen entrepreneurial participation has been limited to holding prospecting licenses and earning limited equity in mining projects through joint venture arrangements.

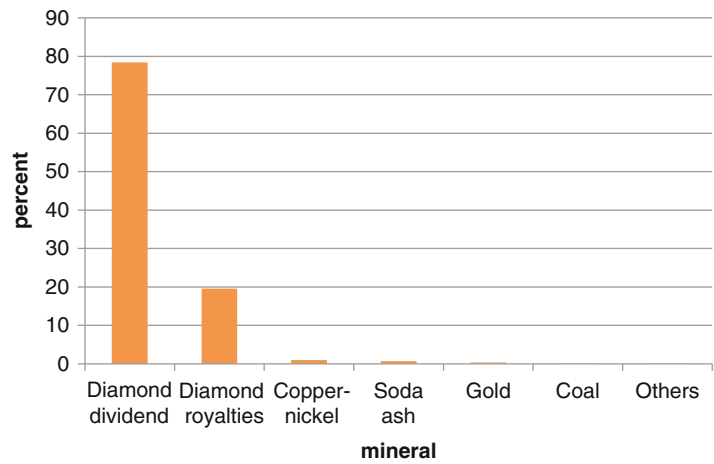
Contribution of the Mineral Sector to National Income

Mineral revenue has been the main contributor to the national GDP and government revenue. The graph below shows that diamonds have contributed the most to the non-tax mineral revenues. A major international diamond company signed a 10-year deal with Botswana in 2012 to move its rough stone sorting and trading division from London to Gaborone by the end of 2013. The move will support Botswana’s downstream diamond industry (Fig. 2).

From the graph below, on exports by principal commodity, it is evident that diamond

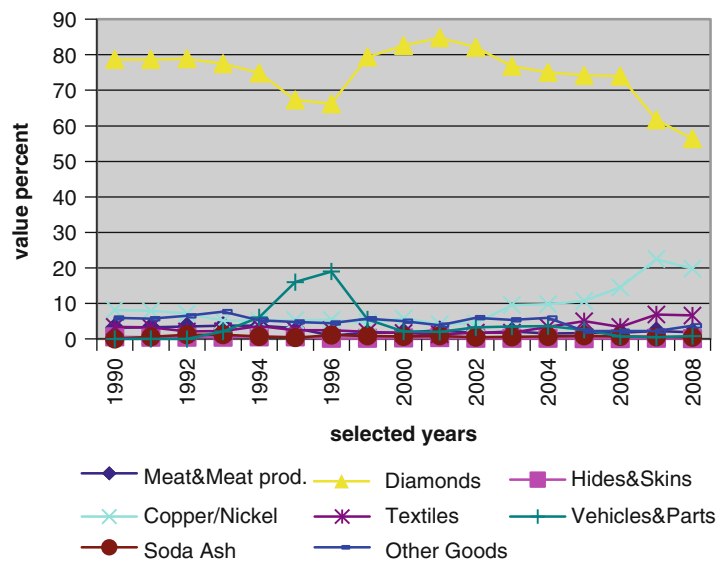
Mining in Botswana,

Fig. 2 Composition of non-tax mineral revenues (2008/09) (Source: Republic of Botswana, National Development Plan 10, 2009)



Mining in Botswana,

Fig. 3 Exports by principal commodity percentage of total value (Source: Central Statistics Office, 2010)



mining has fueled much of the expansion and currently accounts for more than one-third of GDP, 70–80 % of export earnings, and about half of the government’s revenues. A report by the IMF into the long-term sustainability of Botswana’s reliance on diamond mining for its fiscal stability pointed out that, at present rates of mining, the country’s diamond resource could run out by 2029 (Basdevant, 2008). This sets serious long-term challenges that the government is now confronting by continuing prospecting for minerals and establishing new mines (Fig. 3).

The Role of Mining in National Development

The impact of mining on the economy includes net foreign exchange inflows, provision of technical skills, and absorption of domestic resources. The construction of dual-purpose infrastructure such as communications, power, and health facilities has stimulated growth in other sectors of the economy as well as facilitating the movement of goods and services and the population and the diffusion of innovations to other nearby places. Successive surveys of income poverty show that

the percentage of households and individuals with incomes below the poverty datum line has continued to fall (NDP10: 40). In addition, access to public services, notably education, health services, and clean water rose (NDP10: 40). It has maintained a variety of safety nets to cater for the vulnerable groups encompassing the elderly, youth, rural women, and HIV/AIDS victims and orphans Gwebu (2012).

Because of the volatility of the mining sector, the government has embarked on economic diversification efforts that involve manufacturing. Challenges include:

- Passive political commitment, especially with regard to supporting innovation, research, and development
- Slow rate of response toward addressing factors that inhibit private sector growth and competitiveness including utility costs, cost of capital, business registration and licensing, delays in processing work and residence permits, and access to land
- The proliferation of fragmented, uncoordinated policies and strategies, which have seriously undermined implementation and monitoring and accountability in the case of institutions (Sekwati, 2010)

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Mining in Brazil

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Brazil, throughout the five centuries of its history, has always been seen as a supplier of mineral resources of all kinds, whether in popular imagination or in the official and unofficial discourses. The well-known Brazilian historian Sérgio Buarque de Holanda summarized in a clear, even poetic form this view of a country seated on treasures of all sorts, when comparing Brazil and other Latin American countries:

We will also have our *El-Dorados*. Those of mining, for sure, but also those of sugar, of tobacco, of coffee, so many agricultural items pulled out from the fertile soil, as gold is extracted from gravel till it runs out, with no payback of benefits. The procession of miracles will therefore continue throughout the whole colonial period, and it will not be interrupted by the Independence, not even the Republic. (de Holanda, 1969, p. 323)

Among these riches, some always remained the focal point of explorers, as shown, for example, by a survey of all the decrees that authorized the exploration of minerals during the Brazilian Empire, approximately from 1830 to 1885 (Ferreira, 1885). In this period, 37 % of the permits were for gold, silver, and other precious metals, 25 % for mineral fuels (coal, peat, lignite, oil shale and oil), and 10.5 % for iron – i.e., more than two-thirds of permits included only five types of resources. Currently, 80 % of exports correspond to iron ore, and the value of the Brazilian mineral production ranges roughly between 4 % and 10 % of GDP, whether or not

we include oil and gas. The main pillar of the Brazilian economy is agribusiness, confirming a general trend of historical subordination of mining to agriculture, manifest even in organizational terms: a specific ministry for mining matters emerged only in 1960, and until then questions related to the mining industry have always been linked to the Ministry of Agriculture (whatever its multiple and variable names). However, Brazil still ranks among the top 10 countries producing mineral goods, and an obsession with finding riches guided the actions of the Portuguese metropolis since the mid-sixteenth century, with the aim of replicating the success of the Spanish Empire in the Americas.

Mining in Brazil, especially during colonial times, still calls for further studies, although much has been done in the last 25 years. The study of methods and techniques in particular is still little explored, despite its relevance: the sources are scarce, and when one focuses on the sixteenth and seventeenth centuries, the use of several different approaches in addition to the use of manuscript sources is required (Figueirôa, Picanço, & Mesquita, 2012). Among the written sources, some fundamental documents include such texts as the anonymous *Informação sobre as Minas do Brasil* (*Information on Mines in Brazil*), probably written before 1660, which describes in detail the mining of alluvial deposits of Paranaguá (Paraná state). In his book *Cultura e Opulência do Brasil por suas Drogas e Minas* (*Culture and Wealth of Brazil from its Medicines and Mines*) (1711), the priest known as Antonil (*né* João Antonio Andreoni) described the mining methods commonly used in the early development of the ore deposits of Minas Gerais, with woodcuts illustrating the exploitation of alluvia. A somewhat later chronicler, Pedro Taques de Almeida Paes Leme (1714–1777), described methods of auriferous mining, especially in the Province of São Paulo. Also, the two volumes of *Pluto Brasiliensis*, by Wilhelm Ludwig von Eschwege (1777–1855), published in Berlin in 1834, described the occurrences of gold mines, as well as the methods of “plowing” alluvia and auriferous hill slopes of Minas Gerais. Eschwege’s book

was a comprehensive volume and is still relevant and influential in studies of mining in colonial Brazil.

Another important source of information, still waiting to be fully explored, is the iconographic one, such as the woodcuts that show the tools, methods, and techniques of mining, or old maps. The impressive woodcuts of *De re metallica*, by Georgius Agricola, though illustrating European mining, are also important for understanding early European mining in colonial America. Some maps from the seventeenth century, such as the *Planta da Baía de Paranaguá* (*Map of Paranaguá Bay*) (1653), already show the localities of the gold mines (Picanço, 2009). Other important sources are nineteenth-century lithographs, such as the works by the German painter Johann Moritz Rugendas (1802–1858). His engravings, published in his *Malerisches Reise in Brasilien* (1835), are revealing reports of the decline of Brazilian mining at that time.

The first Portuguese to establish initiatives for the mining exploitation of Brazil was Martim Afonso de Sousa, a remarkable nobleman. He founded São Vicente (on the São Paulo coastline) in the year of 1531, the first settlement established by the Portuguese crown in its portion of America. He also tried to find gold, silver, or precious gemstones prior to his return to Lisbon (Guimarães, 1981). His plan was to confirm some news brought by four men of his cortege about the existence of abundant gold and silver mines in the Rio Paraguay region. Under his guidance three expeditions were made, all in 1531, to the hinterland along the coast of Rio de Janeiro, to the south of São Paulo state, and to explore the Rio da Prata, farther south.

In the site of Santo Amaro, on the bank of a tributary of Rio Pinheiros, today within the city of São Paulo, some metallurgical developments took place in 1552. The origin of this was the presence of small iron ore deposits containing hematite (Fe_2O_3) and limonite ($\text{Fe}(\text{OH})_3 \cdot n\text{H}_2\text{O}$), which, despite their small dimensions, were considered, in content, to be comparable to some existing in Europe. It is reported that Bartolomeu Fernandes, a blacksmith who arrived with the expedition of Martim Afonso de Sousa, was the

one who pioneered the metallurgy of these ores. Some years later, Afonso Sardinha and his son developed the iron ore mine of Morro Araçoiaba, in the outskirts of Sorocaba, in São Paulo state. By 1591 they had built the first steel plant in the country, having two kilns and capable of producing up to 100 kg of iron daily. Thus, during the whole of the sixteenth century, Portuguese settlers used funds, labor, soldiers – and craftsmen of all kinds (cutters, miners, builders, and even foreign engineers – German, Flemish, Dutch, French, and Florentine) in expeditions and investigations, under the supervision of the governors (Machado & Figueirôa, 2001).

Unfortunately, the outcome did not meet the efforts and expenditures. Even the most positive results lacked economic significance, both in quantity and in quality of metals. The deposits were rather poor and located in remote places. Conceding that the outcome of this century had been so disappointing, the governor General Diogo de Meneses Sequeira wrote a letter to the King stating that “your Highness should believe that the actual mines of Brazil are composed by sugar and redwood [“pau-brasil”], very much profitable, and for both the Treasury of your Highness did not spend one single cent.” Despite this, efforts continued to be made. The major economic outcome of this epoch was gold extraction in the Paranaguá region. It is estimated that between 1680 and 1697 the annual production was 50–80 kg, decreasing to 20–30 kg from 1697 to 1735, when the local foundry house ended its operations.

At the dawn of the most important mining period of Brazilian gold, expeditions from every corner in the country (São Paulo, Bahia, Pernambuco) and even from Europe took the route towards the hinterland of Minas Gerais. News of the discovery of gold in the Minas Gerais Province around 1693–1695 launched a rush to this locality. Engineer Eusébio de Oliveira states that in the period between 1700 and 1801 an amount of 715 t of gold was extracted in the province of Minas Gerais. Also diamonds were found and exploited with profit: the so-called “Brazilian Diamond Era” stretches from 1730 until 1870, when South Africa took the lead. But almost

unanimously, authors of that period emphasize the need for the modernization of the techniques employed in mineral extraction, the improvement in the training of miners, and also, the need to hire a manager who would instruct them and supervise the work (Figueirôa, 1997).

In resonance with the enlightened spirit of the time, they would appeal to science to redress the situation. At a practical level, one of the measures taken to improve the instruction of miners was the printing of two manuals on mining. Another measure, of great depth and impact, was sending three graduates from Coimbra University, from 1790 onwards, to visit the main scientific and mining centers of Europe “to acquire by means of literate journeys and philosophical explorations, the most perfect knowledge of mineralogy and further parts of Natural Philosophy.” The three students were Joaquim Pedro Fragoso de Sequeira, from Portugal, and José Bonifácio de Andrada e Silva (1763–1838) and Manuel Ferreira da Câmara de Bittencourt e Sá (1762–1835), both from Brazil, attesting the importance of Brazilian mineral deposits, despite all decadence, in the overall economy of the kingdom (Figueirôa, 1997; Varella, 2006). They traveled to Paris, Freiberg, and Germany in general, Hungary, Bohemia, the Alps, Veneto, and Scandinavia. Having returned to Lisbon about 10 years later, both Andrada and Câmara were immediately absorbed by the administrative structure of the kingdom, Andrada in the metropolis and Câmara in the Diamond District (Minas Gerais). Câmara suggested ca. 1800, *inter alia*, the creation of mineralogical and metallurgical schools and specifically “the establishment of mineralogical and metallurgical schools similar to those of Freiberg and Chemnitz, which have brought to those countries highly praised advantages” should be promoted (cited in de Mendonça, 1958, pp. 119–120). But these proposals were not implemented: despite its economic and political importance in the eighteenth century, mining in colonial Brazil did not generate specific institutions, nor did it encourage the emergence of mining schools to meet the demands of productivity, as had happened, for instance, in New Spain (Mexico) (Figueirôa, 1997).

The first mining school in Brazil was to be founded only in 1876, namely, the Ouro Preto School of Mines, in Minas Gerais.

The Portuguese Court transfer to Brazil in 1808 gave continuity to initiatives linked to mining affairs. The concerns of the powerful minister Dom Rodrigo de Sousa Coutinho, Count of Linhares, were manifested as early as May 1808, through official inducements to iron metallurgy—a clear effort to catch up with the first Industrial Revolution. But after Independence (1822), in the period between 1824 and 1889, essentially only British capital was invested in mining activities, mostly in Minas Gerais, and it represented a little over 4 % of the total investment in the country (Libby, 1991). Ministers complained mostly of the legal apparatus, which was blamed for being an intricate, old-fashioned obstacle for the development of the mining industry, as well as the precariousness of the means of communication, the technically unqualified labor force, and the lack of capital (Machado & Figueirôa, op. cit.). The Republic (1889) promoted a revision of the legislation besides the foundation of the Brazilian Geological and Mineralogical Survey (SGMB), in 1907. Iron metallurgy was of paramount importance among the Survey's goals, and both iron and manganese ores were targeted (Figueirôa, 2007).

Also worth mentioning are the actions related to petroleum and other fossil fuels that started already in the second quarter of the nineteenth century. Until 1938, when the National Petroleum Council (CNP) was founded, the initiatives were conducted either by private people/capital or by state agencies, like the SGMB or the Geographical and Geological Commission of São Paulo (CCG-SP). The discoveries, disputes, controversies, and public policies related to the history of petroleum exploitation in Brazil (see Peyerl, 2014) constitute a long story that culminated in the founding of Petrobras, in 1954, which will not be presented here.

Approaching the recent past, one should mention the relevant mineral exploration of the mantles of weathered rocks that took several decades to be confirmed and culminated in the 1980s with the discovery of a mega deposit of iron ore in

Carajás (Amazonia). At the end of the 1920s, the mining engineer Djalma Guimarães (1894–1973) published two studies discussing the exogenous genesis of manganese ore in Brazil, (Guimarães, 1929) still during his period as a staff member of the SGMB. But it was in the 1940s and 1950s that the panorama started to change, thanks to the engagement of Brazilian geoscientists in the war effort, and subsequently in the postwar and Cold War eras that followed. The new geochemical frontier was the search for hi-tech metals and this had a direct impact on geological research and laboratories of analytical chemistry (Dutra, 2002). By that time, Guimarães initiated a period of fruitful research on petrology and mineral prospecting – the latter having been finally based on the understanding of the genesis of deposits so as to better guide the exploration. The success of these works would be confirmed with the discovery and evaluation of the deposit of apatite $[\text{Ca}_5(\text{PO}_4)_3(\text{F},\text{OH},\text{Cl})]$ and pyrochlore $[(\text{Ca},\text{Na})_2(\text{Nb}, \text{Ti},\text{Ta})_2\text{O}_6(\text{OH},\text{F},\text{O})]$ in Araxá (Minas Gerais). Today Brazil leads the world market in supplying niobium (pyrochlore), coming from Araxá, Catalão (Goiás), and São Gabriel da Cachoeira (Amazonas), with a market share of approximately 90 % of the world production of Nb_2O_5 , besides having significant reserves and lateritic deposits of other important metals such as iron, manganese, nickel, aluminum, and phosphates, not to mention clays for different purposes (Brasil, 2012).

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Mining in the Congo

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On July 6, 2013, a public relations representative for Banro Corporation – a Canadian gold mining company whose current projects, as of 2014, lie along the Twangiza-Namoya gold belt in the South Kivu and Maniema provinces of the Democratic Republic of the Congo – met and

discussed relations between the firm and local elders of Luwinda, a city 59 km north of Bukavu. Like many mining companies in the Congo, Banro Corporation gained gold concession in the DRC when Laurent Kabila, a rebel fighting to overthrow the Mobutu government, marched toward Kinshasa in 1996–1997, spurring the First Congo War. When Mobutu fled to Morocco on May 17, 2007, Laurent Kabila became the third president of the DRC and promptly decided to renegotiate all contracts signed while a rebel leader. As a result, Banro Corp. lost their contract and took the government of the Congo to court in New York. Banro Corp. won the suit and, through negotiation with the new government of the Congo under Laurent Kabila’s son, Joseph Kabila, after his assassination in 2001, secured a 25-year contract for the extraction of gold in Mwangaza, Kamituga, and Maboya in South Kivu and Maniema, areas spanning 3,632 km². (BANRO CONGO, Mining S.A.R.L. internal documents).

The Democratic Republic of the Congo, formerly Zaire, has been called a “geological scandal” as it houses perhaps the richest concentration of precious metals and minerals in its soil, yet holds one of the lowest rungs on the world economic ladder. As Michael Wrong accurately states:

The mineral belt that fans out from Katanga’s dry savannah into neighbouring Zambia contains copper and zinc in concentrations rival nations can only dream about and enough cobalt to corner the global market. Nearly 500 miles North-West lies another gift of nature: the dark red gravel banks that trace the winding course of the Kanshi River, second biggest source of industrial diamonds in the world. There are other gifts: diamonds at Tshikapa in the South-West and Kisangani in the North, what was for a time the world’s main source of uranium at Shinkolobwe, and across from the border with Uganda comes the enticing glitter of gold, cadmium and cassiterite, manganese and wolframite, beryl, columbo-tantalite and germanium: metals with mysterious, evocative names. No wonder a US ambassador once memorably referred to ‘the Congo caviar’ in a cable back to headquarters. (Wrong, 2000, p. 108)

The Democratic Republic of the Congo abounds in mineral resources, giving it the

potential to be one of the richest countries on the planet. Instead, the DRC has one of the lowest GDPs per capita in the world. In 2009, African Business Magazine estimated the total untapped mineral wealth of the DRC to be US\$24 trillion, a number equivalent to the gross domestic product of Europe and the United States combined. Unfortunately, the scramble to tap such wealth – which seems to mirror the colonial scramble in Africa – has led to incredible conflict in the DRC.

The technology boom in the 1990s increased the demand for minerals such as niobium, tungsten, pyrochlore, coltan, and germanium which, as Colette Braeckman, (2004) asserts in the *Looting of the Congo*, “are used in hi-tech manufacturing from mobile phones to space-ships” (New Internationalist Magazine Issue 367). It is tragically ironic that the same minerals used in creating the technological and digital devices that have made life in the industrialized world more convenient and productive have also been a major cause of conflict in eastern DRC.

The war of primitive accumulation occurring in the Democratic Republic of the Congo has manifested not only at the individual and social level but also the global level as Western countries, corporations, and financial markets continue the race to dominate the Congo’s rich mining sector. This external competition has fuelled and sustained much of the violence within the eastern part of the country in wars that have been waged for nearly two decades. Therefore, it is not only poverty in the DRC that is structural – as the country is forced to merely assert itself on the world economy as a supplier of raw materials – but also conflict and violence. As a report from the World Bank states, “Since 1998, over 3.5 million people are estimated to have died. During the same period, countless millions of others have been plunged into acute vulnerability due to displacement, loss of economic livelihoods, dilapidated institutions, and a destroyed social fabric” (Report No. 66158-ZR p. 1). The latest violence erupting in the Congo has centralized around its rich mining sector as foreign countries and corporations vie for access to its mineral-rich soil.

If we want to understand the issue of mineral extraction in the Congo, we must first understand the historical factors which led to such exploitation. Eric Hobsbawm cites the search for cheaper raw material as the main catalyst for European and American colonialism:

Between 1880 and 1914...most of the world outside Europe and America [were]...formally partitioned into territories under the formal rule or informal political domination of one or other of a handful of states: mainly Great Britain, France, Germany, Italy, the Netherlands, Belgium, the USA, and Japan...Technological development now relied on raw materials which, for reasons of climate or the hazards of geology, were to be found exclusively or profusely in remote places. The internal-combustion engine, that typical child of our period, relied on oil and rubber...Rubber was exclusively a tropical product, extracted by the atrocious exploitation of natives in the rainforests of the Congo and the Amazon...The new electrical and motor industries hungered for one of the most ancient metals, copper. Its major reserves, and eventually producers, were in what the late twentieth century called Third World: Chile, Peru, Zaire, Zambia. (Hobsbawm, 1989, p. 57, 63)

The Congo was among the most exploited territories during the colonial scramble for Africa. Conceived by King Leopold of Belgium as merely an extractive space, it had no sovereignty. The internal structure of the country, from its network of roads and railways to its health and education systems, was entirely organized for the purpose of facilitating the extraction of raw materials from the DRC to Belgium. Since Adam Hochschild’s (1998) *King Leopold the Ghost*, it is well known that King Leopold’s Congo Free State was little more than a barbaric looting enterprise. Such a space, steeped in the psychology of oppression and carved up as its oppressors saw fit, would never become a politically stable entity after independence as it never had a political consensus between inhabitants in the first place.

The borders of the DRC, like the borders of all African countries, were Western-imposed, man-made boundaries. This is how the Democratic Republic of the Congo, whose surface area (2.3 million km²) spans the equivalent of two-thirds of the European Union and whose inhabitants are diverse in both ethnic and cultural identity, became a single entity, protected and

held together merely for its economic value, its natural resources. One of the major problems the Congo still faces today lies in its ability to transition itself from an extractive space to a politically autonomous one, where people can organize their productive lives for their own development and for the development of their country. Crawford Young, (1965) expressed such a task during independence:

Belgium . . . constructed in Africa a colonial state which stood out by the thoroughness of its organization, the formidable accretion of power through an interlocking alliance of state, church, and capital, and the ambition of its economic and social objectives. The very strength of the system as a colonial structure, and its steadfast refusal to face effectively the problem of political adaptation until it began to disintegrate, made an ordered transfer of power peculiarly difficult. A colonizer who suddenly lost the profound conviction of the righteousness of his policy was confronted with a revolution by the colonized which lacked both structure and ideology. Total colonialism was replaced by total independence virtually overnight, yet the very completeness of the victory of the colonized had as its concomitant an impotence which emptied success of its substance. (1965, p. 572).

In fact, the years following Congolese independence were characterized by violence due to the trauma emanating from this abrupt autonomy. Katanga and Kasai, which presented a semblance of political homogeneity, wanted to secede from the geographical monster King Leopold built, maintained, then suddenly dropped. Though the most natural transition post-independence would have been for the Congo to break into smaller, more politically coherent pieces, the UN's intervention kept these secessions from coming to fruition. Mobutu was placed in power partly due to Cold War logistics, as a way for outside interests to keep the Soviet Union away from the Congo's minerals.

One of the characteristics of this newly independent African country was that it seemed to maintain the economic structure put in place by its colonial power. The economies of the colonies were linked to the world market as providers of raw materials, and these extractive structures were not only protected by the colonial

administration during the colonial period, but, post-independence, were also protected by African leaders who had become, in Fred Cooper words, "gatekeepers." The economies of post-colonial Africa were all extroverted and in many ways continued to function for the benefice of their former colonial powers.

The Zairian state liberated the mining sector in 1983. Ten years later, in 1993, public enterprises were privatized and mining concessions were given to private companies with the hope of boosting state economy. Eleven mining companies won portions of former Gécamines, the state mining company, and signed joint ventures (Kennes, 2000). The war in 1996, by the Democratic Forces for the Liberation of Rwanda or FDLR led by Laurent Kabila, killed the privatization efforts in the mining sector. After Kabila rose to power, his government too tried to rely on the mines to rebuild the economy of the newly named Democratic Republic of the Congo. It failed partly due to the rebellion against Kabila's government by his former allies, Rwanda and Uganda. Each of these countries backed one rebel group; Rwanda supported the Rally for Congolese Democracy (RCD), and Uganda backed the Movement for the Liberation of Congo (ML). These rebel groups and their allies sought to control the DRC's mining sector resulting in the Rwanda and Uganda conflict over Kisangani in 1999. After 13 years as the head of state, Laurent's son, Joseph Kabila, and his family have quite a hold on the mining heritage of the Congo. Today, no investment is made without the involvement of a member of this group-like mafia. The Kabila family has become a kind of parallel government, and the Congo's mining sector has sustained its function as a funnel to finance outside interests, wars, and Congolese elite (Marysse & Andre, 2001).

Mr. Matata Ponyo, the current Prime Minister and former Minister of Finance of the Democratic Republic of the Congo, has been praised by the International Monetary Fund and the World Bank Group for managing to control inflation in the DRC while at the same time announcing a growth of 8.3 % for 2013. Yet, the DRC remains at the bottom of Human Development Index and

famine index and has an average life expectancy of 48 – a number which decreased from 58 in the 1990s. How is it possible to reconcile Mr. Matata Ponyo's figures and praises with the deep and unrelenting poverty of the Congolese people? The answer lies in the type of economic system in place in the DRC, which is linked to the Congo's rich mining sector. As Professor Marysse (2013) asserts, "Congolese economy is extroverted, good performance in mineral area has no incidence on people's life" (2013 Economic Conference paper in Kinshasa). The Congolese economy, according to Marysse, is dissociative: on the one hand, what neoliberals would call "informal" economy – the force that structures people's economic lives – is present, while on the other hand, a billion dollar mineral economy exists, though the profits are rarely seen by the Congolese people. These two branches of the DRC economy are entirely disconnected from one another as there is nothing – no industry, no factories, and no subcontracting firms – which allows money to flow from the intensive mineral production to the informal economy.

The dissociative economy of the Democratic Republic of the Congo mirrors the Congolese's relationship to their historical narrative and, more importantly, to their future. In the advanced capitalist world, what some call the first world, where globalization is about the deepening of commodity relations, the privatization of public services, and the search for cheaper and more productive labor (Moore, 2001; Harvey, 2000), African states, and specifically the DRC, are often interpreted not only in terms of their failure to adhere to a Weberian model of the rational-legal state but also in terms of their limited capitalist possibilities, their inability to insert themselves in the world market with regard to resource extraction, social control, and policy implementation. Africa, in general, and the DRC in particular, has traditionally had its history written by the West. This dynamic is still very much alive today, but in the projection of the DRC's collective future. It is not only acquiring the means to write one's own historical narrative that will be important in

establishing the DRC's identity as a nation but also, and more importantly, their ability to control their own future trajectory.

Across its vast provinces and in many of its activities, the Congolese state and its institutions are either minimally present or entirely absent. Though power has been centralized after peace agreements in 2003 and though national elections have produced a government with at least some political legitimacy, a number of armed groups continue to fight for power, causing population displacement and threatening yet another war. Following the 1996–1997 and 1998–2003 wars in the DRC, the Congo has struggled to strengthen and mobilize its civil society. As United Nations Assistant Secretary General for Political Affairs Haile Menkerios stated, "The problem in the Congo is not only the problem of armed groups, it is a problem of the state. It is a problem of nation-building... Institutions do exist on paper right now, [but] in practical terms, they really need quite some time to strengthen" (Qtd. in *African Renewal*, January 2008, p.12).

Mr. Matata Ponyo and Mr. Mukoko, the Minister of Economy, are products of the neoliberal school which religiously applies the prescriptions of the International Monetary Fund (IMF) and other institutions to control inflation. This is how they are able to celebrate the growth of the GDP, while the people of the country struggle for food, clean water, and general quality of life. However, the modernization discourse of liberal market development and the Weberian notion of state formation do not respond to the economic life of the DRC. Max Weber, (1968) defined the state as a "ruling organization [which] will be called 'political' insofar as its existence and order is continuously safeguarded within a given territorial area by the threat and application of physical force on the part of the administrative staff" (1978:54). In Weber's eyes, the state is a rationalized administrative form of political organization and he identifies legibility as the process par excellence for its creation and retention. Compounded by capitalism and globalization, this Eurocentric conception of statehood has

become a fixed and rigid fact and the gauge by which all other “normative” states are judged.

Yet, the idea of state failure is, itself, misleading. It begs the question that if a state is now falling apart, it was once well-integrated, fully functional, stable, and efficacious, but statehood is a relative concept, particularly the colonially imposed and institutionalized states of Africa. The DRC state, for example, remains profoundly contingent; it was born in a colonial carve-up, and threatened from independence by secessionist movements at the provincial level (Jackson, 2007). There is no general formula for the success of state projects as it is a social phenomenon and must therefore respond to local historical specificities (i.e., the conditions and relations of struggle).

The informal economy of the DRC, which is the backbone of the Congolese people’s economic life, does not conform to either liberal market development or the Weberian notion of state formation. Additionally, there are a number of local economies in the DRC that function around the mining sector of that area. Two types of extraction needs are integral to the understanding of the ways local economies develop around local mining industries. The first type requires immense investment. Minerals like copper, cobalt, uranium, and oil require large outlays of money before extraction is possible, while minerals like gold, diamond, cassiterite, coltan, and wolfram are more easily extracted. Each type of production generates a different type of local economy and, therefore, significantly plays into the economic narrative of its location. For example, diamond extraction in Mbuji Mayi and gold extraction in South Kivu are processed both manually and industrially, whereas coltan, cassiterite, and wolfram are extracted in nonindustrial ways. The artisanal production of extraction is indeed the type of informal mineral business that has served as the backbone of economic survival for many people in South Kivu, Nord-Kivu, Kasai, and Katanga. However, since Congolese people rarely head these extraction efforts, the majority of the DRC’s wealth is quite literally stripped and stolen from underneath their feet.

The disparity between the Congo’s two economic fronts reveals how Mr. Matata Ponyo’s projections and the lived experience of the Congolese people, though polar, are able to coexist. The solution to this gap will not come from neoliberal technocrats, of whom Matata and Mukoko are members, but from economic anthropologists who view economies as a form of social relation. It is only in this context, which takes into account both the holistic experience of the Congolese people and the necessary actions of the state’s administrative control, that any type of lasting change can occur. The DRC must find a way to connect its emerging government to the needs and interests of its populace. If the government is able to invest in the success of its people, the people can effectively support the functioning of its government.

From an anthropological point of view, the neoliberal narrative of modernization and the Weberian notion of state formation must be set aside in order to understand the structural underpinnings which have allowed the people of the Congo to survive, and in some cases thrive, even in the face of great conflict. The Congolese have strong structural links legitimized through communitarian and sub-ethnic belonging which have yet to be recognized, and we posit that these relations are intrinsically necessary for a successful political and economic consensus to begin to form among the people of the Congo. We further posit that economic anthropology, or human economy, must take precedence over mainstream economy and that political positions in the DRC should be held by Congolese who understand the big picture from the bottom-up, rather than the so-called technocrats who currently occupy positions of power in the DRC and who apply mechanically neoliberal precepts to an economy whose structural elements differ fundamentally from the foundations of those precepts.

Conclusion

In the current economic atmosphere of the DRC, where economic sovereignty has deeply eroded,

globalization has expanded, and capital has grown and become more mobile, the challenge for these leaders will be to implement creative and perhaps even radical new policies adapted to and for the specific needs of the Congolese people. In addition to transforming their extractive space into a political one, the Congolese must shape their economy to work for their communities on both the local and national level. Rather than continuing to provide raw material for outside sources, the government of the Congo needs to encourage Congolese small-scale enterprises which might then be fostered, strengthened, and subcontracted by the Congo's intensive mining industry.

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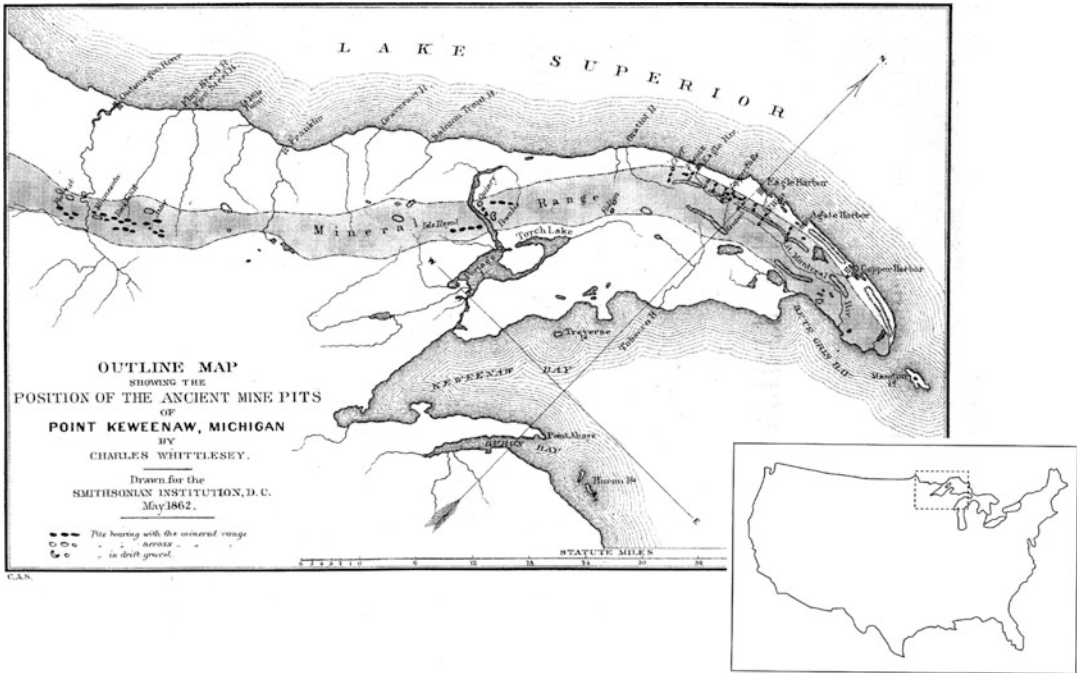
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Mining: Copper Mining in the Great Lakes (USA)

Susan Rapalje Martin

The roots of indigenous metal mining are ancient in eastern North America. Evidence for early metal mining in North America comes from the copper-bearing regions of the western Lake Superior Basin in the central part of the continent. Here are to be found veins of elemental copper dispersed within sandstone and basalt bedrock, lying relatively close to the surface. In addition, pieces of loose elemental copper lie scattered in the glacial drift that is to be found in many streambeds and riverbanks. These pieces of useable copper and their parent veins were discovered and exploited by Native American people as early as 7,000 years ago. Though the first metal-working technologies of North America derived from the same technologies that people worldwide universally applied to reducing and using stone for tools, this long tradition of using copper for tools and ornaments is the product of native North American ingenuity. Moreover, the traces of this industry of copper mining and working (spoil piles, pits, discarded hammers, and other tools) were visible to the first capitalist American mining entrepreneurs of the Lake Superior basin who established their own mines on the same old ground that had proved itself first via native mining efforts (Foster & Whitney, 1850). Archaeological research in the Lake Superior Basin and other copper-bearing areas documents the long-standing importance of copper technologies in the lifeways and practices of the indigenous people of the continent (Fig. 1).

The bedrock geological history of the Lake Superior region is fairly well understood (LaBerge, 1994); its basement of pre-Cambrian bedrock, part of the Canadian Shield, is very ancient. The deposition took place around 1,100 million years ago (MYA), initiated by a period of roughly 25 million years during which a series of



Mining: Copper Mining in the Great Lakes (USA), Fig. 1 Map of the Keweenaw Peninsula, Lake Superior, USA, indicating locations of prehistoric copper mining pits (Source: Whittlesey, 1863)

enormous movements of magma broke through a cross-continental rift and laid down some 200 extensive lava flows. This activity was intermittent, and followed by long periods of erosion and sedimentary deposition. The resulting strata are deformed by faulting and subsidence to a broad syncline that underlies Lake Superior and its drainage basin.

Gases trapped in the cooling lava, especially at the tops of flows, created porous structures in which later precipitation of minerals took place. Fissures in the lava and interspersed sedimentary rocks provided places where deposition of elemental copper occurred. The copper itself “was likely leached from volcanic rocks deep within the rift by hydrothermal solutions and was then deposited in these same rocks at relatively shallow levels closer to the surface. The timing of the widespread deposition of copper postdated the formation of the bedrock strata by about 20–30 million years and occurred from about 1,067 to about 1,047 MYA” (Martin, 1999, pp. 27–28). The result of this activity comprises the largest body of elemental copper

known on earth, and its relatively shallow and accessible position allowed people to recover it. The copper-bearing strata outcrop in a narrow band about 3–6 km wide lying in a southwest to northeast direction along the Keweenaw Peninsula and Isle Royale on the western shores of Lake Superior; the beds also outcrop at the northern and eastern shores of the lake, and extend, deeply buried, further to the west into Minnesota. In other areas, native (elemental) copper is a common though irregular constituent of copper ore deposits in Tennessee, Georgia, New Jersey, Nova Scotia, and elsewhere (Levine, 1999).

The Lake Superior deposits are quite variable in actual copper content and in form. In sedimentary bedrock deposits, the copper is finely dispersed; in the basalt bedrock the copper is more likely to be found in fissures, veins or nodules of varying sizes. Masses of copper weighing several thousand kilograms were occasionally encountered. The most useful deposits for prehistoric people were of two kinds: thin veins that yielded sheets of copper, or fist-sized nodules of copper. Reducing very large pieces to useable sizes was

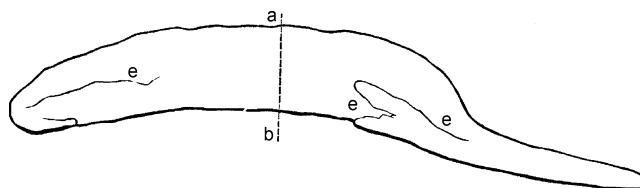
somewhat beyond the reach of native technologies, but smaller pieces of both kinds could be rendered into tools and useful objects relatively easily. Useful nodules were sometimes found as constituents of the local late Pleistocene glacial drift or in redeposited gravel banks along streams and rivers. This copper-bearing drift is also widely dispersed across the central portions of the North American continent, where glacial ice flows carried copper and other detritus far from their points of geological origin.

The simplest and least-effort way to acquire copper in elemental form was to search and dig through the many beds of glacial drift in the rivers and streams surrounding the Lake Superior and adjacent regions. Based upon the many pitted areas observed and mapped by Whittlesey during the mid-nineteenth century (Whittlesey, 1863), these beds of glacial drift were systematically explored for copper nodules. The glacial drift with copper as a constituent was/is widespread across the central part of North America (Salisbury, 1885), and occurred south and west of Lake Superior as far as Iowa and the Dakotas.

In addition to such areas, the bedrock veins were also systematically visited and mined over many thousands of years. Finding the buried veins was a simple matter of being observant. In the western Lake Superior basin, the veins of metal are visible in some surface basalt bedrock outcrops, particularly those that were scoured by glacial action. In other areas, erosion and water action revealed buried veins and nodules. In still others, companion minerals marked the probable occurrence of copper veins. Mining pits on Isle Royale investigated by the University of Michigan in the early 1960s dated to ca. 2470 BCE $\pm$ 150 radiocarbon years (Fitting, 1975, p. 238). The early geologists Foster and Whitney described the pattern of such mining pits on the south shore of Lake Superior; observing that along “a distance of nearly 30 miles, there is almost a continuous line of ancient pits along the middle range of the trap (sic), though they are not exclusively confined to it” (Foster & Whitney, 1850, p. 161). The typical pit was rather shallow and followed the course of a vein of copper in a small-scale simple excavation.

Alvinus Wood described one that he observed during his excavations on the Keweenaw Peninsula in the late nineteenth century. “It was shown to be 14 ft. deep, having been filled up by the sliding-in of material composed largely of broken rock, taken out in sinking the ancient shaft, and left near its mouth” (Wood, 1907, p. 288). According to Wood, the pit measured about 7 ft. in diameter. In scale, these pits were most comparable to quarrying a face of exposed rock, similar to the mining of flint that had been done for millennia, as opposed to the burrowing or tunneling more typical of recent hard rock mining.

The ancient mining was done with stone hammers that people used to crush the bedrock surrounding a copper-bearing vein. The hammers were, for the most part, unaltered impromptu tools found in the local glacial gravel. Mining pits are sometimes most readily identified by the appearance of many of these expended (shattered) hammers. The hammers were of various sizes and materials; most were of basalt or gabbro and weighed about 2–4 kg, although larger ones were also used, especially early in the mining sequence. Some of the hammers had minor surface modifications, such as a partial or full groove pecked into the circumference to allow a withe or handle to be attached. Pry bars of wood or copper were probably also used to loosen the copper within the vein, and there is some suggestion, especially borrowed from other primitive mining locations around the world, that fire might have been used to weaken the trap rock so that freeing the copper took less mechanical effort. Experimental work on Lake Superior prehistoric mining methods demonstrated, however, that such methods did not measurably improve the efficiency of removing copper (Bastian, 1963). Additional artifacts, including copper tools, wooden bowls, wooden ladders, paddles, and other accoutrements of mining were reported to be found in the mining pits investigated by Whittlesey (1863). The size of the mining pits and their conformation suggests that one or two persons could work comfortably within a pit, and experiments showed that ca. a cubic foot of trap rock per hour could be removed from a pit face simply by stone hammering (Bastian, 1963, p. 24).



Mining: Copper Mining in the Great Lakes (USA), Fig. 2 Sketch of copper implement, Keweenaw Peninsula, Lake Superior, USA (Source: Whittlesey, 1863)

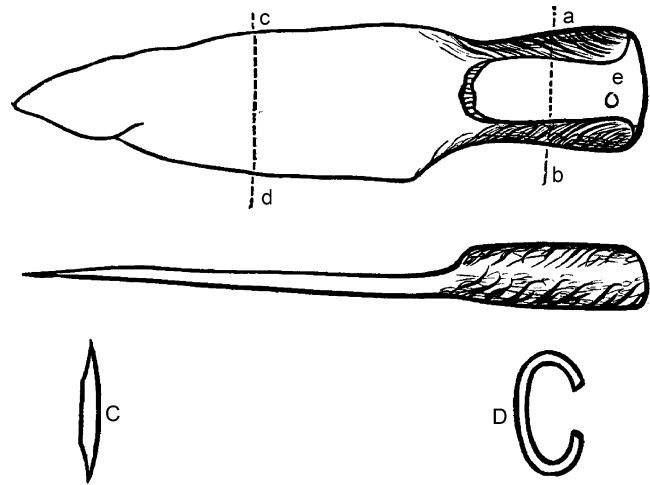
The native people of central North America fashioned myriad forms of elemental copper artifacts, using simple techniques of repeated cold-hammering and annealing. Despite a search that has already lasted for more than 150 years, there is no unequivocal evidence for intentional melting, smelting or casting of metal artifacts in the Lake Superior region or elsewhere in the eastern United States. All known artifacts were produced in much the same way: careful repeated hammering and heating to recrystallization temperatures. The finished copper objects ranged from weighty woodworking tools to finely crafted ornaments and decorative objects. It is probable that the basic knowledge of elemental metal-working was more or less common across North America, because many elemental metal deposits were known and exploited: at multiple localities in the eastern United States, in Mexico, in the southwestern US, and along the western rivers of Canada. The region around the Lake Superior basin with its large numbers of copper artifacts from local sites allows the researcher a fairly comprehensive look at how specific artifacts were designed and manufactured. Modern researchers established, via experimental replication as well as microscopic studies, the basic outline of pre-historic metalworking techniques (Clark & Purdy, 1982; Leader, 1988; Vernon, 1990). Using the methods of cold or hot-hammering and annealing, the artifacts were carefully fashioned by repeated cycles of heating, hammering, and cooling, with carefully directed blows from a stone hammer creating the final form. Annealing, or reheating to recrystallization temperatures (in excess of ca. 250–300 °C), restores malleability and was an essential part of the process; otherwise the hammered copper quickly became

brittle and cracked under additional stress. Metallographic inspection of hammered copper revealed “the hammering technique, although primitive in itself, was carried out with assurance and skill; the sheet metal is often of fairly uniform thickness even though laminations are sometimes present” (Wayman, King, & Craddock, 1992, pp. 133–134). Larger artifacts, such as woodworking tools, were hammered and annealed to render a nodule of copper to a desired form. Or, copper sheets were hammered to an even thickness, rolled and then rehammered to consolidate the copper into a thicker artifact form. Final annealing was frequently done, and annealing temperatures may have exceeded 600 °C for some artifacts. Ornaments (such as beads) and sheets of copper were sometimes hammered around wooden forms, or mandrels, to produce a final artifact shape. Other artifacts, such as Hopewellian earrings and decorative ornaments of some Mississippian cultures, were composite artifacts of wooden cores clad with a thin cover of fine sheet copper (Figs. 2 and 3).

Finishing touches sometimes included additional limited cold-hammering to harden work edges of tools such as knives and projectile points. Grinding or beveling of work edges was also fairly common, and some artifacts such as harpoons or projectiles were perforated to enable the securing of a wooden shaft or handle via a copper rivet. Hopewellian and Mississippian cultures used elaborate finishing techniques on their ornaments. Decorative items were embossed, cut out, and perforated in a wide variety of forms depending upon the particular cultural traditions of the artisans producing the artifacts. Some were finished with a high gloss or polish produced by systematic rubbing with ashes and abrasives such

Mining: Copper Mining in the Great Lakes (USA),

Fig. 3 Sketch of socketed implement with rivet hold 'e' and cross sections 'C' and 'D' (Source: Whittlesey, 1863)



as sand. There is some experimental evidence that prehistoric metal workers were able to draw thin strands of copper wire (Cushing, 1894).

There is ample evidence derived from the study of the physical distribution of worked and unworked copper to claim that prehistoric people surrounding the Great Lakes communicated with one another, in part, through the exchange of raw and finished copper materials. In addition, overall close similarities in finished copper artifact forms that occur among and within regions close to bedded sources suggest active contact between people of different areas, and at least the copying of each other's artifact forms, if not direct/indirect exchange of finished materials. This pattern is well documented for areas east and south of the Lake Superior basin (Brose, 1994; Goad, 1979; Walthall et al., 1982). It is also apparent from research conducted in the northern Plains, where Lake Superior copper may have been exchanged for locally derived lithics such as obsidian and catlinite (Vehik & Baugh, 1994). Other raw materials reported from the western Great Lakes region that may have been involved in regional and interregional trade *vis a vis* copper include hornstone (Pleger, 1996), Hixton orthoquartzite (Clark, 1991), galena (Ritzenthaler, 1957), Burlington chert (Pleger, 1996), Knife River flint (Salzer, 1986), and marine shell (Hruska, 1967). Many authors agree that copper was likely widely distributed via trade over vast distances (Brose, 1994; Goad, 1979; Winters, 1968). Other authors

add that trade in perishable items, invisible for the most part in the archaeological record, was certainly part of the picture; meat, skins, shells, reed mats and tobacco are suggested as important commodities, especially in the seventeenth century (Smith, 1996). Other less tangible commodities and/or motivators to trading activities may have been related to social status, ethnic differentiation, information exchange, and ritual knowledge (Martin, 1999). There is, at least by the seventeenth century AD, a solid body of first-hand reporting that documents the connection between native ideologies and copper materials, which were sought after because they were believed to hold the ritual power to bring good fortune, health, wealth and hunting success (Kellogg, 1917, p. 105).

The use of copper was widespread in prehistory and was an important part of the cultural adaptations of the native peoples of eastern North America, beginning by the seventh millennium BP and extending until the advent of European-influenced cultures. The earliest and strongest evidence for the importance of copper mining in native American technologies and lifeways comes from the region adjacent to the bedded copper deposits of the Keweenaw Peninsula, the southwestern shore of Lake Superior, and Isle Royale, Michigan. Here there is material evidence of systematic collecting for copper within surface glacial deposits as well as extensive evidence of the activities of hard rock mining and

quarrying by native Americans. The technologies of mining and cold-hammering elemental copper have become well understood through the efforts of experimental (replicative) research and metallurgical studies. Copper was an integral part of the technological, social and ideological experiences of the region's first people, and was equally significant as a material from which to fashion a tool, a social interaction or a ritual transaction. Copper's significance included social reckoning as expressed in burial and in decorative contexts among peoples of many regions and cultures, as well as social interactions as expressed through trade contexts, and finally within religious representation as expressed in elaborate beliefs about its ritual power.

See Also

- [Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy](#)

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Mirrors: Metal Mirrors from India

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Metal mirrors have a long antiquity in various parts of the Old World and Asia. Mirrors have had considerable magico-religious and aesthetic

significance in parts of Asia, for example in China and India. The English word “speculation” comes from the Roman words meaning magic for telling the future by looking in a mirror (speculum), and mirror divination is still taught in the Tibetan Buddhist tradition. The motif of the celestial maiden, deity or dancer admiring herself in a mirror is an enduring one in Indian sculpture, as exemplified by a Kushan sculpture of a Yakshi or tree nymph from Sanghol (first and second century CE).

Fine bronze mirrors with figurines on the “tang” or the shank that fit onto their handles are found from ancient Egypt. Early flat, circular or tanged mirrors come from Harappan contexts in the northwest of the Indian subcontinent at Quetta and Harappa in Pakistan (ca. 2000 BCE) and Dholavira in Gujarat, India. These would have been made of bronze with a low-tin content (i.e. less than 10 %).

Subsequently bronze mirrors of a higher tin content came into vogue in various parts of the ancient world. Low-tin bronze consists of the coppery-toned solid solution of tin in copper, known as the alpha phase, which enhances its strength. However, it has limited reflectivity, whereas cast bronze with higher amounts of tin has increasingly higher reflectivity. This is due to the formation upon cooling of higher tin bronze of an alpha plus delta eutectoid phase; i.e. a fine mixture of two solid components, the alpha phase and the delta phase which a silvery white inter-metallic compound of copper and tin. However, since this delta phase component is also highly embrittling, as-cast higher tin bronze mirrors were usually leaded. Such examples of cast bronze mirrors with 20–25 % tin and 5–10 % lead are widely found from Han China and the Roman world from the Christian era (Meeks, 1993). Bronze mirrors have been one of the most prolific and exotic of Chinese *objets d’art*. The addition of lead improves castability, but lead is an opaque material that is not soluble in copper and may have compromised the reflectivity.

At the village of Aranmula in Kerala in southern India, a unique mirror making tradition survives. Here, a cast high-tin bronze mirror of 33 %



Mirrors: Metal Mirrors from India, Fig. 1 Traditional metal mirror of cast high-tin delta bronze (33 % tin) made at Aranmula, Kerala

tin of highly specular or reflective properties is made which is comparable to, if not better than, modern mercury glass coated mirrors (Fig. 1). This is done by optimising the presence of the brittle silvery-white delta phase of bronze while eschewing the use of lead. In an anthropological study, Mukherjee (1978) briefly mentioned the craft of making metal mirrors at Aranmula, while studies were also made by Pillai et al. (1992), Srinivasan and Thomas (1991). The author documented the making of metal mirrors from Aranmula in 1991, followed by detailed technical and micro-structural studies on equipment purchased in early 1992 by Dr. Ian Glover from mirror makers hailing from Malakkara, also in Kerala (Srinivasan & Glover, 1995, 1997, 1998). These comprehensive metallurgical investigations on fragments of the mirror alloys established that uniquely, these were made of a binary alloy of copper with 33 % tin. This may be described as a high-tin delta bronze due to its close match with the composition of the pure delta phase of bronze, an intermetallic compound



Mirrors: Metal Mirrors from India, Fig. 2 Cast oval mirror blank of silvery delta bronze mounted on wooden polishing board

($\text{Cu}_{31}\text{Sn}_8$) of 32.6 % tin and the rest copper. It is this composition, approximating to a pure delta phase, which yields properties ideally suited for a mirror, since it is a hard, stable and silvery compound, which can be polished with great reflectance. The entire mirror manufacturing process seems geared to optimising the presence of this delta phase, which the copper-tin phase diagram indicates forms only within a narrow composition range of bronze of 32–34 % tin at non-equilibrium room temperatures (Scott, 1991, p. 95). While this silvery metallic alloy shatters quite easily like glass, this brittleness is offset not by adding lead but by casting a very thin blank, no more than 3-mm thick, which would thus cool quickly with fewer heterogeneities. Then the blank is reinforced by mounting it with resin on a wooden mount for the polishing process (Fig. 2). A finished mirror from Aranmula consisted of 32.5 % tin, approximating the composition of the pure delta compound of 32.6 % tin. Thus, it is remarkable that merely by using traditional ‘low-tech’ methods and materials a rather sophisticated ‘high-tech’ metallurgical end product is achieved.

At the workshop of Janardhan Achari of Aranmula, a cleverly made jug-shaped crucible-cum-mould of clay is used for the casting process. The lower portion consists of a two-piece clay mould which is connected to the neck, consisting of a hollow cup wherein the metal pieces to be cast are placed and sealed with clay. Then this

Mirrors: Metal Mirrors from India,

Fig. 3 Heating of crucible-cum-mould in a hearth fuelled by coconut husks



Mirrors: Metal Mirrors from India, Fig. 4 Heated inverted crucible-cum-mould being removed from hearth with the lower part containing the metal to be cast. When the jug-shaped crucible-cum-mould is tipped over the molten metal flows into a narrow hollow space for the blank created by two flat disc moulds



closed clay crucible-cum-mould is heated neck down on a hearth (Figs. 3 and 4), whereby the metal melts in the neck, and then the jug-shaped crucible-cum-mould is tipped over so that the molten metal flows into the narrow gap between the oval two-piece mould so that it solidifies into a thin 3 mm oval metal blank. The cast blank, which is retrieved by breaking the mould, is mounted onto a wooden handle and polished over several days with hessian and velvet cloth to get a mirror finish (Fig. 5). The hardness of the delta bronze alloy was found to be between 500 and 540 VPN, which is harder than normal steel, and thus the thin mirror blank could be polished almost entirely free of distortion. Ingeniously, the hard mirror alloy is itself used to give the mirror a final polish since it can be easily powdered, as it is highly brittle. This would usefully serve to smooth out and fill in any defects in

the cast blank with the same alloy to give the best possible mirror finish. The microstructure of an as-cast mirror fragment recently made at Malakkara with 33.4 % tin showed a structure consisting predominantly of a matrix of whitish delta phase interspersed with a bluish network of the alpha plus delta eutectoid (Fig. 6).

Such mirrors yield a precise point image, as they do not suffer from blurring due to refraction through glass encountered in standard glass mirrors. The colours seem to be reflected even more brilliantly. For many high-tech applications, the type of refraction that occurs through glass mirrors is unacceptable and 'front-facing mirrors' are used, such as those, which consist of a layer of softer reflective aluminium under a thin protective quartz material. However, as pointed out by T. Poston, the hard Aranmula mirror alloy has comparable reflectivity to these front-facing

mirrors and does not scratch easily; unlike a layered surface, it can be repolished. Although the mirrors made these days have a blank which is no more than 7–10 cm along its oval length, in 1998



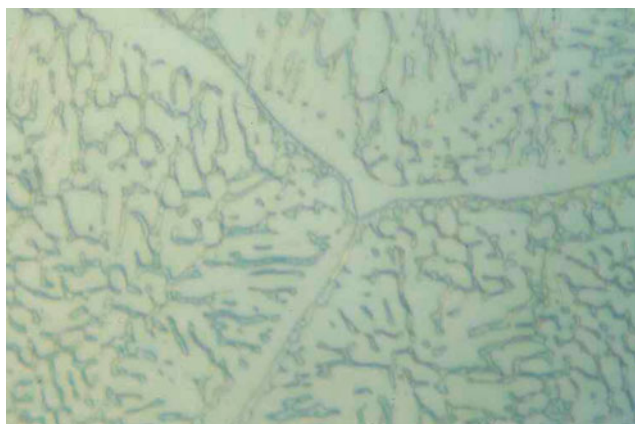
Mirrors: Metal Mirrors from India, Fig. 5 Polishing of cast blank on hessian cloth using the powdered brittle mirror alloy itself for polishing

the elderly Janardhan Achari, perhaps one of the last of the meticulously traditional practitioners, showed a metal mirror with a 30-cm long blank made in his heyday. (Large modern front-facing mirrors are a major challenge to make by the deposition technology).

Figure 7 shows an old metal mirror from Kerala with the insignia of the Travancore Royal family of Kerala, which may date to the seventeenth and eighteenth century. Metallurgical investigations on tiny fragments of the mirror undertaken by the author at the Department of Conservation and Scientific Research, Freer Gallery of Art, Smithsonian Institution in 1998 indicated that the mirror consisted of almost pure crystals of silvery white delta phase (32.6 % tin bronze) (Fig. 8) with practically no eutectoid [as agreed by T. Chase, personal communication]. The absence of the eutectoid suggests that the blank may have been rapidly cooled. This indicates the high level of technological accomplishment in isolating the reflective intermetallic delta compound. This is no small feat even in modern metallurgical terms. The structure of the delta phase is that of gamma brass and contains icosahedral clusters; the icosahedron being the most symmetric of all objects (Srinivasan & Ranganathan, [in press](#)). Metaphorically speaking, it is as if the inner beauty of the intermetallic compound mirror stares back at the onlooker gazing into it (Fig. 9). The shadowy whitish patterns in that image (Fig. 9) are in fact the crystals of the predominant delta phase.

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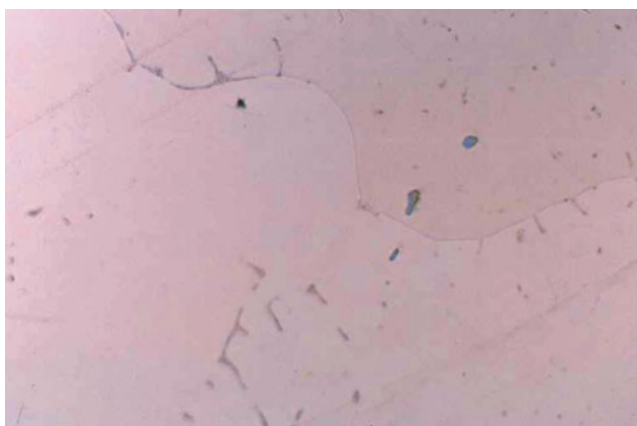
Mirrors: Metal Mirrors from India, Fig. 6 Micro-structure of as-cast 33.4 % tin-bronze mirror fragment from Malakkara showing a matrix of silvery-white delta phase with a fine network of bluish alpha plus delta eutectoid (1,000×)



Mirrors: Metal Mirrors from India, Fig. 7 Old metal mirror from Kerala showing insignia of the Royal family (seventeenth and eighteenth centuries)



Mirrors: Metal Mirrors from India, Fig. 8 Microstructure of fragment of above old mirror showing that it consists almost of pure delta phase crystals with very little inter-granular bluish eutectoid phase (940 $\times$)



This waning handicraft tradition of Aranmula has not only technological significance but also considerable sacred meaning. The Aranmula mirror (*valkannadi* in Tamil and Malayalam), was one of the eight auspicious articles or *ashtamangalyam* set that traditionally made up a bride's wedding trousseau from the Nair and Namburthri communities (Thurston & Rangachari, 1909). A Kushan period Jain votive tablet (first and second century CE) (illustrated in Czuma, 1985) depicts a mirror as part of the *ashtamangalyam* set. Figure 10 shows a celebrated sculptural bracket figure of a *madanika* or temple dancer holding a mirror in the steatite temple of Belur, Karnataka of the Hoysala period (twelfth century), and such depictions are also found in the eleventh and twelfth centuries sandstone temples of Khajuraho. [Such mirrors

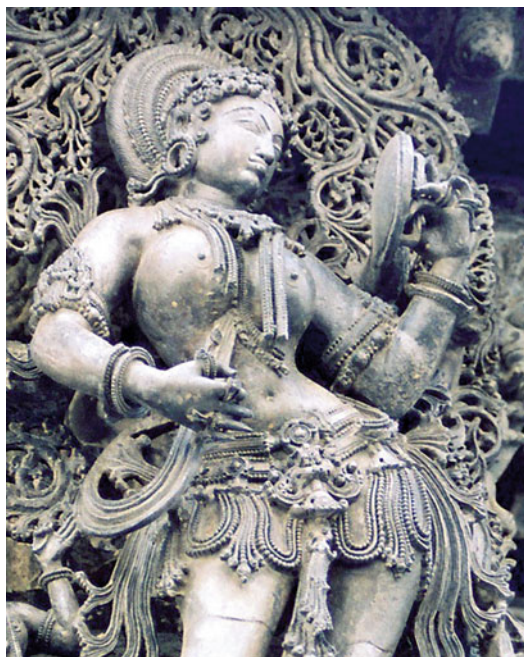
uncannily resemble the thick wooden polishing board with a rear handle from Aranmula onto which the mirror blank is fixed with resin for polishing. Indeed, one might speculate that this could have itself been used as a finished mirror as an alternative to the current traditional practice of mounting the mirror blank into a tanged brass frame]. Metal mirrors are also worshipped in Kerala, where they are known as *kannadi bimba*. In a subsidiary shrine at a temple complex dedicated to the Goddess Bhagavati in Ernakulam, Kerala, an old large metal mirror is worshipped as a form of the goddess.

The manufacture of the Aranmula *kannadi* has been a zealously guarded secret of all but a handful of surviving master craftsmen known as *acharis*. Discussions with them indicate that they believe the craft has an indigenous origin.



Mirrors: Metal Mirrors from India, Fig. 9 Srinivasan demonstrating image reflected in Aranmula mirror with whitish crystals of predominant delta phase being seen in the background

Local legends link the history of the Aranmula mirror to the Parthasarathy temple to Krishna at Aranmula, one of Kerala's five most sacred shrines. One lively story of the origins of the Aranmula metal mirror was reported in 1992 to Glover by mirror maker Janardhanan Achari (Srinivasan & Glover, 1995). Some bronze craftsmen are said to have originally migrated from Tamil Nadu to make artefacts for the Parthasarathy temple. The Raja of Aranmula had threatened to evict, since they had grown fat and lazy. A widow, Parvati Ammal, came to their rescue as she dreamt that Lord Parthasarathy or Krishna had revealed the secret of making an unusual reflecting metal. In an interesting twist, not only was the king placated by the crown made of this material but he also exhorted the artisans to make mirrors for the auspicious



Mirrors: Metal Mirrors from India, Fig. 10 Sculptural bracket figure from Belur, Karnataka showing *madanika* or dancer with mirror which resembles the Aranmula wooden mount for polishing mirror blanks

ashtamangalyam wedding sets of brides-to-be from this alloy dreamt up by the widow.

As indicated before, the unleaded delta bronze mirrors of Aranmula are technologically distinct from mirrors elsewhere, such as the leaded specular bronze mirrors which were common in China. Rather, the Aranmula high-tin delta metal mirror seems to draw from longstanding Indian familiarity with making artefacts of unleaded binary high-tin bronze which had previously been little recognised. Metallurgical investigations were made by the author on vessels from Iron Age burials and megaliths such as from the Nilgiris and Adichanallur in Tamil Nadu, datable to the early to mid first millennium BCE (Srinivasan, 1994; Srinivasan & Glover, 1995, 1997) and one from Adichanallur by Paramasivan (1941). These were to be wrought and quenched high-tin beta bronze with around 23 % tin, ranking amongst the earliest and most finely wrought and elegant examples known in the world, with some having rim thicknesses of

no more than 0.2 mm and with a range of decorations from fluted or carinated (shaped like the keel or prow of a ship) shapes, or ringed and floral motifs. Due to the formation at high temperatures of a plastic beta intermetallic compound phase of a composition of 22.8 % tin (and the rest copper), these specialised alloys can be hot forged considerably between 600 °C and 700 °C. Thereafter, quenching in water results in the retention of the high-temperature beta phase in a rapid martensitic transformation, akin to that found in steel, which is characteristic by needle-like structures in the metallic microstructure as seen the quenched structure of an Iron age bowl from Adichanallur. This yields improved properties of golden lustre, musicality, toughness and corrosion resistance. Also, quenching prevents the formation of the low-temperature alpha plus delta eutectoid phase which due to its embrittling effect was undesirable in this case.

Vessels and cymbals of wrought and quenched high-tin beta bronze are still made in Kerala, bearing similarities in design to the megalithic vessels documented by the author in 1991 and with Glover in 1998. Mirrors were amongst the collections from the Nilgiri cairns (of about 40 vessels each in the British Museum and the Government Museum, Chennai) and Adichanallur burials from Tamil Nadu of the early to mid first millennium BCE. One such sample of unleaded 30 % tin bronze was reported from the Nilgiri cairns by Breeks (1873, pp. 63, 156). From Sonepur in eastern India an early historic period metallic specimen of 32.4 % tin-bronze was reported (Biswas, 1996, p. 187). Minor occurrences of tin have been reported in parts of India such as Hazaribagh in east-central India and in Karnataka in southern India, while the author reported old slags from co-smelting copper and tin ores from the Karnataka region (Srinivasan, 1997) which might suggest that minor local tin reserves could have been exploited in southern antiquity. Indeed, Maloney (1975, p. 26) suggests that tin was one of the items of export from the Karnataka coast by Solomon's army along with peacocks, iron, ivory, apes, gold and silver. Two unleaded bronze samples of 22 % and 26 % tin were reported from the Indus Valley site of Mohenjodaro (ca. 2500 BCE)

(Mackay, 1938, pp. 480–481), although without a metallographic study it is not possible to conclude if these were intentionally quenched beta bronzes. From the Bhir mound in Taxila in Pakistan, a binary high-tin bronze mirror of 25 % tin was uncovered (Marshall, 1951, pp. 567–569). A vessel examined by the author from the Vidarbha megaliths of Maharashtra, carbon dated to about the eighth century BCE, was a quenched high-tin bronze with 21 % tin, as was another with 24 % tin from the Gandharan Grave Culture of Pakistan of the early first millennium BCE. Rich finds of high-tin beta bronze vessels and bracelets have been found from Ban Don Ta Thailand, fourth century BCE (Bennett & Glover, 1992; Rajpitak & Seeley, 1979). These show similarities with the Nilgiri and Adichanallur vessels in the ringed and knob-based decorations, although metallurgical comparisons indicate that the south Indian bowls were much more extensively hot forged prior to quenching. While trace element comparisons do not suggest common metal sources, it is possible that Indianised stylistic influences were common to southeast Asia together with other cultural influences such as Buddhism in the latter first millennium BCE. In the medieval Tamil text, *Arrichantira Puranam*, *kanjanam* is used to describe a shining mirror whilst this word is also used to describe cymbals (Tamil Lexicon), conveying the metallic lustre of high-tin bronzes. Thus, it is probable that the Aranmula mirror making process evolved out of longstanding metallurgical traditions prevalent in the Indian subcontinent for the use of bronzes of a high tin content. Significantly, in recent years this skilled and quaint mirror craft from Aranmula has been awarded a Geographical Indicator (GI) patent in India.

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Moses Maimonides

Y. Tzvi Langermann

Moses Maimonides (1135–1204) is without a doubt the single most luminous figure in Jewish intellectual history since Talmudic times. He possessed professional expertise in most of the sciences of his day, most notably astronomy, mathematics, and medicine. Maimonides' early education in Spain, the country of his birth, seems to have stressed the exact sciences in particular. He refers in his writings to his studies with some students of Ibn Bājja. Furthermore, he edited and taught scientific texts written by two Andalusians, ► [Jābir ibn Aflāh](#) and al-Mu'tamir ibn Hūd.

In matters astronomical Maimonides' chief contributions concern problems of cosmology and the first visibility of the lunar crescent. As to the former, Maimonides devotes an entire chapter (II, 24) of his philosophical *chef*

d'oeuvre, *The Guide of the Perplexed* (Arabic *Dalālat al-Ḥā'irīn*; Hebrew *Moreh ha-Nevukhim*), to a discussion of the various ways in which the then-accepted models for planets violate certain basic principles of Aristotelian natural philosophy, namely that all heavenly motions be uniform, circular, and about a stationary center. (This problem, by the way, seems to have vexed Andalusian thinkers in particular.) Maimonides surveys the proposed solutions of Ibn Bājja and Thābit ibn Qurra, but he finds no way out of the quandary. It remains a matter of debate among scholars whether Maimonides considered the problem insoluble, since the true workings of the heavens are a matter for metaphysics and hence beyond full understanding, or whether he felt the problem had a solution, indeed, one which would yield a system not very unlike the Ptolemaic models which he criticizes.

In the closing chapters of the section of his law code (*Mishneh Torah*) devoted to the sanctification of the new moon, Maimonides develops a full, sophisticated method for computing whether or not the crescent will be visible on the eve of the 13th day of the lunar month. One calculates the "arc of vision," which is the sum of the difference in right ascension between the true positions of the two luminaries, and two-thirds the latitude of the moon. If this arc is greater than 14° , or the sum of the arc and the elongation (the difference in ecliptic longitude between the two luminaries) is greater than or equal to 22° , the moon will be visible. As Maimonides himself avers, the method draws upon written sources, but some of the procedures have been simplified without doing damage to their accuracy.

Maimonides forcefully repudiated astrology. Like nearly all of his contemporaries, he acknowledged a gross physical effect which the motions and luminescence of the heavenly bodies exercise upon terrestrial processes. However, he rejected the notion, central to the astrology of his day, that the stars emanate any noncorporeal force, and he passionately urged that neither individuals nor nations allow themselves to be guided by astrological forecasts.

Maimonides was both a practicing physician and a medical author. According to his account,

he traveled daily to treat the sick at court, and upon his return he found his waiting-room full of patients. His medical writings include condensations of the important works of Galen, and a number of original books and monographs. The final section of his own *Aphorisms* (*Fuṣūl Mūsā, Pirqei Moshe*) consists of a scathing critique of Galen's views on medicine and philosophy. Maimonides' medical writings display erudition, clear and concise formulations, and insight; however, his place in the history of medicine, particularly against the background of his contemporaries, remains to be determined.

Maimonides held definite opinions concerning the history and philosophy of science. Scientific teachings must be founded upon solid logical demonstrations. True, observations are vital, but purely empirical claims – those whose authenticity rests solely upon repeated observations, but cannot be placed within any logical framework – are not scientific. This point is made forcefully in his treatise on asthma, and it is one of the underpinnings of his rejection of astrology. Moreover, Maimonides held the view that science progresses in a cumulative fashion, through the refinement of existing data and the absorption of new information; there are no revolutionary leaps. Thus he was able to have it both ways with regard to unsolved issues, e.g., the question of the structure of the heavens. He took tactical advantage of the problem, using the cosmological quandary to attack the doctrine of the eternity of the universe (which rested on astronomical arguments), yet at the same time he felt confident enough in his basic understanding of the workings of the heavens to make use of that knowledge as a steppingstone in the path to knowledge of the Creator.

The most lasting influence of Maimonides, at least as far as his Jewish readership is concerned, was not in the specific scientific knowledge that he disseminated. Rather, his momentous contribution was to elevate the study of the sciences within the context of the religious life. According to Maimonides, the ritual performances and ethical demands of the Jewish tradition have as their goal the preparation of the individual for knowledge of God (to the extent

that this is humanly possible), and mastery of the sciences is an indispensable step in this process of religious fulfillment. The observant Jew who follows the lead of Maimonides will regard the study of the sciences as a primary religious obligation.

See Also

- Jābir ibn Aflāḥ
- Thābit ibn Qurra

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Mound Builders

Connie H. Rickenbaker

The subject of mound builders is a vast topic involving numerous groups throughout the Eastern United States. Earthen mounds, one of the visible traits of these cultures, are located from the Gulf of Mexico to the Great Lakes with concentrations in the Midwest along the Ohio and Mississippi River drainages. Numerous mound-building cultures were present across this area and through time, and the mounds served a variety of functions.

In some places conical mounds were built to inter the dead while flat-topped pyramidal mounds served as the foundations for important buildings, such as temples or chiefs' residences. Some of the better known mound sites are Cahokia, near St Louis, Missouri (cultural phases and occupation between AD 800 and 1200) of the Mississippian tradition (*Cahokia Mounds*), Moundville, Alabama (a dominant center from AD 1250 to 1500) (*Moundville*), and those associated with the Hopewell Culture (ca. 200 BCE–AD 400), centered in the Ohio Valley (*Hopewell*).

One of the most acrimonious debates of nineteenth century American archaeology concerned the origins of the mound builders of North America. The Europeans first noted the mounds in the late eighteenth century and quickly began arguments as to whether or not the Indians had constructed the structures. These continued until Cyrus Thomas' *Report of the Mound Explorations of the Bureau of Ethnology* (1894) demonstrated that Native Americans had built the mounds.

Styles and raw materials used by individuals varied between cultures based on location and time, but all of the people expressed their creativity and ingenuity through manufactured material artifacts. Indian technology included the actual mound construction, tool manufacture, pottery, and archaeoastronomy. A brief discussion of each technology follows.

Mound Construction

The types of soil and amount of material necessary for mound construction vary with each site whether they were built in prehistoric or historic time periods. The tons of material moved from the point of origin to a mound attest to the division of labor and orderliness of each culture. Individual basket loads denoting the means of transporting the raw material are often visible at excavations. The number of mounds at a single site varies greatly from 1 or 2 to over 100 as evidenced at Cahokia. The number of mounds does not correspond with any particular time

period. Watson Brake, the oldest known earthen works in North America, is composed of 11 mounds all connected by a human-made embankment (*Watson Brake*). One example of mound construction is the serpent mound from the Hopewellian culture which is nearly one-quarter of a mile long (*Serpent Mound*).

The people outlined the structure with small stones and lumps of clay and then dug up tons of yellow clay and then buried their markers. This mound was not a place of burial, but a deliberate religious effigy with the result of a "flawlessly modeled serpent, wriggling northward, mouth agape, trying to swallow a massive egg" (Ballantine, 1993).

Tool Manufacture

People of the mound cultures made projectile points for hunting through the process known today as flintknapping. The knapper of a point used an antler hammer or stream cobble to remove flakes from the larger stone core. Smaller flakes were carefully removed as the work progressed on a single point flake. The final forms evident from some mound sites illustrate the meticulous work of highly skilled flintknappers across time and cultures. Changes in projectile point size probably reflect environmental changes that resulted in variations in prey species and probably also in hunting techniques.

For thousands of years prehistoric hunters used a spear or javelin with a point attached to kill their prey. Forms of points aid archaeologists in dating sites where some designs are similar across time, while others differentiate particular cultures. Eventually the *atlatl* or spear thrower was introduced, which increased the casting distance and power of the throws. The hunter held the *atlatl* which was shaped like a large crochet needle. The hooked end was inserted into a shallow socket in the end of the spear opposite the point and hurled with a smooth gliding motion. The *atlatl* was made from available wood while the *atlatl* point was bone or stone.

The technology of preparing meat after the kill also required specialized tools including knives,

scrapers, and cutters. Although similarities in design exist across time, individual types are indicative of different cultures. The parent material tells much about a mound site and whether or not the people were involved in trading. Some prehistoric mound sites were cultural trading centers such as Poverty Point (1500 BCE) in north-eastern Louisiana where numerous raw materials were used by the people for grafting material artifacts. Trade routes were known to have spanned multiple state areas as the material artifacts were made from copper, quartz, jasper, chert, and flint which were imported into the area (*Poverty Point*).

In addition to the technology for meat preparation, the people of the mound cultures prepared the animal skins for clothing and other utilitarian purposes. Construction of these items required technology for removing, preparing, and sewing the skins. A list of the tools used by people from the different mound cultures includes hammerstones, polishers, and whetstones. These tools required little if any modification of natural materials by the individual. However, once used, the alterations in shape and signs of wear indicate their uses. Other tools such as axes, drills, gouges, celts, and adzes had to be carefully shaped. Drills and gouges were used to make perforations in the skins, while celts and adzes were used for cutting.

Prehistoric technology also included the use of bone to manufacture different tools for the work around a community. The bone tools were made by breaking and grooving animal bones and then grinding the bone to shape the needed object. Fleshers, used to scrape the inside of fresh animal hides, were usually the lower leg bone of a large animal. Awls were used for perforating and sewing along with small hammers, and fish hooks were made from antlers or bone.

Pottery

The need to transport water and store food necessitated the use of containers for these purposes. Pottery making was an integral part of many of the later mound cultures. The earliest designs were simple and fewer vessels were made, but

as time passed the designs and technology for pottery making resulted in works of great beauty and complexity. As with projectile points and other tools, the designs, shapes, and materials of the pottery crafted reveal specific information indicative of particular mound cultures.

In addition to everyday use, pottery was also part of ceremonial practices including burial. Whether a vessel or only a potsherd, the pottery yields valuable information about the technology of the cultures. Various tempering materials, including shell, bone, and sand, were mixed with the raw materials to strengthen it. In most mound cultures both decorated and undecorated pieces were crafted and the use of coloring slip was also part of the technology for some.

Decoration on the pottery, whether bowls, jars, or effigy pieces, was usually applied before the vessel was dried. A variety of methods were used which are significant because the individual expressions reflect change over time and culture. Decorations were often made by using the fingertip or a pointed stick or bone. Potters also used the cordwrapped technique which required wrapping a paddle or stick with a cord or woven material and then pressing it into the wet surface to create a pattern. Check-stamped decorating made use of carved bone or wood which was pressed or stamped into the object. As with the technologies of all the mound cultures, some individuals crafted pieces which are exquisite works of art illustrating the creativity and ingenuity of intelligent people from different mound cultures through centuries of time.

Archaeoastronomy

Native Americans are known for their close association with nature and the heavens. The lives of the people from the mound cultures were also intertwined with the cycle of celestial bodies as they observed eclipses and the solstices, devised calendars for ceremonies, and established planting times. They left messages of their science and wisdom in their artifacts and the earthen works which are the visible legacy of their makers.

Archaeologists have studied two research questions related to Mississippian cultures. They concern measurement and units of measurements used by the mound builders/community planners, and archaeoastronomy. Studies have been conducted at Cahokia near St Louis (list of websites provided) and in Arkansas at the Toltec Mound State Park (*Toltec Mound*) to investigate the utilization of both orientation to celestial bodies and preconstruction engineering by the mound builders.

Results from a preliminary study by Sherrod and Rollingson (1987) show that within the Arkansas community there is a predetermined spacing of mounds. The unit is termed the Toltec Module and is measured in increments divisible by 47.5 m. Alignments of the solstice, equinox, and stellar positions are evidence that the mound builders placed importance on the observation and knowledge of celestial phenomena and the mounds were positioned to mark these alignments permanently (*Alignments*).

Reconstruction planning of the community features including mound construction is evidenced by both standardized distance spacing and celestial alignment. "Interaction among many communities of the Mississippi River Valley may well have been widespread with the use of the Toltec Module a reflection of this interaction" (p. 81).

Questions go unanswered and debates continue concerning the mound builders. What do the mounds mean and why were they built? What were the mechanisms which powered the large exchange and trading systems within cultures such as Poverty Point? Also debated is the issue of size of actual populations at the large ceremonial sites. The study of archaeoastronomy and standardized measurements are still in early research stages and thus the extent of Indian technology and meaning are still open for further investigation (*Archeoastronomy*).

Recent research by Saunders, Allen, and Saucier (1994) of four mound complexes in Louisiana which predate Poverty Point raises the question as to whether mound construction technology diffused from a single area or

independently developed within several cultures. In relation to actual construction of the mounds anywhere, did their makers build one at a time or were multiple mounds under construction at the same time? See below for websites on Watson Brake.

A growing area of research which includes the mound builders is the archaeology of gender (Gero & Conkey, 1991; Walde & Willows, 1991). Interpretation of archaeological sites has been dominated by views in which women and children were underrepresented if present at all in much research. As the mound builders are studied from more equitable views, questions emerge on women's roles as tool makers and hunters. One theme which unifies the research is the theoretical outlook which views gender relationships as the fundamental structural component to social organization.

Peoples in other parts of the world also built mounds and earthen structures. They frequently consist of only one structure. Several examples are found in Ireland referenced as megalithic tombs and include Newgrange and Knowth (*Knowth*). Lennart S. Madsen discussed earthworks in Scandinavia in his presentation, "The Role of Earthworks in Establishing the Danish Kingdom – second to thirteenth Century AD." At the same Society for American Archaeology 2001 Conference, Maximilian O. Baldia presented "Monuments at the Crossroads: Comparative Archaeology of North American and European Monuments." Their abstracts can be accessed via the internet (SAA Conference, 2001).

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Moxibustion

Shigehisa Kuriyama

Moxibustion, also spelled moxabustion, is a traditional East Asian therapeutic technique involving the burning of tinder made from the artemisia plant. The technique has three major variants. In one, small cones of the artemisia are burned directly on the skin; in a second, some intermediary substance – commonly a thin slice of garlic or ginger, or a layer of soybean paste – separates the tinder cone from the skin; and in a third, smoldering sticks of artemisia, about a half inch in diameter, are held about an inch to 3 in. away from the skin. The last two methods fall under the rubric of “warming” or “traceless” moxibustion: both heat the treated sites, but unlike the first technique, they leave no scars. There is, in addition, a hybrid combination of acupuncture and moxibustion in which a clump of artemisia is burned at the protruding end of an implanted needle.

The word *moxa* comes from the Japanese term for the artemisia tinder, *mogusa*. Though the term may have made its way into Portuguese as early as the sixteenth century, printed Western language accounts of the technique began to appear only in the 1670s. For a brief while, it enjoyed a minor vogue in Europe, particularly as a treatment for the gout, but ultimately it did not take root. Still, occasional theses on moxibustion continued to be presented at European medical faculties into the nineteenth century.

The details of moxibustion’s origins in China are uncertain. In the most ambitious review of the subject to date, Yamada shows that the therapy originally had magical implications: the aim of cauterization was to drive out alien, noxious spirits. He argues that by the early Han dynasty (206 B.C.E.–A.D. 220), however, moxibustion had begun to assume a new, quite different identity. Gradually shedding its ties to demonic expulsion, it came to be conceived, instead, as a form of stimulus therapy. The purpose of burning

now was to clear blockages in the flow of the body’s own essences and rectify imbalances in the distribution of blood and vital breath (*qi*). Yamada’s analysis of this change builds upon three theses (1) that the key to the transformation of moxibustion was the “discovery,” in the third century B.C.E., of a series of *mo* – vessels thought to carry blood and vital breath throughout the body; (2) that the theory of the *mo* first arose in the context of moxibustion; and (3) that the practice of acupuncture followed, and was made possible by, the discovery of the *mo* in moxibustion.

Yamada’s account may not cover the full story; some evidence suggests that the experience of bloodletting also contributed to the rise of acupuncture. But two points are indisputable. The first is that the earliest descriptions of the *mo* – those in the Mawangdui manuscripts (third century B.C.E.) – concentrate exclusively on moxibustion, and do not mention needling. The second is that from the Han dynasty onward the histories of moxibustion and acupuncture were intimately intertwined. More often than not, acupuncture treatises were, at the same time, treatises on moxibustion. The titles of major traditional texts – from Huangfu Mi’s ► [Zhenjiu jiyajing](#) (A.D. 282), through Wang Zhizhong’s *Zhenjiu zisheng jing* (1220), to Gao Wu’s *Zhenjiu jiejiao* (1536) and Yang Jizhou’s ► [Zhenjiu dacheng](#) (1601) – all evoke needling (*zhen*) and moxibustion (*jiu*) together in the same breath, as a compound, *zhenjiu*. The reason is clear: healing with moxa entailed burning artemisia along the same *mo*, and indeed on the same sites, needed in acupuncture.

Physicians did distinguish between the two therapies. For Yang Jizhou, in fact, the ability to discriminate between when and where to burn and not needle, and conversely, when and where to needle but not burn, marked the superior physician. Gao Wu’s *Zhenjiu juying* (1537), for instance, names 45 “forbidden points” for moxibustion (sites where treatment was to be avoided or at least pursued with special caution), but for acupuncture names only 22. The two lists, moreover, have no points in common.

Between the seventh and thirteenth centuries, physicians also composed several treatises

devoted to moxibustion alone. Cui Zhiti's *Guzhengbing jiufo* (640) discussed how to treat tubercular diseases with moxa and Wenren Qian's *Beiji Jiufo* (1226) explained how to deploy moxibustion in emergencies; Zbuang Zhuo's *Gaohuang jiufo* (1128) detailed the special benefits of burning moxa on the so-called *gaohuang* points, whereas the *Mingtang jiujiing* (seventh century) reviewed treatment sites more generally, identifying for each site the various ailments treatable by moxibustion.

By slight modifications in technique, moxibustion could be used either to tonify deficiencies in vital energy, or to disperse pathological excess. For example, to tonify, one simply allowed the moxa cone to burn down naturally; to disperse, the therapist blew gently upon the burning cone to make the heat more intense. Traditionally, however, the tendency was to deploy moxibustion primarily as a tonifying technique, and to favor it for treating chronic disorders.

People also turned to moxibustion to prevent illness. In his *Yaofang* (seventh century), Sun Simiao ► ([Sun Simo](#)) notes that officials going to the regions of Wu and Shu made sure always to keep several unhealed moxa spots on their bodies. This, they believed, protected them from a variety of epidemic diseases. More generally, it became proverbial wisdom that burning moxa regularly on special sites like the *sanli* points of the legs warded off sickness of all kinds, and promoted longevity.

Moxibustion's popularity as a prophylactic measure and as a treatment for chronic complaints drew theoretical support from the belief in its tonifying influence. But it also reflected a more basic fact: unlike needling, burning moxa did not require sophisticated technical skill. Once patients learned where to burn – whether guided by illustrated books, tradition, or doctors, then they could treat themselves, or be treated by family members. Thus, while acupuncture and moxibustion shared common historical origins and a common understanding of the body, the sociology of their practice diverged. Whereas acupuncture remained largely the preserve of specialists, moxibustion tended to become part of popular self-treatment.

Professional acupuncturists in East Asia today still make use of moxibustion, but so do many patients who have never been needed.

See Also

- [Acupuncture](#)
- [Huangfu Mi](#)
- [Medical Texts in China](#)
- [Medicine in China](#)
- [Medicine in Japan](#)
- [Sun Simo](#)

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Mummies in Egypt

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Mummification was practiced in ancient Egypt to ensure the continued existence of the deceased.

At death, several spirits were believed to be released, the most important of which were the Ka, the Ba, and the Akh. A person's fate in the afterlife, in the form of these three spirits, was believed to be directly tied to the continued existence of the physical body.

The Ka, appearing at birth, resembled the human physical body in all aspects. After death, it remained in the tomb with the mummified body, acting as a protective spirit, and fed on the daily offerings presented at the tomb. The Ba embodied the personality and individual characteristics of the person. It also appeared at birth but, after death, was believed to fly off to heaven, returning regularly to visit the Ka and the body. It sometimes seemed to serve as the "spiritual link" between the two. The Akh, after a silent or dormant existence during the person's life, separated from the body at death and embarked on a journey through the land of the dead, never to return. All three spiritual elements were essential for the continued existence of the individual and their continued survival depended on the existence of the human body.

Egyptians in the pre-dynastic era (prior to 3100 BCE) buried their dead in shallow graves under the hot desert sands, where they were naturally desiccated and preserved. But this left the body prey to wild animals and desert thieves. From the first dynasty (ca. 3100–2900 BCE) onward, the Egyptians built mud brick burial chambers to protect the dead, but these tombs separated the body from the dry desert sand so that it failed to become desiccated and slowly deteriorated.

By the end of the Old Kingdom (ca. 2600–2180 BCE), the Egyptians had begun to embalm their dead (Koller, 1998), achieving desiccation by means of natron (a mixture of sodium carbonate and bicarbonate). The technique was later termed "mummification" from the Persian word *mummiya*, meaning bitumen or pitch. Corpses embalmed by the Egyptians took on a darkened color, and this effect was mistakenly attributed to bitumen.

By the Middle Kingdom (ca. 2150–1780 BCE), the desiccation process of mummification and its associated rituals had taken shape. After

death, the body was taken to the "place of purification" where it was stripped and washed in a dilute natron solution. It was then moved to a special "embalming house" where it was placed on a large wooden board. The brain was often removed. This was done through the nose (to avoid damaging the features of the face) by breaking through the ethmoid bone and inserting a hooked utensil which was moved around and around until the brain tissue was broken down. The empty skull was filled with sawdust, resin, or resin-soaked linen.

An incision was then made on the left side of the abdomen using an "Ethiopian stone" (obsidian glass), and the liver, stomach, and intestines were removed. A puncture in the diaphragm allowed the removal of the lungs. The heart was left in situ since it would be needed for the "weighing of the heart" ritual when the deceased began his journey to the afterlife. (As the center of consciousness in which the good and evil deeds of the individual accumulated, the heart was weighed against a feather representing the goddess Ma'at – a lightweight heart (free from evil) at the day of reckoning would ensure an afterlife for the individual.)

The removed organs were washed with a natron solution, desiccated by immersion in dry natron, wrapped in linen, and sealed in canopic jars (often with a solution of natron). These canopic jars were eventually placed in the tomb with the mummy. The empty abdominal and cranial cavities were washed with palm wine and myrrh and packed with small linen bags of natron. The body was then placed on a slanting board and covered with dry natron for 35–40 days during which it was desiccated by osmosis (the skin acting as a semipermeable membrane).

Following the dehydration of the body came a ceremonial anointing with oil to restore some flexibility to the body. The cranial and body cavities were repacked with linen soaked in resin or sometimes with sand or even rolls of linen cloth, the abdominal incision was closed, and onions or linen balls might be inserted into the eye sockets and the cheeks padded with linen in order to give

the mummy a more lifelike appearance. The body was then coated with molten resin and subsequently wrapped, beginning from the extremities, using strips of linen arranged in intricate patterns. In some cases, the body would be adorned with jewelry, and amulets conferring special protection on the mummy would be enclosed in the linen wrappings.

The entire embalming process (desiccation and wrapping) took 70 days, after which the ceremony of the “opening of the mouth” took place. A priest would symbolically touch the mouth, eyes, and ears of the wrapped mummy with a ceremonial adz so as to reawaken the senses and allow the deceased to function in the afterlife. This would be followed by an elaborate succession of rituals and prayers as the deceased was placed in the tomb where he would live forever and the door was ceremonially sealed.

The practice of mummification, with some variations in the process of preparation and wrapping, continued in Egypt until the fourth century AD, when Christianity had become the principal religion. The practice then steadily declined.

For the last century, mummies have been intensively studied using modern autopsy techniques. These studies have revealed many important details about types of diseases prevalent in ancient Egypt, health care, diet, lifestyle, and similar characteristics of the ancient Egyptian lives (Cockburn, 1980; Nerlich, 1997; Aufderheide, 2003; David, 2008).

Although we know a great deal about the general process of mummification both from the study of mummies and from documentary and iconographic evidence, the details are still sometimes unclear. Several recent experimental attempts to recreate Egyptian mummies have been made. The first was by Bob Brier and Ron Wade (1994), who mummified a human cadaver by immersing it in dry natron for 35 days (Brier, 1996). More recently, Frank Rühli and his team attempted to mummify the two legs severed from a female cadaver using the same technique. And in 2010, Steven Buckley and his team at the University of York mummified a cadaver using a different technique – immersing the body in an aqueous natron solution for 35 days, after which

the body was wrapped in linen bandages and allowed to desiccate in warm dry air. (Both the Brier experiment and the Buckley experiment were the subject of TV documentaries.) Each of these experimental techniques was done under carefully controlled scientific conditions. Each study has revealed more details about the ancient Egyptian process of mummification although several questions remain unresolved.

Animals were also mummified in ancient Egypt (Ikram, 2005). Some of these animals were apparently personal pets, such as dogs that the owners wished to accompany them in the afterlife. Others were sacred animals, such as the Apis bulls. These bulls received exceptional preservation treatment. Still others, such as cats (sacred to the goddess Bastet) and ibises (an incarnation of the god Thoth), were mummified by the millions and presented to the temples as votive offerings. These mummies were often stored in subterranean tunnels and chambers. Such votive mummies were typically created simply by wrapping the dead animal tightly and allowing it to desiccate in the air. Some of these votive mummies are incomplete (“fake” mummies) – in some cases only a few bones or feathers – for reasons that are not well understood.

See Also

► [Animal Mummies](#)

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Mummies in South America

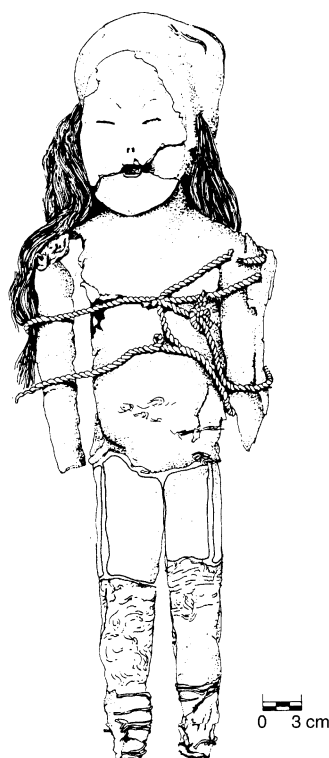
Bernardo Arriaza and Vicki Cassman

The Atacama desert, along the west coast of Chile and Peru, is an area of extreme aridity which has provided for unique preservation of human remains and cultural materials from thousands

of years ago. The incredible preservation, especially of human mummies, has furnished us with a glimpse at mortuary traditions and rites associated with the first settlers beginning at least 9,000 years ago, through to the arrival of the Spanish Conquistadors.

The Chinchorros fishermen, who lived from 7000 to about 1500 BCE, are of special interest because from 5000 to 1700 BCE, they practiced artificial mummification of their dead. The Chinchorro people lived in the Atacama from Ilo in Southern Peru to Antofagasta in Northern Chile, and occupied about 900 km of the Pacific coast of South America. The area surrounding the modern city of Arica, in northern Chile, was where Chinchorro artificial mortuary practices originated. From this area artificial mummification customs (or intentional interventionary preservation) spread north and south. The bodies were prepared for the journey to the afterlife in remarkable ways. For example, some bodies were completely disarticulated and then wholly reassembled and sculpted. Various styles were practiced through time, such as Black, Red, and Mud-Coated styles. All these styles have two things in common: human intervention in the preservation of the cadaver, and an extended body position for interment.

The Black Mummies were the oldest and most complex, beginning about 5000 BCE and lasting for about two millennia. To make the Black Mummies, the morticians completely cleaned and separated the deceased's bones and soft tissue. Subsequently, the skeletons were reconstructed, and the bodies rebuilt into statue-like rigid forms, using long sticks for internal reinforcement along the extremities and spine. Reed cords bound the bones and sticks together, and a light gray ash paste was applied to stuff and model the individual. The skin was often replaced, and sometimes pieces of sea lion skin were added when the person's own skin did not suffice after drying. Facial features and sexual organs were insinuated. A short wig of human hair was added to the head and secured with cords. Then the morticians painted the entire body with a black manganese paste, which was polished to a high sheen, hence the name Black Mummies.



Mummies in South America, Fig. 1 Chinchorro child in the Red Mummy Style (Drawing by Raul Rocha, used with permission of the author)

In contrast, the Red Mummies often were made without disarticulation of the body. Instead incisions were made to remove organs. Long sharpened sticks were pushed under the skin of arms, legs, and the spine to add rigidity, and body cavities were stuffed. After suturing the incisions, the body was painted with red ocher, but the facial mask was often painted black. In a few cases the skin was replaced bandage style. A wig made of long black human hair was added to the head and secured with what looks like a red clay motorcycle helmet. This Red style appeared about 2000 BCE and lasted about 500 years (Fig. 1).

After the Red style, artificial mummification techniques were simplified. The bodies were not eviscerated; they were simply encased in a thick cement-like coating that prevented decomposition. This Mud-coated style lasted only a couple of centuries. After this period, ca. 1700 BCE, the

Chinchorro bodies were still buried in an extended position, but were preserved only through the desiccating forces of the environment; they were no longer artificially mummified.

Often the Chinchorro mummies were enshrouded in twined reed mats and buried in shallow pit graves in groups of about six bodies of various ages and both sexes. The cemeteries were located in the sandy coastal dunes beyond the reach of the tides. The few grave goods accompanying the dead were fishing lines, shellfish and cactus fishing hooks, harpoons, bone and stone tools, stone mortars, and gill nets. No individual had a substantially larger number of grave goods that would set him apart as socially above the others. The Chinchorros also received similar mummification and burial treatments regardless of age and sex. Even fetuses were mummified. Apparently everyone was treated equally, with the same mortuary treatment, as would be expected in an early egalitarian society.

Although Chinchorros were simple fisherfolk without knowledge of ceramics, agriculture, or loom weaving, their spiritual and religious life must have been highly sophisticated, as the mummies have demonstrated. The sophistication of the mortuary treatment, the repair of the mummies, and the millennial duration of their practices, all indicate that mummification was central to the social lives of Chinchorro people. It appeared they venerated the mummified bodies of their ancestors by placing them on display for an extended period before burial. Perhaps they petitioned the mummies for blessings during their daily lives. Later South American cultures like the Incas revered their desiccated ancestor mummies (natural mummification). For the Inca the dried bodies of their ancestors were considered *Huacas* or deities that had the power to provide fertility, good crops, and happiness. The Inca brought food and drink to the dead and included the mummies in their religious celebrations. For the Incas and the Chinchorros, the mummies linked the real world with the spiritual world.

The Chinchorros did not vanish after their artificial mummification disappeared about

1700 BCE. On the contrary, their descendants continued to thrive along the Pacific coast, with increased social and political complexity. However, for most areas, after 1500 BCE, the dead were buried in a flexed or seated position, and became natural mummies by the desiccating action of the desert. Post-Chinchorro cultures developed and took advantage of new technologies such as agriculture, weaving, ceramics, and metallurgy, and now the dead were furnished with paraphernalia related to these achievements. Thus, from the numerous grave goods accompanying the dead, it can be seen that post-Chinchorro people also had powerful spiritual concerns about death and the afterlife.

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Muniśvara

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Muniśvara, also known as Viśveśvara, was a seventeenth-century mathematician from Vārāṇasi (Benaras). He was the author of a number of works like the *Pāṭisāra*, the *Gaṇitaprakāśa*, and the *Siddhāntasārvabhauma* and wrote two glosses on the treatises of Bhāskara II, the *Niṣṛṣṭārthadūtī* on the *Līlāvatī* and the *Marīcī* on the *Siddhāntaśiromaṇi*. He seems to have served the Mughal ruler Shah Jahan (r. 1628–1658).

Muniśvara (b. 1603) belonged to a long and illustrious pedigree of mathematicians and astronomers hailing from Maharashtra. His father Raṅganātha came from the village of Elachpur near Dewas in Madhya Pradesh and was the author of the *Gūḍhārthaprakāśikā*, a commentary on the *Sūryasiddhānta*. Raṅganātha's brother Kṛṣṇa Daivajña was also an accomplished mathematician who wrote two glosses on Bhāskara II, the *Navāṅkura* on the *Bījagaṇita* and the *Kalpalatāvatāra* on the *Līlāvatī*. Kṛṣṇa Daivajña is known to have served at the court of the Mughal ruler Jahangir (r. 1605–1628). Both Kṛṣṇa Daivajña and Raṅganātha were taught by Viṣṇu, the son of Divākara Daivajña from Golagrāma on the Godāvari in Maharashtra, who was in turn a student of Gaṇeśa Daivajña of Nandigrāma near Mumbai, who promulgated the grating method (gelosia method) of multiplication.

Muniśvara is known more for his elaborate and lucid exposition of astronomical and mathematical principles than for the originality of his contribution. However, he seems to have been a controversial figure during his lifetime. Raṅganātha (not to be confused with Muniśvara's father of the same name), who wrote the *Siddhāntacūḍāmaṇī*, took exceptions to the winding (*bhaṅgī*) method Muniśvara adopted for calculating true planets, which in turn provoked Muniśvara's criticism in the *Bhaṅgīvibhaṅgīkhaṇḍana*. Muniśvara was sympathetic toward Persian and Arabic systems of trigonometry and adopted them at different times. Nevertheless, he slated Kamalākara, who had adopted Persian and Arabic systems and principles from the *Elements* to criticize Bhāskara II. His response to Ekanātha's critique of his gloss on three verses on *krāntī* (declension) in Bhāskara II's *Siddhāntaśiromaṇī* was spirited and aptly titled *Ekanāthamukhabhañjana* ("a slap on Ekanātha's face").

Among the other works of Muniśvara's are the gloss on an obscure work called *Āśayaprakāśinī* and another on Gaṇeśa Daivajña's *Pratodayantra* (also called *Cābukayantra*), a work on a clocklike instrument.

See Also

- [Astronomy in Medieval India](#)
- [Bhāskara II](#)
- [Kamalākara](#)
- [Mathematics in India](#)

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***Nāgarasarvasva* of Padmaśrī**

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The *Nāgarasarvasva* is a medieval treatise on the “Science of Desire” (Kāmaśāstra), composed in South Asia probably around the year 1000 (although its date is far from clear and could be anywhere between 800 and 1300 CE). It comprises 38 chapters, altogether 330 Sanskrit verses, covering a number of related topics that are intended as the totality (sarvasva) of what an urbane townsman (nāgara) should know, in order to refine and amplify one’s sexual pleasures.

The author, Padmaśrī, shows a rather clear affiliation to Buddhism. The treatise begins with a praise of Red Mañjuśrī, the great Bodhisattva of Insight, here invoked in connection to success in one’s enjoyment of women. The initial sections of the treatise also explain the necessity of this branch of knowledge, in terms of benefitting others (especially desirous women), and quote a Buddhist stanza that stresses the importance of relieving others’ suffering. More precisely, the text praises those meritorious men who go beyond their own desire and focus solely on bringing relief to women afflicted by the “fever of desire.”

The text is remarkable in its assortment of topics and techniques, many of which are related

to personal cultivation and refinement, proper deportment during courtship, or recognition of female behaviors and types, rather than to the sexual act per se. Thus, we find a chapter on the qualities and flaws of gems and what this will bring to their bearers; another chapter describes the preparation of betel-nut boxes and the many coded messages to be discretely passed through them. Similarly, the text offers a lengthy explanation of signs (often hand gestures) that will allow understanding the wishes and secret indications of refined women – as they are easily annoyed at men’s lack of recognition of their signals. A long chapter describes the amorous attitudes of women, called *hāva*, in verses that delineate and then exemplify situations of flirting, jealousy, and a number of enjoyable behaviors suggestive of internal states and thus related to dramaturgy and literary aesthetics. The *Nāgarasarvasva* was often quoted in later treatises on *Alaṅkāraśāstra* – the science of literary ornament – enjoying a long-lasting popularity beyond its immediate subject matter.

A remarkable feature of the *Nāgarasarvasva* is its obvious link to Tantra, here mostly understood and employed as a technique to operate on the subtle functioning of the body, through visualization and mantras, and by accessing an inner physiology of channels (*nāḍī*). The author explicitly mentions at least one Buddhist Tantra related to Mañjuśrī and offers a gamut of mantras, seed syllables, and magic procedures, which will either enhance sexual performance or bring

about the conditions to obtain one's desired woman. Visualization and mantra recitation is described as being so efficient that one may satisfy a woman even without any physical contact. We also find a chapter on how to ensure the birth of a son, where two alternative methods are presented: one related to the worship of Tārā (for the Buddhist) and one related to the worship of Śiva (for the non-Buddhist).

The sections on sexual activity proper include anything from kissing and scratching to full-fledged copulation in a variety of positions. The text seems to be thoroughly concerned with refining and mediating one's sexual activity; this is well captured by an initial verse that explains how this branch of knowledge will allow one to take full advantage of one's birth as a human, by being able to have sexual enjoyments at least higher than what bulls may obtain with cows.

The existence of a significant manuscript tradition shows that this text was popular in Nepal; in fact, the text survives with a commentary ascribed to King Jagajjyotirmalla, ruler of the Kathmandu Valley between 1617 and 1633 CE. The commentary makes some of the more esoteric procedures explicit, at least suggesting the possibility of a long-lasting living tradition associated with the *Nāgarasarvasva* between the time of its composition and the Malla period.

The modern editor of the text (Tanusukharāmaśarma, probably a pseudonym) offers an interesting twentieth-century commentary, including unusual ideas about the history of Buddhist literary aesthetics, and the cultural translation of ancient technology (*kṛtrimaliṅga* is glossed in Sanskrit as *ḍiḷḍo*).

The *Nāgarasarvasva* shows that the intersection and classification of human concerns and activities in medieval South Asia was complex and rather different from most contemporary societies. The premodern South Asian science and technology of pleasures included a vast array of knowledge and trainings. These were intended to refine one's awareness of the body and its pleasures, in their inner resonance with an esoteric map of sounds and invisible passages.

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Namoratunga

Lawrence H. Robbins

Archaeoastronomy is the study of archaeological evidence documenting that ancient peoples made systematic observations of astronomical phenomena such as solstices and equinoxes (Robbins, 2003, Chap. 6). Most typically, archaeoastronomical evidence is reflected in the positioning and alignments of buildings, earthworks and megaliths, such as at Stonehenge in England (Robbins, 2000). There, the sun rises over the heel stone on the summer solstice, or first day of summer. In most cases, archaeoastronomical sites are thought to reflect religious beliefs in which the seasons of the year were being monitored for ceremonial purposes as well as for agricultural planning. For example, at the Egyptian desert site of Nabta Playa (Malville et al., 1998, p. 488) have found megalithic alignments dated to before 4,800 years ago, suggesting “a symbolic geometry that integrated death, water and the sun.” This Saharan site is reasoned to have been even older than Stonehenge and other European megaliths. Among other alignments, the stone circle at Nabta Playa known as E-92-9, appears to have been a place that monitored the initial rising of the summer solstice sun.

Namoratunga,
Fig. 1 View of
Namoratunga II stone
pillars near Kalakol
(Photo by Robbins)



Namoratunga,
Fig. 2 Another view of
Namoratunga II stone
pillars (Photo by Robbins)



N

In Africa south of the Sahara, much less is known about the archaeological record relative to many other areas because of the comparative lack of intensive research. Therefore, the announcement of the discovery of the first archaeoastronomical site in 1978 was of considerable interest (Lynch & Robbins, 1978). The site of Namoratunga II, overlooking the barren western shore of Lake Turkana in Kenya has been compared to a miniature Stonehenge. Namoratunga II consists of a series of 19 basalt pillars that have been placed in the ground at angles (Figs. 1 and 2).

The basalt used at Namoratunga II is locally available in the Losidok range. A stone circle

surrounds the alignment of pillars, and there is at least one nearby grave marked by upright slabs. This grave is similar to graves at the Namoratunga I site (although Namoratunga I lacks stone pillars) located far to the south adjacent to the Kerio river valley (Fig. 3).

Faint rock engravings which are thought to represent brand symbols used on domesticated animals occur on some of the pillars at Namoratunga I (Fig. 4). The Namoratunga sites are believed to date to approximately 300 BCE.

Mark Lynch, who was working on his Ph.D. in Anthropology at Michigan State University, initially proposed that Namoratunga II was an archaeoastronomical site. Lynch believed that

Namoratunga,

Fig. 3 Namoratunga I cemetery site showing upright slabs marking graves. Pickup truck for scale (Photo by Robbins)



Namoratunga, Fig. 4 Namoratunga cemetery rock art on hill (Photo by Robbins)

the site was most likely reflective of a calendar system similar to the traditional calendar used by eastern Cushitic speaking peoples of southern Ethiopia. Peoples such as the Borana have a 12-month, 354-day calendar that is based on the rising of Triangulum, Pleiades, Bellatrix, Aldebaran, Central Orion, Saiph, and Sirius. In the Borana calendar, the rising of the above stars and constellations is related to phases of the moon. Lynch found that there were positive correlations between the rising of the seven stars or constellations used in the Cushitic calendar and the alignments of the stone pillars at Namoratunga II.

Like many other archaeoastronomical sites including Stonehenge, the interpretation of

Namoratunga II has been controversial. Soper (1982) remeasured the site and argued that the original compass measurements were in error because of magnetite in the stone pillars. For this reason, the view of the site as a calendar similar to the one used by the Borana people has been questioned. Follow up work by Laurence Doyle of the NASA Ames Research Center and Wilcox has confirmed the measurement error detected by Soper. However, when using the tops of the pillars for testing the alignments, Doyle and Wilcox (1986, p. 129) concluded, “the pillars were used for the specific purpose of aligning with the 300 BCE positions of the Borana calendar stars.” (Doyle & Wilcox, p. 129). They “found 25 two-pillar alignments with the 300 BCE horizon rising positions of the seven Borana calendar stars...” and an equal number of setting positions for the appropriate Borana stars (Doyle & Wilcox, p. 127). Their statistical tests show that there is a very small chance that these correlations could be random. In a more recent paper Doyle and Frank (1997, p. 98) have advocated a cautious conclusion by stating that “the Namoratunga II pillars may have been the site of an ancient calendrical observatory, but much yet remains to be done for this to be convincingly concluded.”

Interestingly, another stone pillar site has been reported for the eastern side of Lake Turkana at Jarigole, near Alia Bay (Nelson, 1995, also see

Nelson's paper on Jarigole at <http://www.arkeologi.uu.se/afr/projects/BOOK/nelson.pdf>. The Jarigole site contains at least 28 basalt pillars as well as a thin oval shaped platform and a mound that is about a meter in thickness. Like Namoratunga II, some of the pillars are decorated. However, the decorations appear to be freshly pecked into the surface in comparison to Namoratunga II and, therefore, may well have been added after the site was abandoned. Nelson believes that the site dates to early in the Pastoral Neolithic based on the discovery of numerous Nderit potsherds, a highly distinctive ceramic tradition centering in the Lake Turkana basin. At the east Turkana site of Dongodien such pottery dates to approximately 4,000 years ago, implying that Jarigole may be about the same age, assuming that the pillars were erected at the same time that the Nderit pottery was deposited at the site. If the age estimate for the pillars is correct then the Jarigole pillars are substantially older than those at Namoratunga II, (ca. 2050 BCE versus 300 BCE) unless the age of the latter site is much too recent.

Nelson (1995, p. 52) writes that many of the pillars at Jarigole "are badly tilted and are probably shifted from their original position. Therefore, it will not be possible to determine if there are significant astronomical alignments among the pillars." However, Lynch (1978) has noted that pillars are intentionally set in the ground at angles by some Eastern Cushitic peoples in nearby southern Ethiopia. Based on the discovery of human remains and other information, Nelson has concluded that Jarigole was primarily a mortuary or burial site. Could this stone pillar site be related to Namoratunga II?

Clearly, it would be important to establish accurately the age when the pillars were erected at both Namoratunga II and Jarigole. The age of Namoratunga II is currently based on similarities to Namoratunga I which has yielded a radiocarbon dated human bone sample of ca. 300 BCE (and the good fit between this date and the Borana star alignments at that time), while the age of Jarigole is based on the presence of Nderit pottery. Unfortunately, it is not possible to date when the pillars at either site were erected by the

radiocarbon method. However, I have suggested elsewhere (Robbins, 2006) that it may be possible to obtain optically stimulated luminescence (OSL) dates from the sediments that lie directly beneath the base of the upright pillars at both sites. OSL dating is now widely used in African archaeology to date the last time that sediments were exposed to sunlight before they were buried. We have used it successfully to date sediments at archaeological sites in the Kalahari Desert of Botswana. In the case of the erection of the Lake Turkana pillars the last time the sediments were exposed to sunlight would have been when the holes were excavated immediately before the pillars were placed in them. The OSL sediment samples could be readily obtained by using a sand auger to dig at an angle directly underneath of the pillars. The resulting ages would for the first time allow for a close comparison of when the pillars at both of these sites were erected, and the OSL method could also be applied to the dating of other stone pillar sites located to the north of Lake Turkana in Ethiopia.

Is the Namoratunga II stone pillar site an archaeoastronomical site? Megalithic sites such as Stonehenge, Namoratunga and Jarigole provide a powerful testimony to the work efforts, symbolism, and beliefs of ancient peoples. Whereas archaeologists have learned much about these sites it is quite likely that they had multiple meanings to the people that created them. It is also clear that such sites can have different meanings to other people through time, such as the use of Stonehenge by hippies, modern druids, and others (Chippindale, 1986).

In the local Turkana language Namoratunga means "people of stone," referring to a legend that the pillars (as well as upright grave slabs) were once people who were turned to stone while they were dancing because they mocked a spirit that had appeared to them. It is useful to conclude with the first two lines of a Turkana song that expresses their view about Namoratunga (see Lynch, 1978 for the remaining verses).

Who knows how the standing stones were forged?
Who knows how to make the fire of
Namoratunga?

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- to have lived in the sixth century BCE. Attribution to an ancient legendary doctor is common in Chinese medical works. The most valued commentary is the *Nanjing Benyi* (The Genuine Significance of the *Nanjing*), compiled by Hua Shou in 1366. The book further develops the ideas of the ► [Huangdi Neijing](#) in question and answer format, revealing an increasing tendency for medical books to concentrate on acupuncture.

The following are outlined in the *Nanjing*:

- The criteria for pathology and health
- The existence of *xu* (weak, deficient) or *shi* (full, excessive, toxic) conditions
- The passage of disease through the various organs
- Pathology, especially that concerned with dissipation and cold-induced fevers
- The attributes of a skilled or “divine” physician
- The structure of the organs, including their weights and measurements
- Needling technique

Methods of tonification and sedation are particularly focused upon. Acupuncture points appear for the first time in various groupings, with a concentration on the *shu* (passage) points on the lower parts of the four limbs. One of its most influential ideas is the use of the points for particular categories of disease. Pathologies of the channels, and pulse diagnosis, are also touched upon.

The *Nanjing* contains 81 chapters. The *jingluo* (channels) appear in Chapters 23–29, the *shu* points (passage points) on the limbs in Chapters 62–68, whilst Chapters 69–81 concentrate on needling. These sections show the development of extreme precision in needling, and a focused rationale during practice.

Nanjing

Richard Bertschinger

The *Nanjing* (Canon on Medical Difficulties) appeared probably in the first or second century AD. However, the Chinese believe it was written in the first or second century BCE. Its authorship is unknown, although tradition has ascribed it to Qin Yueren, the usual sobriquet for Bian Qiao, the eminent Zhou Dynasty physician who is said

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Nārāyaṇa Paṇḍita

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Nārāyaṇa was one of the major authorities on Indian mathematics after ► [Bhāskara II](#). We do not know when or where he was born. All we know about his life is that he is the son of Nṛsiṃha (or Narasiṃha). Nārāyaṇa wrote two Sanskrit mathematical texts: the *Gaṇitakaumudī* on *pāṭī* (arithmetic) in 1356 (which is confirmed by the final verses of the book) and the *Bījagaṇitāvataṃsa* on *bīja* (algebra). The two books consist of rules (*sūtras*), examples (*udāharaṇas*) and commentary (*vāsanā*) thereon. A reference to the *Bījagaṇitāvataṃsa* is found in the *vāsanā* on the *Gaṇitakaumudī* but not in the *mūla*.

The *Gaṇitakaumudī* consists of *paribhāṣā* (metrology units), *parikarman* (basic operations) and 14 *vyavahāras*: the traditional 8 *vyavahāras kuṭṭaka* (a linear indeterminate equation such that $y = ax + c/b$), *vargaprakṛti* (a quadratic indeterminate equation such that $Px^2 + t = y^2$), calculations for fractions, rules for fractionizing, the net of digits (combinatorics), and magic squares. The 12 *vyavahāra* includes rules to express the number one as the sum of a number of unit fractions, which are similar to those given by ► [Mahāvīra](#). The rules in chapter 13 are modeled on those of the *Līlāvātī* but are further advanced and can be compared to the rules for combinatorics in metrics and music. The *Gaṇitakaumudī* is the first Sanskrit mathematical text so far available that deals with magic squares.

The *Gaṇitakaumudī* was published by Padmākara Dvivedī in two volumes based on a single manuscript which had belonged to his late father. The numberings are not accurate. A critical edition of the last two *vyavahāras* with an English translation and his own commentary was published by Kusuba in 1993. The entire

Nārāyaṇa Paṇḍita, Table 1 Pattern 1

1	1,236	7	1,263	13	1,362	19	2,361
2	2,136	8	2,163	14	3,162	20	3,261
3	1,326	9	1,623	15	1,632	21	2,631
4	3,126	10	6,123	16	6,132	22	6,231
5	2,316	11	2,613	17	3,612	23	3,621
6	3,216	12	6,213	18	6,312	24	6,321

Nārāyaṇa Paṇḍita, Table 2 Pattern 2

1	1,124	4	1,142	7	1,241	10	4,121
2	1,214	5	1,412	8	2,141	11	2,411
3	2,114	6	4,112	9	1,421	12	4,211

Nārāyaṇa Paṇḍita, Table 3 Pattern 3

1	333	10	332	19	331
2	233	11	232	20	231
3	133	12	132	21	131
4	323	13	322	22	321
5	223	14	222	23	221
6	123	15	122	24	121
7	313	16	312	25	311
8	213	17	212	26	211
9	113	18	112	27	111

Nārāyaṇa Paṇḍita, Table 4 Pattern 4

1	133	12	2,122	23	2,131	34	3,211
2	223	13	11,122	24	11,131	35	12,211
3	1,123	14	1,312	25	1,321	36	21,211
4	313	15	2,212	26	2,221	37	111,211
5	1,213	16	11,212	27	11,221	38	13,111
6	2,113	17	3,112	28	3,121	39	22,111
7	11,113	18	12,112	29	12,121	40	112,111
8	232	19	21,112	30	21,121	41	31,111
9	1,132	20	111,112	31	111,121	42	121,111
10	322	21	331	32	2,311	43	211,111
11	1,222	22	1,231	33	11,311	44	1,111,111

work was translated from Dvivedī's edition into English by Paramanad Singh in 1998–2002.

There are five cases of enumerations of digits discussed in the 13 *vyavahāra*. Pattern 1: digits unequal to each other are arranged in a fixed number of places. For example, there are four digits, 1, 2, 3, 6, in four places (Table 1).

Nārāyaṇa Paṇḍita, Table 5 Pattern 5

1	678	9	368	17	248	25	267	33	147	41	346	49	145
2	578	10	268	18	148	26	167	34	237	42	246	50	235
3	478	11	168	19	238	27	457	35	137	43	146	51	135
4	378	12	458	20	138	28	357	36	127	44	236	52	125
5	278	13	358	21	128	29	257	37	456	45	136	53	234
6	178	14	258	22	567	30	157	38	356	46	126	54	134
7	568	15	158	23	467	31	347	39	256	47	345	55	124
8	468	16	348	24	367	32	247	40	156	48	245	56	123

Pattern 2: digits, some of which are the same, are arranged in a fixed number of places. For example, there are four digits, 1, 1, 2, 4, two of which are the same in four places (Table 2).

In the following three patterns the digits are variable. Nārāyaṇa calls the highest possible digit the final digit. In pattern 3, the number of places and the final digit are fixed, but the sum of the digits in each extension is variable. For example, the final digit is 3 and the number of places is three (Table 3).

Pattern 4: the final digit and the sum of digits are given but the number of places is variable. For example, the sum of digits is 7 and the final digit is 3 (Table 4).

Pattern 5: the number of places and the final digit are fixed but the sum of the digits is variable. This is an example where the final digit is 8 and the number of places is three. The digits are arranged in ascending order.

For each pattern the order of the extension is determined in one and only one way. The numbering is put into each table. The method to restore an arrangement which is unknown though the number of extensions is given and the method to find a serial number when an arrangement is indicated are given. The calculation of the number of variations available and the rule for counting the times of each digit are also given. The arrangement of digits is treated as a number; the sum of all the numbers enumerated is to be calculated (Table 5).

The *Bījagaṇitāvatamṣa*, which seems to be modeled on the *Bījagaṇita* of ► [Bhāskara II](#), is divided into two parts. Part I deals with six operations (addition, subtraction, multiplication, division, squaring, and extracting the square root) for

positive and negative numbers, zero, unknown quantities and surds as well as *kuṭṭaka* and *vargaṇaprakṛti* mentioned above. The rules for indeterminate equations in the extant portion are similar to those in the *Gaṇitakaumudī* as well as those of Bhāskara II. Part II deals with four subjects: (1) linear equations in one unknown, (2) linear equations in more than one unknown, (3) quadratic equations in one unknown, (4) equations involving the product of different unknowns.

Only Part I and the opening lines of Part II were published based on a single and incomplete manuscript at Benares. The part of Sect. 1 of Part II was published by Hayashi with English translation and his commentary.

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Naṣīr al-Dīn al-Ṭūsī

F. Jamil Ragep

Abū Ja‘far Muḥammad ibn Muḥammad ibn al-Ḥasan Naṣīr al-Dīn al-Ṭūsī was born on 17 February AD 1201 in Ṭūs in the northeastern Persian province of Khurāsān and died in Baghdad on 25 June 1274. He was a preeminent figure in medieval Islamic history, being a major participant in both political and intellectual life during a century that witnessed monumental changes in the Islamic world. Politically, he was active at the courts in Iran of both the Ismā‘īlīs, a Shī‘ite sect, and the Mongols who brought to an end both the formidable political power of the Ismā‘īlīs as well as the 500-year old ‘Abbāsid Caliphate. Intellectually, he played an even more important role, forging an intellectual synthesis that can be compared to that of Zhu Xi (d. AD 1200) in China and Thomas Aquinas (d. AD 1274) in the Latin West. Ṭūsī, though, was not simply a synthesizer and rejuvenator of the Hellenistic tradition in Islam; he also made innovative and significant contributions in science and mathematics.

Ṭūsī was born into a scholarly family of Imāmī (Twelver) Shī‘ites, one of the two major sectarian divisions of Islam. Although he received religious education at home, Naṣīr al-Dīn tells us in his autobiography, written when he was in his 40s, that his father, “a worldly man,” encouraged him to explore different sciences and listen to the masters of various sects and opinions. This he did and began studying the diverse branches of ancient science and philosophy, especially mathematics. Not content to remain in his hometown, he traveled while still a teenager to Nīsābūr, a major city in Khurāsān located to the west of Ṭūs, and became the student of a noted physician and a philosopher. It was at this point in his life that he began to study the works of his famous Persian predecessor ► **Ibn Sīnā (Avicenna)**, whose works were influential in both the Middle East and Europe. He would later travel to Iraq and study both religious and secular subjects with several noted scholars. Though Ṭūsī’s education was far

from typical, one can gain some valuable lessons for trends that were occurring at the time. The fact that Ṭūsī was a Shī‘ite did not prevent him from studying with persons of different sectarian affiliations. Furthermore he was motivated to travel fairly widely to receive an education. Finally, he studied both religious subjects (*al-‘ulūm al-shar‘iyya*; “the Islamic sciences”) and the rational sciences that had been appropriated into Islam (*al-‘ulūm al-awā’il*; “the ancient sciences”). The latter is important because Ṭūsī, especially in his later writings, felt that the ancient sciences – both philosophical and mathematical – could provide the means to transcend the religious disputes that had plagued Islam.

His formal education completed, Naṣīr al-Dīn would spend some 25 years (from the early 1230s until 1256) at the Persian courts of the Ismā‘īlīs, a powerful Shī‘ite group that had for a time vied for ascendancy in the Islamic world. (These were the Assassins of Crusader lore.) Whether Ṭūsī himself willingly converted to Ismā‘īlism or simply pretended to do so is a matter of dispute; whatever the true state of affairs, he did find a refuge from the ravages of the Mongol invasions and did produce some of his most important work during this period of his life.

After the fall of the last Ismā‘īlī stronghold at Alamūt in 1256, Naṣīr al-Dīn, by then a famous scholar, was enlisted by the Mongol conquerors of Iran into their entourage, becoming court astrologer as well as minister of religious endowments. He was also charged with building an astronomical observatory in the town of Marāgha in Ādharbayjān in northwest Iran. This was one of the most ambitious scientific institutions that had been established up to that time; because of the resources placed at his disposal (which included the religious endowments), Ṭūsī was able to oversee construction of the observatory and its instruments as well as a large library and school. A substantial number of scientists and students were attracted to Marāgha; indeed there are reports of Chinese astronomers on the staff. In 1274, Naṣīr al-Dīn left Marāgha with a group of his students for Baghdad and died there in that same year.

Works

Ṭūsī was one of the most prolific authors of the Islamic medieval period, and his works, written in both Persian and Arabic, number something over 150. (This does not include his poetry.) He wrote on both religious topics and on nonreligious or secular subjects that had been inherited in the main from ancient Greece. Here we have an example of an important trend that was beginning to take root in the thirteenth century, namely the breaking down of the earlier division between those who wrote exclusively in the “Islamic” or “Arabic” tradition and those who devoted themselves to the Greek tradition. Among Ṭūsī’s religious writings are seminal works on Shīʿite law (*fiqh*), dialectical theology (*kalām*) and Sufism. Works in the tradition of Greek philosophy included the very influential *Nāṣirian Ethics* and his commentary on Ibn Sīnā’s *al-Ishārāt wa ‘l-tanbīhāt* (Book of Directions and Remarks), which helped engender a renewed interest in his great Persian predecessor. Ṭūsī very much hoped that philosophy could provide a means toward rising above the many religious disputes that so racked Islam during his lifetime. In writing his commentary to Fakhr al-Dīn al-Rāzī’s work on *kalām*, he wished to widen the opening Rāzī had made in allowing Greek philosophical concepts to enter the intellectual space of *kalām* while at the same time defending those concepts (as expounded by Ibn Sīnā) against Rāzī’s attacks.

Naṣīr al-Dīn was especially attracted to the exact sciences, which, as Ptolemy had argued, provided a more sure means to truth than the murkier disciplines of physics and metaphysics. He thus devoted a considerable amount of his intellectual efforts to mathematics and astronomy. His recensions of Greek and early Islamic scientific works represent one of his most important contributions to the Islamic scientific tradition, an attempt to give vitality and renewed meaning to the translation movement of ninth century Baghdad. Because of the lack of an ongoing institutional structure for the teaching and perpetuation of science, Ṭūsī’s reeditions, which often included insightful and original

commentary, provided the means by which generations of students of late medieval Islam could assimilate the Greek scientific tradition, either with or without a teacher. These included Euclid’s *Elements*, Ptolemy’s *Almagest*, and the “Middle Books” of mathematics and astronomy with treatises by Euclid, Theodosius, Hypsicles, Autolycus, Aristarchus, Archimedes, Menelaus, ► [Thābit ibn Qurra](#), and the ► [Banū Mūsā](#).

In addition to this monumental role as textbook writer, Ṭūsī is also known for his original work, some of which occurs within these recensions. In mathematics, this included a highly sophisticated attempt to prove Euclid’s parallels postulate, part of a long tradition that would eventually culminate in the nineteenth century with the realization that such “proofs” were not possible and that consistent non-Euclidian geometries using alternative postulates were constructible. In spherical trigonometry, Ṭūsī produced an important synthesis of earlier results of Islamic mathematicians; this marked a significant step in treating trigonometry as a discipline independent of astronomy, comparable in many respects with what was done later in Europe by Regiomontanus (1436–1476).

Ṭūsī, though, was most famous for his work in astronomy. In addition to a number of elementary treatises on practical astronomy, instruments, astrology, and cosmography (*hay’a*), many of which were meant for students, Ṭūsī also composed his *Zīj-i Īlkhānī*, a major astronomical handbook, for his Mongol patrons in Marāgha. Though not very original, and apparently compiled in haste without incorporating the Marāgha observations, it was destined to be widely used.

Ṭūsī’s most original achievement was in theoretical astronomy. From a rather early date, Islamic astronomers had been disturbed by a number of inconsistencies in the Ptolemaic system, for example that some models violated the fundamental principle that all motions in the heavens should conform to the dictate of uniform circular motion. Ṭūsī responded to this by devising an astronomical model consisting of two rotating spheres the smaller of which was internally tangent to another twice as large. By having the smaller rotate twice as fast and in the opposite

direction as the larger, Naṣīr al-Dīn was able to produce the linear oscillation of a given point, a property he was able to use in lunar and planetary models that could reproduce Ptolemaic accuracy while preserving uniform circular motion. Ṭūsī's new models had a decisive influence during at least another three or four centuries of late medieval Islamic astronomy, where they provided the starting point for numerous attempts to reform the Ptolemaic system. His device, which has been dubbed "the Ṭūsī couple," found its way into Sanskrit and Greek texts, and was influential in the work of several Renaissance astronomers, including Copernicus.

But Ṭūsī's most enduring influence, in fields as diverse as ethics, natural philosophy, mathematics, Sufism, astronomy, *kalām*, *fiqh*, music, mineralogy, and logic, was in the Eastern Islamic world, and in particular Persia, where his works continued to be studied and commented upon into the modern period.

See Also

- ▶ [al-Rāzī](#)
- ▶ [Almagest: Its Reception and Transmission in the Islamic World](#)
- ▶ [Astronomy in China](#)
- ▶ [Astronomy in the Islamic World](#)
- ▶ [Hay'a](#)
- ▶ [Ibn Sīnā \(Avicenna\)](#)
- ▶ [Marāgha](#)

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Nāṣir-i Khusraw

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Abū Muʿīn Nāṣir ibn Khusraw al-Kabādhīyānī was a Persian philosopher, poet, and traveler. Born at al-Kabādhīyān in Transoxania (now in Tajikistan) in 1004, he was one of the founders of Ismāʿīlī theosophy and lived at Balkh and Ghazna (now in Afghanistan) at the court of the Ghaznavid sultans Maḥmūd and Masʿūd. After the Seljuqid conquest, he lived at Marw at the court of Seljuqid Chaghri Beg. He traveled from the Maghreb to India. In Egypt he became Ismaʿīlī and was made the Ismaʿīlī missionary in Persia and Transoxania. In this he was persecuted and was forced to take shelter in Yomghan in the Pamir mountains (now in Afghanistan). He wrote in both Persian and Arabic.

His main work is the *Safar-nāmeḥ* (*Book on Travels*), the diary of his journeys, containing an account of life in Egypt under the Fatimid Caliph

Boris A. Rosenfeld: deceased

al-Mustanşir (1035–1094) and various geographic, ethnographic, and archaeological information.

In his philosophical treatise, *Kitāb zād al-musāfirīn* (*Book Supply of Travelers*), which is a survey of Ismaʿīlī theosophy, there is information on the history of science and fragments of the philosophical treatises of Abū Bakr al-Rāzī (854–935) on space, time, and matter.

His philosophical *Kitāb jāmiʿ al-ḥikmatayan* (*Book Joining Two Wisdoms*) is devoted to the harmony between Greek philosophy and Ismaʿīlī theosophy. He also wrote a philosophical *Rowshanāʾī-nāmeḥ* (*Book of Light*) in six chapters, *Saʿādat-nāmeḥ* (*Book of Happiness*), *Kitāb gushāyish wa rahāyish* (*Book of Unfettering and Liberation*), *Wajh-i dīn* (*Face of the Faith*), and *Khān al-ikhwān* (*Meal of the Brethren*).

He also was the author of a nonextant mathematical treatise, *Gharāʾib al-ḥisāb wa ʿajāʾib al-ḥussāb* (*Marvels of Arithmetic and Wonders of Calculators*), containing 200 problems with solutions and demonstrations to solve them correctly. In this treatise Nāṣir-i Khusraw complains of the absence of good mathematicians in Khorasan in his time. He died in ca. 1088.

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Nautical Technology in Cambodia

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The geography of Cambodia is dominated by the depressed basins of the Mekong River and the Great Lake (Tonle Sap), two large bodies of water that have been used since prehistoric times as a means of transportation and food production. Their extension is gravely affected by the climate, which is characterized by the seasonality of rain and draft. The dry season lasts from mid-November to late April. During this time the temperatures are very high, the climate is very dry, especially in April, and the water levels drop drastically in rivers and lakes, especially in the Tonle Sap Lake. In May the winds change, bringing moist clouds from the northeast. Humidity increases, temperatures decrease, and a constant supply of rain increases the water levels of ponds, rivers, and lakes. Far north, in Tibet, the snows start to melt as well, adding to the flow of the Mekong River. These coincidental events have a distinctive effect on the Cambodian landscape. During the dry season, the Mekong River has a 1,700 m³ flow rate, but the monsoon rains and the melting snow augment the rate to 34,000 m³, with around 10,000 kg of silt per second (Mabbett & Chandler, 1995, p. 36). This massive change has dramatic consequences downstream between the end of July and the end of October. At the height of Phnom Penh, where the Mekong River meets the Tonle Sap River, the force of the Mekong is such that it does not allow the Tonle Sap River to



Nautical Technology in Cambodia, Fig. 1 The floating village of Kompong Phluk in the floodplain of the Tonle Sap. During the height of the rainy season, boat is the only means of transport in this town (Source: V. Walker)

discharge its waters. The Tonle Sap is forced to change its course into the Great Lake, which is located in a large flat plain, thus leading to massive flooding (Fig. 1). It is estimated that the Great Lake increases from an extension of 160×35 km during the dry season to 250×100 km during the height of the rainy season (Kummu, 2003, p. 13). The maximum depth of the lake varies between 1 m in the dry season to 6–10 m during the rainy season. Around October, when the land is completely saturated with water, the rains cease and the water levels start to drop. At this time the Mekong River decreases its flow and the Tonle Sap changes its course once again.

These changing rivers, lakes, and floodplains provide the background for the development of nautical technology in Cambodia, not only in terms of boat design but also in the way Cambodians approach the processes of boat construction, from the selection of the material to the launching of the new boat. The never-ending cycle of rain and draft and the constant struggle to control the powers of nature are reflected in the Cambodian worldview, where nature is seen with an apprehension that is carried onto all aspects of their lives, including nautical technology.

In the Cambodian culture, the world is divided into two landscapes that are marked by physical and psychological barriers: the landscape of the village (*srok*) and the landscape of the wilderness (*prei*). The *srok* is the domesticated space of humans – the village and the paddy rice fields – a space of social organization (Ang, 2004, p. 58). The *prei*, on the other hand, is the forest, a place of uncertainty dominated by wild and dangerous spirits (2004, p. 58; Forest, 1992, pp. 15–16). This dichotomy has been incorporated into nautical technology with the separation of labor in two marked spaces – the forest and the village – and the celebration of rituals during the construction process, as will be discussed in what follows.

Note: although there are other ethnic groups in Cambodia, this entry is focused on the largest ethnic group in the country, the Khmer.

Traditional Approaches to Boat Construction

The most traditional form of boat construction in Cambodia is the dugout, a kind of boat that is

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Fig. 2 Located in a pond north of Phimeanakas temple, this nautical bas-relief from the Angkor era (ninth to fifteenth centuries CE) shows great similarities with the contemporary boats in Cambodia, particularly in the design of the hull (Source: V. Walker)



build using a single log. This type of construction technique has been documented as early as the thirteenth century by the Chinese emissary Zhou Daguan who recorded that the small boats of Angkor (the polity that ruled the region of Cambodia between the ninth and the fifteenth centuries CE) were made from a single very large piece of wood, hollowed out by chiseling (Harris, 2007, p. 69). This was recently confirmed by archaeological data after the remains of a dugout found in the area of Siem Reap were dated to the fourteenth to fifteenth centuries CE (An, 2014). Nautical scenes represented in bas-reliefs (Fig. 2) from the Angkor appear to share many similarities with contemporary boat design and have often been identified as being dugouts (Poujade, 1946, p. 6).

The dugout is known in Cambodia as *touk meat* or *touk pilan*; it has a shallow draft (the section of the boat that is submerged in water), a wide beam (width of the boat), and the bow and stern end in a characteristic triangular form. A deck is often used to cover most of the boat, and the section underneath it is usually used as storage. The flat bottom of the hull and the shallow draft allow for easy navigation of rivers, lakes, and ponds, even during the dry season when the water levels drop. It also makes transportation possible in flooded areas, where it would be risky to use boats with deeper drafts.

The Carpenter of the Forest

The construction process of a dugout reveals the dichotomy of the Cambodian spiritual beliefs as early on as in the selection of the material. Dugouts are usually made from the koki tree, a type of hardwood that is endemic to the forests of Cambodia. The largest specimens are found in the wilderness, a space controlled by untamed spirits. One of the key roles of those who venture into the forest is to intermeditate with the spirits by preventing actions that would anger the spirits and conducting appropriate rituals and offerings to gain their favor. Such is the role of the *chieng prei*: the carpenter of the forest (Hoc, 2001, pp. 5–7). Those who penetrate the forest must ensure that they have a pure heart and that they remain silent throughout their stay; laughter is forbidden, particularly during the felling of the tree. Following these rules, the *chieng prei* advances through the forest with his workers until he finds the perfect koki tree. In Cambodian traditional beliefs, many spirits dwell in trees, so before the workmen can start cutting down the tree, the *chieng prei* must evict the spirit that lives in it. To do so he makes some offerings and recites an invocation to attract the attention of the spirit and inform it of their intentions: “We, your servants, request this koki tree to make a *touk*. We pray for you to agree to our request.”

Nautical Technology in Cambodia, Fig. 3 Detail of the interior of a “wild boat” with marks of a chiseling tool. The boat was left unfinished in a pagoda of Kompong Khleang flooded village (Source: V. Walker)



(2001, p. 6). In Cambodia, *touk* is a word used to define a wood that floats, while *koki* refers to the tree in its wild form. With this prayer the *chieng prei* is asking the spirits for permission to transform the material from wood to a floating device (but not yet a boat). After the prayer is made, a letter is placed on the tree to inform the spirits that after 7 days they will return to fell the tree and to ask the spirits to remain but to stay as far away as possible (Porée-Maspero, 1964, p. 371).

After the allotted time has passed, the *chieng prei* and his team return to fell the tree. A mock felling is conducted thrice in complete silence. Holding an adze in his hand, the *chieng prei* asks “Have the lords conceded to give us this tree?” To which the crew responds: “Yes, they have.” The *chieng prei* interpellates the spirits once more: “Is this true?” And he is answered again by his crew: “Our lords have clearly given it” (Hoc, 2001, p. 6). After this ceremony has been celebrated, a small offering is prepared to invoke the protection of Preah Pissnkar, the artisan god, to ask him to watch over the workers and protect them from the wrath of the evicted spirit in this ominous moment.

After these rituals are finished, work begins to cut down the tree and debark it. Three equal longitudinal marks are made and the side of the

trunk that will be hollowed out is squared (Fig. 3). The bow will be made on the side closest to the stump. The trunk is marked in quarters, and a figure of eight is drawn to guide the carpenters during the chiseling process. The opening has to be wide in the upper section, tapering downward in a sharp angle. The bow is yet to be given form, while the stern is always slightly higher than the bow, between 15 and 35 cm. Once the tree is hollowed out, the boatbuilders light a fire with the debris, and the boat is then placed upward on top of the embers (Poujade, 1946, p. 6). A series of weights are placed inside of the hull to open the walls of the trunk. Once the sides of the dugout have been softened, beams are placed inside it to keep the walls open. The dugout is then left upside down in the woods to dry for 1 or 2 weeks. The end product at this stage is known as *touk kamrol*, the wild boat. Once the time has passed, the *chieng prei* and his team go back to the forest and start the process of extracting the wild boat and taking it to the village. They leave offerings to the wild spirits to appease their anger for the intrusion, and once in the *srok* (the realm of humans), the team asks the guardian spirit of the village (the *neak ta*) for protection. This ceremony is conducted by the owner of the boat and the *chieng srok*, the carpenter of the village.

The Carpenter of the Village

After the wild boat has been properly introduced in the village, further work is conducted to polish the trunk and transform it into a proper boat. The first action is to trim the outside of the hull, then the dugout is turned upside down, and the rows of holes of the same size and depth are drilled into the exterior walls at regular intervals of 1 m. The aim of the holes is to help the boatbuilders to even out the thickness of the hull. The dugout is then turned over to even out the inside. This is done with an adze, reducing the surface until the holes are found. Once this is done, the dugout is placed over the heat of embers again in the sections where there needs to be further bending of the wood. Wooden pegs are then used to cover the holes. A short adze and pumice stone or sandpaper is later used to polish the surfaces of the boat. After the hull has been polished, the boatbuilders apply a coat of resin, known as *mrak*, and leave it to dry in the sun for 3 to 7 days (Hoc, 2001, p. 4). Once it is dry, the thwarts are placed inside. Though from a technical point of view the boat is ready to launch, in Cambodian nautical technology, there are still some actions that need to be undertaken.

The most delicate part of nautical construction in the village is the opening of the eyes. This ritual is destined to open the eyes of the boat so that the spirit that dwells in it can see. There is still much to be learned of this process, and some details are yet unanswered. The eyes were traditionally made from wood and both have to weigh exactly the same to prevent the boat tilting to one side. Once the eyes are made, boatbuilders take great care in not angering the chief carpenter or breaking things in front of him since it is believed that the spirit is watching. Before placing the eyes on the hull, mandatory offerings are made to Preah Pissnkar: a cooked pork face, a cooked chicken, a hand of *nuon* bananas, five candles, five incense sticks, five cigarettes, five betel leaves, two *sla thor* (a banana leaf stem or a green banana provided with a stand), a bottle of rice wine, sambour (holy water), and gold and silver leaves (Hoc, 2001, pp. 6–7).

Once the offerings are placed, the *chieng srok* proceeds to sing a victory song known as *cheyanto* as he pours water over the eyes of the boat. He then ties a ribbon around the wrists of those who have participated in the construction of the boat. The boat is then ready to be launched.

The launching of a boat also follows a set of rituals to attain the protection of the spirits that will guide the boat (i.e., the spirit that dwells in the boat and the three spirits that will bring luck and prosperity to the boat). The date of the event is arranged according to the date of birth of the owner unless this falls on an inauspicious day; if so, then the birthday of the wife is selected. The family gathers to witness the launching, and new offerings are made. A red cloth that has been weaved using magic formulas is knotted around the bow. All the equipment of the dugout is placed inside the hull. Three incense sticks and a large candle are lit and positioned at the bow, another large candle is lit and placed at the stern, and smaller candles are placed on the thwarts. Once the offerings and preparations are completed, the *chieng srok* recites the following magic incantation:

Oh! Powerful spirit protector of the village, of Preah Thorani (Earth); today we have organized this ceremony to request your permission to launch the touk on the water. Lord, deign to grant us prosperous trade, and gentle and solid fortune, to all of those gathered here today, our children, our grandchildren, husband and wife. And you, touk, when you were in the forest we called you koki, but now you are in the village and you are a touk and we name you Sok Chamroen, "Fortune and Prosperity." (Translated from Hoc, 2001, p. 7)

The orchestra then plays three songs to please the spirits; the first tune is dedicated to *Chum Teav Haira*, who will guide the ship and act as a steerswoman; the second song is for *Chum Teav Mao* (Black Lady), the guardian of the spirits of the forest who will act as the vigil; and the third song is for the damsel *Kantong Khiev* whose task is to float and move the boat. After the music is over, the family gets on board and they navigate thrice around the port, honoring and thanking the spirits. Once these

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Fig. 4 Boatbuilder from Siem Reap working on one of the logs that will be used as a stern or bow of a boat (Source: V. Walker)



ceremonies are over, the process of transformation of the koki tree into a boat (*touk meat* or *touk pilan*) is over.

The processes involved in the Cambodian boat construction suggest that technology is deeply intertwined with spiritual beliefs. Without understanding this connection, it would be difficult to comprehend the choices behind nautical construction, from the selection of the material to the hull design. However, finding a *touk pilan* made from a single log is not that common any longer. Although the form of the hull remains the same, nowadays most of the boats in Cambodia are built using planks. This type of plank boat (Fig. 4), called *touk loeuk kdar*, is derived from the dugout not only in form but also in its construction. The bow and stern are chiseled from a log following the traditional three-point design, though in some cases this piece is made with assembled wood (Poujade, 1946, pp. 7–8). A rabbet joint is made in the inside part and both sections are attached with planks. The rabbet joint allows for the planks to be assembled seamlessly to the chiseled logs, thus keeping the integrity of the dugout hull design intact. The reasons for this change in technology seem to be the lack of resources – the price of logs for dugouts are several times higher than the price of planks – loss of knowledge brought about by disruptions in the transfer of knowledge, and the spiritual elements involved in the construction (Hoc, 2001, p. 7).

Types of Boats

Apart from the *touk pilan*, there are other types of boat designs that are made from a single log, including raised dugouts (i.e., a dugout to which planks are added to expand the sides).

Touk ngor and *touk prasat kdar* (Fig. 5) are racing boats used in the celebrations of the Bon Om Touk festival, the Water Festival. This 3-day celebration occurs when the waters are receding, usually around mid-October. They have been linked to the nautical representations of Angkor due to their decorations (Jacq-Hergoualc'h, 2001, p. 9). Its function has been connected to fertility rites and its origin has been traced to boat representations of the Dong Son bronze drums (Loofs-Wissowa, 1991, p. 47). They are traditionally made from a single log, with planks added to the sides. The lack of large koki trees has probably affected the size of these boats, and in earlier times they were probably longer and wider. Nonetheless, they usually carry around 60 paddlers during the races. They are traditionally kept in the enclosure of pagodas or in the premises of shrines.

Touk Thnaot (Fig. 6) is a type of dugout that is made from the sugar palm tree (Heng, 2011, pp. 5–6). This type of boat is often seen in flooded ditches by the road, in ponds, and in flooded rice fields. It is not usually used for navigating open waters; instead it appears to be used as a simple flotation device for fishing or conducting other farming activities such as planting rice.

Nautical Technology in Cambodia, Fig. 5 Racing boats from the Bon Om Touk festival kept in a pagoda in Kompong Khleang. The central boat has wooden eyes (Source: V. Walker)



Nautical Technology in Cambodia, Fig. 6 Two boats made from palm trees. The boatbuilders use the stem of the tree to give maximum space for the user (Source: V. Walker)



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Navigation in Africa

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The physical geography and environment of the African continent precluded extensive water transportation on the interior waters, although light boats have been in use at least since the Middle Ages for fishing and transit on lakes and stretches of rivers between rapids and where permitted by depth or the tides. Navigation properly speaking was determined by three distinct regional environmental systems in the north, west, and east. Available historical data are uneven over time and area. Participation of native African peoples in naval activities originating in

Africa is not always attested by the sources. In the Mediterranean Sea, ancient Egyptian rulers, the kingdom of Israel, and Carthage made use of the sailing and shipbuilding skills of Phoenicians. Pharaonic Egypt, Israel, and ancient Ethiopia (Axum) used the Red Sea as part of a commercial system linking the eastern Mediterranean with the Middle East, East African coast, and India.

Under the Old Kingdom expeditions had been sent to the land of Punt (southwest coast of the Red Sea or the Somali coast facing Arabia) for gold, ivory, ebony, and myrrh. Ships built at the head of the Gulf of Suez traveled south under the Fifth and Sixth Dynasties (ca. 2470–2280 BCE). A Red Sea shipwreck under the Middle Kingdom (ca. 2000–1800 BCE) is recorded in the *Egyptian Story of the Shipwrecked Sailor*. Under the New Kingdom, expeditions were resumed by Queen Hatshepsut (ca. 1495 BCE). According to Herodotus, the pharaoh Necho II (ca. 610–595 BCE) was first to attempt linking the Nile with the Red Sea by a canal. After calling off the construction he sent a fleet manned by a Phoenician crew to circumnavigate Africa clockwise. They took over 3 years to complete the journey, discovering in the process that Africa was surrounded by water. Some time before 480 BCE, a counter-clockwise circumnavigation was attempted by Carthage. This voyage, described in the Greek document known as the *Periplus of Hanno*, may have discovered both the Canary and Cape Verde islands, subsequently forgotten and rediscovered again centuries later. In the north, Carthage reached out into the Atlantic as far as the British Isles and possibly the Baltic. Access to these routes was strictly controlled and outsiders were attacked to prevent competition. In the Mediterranean, Punic trade interests inevitably ran into conflict first with Greece and then with Rome. With the decline of Carthage, navigation on the Mediterranean effectively became part of the western scientific and technological tradition.

Oceanic navigation in the African Atlantic is poorly documented. There is no evidence of sea-worthy vessels being constructed in sub-Saharan West Africa in premodern times. However, several reports indicate that sailing in

the Atlantic was occasionally attempted, usually resulting in failure. Juba II, king of ancient Mauretania and a Roman ally, sent a fleet to the Canaries in about 25 BCE and later had the Atlantic coast of Morocco explored. In the Islamic period, the route to the Canaries seems to have been forgotten, although the Arab geographers inherited knowledge of the islands from Ptolemy. The legend of a statue at Cadiz forbidding travel beyond the Pillars of Hercules was transferred to the Fortunate Isles (*al-Sa'ādāt*), or Eternal Isles (*al-Khālīdāt*), as the Arabs called them after Ptolemy. A report by the geographer ► *al-Idrīsī* (ca. 1154) tells of an attempted expedition to the Canaries under the Almoravid ruler Yūsuf ibn Tashfīn (1061–1106) who controlled parts of western Africa from the Senegal River to Morocco and Algiers. The admiral in charge having died before departure, the voyage never took place. *Al-Idrīsī* also describes an intriguing adventure originating in Lisbon. Some time before 1147, 80 explorers (*mugharrirūn*) of Lisbon built a large ship, loaded it with enough food and water for several months, and after sailing west and south for a total of 35 days came to an island where they were forced to land by light-skinned men in boats. The king, speaking through an Arabic interpreter, told of an expedition ordered into the sea by his father. After sailing “across” the sea for a month, that group had returned having found nothing. The explorers were then taken to the mainland, reached after sailing with the west wind for “three days and nights.” Their final rescue was effected by the Berbers of the Atlantic coast of Morocco.

Arabic accounts of the thirteenth and fourteenth centuries, especially those by Ibn Fātima (related by Ibn Sa'īd al-Maghribī) and Ibn Fadl Allāh al-'Umarī suggest continuing but accidental maritime contacts between Morocco and Spain on the one hand, and black West Africans on the other. The availability of Arabic or Berber interpreters among peoples encountered by Muslims in these voyages undermines the speculation that these expeditions constitute an African discovery of the Americas. Of special interest is one report by al-'Umarī which

describes an attempt at exploration of the Atlantic by a ruler of Mali, Abū Bakr II, who was the predecessor of the famous Mansā Mūsā (1307 or 1312–1327). An expedition of 200 light boats was sent down the Senegal River with provisions “to last many years.” Only one vessel returned, with a story of the others disappearing in a violent current at sea. The persistent ruler equipped 2,000 new boats (1,000 of them filled with stores of food and water) and departed on a second expedition, never to return. Some have suggested that Morocco was the intended destination but the text gives no such indication, citing “the extremes of the ocean” in the king’s order. No such further attempts are known.

Early modern European travelers in West Africa noted the existence of large canoes in the estuaries of rivers from Sierra Leone to the Niger Delta. Some of the large dug-out canoes, made of a single tree trunk, could carry small cattle, several horses, or up to 80 men and their sleeping mats. They had cooking hearths and occasionally “a sort of quarter deck, made of strong reeds” or a platform amidships. The canoes were propelled by wooden paddles and ► *bamboo* or palm-tree poles and could have sails made of grass mats (later of woven cloth) attached to masts of light cane. Their speed varied from 1 to 3 miles per hour. Larger vessels from planks may have been made from the sixteenth century on. There is no evidence of the use of outriggers or leeboards until the twentieth century. Boat builders and crews were sometimes drawn from servile populations. In West Sudanese empires, especially Songhay, heavy river canoes were used not only for trade and fishing, but also to enhance the cohesion of the state, to move troops and captives (slaves), and to conduct “naval” attacks or blockades. States had court officials in charge of matters relating to the river or state canoes: in Songhay it was the *hari-farma* (chief of the waters), while Lagos had the *aromire* (friend of the waters). From river estuaries the largest canoes reportedly ventured into coastal waters, against prevailing currents and winds, reaching from the Niger Delta as far as Angola.

Premodern naval communications in Eastern Africa were subject to different conditions in the

three subregions: the Red Sea, the East African coast with the adjacent islands, and Madagsacar with the Comoros. Numerous port cities on the coasts of Eritrea and northern Somalia are mentioned in the *Periplus of the Erythrean Sea* and in Ptolemy's *Geography* for the first and second centuries AD, respectively. Adulis (ancient Berenice, at Massawa) became the principal port of the Ethiopian empire (Axum). Both Pseudo-Callisthenes (third century) and Cosmas Indicopleustes (sixth century) attest to the presence of Ethiopian merchants in India and Ceylon (Sri Lanka). However, it is not always clear in these or later reports who the sailors and navigators were. *The Periplus of the Erythrean Sea* specifies Arab supremacy on oceanic routes leading from Yemen to Africa and India. Early Islamic history records attacks on Arabian ports and shipping by Ethiopians, repulsed by the Arabs who established their firm control on the Red Sea by the early eighth century. However, Africans from the coasts of Ethiopia, the Horn and the Dahlak islands continued to be involved in trade and piracy on the Red Sea. They also served as sailors on boats sailing the Indian Ocean owned by Arabs, Persians, Swahili, Indians, and even Portuguese. Massawa boats were described in the eighteenth century as "very slight and unsafe," but capable of carrying a "great weight." They were, as in previous centuries, of the sewn type with mat sails, equipped with a crew of seven or eight men.

Zeila and Barbara were major African counterparts to Aden, receiving fleets from Africa heading north or Indian and Persian Gulf vessels destined for Jedda. From Zeila and Massawa trade routes led inland, providing important access for Ethiopia to major commercial networks even during the centuries of its isolation from the world by a ring of Muslim principalities bordering on the sea. The port of Suakin attracted shipping largely because of Abyssinian gold. So many Ethiopians were engaged in oceanic shipping that an important social class of *Habshis* (i.e., Abyssinians) evolved in India's mixed coastal communities. Ibn Battūta first reports their presence at Calicut and Ceylon in the fourteenth century. Sometimes associated with the East African immigrants called Sidis (who

spoke Swahili and often originated as slaves from Mozambique and Mombasa), Habshis acquired special influence in the seventeenth and eighteenth centuries as sailors and soldiers protecting shipping from Gujarat in the northwest to Surat and even Bengal. One Sidi was the admiral of the Bijapur fleet and had under his jurisdiction the coast north and south of Janjira, the port attacked by the Moghuls in 1659. In the Bombay region in 1648 one area was controlled by a Habshi responsible for maintenance of a marina for the purposes of transporting pilgrims to the Red Sea and protecting commerce. The office carried the title of *wazīr* and was attained through merit. Some Habshis were non-Muslims. Habshi crews serving on Portuguese and Arab-owned ships often carried their families aboard. African sailors were apparently also involved in piracy on the West Indian coast.

In the southwestern part of the Indian Ocean, sailing between the African mainland and the island of Madagascar was made difficult by the strong southward currents in the Mozambique channel and the weak reach of monsoons. Swahili legends of origin would put Muslim settlers on the Comoros as early as the eighth century, but the first trustworthy reports speak of Malay (Wāqwāq or Qumr) people reaching African destinations at a time when Mozambique was barely known to the Arabs and no evidence exists for African voyages from the mainland.

The earliest report of a Malay attack against a northern Swahili town (Qanbalū, on Pemba Island) dates back to 945. The Arabic book *Marvels of India* tells of a 1,000 boats attacking the city from the sea and surrounding channel. The assailants had plundered parts of Mozambique and an island 6 days' distance away. Their home was at the distance of 1 year's journey. In the thirteenth century Ibn al-Mujāwir speaks of an earlier, vaguely ancient, invasion of Aden by the Malagasy people (al-Qumr) who arrived in great numbers in boats to displace local fishermen. They were later expelled by Kushites from the Somali peninsula (Barābir). These people disappeared, and their skill had been lost, but a boat from al-Qumr arrived at Aden in AH 626/AD 1228–1229. Ibn al-Mujāwir describes it

as an outrigger vessel; he admires the sailing skill of these people who managed to sail from Madagascar to Aden in “one monsoon,” instead of three stages involving layovers at Kilwa and Mogadishu. Around 1500 Ahmad ► [ibn Mājid](#) includes the Comoros in the scope of Arab navigation. After the arrival of Portuguese, and especially after hostilities developed in the north, Swahili migrations to northwest Madagascar and the Comoros expanded while the Malagasy navigation declined. Comorian sailors became occasional pirates and were involved in slaving raids against the mainland coast until the nineteenth century. Malagasy in turn attacked the Comoros from the eighteenth century, adapting for slaving raids large canoes otherwise used for whaling and capable of carrying 30 men. Some raids even reached across the Channel. Outrigger canoes were called *parabou*. There were also two-bridge galleys *coracores*, one-mast ships (*pajalas*) and *palans*, similar to small galleons.

The coast of East Africa proper, subject to the monsoon regime, is distinguished by the great number of coastal sites used as trading ports and fishing settlements. African participation in trans-oceanic navigation has not been documented for pre-Islamic or even early Islamic times but local inter-island shipping must have evolved sufficiently early to allow offshore island settlement by at least the ninth century. According to ► [al-Idrīsī](#) (mid-twelfth century) the Zanj people did not have seaworthy vessels and ships from Oman and elsewhere exported their goods. By that time a network of sailing routes connected harbors from southern Somalia to northern Mozambique. The Swahili-speaking coastal Africans dominated local shipbuilding and trade but other groups, including the Bajun, provided sailors as well. Navigation on the Swahili coast carried many general characteristics of Indian Ocean navigation, including the sailing calendar, dependence on the monsoon, sidereal rose, some boat types and terminology rich in loan-words from Arabic, Persian, and Indian languages. It also had some distinctive features and deeply affected the social culture of the coast. The best known is the maritime Swahili culture of the island city of Lamu (Kenya).

The sailing calendar was based on monsoons within the solar year. The marine year began in early August, when the gusty southern kusi wind subsided. The New Year’s celebration, called *siku ya mwaka*, marked the resumption of shipping activity after a pause during May-July. The Persian word Niruzi, also used for this festival, gave rise to the false impression that this calendar was Persian in origin. Different subperiods within the monsoon were best suited for plying the routes between Malindi and Madagascar, Kilwa to Sofala and back, Sawāhil (northern Tanzania) to Mogadishu, Aden and thence to Hormuz or Gujarat and the Maldives. Travel north was more difficult due to both the southwest monsoon and the strong contrary currents in channels between the mainland and the islands. The “normal” boundaries of Swahili travel were Cape Delgado in the south and Mogadishu in the north. In the fourteenth century the city of Pate briefly attempted to dominate the coast, but it always had to compete with its neighbor Lamu and the more remote Mogadishu, Malindi, Mombasa, and the powerful Kilwa. Regional and local rivalries involved sailing to foreign lands (Arabia or India) or to the mainland, and attacks and blockades from the sea. In island setting, it was generally faster, easier, and safer to sail from one destination to another than travel overland well into the nineteenth century. Traditional histories reflect everyday awareness of the tides, currents, and coastal breezes. The Portuguese arrival in East Africa did not noticeably change local shipbuilding and sailing practices, although this was not so elsewhere; the Eastern Arabian and Persian Gulf influences both pre- and postdated this European infusion. Local ships still carried traditional trade goods and even revived with the rise in slave trade before its suppression by the British in the late nineteenth century. By that time Zanzibar and Kilwa were the two leading ports of the coast, followed by Mombasa and Lamu.

Navigation proper was not highly developed. Given limited distances, boats mostly coasted. The steady daily and seasonal pattern of the winds made observation of local features such as banks, current speeds and tides more important than instruments. Actual stars rather than

compass rhumbs were used for determining latitude. (A line which crosses successive meridians at a constant angle; called also rhumb line, and loxodromic curve. To sail on a rhumb means to sail continuously on one course, following a rhumb line.) Travel was slow, averaging one knot an hour, if rest days are included. In the fourteenth century Ibn Battūta was told that the area of Sawāhil was 2 weeks' sail from Mombasa. In the early nineteenth century it still took 2 weeks to reach Madagascar from Kenya with a fair northerly wind *kaskazi*. Traffic between Lamu and Somalia resumed immediately in August, reached its peak in November and died down in January. Foreign craft from the north began to arrive in November.

The sailing calendar was paralleled by a ritual calendar. At Lamu, a local ship owner held the hereditary office of *mkuu wa pwani* (master of the strand). This dignity led the dhow launching, invariably accompanied by both an African *ngoma* festival and a Muslim ceremony. Other elders (*wazee*) gave the blessing and burned incense. The shipwright (*fundi*) was given a ceremonial present and the captain (*nakhoda*) declared by the *mkuu*. Magic was resorted to in order to bring favorable sailing conditions or take wind out of an opponent's sail, break his mast, etc.

Today's dhows (*daus*) are sea-going sailing ships with very large lateen sails, which still may be rowed or poled when necessary. They serve as fishing vessels and may be flat-bottomed or keeled. Newer dhows are made of fiberglass and have motors. The formerly prevalent *mtepe* (*dau la mtepe*), no longer in existence, was a type of sewn boat of up to 30 tons carrying a square sail of matting, double-ended with an upright mast. The local "big ship" is *jahazi*, a fairly recent type of sea-going coaster, single-masted, transom and with upright stem, with a cargo capacity of 25–60 tons. A smaller version of the same type used for intercoastal shipping is called *mashua*. *Buti* was a large (20–60 tons) coastal vessel type, now obsolete, with one mast, and a slightly curved upright stem and square stern. *Baghala* is the most beautiful and largest (100–300 tons) of the dhows, a two-masted vessel with square

stern, originally from the Persian Gulf. Bum is a layman's name for lateen-rigged sea-going dhows. The small-keeled *msumari* (*dau la msumari*) also carries a lateen sail. The double-outrigger canoe *ngalawa* rarely occurs north of Mombassa. Lack of timber limits shipbuilding; local wood may suffice for plank-built boats of small dimensions but dugout canoes have to be imported (for example, from Madagascar).

See Also

- [al-Idrīsī](#)
- [Ibn Battūta](#)
- [Medicine in Africa](#)

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Navigation in China

Ho Peng Yoke

Did the Chinese visit North America before Columbus? Did Chinese navigators land in Australia before Dampier and Cook? These two puzzles often pass our minds when we turn to the topic of Chinese navigation. In 1761 C.L.J. de Guignes wrote that in the early part of the sixth century a Chinese monk named Huishen had sailed to the west coast of North America. The story did not gain much support, but some interest in the issue was revived in the last two decades by the discovery of two pre-Columbian stone anchors off the Californian coast. One of the anchors is in the shape of an equilateral prism, and the other looks like a large cylinder with a hole bored through the center. Both were suggested to be of Chinese origin. As for Australia, aborigines along the northern coast still remember contacts with their northern neighbors who visited them annually in the past for the purpose of trade. Among them were the Macasarese and the Buginese; the former were preceded by the Baijini. The Baijini were said to be technologically advanced, with much lighter skin color; among the things they bartered for was *trepan*, from which the typical Chinese delicacy sea-slug was prepared. Hence they could be

identified with the Chinese, the only people who knew how to prepare sea-slug. While we cannot yet arrive at a definite answer to the two questions it is possible to show that at least the technology and skill were already there in the past for Chinese ships to reach their destinations.

The Chinese must have navigated their rivers and coastal waters since the dawn of history. The character *zhou* for boat written on tortoise shells and buffalo shoulder-blades used for the purpose of divination during the Shang period (traditional dates 1766–1122 BCE) took the form of a boat. Documentary records on navigation in ancient China are, however, rather scanty. Confucius himself once made a remark on venturing upon the open sea in a raft. Then comes the story about the emperor Qin Shihuangdi sponsoring expeditions to the East China Sea to seek the elixir of immortality during the third century BCE. Modern archaeology has provided evidence that Chinese sailors had taken to the high sea at least by the third century BCE. In 1976 the ruins of a large shipbuilding site of that period was discovered at Guangzhou in South China. The site could hold ships weighing between 50 and 60 tonnes and measuring up to 30 m in length and about 8 m in width.

In the year 118, the Han astronomer ► [Zhang Heng](#) (78–139) noted that there were stars not visible to people in China itself, but that were seen by seafaring people. There were already a number of books on this subject then, but unfortunately none of them has survived. Those seafaring people could have steered their boats by the sun and the stars. Star catalogs were already available in China, even before Zhang Heng made observations with the new astronomical instrument he constructed. By about the seventh century maritime trade between China and the Arab countries saw Chinese and Arab sailors traveling between the ports of east and southwest Asia. Arab merchants traveled in Chinese boats. The large number of Tang potsherds of about the mid-eighth century discovered by the Japanese Idemitsu Archaeological Mission in 1966 at Fustat near Cairo and in Aidhab on the Red Sea coast of Egypt bear testimony to this trade. It could be during the mid-ninth century that Chinese navigators first made use of the magnetic

compass. This could have taken place later, but not after the mid-eleventh century when Shen Gua (1031–1095) described the mariner's compass. This early form of compass consisted of a magnetic needle suspended by a thread.

With the invention of the mariner compass and increase in maritime trade the shipbuilding industry became highly developed during Song China (960–1279). In 1960 the remains of a Song wooden craft measuring 24 m long and about 4 m wide for navigating in rivers and canals was discovered in Yangzhou, Jiangsu province. Then in 1974 the remains of a *Fuchuan* – Fujian-built ship – was recovered in Quanzhou, Fujian province. Measuring over 34 m and weighing about 374 tonnes, it was composed of 13 water-tight compartments, the bulkheads. The shipbuilding industry continued to flourish during the time of the Mongols (1271–1368). Marco Polo gave an estimate of over 200,000 sailing vessels in China.

The most famous maritime exploration ever made by the Chinese was that of ► [Zheng He](#) (1371–1434). His fleets included some very large vessels. According to the *Mingshi* (Official History of the Ming Dynasty), the largest ones measured 134 m in length and up to 55 m in width. Modern scholars gave different estimates for their displacement, varying from over 3,000 to just over 800 tonnes. In 1405 Zheng He made his first expedition to Southeast Asia and the Indian Ocean, employing a fleet of 63 ocean going junks. During the next 30 years he made six other expeditions to the Indian Ocean. His explorations preceded the Portuguese by several decades. For example, he visited Calicut in India in 1405, some 90 years before the latter arrived. He brought home strange animals like zebras and giraffes, and rare drugs, minerals, and other curiosities during his visits to Africa. He sailed along the eastern coast of that continent. One unanswered question is whether he had navigated round the Cape of Good Hope and ventured into Atlantic waters.

The late Ming military compendium *Wubeizhi* (Treatise on Armament Technology) compiled by Mao Yuanyi in 1628, contains the original schematic sailing charts tracing the routes followed by Zheng He and navigational diagrams indicating

the star positions to be maintained during the voyages. The charts show the courses of the ships across the seas, with legends giving detailed compass-bearings, with distances expressed in number of watches. They also describe more interesting coastal features, showing half-tide rocks and shoals as well as ports and havens. For example in the description of the voyage from Bengal to Malé in the Maldiv Islands through Sri Lanka, it gives the polar elevation for every stage of the journey, such as mentioning that a certain mountain in Sri Lanka would be sighted when the polar altitude had sunk by a certain number of degrees. Hence Chinese sailors in the early fifteenth century already knew the method of finding and running down the latitude. For measuring the altitude of a star, Zheng He's crew probably made use of the cross-staff, which was an instrument used by Chinese surveyors as early as 1086. The traditional Chinese clepsydra would not function properly at sea. Needham suggests that they had an alternative, by simply using the incense or joss-stick, which was a popular method used for timekeeping.

The Chinese constructed many types of sailing vessels to suit different needs and environments. Navigating rapid shallow streams, sailing on big rivers and along the coast, transporting food and merchandise along the Grand Canal, and venturing further afield to the Indian Ocean would require different types of ships. Chinese sailing vessels differed from Western sailing ships in their hull structure and in their sails, as well as in their methods of propulsion. The word “junk” was first given to Chinese ships in records of the travels of Odoric of Pordenone and that of ► [Ibn Baṭṭūṭa](#) during the fourteenth century, but the origin of this word is uncertain. Needham suggests that it could have come either from the Chinese word *chuan* or from the cognate Javanese and Malay words *jong* and *ajong*. The term *sampan* is used for smaller Chinese sailing vessels. Undoubtedly it originated from the Chinese term *sanban*, which is written in two forms. One form literally means “three boards”, indicating its size. In the nineteenth century the term referred to river gunboats rowed by eight oars on each side.

The oldest form of Chinese ship had a carvel-built hull without the keel, the stempost and the sternpost of European and Arabian ships. Generally, the Chinese junk could be either flat or slightly rounded at the bottom. However, there were also junks with a V-shaped bottom as in the case of the Fujian-built ships. The planking of the Chinese junk did not meet at a point at the stern and the stem, but stopped abruptly and was joined transversely by straight planks.

Also unlike its European counterpart, the Chinese junk had neither frames nor ribs; instead it was composed of solid transverse bulkheads, which gave rise to several water-tight compartments. This valuable shipbuilding technique could have been inspired by the ► [bamboo](#) that the Chinese used for some smaller rafts and for so many other purposes. Many types of bamboo raft still ply the rivers in China today. Some of them are made with the giant bamboo *dendrocalamus giganteus* that grows to a height of some 25 m and has a diameter of about 30 cm. To enable the raft to slide over river rocks, the bow is usually bent upward by heating. If a piece of bamboo is bisected longitudinally the nodal septa would represent the transverse bulkheads and the stem and stern transoms.

The sails used in Chinese ships were also different from those of their European counterparts. Different cultures developed different types of sails to take advantage of winds coming from different directions. For example the ancient Egyptians had the symmetrically hoisted square sail. The Chinese on the other hand had the lug-sail, which consisted of an upper sail support slanting upward away from the mast, called the canted yard, and a horizontal sail support at the bottom called the horizontal boom. The sail was often strengthened by battens of bamboo, the ends of which were fastened to bolt-ropes suspended from the yard to take the weight of the sail. The sail was often made of bamboo matting and was kept flat and taut by using multiple sheets of matting. Several masts were used for larger vessels, the number varying from two to five. These masts would be staggered thwartwise such that one would not becalm another. The rake of a system of masts often radiated

like the spine of a fan. The Chinese mat-and-batten sail had several advantages over the canvas sails used in European ships. It could manage with a material which, although not as strong as canvas, was aerodynamically more efficient. It offered more protection against tearing, and could easily be furled, as it would readily fall into pleats thus dispensing with having to send some crew member aloft to take in reefs.

The Chinese propelled their boats by punting with long poles and by rowing using steering oars and stern sweep. However, they also employed an ingenious method of mounting the oar approximately in the line of the main axis of the boat, and moving the oar from side to side about a fixed fulcrum. This was the Chinese *yaolu* that had fascinated many Western observers in the past. Louis Lecomte remarked that they made use of the *yaolu* as the fish did its tail.

The rudder is standard equipment in a sailing craft to control the direction of movement, although the same function may be performed by other means, such as by the oar and the paddle, albeit less efficiently. In the Western tradition the sternpost rudder is hung on pintle and dudgeon. What the Chinese did was to develop an axial rudder that could move up and down in guides. In shallow water it could be raised to its highest position to avoid damages, while in a heavy monsoon in the open sea it could be set in the lowest position for protection from the breaking water and to improve the ship's windward sailing quality. Sometimes the rudders were riddled with holes. These were fenestrated rudders. The holes were supposed to minimize the drag on the ship caused by the turbulence of the water flowing past the rudder, thus improving the hydrodynamics of the rudder. A ship would sometimes carry rudders of different sizes for use in different conditions. Sometimes instead of the rudder, the steering oar was developed into a long stern-sweep in boats that navigated rapid rivers and land-locked waters. The rudder is only effective where there is relative motion between the boat and its surrounding water. When a boat comes down with the same speed as a descending rapid, the rudder does not operate. A long sternsweep, however, depends on the

reaction to water resistance and controls the movement of the boat.

Thus Chinese ships ruled the waves in East Asian waters for a long period of time until the sixteenth century when the Portuguese arrived in East Asia and found no equal to their *calivers* outside the Atlantic. In the meantime from the days of the arrival of the latter until the second half of the twentieth century, the progress of modern science and technology had also left Chinese shipbuilding far behind. Although modern technology has already taken over from the traditional shipbuilding industry in China, we can still see Chinese junks and sampans navigating between ports in coastal waters in the China Sea and traditional rafts of all kinds sailing the rivers and the lakes in China today.

See Also

- [Bamboo](#)
- [Shen Guo](#)
- [Stars in Chinese Astronomy](#)
- [Zhang Heng](#)

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Navigation in India: Sea and Inland Navigation

R. S. Varshney

Ancient Tradition

The great landmass of India is surrounded by sea on the east, south and west and has a large number

of sheltered harbours situated all along its 5,700 km long indented coastline. There are also many large navigable rivers. Careful examination of ancient scriptures and archaeological discoveries has brought to light actual remains of docks, wharfs, jetties and warehouses in ancient times. References to sea journeys, navigation, boats, ships and docks are scattered in various verses of the *Vedas*, *Purāṇas*, *Meghamala*, *Mayurcitṛaka*, *Vṛhatsaṃhitā*, *Harivamsa* and other texts.

The *Ṛgveda* Aryans knew the slopes of a region by the help of rivers. That Aryans navigated on seas is clear from their worship of Jalnath (The Lord of the Sea). The *Ṛgveda* says, “Do thou convey us in a ship across the sea for our welfare.”

Aryans possessed knowledge of boats which were something like submarines. Here is a *shloka* (verse) from the *Ṛgveda*. “O Pushan, you work as a messenger by use of your boats which move under the ocean and also in the air. These boats have instruments with which things inside and outside sea can be seen.” The Vedic Aryans understood the construction and operation of sea boats.

In the *Ṛgveda*, the God Varun has knowledge of the routes of the oceans and also of the vessels sailing on them (*Rig*. 1.25.7). The same text further adds that merchants used to send out ships to foreign countries. A hymn in the *Atharva Veda* says that the boats which rode the waves were broad in beam, spacious, comfortable, resplendent with strong rudders and faultless in construction. The *Ramayana* refers to distant lands where the worm grew that yielded the silken thread and to the Lohit sagar, the references being to China and the Red Sea, respectively. *Rāmāyaṇa* also describes the boat journey undertaken by Bhagwan (Lord) Rama. The epic *Mahābhārata* mentions the naval activities of Pandavas. *Vriksha Āyurveda* a botanical treatise written in the sixth century BCE, mentions the types of wood best suited to boat building. *Yuktikalpatru* by Bhoj served as a textbook to later Indian shipbuilders.

The *Ṛgveda* mentions a naval expedition sent out by Rsi-king Turgā under the command of his

son Bhujyu. The ship was wrecked in a storm, but some of the occupants, including King Turga and his followers, were rescued by Ashvins, the twin brothers, who came in their hundred-oared galley.

Three things emerge from these references: first, ships were sent to foreign countries for trade; second, multi-oared boats were used in expeditions, and third, Vedic Aryans knew sea routes.

Archaeological excavations have revealed that, during the Harappa period (2500 BCE), there was a flourishing maritime trade between Kathiawar and the Persian Gulf countries. Of special significance is the evidence of the existence of a port city, called Lothal, 80 km south-west of Ahmedabad, which had docking facilities comparable to the modern ports of Mumbai and Vishakhapatnam. There were other ports also along the Gujarat Makrau and Konkan Malabar coasts.

The Bible also refers to early maritime commerce from India. In the days of Solomon items such as ivory, spices and peacocks could only have come from India.

In Mauryan times, for an account of navigation, we rely mostly on the *Jataka* stories. Greek writers often corroborate the facts mentioned therein. According to Greek writers like Arrian and Curtius, shipping was a highly developed industry in India in the fourth century BCE, and the same facilitated the passage of Alexander's army of over 100,000 soldiers through the Indus. Mauryan kings not only encouraged sea trade but also streamlined the administration of the navy. The *Arthaśāstra* of Kauṭilya (321–297 BCE) vividly describes the duties of the head of the naval department and the port officers. Important port installations of this period have been found recently at Kaveripattinam and Dharnikota on the east coast. Overseas navigation encouraged by the Mauryan emperors received further impetus under the Andhra-Satavahan kings and the rulers of the Chola-Pandyan kingdoms. The most important source of information concerning seaports of India in those days is the author of *Periplus* who hailed from Alexandria. He mentions a number of ports on both the western and the eastern coasts.

The Shravathi River in Karnataka is navigable from Honavar up to Gersoppa, which is mentioned in ancient texts. The most important port discovered is at Udyavara (called Odara in the *Oxyhydrinchus papyrus*), a small village 6 km south of Udipi, from which the saint Madhavacharya hailed. The mound known as Baleragudda marks the citadel of this ancient port city.

The early Tamil works of the first century AD describe at length the port establishments of the east coast such as Poomphar, i.e. Kaveripoottattinam, the chief port of the Chola kingdom. Other ports which are significant from the point of view of commerce during the first few centuries of the Christian era are Arikamedu near Pondicherry now identified as Pokduke or Poduca and Kainapara or Konark in Orissa. The Gupta emperors also encouraged inland and overseas navigation for trade. In the fifth century AD, Hamza of Isahan writers mention that Indian ships used to be moored at Hira near Hufa on the Euphrates River, the major role in the sea trade being played by the merchants from Sindh and Gujarat. The merchants of Gujarat colonized Java.

After the decline of trade with Rome, the Chalukyan and Chola kings encouraged sea navigation with the eastern countries especially Burma, Sumatra, Java, Borneo and the Island of Bali. I-tsing, the Chinese traveller who visited India (630–644 AD) says that Indian navigators and traders could be seen at all the busy ports of the east coast from Burma to China and in the Malayan Archipelago.

The four centuries between 200 BCE and 200 AD marked the heyday of Indian shipping. It was during this period that the Indians carried on their colonization of distant lands as far as Sumatra and Java, the latter of which still manifests its ancient Indian connection.

Marco Polo, who visited India in the thirteen century, left a vivid description of Indian ships. He saw ships that carried ten small boats slung on the sides, like present day lifeboats, with falls and tackles to lower them into water and heave them over the sides, along with 60 cabins below the rain deck for passengers. They were mostly foremasts and with as many as 14 watertight compartments.

A notable event of the early eighth century was that under the Arab onslaught on Persia, a good number of Persians, refusing to be converted to Islam, left their motherland by sea and sought asylum in the western ports of India. Their descendants are the Parsis of India. They contributed greatly to the commercial, shipping, shipbuilding and industrial development of the land of their adoption.

► **Ibn Baṭṭūṭa**, in the account of his travels in India, mentions the large boats that plied in the Indian rivers. He also describes in detail the manufacturing techniques of Indian ships. In the first quarter of the sixteenth century, on the western coast, the Zamorins of Calicut maintained a great naval force. Vasco da Gama also left a graphic description of the fleet of Calicut.

European travellers in India spoke highly of the strength and durability of Indian boats and ships. Nicolo Conti observed, “They build some ships larger than ours with five sails and as many masts.”

India’s maritime supremacy was maintained with the Mughals. Emperor Akbar gave impetus to shipping and shipbuilding. According to the *Ain-i-Akbari*, 40,000 vessels were engaged in commerce in the river Indus alone. Abul Fazal, the author of *Ain-i-Akbari*, mentioned the elaborate rules for the organization of the navy.

Advent of Europeans

In the last few years of the fifteenth century, events took place which had far reaching effects on navigation and the maritime world. The hostility between the Christians of Europe and the Muslims of Asia acted as a powerful factor in intensifying the efforts towards navigational exploration. In 1487 Bartholomeu Diaz passed the Cape of Good Hope and reached the Indian Ocean. The ‘Hope in Good Hope’ was the hope of the imminent discovery of the sea route to India. Vasco da Gama sailed from Portugal on 8 July 1497 and landed at Calicut on 27 May 1498. For the first time, a ship from Europe had arrived in India by an all-sea route.

By the middle of the seventeenth century the Dutch had become the masters of the trade of the Eastern Archipelago, ousting the Portuguese from the area. They then turned towards India, drove the Portuguese out of Sri Lanka, and operating with Colombo as their base, unleashed a sustained attack on Portuguese settlements in India. The Cochin establishment soon came under Dutch control; only Goa, Diu and Daman were left to the Portuguese.

It was now the turn of the English to establish direct contact with India. The East India Company was formed to break the Dutch monopoly and got a charter from Queen Elizabeth on the last day of the year 1600 granting it the monopoly of the Eastern trade. By and by Indians lost control of navigation of sea routes and Indian shipping gradually declined.

For nearly a 150 years the East India Company’s main activities were confined to commercial aggrandizement. Within 50 years of Auragazeb’s death (1707), the country was so confused in its political affairs that it provided an inviting ground for adventurers. The English emerged superior in naval power and they were able to displace the French and others.

In the final burst of glory, preceding extinction as it were, Indian naval power under the Marathas put up a brave fight against the supremacy of the European powers. Shivaji, the builder of Maratha power, had patronized the shipbuilding industry too. With the help of Tukoji Angray, the head of the Koli community of Ali Bagh, he built up a formidable fleet which, from 1694 to 1758, under the command of the Angrays, established complete control of the sea from Malabar to Travancore. The Indian shipbuilders of those times had such a high reputation that the Dutch and the English had some of their ships built by them.

During all this time, the seaborne trade of India had been rapidly increasing. But with the passing of trade in the more important commodities and the control of navigation on the high seas into English hands, Indian merchants and their shipping gradually disappeared from the scene. In a limited way, Indian shipping operated in the coastal waters and there were perhaps a few ships in trade with the Persian Gulf, the Arabian and the

East African ports. The pilgrim traffic to Jeddah which had state patronage under the Mughals continued in Indian hands. Despite heavy setbacks, there were still many Indians who ventured into shipping and kept alive the tradition of shipping enterprise. It is on record that even after the rule of the sea had passed to the Europeans, Gurjarat businessman continued to show courage and skill as merchants, seaman and pilots. According to historian Tod (1025 AD), for Biji Singh of Bhavnagar, his port was his grand hobby and shipbuilding his chief interest and pleasure.

Any account of shipbuilding in the eighteenth and nineteenth centuries must include the work of the great Parsi family of Wadias. For nearly a century and a half, from 1736 to 1884, the members of this family were master builders at Bombay dockyard and built over 350 vessels.

However, the encouragement to Indian shipbuilding in the early days of the Company's rule had been vigorously opposed in Britain by many of the Company's Directors themselves. In India itself measures were taken to discourage shipbuilding.

Steamships

In the meantime, a great revolution had taken place in shipping. Steam had begun to be used for propelling ships. Only those countries that were mechanically advanced could rule the high seas. All these advantages were held mostly by England and she made the fullest use of them. In the third and fourth decades of the nineteenth century the steamship began to prevail over the sailing vessel which gradually disappeared from the high seas. In 1825, the steamship "Enterprise", a small ship comparable with the coasters of today, left England on August 16 and reached Kolkata on December 7. This was the first steamer to perform a transoceanic voyage to India.

The 2 years, 1819 and 1919, stand out significantly in the history of modern Indian shipping. While 1819 saw the steamboat appear in Indian waters for the first time, 1919 saw the establishment of the first large Indian steamship company.

Decline of Indian Shipping

A number of small shipping companies owned by Indians were registered in the nineteenth century mainly to carry on coastal trade. All of them faced stiff competition and hostility from the British companies, mainly the Peninsular and Oriental (P&O) and the British India Steam Navigation Company (BI); they could not survive long.

But in the wake of the *swadeshi* movement at the turn of the nineteenth century, Chidambaram Pillai, a disciple of Lokmanya Tilak, entered the fray by launching the Swadeshi Shipping Company of Tuticorin in 1906. The flag of Swadeshi Shipping vessels bravely bore the words "Vande Mataram" (Mother, I bow to thee, which is the National song of India) a slogan which then served as a red rag to the bureaucratic bull. The fate of such a defiant patriotic venture can easily be imagined. An offensive was promptly launched against it. Pillai was arrested and sentenced to a long term of imprisonment for taking part in political meetings. The company crashed on the rocks of politics, not on the rocks of business. Similar was the fate of the Bengal Steamship Company, established in 1907 by Jyotindranath Tagore, brother of the famous poet and Nobel laureate Rabindranath Tagore. How disappointing the situation was is clear from the fact that about 80 shipping companies were registered in India between 1836 and 1918. By 1946 only seven still existed, and all of them were very small.

Revival

By now the patriotic fervour of the country had developed a strong economic flavour. Impressed by the generous contribution of the people to the war effort and especially by the bravery of Indian soldiers, the Government of India also was inclined to modify its imperialist policy a little.

The year 1919 provided a suitable setting for the entry of the Scindias on the Indian maritime scene. Scindia's owe their birth to a stroke of inspection, a moment of illumination, almost to

an accident of history. It was a chance meeting between Walchand Hirachand and Watson, a British engineer, during the former's railway journey from Delhi to Bombay on sixteenth Feb. 1919, that disclosed to him that a passenger ship was for sale in Bombay. It was the S. S. Loyalty owned by the Maharaja Madhavrao Scindia of Gwalior.

Walchand decided to bid for it. After getting down in Bombay he proceeded straight from the Victoria Terminus station to the dock to have a look at the Loyalty. After inspecting the ship, Walchand decided to form a syndicate to buy the Loyalty and establish a limited company to run it. On March 27, 1919, the Scindia Steam Navigation Company was registered with an authorized capital of Rs. 4.5 crores. On April 5, 1919, the S. S. Loyalty sailed from Bombay as an Indian passenger ship bound for Europe and the United Kingdom. It was a historic day in India's maritime annals, the day on which Indian shipping was reborn. Appropriately, since 1964, April 5 is celebrated annually as India's National Maritime Day. Although the Gwalior Maharaja retained no interest, financial or otherwise, his name came to be permanently associated with the company.

River and Canal Navigation

Rivers have been used for navigation since the earliest times, and in some cases water transport was the only means of communication between places. Big rivers in the north, like Ganga and Yamuna, have always been used extensively for navigation especially in eastern UP, Bihar and Bengal. Similar is the story of southern rivers like Krishna, Kaveri, Godavari, etc. The central India rivers have also been used as waterways.

Steamers on the Ganga

Various types of Indian boats were used on the Ganga and houseboats were popular among European officers. Boats carrying merchandise from Allahabad to Calcutta, a distance of

1,300 km normally took about 20 days in the dry season. The Journey upstream was difficult and took almost 3–4 months.

Lord William Bentinck, Governor General of India (1828–1835), showed keen interest in the development of steam traffic on the Ganga. In 1834 a regular passenger service started on the Ganga. The passenger boat, William Bentick, was launched in Calcutta in April 1834. In October, its sister ship, "Thames" was also commissioned for service.

River and Canal Navigation in the South

The Madras Presidency also experienced water transport improvements early in the nineteenth century. A canal linking Madras with the Egmore backwater was completed in 1806, and it was named after Cochrane, who became its proprietor. Lord Dalhousie, Governor General (1846–1856), acknowledging the benefit derived from the Ganga Steamers, was eager to extend such facilities to the Godavari, Indus and other rivers. On the west coast, canals were also built. In Malabar the important canals were from Cochin to Tirur, 125 km from Baypore to Badagara, 69 km and from Balapatom to Canara frontier, 35 km.

Indian Ports, Maritime Transportation and Inland Waterways After Independence

After Independence there was tremendous progress in sea and inland navigation. India has 11 major sea ports: Kandla, Mumbai, Nhava Sheva, Marmagao, New Mangalore and Kochi on the west coast and Kolkata Haldia, Vishakhapatnam, Chennai, and Tuticorin on the east coast. The 11 ports in India are the responsibility of the Ministry of Shipping but are managed by semi-independent port trusts overseen by boards appointed by the Ministry from Government departments, including the navy, port labour and industry, ship owners and shipping companies.

In order of gross weight tonnage conveyed annually, Mumbai, Vishakhapatnam, Chennai and Marmagao are the most important ports in India. In addition there are some 139 minor working ports along with the two coasts and on off-shore islands. Total traffic at the 11 major ports increased from 107 million tonnes in 1984 to 179 million tonnes in 1993. In 1993 there were three Indian government owned Shipping Corporations, the most important of which was the Shipping Corporation of India. There were also between 50 and 60 private companies operating a total of 443 vessels amounting to 6.5 million gross registered tonnes, more than 300 of which were 1,000 gross registered tonnes or more. Indian tonnage represented 1.7 % of the world's total. Over all, the share of Indian vessels in total Indian trade is around 35 %.

Some of the important shipping companies are: Indian National Ship Owners Association, Mumbai; Varun Shipping Co., Mumbai; Great Eastern Shipping Co. Ltd, Mumbai and Essar Shipping, Bangalore. India has four major and three medium sized shipyards, all government run. The Kochi Shipyard in Kochi, Hindustan Shipyard in Vishakhapatnam and Hooghly Dock and Port Engineers in Kolkata are the most important ones in India. Thirty-five smaller shipyards in India are in the private sector. Dry docks at Kochi and Vishakhapatnam accommodate the nation's major ship repair needs.

In addition to its coastal and ocean trade routes, India has more than 16,000 km of Inland waterways. Of that number, more than 3,600 km are navigable by large vessels, although in practice only about 2,000 km are used. Inland waters are regulated by the Inland Waterways Authority of India, which was established in 1986, to develop, maintain and regulate the nation's waterways.

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Navigation in Polynesia

Richard Feinberg

Polynesian dispersal through the Pacific islands is one of the great maritime accomplishments of human history. In wooden boats held together with cord fashioned from coconut husks, and following the stars, sun, waves, and wind, they populated the vast triangle bounded by Hawai'i, Rapanui (Easter Island), and Aotearoa (New Zealand).

The Polynesians' ancestors migrated from Island Southeast Asia to the Bismarck Archipelago in northeastern Papua New Guinea by 2000 BCE, where they left their distinctive Lapita pottery. Around 1500 BCE, they moved out into Fiji, and then to Tonga and Samoa. During the next two millennia they spread throughout the area now known as Polynesia. Later, a series of back-migrations populated the western Polynesian "outliers" scattered through the regions commonly identified as Melanesia and Micronesia.

Some of these voyages were likely purposeful exploratory forays. Others were forced migrations resulting from population pressure or political and military conflict. Some were accidental drift voyages by sailors who had lost their way, or by fishermen swept out to sea. At each stage, return voyages probably were made for purposes of trade, marriage, and exchange of information.

Thinking about Polynesian seafaring abilities has shifted several times since early European

contact. The French explorer Bougainville was so impressed by the canoes he witnessed in Samoa in 1768 that he called the archipelago “The Navigators’ Islands.” Britain’s Captain James Cook noted that Polynesian canoes were often as fast and maneuverable as his ships, and he carefully recorded Raiatean Tupaia’s impressive geographical knowledge. Even as late as the middle twentieth century, Sir Peter Buck (Te Rangi Hiroa), director of Hawai’i’s Bishop Museum, took Polynesian traditions of voyaging, exploration, migration, and settlement quite literally.

The tone of the discussion altered radically with the publication in 1957 of Andrew Sharp’s *Ancient Voyagers in the Pacific*. Sharp argued that, in the absence of instruments, human beings lacked the ability to navigate successfully for more than a few hundred miles. In particular, he argued, one could not detect, accurately estimate, and correct for current or leeway drift. Over distances of the many hundreds (sometimes thousands) of miles claimed by Polynesian oral traditions, he argued, errors would have been compounded, making the prospect of intentional landfall almost nil. Therefore, exploration and settlement were almost certainly the result of accidental drift voyages by sailors blown off course or forced, against their will, to put to sea.

This view again shifted with the pioneering ethnographic work of Thomas Gladwin (1970) on the Micronesian atoll of Puluwat and David Lewis’ more wide-ranging survey in 1972. They and others have documented voyages of hundreds of miles with accuracy comparable to that achieved with modern instruments, as well as the techniques through which this is accomplished. Most of the active voyaging in recent times has been conducted by Micronesians, but the techniques are similar to those employed by Polynesians in the past. This is confirmed by comments from Polynesians recorded by early European explorers, and those few Polynesian communities where traditional wayfinding techniques have been retained in recent times.

A second line of evidence casting doubt on Sharp’s drift voyage argument is provided by the direction of settlement. Linguistic and archaeological data make it clear that migration was

predominantly west to east, against the prevailing winds. Recorded drift voyages, by contrast, are almost always in the opposite direction. Such voyages have certainly occurred, and more than a few sailors have been lost at sea. This however, cannot account for exploration and settlement of the Pacific.

A third strand of evidence comes from computer simulations. Importantly, in 1973, Levison, Ward, and Webb demonstrated that Oceanic exploration and settlement could not have been a result of accidental drift, but must have resulted primarily from purposeful voyaging by skilled seafarers and navigators. They did this by taking into account prevailing winds and currents, and comparing them with the geographical relationships among the various islands and archipelagoes.

The final line of evidence supporting the proficiency of Oceanic navigators comes from experimental voyages with replicas of traditional voyaging canoes, using traditional navigational techniques. In 1980, a group of Taumako (Duff) Islanders from the eastern Solomon Islands built a traditional voyaging canoe (*te puke*), which they successfully sailed to Guadalcanal, over 400 miles away.

At least equally impressive are the exploits of *Hōkūle’a*, a replica Hawaiian double-hulled voyaging canoe, built with modern materials but to traditional design, which has been sailed successfully through most of Polynesia. Its first major voyage was to Tahiti, following traditionally prescribed star paths, and performed under the guidance of Mau Piailug, a master navigator from Satawal Island in Micronesia. Later, Nainoa Thompson, a Hawaiian trained largely by Piailug, navigated *Hōkūle’a* without instruments through all the major Polynesian archipelagoes. From 1991 to 1994, the Hawaiian Voyaging Society constructed *Hawai’iloa*, a double-hulled canoe built of traditional materials. Since that time, *Hawai’iloa* has been sailed through much of Polynesia. Most prominently, in 1995, she joined a fleet of voyaging canoes from Aotearoa (New Zealand), Cook Islands, and Hawai’i to sail, without instruments, from French Polynesia to Hawai’i (Finney, 2003).

Canoe Design

To travel safely on the vast Pacific Ocean requires seaworthy vessels. These had to be sturdy, maneuverable, able to resist leeway drift, and (to some degree) sail into the wind. For lengthy journeys, they had to be large enough to carry a good quantity of food, drink, and sometimes crops and livestock. This was accomplished differently in different parts of Oceania.

Most common were single-outrigger canoes ranging from small vessels paddled by one or two men (or occasionally women) for coastal travel and inshore fishing to the great Fijian *camakau* which might approach 100 ft in length and rival European sailing ships for speed. Resembling the *camakau* were voyaging canoes of several Polynesian outliers: e.g., Takuu (*vaka fai laa*), Nukumanu (*vaka hai laa*), and the Polynesian islands of the Santa Cruz group in the eastern Solomons (*puke*). Outlier Polynesians on Anuta still make single-outrigger sailing canoes which they have been known to sail hundreds of miles – to Vanikoro, northern Vanuatu, and recently to Santa Ana Island off Makira. In the outlier atolls, such as Nukumanu and Takuu, islanders have adapted the Fijian and Micronesian design of interchangeable bow and stern, where the canoe is tacked by moving the sail to the opposite end of the vessel, thereby always keeping the outrigger upwind. On other islands, such as Tikopia and Anuta, the more common Polynesian pattern was adopted. Bow and stern are distinct; the outrigger is always kept to the same side (most often, to port); and the canoe is sometimes sailed with the outrigger to the lee side of the craft.

Most imposing of the Polynesian voyaging canoes undoubtedly were the great double-hulled vessels of the Polynesian heartland. Such canoes have been reported from Rotuma and Tuvalu, south to Tonga and Aotearoa, and north to Hawai'i. More specialized developments included the New Zealand Maori's impressive single-hulled, outriggerless canoes, designed to carry scores of warriors primarily in coastal waters. For an inventory of Pacific Islanders' canoe construction and design, Haddon, and Hornell's encyclopedic treatment remains unparalleled.

Polynesian voyaging canoes could cover well over 100 miles a day with a favorable wind. The outrigger or double-hull design provides resistance to leeway drift without the need for a deep keel, which is a hazard sailing through a sea studded with shallow reefs. It is difficult, however, to beat into a head wind; and even the best outrigger canoes cannot sail at better than a close reach or approximately 75° off the wind.

Navigational Techniques

The most important tool for Oceanic navigation is the stars. Near the equator, stars rise from the east, travel more or less straight overhead, and set toward the west. The expert navigator knows the relationship between the bearings of various islands and the rising and setting points of various stars. Ideally, he identifies a star that he knows rises directly over the target island and points the bow of the canoe toward that star. When the star rises too high to be a reliable guide, the navigator turns his attention to another star following approximately the same trajectory. A sequence of such stars may well continue through the night, and it forms a star path.

In reality, it is unlikely for a sequence of stars to rise or set directly over the target island, so the navigator must set off the bow at an appropriate angle from the stars' actual position. In addition, the navigator must be able to estimate the direction and speed of wind, current, and leeway drift in determining a proper heading.

Wind strength and direction are not overly difficult to estimate as long as one can see the stars, moon, or sun, while leeway drift depends on the contours of the canoe's hull and heading in relation to the wind. It often can be gauged by the angle between the canoe and its wake.

Current is most difficult to estimate, but not impossible. First, a navigator knows the prevailing currents in the region that he plans to sail. These tend to be fairly constant at a particular time of year. The current's velocity is confirmed when the canoe is still near the point of embarkation, or when sailing over shallow reefs. The greatest danger is if currents change

direction while one is in deep water, far from land. Such shifts are difficult to detect, but there are sometimes useful clues. Anutans, for example, say that when the current and wind are running in opposite directions, seas tend to be unusually steep and white-capped. Conversely, when wind and current coincide, the seas are exceptionally flat in relation to the strength of the wind. Thus, by feeling wind strength and seeing or feeling the condition of the sea, one often discerns the current's direction even in deep water.

Fixing one's position on the ocean is another major problem. Latitude can be gauged with some accuracy by identifying zenith stars: stars located at a point that is directly above the observer. In addition, the configuration of stars at a given latitude at the same time on any given night is identical regardless of longitude. Therefore, one can estimate latitude by observing the altitude at which specific stars rise and set. Longitude, however, cannot be gauged from observation of the sky and must be estimated by dead reckoning. This means that the navigator fixes the position of his canoe in relation to the islands in his universe by estimating the vessel's speed, direction, and how long it has been at sea.

This is difficult, requiring the navigator to keep a running total of his vessel's progress at all times. One consequence is that he cannot sleep, other than occasional brief naps, even on a lengthy journey. Sharp argued that the element of human error inherent in dead reckoning is cumulative and, over a distance of many hundreds of miles, would be too great to permit accurate landfall. Empirically, it has been demonstrated, however, that the error is random and tends to cancel itself out. Therefore, the longer the voyage, the smaller the probable error.

During the day, when stars are unavailable, Polynesian navigators use the sun. This is practical in early morning and late afternoon, when the sun is low on the horizon. Toward mid-day, however, it loses value as a navigational aid. The sky also loses its navigational value when it is obscured by clouds, whether in the day or night. Under such conditions, auxiliary techniques are needed.

Navigators are aware of the prevailing wind patterns. If the sky is overcast, they assume that winds will remain constant until the stars and sun can once again be seen.

Still more stable and reliable are swells. A regular ground swell is produced by winds from far away, blowing over a vast expanse of ocean. Such swells remain constant despite shifts in local wind direction. An expert navigator can distinguish the regular ground swell from choppy seas produced by local winds. Indeed, some Micronesians have demonstrated the ability to distinguish several swells caused simultaneously by different far-off wind patterns. Polynesian master navigators almost certainly could do the same. By holding a steady course in relation to the swell pattern, then, the navigator maintains his bearings until celestial bodies become visible again.

In addition, sea marks such as deep reefs that can be detected from the color of the water may help indicate one's route. Use of such marks has been reported ethnographically for Micronesia, and at least some Polynesian navigators undoubtedly employed similar techniques.

Sailing strategy, particularly for exploratory voyagers, was clearly to sail counter to prevailing winds. This could be accomplished by waiting for a westerly shift at a time when the prevailing winds were from the east. If landfall was not made in a reasonable amount of time, it was expected that the wind would shift again, making for an easy return home. This accounts for the generally west-to-east direction of Polynesian migration.

Likewise, in historic times, Anutans like to sail at the beginning and end of the trade wind season, when breezes are relatively light and unstable, but the prevailing wind is from the southeast. During this period, they can usually find a period of a few days when wind of moderate strength is blowing in the preferred direction. Should it shift before they reach their destination, they can almost always return to their point of departure.

Geoffrey Irwin further suggests, plausibly although without definitive evidence, that long-distance voyagers employed "latitude sailing."

This involves sailing to the latitude of the target island but at a point well to windward, then making landfall by running downwind. Sailors from all parts of the Pacific also minimized their risk by island hopping, thereby breaking lengthy journeys into shorter segments. And they aimed, wherever possible, for groups of islands rather than isolated targets.

Land-Finding

As the navigator approaches land, he uses a variety of techniques for homing in on his objective. These include attempting to make landfall during daylight to minimize the chance of either being swept onto an exposed reef or overrunning the target. Then, before land is visible, it may be located via one of several indicators.

Among the most important of these are the flight patterns of birds that roost on land at night and fly to sea to feed during the day. Reflected waves are shaped differently from waves produced directly by the wind, and they can, at times, be felt at distances of more than 20 miles from land. Refraction patterns are more difficult to decipher but are used by a few peoples. Clouds tend to accumulate around the peaks of high islands, indicating their presence; and a greenish tint to clouds may sometimes indicate the presence of an atoll when it still cannot be seen from a canoe.

Polynesia in Comparison with Other Culture Areas

A few writers have made much of the distinction between Polynesia and other Oceanic culture areas in terms of seafaring acumen. Edward Dodd, for example, has suggested that the comparatively short distances traversed by Melanesians and even Micronesians means their vessels and wayfinding techniques could be less sophisticated than those of Polynesians, who sometimes had to sail thousands of miles, e.g., on journeys from Tahiti to Hawai'i or Aotearoa.

Clearly, the logistics of such lengthy voyages posed problems not faced by Micronesians

sailing from the Carolines to Saipan – a distance of about 500 miles. On such journeys, for example, the importance of dead reckoning increases and a smaller proportion of the voyage is guided by land-finding techniques such as reflected waves or flight patterns of birds. However, modern ethnographic evidence from around the Pacific and beyond supports the view that navigational techniques were fundamentally similar throughout Oceania. The transferability of old skills to new locations, and their ability to meet new challenges, is demonstrated by the success of Mau Piailug and Nainoa Thompson, piloting the *Hōkūle'a* through major portions of the Polynesian Triangle.

See Also

► [Seafaring in the Polynesian Outliers](#)

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Navigation in the Indian Ocean and Red Sea

Marina A. Tolmacheva

Navigation in the Indian Ocean has historically used the monsoons. The Chinese knowledge of monsoons was documented first but the Indians and Middle Easterners benefited from them as well. The Greeks learned about sailing with monsoons between the Red Sea and northwest India no later than the expedition of Nearchus (326–325 BCE). A Roman port was established at Adulis on the Red Sea to trade with India under Ptolemy III Euergetes (247–221 BCE). The Greek *Periplus of the Erythrean Sea* (first century AD) attests to the Arab domination of routes between Arabia, East Africa, and India. With the rise of the Persian Sassanid Empire, Yemen, a crossroads of sea trade, became subject to rival interests of Persians, Byzantines, and Ethiopians. Persians seemed to control the navigation in the western part of the ocean until shortly before the rise of Islam. In the mid-sixth century, the Nestorian Christian merchant Cosmas Indicopleustes of Alexandria described travel by sea to Yemen, Axum (Ethiopia), and Taprobane (Sri Lanka), where he observed various ethnic groups participating in the Indian Ocean trade. It is often believed that Indian participation in ocean navigation was discouraged by Hindu restrictions on

travel, but South Indian archaeology shows the existence of deep-water harbors accessible to large vessels at least from the second century BCE, and South Indian languages contain extensive vocabularies related to ships, shipbuilding, and navigation, albeit recorded sometimes in sources dating from the tenth century AD or later. Established practices of shipping, travel and contact were behind the faster progress of Islamization in the coastal areas of India, and there was a smooth transition of groups engaged in navigation and trade to participation in the networks following the Islamic religion and using Arabic as one of their languages.

Islamic navigation in the Indian Ocean and the Red Sea and the Persian Gulf is often referred to as Arab navigation largely because the known sailing instructions and literary works describing methods of navigation are in Arabic. Early statements by some European scholars to the effect that the Arabs did not like or know the sea ignore the fact that Islam arose among northern Arabs at the time when south Arabians had accumulated many centuries' worth of sailing experience. The revival and expansion of oceanic trade under the Abbasid caliphate (750–1258) must have involved not only Arabs and Persians but also coastal populations who converted to Islam later, but the sources are not specific on this point. Participation of Gujarati sailors is well documented in medieval and early modern periods. The Sind port of Daibul (Dewal, east of Karachi) gave the name to the East African group WaDabuli, descendants of the Daibul settlers who are mentioned in Swahili chronicles and dynastic oral histories recorded in the sixteenth–twentieth centuries. The first Dabuli migrations probably took place before 893, when an earthquake severely damaged the city, which was later abandoned. In the fourteenth century, participation of Indian Muslims as well as non-Muslims in merchant navigation and piracy is recorded by Ibn Baṭṭ ūta. According to Marco Polo and Conti, the Malabar coast of southwest India was where ships from China met with those arriving from the west.

The Red Sea was the scene of early contacts between Muslims and Africa, especially Egypt

and Ethiopia. It continued to play a role of conduit between the Mediterranean and the Indian Ocean and eventually carried heavy annual pilgrim traffic to Jedda and al-Jār (the port of Medina during much of the Middle Ages). Mocha was the main port in the south, Aqaba in the northeast, Qulzum (a major naval base) and Qusayr were prominent on the Egyptian coast, and 'Aidhāb on the African coast opposite Jedda. Outside the Bab el-Mandeb the ships stopped at Aden on the Arabian side or Zeila on the African side. Pirates found refuge on Dahlak and the smaller islands; once out in the Gulf of Aden, Socotran piracy was a threat.

During the Crusades the Red Sea became a scene of European attacks on Muslim shipping. Rulers of Egypt always tried to gain control of both coasts of the sea as well as Yemen. The Turkish conquest of Egypt and Yemen in the early sixteenth century made the Ottomans masters of the Red Sea and allowed them access to the Indian Ocean, where they tried to take over shipping routes leading to India, the Persian Gulf, and Africa. However, they were forced to yield to superior Portuguese force and later suffered naval intrusions into the Red Sea by both European and Indian (Gujarati) vessels. A major concern for Turkish authorities at Mocha and on the Ethiopian side (*eyelet of Ḥabasha*) was the security and provisioning of the pilgrims to Mecca. Bombay, Goa, and Surat served as major ports for the Red Sea India trade, and Massawa had a colony of Indian merchants (*Banyans*) from the late sixteenth century.

Sailing from the north was relatively easy, although passing the tip of the Sinai Peninsula was feared because the winds from the Gulf of Aqaba and Gulf of Suez met there. Ships carried from the ocean to the Red Sea by the monsoon had to sail against northerly winds once past the strait of Bab el-Mandeb. Jedda was the terminus of oceanic routes; transit further north had to use smaller boats. The only extant sailing instructions for the Red Sea cover the distance from Jedda to Aden (by Ahmad ibn Mājīd, ca. 1500). Latitude measurements taken by the stars could use the *Polaris Jāh* because of the northerly location.

"Triangular instruments," not described otherwise, and quadrants are mentioned. Finding one's location was not difficult in confined waters but navigation was dangerous because of numerous coral reefs, contrary winds, and currents. The journey from the north to the south end took 30 days (sailing by day only and coasting), but the ships of Saladin's navy could reach the speed of four to five knots. The north wind of the Red Sea *shamāl* reached the southern part only from May to September, coinciding with the short period when the prevailing wind in the Gulf of Aden was westerly, thus propelling ships into the Indian Ocean. The southeasterly wind of the Red Sea *azyab* reached half way up.

Navigation in the Indian Ocean was dominated by the monsoon (from Arabic *mausim* 'season'), a wind system that reverses direction seasonally. Both halves of the Indian ocean are subject to monsoon regime. The southwest monsoon *kaws* begins in March on the East African coast, slowly spreading eastwards. It reaches its maximum strength in June and blows across the ocean until October, bringing the heaviest rains to India in June and July and causing heavy swells which made landing difficult and even closed the ports. The northeast monsoon *azyab* originates from the Indian mainland in early October, reaching Zanzibar by late November. It makes it easy to sail almost directly from Malacca to Jedda as the wind continues into the Gulf of Aden. Between the monsoon periods, voyages were made in other directions, using variable winds and breezes. March to May are such changeover months in the northwest corner of the ocean. In the Gulf of Aden the predominant non-monsoon wind is easterly. Travel from India to Africa had to be begun by early February. From Aden and Yemen one needed to leave in mid-October, and from northeast Arabia by late January, but one could not sail to Socotra during the same season. From Socotra to southeast Arabia one sailed in March–April, while India could be reached also by departing in May and during the August–September season *dūmānī*. Travel down the African coast was recommended from mid-November to April. From Bengal one had to

leave westward by January; leaving from Malacca, Java, and Sumatra in February or March one could still reach Ceylon. Travel from Gujarat to Bengal and Indonesia began in April or late summer. October brought cyclones to the Bay of Bengal. The eastbound roundtrip journey from the Persian Gulf across the ocean took 18 months. China-bound ships started from the Gulf in September or October, reached Kalah Bar in January and passed through the Strait of Malacca in time to use the southern monsoon in the Sea of China. Return to Malacca took place with the NE monsoon between October and December, then ships could cross the Bay of Bengal in January and reach Arabia in February or March.

Navigation between the Middle East and China is confirmed by reports of an Arab embassy to China in the seventh century, a Persian settlement in the island of Hainan in 748, and a mixed Arab-Persian colony at Canton in the eighth-ninth centuries. In the seventh century Persian ships took 20–30 days to reach Sumatra from China, and 1 month from Ceylon to Palenbang. In the ninth century “Chinese ships” or “China ships” (that is, ships sailing to China) are reported in the Persian Gulf. Smaller boats brought goods from Basra and other ports of Siraf where they were reloaded on the large China boats. Ceylon (Sarandīb) was also visited and described by Arabic authors. Sea travel from the Persian Gulf to East African islands is mentioned by Arabic sources in the ninth century and described as routine in the tenth by the historian and traveler al-Mas’ūdī, although the country of Sofala (southern Tanzania and northern Mozambique) was then still poorly known. The Persian Gulf ports of Siraf and Hormuz as well as Oman were dominant on that route at the time; Aden emerged to prominence somewhat later. Some of the tales of Sindbad the Sailor (of Basra) originated in stories of Indian Ocean sailor and merchant adventures collected in the book *The Marvels of India* by Buzurg ibn Shāhriyār (ca. 950). Much of Marco Polo’s return journey in the late thirteenth century must have taken place in Muslim boats and followed routes mentioned in this book. In the fourteenth century Ibn

Baṭṭ ūta. traveled by ship across the Red Sea and later to Africa, visiting Mogadishu, Mombasa, and Kilwa. On other occasions he sailed along the west coast of India and possibly to China. In India he encountered merchants from Cairo and Northwest Africa and fell victim to Indian pirates. He reported the presence of Chinese junks at Ceylon and planned to travel on one himself. The famous Chinese voyages led by the Ming court official ► [Zheng He](#) (Jeng Ho) constitute the last known attempt by China to break into the Indian Ocean network. Two of these, in 1417–1419 and 1421–1422, reached Africa, visiting Malindi and the Horn of Africa. Even the arrival of the Portuguese caused only a disruption and reorganization of shipping. Lodovico Varthema (ca. 1510) and the early Portuguese sources note the continuing international presence at western Indian ports: Egyptians and “Moorish” merchants and ships from Hormuz, Arabia, Abyssinia, Kilwa, Malindi, Mombasa, and Mogadishu at Cambay, on the Malabar coast and the islands (Maldives and Laccadives). Early naval battles between the Portuguese and combined Muslim navies (e.g., at Diu in 1512) resulted in capture and destruction of numerous Muslim vessels (In the sixteenth century only the Chinese had ships able to withstand attacks of the Portuguese galleons). However, the Portuguese soon realized that they would be unable to stop native shipping, and turned their efforts to diverting trade to ports which they controlled, carriage in their own ships, and taxation of all others. By the time the Dutch and the English arrived, an accommodation had been reached. However, intra-European competition, added to Christian-Muslim rivalry, contributed to preexisting pirate activity, especially in the Persian Gulf and on the Gujarat and Malabar coasts. The maritime Muslim trade revived somewhat in the seventeenth to eighteenth centuries and declined again in the nineteenth century, at least in part due to increased British control over the routes and ports of the western Indian Ocean. Another factor was the growing dominance of European companies in the long-distance East-West trade and their penetration of local trade.

The sources for traditional Arab navigation date mostly from the late fifteenth through the sixteenth century, while our knowledge of ships and shipbuilding in the region is modern or contemporary. There are vague, scattered references to earlier sailing guides *rāhnāmaj*, devices and ships. Naval law is best known from the Malacca code of Shāh Maḥmūd (1488–1530). A sixteenth century Persian source lists 12 categories of crew members with job descriptions. The best information on navigation proper and sailing routes comes from the works of Aḥmad ► [ibn Mājid](#) of Julfar in Oman (d. ca. 1504) whose recognized expertise made him into a patron saint of Muslim sailors. A learned practitioner, he composed navigation manuals and sailing instructions, largely in verse, to ease memorization. From him we learn the names of several earlier pilots, dating back to the tenth to twelfth centuries. To these Aḥmad ibn Mājid added the names of his own father and grandfather; apparently, the profession of pilot was hereditary but not highly regarded. It has been asserted by some scholars that Aḥmad ibn Mājid was the pilot who guided Vasco da Gama from Malindi to Calicut but this has been contested by others. Although he spent his life on the Indian Ocean, it appears that Aḥmad ibn Mājid was aware of the different methods of navigation in the Mediterranean. Other extant works on Islamic navigation belong to Sulaymān al-Maḥrī (ca. 1511), a native of Shihr who wrote several practical and theoretical treatises, and the Ottoman writer Sidi Ali Çelebi who compiled a Turkish summary of the former two authors' work while moored in Gujarat in 1554 after a Portuguese attack on the Turkish Indian Ocean fleet originally commanded by the portolan-maker Piri Reis.

Contemporary Arabic names of ships, *baghala*, *ganja*, *sanbūq*, *jihāzī*, apply to vessels with square, transom, sterns showing European influence. The older type is represented by vessels now called *būm* and *zārūq* – double-edged, coming to a point both at bow and stern. The name *sanbūq* was formerly applied to the small craft of the Red Sea; *jalba* was the sewn boat

typical of the Indian Ocean region. First mentioned in the *Periplus of the Erythrean Sea*, sewn boats were carvel built, with planks edge-to-edge, and stitched with ropes of palm fiber. The timber was teak or coconut wood. They were leaky and frail but had advantage over clinker-built boats with overlapping planks when striking a coral reef. A common legend explained that nails were not used because of the dangerous power of a magnetic rock somewhere in the middle of the ocean which could attract the nails. However, iron as well as stone anchors were used. The generic names for “ship” were *markab* and *safīna*. Indian pirates had *bārijas*; smaller boats called *zawraq*, *qārib*, and *dūnij* are also mentioned in medieval texts but no particular shape is indicated. *Dau* is a generic name for lateen-rigged vessels; the Arabs do not use it. The basis of classification was the form of the hull. The ships were usually one-masted, often without decks, with a cargo capacity of up to 200 tons. Erecting the mast and the rigging, and even making the sail was the responsibility of the owner *nakhūda* and the crew rather than the shipwright. The lateen sail associated with Arab ships probably evolved from a square sail on the Indian ocean; its use in the Mediterranean is first noted in the ninth century. African and Indian vessels continued using square sails of coconut matting into the twentieth century. The lateen is a tall, triangular fore-and-aft sail with the fore angle cut off to form a luff [the front edge of a sail]. It allows sailing into the wind by going on the tack, although Arab mariners preferred not to sail closer to the wind than 90°. It is possible that a second sail (topsail) was sometimes used. No reefing was done in strong wind, but the yard could be lowered. Two side rudders were originally used for steering, although by the thirteenth century the stern rudder was known. Sailing speeds averaging one to three knots were normal but could reach six knots under favorable winds.

The most important person on board ship was the *mu'allim* who served both as captain (*rubḥān*) and pilot. He was hired for the voyage and allowed to carry merchandize as part of his pay.

The shipmaster (*nakhūda*) was a merchant; ships were often owned by shareholders. We know Persian terms for 11 ranks of crew members; of these, the most important were the bo'sun (*tandīl*), the ship's mate (*sarhang*), the steersman (*sukkān-gīr*), and the look-out (*panjarī*). Sailors were called *khallāsī* or *khārwah*. The captain was responsible not only for navigation but for the safety of passengers and goods as well. Among the necessities he carried were a nautical directory (*rahnāmaj*), measuring instrument (*qiyās*), bussol (a very exact compass) (*huqqa* or *dīra*), lodestone (*Hajar*), lot (*buld*) and lantern (*fānūs*). The pilot's principal science consisted of knowing the coasts, winds and seasons, and his ship. Before departure, the Muslim prayer, *Fātiḥa*, was recited and an invocation was made to Khidr, the mythical patron saint of mariners.

By the sixteenth century, Arabic sailing manuals list over 30 different routes. Navigational books (*dafātīr*) and charts (*Ṣuwar*) carried on board are mentioned in the tenth century; Aḥmad ibn Mājid calls his "chart" *qunbās*, but no charts have come to light. G.R. Tibbets argues that the Arab pilot plotted his course in his head and did not need a chart; besides, proper charts could not be made because the Arabs had no way of correctly determining longitude at sea. The winds and geography of the Indian Ocean allowed the pilot to be guided roughly by the latitude of his destination (determined by the Pole star altitude). Once that was reached, he sailed down the latitude toward his goal. Another way was to keep to a recommended bearing until land was in sight and then make corrections. Extant Arab maps do not allow practical application to navigation. A Chinese chart based on the Zheng. The expedition shows the routes from China to Hormuz, the Red Sea and Africa, but no measurements can be taken from it. Charts from Muslim Indian (Gujarati) nautical manuals (*roz nāmah*) of the seventeenth to eighteenth centuries show some European influence and use stellar compass bearings and Arab units of time-distance. A possibility of Chinese influence has been suggested as well. Considering that Arab information is already found on early

sixteenth century Portuguese maps, it is clear that the sharing of information among mariners created a truly international maritime culture drawing on indigenous and regional traditions and innovations.

The Arab system of nautical orientation evolved on the Indian Ocean in the intertropical region, but probably north of the Equator; it may have been representative of all Indian Ocean sailing. It is based on a 32-rhumb (*khan*) sidereal rose (*dīra*) divided into eastern and western halves separated by the Polaris (*Jāh*) in the north and the South Pole (*al-Qutb*) in the south. The ► [east](#) and [west](#) divisions approximate the rising and setting of certain bright stars and constellations (Ursa Minor, Ursa Major, Cassiopeia, Capella, Vega, Arcturus, Pleiades, Altair, Orion, Sirius, Scorpio, Antares, Centaur, Canopus, Achernar). This system may have been in place by the ninth century. The bearings (*majrā*) were set by the actual stars, visible in the clear skies, not by the mathematically correct rhumbs. The compass was not unknown but rarely used or even carried. Star altitude (*qiyās*) was measured in units called *iṣba'* (finger), supposed to correspond to the arc covered by the little finger of an outstretched hand. Its degree value measured 1/2 of the distance from the Polaris to the true pole, and thus varied with precession. In 1394 one *iṣba'* equalled 1°56' but in 1550, 1°33'. The full circle of 360° corresponded alternatively to 210 or 224 *iṣba'*. *Iṣba'* also measured 1/24 of a cubit. For longitude estimates, one *iṣba'* equalled 8 *zām*, each *zām* corresponding to the distance covered in 3 h of sailing. A variety of other measurements, including something approximating triangulation, were calculated in these units. The altitude of the Polaris was supposed to be taken at its inferior elevation.

The instruments used for measurements included the *kamāl*, *lawḥ*, and *bilistī*. The *kamāl* was a rectangle of horn or wood with a string through the middle. It was held against the horizon in an outstretched hand, with the cord held in the teeth by the knot. Knots tied at certain intervals on the cord corresponded to the varying arcs covered by the rectangle. Variations of this

instrument included knots tied at intervals corresponding to locations on a set route, a set of boards (*lawḥ*) corresponding to different arc values fixed on the cord, and the cord being held to the nose. The *bilistī* was a later version of the *kamāl*, with a rod replacing the cord, and four sliders of different sizes; most likely it postdates the Portuguese arrival because its function is essentially that of the *balestilha* (a nautical instrument of orientation, similar to the astro-labe). By the nineteenth century, the traditional system and the instruments had been largely driven out of use or forgotten, although the name and expertise of Aḥmad ► *ibn Mājid* were still respectfully remembered. Today's fiberglass dhows are equipped with motors and navigated with modern charts and instruments.

See Also

- *Al-Mas'ūdī* (Abu) 'I ḥasan 'Alī Ibn al-ḥusayn al-Mas'ūdī)
- *Geography in the Islamic World*
- *Ibn Baṭṭūṭa*
- *Ibn Mājid*
- *Maps and Mapmaking: Islamic World Maps Centered on Mecca*
- *Navigation in Africa*
- *Pirī Reis*

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Navigation in the Pacific

Nicholas J. Goetzfridt

Three thousand years ago, Polynesian voyagers had already reached the small Pacific island chains of Tonga and Samoa. A thousand years later, following, as some scholars believe, the refinement of navigational capabilities and canoe design, they reached the far distant Marquesas, Tuamotus, and Society Islands. Geoffrey Irwin maintains on the basis of archaeological evidence and empirical analysis that there probably was no pause in the prehistoric settlement of eastern Polynesia. The rate of voyaging may very well have increased in accordance with the larger ocean gaps between archipelagoes. Voyagers eventually reached the small and very isolated Easter Island, may very well have established voyaging routes between the Society Islands and Hawaii, and may have even reached the coast of South America as is suggested, among other things, by the transmission of the sweet potato.

The questions of when the Pacific was settled are not as variable and questionable as those about how it was settled. The challenge of this issue, at least in terms of distance and the diminishing target areas of land as one moves east, becomes increasingly great as one can see by looking at a map of the Pacific Ocean. Several scholars consider all of these movements to have been the consequence of population demands, warfare, and the basic desire to explore and keep seeking. But the notion of great navigators who controlled their destiny and the destinies of those who put their trust in them, and who could ride the sea at will, prompted many articles and treatises. It also provided the easy and attractive answer to the haunting questions concerning the ancient settlement of Oceania.

Percy Smith, who wrote mostly between 1890 and 1920, promoted a migration of deliberate and controlled dimensions which he believed was most evident on the basis of Polynesian traditions

and the inferences that one could make from them. He acknowledged the importance of applying the fields of ethnology, historical linguistics, and especially oral traditions to his theories on the ancient Aryan origins of the Polynesians. These alleged achievements included a voyage from Borneo to Hawaii in about AD 450 (the fact that voyagers continued on to Hawaii even after reaching hospitable islands along the way indicated to Smith that they were following the directions of a previous navigator), the reaching of Antarctic waters by two deliberate voyagers described in traditional histories, and the frequent voyaging between Tahiti and Hawaii (using the Line Islands as resting points) which eventually ceased in the fourteenth century, because the "boldest navigators of the race" had departed to New Zealand in the fourteenth century Great Fleet of the Maori people.

Elsdon Best, writing during the same time, also endowed navigators and voyagers in the Pacific with a perceptiveness of the environment and an adherence to the messages of traditions which made well planned, deliberate voyagers of settlement and communication a reality among the far flung islands of Oceania. While numerous early European explorers in the Pacific expressed wonderment in their journals at the existence of complex and populous societies on both low and high islands, which were at one stage thought to be remnants of a sunken continents occupied by survivors, very little was ever recorded on the actual means by which indigenous navigators dealt with practical problems related to the art of oceanic path-finding.

Buck, during the next 30 years, considered more practical questions on canoe capabilities and types, and the evidence that ethnology in Polynesia suggested in relation to early Polynesian migration. He also asserted the probable movements and routes used by Polynesians to reach islands throughout Polynesia and the eastern regions of Micronesia and Melanesia. He recognized the relevance of Polynesian traditions and related genealogies for tracing Polynesian origins and for understanding early voyaging and settlement in the Pacific, with an emphasis on voyages between the Society Islands and New Zealand.

But these speculations and the assignment of great skills to navigators who then sailed the Pacific with complete control, denied, or superficially addressed issues. They thus failed to consider the diverse problems of both natural and human origin which confront a navigator without modern instruments on an open ocean. Were there explicit strategies followed for the initial exploration of islands to the east of the easier "voyaging corridor" from Southeast Asia to Melanesia? If they were deliberate voyages with the intention of settlement, were such initial voyagers and those that were to follow one-way or two-way voyages? If two-way voyages were accomplished, were they done so regularly or perhaps even for the purposes of inter island communication? What might have been the distance limit for such intentional voyages of return? How did changes in climate and stellar positions over a long period of time affect the success rate of such voyages? Why did voyaging in some areas apparently cease before it did in other areas? Then, there is the question which has generated a significant amount of literature on the overall issue of oceanic voyaging and settlement. This involves numerous practical problems of reaching land, including the use of land indicating signs such as the flight of birds, the swell of waves generated from an unseen island or islands, the "loom" of land produced from an island's white sand and a still lagoon reflecting the sun's glare, the ability to determine set and drift en route, the ability to steer and maintain a course from a known sequence of stars, and the ability to maintain or to eventually recover such a course when stars are obscured or the winds change.

Was it possible that early voyagers in the Pacific were capable of using island "blocks" and "screens" that are created by the ability to perceive and interpret these wave patterns emanating from unseen islands, the flight of certain sea birds (or "bird zones"), types of fish, seaweed, water color, and clouds gathering over a distant island? These elements may have offered a 30–40 mile radius around each island which essentially expanded the size of an island target. Such perceived circles ultimately overlap throughout significant areas of the Pacific and

could have enabled navigators to sail for an archipelago from even great distances before seeking a specific island within the archipelago.

Voyaging researcher David Lewis in his numerous voyages with present-day indigenous navigators of the Pacific has also recorded the glowing plaques of bioluminescence that can indicate the existence of land 80–100 miles away. But the elements of darkness and overcast skies have often been used by critics to maintain that many components of these blocks were not consistent enough to be dependable.

The academic granting of voyaging prowess to indigenous voyagers of the Pacific by these early writers and the lack of precise information on the practicality and effective means of using these natural elements to find land (not to mention the formidable question of how a course could be maintained over long distances before arriving at these island blocks), was underscored by Andrew Sharp's books and articles between 1956 and 1969 which dismissed the ability of Polynesians to exercise any significant control over their voyages. Sharp maintained that these voyagers were incapable of compensating for set and drift during the course of a voyage, of maintaining a course in accordance with star paths or movements when the night sky was obscured, and of being unable to comprehend their position and the position of their destination once they were driven off course by a gale or storm. According to Sharp, Polynesian traditions with names of distant islands and directions for reaching them were actually derived from European contact. Polynesians knew of distant archipelagoes. The Raiatean navigator Tupa'ia expressed this knowledge to Captain James Cook in 1769 whose assistants in turn created a map (apparently misunderstanding Tupa'ia's directions for north and south) that stretched from Fiji to the Marquesas. This merely demonstrated that Polynesians had traveled these distances but not necessarily as a result of deliberate and return voyages. Sharp also stressed that the apparent random distribution of several important plants and animals is simply reflective of the haphazard nature of Pacific settlement. While the accidental settlement of Polynesia, according to Sharp, did occur primarily from west to east (a direction which is generally

agreed upon by Pacific scholars), winds and currents drove later voyagers in all directions. Although Sharp did allow for the ability of Polynesians (particularly in Tonga and the Tuamotu Archipelago) to undertake voyages of no more than 300 miles without intervening islands with the intention of marking a return voyage home, the severe limitations of a noninstrumental navigational system nevertheless made even these voyages open to chance. The use of this "primitive navigation" by Pacific voyagers made them unable to protect themselves against any lateral displacement and did not enable them to derive much consistent and valuable information from horizon stars or to use stars to establish either latitude or longitude.

Thor Heyerdahl meanwhile challenged the general acceptance of an oceanic settlement pattern from west to east, maintaining that archaeological, botanical, ethnological, biological, geographical, and navigational evidence supported a Peruvian movement from South America into Polynesia using balsa rafts with strategically arranged guará hardwood centerboards. He maintained that Spanish expeditions into Polynesia actually followed sea routes established by the Incas and often referred to traditional accounts of the voyager Yupañqui Inca Tupacur Tupac Inca. He was said to have departed from Peru in search of legendary Pacific islands, using the traditionally known island of Sala-y-Gómez as the primary landmark for beginning a voyage to the west, and to return 9–12 months later with "dark" people, which suggests that he may have voyaged as far west as Melanesia. In an attempt to prove that such voyages were possible, Heyerdahl and a crew sailed the *Kon Tiki* balsa raft from Peru to an eventual landfall on the atoll of Raroia in the Tuamotus in 1947. Heyerdahl, however, has been criticized by various scholars for, among other things, selectively neglecting evidence which strongly suggests a Southeast Asian origin of the Polynesians, his contention that "primitive asiatic craft" could not have successfully sailed from Southeast Asia to Polynesia, and for undermining or ignoring the fact that seasonal shifts in the prevailing winds of the Pacific do occur, making well planned voyages from west to east possible.

Sharp's works instilled what researcher Ben Finney characterizes as a "healthy corrective to some extravagant claims." The inferring of the abilities or inabilities of indigenous voyagers to control their destinies at sea on the basis of poor references in the journals of European explorers, simply produced theories which had little practical, at-sea evidence to support them. Ben Finney's and David Lewis' investigations into the navigational abilities of indigenous voyagers in the Pacific have made significant contributions to scholarship in this area.

Finney was and has been involved for a number of years in the building and sailing of the Hawaiian double canoe *Hōkūle'a*. Beginning with its first, noninstrumental voyage from Hawaii to Tahiti in 1976, it has provided an important component to Hawaiian cultural revival in the immediacy of its connections with the voyaging heritage of the Hawaiian people. It has also offered numerous opportunities for navigators (first the Satawalese navigator Mau Pailug and more recently the Hawaiian navigator Nainoa Thompson) to test and develop their use of various noninstrumental, navigational strategies to deal effectively with the voyaging problems of maintaining an accurate course under various natural conditions. This has also given other scholars the opportunity to apply these voyaging experiences to important questions related to the early settlement of Oceania, particularly the question of the movement from west to east which is normally a movement against prevailing winds. The *Hōkūle'a* 1985–1987 "Voyage of Rediscovery" in the Pacific engaged in experiments in west to east movements (in this case, from Samoa to Rarotonga via Aitutaki and from Rarotonga to Tahiti) to attempt to understand how voyagers effectively exploited periodic westerlies to cross the crucial gap between the Western Polynesia and Eastern Polynesia cultural provinces via the Samoa-Tahiti expanse. These methods for exploiting changes in the trade winds, often interrupted by low pressure systems, if they were undertaken by skilled navigators, would necessarily have required strategies for perhaps specific legs between western and eastern Polynesian islands.

Some items out of the rather voluminous literature on indigenous noninstrumental navigation

and voyaging in the Pacific address the impact that climatic changes between the warming period of the Little Climatic Optimum (up to the twelfth and thirteenth centuries) and the advent of the Little Ice Age (approximately the fifteenth century) could have had on the occurrence of storms and thus the ability of voyagers to engage in long distant trips of exploration and settlement. Some scholars theorize that although voyagers from Eastern Polynesia were able to reach and settle in New Zealand by the early fourteenth century, this climatic change may have ultimately prevented them from going further to reach Australia and Tasmania. Some scholars have also conjectured on the impact that changing star patterns over several millennia may have on present-day investigations into this great achievement of human migration. At least one scholar has investigated how this change may provide a historical link between Arab and current Carolinian navigational star systems (Halpern, 1986).

It should be emphasized, however, that all this scholarship on indigenous navigational abilities in relation to the chronology and patterns of human settlement on Pacific islands is incomplete without incorporating the findings and theories of other areas of scholarship, particularly archaeology. While not necessarily being directly concerned with navigational capabilities, they often provide solid physical evidence of the past, from which theories on such migration and voyaging achievements can be made and developed and/or challenged. The part that archaeology plays in attempting to answer many of these questions cannot be understated, although the extensive work that has been done in the field and remains to be done cannot be given adequate summary in this article.

The literature on indigenous voyaging in the Pacific has also covered the use and possible use of several indigenously devised navigational aids – the best known of which are the Marshall Islands stick charts which a German writer, Schück, attempted to describe in 1887, noting European references to the existence of Marshallese maps as early as 1817. Europeans in the late nineteenth century noted the use of these charts which are basically intended, through unique

connections of various sticks of wood and shells, to document wave patterns and swells in relation to specific islands in the two archipelagoes of Ratak and Ralik in The Marshall Islands. Several articles refer to the secrecy that was once associated with them, while Hops noted that only the Marshall Islands may have the natural prerequisites which make the existence of stick charts unique to them. Another device that has been explored in the literature has been the sacred calabash filled with water whose holes near its top allegedly enabled a navigator to establish the latitude of Hawaii. This was accomplished by lining up Polaris at a 19° angle during a voyage from the south, and thus allowed a navigator to turn confidently to the west where he would eventually find Hawaii. Although confusion over a large calabash in the Bishop Museum in Hawaii added to the controversy, the use of the sacred calabash has generally been dismissed as being impractical. Others include the existence of nine coral stones on the northwestern end of Arorae atoll in Kiribati, perhaps used at one time by voyagers to set their courses to neighboring islands in Kiribati, a stone canoe in Beru (*kiribati*) for instructional purposes, a coconut wind compass with four directional holes used by Tahitian voyagers, the use of dials with wood hanging from strings with knots to indicate the position of stars, a bow hole and cord used for star course steering, the seeking of divination before a voyage through the tying of knots in palm leaves, and a cane filled with water to determine latitude and perhaps used in the Caroline Islands.

Research on the cognitive systems of indigenous navigators who still undertake voyages in the Pacific, particularly from the atolls of Satawal and Polowat in the central Caroline Islands of Micronesia, is far more extensive than these occasional references (with the exception of Marshallese stick charts) to these unique devices. Gladwin's groundbreaking study on thought processes involved in Polowatese navigational knowledge which he related to the academic test performance of economically underprivileged individuals in the United States, has been followed by numerous works concerned with the canoes, navigators, and navigational systems of Polowat and Satawal.

There are also ethnographic concerns about cultural and social elements which enable noninstrumental indigenous navigation on these islands to survive in a modern technological world. While Western material influence has contributed to the decline of indigenous voyaging in areas where it was pursued until relatively recently, as has the actual government banning of voyaging, traditional navigation on these two atolls forms an integral part of their identity and society.

One well documented navigation technique found in the literature which discusses these esoteric systems is the technique of *etak*. The system of *etak* defies Western conceptualizations of movement in that a reference (sometimes imaginary island) to the side is seen as moving toward and past the voyager's canoe while the canoe remains stationary. The navigator is subsequently able to determine his position and progress in relation to stars and the *etak* segments that they provide. The survival of these systems of course depends upon how successfully they are transmitted to the young. The maintenance of star courses through songs and chants allowed for these courses to be used in recent 600 mile voyages between Satawal/Polowat and Saipan in the Northern Mariana Islands, despite the fact that such voyages had apparently not been undertaken since the early part of the twentieth century.

We now know of this rich voyaging heritage which many Pacific islanders value in the context of their cultures today. And we are aware of the questions that relate to what must be seen as an astonishing achievement in human movement throughout a vast Pacific Ocean at a time when Europeans were still depending (and would continue to depend for a long time) upon the sight of a coast. It is little wonder why the literature on indigenous navigation voyaging in the Pacific has developed as it has since the latter portion of the nineteenth century.

See Also

- [Maps and Mapmaking: Marshall Island Stick Charts](#)

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Navigation: Inland Navigation in Amazonia

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The Amazon River, with its tributaries, as well as the São Francisco, Tietê and Paraguay Rivers, and the Rio da Prata are important inland waterways which have functioned for centuries as communication and transportation routes into the interior of Brazil. Well before the arrival of the Portuguese on the Brazilian Atlantic coast (1500), indigenous peoples utilized these rivers for travel, supplementing overland treks with frequent riverine connections. On totally fluvial trips, portage of lightweight vessels (canoes) overland was often necessary to avoid the treacherous rapids characteristic of the inland rivers. Although Francisco de Orellana descended the Amazon for the Spanish in 1541–1542, neither the Spanish nor the Portuguese Crown attempted to penetrate the interior of Brazil in the sixteenth century. Essentially, the arrival of the Europeans in the hemisphere did nothing to change the traditional pattern of riverine transport.

This situation changed dramatically in the seventeenth and eighteenth centuries when waves of adventurers (some Portuguese, some of mixed ethnic background, and all only nominally under colonial control) traversed the backlands of Brazil seeking gold, precious stones, and Indian slaves. Eager to take commercial advantage of these discoveries, in the eighteenth century, the Portuguese ordered military engineers and Crown officials into the region, tasking them with establishing townships and captaincies (administrative units) in what had essentially been lawless territory. By the mid-eighteenth century, the Portuguese would lay claim to the interior of Brazil, with navigable rivers sometimes marking the boundaries between Portuguese and Spanish claims (Burns, 1993, p. 60). Of all of these rivers, it was the Amazon and its

tributaries which most significantly contributed to the commercial viability of the Portuguese colonial empire.

However, not even the goal of reaching remote destinations in the Amazon in a bid to establish royal authority resulted in a major change to the prevailing mode of transport. Instead, the Portuguese continued to rely on the indigenous canoe as the vessel of choice to move goods and people up and down the Amazon River and its tributaries. Utilizing indigenous craft, albeit with some modifications, to penetrate the interior of Brazil was a reasoned response to the local conditions. The reality was that, despite their own substantial shipbuilding prowess, the canoe presented the Portuguese with several advantages over European-designed ships. Given the shallow draft of the rivers, especially in the Amazon region, even when loaded with heavy cargo, the canoe could easily navigate the shoals without rupturing on the river bottom; moreover, it proved consistently stable and righted easily. In a remarkable combination of local knowledge of canoe building with the Portuguese experience in naval construction, indigenous craft (both traditional and some slightly modified) proved to be the most reliable vessels for inland navigation. With such canoes the Portuguese were able to establish trade routes into the Amazonian region bringing tropical products, including medicinals, lumber, and other tropical products to the coastal city of Belém where they would be off-loaded and shipped to Portugal. However, the most ambitious trade of the eighteenth century saw the Portuguese sending gold mined in the interior region of Mato Grosso (emanating from the city known as Vila Bela) down the Guaporé and Madeira tributaries of the Amazonian River to the main channel of the river via canoes expressly outfitted for this purpose. Convoys of large canoes reached the coastal city of Belém, not directly but through a series of channels. In the city, the gold would be transferred to ocean-going ships and transported to Portugal. Altogether this resulted in a remarkable voyage of 764 leagues (Delson, 1995, pp. 18–19) and represented a journey of several months duration. The local, shallow draft canoe capable of transporting gold

became the workhorse vessel of an expanding colonial economy.

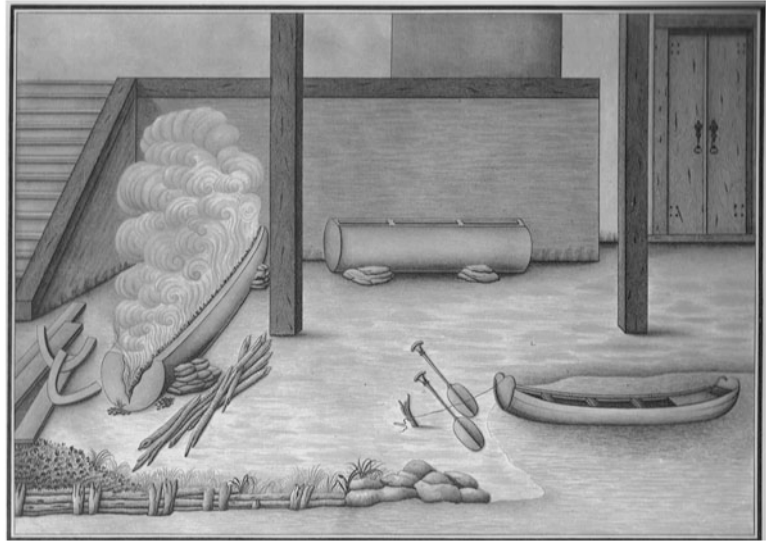
By the eighteenth century, two types of canoes were used for traffic along the Amazon: the *ubá*, representing the more traditional form, and the *montaria* (also known as the *igarité*), which employed some modifications. Both vessels were basically variants of dugout canoes, achieved by setting a fire within a substantial log and hollowing it out (see Fig. 1), but the *montaria* represented a hybridized creation, in which the original autochthonous shape was modified to meet Portuguese demands.

Both types of vessels had long bow sections with pronounced flares, but the taper and flare of the *montaria* were reduced a bit to allow for more cargo to be carried in the forward section. This, in turn, suggests that the *montaria* would be docked near to the shore rather than being hauled up on the littoral like the traditional *ubá*. If the *montaria* was tied up alongside a dock, its cargo could be unloaded all along the side, rather than from the bow only, as would be the case in a grounded *ubá*. For large cargo loadings, the *montaria* would, most likely, have been the more stable vessel.

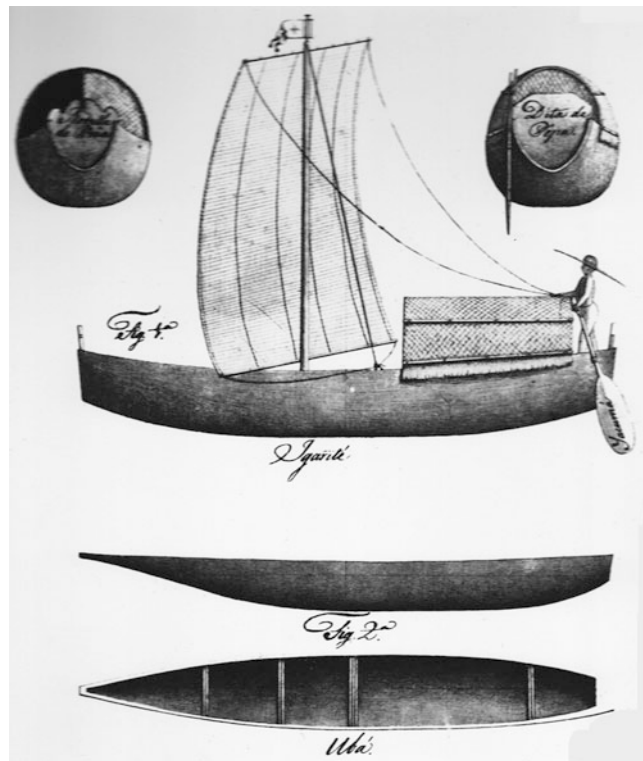
The *montaria* also had a more pronounced curve to the stern, often with an over-the-stern docking oar which would allow it to pull alongside a dock with greater ease. The Portuguese also modified the basic canoe by adding a canopy to the *montaria* (see Fig. 2). This gave the vessel a shaded area for passengers and could protect cargo from frequent rain showers. Made of leaves originally, and later of woven mats, these canopies added little additional weight to the vessel; the advantages thus accrued clearly outweighed any possible disadvantages.

A further departure from the basic *ubá* was the addition of stiffening devices, or supports, to the floor of the *montaria* in an effort to reduce the overall weight of the vessel; with the stiffeners the hull would not need the same thickness as that of the *ubá*. Finally, the adoption of a “tumble-home” curvature to the *montaria* may have resulted in more cargo space lower in the hull, in turn lowering the center of gravity (see Fig. 3). It was, additionally, a stylistic device

**Navigation: Inland
Navigation in Amazonia,**
Fig. 1 Making a canoe by
the indigenous approach of
hollowing out the log with
fire (Ferreira, 1783–1792,
plate 138)



**Navigation: Inland
Navigation in Amazonia,**
Fig. 2 Two kinds of
Amazonian canoes:
a *montaria* or *igarité* with
a sail, canopy, and over-
the-stern docking oar
(above) and a basic *ubá*
(Ferreira, 1783–1792, plate
35)



often seen on early Portuguese sailing vessels and one with which the colonial authorities would have been familiar (Delson & Meng, 1995, pp. 176–179). Both the *ubá* and the *montaria* had a draft of approximately 1.5 ft, rendering

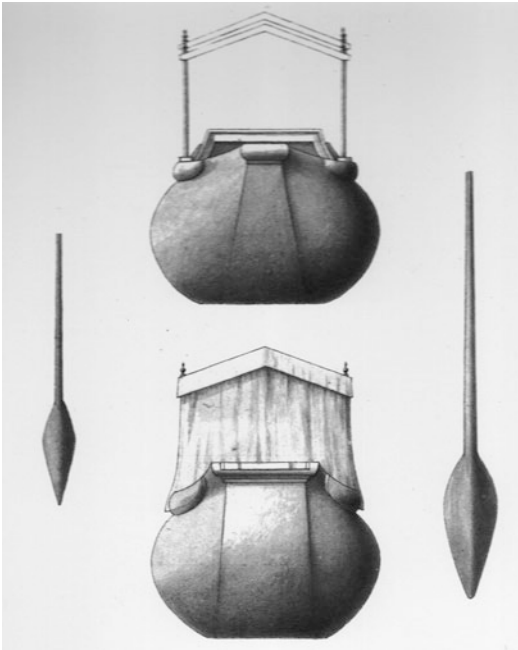
them ideal for sailing the shallow waters of the Amazonian region. Even with heavy cargos (6.0 long tons), both types of canoes maintained excellent stability. The TPI (or tons per inch immersion) for both vessels was approximately

0.5 t per inch, and they both rode at approximately the same level in the water (Delson & Meng, 1995, pp 182–184).

The loads carried by both types of canoe were impressive: by the late eighteenth century, they were capable of hauling many thousands of pounds. Routinely they would carry six long tons (c. 13,000 lbs.), but as the end of the century

approached, they carried even more (Delson, 1995, p. 14). Even with this great weight, such canoes displayed positive stability (the canoe would right itself if tilted), which made them even more attractive to the Portuguese (Delson, 1995, p.21). Such canoes were capable of transporting 20–30 people at a time (Delson, 1995, p. 14). On occasion, canoes were lashed together in tandem and provided with a raft on top; known in this formation as *ajoujos*, such craft were utilized for transporting cattle from the city of Belém to the nearby Ilha of Marajó (Camara, 1888, p. 25). More luxurious models of canoes (see Fig. 4), some with interior cabins decorated with fine fabrics, were designated for the transport of dignitaries, and some were even known to have been outfitted with small, mounted cannon fore and aft. These were deployed as patrol boats at the mouth of the Amazon (Delson, 1995, p. 12).

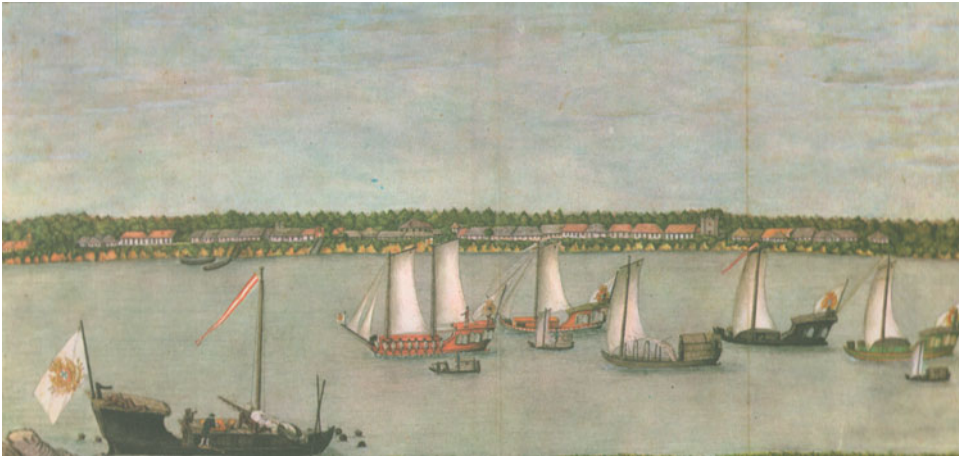
Whether it was the *ubá* or the *montaria* which was chosen for transport, both vessels were invariably crewed by experienced indigenous sailors familiar with the Amazonian river system. The Crown recognized the importance of these inland sailors to their commercial goals, affording them unusual respect in the colonial social hierarchy; beginning in 1755, the Portuguese paid salaries to these mariners, thus creating an early wage labor force (Maclachlan, 1973, p. 210). The greater the success of trade along the Amazon, the larger the number of Indians who could be employed in this



Navigation: Inland Navigation in Amazonia,
Fig. 3 *Montaria* with pronounced tumble-home curvature and pointed oars (Ferreira, 1783–1792, plate 36)

Navigation: Inland Navigation in Amazonia,
Fig. 4 Elegant modified canoe (Ferreira, 1783–1792, plate 34)





Navigation: Inland Navigation in Amazonia, Fig. 5 Fleet of various canoe forms in the harbor of Vila de Cametá, Amazonas (Ferreira, 1783–1792, plate 57)

venture. Additionally, Indians were the backbone of the colonial shipbuilding industry and constituted the workforce at the several shipbuilding yards established in the mid-century in the Amazon region, where their work was overseen by Portuguese master shipbuilders. Notwithstanding the fact that later in the eighteenth century *montarias* were equipped with sails, every canoe was provided with sets of oars. These were pointed at their tips, rather than rounded, again reflecting indigenous design. Useful in breaking through reeds, such oars were based on centuries of experience. Indians, in fact, were universally admired for their skill in rowing. Moving in tandem, the indigenous crews could maintain a steady speed and cover a distance calculated at roughly 3 km an hour. In fact, oars were essential to successful navigation against prevailing winds, when the sails were useless (Delson, 1995, p. 16).

The shipping network which was developed in eighteenth-century Brazil thus represents a fortuitous amalgam of indigenous and European technology which allowed for a high degree of regional integration (see Fig. 5). The fleets of canoes which transported gold had carefully planned departures, from either Belém on the coast or Vila Bela in Mato Grosso; these took advantage, going inland, of prevailing trade winds sweeping across the region from the ocean and, on the return, utilized the seasonal

flooding of the Amazon's tributaries allowing vessels to pass through these rivers unscathed when the waters had risen to their high points. Finally, when cataracts in the rivers proved impossible to sail through, the fleets were divided into two parts: goods were off-loaded from one fleet and carried through the rapids to another fleet waiting in calmer waters, and the journey could continue seamlessly (Delson, 1995, p. 21).

In the nineteenth century, this carefully coordinated riverine trade route was discontinued. After Brazil's independence from Portugal (1822), the Amazon and its tributaries continued to see canoe traffic but not at the level sustained by the network which had been created under colonial rule. Nonetheless, the canoe continued to be the vessel of choice for all riverine traffic until the late nineteenth century when steamboats made an appearance on the Amazon. With the opening of the great river to international traffic in 1867 (Burns, 1993, p. 181), and the growth of the rubber industry at the end of the century, the Amazon witnessed, once again, an enormous spurt of activity. The collapse of the rubber boom in 1910, however, saw traffic reverting to a more limited level, although the major cities along the Amazon, including Manaus, Santarém, and coastal Belém, continued to experience considerable growth.

Today's Amazonian river network hosts many foreign visitors who visit to either fish or explore

the interior from the comfort of shallow draft luxury yachts. Commercial traffic through the Amazon basin is shipped in a combination of shallow draft barges, push boats, and container ships; in the last decades of the twentieth century, the port of Manaus was modified to receive substantial container activity (Knight, 1988, p. 75). Nonetheless, the canoe, sporting outboard motors on traditional hulls, continues to be the craft of choice for inland navigation because centuries have proven it to be the ideal vessel for such use in the region.

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Navigation: Inland Navigation in China

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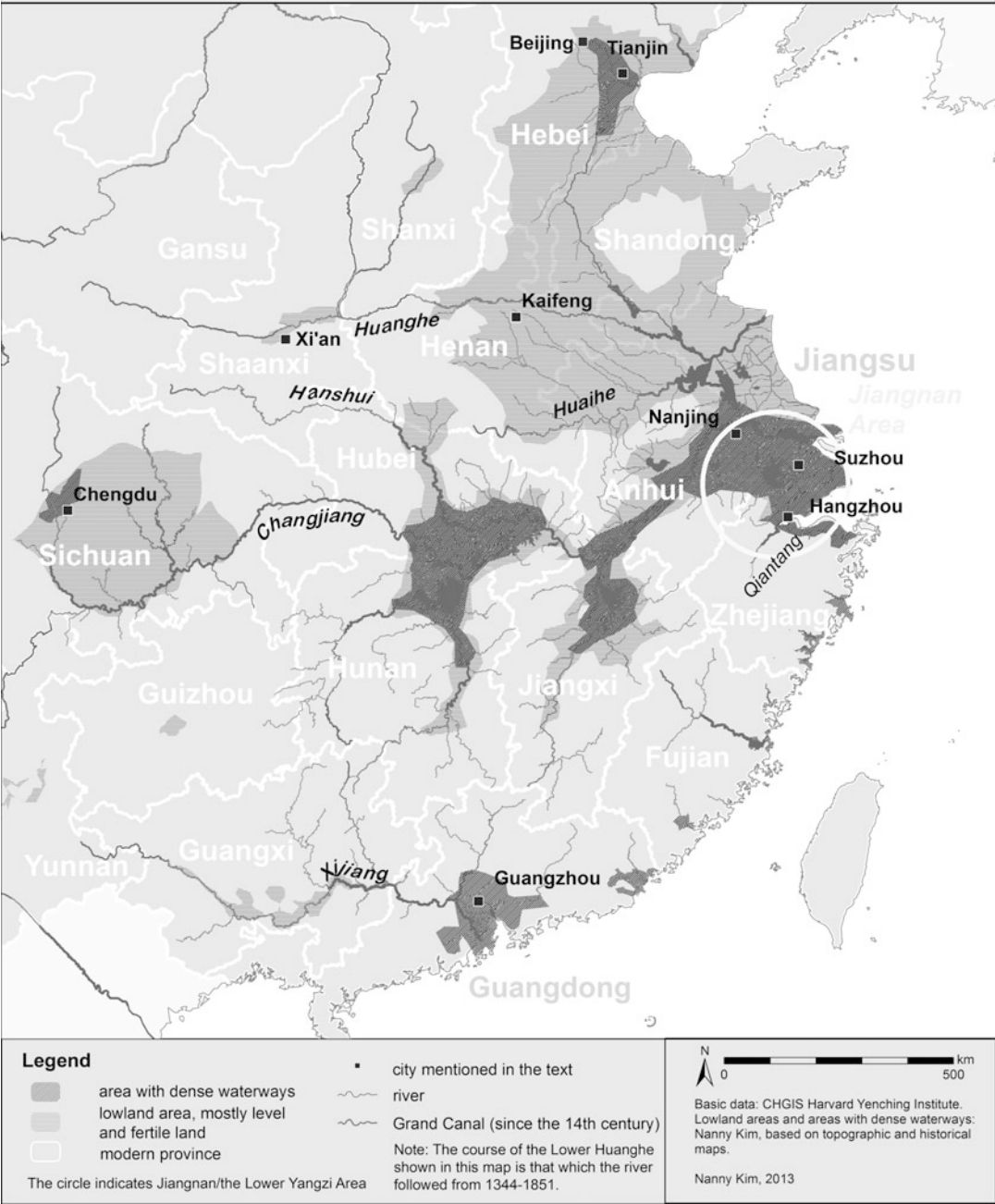
In the geographic region of modern China, rafts, dugouts, and boats built from planks go back to prehistory. Water transport on rivers, lakes, and canals has remained important throughout the

historic period. Lowland areas endowed with dense networks of rivers, lakes, and marshes formed cultural and economic heartlands, while the major river systems provided the main avenues of long-distance transport. Outside the plains and lowland areas, navigation faced many challenges. Due to the topography of steep gradients and narrow valleys in combination with the monsoon pattern of rainfall, most rivers displayed great seasonal difference in high and low water levels, which frequently caused changes in riverbeds as well as dangerous currents, shoals, and rapids in constricted sections. Many developments in navigation technologies can be regarded as innovations developed to overcome difficult shipping conditions.

Map 1 shows the main waterways, the lowland areas, and the areas endowed with dense waterway systems in late imperial China. The areas of dense waterway systems in part were transformed marshes that were developed over millennia. The Huang He (Yellow River) in the map is the course that the river followed from 1344 to 1852. The Grand Canal in the map was built and extended in the Yuan and early Ming periods (thirteenth to early fifteenth centuries) and fully maintained until 1852.

Details on boats and shipping technologies are rarely available for the early period and through most of the first millennium CE. The importance of water transport is reflected in the construction of a canal system that linked the Changjiang (Yangzi) and the Huaihe River systems from the fifth century BCE, in the construction of gallery roads built into the sheer walls of the Sanmen Gorges of the Huang He during the Han period (206 BCE–221 CE), the Sui period (581–618 CE) canal that linked the Changjiang and the Huang He, and increasing boat sizes with carrying capacities possibly approaching 1,000 t on the Lower Changjiang during the Tang period (618–906).

Boatbuilding and navigation technologies become more visible from the late Tang to Song periods, about the tenth to twelfth centuries, when the population doubled, economic and cultural patterns changed, and water transport underwent a “revolution” (Elvin, 1973).



Navigation: Inland Navigation in China, Map 1 Lowland areas and dense waterways in China (Cartography by the author, 2013)

The construction of hulls in Chinese and East Asian boats and ships began by laying down the keel or bottom of the boat. Compartments in the shape of cross sections of the hull or of ribs are built on the keel planks. Planking is by boards

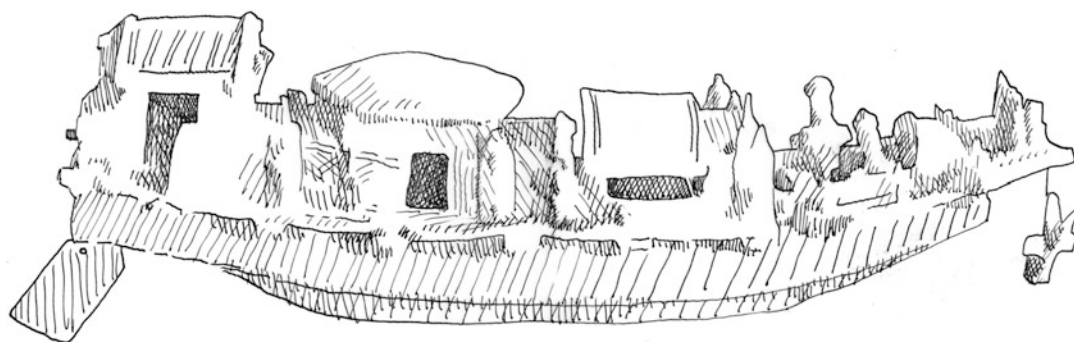
that are nailed onto the compartments. The compartments were often made watertight, subdividing the hull into sections that served as separate holds. The basic structure can be safely assumed to have been present since antiquity,



Navigation: Inland Navigation in China, Fig. 1 A riverside boatyard on the Minjiang near Leshan, Sichuan Province. The boat under repair in the foreground shows the sectional structure of the hull. A workman is standing

in the false stern (Photograph by Archibald Adams, ca. 1915–1925. Special Collections, Yale Divinity Library)

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Navigation: Inland Navigation in China, Fig. 2 A pottery model of a houseboat excavated from an Eastern Han grave. The boat has a balanced rudder worked from the rudder house in the stern, two further deck houses

flanked by poling galleries, and an anchor dangling from the bow (Drawing by the author after photograph in Needham 1965, plate 963)

as the graph of the oldest character for boats, *zhou* 舟, shows a graph of a boat that consists of two sections. Additional longitudinal strength could be provided by gunwales, while rigidity could be

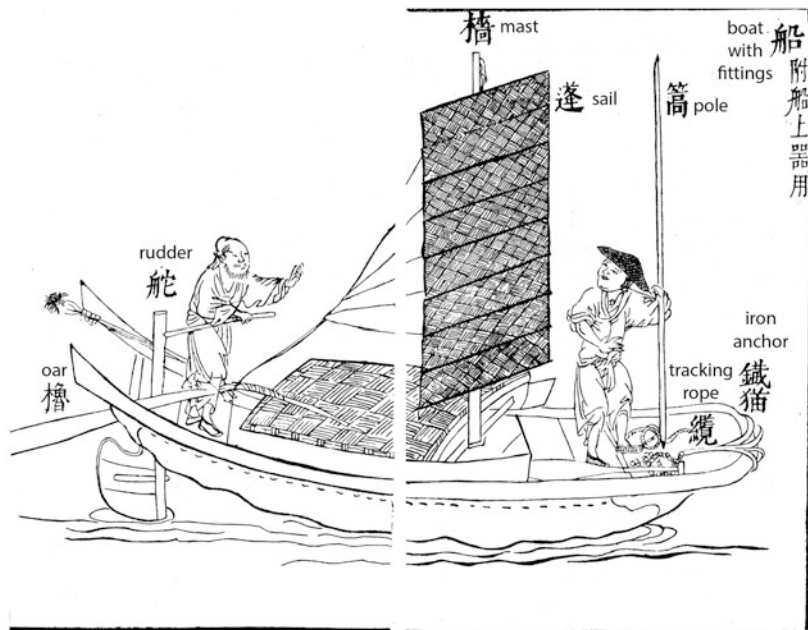
increased by bulkheads built into the compartments, often at deck level. For caulking, a mixture of tong oil, hemp, and lime or crushed shells was used. Tong oil, which possesses excellent



Navigation: Inland Navigation in China, Fig. 3 A large balanced rudder in a shipyard at Yichang on the Middle Changjiang (Photograph by G. Warren Swire,

1907. Historical photographs of China, University of Bristol (<http://hpc.vcea.net/>))

Navigation: Inland Navigation in China, Fig. 4 Early-seventeenth-century schematic drawing of a canal boat with the main devices for steering and propulsion (From *Sancai tuihui*, no pagination)

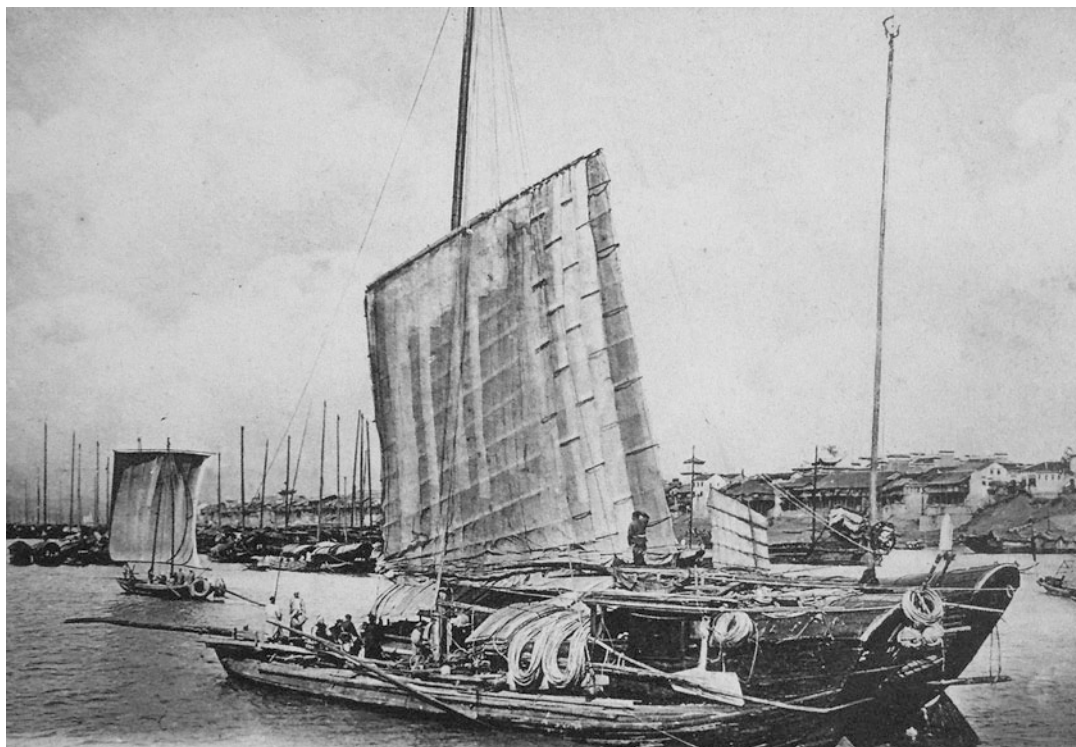


protective and resinous qualities, was also used for varnishing (Fig. 1).

The basic construction employed in all but the smallest boats was highly adaptable in overall size and shape. In inland shipping, most boats were built to minimize draft. In general, hulls with a round keel were preferred in rivers in

which difficult passages were strong currents and soft shoals, such as the Huang He, while flat-bottomed boats were common in rivers with rocky shoals and rapids. Boats for navigating strong currents had high bows and sterns.

Effective steering technologies were developed early. The rudder is firmly documented in



Navigation: Inland Navigation in China, Fig. 5 A boat adapted for the passage through the Three Gorges of the Changjiang getting under way at Yichang harbor. The boat type, called *mayangzi*, probably was developed in the eighteenth century. The one-masted boat carries a

long bow sweep and two *yaolu*. Bamboo tracking-hawsers of different length and thickness are coiled on the deck house, while several spare spars and oars lashed alongside (Postcard ca. 1920s, probably based on a photograph by Cornell Plant, ca. 1911–1919)

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Navigation: Inland Navigation in China, Fig. 6 Two small freight boats specialized for the Middle Minjiang, Fujian Province. The boats carry enormous stern sweeps

that are worked from a high bridge (Photograph by Ralph G. Gold, ca. 1915–1925. Special collections, Yale Divinity Library)



Navigation: Inland Navigation in China, Fig. 7 Small freight boats beached during low water in a canal near Shanghai, displaying the leeboards (Photograph by Wilhelm Wilshusen. Collection of the Overseas Museum, Bremen)

houseboat models used as grave goods in the Eastern Han period (25–220 CE). The boats look confidence-inspiring and comfortable.

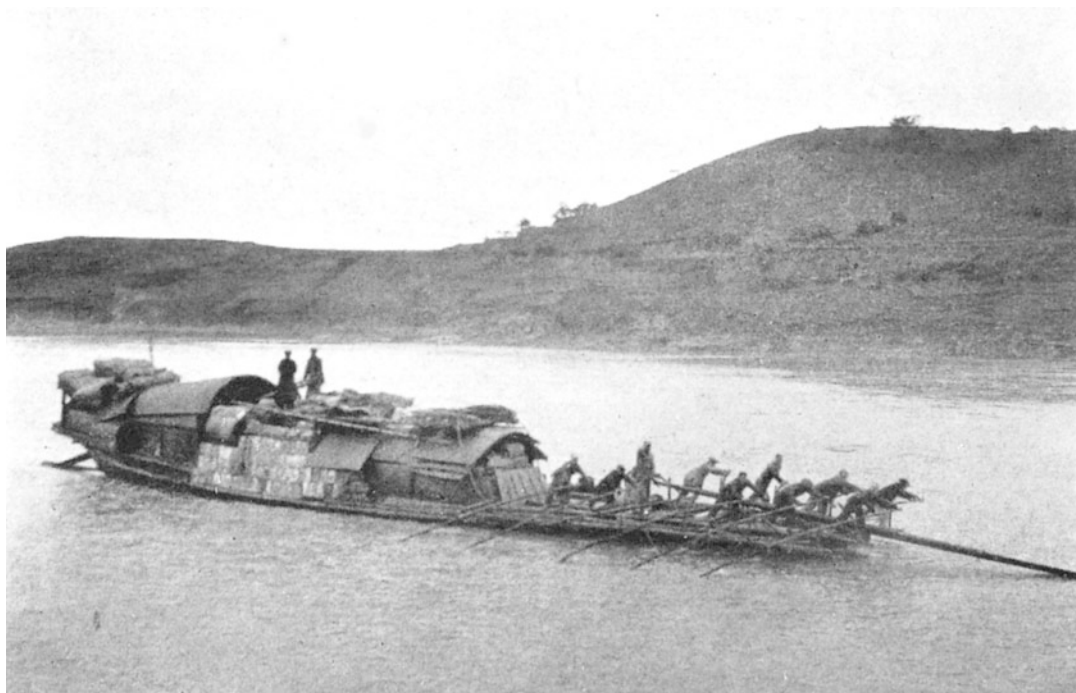
With few exceptions, boats of the late imperial period typically had large, balanced rudders. These were often mounted under a false stern and could be lifted and lowered in boats that needed to operate in shallow waters (Figs. 2, 3, and 4).

Additional steering devices are bow and stern sweeps. Of uncertain origin, they are firmly documented by the Song period (960–1276). Both were basically enlarged oars mounted on an extra long loom, occasionally over 10 m in length. These steering sweeps placed the pivoting point well ahead or behind the boat, allowing for sudden turns but requiring great skill. In particularly dangerous and shallow rivers, bow and stern sweeps were the only steering devices because

rudders were liable to hit bottom in shallow or narrow passages (Figs. 5, 6).

To compensate for the tendency of shallow craft to drift sideways, sailing boats adapted to shallow waters commonly had leeboards that were mounted to be lowered or pulled up as water depth allowed. Evidence of leeboards is not available prior to the Ming period (1368–1644). There is a possibility that the technology was available somewhat earlier, supported by the development of shipping especially along the North China Coast during the Yuan period (1276–1368) (Fig. 7).

Propulsion of boats was by rowing, poling, tracking, and sailing. Rowing by paddles is documented in early pictorial evidence. Hand-held paddles were rarely used in everyday transport by the late imperial period but have remained the means of propulsion in dragon boat races to



Navigation: Inland Navigation in China, Fig. 8 A team of rowers working straight oars common in Sichuan on an Upper Changjiang boat. Note the massive bow

sweep that reaches out over the bow (Photograph by Harry Franck (Franck, 1925, plate opposite 352)



Navigation: Inland Navigation in China, Fig. 9 Early clear pictorial evidence of the *yaolu*: Drawing by the author after detail showing a small tourist boat in “The Xiao and Xiang Rivers” (潇湘圖) by Dong Yuan 董源

(ca. 934–ca. 962). Handscroll, 50 × 141.4 cm, ink and color on silk (Drawing by the author to enlarge detail. Collection of the Palace Museum, Beijing)

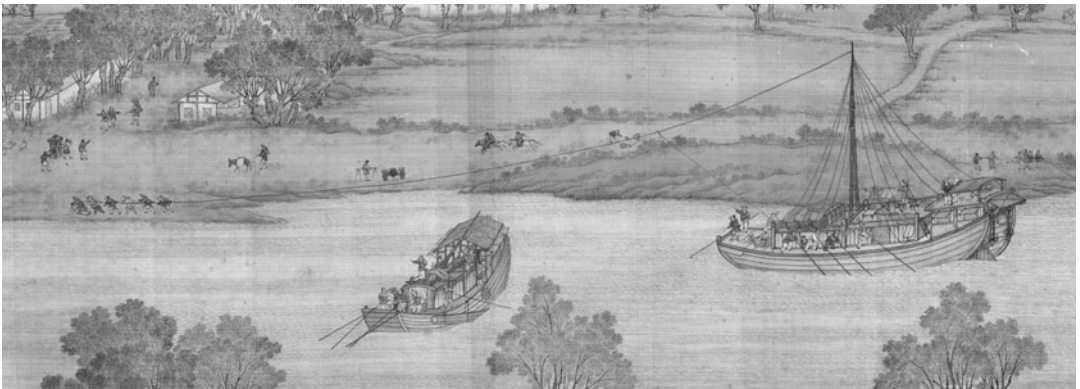
the present day. Oars resting on pins probably were in use by the late pre-imperial period. An important innovation in rowing was the *yaolu* (commonly *lu* 櫓 in Chinese, “yuloh” in the older English literature). In this type of oar, the loom is lengthened and has a slight S curve. In the bend of the curve, the loom rests on a metal pin, while a rope is attached to the top end and a metal ring in the deck. The *yaolu* is worked by pushing

the boom and pulling it down, making the blade move in a continuous zigzag line without being lifted out of the water. Origins of the technology are unclear. Firm pictorial evidence dates to the tenth century, but it may have been present much earlier. In the late imperial period, the energy efficiency of rowing by *yaolu* made it the most widespread form of propulsion when wind power for sailing was insufficient. The oar could be



Navigation: Inland Navigation in China, Fig. 10 Small freight boat passing under a bridge in the Shanghai area. Propulsion is by a *yaolu* worked over the stern by two men. The A-frame mast is lowered for

passing under the bridge, and the rudder is lifted out of the water, presumably because of the shallowness of the canal (Photograph by Wilhelm Wilshusen, before 1912. The collection of the Overseas Museum, Bremen)

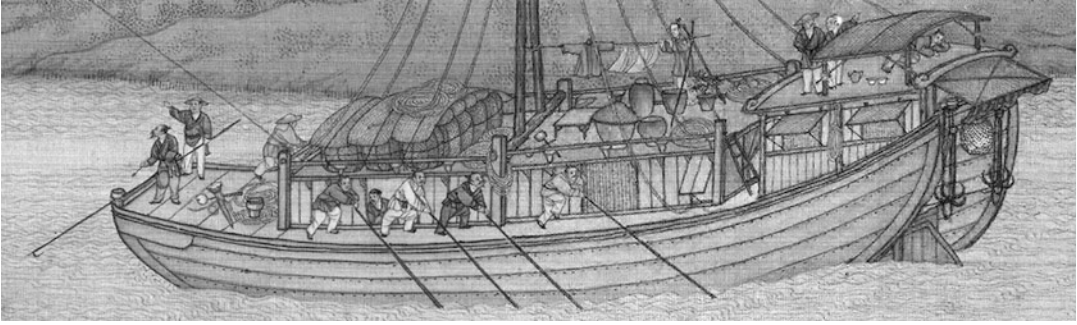


Navigation: Inland Navigation in China, Fig. 11 A mid-eighteenth-century depiction of a canal boat being tracked and punted (Detail from “Upriver on the

Qingming festival” (清明上河圖) by Chen Mei 陳枚 et al., 1736. Long scroll, 35.6 × 1,152.8 cm. The Collection of the National Palace Museum, Taipei

mounted over the stern or the sides of the boat with the loom pointing backwards. In small boats, a single person could work and steer a boat using a *yaolu*. This form of propulsion with the *yaolu*

mounted over the stern was particularly suited to crowded waterways. In large boats, great oars were worked by up to a dozen men (Figs. 8, 9, and 10).



Navigation: Inland Navigation in China, Fig. 12 Enlarged detail of the boat only



Navigation: Inland Navigation in China, Fig. 13 Two small freight boats in the Three Gorges. The boat in the foreground is pulling into shore, probably in order to wait for the boat in front to ascend the rapids. The man on top of the mat floor is working a break spar against the riverbank, while the man in the bow apparently has wedged a large

oar between rocks. The larger boat is being tracked, visible from the pull of the hawser attached half way up the rope ahead of the mast. A sailor is working a spar to push the boat from the rocky bank (Postcard ca. 1920s, probably based on a photograph by Cornell Plant, ca. 1911–1919)

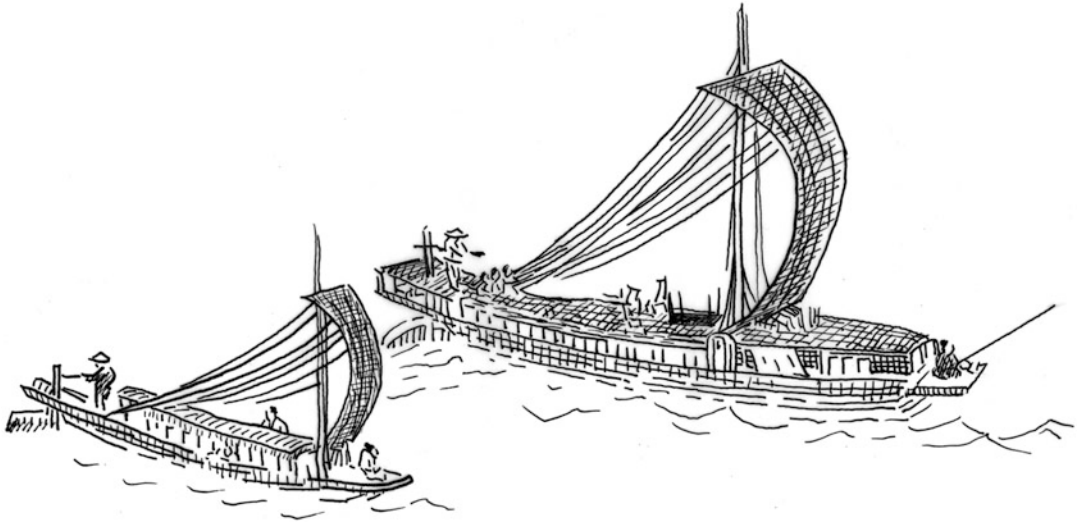
In shallow water, punting (or poling) rather than rowing was employed, as energy efficiency was higher. It seems that the widespread use of this form of propulsion led to two other

applications of punts. In shipping on dangerous, fast-flowing rivers, break spars were used for staving off the boat from rock or from the bank. The technique is documented in pictorial sources



Navigation: Inland Navigation in China, Fig. 14 A tracking team of four men pulling a boat under sail (Photograph by Mary W. Caldwell, ca. 1926, location

unclear, possibly on the Huang He, North China Plain. Special Collections, Yale Divinity Library)



Navigation: Inland Navigation in China, Fig. 15 Two riverboats under sail in "Small landscape of the Changjiang and hills" (江山小景圖), attributed to Li

Tang 李唐 (active late eleventh to early twelfth century) (Drawing by the author to enlarge detail. Original painting in the Collection of the National Palace Museum, Taipei)

of the Song period, showing numerous men in the bow of a boat, each equipped with a long pole. In the Qing period, to navigate through the Three Gorges of the Changjiang, a modified application is found that adds leverage by attaching the pole

just below deck level so that it can be worked as a lever between a submerged obstacle and the side of the deck. Another development that appears to be based on poling is the use of poles as anchors that was very widespread with smaller boats.

**Navigation: Inland
Navigation in China,**

Fig. 16 Canal freight boat with tall lugsails made from bamboo cloth. Note the raised leeboard. The mats hung up to the side of the roofed area in the stern will be the walls of a makeshift deckhouse for the crew at night (Photograph by Wilhelm Wilshusen, before 1912. The collection of the Overseas Museum, Bremen)



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To minimize pulling and pushing forces, many boats were equipped with a watertight hole through the stern for this purpose. Larger boats mostly used iron anchors (Figs. 11, 12, 13).

Tracking (or towing), mostly by human labor, was widespread in areas of dense, quiet waterways and for upriver shipping on fast-flowing rivers. By the tenth century, larger boats had tracking masts. These were not very high and often foldable A-frames that could be taken down when passing under bridges. The tracking rope was run from the winch through an iron ring near the top of the mast in order to prevent it from getting caught and also for keeping it out of the water. Trackers usually attached themselves to the main hawser by short ropes with cloth slings. Hawsers were made of hemp rope across most of China, but bamboo hawsers were used on the Upper Changjiang and other dangerous mountain rivers. Hawsers made of sliced bamboo possessed

exceptional strength and lightness but were difficult to work because of their stiffness and the razor-sharp edges of the splices. In slow-flowing or stagnant waterways, eight trackers were sufficient for a 100 t boat. For tracking upriver on the Upper Changjiang, at least 50 men were needed for a 50 t boat. For the passage through the Three Gorges, up to 200 trackers had to be employed for passing the worst rapids, where currents reached 20 kmh.

Tracking by human power, despite its loathsome reputation, is the most energy-efficient means of waterborne propulsion where wind power was insufficient or sailing provided insufficient traction. The extremely widespread use on all Chinese rivers in part was an adaptation to the preponderant agricultural lowland regimes in which all cultivable land was used to produce crops for human consumption and commercial use, making the maintenance of laboring animals



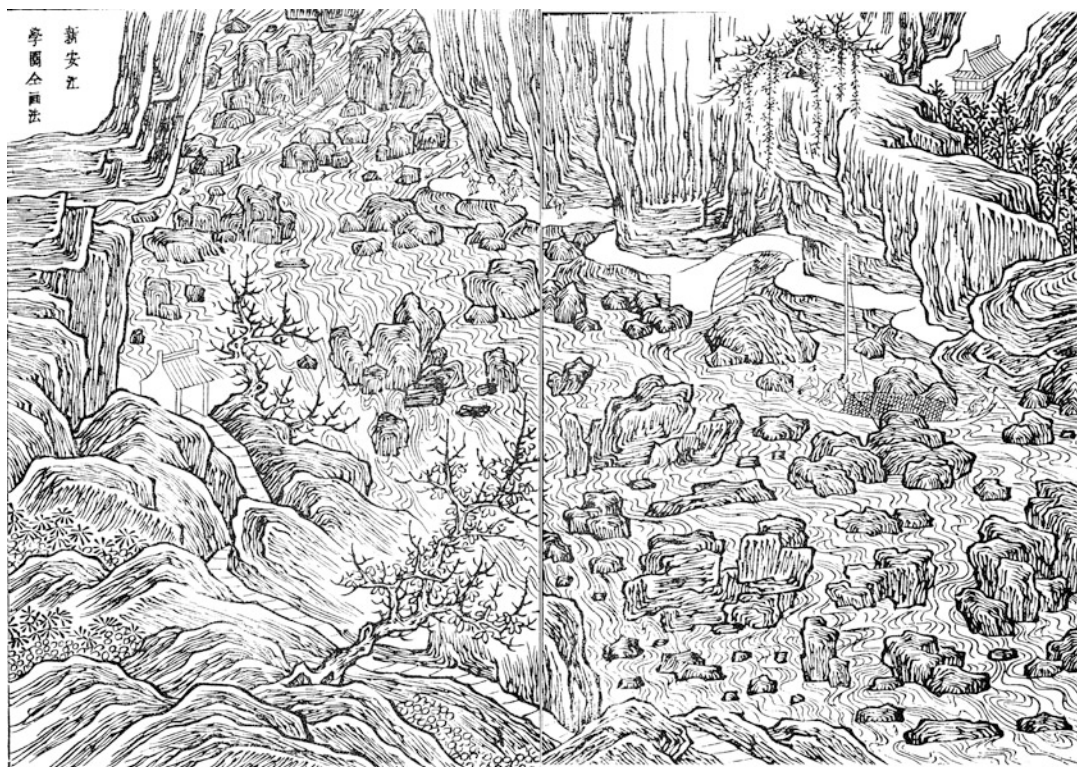
Navigation: Inland Navigation in China, Fig. 17 Small three-master under sail, with additional topsail, probably Changjiang estuary. The two lesser

masts are slightly tilted as was typical with seagoing ships (Photograph by Wilhelm Wilshusen. The collection of the Overseas Museum, Bremen)



Navigation: Inland Navigation in China, Fig. 18 Small boat being towed over a slip-lock on a small canal in Jiangnan. The boats are dragged over the wet incline with the help of two winches that are housed

under the thatched roofs and worked by four men each (Photograph by Wilhelm Wilshusen. The collection of the Overseas Museum, Bremen)



Navigation: Inland Navigation in China, Fig. 19 Qing period depiction of shipping on a mountain river. The tracking path with a bridge for crossing over a small tributary is shown on the far bank; the path in the foreground is stepped and seems to be leading to the

pavilion. The boat traveling upriver is tracked by a team of four men and punted by three men on board. Another boat coming downriver is partly shown with a man working a spar in the bow (Woodcut from *Linqing* 1847, unpaginated)

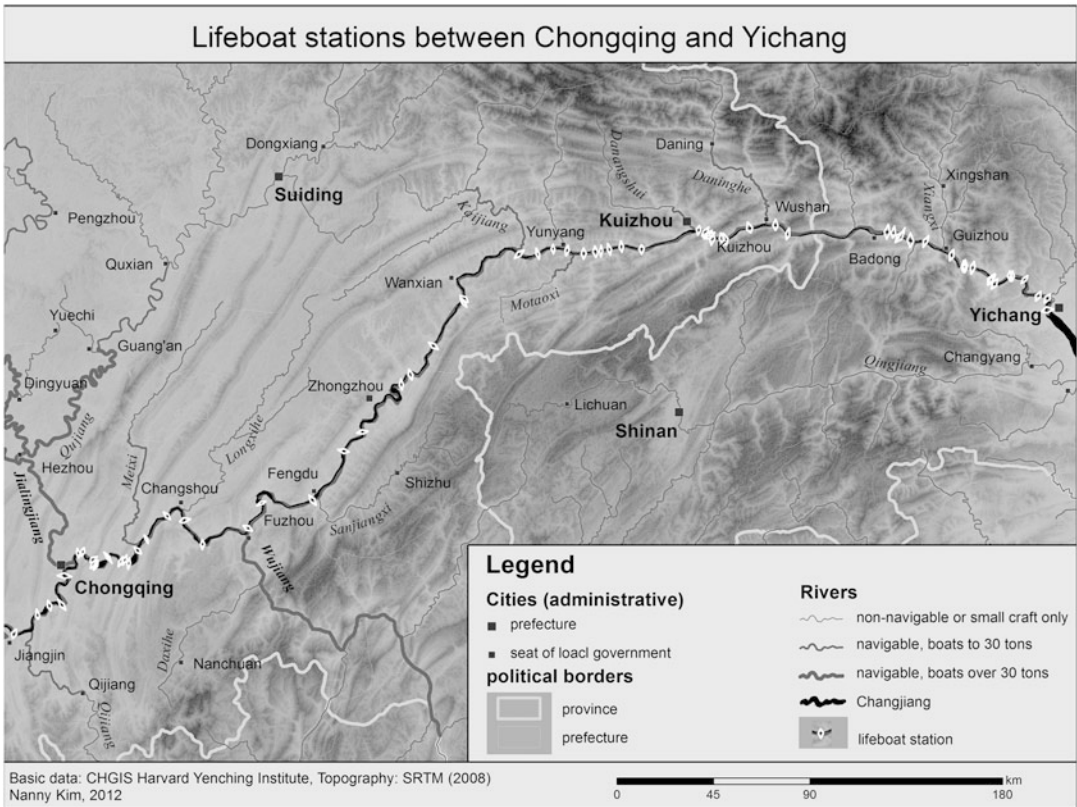
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expensive. At the same time, human trackers were the only option on the busiest waterways. In areas of dense waterways and high population density, the tracking team frequently had to negotiate passages under bridges and confluences, while the large teams employed in shipping upriver through mountain zones had to deal with broken terrain and work in perfect coordination (Fig. 14).

In open waters, sailing was the means of choice, and tall sails were also set for additional traction on narrow waterways when the wind was favorable. Lug sails that were able to sail at the wind probably were present in the southern coastal regions by the third century CE. Most sails were roughly rectangular and stiffened with battens; the sail itself was made of woven mats or cloth. The stiffening battens increased

efficiency as they kept the sail flat and maintained a good draft even with torn cloth. The rigging and the battens permitted rising and lowering sails from the deck. Most Chinese sails were reefed from the bottom and could be quickly adjusted to wind conditions. Topsails and sails without battens for sailing before the wind were occasionally used for additional traction (Figs. 15, 16, 17).

Boats of lakes and wide rivers, such as the Middle and Lower Changjiang, often carried several masts and primarily relied on wind power for propulsion. These boats reached the greatest carrying capacity of inland boats, probably about 400 t in the Qing period. Sailing was more restricted in river craft. Many boats carried high masts and large sails that were hoisted under favorable conditions only and mainly provided additional traction.



Navigation: Inland Navigation in China, Map 2 The lifeboat station along the Upper Changjiang in the eighteenth to early nineteenth century (Map by the author)

On many rivers, canals, and canalized rivers, however, boat sizes were restricted. Boats adapted to shallow waters were flat-bottomed and often elongated; some were adapted to shallow, stony riverbeds and had somewhat flexible bottoms to reduce the danger of serious damage. In rivers with dangerous rapids, the most constricted passage set the maximum limit for boat sizes. In the shallowest rivers, bamboo rafts, combining minimal depth and weight, remained the main carriers. In canals, depth was often restricted. The northern part of the Grand Canal had a depth of little over 1 m in the summit sections across Shandong even during the period of constant maintenance. In canalized waterways, sluices constituted the main limitation. In many places, slip-locks were installed as a means for maintaining water levels where water supply was difficult and in minor canals. These structures consisted of two ramps, with the summit point

just above the higher water level. Boats were dragged up the moist slip by ropes attached to the stern that were worked by two large windlasses turned by men or oxen. The procedure obviously involved considerable strain and wear on the hull as well as constricting boat sizes (Fig. 18).

Shipping infrastructure along inland waterways mainly consisted of tracking paths that were built along all rivers and canals. In constricted valleys and gorges, these contained numerous bridges across small tributaries and sometimes were wooden gallery roads built into the cliff. Due to the differences between high and low water levels, however, tracking paths were frequently damaged and destroyed by summer floods and trackers often had to work their way along the bank during the low water season. In the late Ming period, structures for reducing the impact of accidents appeared along the Upper

Changjiang. Lifeboat stations with small boats and teams of three to five skilled men were set up to rescue victims of boat wrecks. During the High Qing, the system was expanded and came to form a string of semi-military stations along the Upper and Middle Changjiang (Lan Yong 蓝勇, 1999, 2005) (Fig. 19; Map 2).

Some special technologies for overcoming danger spots are recorded. Since the Song period, iron chains were attached to some cliffs so that boats traveling upriver could be pulled up with the help of hooked poles. For the Qing period, wooden ramps built along the bank along unnavigable rapids of the Jinshajiang are recorded, over which unloaded boats would be dragged as in tracking to avoid the rapids.

See Also

► Navigation in China

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Nazca Lines

David M. Browne

On the desert plains and the fringes of the valleys that form the heartland of the ancient Nasca culture of the south-central coast of Peru is a vast array of ground markings that are known collectively as the “Nazca Lines.” The most extensive

Nazca Lines,

Fig. 1 Nazca biomorph:
hummingbird (From the
author's photo collection)

**Nazca Lines,**

Fig. 2 Nazca biomorph:
stylized bird with long
zigzag neck (From the
author's photo collection)



concentration of these constructions, termed *geoglyphs* by archeologists, is found on the Pampa de Nazca between the Ingenio and Nazca valleys. The pampa is an elevated desert plain 200 km², between 400 and 600 m above sea level. It is severely dissected by dry watercourses formed by periodic flash floods. About 3.6 million m² of this area are covered by geoglyphs. Concentrations of markings also occur on the slopes of and on the plateaux and pampas between the other valleys of the Nazca drainage, and are particularly dense in the Palpa area. Geoglyphs are also known further north, in the Ica valley, where the other major centers of the Nasca culture are found.

Geoglyphs take many forms, but can be grouped into four main classes: biomorphs, enclosures, lines, and geometric figures.

Biomorphs are stylized representations of various creatures, the commonest being birds, among which are hummingbirds, the condor, pelican, and frigate bird (Figs. 1 and 2). There are also depictions of a monkey, fox, lizard, spider (Fig. 3), killer whale (Fig. 4), and fish, as well as a few drawings of plants or flowers and bizarre combinations of body parts (Fig. 5). Humanlike figures are also found, particularly in the Palpa area. Most forms are outlined by a continuous line usually about 0.6-m wide, which never crosses and ends near where it starts.

Nazca Lines,

Fig. 3 Nazca biomorph: spider (From the author's photo collection)

**Nazca Lines,**

Fig. 4 Nazca biomorph: stylized killer whale with trophy head (From the author's photo collection)



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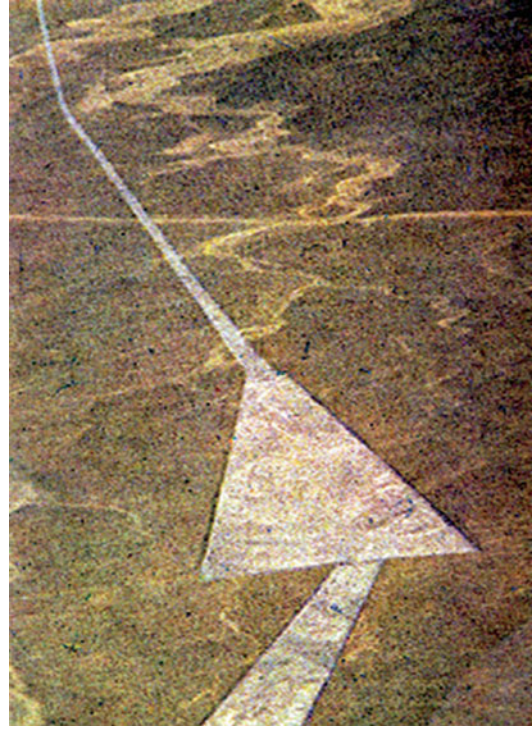
The greatest concentration of biomorphs occurs in the northwest corner of the Pampa de Nazca, above the south edge of the Ingenio valley and close to a major regional center of the Nasca culture. Some biomorphs appear to be isolated drawings, but others, for example the monkey, seem to have a direct association with other geometric figures. Despite the impressive size of some drawings they are generally insignificant in scale when compared to many of the enclosures.

Enclosures are trapezoidal, triangular, quadrangular, and rectangular clearings defined by stone banks up to 1-m high (Fig. 6). They vary

greatly in area and proportion, the largest occupying the space of several football fields. This class of geoglyphs is the most frequently occurring form outside the Pampa de Nazca. Where they are built on the flat spurs between valleys they follow the long axis of the topography; on hillsides their narrow ends point toward the top of the hill; and where they are constructed in the bottom of a small, dry tributary valley their narrow ends point toward its head. About 300 are found across the Pampa itself, roughly two-thirds of which are orientated to the line of watercourses, with their ends pointing upstream. Enclosures are commonly found in association



Nazca Lines, Fig. 5 Nazca biomorph: “pair of hands”; possibly stylized root crop (From the author’s photo collection)



Nazca Lines, Fig. 6 Nazca Lines: trapezoids (From the author’s photo collection)

with other forms of geoglyphs such as line centers, spirals, and zigzags.

Line centers consist of a series of straight lines converging on or radiating from usually a hillock or low mound on the periphery of the Pampa de Nazca. The lines vary in width and length, some running for several kilometers. Over 90 % of the geoglyphs found on the Pampa are associated with the 62 line centers identified so far. However, only about a quarter of the centers are interconnected, suggesting that these features cannot be interpreted as a simple coherent system. Line centers are frequently connected to enclosures. Long lines, unconnected to line centers, running dead straight for several kilometers with no regard for topography are another feature of the Pampa and elsewhere, as are pairs of parallel straight lines.

The most prominent of the geometric forms found are spirals created by a single line along which it is possible to enter and exit in an unbroken progress. Other figures include zigzags and

“fingers” consisting of a series of concentric semicircles formed by a single line continuously running parallel to itself in a set of arcs.

Contrary to some assertions, constructing the geoglyphs required no great engineering skill and no more complicated surveying equipment than simple stakes and rope. The surface of the pampa is covered by rocks which are subjected constantly to daily extremes of temperature and humidity which lead through bacterial action to the formation of characteristic dark-collared varnish on their upper parts. The underlying soil is lighter in color, and if the surface stones are removed a bright patch of ground is created, contrasting strongly with the darker, undisturbed desert floor. This contrast will persist for centuries, only gradually diminishing as the same weathering agencies act upon the newly created surfaces. In most cases the construction of a Nazca geoglyph involved nothing more than stripping the required width or area of its upper stones and regularly piling the rocks along the edge to form a boundary. Judging from some

apparently incomplete examples, an intermediate stage in the construction of an enclosure was to collect the surface stones in a series of small piles on the surface of the intended clearing, probably in baskets rather than by sweeping, before removing them to the edges. It has been estimated that it would take ten people to clear 16,000 m² in a week, and in a trial a spiral of 10-m diameter was built in less than 2 h. The construction of the biomorphs probably required a preliminary model such as a figure etched on wood, sand drawing, or textile embroidery. The precise method whereby the final geoglyph depiction was scaled up from this model is unknown, although several geometric systems have been suggested. Attempts to demonstrate the use of a particular standard unit of measurement in their formation have been unconvincing.

The practice of etching or building figures in the unoccupied desert adjacent to settlements seems to have been started by the communities sharing the Paracas material culture in the two centuries before ca. 200 BCE. Evidence is emerging to show that the activity may have started in the Palpa region with the construction of humanlike figures, perhaps inspired by a tradition of inscribing petroglyphs. Roughly contemporaneously, mythical beings related to the so-called "Oculate Being" of Paracas iconography were built on the Pampa de Nazca. There is little doubt, however, that most geoglyphs were built by the peoples of the Nasca culture (ca. 200 BCE–AD 600), although the practice was continued locally on a small scale by some communities until the late fifteenth century. Two radiocarbon dates from wooden posts supposedly associated with lines fall within the later Nasca period. Nasca pottery is found so repetitively on the surface of many enclosures as to indicate their construction and use during its currency. Radiocarbon dating of the organic material sealed under the varnish on rocks lifted by line builders indicates a similar date range. Additional support is given by the clear association of some geoglyphs with Nasca ceremonial architecture at the great pilgrimage center of Cahuachi and the lesser complex at Llipata.

Various explanations have been advanced for the Nazca Lines that they were fields, the sites of

textile workshops, a giant sports arena, and even markers and landing places for extraterrestrial spacecraft! The idea that they fulfilled primarily an astronomical function has been championed by the principal fieldworker on the Lines, Maria Reiche. In her view the linear geoglyphs functioned to mark the solstices, the rising and the setting of the moon, and the rise of the Pleiades. The multiplicity of some lines she explained as the attempts of ancient astronomers to compensate for the precession effect, the subtle shifts over time in star rising and setting positions. The biomorphs were regarded as representing constellations, for example the spider for Orion and the monkey for Ursa Major. The whole system was supposedly elaborated for calendric purposes, principally to predict the onset of the rains so essential to agriculture in the extremely arid Nazca environment.

Reiche's claims for significant, repetitive astronomical alignments have not been supported by other studies. A more basic objection to her approach is that it projects on to the evidence a European, Northern Hemisphere perspective which ignores Andean peoples' astronomical perceptions. By using historical and ethnographic analogies it is possible to offer plausible explanations of the geoglyphs' forms and functions which make sense in the context of a general Andean religious tradition.

The location and form of the Lines leaves little doubt that they were built for ritual purposes. Many of the lines connected to line centers bear a general resemblance to Inca roads, and footpaths are still discernible within them, supporting the view that they were processional ways. The use of straight-line paths has been shown to have been in widespread use up to the present day in Andean religious observances. The lines defining biomorphs and geometric figures are also laid out in a fashion which would allow uninterrupted procession through the figure. The core of the line centers, and the enclosures, were probably the foci of the processions where the principal rites and offerings were enacted. Depictions on Nasca pottery suggest that the participants in these rituals would have been specially attired, often wearing masks, and proceeded by rhythmic dancing to the accompaniment of drums and



Nazca Lines, Fig. 7 Early Nazca figurine: masked shaman (From the author's photo collection)

pan pipes (Fig. 7). The evidence of broken pottery and offerings of foodstuffs attests to ritual feasting and sacrifice.

It is highly probable, given general Andean practice, that kinship groups (*ayllus*) in acts of obligatory communal labor would have been responsible for the construction and maintenance of particular lines and figures and for the organization of the relevant rites at a certain time of year, imparting a type of calendric significance to the geoglyphs. Some of the biomorphs, such as those along the edge of the middle Ingenio valley, may have been ancestral emblems of such social groups. The palimpsest of geoglyphs found can be explained in part by a practice of periodical renewal of the sacred site at a slightly different location.

The basic concern of the Nasca people was the fertility of their valleys, which was entirely dependent on the arrival of waters from the Andes to the east. It is not unlikely that peaks in these mountains were deified and perceived of as the sources of this

life force. The shape and orientation of many of the enclosures can be argued to be symbolic of the flow of water from the highlands. Similarly, certain geometric geoglyphs such as spirals and zig-zags may have been symbols of a water cult. Offerings of *Spondylus* shells, associated with rain in Andean lore, have been found in connection with mounds, possibly altars, at the ends of some trapezoids. One recent theory (Silverman & Proulx, 2002) proposes that the geometrics actually indicate the position of water-bearing faults and that the trapezoids show the line of subterranean watercourses determined by dowsing. In some cases, such as at Cantalloc, south of Nazca, the layout of a trapezoid in relation to a lesser hill seems to be a model of the topographic relationship of a valley with an adjacent mountain.

The Nazca Lines were a product of intense, repetitive ritual activity over several centuries, concerned with guaranteeing the continuing fertility of the valley oases upon which human society is utterly dependent in southern Peru.

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Nīlakaṇṭha Somayāji

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Nīlakaṇṭha Somayāji (ca. 1444–1545), son of Jāta vedan, was a leading astronomer from Kerala.

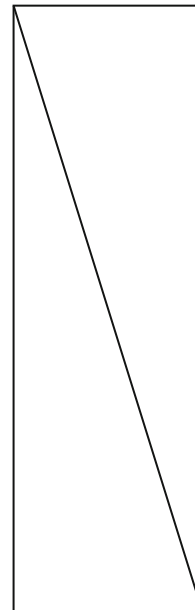
Being the author of a number of treatises on astronomy, like the *Golasāra*, the *Grahaṇanirṇaya*, the *Siddhāntadarpaṇa*, the *Chandrachhāyāgaṇita*, the *Jyotirmīmāṃsa*, and the *Sundararājapraśnottara*, he is best known for the *Tantrasaṅgraha* and the *Āryabhaṭīyabhāṣya*, his commentary on the *Āryabhaṭīya*.

Born at Trīkkaṇṭiyūr in the Malappuram district of southern Malabar, Nīlakaṇṭha Somayāji studied under the great Vāṭaṣṣeri Parameśvaran, who propounded the *dṛggaṇita* system of astronomy. He was also a student of Parameśvaran's son and disciple, Dāmodaran. As with most Indian astronomers, we know precious little about his life. We learn that he was married to Āryā and had two sons, Rāman and Dakṣiṇāmūrti, and that the Taṃpṛākkaḷ of Ālyāñcēri, the prominent Nāmpūtiri brāhmaṇa family of southern Malabar, patronized him. Nīlakaṇṭha Somayāji belonged to an illustrious pedigree of astronomers and mathematicians starting with Saṅgamagrāma Mādhavan in the fourteenth century and extending well into the nineteenth century. He is also believed to have been teacher to the renowned devotional poet, Tuñcattū Eluttaccan, the author of the *Adhyātma Rāmāyaṇam* in Malayalam. That Nīlakaṇṭha Somayāji was a contemporary of the Tamilnadu astronomer Sundararāja is evident from the *Sundararājapraśnottara*, which answers questions raised by the latter. Sundararāja referred to the Somayāji as the one versed in the six schools of thought (*ṣaḍ-darśanī-pāraṅgata*).

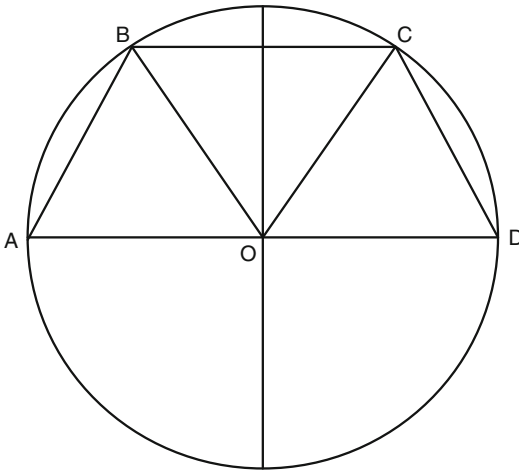
In the *Āryabhaṭīyabhāṣya*, Nīlakaṇṭha Somayāji proposed a new model of the solar system, which historians of astronomy regard as superior to the one proposed by Tycho Brahe a century later. In this model, which was in essence geocentric, the five planets visible to the naked eye, Mercury, Venus, Mars, Jupiter, and Saturn, revolve around the sun in an elliptical orbit, and the sun in turn around the Earth. In the *Tantrasaṅgraha*, Nīlakaṇṭha Somayāji proposed corrections for the model proposed by Āryabhaṭa for Mercury and Venus. As a result, says the historian George Gheverghese Joseph, he “arrived at a more accurate specification of the equation of the centre for these planets than any other that existed in Islamic or European astronomy before Kepler,” who lived

nearly a century and a half after the Somayāji. Before Nīlakaṇṭha Somayāji, astronomers in India adopted two different methods for determining the latitudes of the planets, one for the inner planets, Mercury and Venus, and the other for the outer planets, Mars, Jupiter, and Saturn. Nīlakaṇṭha Somayāji showed that this method was flawed, as in this system the planet itself was wrongly identified with the apex of the motion (*śīghrocca*) and used to determine its latitude. Nīlakaṇṭha Somayāji, instead, suggested that the mean sun must be taken into account for the *śīghrocca* for the planets, as all planets revolved around it. He also held that the latitude of a planet must be treated as a measure of deflection from the ecliptic. With the help of the computational *dṛggaṇita* system, he developed a unified model for all five planets.

Many interesting propositions are found in Nīlakaṇṭha Somayāji's commentary on the *Āryabhaṭīya*. One is that the area of a circle is equal to the product of half its circumference and half its diameter. Here, a circle is divided into a large number of radii in such a way that they are equidistant from the adjacent radius and the arc formed between two adjacent radii at the circumference is small enough to be like a straight line. Juxtaposing two such adjacent segments yields a rectangle, as in the following diagram (after Joseph, 2009).



The length of this rectangle is equal to the radius and the breadth, equal to the arc. Continuing this process, one arrives at a large rectangle, with the circumference of the circle transformed into the two breadths of the rectangle. A circle has thus been transformed into a rectangle. The area of the circle will then be equal to the area of the rectangle, with the length of the rectangle being half the diameter and the breadth being half the circumference. Another of the Somayāji's propositions is that the chord of one-sixth of the circumference of a circle is half the diameter. This is demonstrated by drawing three equilateral triangles in one half of a circle, as indicated by AOB, BOC, and COD in the diagram below (after Joseph, 2009). Thus, the chord's AB, or BC, or CD, will be equal to AO, which is half the diameter.



Many of these innovations do not seem to have had anything more than recreational value. Nīlakaṇṭha Somayāji's claim to the hall of fame certainly rests on the new planetary model he proposed, which his renowned successors like Jyeṣṭhadevan, Acyuta Piṣāraṭi, and Śaṅkara Vāriyar adopted in earnest.

See Also

- ▶ Āryabhaṭa
- ▶ Astronomy in Medieval India
- ▶ Parameśvara
- ▶ Yuktibhāṣā of Jyeṣṭhadeva

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Nilometer

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The Nile played an important role in the historical and the economic life of Egypt. Throughout history, Egypt was an agricultural nation that became the granary of the Mediterranean Basin. The river Nile is one of the most predictable rivers in the world. The rise and fall of the Nile is regular and quite precise with floods that are rarely destructive. After the beginning of the rainy season in Ethiopia, the Nile starts to rise in early June and gradually swells to its maximum by the end of September, when the lands in Egypt are flooded with the appearance of islands. Diodorus Siculus gives a detailed description of this phenomenon:

The rise of the Nile is a phenomenon which appears wonderful enough to those who have witnessed it, but to those who have only heard of it, is quite incredible. While all other rivers begin to fall at the summer solstice (around June 21) and grow steadily lower, this one (Nile) begins to rise at that time and increases so greatly in volume day

by day that it finally overflows practically all Egypt. . . And since the land is level plain, while the cities and villages, as well as the farm-houses, lie on artificial mounds, the scene comes to resemble the Cycladic Islands. (Diodorus, I.36.7–9)

This period of the inundation is also dedicated to festivals and ceremonies such as the account given by Diodorus:

The masses of people being relived from their labours during the entire time of the inundation turn to recreation, feasting all the while and enjoying without hindrance every device of pleasure. (Diodorus, I.36.10)

The flood remained quite static for about one month and then subsided more and more until December or January, when the Nile returned to its original bed. In early June, the river was reduced to its half of the flood breadth (Said, 1993, p. 96).

Metrology and the Inundation

The Nilometer was invented for recording the annual inundations in Egypt and to control the floodwater. As the name suggests, the device originates from the area of the Nile in Egypt. The Nilometer's function was based on the physics principle called "communication vessels." At three different levels in the Nilometer shaft, three channels were connected to the Nile River (Fig. 1). During the flood, the water would enter through the channels and fill in the shaft's bottom. If the water rose up to 16 cubits marked on the pit, that would indicate a good prosperity for the year. If the level was less than 16 cubits (e.g., 12 or 14 cubits), that meant famine, whereas a higher level of 19 cubits would indicate a catastrophe, and the soil with the sown seeds would be washed away. The inundation levels control became the responsibility of the priests. Thus, Nilometers were mainly enclosed in temples where only the priests and the ruling pharaoh could have access to these devices. The significance of the Nile's floods is associated with Memphis, which is located at the root of the Delta. Diodorus (1st century BCE), wrote that the kings of Egypt constructed a *Niloscope*



Nilometer, Fig. 1 Kom Ombo temple Nilometer (From: http://upload.wikimedia.org/wikipedia/commons/e/e0/Kom_Ombo_temple_Nilometer.JPG). This device is a well-type Nilometer. Two channels at different levels are set within the wall of the well. A third channel was set close to the bottom of the well

(Nilometer) at Memphis where administrators were appointed to make accurate measures of how many cubits or fingers the river (Nile) had risen or when it commenced to fall (Diodorus, I.36.11). These inundation levels could predict the grain and corn harvest, since the Egyptians kept accurate records of their observations over a long period of terms (Diodorus, I.36.12).

The surveying records of the Nile's levels are difficult to interpret since various measuring devices throughout historical periods did not use the same zero point and most probable not the same scale. The oldest records come from a stone stela, dated to Dynasty V (2480 BCE), known as the "Palermo Stone," named after the Museum of Palermo, where it is found (Fig. 2). Additional parts of this stone are found in the Cairo Museum. The Palermo Stone is assumed to come from the Memphis area. W. Helck completed a study of the stone in 1966 and also converted these records into the metric system: The gauges to record the Nile flood levels were marked in cubits, a metrological unit comprising 6 or 7 palms, thus indicating two kinds of measures: the small cubit = 6 palms and the royal cubit = 7 palms. The hieroglyph used on cubit rods to indicate metrological fingers appears as 4 (a palm with four stretched fingers), 5 (a palm with five stretched fingers), and 6 (a clenched fist). The small cubit was



Nilometer, Fig. 2 Palermo Stone (From Said, 1993, p. 135, Fig. 2.13). 1 cubit = 7 hands/palms = 28 fingers = 2 spans = 0.524 m (Said)

considered the length of the forearm from the elbow to the thumb, equaling 45 cm, while the royal cubit was the length of the forearm from the elbow to the tip of the middle finger, equal to 52.5 cm (Robins, 1982). Since the cubit was the length of a forearm and Egyptian men were of varied height and arm length, there were different cubit units. The royal cubit was divided into 7 palms or 28 fingers (524 ± 5 mm), while the small cubit into 6 palms or 24 fingers (449 mm). The double remen (740.7 mm) was the length of the diagonal of a square with each side of one royal cubit (Singer, Holmyard, & Hall, 1965, p. 777). This metrological unit was the base of the Egyptian land measure. The double remen was divided into 40 digits (each digit = 18.5 mm).

One of the most significant Nilometers in history was found at Memphis; in ancient literature, it was referred to as the “House of Inundation.” The zero point in this Nilometer must have been at the ground level of the Memphis agricultural plains. In the Aswan Nilometer at the Temple of Khnum, there were two zero points: the lower

level corresponded to the low water level of the Nile; the high level equaled the level at which the fields were watered. Said (1993) suggested that the Memphis Nilometer may have had two zero points; thus, the records of the flood levels on the Palermo Stone were probably taken in the same way as at Aswan.

The Elephantine Nilometer was considered the most significant station for measuring the Nile’s levels (Herodotus II.32, Diodorus I.36.11, Pliny, *NH* V.x.58, Popper, 1951; Pearl, 1956, p. 52), due to its location off the First Cataract, where the floodwaters reached their maximum height. Plutarch said that the greatest rise at Elephantine amounted to 28 cubits, at Mendes the smallest was 6 cubits, while at Memphis the intermediate (between the high scale at Elephantine and the smallest at Mendes), when normal, was 14 cubits (Pearl, p. 52). The inundation heights of 15 or 16 cubits given by Herodotus (II.23.) appeared to be the adequate level for the fifth century BCE. The big difference between 28 cubits at Elephantine and 14 cubits at Mendes shows that the readings from the Elephantine Nilometer were done from a scale and not from high and low waters (Pearl, p. 57). The high numbers in these scales were probably done when they attempted to establish the same zero point at the Nilometers upstream from the Nile’s mouth starting at the Delta, on a theoretical fall line which did not correspond to the gradient of the river (Pearl 1956).

The level of 16 cubits was considered the optimal level for the inundation of fields from the Greco-Roman and early Arabic periods (the measures were taken at the newly built Cairo Nilometer at Roda Island, 715 CE). Pliny (V. x.58) said that when the flood level was 12 cubits (in the province of Memphis), it was a sign of starvation, and even with 13 cubits it still meant hunger, 14 cubits brought joyfulness, 15 was freedom, and 16 sheer delight. At Elephantine, a good flood meant a rise of 28 cubits, while at Edfu 24 cubits and $3\frac{1}{4}$ palms were required (Elephantine and Edfu were the main stations off the First Cataract) (Moret, 1927, p. 32). Descending northwards to the Delta, the needed flood level was less than in Upper Egypt; at



Nilometer, Fig. 3 The California Nilometer (From: Lutz, 1923, p. 49)

Mendes and Xoïs, 6 cubits were sufficient (Moret, p. 32). A record for a “good flood” in the Middle Kingdom during the reign of Senwosret I (1971–1928 BCE) was registered at the level of 21.5 cubits (11.3 m) at the Elephantine Nilometer, 12.5 cubits (6.6 m) in the “House of Inundation” at Old Cairo, and 6.5 cubits (3.4 m) at Diospolis (Tell Balamoun), in the northern Delta.

A rare record of the Nile’s level inscribed on a limestone slab is found in the Egyptian collection of the Museum of Anthropology and Ethnology of the University of California. The stone comes from Nag’ed-Deir, on the south bank of the Nile, opposite Girgeh. The inscription reads:

Year 23, month Mesore (December), the 23rd day:
The moth of the Nile ender his majesty the king of
Upper and Lower Egypt, Ne-maat-Rê, living
forever.

The height of the Nile is indicated by the line drawn beneath the inscription. In the middle of the line is a mouth, referred to in the text (Fig. 3). This inscription indicates that the Nilometer built near Nag’ed-Deir in the 23rd year of Pharaoh Amenemhet III (Ne-maat-Rê; the 6th Pharaoh of the 12th Dynasty; 1860–1814 BCE), the interest of the ruler in the regulation of the inundation and particularly for his reclamation of the Fayyûm district.

The Roda Nilometer, opposite Cairo, built at the southern tip of the Island, during the reign of Caliph Abdel ibn-Marawan (715 CE), and later rebuilt by Caliph el-Mutawalik (861 CE), is a

covered structure with a well inside. An octagonal marble pillar stands in the middle of the well. On the pillar are inscribed the calibration units in cubits and subdivisions in fingers (Figs. 9, 21). Due to the accumulation of sediments on the bottom of the well it brought to changes of Roda Nilometer, and therefore the scale had different values. The cubits in the oldest scale were divided into 28 fingers from cubit I to XII, and the new scale was divided into 24 digits from cubit XIII to XXI. Since the finger in both scales is the same (1 finger = 1.925 cm), the cubits in the lower part measure 53.9 cm (royal cubit), while those on the upper part equal 46.2 cm (small cubit). The zero point of the scale was fixed at the level of the well’s floor; thus the cubit XVI was 8.3 m above the floor of the well (or 16.4 m above sea level). At the time of building the Nilometer, level XVI was considered the effective level of the flood at which the dikes were opened to release the water in the fields at the inundation season.

In the Greco-Roman periods, the figure XVI and the floodwaters of the Nile became the symbol of life and prosperity not only in the Egypt but also through the Mediterranean World, where the cult of the Nile developed. The Nile Statue at the Vatican Museum in Rome is a relevant example of the personification of the Nile’s fertility at the inundation season; 16 *putti*, each of one royal cubit height, surround the god Nile reclining on his left side, while he holds ears of corn and a cornucopia (Fig. 4). The *putti* symbolize the optimal 16 cubits required for a successful flood.

In ancient Egypt, the god Hapi was the incarnation of inundation and deification of the flood, as attested by many Egyptian paintings, statues, and reliefs. He was the god bringing fertility to the land (See: Appendix).

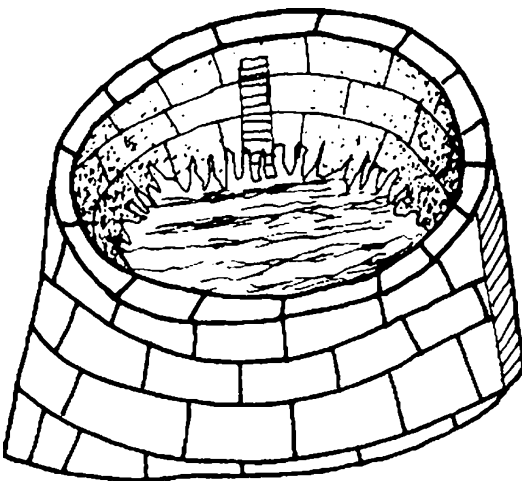
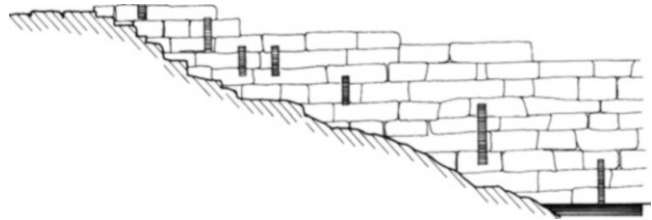
Types of Nilometers

Surveying the remains of ancient Nilometers and their representation in art, we may classify them in three main types and some combined types: a wall or corridor with steps (Fig. 5), a well (Fig. 6), and a column (Fig. 7).

Nilometer, Fig. 4 God Nile with 16 *putti*, each one royal cubit height (From Freeman & Ray, 2000, p. 147)

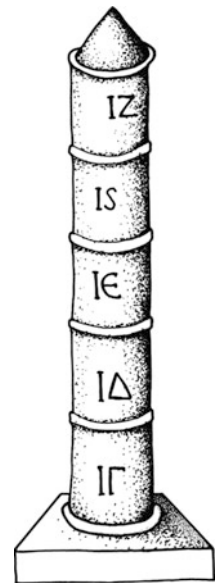


Nilometer, Fig. 5 Wall or corridor Nilometer (From Said, 1993, p. 153, Fig. 2.25)



Nilometer, Fig. 6 Well Nilometer (Drawing by Z. Friedman)

Nilometer, Fig. 7 Column Nilometer (Drawing by Z. Friedman)



The combined types are a well with a projecting column (Fig. 8), or a covered structure with a well in which a column is set in its center, as represented by the Islamic Roda Nilometer (Figs. 9, 21). In all Nilometers, the gauge is marked in cubits and subdivided into fingers. Nilometers depicted in art are shown with whole metrological units missing the

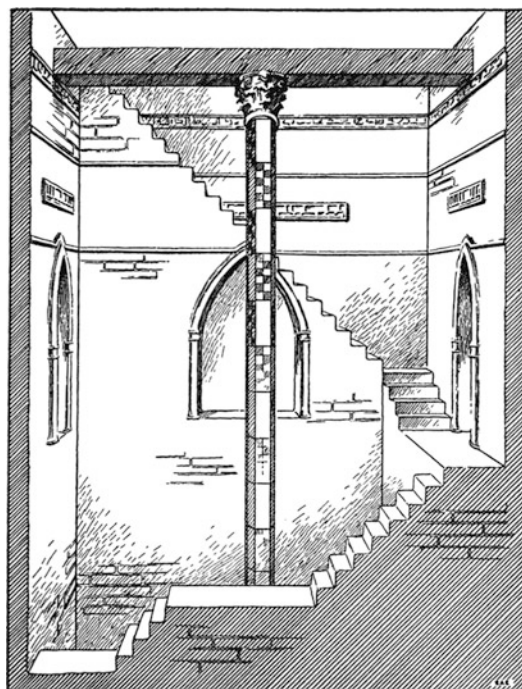
subdivisions in fingers. The cubits value is indicated by Greek letters. These representations were done for convenience, with the purpose to transfer to the viewer the symbolism of the device and its importance associated with the floodwaters of the Nile. Each type of Nilometer will be described and illustrated with relevant examples.



Nilometer, Fig. 8 Composed type of well with column
(Drawing by Z. Friedman)

1. Wall or corridor types of Nilometers had their zero point set where the water level was against the steps, thus showing the height of the floodwaters (Fig. 5). Such Nilometers were built in temples at Elephantine, Philae, Edfu, Kom Ombo, and Dendera (Fig. 10). These devices have the calibration marked on the wall and were built from the Pharaonic periods to the Roman era. The Nilometer on Elephantine Island (Fig. 11a, b), north of the First Cataract, was one of the most important devices, due to its location where the floods began. This device was located in the Temple of Khnum dedicated to the ram-headed god of Inundation. The Nilometer dated to Dynasty XI was replaced by a new one built during Dynasty XXX, at the Temple of Satet, one of Khnum's celestial consorts. When Egypt fell to the Roman Empire, the Nilometer at Khnum temple underwent some changes. The new calibrated staircase was roofed with granite slabs.

On the quay of the Karnak Temple, gauges were engraved to measure the height of the floodwaters. Many authors have researched them since the late nineteenth century.



Nilometer, Fig. 9 Roda Nilometer (From Popper, 1951: inner cover)

Legrain (1896), Borchardt (1906), and von Beckerath (1966) recorded 45 levels of inscriptions running from the reign of Shosheq I to Psammetik I (Dynasties XXII–XXVII). The elevation of the zero point of the Nilometer was fixed at 64 m above sea level. The flood rises recorded at Karnak quay ranged from 9.22 to 11.1 m. The years marked “joyful” were those which had an average flood rise of 10.6 m (Said, 1993, p. 152).

2. Well Nilometers seem to be a later type that appeared during the Ptolemaic period. Strabo (1st century BCE) gives a detailed account about where such Nilometers were placed at Syene and Elephantine Island:

The Nilometer is a well on the bank of the Nile constructed with close-fitted stones, in which are marks showing the greatest, least, and mean rises of the Nile; for the water in the well rises and lowers with the river. . . . Accordingly there are marks on the wall of the well, measures of the complete rises and of the others. So when the watchers inspect these, they give out the word to the rest of the people, so that they may know. (Strabo *Geo.* 17. 1.48)



Nilometer, Fig. 10 Map of the Nile with locations of Nilometers (From Freeman & Ray, 2000, p. 133)

Pliny informs us that when the inundation season started, it was observed through the well Nilometers and that it was also advisable not to sail during the high floods:

The view has been held that it is unlawful for kings or rulers to sail on the Nile when it is rising. Its degrees of increase are detected by means of wells marked with scales. An average rise is one of XVI cubits. The smaller volume of water does not

irrigate all locations, and a larger one by retiring too slowly retards the agriculture (*NH. V.x.57–58*).

Both Strabo (*Geo. 17.I.48*) and Pliny (*NH. II.183*) said that the midday sun in the summer solstice did not cast any shadow in the wells and that the light reaching their bottom showed the water level, probably at the crest of the flood (Friedman, 2001, p. 59). The well

Nilometer, Fig. 11

(a) Staircase Nilometer at Elephantine: <http://www.lexicorient.com/egypt/aswan04.htm>. (b) Close-up of the Elephantine gauge: <http://www.touregypt.net/featurestories/nile.htm>



Nilometer, Fig. 12 Well Nilometer in the Nile mosaic from Palestrina (Photo by Z. Friedman)

in the Palestrina Nile mosaics may be considered an illustrative example for a well-type Nilometer (Fig. 12). The rounded well is built with stone blocks. On its right lower edge (at the water level), there are two arched openings that water goes through. The well is placed on the bank in the vicinity of a Hellenistic temple. The splashing water inside the well, viewed from above, may suggest rising floodwaters. A gauge may have been engraved on the walls of the well. Well-type Nilometers were modified during the Ptolemaic periods, with stairs in or around them. Such wells were found in temples at Kom Ombo and Edfu.

A spiral staircase set in the inner side of the well reached the water level in Kom Ombo Temple (Fig. 1). A gauge may have been engraved on the walls of the well or on the steps as well. A similar type of Nilometer with a rectangular basin with stairs leading to it, dating from early Imperial period, is found in the Temple of Khnum at Elephantine (Meyboom, 1995, p. 244, n. 77).

3. Column Nilometers appeared during the later Imperial period, when the scale was removed from the well to a column. It was much easier to carry such a device and place it at different points to record the flood levels. Toussou (1925, p. 302) mentions that at least during the Greco-Roman periods there was a portable device, which, when not in use, was kept in the Temple of Serapis (Moret, p. 302). In the flood season, it was taken out and set up in a well shaft (Bell, 1970, p. 571).

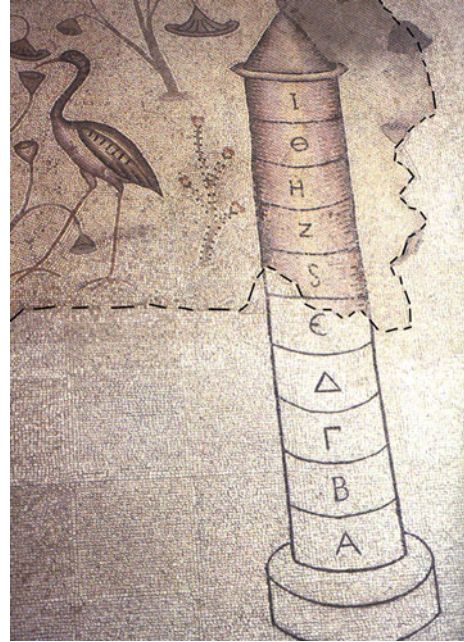
A column Nilometer is quite a common object in art. It is depicted as an individual item or shown with human figures engraving the newly risen flood level. Such an example appears on a Roman glass cup (Fig. 13), probably of Campanian origin, dated 200–300 CE, now at the British Museum (Reg. 1868.5.919; Versluys, 2002, pp. 169–170). A single column Nilometer with a conical top appears in the mosaic floor, to the right of the transept, in the Church of Multiplication of the Loaves and Fishes, at Tabgha, on the



Nilometer, Fig. 13 Column Nilometer on a Roman glass cup (From Harden, 1987, p. 200, Fig. 109 bottom)

northwestern shore of the Lake of Galilee (Kinneret), Israel (Fig. 14). A considerable part of the mosaic was destroyed, and in the past several years, it had been reconstructed. The upper part of the Nilometer belongs to the original mosaic, while the lower section is reconstructed (Fig. 14). The mosaic was dated to the 4th to 5th century CE (Schneider & Gordon, 1937). On the shaft are inscribed Greek letters referring to the calibrations from 6 to 10 cubits: S = 6, Z = 7, H = 8, Θ = 9, and I = 10 (Friedman, p. 60).

A column Nilometer associated with Alexandria appears in two mosaics from Israel. The first device is found in the lower frame with a Nilotic scene, in the mosaic floor from the House of Leontis, at Beit Shean. The mosaic was dated to the 5th to 6th century CE; now it is found at the Israel Museum, Jerusalem. The vertical shaft set on a rectangular pedestal and topped by a rounded tip is placed to the left side of a small temple with a tiled pitched roof (Fig. 15). On the shaft are inscribed the cubits from 10 to 16: I = 10, IA = 11, IB = 12, IΓ = 13, IΔ = 14, IE = 15, and IS = 16. The adjacent building may have been the checkpoint where the keepers recorded the flood levels. Above this structure, Alexandria is written in Greek letters. The House



Nilometer, Fig. 14 Tabgha mosaic (Friedman, 2001, p. 86, Fig. 105)



Nilometer, Fig. 15 House of Leontis, Beit Shean (Photo by Z. Friedman)



Nilometer, Fig. 16 Nile festival mosaic from Sepphoris (Friedman, 2001, p. 86, Fig. 104)

of Leontis was a synagogue, and the room where this mosaic was found probably served as a guest room. The second Nilometer associated with Alexandria appears in the Nile festival mosaic from Sepphoris (Diocaesarea), in the Lower Galilee (Fig. 16). This mosaic in situ was dated to the 5th to 6th century CE (Netzer & Weiss, 1992). The rounded column is set on a square structure with four arched openings placed in the water. The cubits on the shaft are inscribed with Greek letters, from 13 to 17: IΓ = 13, IΔ = 14, IE = 15, IS = 16, and IZ = 17 (Friedman, p. 60). Mark 13 is not visible, due to the damage of the mosaic in this section, while the head of the man bent to support on his back the person who engraving the new flood level at 17 hides cubit 14. Alexandria is inscribed above a tall fortified structure; a rounded tower on each side flanks its entrance. The structure is found beneath the lower bank of the river. The number 17 appears twice on the lower bank; the first is found just to the right side of the right-hand tower, and the second is beneath the right arm of the figure placed on a Corinthian column. The newly engraved cubit 17 on the



Nilometer, Fig. 17 Nilometer in the Sarrīn mosaic, Syria (From Balty, 1990, Pl. XXXIII/1)

Nilometer and the marking on the lower bank indicate that this level was reached at that particular period of the flood. To the right side of the Nilometer is a large naked figure, with his back turned to the device. He holds a staff in his right hand, probably a ruler of double remen used for measuring the land after the inundation, for tax evaluation. In a mosaic from Sarrīn (Osrohoène), Syria, dating 5th to 6th century CE (Balty, 1990, p. 83), is a Nilotic scene within a wide border. On the left side of a stone-built structure with a pitched tile roof is a two-storied square pillar. The calibration numbers are inscribed with Greek letters on the upper part of the shaft. A large naked figure with a hammer in his right hand and a chisel in the left engraves the number IH = 18 above the existing IZ = 17 (Fig. 17), which seems to show the new flood level at that particular time.

A rare coin called *chalkous* (or *dichalkous*, *hemichalkous*) was minted at Alexandria during the reign of Hadrianus. On the obverse, the head of the emperor in profile looks to the left and is crowned with a *modius* as a headdress. To the right, beneath the chin of the figure, appears a column standing on a slightly raised and flat base (Fig. 19a, b). On the reverse is depicted a cornucopia full of ears of corn and the inscribed date of LIB (127/128 CE) (the coin is bronze,

diameter = 12 mm, weight 0.95 g). The *modius* (measure of grain) headdress is an attribute of Serapis. The motifs of the cornucopia full with ears of corn and the *modius* headdress are symbols of fertility and abundance. Their depiction on the Hadrianic *chalkous* suggests a prosperous year in the Egyptian economy after a good flood cycle of the Nile, usually marked as 16–17 cubits on Nilometers set at varied stations in the Delta. Eidelstein suggests that the object depicted beneath the chin of the emperor is a column-type Nilometer and the inscription IZ on the lower left side of the head indicates the 17 cubits (Fig. 19a), the level of the Nile probably reached in the 12th year of Hadrian's reign (127/128 CE). This rare coin of Hadrianus belongs to the small mints intended to attract local countrymen and commemorate the event of a good flood cycle of



Nilometer, Fig. 18 Silver plate from the Hermitage Museum (From Balty, 1990, Pl. XXXIV/2)

the Nile, thus being understandable to all his Roman-Egyptian subjects.

Combined types of Nilometers comprise a well with a rounded or square column projecting from it. There are several art depictions dating from the 5th to the 7th centuries CE. A silver plate, which probably was produced at Constantinople at the turn of the 5th or beginning of the 6th century CE, depicts a slim rounded column projecting from a well built with stone blocks (Fig. 18). One man standing on the back of another engraves cubit 5 ($\Theta = 5$), on the upper part of the shaft. This plate is found at the Hermitage Museum at St. Petersburg, Russia.

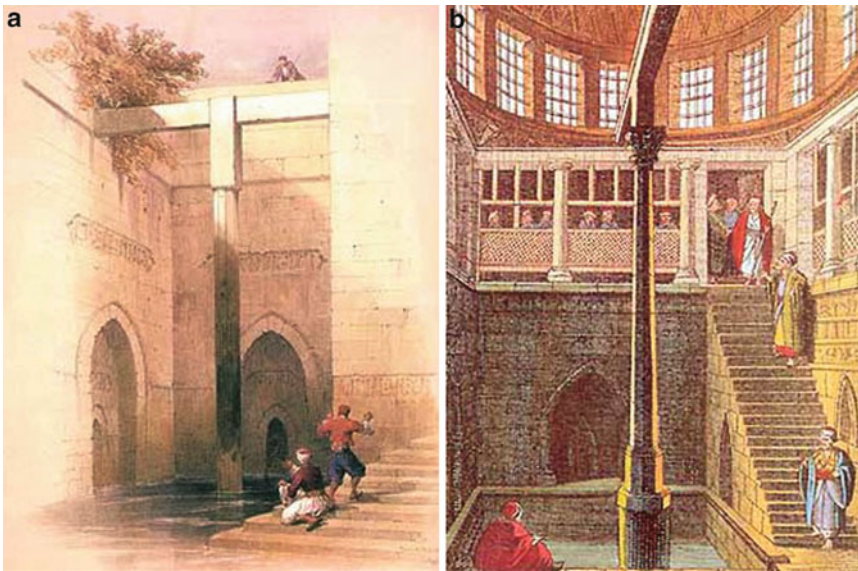
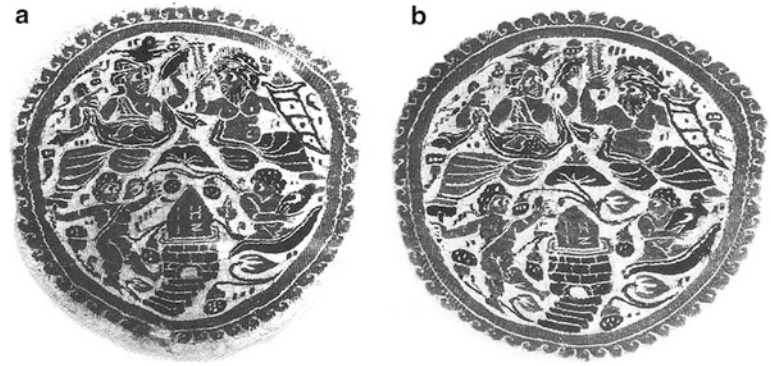
Two Coptic rounded frame textiles dating to the 6th or 7th century CE, at the Louvre Museum, Paris, depict the personification of the Nile together with the Abundance (Euthenia), (Maguire, 1990, p. 218). On the lower part of both textiles is a rounded well, built with stone blocks, with steps ascending to an arched opening at the base of the well (Fig. 20a, b). A large naked figure with a hammer in the right hand and a chisel in the left engraves the number IH = 18 above the existing IZ = 17, on the upper part of the square column. The new number may refer to the new flood level reached at that particular moment (Fig. 20).

The Roda Nilometer is a combined type of well with a column set in its center and placed into a covered structure roofed by a dome (Fig. 21a, b). This first Islamic device was built in 715 CE, at the southern tip of Roda Island, opposite Old Cairo. In Arabic, the Nilometer is known as *miqyas* (al-Mikyās) (Hansen, 2003). The Roda Nilometer was built by the Umayyad

Nilometer,
Fig. 19 Hadrianic
chalkous (From: Eidelstein,
2013, p. 4, Fig. 4)



Nilometer, Fig. 20 (a) Coptic textile (From Maguire, 1990, Fig. 14 top). (b) Coptic textile (From Maguire, 14 bottom)



Nilometer, Fig. 21 (a) Roda Nilometer (David Roberts: <http://www.touregypt.net/featurestories/nilometerroda.htm>). (b) Inside the Roda Nilometer <http://www.touregypt.net/featurestories/nilometerroda.htm>

Caliph Abd al-Malik ibn Marawan, which later was rebuilt by Caliph el-Mutawalik in 816 CE. A flood in 850 CE destroyed this Nilometer. When the new device was built, Abu el-Raddad of Basra was appointed as the guardian of the Nilometer. The priests kept the records of the Nile's levels in ancient times. After Christianity was introduced into Egypt, the office was kept until the Arab conquest, but the Coptic priests still kept the records al-Mikyās (Nilometers). The guardian of the Nilometer was Said Mahommed el-Sowafi, a man with no formal education. His records were done by the rule of the thumb, handed down to

him by his forefathers who did not pay attention to the original column (gauge) or its gradations (Said, 1993, p. 155).

The Roda Nilometer comprises a covered structure with a well and the level of the floor is connected to the Nile by three tunnels. The southern one is at the level of the well's floor (8.15 m above the sea level), while the other two are at the east and are placed one above the other (Said, 1993, p. 155). The octagonal column inside the well is set on a pedestal (Fig. 21b). Inside the Nilometer structure, leading down to the well, are 45 steps; the height of each is 24 cm (Hansen, 2003).

The steps also allowed for a quick reading of the water level of the Nile. The scale on the pillar is marked in cubits with a subdivision of fingers. It was mentioned above that the metrology of this column comprises two scales: one subdivided into 28 fingers (royal cubit), from cubit I to XII, while the other is divided into 24 fingers (small cubit), from cubit XIII to XXI. The zero point was fixed at the level of the well's floor. In different periods, this Nilometer underwent changes. In 1517 (5 years after the Turkish conquest of Egypt), a new scale was set up in which the zero point was elevated by 1.62 m above the level of the well and the cubits from IX to XXVII were reduced to 36.1 cm each. In 1861, during the reign of Khadive Ismail, his engineer Mahmoud Saleh el-Falaki repaired the gauge and replaced the older one by a new scale in which the zero point was fixed at 66 cm above the well's floor, and the elevations in meters was changed. Each cubit in the new scale measured 54.1 cm, except for cubits XVI to XXII, which measured 27.1 cm. This change was done to adjust the Cairo readings to those at Aswan. When the level reached 16 cubits at Aswan, the basins in Upper Egypt were inundated, while in Cairo the level was reduced to one half (Said, 1993).

In the medieval era, the importance of the Roda Nilometer was celebrated in Fath al-Khalij, the festival of the opening of the canal. The canal was blocked with earth dams and cleaned before the flood. When the Nile reached the level of 16 cubits, the dam was opened to water the agricultural lands. The celebration started at this time and lasted for 7 days. During this period, decorated boats crowded the waters. In the hot summer months, the Khalij canal and the ponds were still crowded with boats, and along the shores there were many kinds of entertainment. The grand celebration was not an annual event. When the floodwaters failed to reach the 16 cubits level, the celebrations were canceled, and prayers were held instead, to ward off the drought and famine (Abaza, 2003). These celebrations ceased in 1899, when the Khalij canal was filled in. The Roda Nilometer was no longer necessary after the

building of the High Dam at Aswan in the 1970s, which continues to regulate the Nile waters.

The purpose of this entry was to survey the Nilometer historically and its metrology to show how it was depicted in varied art forms. The Nile and its floodwaters were subjects for many historians (ancient and modern) while it symbolized fertility, plenty, and prosperity. Through different periods and even in the modern era, measuring the Nile flood levels was an important factor in the economics of Egypt, which made her the main granary of the ancient world in the Mediterranean Basin. A survey of Nilometers from the early Pharaonic dynasties revealed that Egyptian society was unified and had an organized system of recording the distribution of the floodwaters, dividing the agricultural lands, and assigning tax levels according to the quality of the year's flood.

Pliny (*NH*. V.x.57–58) and Strabo (*Geo*. 17. I.48) attested that the optimal flood level of the Nile was 16 cubits at Memphis. The numbers inscribed in the Sarrin mosaic and the Coptic textiles (IZ = 17, IH = 18), as well as the lower numbers in the Tabgha mosaic and in the Hermitage plate, do not refer to the desired flood level. They symbolize the importance of the Nilometer and the Nile waters. From historical references, we know that a flood level less than 16 cubits brought famine, and if it exceeded that disaster came and the crops were destroyed. This survey of the Nilometers attests that the flood levels were not the same along the course of the Nile and also their readings were not based on the same zero point. It appears that there were at least two local zero points, which corresponded to the agricultural plain levels and also to the level where the floodwaters were released into canals to irrigate the fields.

Appendix: Nilometer, Irrigation, Egyptian Calendar, and Taxation

The Nile and its flood cycles made possible the development of ancient agriculture and shaped Egyptian society from the Neolithic era to modern times. The earliest written statement that

“Egypt is the gift of the Nile” comes from Herodotus (5th century BCE), who also referred to the fertilized soil by the silt left after the flood recess:

Egypt which the Greeks sail is a land acquired by the Egyptians, given to them by the river (Nile). (Book 2.5)

For the river (Nile) that brought the staff (silt) to make these lands is none worthy to be compared for greatness with one of the mouth of the Nile; and the Nile has five mouths (referred to the Delta). (Book 2.10)

The Nile also was the source of fish for the Egyptian diet, hunting in the marshes and the main water transportation that contributed to the development of the ancient Egyptian economy and trade. Towards the summer solstice when the floodwaters of the Nile flowed down from Syene (the ancient Swenet) and reached Silsileh (the apex of the Delta), the priests and the reigning sovereign sacrificed a bull or geese then rolled them up in papyrus and cast them into the Nile. Apparently, this sacrifice was a written order to insure a successful inundation. The pharaoh officiated this event by himself which was recorded on a *stela* engraved upon the rocks on the Nile banks. Swenet (Syene) was formerly an island in the Nile at the 1st Cataract. Under every dynasty, it was a garrison town; here tolls and customs were levied on all boats passing southwards and northwards. Silsileh is a range of sandstone hills stretching on both banks of the Nile, 70 km north of Aswan and 145 km south of Luxor. Through this area, the narrowing Nile runs through a channel ca. 395 m wide and one kilometer long. In antiquity, there was a series of rapids, dangerous to navigation, which naturally formed the border between the regions of Elephantine (Aswan) and Edfu. In Pharaonic times, the Nile in this region was known as *Khennui*, the “place of rowing.” This area also was famous for its quarries and for the quality of its building stones.

Actually, the realm of ancient Egypt is an interwoven relationship between administration, technology, and religion. The Egyptians assumed that their nation survived by the grace of the gods. They believed that the annual flood of the Nile

was given by the god Hapi (also considered “father of the gods”). Hapi is one of the most popular and powerful deities in Ancient Egypt, and yet no temple has been discovered as specifically dedicated to him. One of the oldest references to Hapi is in the *Pyramid Texts of Unas*. In the text, he is called *Hep*, being locked at Kenet (the 1st Cataract and the island of Elephantine, Sahel, Philae, etc.) and to *Wepwawet* (the opener of the ways). Unas was the last pharaoh of Dynasty V; he was the first sovereign to incorporate the Pyramid Texts in his pyramid. Hapi was the god of the Nile, the bringer of fertility. He was depicted as a male figure with bisexual appearance, with large breasts and blue or green skin, and wearing a false beard of the pharaoh (Fig. 22a). The female breasts and his skin color indicate that he is a fertility god, while the false beard reaffirms his link to the pharaoh. Hapi also represents the unified Upper (southern) and Lower (northern) Egypt. Therefore, he often is depicted as twin deities: *Hap-Reset* (representing the source of the Nile) is adorned with a head-dress of papyrus, whereas *Hap-Meht* (representing the Delta) is adorned with a head-dress of lotus (Fig. 22a). According to the myth, the Nile flowed from Hapi’s home (near the 1st Cataract) through the heavens and the land of the dead before emerging from a cave somewhere in the mountains (Fig. 22b). The inundation was referred to as the *Arrival of Hapi*, and during this period the Egyptians would place statues of the god in the towns and cities followed by instrumental music and chanting hymns, so that they could be assured with a successful flood cycle:

Bring food, rich in substance (silt), creator of all good things, lord of all seeds of life, pleasant unto his elect, if his friendship is secured, he produces fodder for the cattle; . . . he (Hapi) takes position of two lands, and the grainers are filled, the store-houses are prosperous, and the goods of the poor are multiplied.

. . .and when thou art implored to give water of the year, the people of Thebaid and of the North are seen side by side, each man with the tools of his trade. . .

In ancient Egypt, the cosmic order was identified with the Nile, its flood cycles, as well as the



Nilometer, Fig. 22 (a) God Hapi from Medinet Habu – New Kingdom Dynasty XX; from: Wildung, 2009, p. 135 (b) God Hapi in the cave at the source of the Nile, the 1st Cataract; from: Wildung, p. 197

solar and lunar cycles. It was believed that the Pharaoh caused the life-giving water that brought the rich fertility of Egypt. The Pharaoh was believed to be descended from the gods, but he was not a god. He acted as the intermediary between his people and the gods and thus was obligated to sustain rituals and offerings to the gods, so that they could maintain order in the universe.

The beginning of the Nile's annual inundation cycle occurs at the time of heliacal rising of the star Sirius (*Canis Major* or the Dog Star), which is the first day when the star can be seen before the sunrise. The consistent observations of the sun's cycle made the Egyptians the first to adopt the solar calendar ca. 5000 years ago. The heliacal rise of Sirius always precedes the Nile flood by a few days. The earliest recorded solar year seems to have begun in 4236 BCE, when the Egyptians also divided the solar calendar into 365 days. We find this record from Herodotus (*Book 2.4*) when he wrote:

...the Egyptians were the first men reckoned by years and made the year to consist twelve divisions of the seasons. They discovered this from the stars...

Herodotus also informs us that the Egyptians divided each month into 30 days, and the year into 12 months, and added 5 days at the end of each year, so that there were 365 days in the solar calendar. The ancient Egyptians used three different calendars: the stellar calendar (rising of Sirius) was used for agriculture, the solar year or civic calendar (12 months $\times$ 30 days/month + 5 days), and the lunar calendar (average 354 days) for festivals. The civic or solar calendar was divided into three seasons, each comprising 4 months (Fig. 23). This calendar served the government and administration for the taxation of lands after the inundation cycle. The Egyptian seasons correspond to the cycles of the Nile, and thus they were named after significant events for farming:

Akhet (inundation): Occurred between July and December, the period of the annual flooding. During this period, irrigation canals redirected water from the Nile to more arid areas.

Proyet/Peret (emergence; the winter season): At this period, the Nile receded from December to March. This was the time when the farmers sowed their crops.

Agri-Cycle	Kemetic		Gregorian
 Akhet Harvest	Tehuti	1	January
	MenKhet	2	Febuary
	HetHeru	3	March
	Renutt	4	April
 Shemu Inundation	ShefBdet	5	May
	Rekh-Nedjs	6	June
	Rekh-Wr	7	July
	Ka-Her-Ka	8	August
 Pert Planting Seeds	Khenti-Kheti	9	September
	Khonsu	10	October
	Ipet	11	November
	Mes-Ra	12	December
	Wep Renpet		5 Days Over

Nilometer, Fig. 23 The Egyptian Calendar with the cycle of the seasons (<http://blackhistoryfactorfiction.com/the-calendar-project/egyptian-calendar/>)

Shumo/Shemu (low water): This cycle corresponded to the summer season, lasting from March to July. It was the dry season when the crops were harvested, and also was the busiest time of the year in Egypt (considering that Egypt was the main granary source in the Mediterranean in antiquity). This period also corresponded to tax collecting for the treasury of the pharaoh. The tax was usually taken from the crops that the farmers grew.

During the inundation period, the farmlands were covered with water, and the soil was enriched by the deposition of silt after the receding of the floodwaters. This cycle of flooding and recess of the waters is described by Herodotus in *Book 2.19*:

...the Nile comes down with a rising flood for an hundred days from the summer solstice, and when this tale of days is complete sinks again with a diminishing stream, so that the river is low for a whole winter till the summer solstice again.

Herodotus also referred to the means of tax collecting during the reign of Sesostris III and the allocation of agricultural lands to his subjects. Sensusret III (Senworset III or Sesostris III) was

the 5th pharaoh of Dynasty XII of the Middle Kingdom and ruled from 1878 to 1839 BCE, during a time of great power and prosperity in Egypt. Among his achievements, he built many irrigation canals; he also was known as the “Pharaoh of the Canal”. He also cleared a navigable canal through the 1st Cataract.

The king (Sesostris) moreover, divided the country among all Egyptians by giving each an equal square parcel of land, and made this his source of revenue, appointing the payment of a yearly tax. (*Book 2.109*)

Further on, Herodotus referred to the tax land payment if the agricultural lots suffered damages caused by a higher flood than the annual average of 16 or 17 cubits. Thus, the landowner would approach the pharaoh, who would send men to examine and measure the land damaged in order to pay a proportionate amount of the required tax:

And any man who was robbed by the river (Nile) of a part of his land would come to Sesostris and declare what had befallen him; then the king would send men to look into it and measure the space by which the land was diminished; so that thereafter it should pay in proportion to the tax originally imposed. (*Book 2.109*)

Not much is known about artificial irrigation during the late prehistoric period in Egypt. The earliest pictographic evidence of artificial irrigation in Egypt comes from the mace-head of the Scorpion Pharaoh, dated to ca. 3200 BCE, and discovered at Hierakonpolis. Hierakonpolis was one of the largest urban centers along the Nile. It was a lively city comprising many of the features that later came to typify the dynastic Egyptian civilization. The Pharaoh is depicted with a large wooden hoe in his hands and is ceremonially cutting an irrigation ditch (Fig. 24). Two other men with hoes in their hands appear to excavate or deepen the lower canal in the scene. This agrarian scene is very significant because it shows the transition from natural to artificially regulated irrigation in the late pre-Dynastic era in Egypt. By artificial irrigation, the ancient Egyptian could control the water ingress or egress from the flood basins by digging short canals and temporary cuts



Nilometer, Fig. 24 The Scorpion Pharaoh cutting an irrigation canal; from: Butzer, 1976, p. 21, Fig. 2

(or mud-brick gates), thus strengthening the natural riverbank by digging longitudinal dikes and subdivisions of natural basins by transverse dikes. The records of early canal digging suggest that the government supported artificial irrigation rather than an attempt to centralize the irrigation administration. During the 1st Intermediate Period (2255–2035 BCE), the irrigation systems of natural or artificial flood basins were organized at local levels. By the Middle Kingdom (2035–1668 BCE), the viziers were responsible by ordering canal digging nationwide. During the New Kingdom (1570–1070 BCE), irrigation management was a local issue. Actually, the government was interested in agriculture as a tax base, and it had little contribution to its direct organization and management.

The Egyptians learned to measure the height of the Nile at varied periods, especially during the flood cycles apex, by the device known as Nilometer. These devices and structures were built at several locations along the Nile from the 1st Cataract near Aswan to the Delta. The Nilometer built on the Elephantine Island near the 1st Cataract held a very important position

because at this site was the first output where the flood exerted. Other Nilometers were built at the temples of Philae, Edfu, Esna, Kom Ombo, and Dendera (Fig. 10).

In dynastic Egypt, the priests under the pharaoh also had administrative duties and science skills. They collected hydrological and astronomical data that were used to predict the floods that irrigated the arable lands, as well as being active in taxation. Therefore, the priests had a great influence on the pharaoh. The priests operated and controlled the Nilometers. They also built irrigation systems which made them important members in the Egyptian administration. By keeping systematic records of the Nile's flood levels throughout the centuries, the priests were able to calculate the harvests, and these accounts were used in levying taxes. Also, the priests were directly involved in organizing festivals during the flood seasons. One of the most important festivals was *Opet*. The *Opet* festival was celebrated in the second month of *Akhet*, the season of the flooding of the Nile, during the New Kingdom (1550–1070 BCE). In the celebration of *Opet*, the god Amun, his consort Mut and their son Khons, made a ritual journey from their shrine at Karnak to the temple of Luxor. The statues remained in the temple of Luxor for about 24 days, during which the city remained in festival. The statues and barks of the deities were placed on barges and floated on the Nile before returning back to the temple. The purpose of the festival on the Nile was the meeting between the god and the pharaoh to ensure a good flood needed for a prosperous harvest. Thus, the pharaoh ensured the fertility of the lands by communication with the gods. The most important Egyptian gods were Osiris and his son Horus (whose symbols was a falcon, the most sacred of all birds in ancient Egypt). These deities could merge one with another and also change roles, e.g., the sun-god Ra sometimes merged with Horus and became Horus-Ra, appearing as a human body and a falcon head, being crowned with a sun disk. Ra also could merge with Amun and become Amun-Ra, having a human body with a ram-head and crowned with a sun disk.

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miloko miraru (tens three). *Thanu* (5) and *nloko* (10) are the bases of the Makhwa system of numeration.

The most common bases in Africa are 10, 5, and 20. Some languages like Nyungwe (Mozambique) use only base ten. Others like Balante (Guinea Bissau) use 5 and 20 as bases. Verbal numeration in the Bété language of Côte d'Ivoire uses three bases: 5, 10, and 20. For instance, 56 is expressed as *golosso-ya-kogbo-gbeplo*, that is 20 times 2 plus 10 (and) 5 (and) 1:

	Number word	Structure
1	Blo	
2	Sô	
6	Gbeplo	5 + 1
20	Goloblo	20 × 1
40	Golosso	20 × 2
50	Golosso-ya-kogbo	20 × 2 + 10
56	Golosso-ya-kogbo-gbeplo	20 × 2 + 10 + 5 + 1

Number Theory in Africa

Paulus Gerdes

Through the ages the peoples in Africa south of the Sahara invented hundreds of numeration systems, both spoken systems and symbolic ones that use body parts or objects to count or to represent numbers.

Verbal Numeration

The most common way to avoid the invention of completely new number words as one counts bigger quantities has been to compose new number words out of existing ones by relying on the arithmetical relationships between the involved numbers.

For example, in the Makhwa language spoken in northern Mozambique, one says *thanu na moza* (five plus one) to express six. Seven becomes *thanu na pili* (five plus two). To express 20, one says *miloko mili*, tens two or 10 × 2. Thirty is

The Bambara of Mali and Guinea have a ten-twenty system. The word for twenty, *mugan*, means one person; the word for forty, *debé*, means mat, referring to a mat on which husband and wife sleep together, and jointly they have 40 digits.

The Bulanda of West Africa use six as a base: 7 is expressed as 6 + 1, 8 as 6 + 2, etc. The Adele (Togo) count koro (6), *koroke* (6 + 1 = 7), *nye* (8) and *nyeki* (8 + 1 = 9).

Among the Huku of Uganda the number words for 13, 14, and 15 may be formed by the addition of 1, 2, or 3–12. For instance, 13 is expressed as *bakumba igimo*, meaning 12 + 1. The decimal alternatives 10 + 3, 10 + 4 and 10 + 5 were also known.

A particular case of the use of addition to compose number words occurs in the situation where both numbers are equal, or one of the two is equal to the other plus one. For instance, among the Mbai one counts from 6 to 9 in the following way: *mutu muta* (3 + 3), *sa do muta* (4 + 3), *soso* (4 + 4), and *sa dio mi* (4 + 5). Among the Sango (northern Zaire), 7 is expressed as *-na na-thatu* (4 + 3), 8 as *mnana* (4 + 4) and 9 as *-sano na-na* (5 + 4).

In several African languages, besides the additive and multiplicative principles, subtraction has also been used in forming number words. For example, in the Yoruba language of Nigeria, 16 is expressed as *eerin din logun* meaning four until one arrives at twenty:

	Number word	Structure
16	Eerin din logun	4 until 20
17	Eeta din logun	3 until 20
18	Eegi din logun	2 until 20
19	Ookan din logun	1 until 20
20	Ogun	
21	Ookan le logun	1 + 20
34	Eerin le logban	4 + 30
35	Aarun din logoji	5 until 20×2

Another example of the use of the subtractive principle may be found among the Luba-Hemba of Zaire. Seven is expressed as *habulwa mwanda* (lacking one until eight), and nine is *habulwa likumi*, lacking one until ten.

That spoken numeration systems may vary greatly in relatively small geographic regions is shown by the example of Guinea Bissau. The Bijagó have a pure decimal system; the Balante use a five-twenty system; the Manjaco have a decimal system with exceptional composite number words as 6 + 1 for 7 and 8 + 1 for 9; and the Felup use a ten-twenty system in which the duplicative principle is also employed in forms like 7 as 4 + 3 and 8 as 4 + 4.

Sometimes some number words are adjectives, while others are substantives. Where this happens, number word structures may appear that do not correspond directly to an addition, multiplication or subtraction. For instance, in the Tshwa language (central Mozambique) 60 is expressed as *thlanu wa makumi ni ginwe*, five times ten plus one more (ten).

In those contexts where it was necessary to have number words for relatively large numbers, there often appear completely new number words or ones that express a relationship with the base of the numeration system. For instance, among the Bangongo of Zaïre one says *kama* (100), *lobombo* (1,000), *njuku* (10,000), *lukuli*

(100,000), and *losenene* (1,000,000). Among the Ziba (Tanzania) one says *tsikumi* for 100, *lukumi* for 1,000, and *kukumi* for 10,000. All three terms are clearly related to *kumi* (10). Only the prefixes change.

Gesture Numeration

Gesture counting was common among many African peoples. The Yao (Malawi, Mozambique) represent 1, 2, 3, and 4 by pointing with the thumb of their right hand at 1, 2, 3, or 4 extended fingers of their left hand. Five is indicated by making a fist with the left hand. Six, seven, eight, and nine are indicated by joining one, two, three, or four extended fingers of the right hand to the left fist. Ten is represented by raising the fingers of both hands and joining the hands. On the contrary, the Makonde, who are also in the North of Mozambique, start counting on their right hand with the help of the index finger of the left hand. Five is indicated by making a fist with the right hand. For six to nine, the representation is symmetrical to that of one to four, that is, right and left hands change roles. Now the index finger of the right hand points at the fingers of the other hand. Ten is represented by joining two fists.

The method of gesture counting adopted by the Shambaa (Tanzania, Kenya) uses the duplicative principle. They indicate six by extending the three outer fingers of each hand, spread out; seven by showing four on the right hand and three on the left, and eight by showing four on each hand.

To express numbers greater than ten the Sotho (Lesotho) employ different men to indicate the hundreds, tens and units. For example, to represent 368, the first person raises three fingers of the left hand to represent 300, the second one raises the thumb of the right hand to express six tens, and the third one raises three fingers of the right hand to express eight units. This is in fact a positional system, as it depends of the position of each man if he indicates units, tens, hundreds, thousands, etc.

Tally Devices

Many types of tally devices were used in Africa south of the Sahara. Two examples of widespread tallies are the following from Mozambique.

Among the Tswa, trees are used to record the age of children. After the birth of a child a cut is made on a trunk of a tree. Each year one adds a new cut until the person is old enough to count for him or herself. Tally sticks are used to control the number of animals in a herd. Each cut corresponds to one animal.

Among the Makonde, knotted strings were used. Suppose a man was going on an 11 day journey. He would tie 11 knots in a string and say to his wife, “This knot” (touching the first) “is today, when I am starting; tomorrow” (touching the second knot) “I shall be on the road, and I shall be walking the whole of second and third day, but here” (seizing the fifth knot) “I shall reach the end of the journey. I shall stay there the sixth day, and start for home on the seventh. Do not forget, wife, to undo a knot every day, and on the tenth you will have to cook food for me; for see, this is the 11th day when I shall come back.” Pregnant women used to tie a knot in a string at each full moon, to know when they were about to give birth. In order to register the age of a person, one uses two strings. A knot is tied in the first string at each full moon; once 1 has completed 12 knots, 1 ties a knot in a second string to mark the first year, etc.

Other Visual Numeration Systems

There are a variety of numeration systems in Africa that are written in one way or another.

The *koti zigi* game is played by the Gbundi and Mende in Liberia and in the western parts of Côte d’Ivoire. The players form standardized patterns of stones on the ground to represent numbers. One observes that 6 is expressed 3 + 3, 7 as 3 + 1 + 3, 8 as 4 + 4, 9 as 4 + 1 + 4, and 10 as 5 + 5 or 4 + 2 + 4 (see Table 1).

Number Theory in Africa, Table 1 The *koti zigi* game

•	•	•	•	•	••	•	••	•	••
	•	•	•	•	••	••	••	••	•
		•	•	•	••	••	••	••	••
			•	•		••	••	••	••
				•				••	•
									••
1	2	3	4	5	6	7	8	9	10

The Fulani or Fulbe, a seminomadic pastoral people of Niger and northern Nigeria, place sticks in front of their houses to indicate the number of cows or goats they possess. One hundred animals are represented by two short sticks placed on the ground in the form of a V. Two crossing sticks, ×, symbolize 50 animals. Four sticks in a vertical position, llll, represent four; two sticks in a horizontal and three in a vertical position, - - lll, indicate 23 animals. For example, the following was found in front of the house of a rich cattle owner:

V V V V V V V × ||

showing that he had 652 cows.

The Akan peoples (Côte d’Ivoire, Ghana, Togo) used money weights. That is to say, they used figurines in stone, metal or simply vegetable seeds as coins. The weight of a figurine was agreed to represent the monetary value that corresponded to a certain quantity of gold dust of the same weight. The figurines show animals, knots, stools, sandals, drums, etc. Figurines may also have diverse geometric forms such as step pyramids, stars, or cubes. Many display graphic signs representing numbers. Although in the languages spoken by the Akan peoples, like Anyi, Baoulé, Aboure, Attie, and Ebrie, only base ten is used, base five is also found on the money weights (Fig. 1):

5=5 6=5+1= 7=5+2= 8=5+3= 9=5+4= 10=

and

9=5+4=

1	i				
2	u	∩	∪		
3	W	∩	ε		
4	W	—	3		θ
5	W	卐	○		6
6	W	~~~~		⬡	6
7	W	▽	/		6c
8	W		X	⬡	6e
9	W	卐	\		6-
10	W	卐	+		
11	W		30ε	□	
12		~~~~			
13		~~~~			-6-
14		▽			
15		卐卐卐	⊠		
20		卐			

Number Theory in Africa, Fig. 1 Examples of numerals on Akan gold weights (See *Weights and Measures: Akan Gold Weights*)

The symmetric structure of one of the symbols for 11 and of one for 13 may be observed:

11 = 3+5+3 = 30ε
13 = 4+5+4 = -6-

Duplication may be observed in the transition from

6 = ~~~~

to

12 = 6+6 = ~~~~~

See Also

- [Mathematics](#)
- [Weights and Measures in Africa: Akan Gold Weights](#)

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Number Theory in India

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It is difficult to find “number theory” in its proper sense in Indian mathematics. What I am going to describe below is how the Indians have treated kinds of numbers.

In the Vedas (ca. 1200–800 BCE), the oldest Hindu literature, a number of numerical expressions occur. Their favorite numbers were three and seven as well as a hundred and a thousand. The largest number contained in their common list of names for powers of ten is 10¹² (called *parārdha*). Later (by the fourth century AD), those names came to be employed for denoting

Number Theory in India, Table 1 Classification of numbers according to the Jainas

numbers for counting	countable.....	lowest: 2 middle: 3,4, ..., $a-2$ highest: $a-1$
	uncountable	restrictively uncountable lowest: $a(= \aleph_0 ?)$ middle: $a+1, a+2, \dots, b-2$ highest: $b-1$
		properly uncountable lowest: $b=a^a$ middle: $b+1, b+2, \dots, c-2$ highest: $c-1$
		uncountably uncountable lowest: $c = (b^2)^{b^2}$ middle: $c+1, c+2, \dots, d-2$ highest: $d-1$
	infinite	restrictively infinite lowest: $d = c^c$ middle: $d+1, d+2, \dots, e-2$ highest: $e-1$
		properly infinite lowest: $e = d^d$ middle: $e+1, e+2, \dots, f-2$ highest: $f-1$
	infinitely infinite	lowest: $f = (e^2)^{e^2}$ middle: $f+1, f+2, \dots$ highest: does not exist

decimal places and became the nucleus of the Hindu list of decimal names (18 in number), while the Buddhists and the Jainas developed longer lists, which contained numbers as large as 10^{53} (*tallakṣaṇa*) or more.

The Jainas even speculated about different kinds of uncountable and infinite numbers (*Aṇuogaddārāṃ*, between the third and the fifth centuries AD). They divided the whole set of “numbers (*saṃkhyā*) concerning counting (*gaṇanā*)” into three subsets – (1) countable (*saṃkhyeya*), (2) uncountable (*asaṃkhyeya*), and (3) infinite (*ananta*) numbers – and further divided the last two sets into three each (Table 1).

The entire system of countable-uncountable-infinite depends upon the smallest number (a) of the “restrictively uncountable” set, which in turn is defined by means of white mustard seeds. The text is not very clear on this last point, but its intention was probably the same as what is meant by “the aleph zero” in modern mathematics, the smallest transfinite cardinal number.

Vedic stanzas also contain various series of numbers such as an integer series up to 200, an odd series (1, 3, 5, ...) up to 99 (accompanied by 100), an even series (2, 4, 6, ...) up to 100, and series made from multiples of 4, 5, 10, and 20, up to 100, etc.

The Vedas tell us that only the gods Indra and Viṣṇu could divide a thousand equally into three, but it is a matter of argument how they did it. Natural fractions (1/2, 1/4, 1/8, and 1/16) also occur in the Vedas.

The *Śulbasūtras* (ca. 600 BCE and later), compendia of geometric knowledge related to the construction of various altars for the Vedic ritual, clearly state the so-called Pythagorean theorem: “The diagonal rope of an oblong produces both [areas] which its side and length produce separately.” They explicitly mention several Pythagorean triples also: (3, 4, 5), (5, 12, 13), (8, 15, 17), (7, 24, 25), and (12, 35, 37). Moreover, they give an algorithm for calculating the diagonal d of a square whose side is a :

$$d = a + \frac{a}{3} + \frac{a}{3} \cdot \frac{1}{4} - \frac{a}{3} \cdot \frac{1}{4} \cdot \frac{1}{34}$$

and call this value “one that has a difference” (*saviśeṣa*), which probably means the difference between this approximate value and the true one ($\sqrt{2 \times a}$). The latter was called “one that makes [a square equivalent to] two [unit squares]” (*divikaraṇī*). There is, however, no indication that they recognized the incommensurability of the diagonal and the side. A root approximation formula of the same type is employed in the Bakhshālī Manuscript.

Later Indian mathematicians and astronomers, such as Varāhamihira (ca. AD 550) and Brahmagupta (AD 628), used the word *karaṇī* in the two contradictory (but mutually related) senses, the square root of a nonsquare number and the number whose square root should be obtained (or the square of any number), and easily performed the six arithmetical operations involving irrational numbers. Even the irrationality of *karaṇīs* may have been understood by Bhāskara of the seventh century, because he says, in his commentary on the *Āryabhaṭīya* (AD 629), “*Karaṇīs* have a size that cannot be stated exactly,” although whether he proved it or not is not known.

Varāhamihira recognized zero (*kha*, *śūnya*, etc.) as an object of the arithmetical operations. In the *Pañcasiddhāntikā* he added and subtracted zero in exactly the same way as he did in

other integers. Brahmagupta in the *Brāhmasphuṭa-siddhānta* gave a complete set of rules for the six arithmetical operations involving zero as well as negative and irrational numbers and referred to the quantity called “zero divisor,” $\frac{a}{0}$. Thus by the seventh century AD, the Indians acquired a very large domain of numbers including positive and negative integers (they accepted both the positive and the negative roots of a square number), fractions, irrational numbers (though no “proof” of “irrationality”), and zero, which enabled them to develop *bījagaṇita* (“seed mathematics”) or algebra, the theory of equations.

In his *Āryabhaṭīya* (AD 499), Āryabhaṭa provided a solution (called *kuṭṭaka* or the pulverizer) to the linear indeterminate equation: $n = ax + r = by + s$ or $y = (ax + c)/b$. He “pulverized” (i.e., reduced) the coefficients a and b by means of their mutual divisions (the so-called Euclidean algorithm) and found a set of solutions to the reduced form by trial and error. Mahāvīra (ca. AD 850) removed the trial and error by carrying out the mutual divisions until the remainder became one.

Brahmagupta treated indeterminate equations of the type $Px^2 + t = y^2$. He showed, among other things, that this equation (called *vargaprakṛti* or the “square nature”) can be solved for $t = 1$ if it is solved for $t = \pm 4, \pm 2$, or -1 . Jayadeva (the eleventh century or before) gave a rule for arriving at a solution for $t = \pm 4, \pm 2$, or -1 from any solution for any t . Bhāskara of the twelfth century called it the “cyclic” (*cakravālā*) method.

Several rules given by Mahāvīra in his *Gaṇitasārasaṃgraha* indicate that he recognized two roots of a quadratic equation with one unknown, but all of his examples for those rules have two positive roots. (He, however, admits the negative root of a square number when he gives his rules for the six arithmetical operations.) He was interested in the partition of numbers, and gave many rules for partitioning unity into the sum of unit fractions, a fraction into the sum of several fractions, etc. He also treated various mathematical progressions.

Śrīpati, perhaps for the first time in India, gave several rules for factorization in a chapter devoted to algebra in his astronomical work,

Siddhāntaśekhara (ca. AD 1040). This topic and the partition of numbers, mathematical progressions, combinatorics, and magic squares were highly developed by Nārāyaṇa in his *Gaṇitakaumudī* (AD 1356).

Bhāskara challenged various types of polynomial equations of the second and higher degrees (of special types) with the help of the “pulverizer” and the “square nature” in his work, *Bījagaṇita*, AD 1150. He compared the infinity and the invariability of the “zero divisor,” $\frac{a}{0}$, to those of god Viṣṇu and interpreted the negativeness of a quantity as the contrariness of direction. Jñānarāja in his *Bījagaṇita* and Gaṇeśa in his *Gaṇitamāñjarī* declared that the “zero divisor” is not “invariable” when fractions are added to, or subtracted from, it.

Mādhava (fl. AD 1400) and his successors obtained, for the first time in the world, a number of power series for the circumference of a circle, sine, cosine, arctangent, etc. One of the most eminent scholars in his school was Nīlakaṇṭha. A great mathematician and reformer of Indian astronomy, he explicitly stated the incommensurability of the diameter and the circumference of a circle in his commentary on the *Āryabhaṭīya* (ca. AD 1540). He also understood the notion of limit in treating infinite geometric series.

See Also

- [Algebra in India: Bījagaṇita](#)
- [Arithmetic in India: Pāṭīgaṇita](#)
- [Bakhshālī Manuscript](#)
- [Bhaskara I](#)
- [Brahmagupta](#)
- [Combinatorics in Indian Mathematics](#)
- [Geometry in India](#)
- [Jayadeva](#)
- [Mādhava of Saṅgamagrāma](#)
- [Mahāvīra](#)
- [Magic Squares in India](#)
- [Nārāyaṇa Paṇḍita](#)
- [Nīlakaṇṭha Somayājī](#)
- [Śrīpati](#)
- [Śulbasūtras](#)
- [Varāhamihira](#)

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Number Theory in Islamic Mathematics

Jacques Sesiano

Islamic number theory is characterized by two main developments, both of which stemmed from Greek knowledge. One of them is the relation between natural numbers and the sum of their proper divisors, the other the field of quadratic indeterminate equations.

Numbers and Their Sums of Divisors

If N is a natural number, $\sigma(N)$ the sum of its divisors, and $s(N)$ the sum of the divisors without N itself, then $\sigma(N) = s(N) + N \geq 1$. The Greeks

called N “abundant” if $s(N) > N$, “defective” if $s(N) < N$, and “perfect” if $s(N) = N$. Euclid had demonstrated that $N = 2^{m-1}(2^m - 1)$ is perfect if $2^m - 1$ is prime; we know today that it gives all even perfect numbers and possibly all perfect numbers. Thābit ibn Qurra (836–901) noticed that 2^{m-1} , p , m given and p prime, is defective or abundant depending on whether $p > 2^m - 1$ or $p < 2^m - 1$. In the same treatise, he provided for the first time a rule for finding a pair of “amicable” numbers, in which each number is equal to the sum of the proper divisors of the other: numbers N_1, N_2 such that $s(N_1) = N_2$ and $s(N_2) = N_1$. The Greeks knew of only one pair (220, 284). His rule, proved in true Euclidean manner, is: if $s = 3 \times 2^m - 1$, $t = 3 \times 2^{m-1} - 1$, $r = 9 \times 2^{2m-1} - 1$ ($m \neq 0, 1$) are prime, then $2^m \times s \times t$ and $2^m \times r$ are amicable numbers. The severe restrictions on N_1 and N_2 , however, limit the numerical application considerably.

Evidence of an apparently novel consideration appears in two incidental remarks made by al-Baghdādī (ca. 1,000) concerning the solubility of $s(N) = k$, k given natural. It is asserted that $s(N) = k$ has no solution N for $k = 2$ and for $k = 5$. It is indeed true that, among all odd k , only five cannot be a sum of (proper) divisors, and a simple rule used by al-Baghdādī for finding numbers N_1, N_2 such that $s(N_1) = s(N_2)$ may be used to verify it (under assumption, though, of the still unproved Goldbach conjecture). If k is even, we know today that, besides 2, there is an infinite number of exceptions.

Quadratic Indeterminate Equations

Two Greek sources inspired Islamic mathematicians. The principal one is Diophantus’s *Arithmetica*, of which 7 of the original 13 “books” (i.e., large chapters) were translated into Arabic. The other one is unknown to us today but was the origin of a set of indeterminate equations solved in Abū Kāmil’s *Algebra* by Diophantine methods. ► [Abū Kāmil](#) says that such problems were the subject of discussion in his time. A good introduction to Diophantine

methods occurs in al-Karajī's *Badī' fī'l-ḥisāb* (Wonderful on Calculation). The theoretical approach to the solution of finding a square which, increased or diminished by a given integer, produces a square in both cases, was treated in the tenth century by al-Khazīn; it later became the central subject of Leonardo Fibonacci's *Liber quadratorum*.

Other Indeterminate Equations

The above-mentioned indeterminate equations always require positive rational solutions. Linear indeterminate equations with positive integral solutions were the subject of a separate treatise by Abū Kāmil, who searched for all such solutions for six typical pairs of linear equations with three to five unknowns. Of note also are attempts to prove the impossibility of $x^3 + y^3 = z^3$ in the tenth century.

See Also

- [Abū Kāmil](#)
- [al-Karajī](#)

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Nyāya

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Nyāya is one of the major schools of orthodox Indian philosophy (ca. 450 to 1100 CE). It represents reasoning or logic, *nyāya*, into the ideals of *adhyātma* (treating of things elusive, such as *being* and the self) and *hetu* (reason, treating of things conventional and empirical) (Halbfass, 1992, p. 32). While the former inquiry is reminiscent of the medieval reconfiguration of Aristotelian metaphysics from Aquinas to Duns Scotus, Nyāya metaphysic does not easily fit this frame. Rather, the goal of inquiry is *niḥśreyasa* or the greatest good of wisdom and liberation from ignorance and suffering or *duḥkha*. Thus, this *prācīna* or “ancient” school of Brāhmaṇic thought is enlisted in the service of the erstwhile Vedic orthodoxy (*śruti*) to bolster defense against the “negative ontology” of a threatening Buddhist anti-realism. However, the Nyāya is better known for continuing a certain development of the realist thrust of a prior system known as Vaiśeṣika that is described as “physics” or “rigorous descriptive metaphysic” (Mukhopadhyaya, 1984 via Mohanty, 2001a, p. 209). In time it provided the nascent Brāhmaṇic philosophy with the needed natural-kind category of substance, a theory of universals, and the assumption of a well-structured universe of enduring and individually identifiable entities or particulars described as objectively as possible, albeit, with a parsimonious stringency, foreshadowing the positivist movement in science and (“natural”) philosophy closer to our era. This came to imply that we *can* have true knowledge of what there is *as is* (*astitva*). As such Nyāya embodies a metaphysic of thinking and doctrines on what is knowable and the proper means to their knowing – under a theory known widely in the Indian scientific tradition as *pramāṇa*. Both the Vaiśeṣika and the Nyāya begin their disquisition by enumerating the large number of *padārthas*

(literally, a “thing denoted by a word”) or epistemic categories which the correct application of *pramāṇas* will disclose as expanded *prameyas* or things so known. Unlike Kant’s categories of understanding as the analytic conditions for knowledge of things, the Vaiśeṣika-Nyāya categorical schema goes much beyond the reductive rational schema and captures substances, properties, universals, and episodic events in the real world.

Enumerating Vaiśeṣika

Let us begin with a discussion of the *padārthas*. The Vaiśeṣika had settled for seven positive categories as evidence of the independently existing reals taken to cover the entire sphere of knowable objects, visible and absent, including the subjective process of thought, emotions, and the unconscious (such as memory, imagination, and dreams). Although stated as ontological descriptors, they really underpin the epistemic fact of what these are expressively known as. These are substance (*dravya*, e.g., a banana), quality (*guṇa*, yellowness of its skin), motion (*karman*, its ripening, falling), universal (*sāmānya*, its fruity banana-ness), particularity (*viśeṣa*, this banana fruit in my hand), and the relation of inherence (*samavāya*, whole to its parts). Absence or *abhāva* is inducted later. Each category is further classified into subsets of different natural kinds (a class-defining property within a unique class), again epistemically laden, e.g., there are nine substances (that are marked by their unique respective *jāti* or universals), notably, earth (*pṛthivī*), water (*apa*), heat (*teja*), air (*vāyu*), space (*ākāśa*), time (*kāla*), place (*dik*), self (*ātma*), and mind (*manas*). Qualities (*guṇa*) comprise pain (*duḥkha*), desire (*icchā*), aversion (*dveṣa*), and pleasure (*sukha*). Why are there just nine substances? That is because of the commitment to *jātibādhaka*, “a reductive mechanism necessary to avoid excessive realism which posits universals for every general term” (Mukhopadhyaya, 1984).

Besides, all other entities can be subsumed and explained under this category, or rather admitted

under newly formed *concepts*, such as of a composite of natural kinds in an artifact that invites apprehension of a general property, e.g., potness (*ghatatva*) in respect of a wheel-turned pot. Motion or *karman* involves a cause-effect process, within strictures. For instance, even though something cannot come out of nothing, the effect is thought not to be preexistent in the originary or prior causal base (e.g., milk), which is radically different from, say, the curd or butter that is produced from it, as the causal process enlists various instrumentations and additional conditions or qualifiers (e.g., moisture, enzyme culture, ambient bacteria, churning, solidifying, and *kāma* or desire of the consumer): a transformation is more than a mere manifestation (Chakrabarti, 1995, pp. 318–323). In this descriptive ontology, substance, quality, and motion or effect-cause are coextensive; one and the same being (*sat*) may possess all three; and nothing is possible without these inhering in a substance of one sort or another. So “is-ness” which accounts for self-identity and individuation, along with the ability to designate (*abhidheyatva*) and to know (*jñeyatva*), is the common characteristic of the six categories or classes of reals (Prašastapāda via Sharma, 1995, pp. 138–155).

It was in the latter-day Vaiśeṣika school itself that an amendment to relations that existed among the apparently simple list of “things” was created, which made it clear that the ontology was of much greater complexity than anything known in the history at least of Brāhmaṇic thought (with the exception perhaps of Sāṃkhya). This was the clarification that a substance as a substratum was not to be understood as ever being devoid of quality (*guṇa*) – or, in more technical parlance, “property” (*qualia*) – as such or that quality could be absolutely nonexistent in that substratum. Nor is it possible to conceive of substanceless property: as though coldness could float about without its locus in a substratum as made possible by the substance water, whose property is to change its form in response to temperature and the environment. (The Mīmāṃsā championed the view of

substanceless property along with Buddhist idealist school of Cittamātra in their view of radically free mentalese qualias.) So even though the liquid we know and consume as water (*aquafina*) may change variously into fog, mist, clouds, moisture, vapor, steam, rain, flakes of snow, snowman, icicles and ice, and hosing missiles (against protestors), the substance *qua dharmin* (what chemistry identifies on our planet as H₂O and may bear a different chemical configuration on “twin earth”) has not changed one iota. And when substances are combined in complex dyadic and triadic helixes, with the properties (*dharmas*) and causal relations interlooping, one can imagine the complexity of the thing or object, or event, that results from this constellation. The curious element here is that the Nyāya would postulate this sort of complexity in respect of the *padārthas* also for *ātman* (self), *karman*, *Īśvara* (God-like Being), *aṇu* (atomic particles), *ākāśa* (space), and *viśva* (the cosmos), among other *vibhus* (pervasives).

The Nyāya Canon

The first systematic exposition of the Nyāya metaphysics occurs in the celebrated work of one Gautama (c. 200–450 CE), in his canonical *Nyāya-sūtras*. (Gautama’s date is given by Vidyābhusan as circa 553 BCE, but this may be way off the mark; Jacobi places the date of *Nyāyasūtra* between 200 CE and 450 CE, but then there is controversy as to whether this is not the date for the later redaction of the *śāstras* by one Akṣapāda. seven) and see Bijalwan (1977), Daya Krishna (1991, p. 133)). The etymological nuance of “*nyāya*” is derived from the exegetical hermeneutic of *reasoning with texts* (*naya*, via the hermeneut Mīmāṃsā) and artful practice of *ānvīkṣikī* (inquiry, wisdom, investigation, via the more ancient *Arthaśāstra* of Kauṭilya). With this *technē* grounded in logic, there is a decisive shift toward articulating the epistemic foundations for knowing, garnered by good debate and clinching arguments. This exercise of quasi-formal reasoning is aided by other technical discursive moves which came into

currency, namely, doubt, rules of discussion, criteria of coherence and noncontradiction, proofs, disproofs, basis of agreement and disagreement, cavil, sophistry, time and point of defeat, and treatment of the vanquished (*saṃśaya*, *vāda-vivāda*, *bādhā*, *pakṣa*, *pūrva-pakṣa*, *vitaṇḍa*, *jalpa*, *nigrahasthāna*, *samayabandha*). Thus “*nyāya*” becomes the formal structure and format of such argumentation and by refuting the adversaries, or demonstrating the superiority of its own paradigm for understanding and overcoming suffering (*duḥkha*), establishes its own or “*ortho-doxa*” (Daya Krishna, 1996, p. 81). This would also help check the excessively ritualized irrationalism – the midway ontology between realism and anti-realism – of the Mīmāṃsā (their shamelessly atheistic pretenses to be the self-elected guardians of the same orthodoxy notwithstanding). The Brahmanic tradition would thereby be better redeemed – in logic rather than in ritual metaphysic.

Now three moves occur in respect of these schemata when Gautama enters the scene. First, the *adhyātma* or theological quest is all but shunned. Second, Gautama shifts the metaphysical emphasis from the Vaiśeṣika framework of substance ontology to a more narrowly conceived epistemic taxonomy. Third, he reconfigures the catalog by expanding it to cover 16 *padārthas*, headed by *pramāṇas* or methods of knowledge. Only one of these is ontological, *prameya*, restricted object of knowledge, as the second *padārtha* in the constellation. Things that fall under the *prameya* set and its subsets are alone truthfully cognizable (*prameyatva*). Gautama reduces these to 12, namely, self (*ātma*), body (*śarīra*), sense organs (*indriya*), mind (*manas*), cognition (*buddhi*), sensoria (*artha*, like smelling), activity (*pravṛtti*), its outcome (*phala*), impurity (*doṣa*), pain (*duḥkha*), transmigration (*pretyabhāva*), and finally, release through *theoria* (*apavarga*) of the self from all these insufferable tropes. Again, for reasons of economy, the ontic-*prameya* class of reals is kept to the minimum. For instance, “darkness” need not be taken to be a separate entity because its presence can be explained in terms simply of the absence of light. Note however that nameability

and knowability do not necessarily make the “isness” (*esse*, or “essence”) of the object supervenient on the conscious minds, for things exist in their own right independently of being perceived: it is enough that they are perceivable (and nameable). Even after God enters the Nyāya’s possible worlds, the Berkeleian imperative of subsuming *esse* to *percipii* is here resisted to the end.

Modern Development

In more recent times, in the hands of a leading Indian philosopher, Bimal Matilal, a somewhat muted form of common sense realism – “direct realism” – both defends and qualifies the thesis of the inexorable independence of things from the perceiving mind. (Matilal (1935–1996) was a rare kind of thinker, a philosopher of sensibility who embodied east and west in balanced proportions and who demonstrated that Indian thought, even in its most metaphysical and soteriological concerns, was rigorously analytical and logical as well as discursive. His work has found broad endorsement and inspired lively debate not only among many contemporary Indian philosophers and Indologists but also in international philosophical circles.) It begins by suggesting that we do indeed see the objects we take ourselves to see, that those objects exist by having parts without being merely the sum of their parts, and that they fall into objective, natural categories. Thus, we see “redness” as a patch (substantial ground) and thence attach qualities of “hot,” “round,” and “pepperness” to it. Two ingredients in Matilal’s defense of this theory have a particular significance: the doctrine that perception is nonpartitive and an interpretation of the concept of objectivity. Nonpartitive indicates that we can see objects without seeing their parts (e.g., their front surfaces) or their class properties (e.g., color and shape). Further, the parts and properties of an object may well feature in the explanation of our coming to see it; but the thesis denies that the parts or properties of the object can enter into the explanation only if they themselves become entities of perceptual awareness. If this is correct,

Matilal points out, then the move typically made by the Buddhist phenomenologists that the “support” (*alambana*) for perceptual awareness must be unstructured and immediately given is blocked. This leads to what Matilal recognizes to be the infeasible challenge for the Nyāya realist: if phenomenal entities like sense-data have no explanatory role in perception, how do we account for such apparently purely phenomenal illusions as seeing the blue dome of the sky, a rainbow, or a circular disk as elliptical? Matilal’s solution introduced a new concept of objectivity. To be objective is to be independent of minds. Being “mind dependent,” however, need not mean being a private, intentional object in the way that sense-data and other purely phenomenal entities are. It can mean simply having a mental event as a causal condition, an event on whose continuing existence the object depends. Although illusory, the blueness of the sky and the ellipticity of the disk are objective at least in the sense that they are not purely private objects of sensation but are produced and shared by the perception of any observer located in the appropriate position. This is a softer realism than that to which skeptics (and at least some mystics) are committed, according to which objects can exist independently of anyone’s capacity to know they exist.

From Absence to the Ultimate

A category Gautama is conspicuously silent on but which becomes increasingly important in Nyāya epistemology is *abhāva*, “absence.” It comes in three forms: prior and post-nonexistence (before the food is made and after it has been eaten), unnilatable nonexistence (once born cannot be rendered *dhvaṃsita* or extinguished, e.g., the absentee gods), and atemporal nonexistence (the blue of the sky).

Notice here another line of controversy that arises between earlier and later-day Nyāya stalwarts. Vaiśeṣika began with a fixed number of *padārthas* (six, latter seven), whereas the *navya* (new-) Nyāya school (circa thirteenth century) came to advocate a theory of almost

undetermined number of *padārthas*. The economy of distinguishing “limit categories” from limitless concepts is blurred. As Mohanty rightly notes, “[T]here is no doubt something dissatisfying about making a list of categories open. It goes against our love for order, simplicity and system” (Mohanty, 2001, p. 212). (Mukhopadhyaya, whose reconstruction of the division between restricted categories (of which he admits only three) and the open-ended concepts Mohanty is questioning, nevertheless is confident that the controversy is settled by his own conceptual intervention in just this manner and further that his liberalization of concepts assures progress of knowledge and new epistemes and dimensions of experience (*Explorations* 212)).

Coming now to the end or goals of this ardent pursuit for knowledge of the reals, actual, possible, and their relative absences, paradoxically, at the end of the journey, even the strictly knowables have their downside – in that they vanish. Nevertheless, these constitute the “ultimates” or necessities of human knowledge; all else is of contingent value. Everything is determinable in their specific particularity, including the self (*ātman*), which is an object of positive inference (via recognition) based on desire, aversion, motivation (*prayatna*), pleasure, pain, and knowledge: not unlike the instance of the single glance at the dancing girl that evokes several aesthetic and other sorts of responses in the cultured mind (*Vārtika on Nyāya-sūtras*. 1.I.10).

Theoria and Nirvāṇa-Soft

Some remarks are apposite at this point. First, the *whole* is always greater in complexity and composite relations than the *sum* of its parts, such that the Buddhist alternative of partible aggregation, from simple to general and from *dharma*s to *nirvāṇa*, will just not do. Second, the objects of knowledge are subordinate to and supervene on correct cognition, deliverable by the *pramāṇas* and aided by logical illumination at every stage. However, there is an incremental recourse to *yogaja-pratyakṣa*, or “empirical mysticism,”

which provides the wherewithal through appropriate yoga culture, for quantum shifts toward grasping more elusive universals and universals undergirding generals, composite universals, and such higher-order universals in the hierarchy of omniscience that God might be entertaining on a good day or night. Third, there is the possibility of release from the pleasure and pain in a state of perfection or greatest good – *niḥśreyasa* – which results from reaching a state of *theoria*, which in Nyāya amounts to attaining comprehensive knowledge (*tattvajñāna*) of the *padārthas* in toto (or “what all there is to know”).

This is not tantamount to some-such transcendental state that is underscored in the more “spiritually” aligned philosophical systems – such as, in particular, *mokṣa*, or salvific liberation from embodied existence – although *niḥśreya* of the Nyāya will presumably inform the inquirer’s ethico-religious practices as well. It is this that is the veritable philosophic end or *theoria* and as such has no necessary connections with life-hereafter, in some remote *loka* (possible planetary world), or merger with the ultimate Being and so on (Mohanty, 1996, pp. 46–50; cf. Potter, 1995, pp. 29–59). It amounts to nothing more nor less than the destruction of all *mithyajñāna*, false understandings, as Gautama tells us (*Nyāya-sūtras*. I. i. 22): “Absolute freedom from the afore-said (pain, wrong knowledge, attachment, etc.).” The commentators dispute the view that in the final release, the self manifests happiness, being the untenable view of the Vedāntins. For a self that is still enmeshed in *saṃsāra* exudes happiness and so it would make no difference. No pleasures are transported across to the *niḥśreyas* state, not even the positive pleasures of life, desire-driven satisfaction, from luxuries of appetite to Donigerian *kāma-sezama*, or other such sensual-sexual pleasures (Halbfass, 2003, p. 156).

Thus, like the Buddha’s Third Noble Truth and more like the negative utilitarians’ liberative ethics, this embeds simply the minimization of pain and suffering, and the eventual elimination of all pains and pleasures, beginning with the exemplary individual (*stoic*) and universalizing this preference satisfaction for the entire human race. If not that of a semi-somnambulant

zombielike stupor, it is at least a godog's life – a joyless unending free-time verizone – and steeped in *svapnavastha suṣupti*, deep-sleep dreamy state minus the dreams, which in Freudian terms would amount to the sublimative fantasy or working out of unconscious desires, compulsive-obsessive traces, etc. (*Vārtikka* on *N.S.* 4.1.62). There is also a suggestion of the possibility of omniscience without self-consciousness – on a parity apparently with the natural light of divinity. Herein the self reposes in its disinterested or detachedly indifferent beingness, released from both the polarities of pain and pleasure (*Vārtikka* on *N.S.* I.i.22). More than knowledge of the self, it is an all-encompassing knowledge state. And there is no merging with the Other, no greater or smaller of which could be thought: all such assumptions are tantamount to the transcendental illusion (*viparītabhāvanā*) or, worse, transcendental reductionism. The end amounts to “release without transcendence”: perhaps “*Nirvāṇa*-lite” is after all merely the desire-cleansed imaginary of *saṃsāra*. And this is the Nyāya's alternative modal possibility of liberation to the Advaita Vedānta and Buddhist contingents.

And so this end-game of all quests is nothing like the unity of all categorical knowledge (as, say, in Kant's “kingdom of ends”), much less the “Thing-in-Itself” or the World-as-Will, nor merely *contemplative theoria* as in Aristotle, nor the nondual self-knowledge as in Śāṅkara's Advaita philosophy, or realizing the intrinsic Buddha nature of latter-day Buddhism. (Although Śāṅkara approbatingly cites Gautama from *N.S.* IV.ii.35 where this issue is discussed, under *Brahmasūtra* I.i.iv, because the Advaitin Adiguru also believes that in this state the self has no further contact with the mind, sense organs, *antaḥkaraṇa*, or inner unifying sense, much less with the world of objects outside. The difference between *apavarga* and *ātmataṭṭva* in Śāṅkara's ideology is that for the latter, there is knowledge of the self by the self, while in Nyāya there is no knowledge of it as it is not necessary. For other Vedāntins of course, this state of *mokṣa* is full of all kinds of knowledge, including *sarvajñāna* or omniscience (except at its very peak, since Brahman has no name and distinction from the self,

Brahman is not an object of knowledge, whatever kind of “knowingness” this might involve). Later Nyāya writers introduce *sarvajñāna* via *yogic pratyakṣa* (mystic perception) in one of its two types. On some problems with Śāṅkara's treatment of self, its knowledge, and *ānandas*, see two articles on Śāṅkara in the Matilal Memorial Volume I (*Bibliography*), Bilimoria 2003, pp. 252–277, and Julius Lipner, “Śāṅkara on *Satyam*, *Jñānam* *Anantam* *Brahma*” (pp. 301–335)). It is as though the diaphanous self reaches a near-death moment, detached from the body and the mind, but not (yet) dying or euthanized, because that which is external and *nitya* (atemporal) cannot be extinguished. In the end it may be said that the feared anti-realist apparition of the Buddha (or more like Nāgārjuna and Vāsubandhu's) did manage to make a dent in the parsimonious realist ontology of the Vaiśeṣika and its rescue operation in the epistemologically driven anti-theological poundings of the Nyāya “analytical” philosophy, despite itself.

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Obelisks in Ancient Egypt

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Among the characteristic monumental forms employed by the Egyptians – pyramids, sphinxes, etc. – the obelisk seems to have enjoyed the richest and most distinctive “afterlife.” Over the two millennia of their original production, Egyptian obelisks varied in size from relatively small funerary stones to the slender, towering monoliths of red Aswan granite that were erected before and within the precincts of the greatest Egyptian temples. Obelisks were dedicated in most cases to the solar gods of Egypt, and their soaring height and tapering shape – capped by a pyramidal (and originally gilded) pinnacle called a *pyramidion* – seemed to reach from the earth into the heavens and touch the rays of the life-giving sun. For centuries to come, these great stones have challenged the imaginations of spectators: Greek and Roman, Christian and Muslim, Renaissance, and Modern – who were awed by their soaring height, titanic weight, and paradoxically slender and tapering shape. They were endowed with an aura of sanctity and power through their association with the gods and rulers of a civilization that was already viewed as almost unimaginably ancient by the Greeks and Romans. This aura was embodied for many by the hieroglyphic carvings that covered their four faces,

which were believed from classical times to the age of Napoleon to encode, in veils of allegory and enigma, the most secret doctrines of Egyptian religion and science (Curran, 2007; Curran, Grafton, Long, & Weiss, 2009; Iversen, 1961).

In the classic formula of the New Kingdom, best represented until the 1830s at the Temple of Amun-Ra in Luxor, a pair of obelisks was erected before the sanctuary’s main entrance pylon. These pylons were conceived as sacred “horizons” that marked the passage from the realm of mortals to the kingdom of the gods. In this context, the obelisks literally rose to “pierce” the sky and commune with the deities of the rising and setting sun, just as the ceiling of the temples’ colonnaded halls supported ceilings carved with the stars and constellations of the heavens (see Bell, 1997, pp. 133–134). But the biggest obelisk ever erected – the 32.15 m (105.5 ft), 455–510 t obelisk of Thutmose III (1479–1424 BCE) – was set up as a single monument at the Great Temple of Amun-Ra in Karnak. This towering monolith of red granite was quarried – like all the major Egyptian obelisks – at Aswan in Upper Egypt. Still incomplete at Thutmose III’s death, the obelisk was completed (with additional inscriptions) and erected some 35 years later by the king’s grandson, Thutmose IV (1400–1390 BCE). For nearly two millennia, the great obelisk stood alone as an object of special veneration at Karnak, until it was torn from its base by order of Emperor Constantine (306–337 BCE) and, after a series of delays, transported to Rome



Obelisks in Ancient Egypt, Fig. 1 Lateran obelisk of Thutmose III and IV, Rome

by his successor, Constantius II (337–361 BCE), in 357 BCE. Upon arrival, it was raised on the *spina* or median strip of the Circus Maximus, next to a very large (but smaller) obelisk erected more than three centuries earlier by Augustus (see below). In 1587–1588, the obelisk was located and excavated from the ruins of the Circus by order of Pope Sixtus V, who initiated the second great phase of obelisk installations in Rome. The obelisk was moved to the Piazza of San Giovanni in Laterano, and its broken pieces were set in place by a great “obelisk machine” devised by Domenico Fontana (for its present location, see Fig. 1). In 2006, the obelisk was again surrounded by scaffolding, erected to preserve and restore the monument from the ravages of traffic, pollution, and a terrorist bomb (for the history of the Lateran obelisk, see Curran et al., 2009, pp. 22–23, 136–137; D’Onofrio, 1992, pp. 243–259; Habachi, 1984, pp. 112–117; Iversen, 1968–1972, Vol. 1, pp. 55–64; Sorek, 2010, pp. 101–106).



Obelisks in Ancient Egypt, Fig. 2 Alexandria/Central Park obelisk of Thutmose III, New York City

History

As the story of this largest of all Egyptian obelisks amply illustrates, these monuments attracted the envious and acquisitive eyes of self-styled successors of the pharaohs from the time of the Ptolemies and Roman emperors to relatively modern times. As a consequence, a large number of them have been yanked from their original locations in Egypt and transported at great expense (and with great fanfare) to provide ornaments for the capital cities of the Roman and later empires. Rome received the bulk of them, to the extent that some 48 of them were visible in the city by the middle of the fourth century BCE. Thirteen of these can be seen in the city today, thanks to the efforts of generations of popes and other patrons who sought to associate themselves with the majesty of the pharaohs and emperors who originally made or appropriated them. Still others may be admired in Istanbul, Paris, London, and New York (Fig. 2), where they testify to the enduring attraction of the

obelisk's pharaonic and imperial legacy. In addition to their symbolic power, the obelisks also posed, at virtually all stages of their history, a daunting challenge to the skill and ingenuity of the engineers and builders who sought to move and reerect them. In a very real sense, the story of the obelisks may be understood, at least partially, as a history in microcosm of engineering and transportation technology in the Mediterranean world (on this point, see Carugo, 1978; Curran et al., 2009; Dibner, 1950/1970; Engelbach, 1922, 1923; Fontana, 1978; Parker, 2007; Parsons, 1939/1968, pp. 155–173).

The modern name obelisk derives from the Greek *obeliskos*, a diminutive that means “little spit.” It is from this perhaps deliberately ironic term that the Romans derived the Latin *obeliscus*. Among the Ancient Egyptians, these monuments were called *tekhen* – plural *tekhenu* – which derives from a verb meaning pierce (Iversen, 2006, “Obelisk,” Grove Art website). The precise meaning of their distinctive shape is also uncertain, although the Roman author Pliny the Elder's report that “an obelisk is a symbolic representation of the sun's rays, and this is the meaning of the Egyptian word for it” may have much to recommend it (Pliny, *NH* 36.14.64). Most scholars associate the obelisk's origin with the ancient solar cult at Heliopolis, and it seems like its prototype was a much older type of stone monument known as the *ben* or *benben*. These cultic stones, which apparently took a pyramidal form, were dedicated to the sun gods Atum and Re or Re-Harakhti in the sanctuary at Heliopolis. The Egyptians believed that the *benben* originated at the beginning of time, when it provided the seat for the Atum's creation of the universe. The *benben* was also associated with the sacred phoenix or Benu-bird, whose cycle of self-creation and resurrection was associated with the cults of the dead and the rising and setting of the sun (Curran et al., 2009, pp. 13–33; Habachi, 1984, pp. 3–6; Iversen, 1968–1972, Vol. 1, pp. 11–15).

Both archaeological and inscriptional evidences make it clear that obelisks of various types were being erected by the rulers of Egypt during the later dynasties of the Old Kingdom

(2686–2160 BCE). Among these, perhaps the most notable was a pair of obelisks transported on large ships from southern Egypt to Heliopolis by the sixth dynasty Pharaoh Pepi II (2278–2184 BCE – Habachi, 1984, pp. 40–41). During the preceding fifth dynasty (2494–2345 BCE), a series of solar temples with obelisk-like centerpieces were erected near the pharaonic cemetery at Abu Sir. These “obelisks” were fashioned not from single blocks of stone, but from masonry blocks and sheathed with fine white limestone in the manner of the pyramid tombs of the time. During the same period, diminutive obelisk-shaped stones began to be erected in pairs at the entrances to tombs. These were generally installed facing east, presumably to present themselves to the rays of the rising sun, which represented the resurrection of the deceased in Egyptian belief. These early funerary obelisks were usually fashioned from limestone and were inscribed on one side with the name of the deceased (Habachi, 1984, pp. 41–46; Kuentz, 1932).

The earliest surviving large-scale, monolithic obelisk was erected by the 12th dynasty Pharaoh Senusret I (1850–1837 BCE) in the sacred city of Heliopolis on the occasion of his Jubilee year. This was originally one of the pairs that was carved from the durable mottled-red granite (or *syenite*) from Aswan in Upper Egypt, where later obelisks of this size were also quarried. They were shipped up the Nile and erected before a new or rebuilt temple dedicated to the sun god Re-Harakhti. The Heliopolis obelisk, like all succeeding obelisks of the “classical” type, is a four-sided monolith, carved from a single piece of Aswan granite. It stands some 67 ft (20.4 m) high on a squared base and weighs some 120 t (Habachi, 1984, pp. 46–50; Sorek, 2010, pp. 137–138).

Since no other obelisks datable to the Middle Kingdom have survived, the true successors of Senusret's monuments are the ones produced by the New Kingdom rulers of the 18th and 19th dynasties (1550–1186 BCE). This great series of obelisks begins with a pair dedicated to Amun-Ra at Karnak by the 18th dynasty Pharaoh Thutmose I (1504–1492 BCE). One of these, which rises



Obelisks in Ancient Egypt, Fig. 3 Obelisk of Thutmose I, Karnak



Obelisks in Ancient Egypt, Fig. 4 Obelisk of Hatshepsut, Karnak

nearly 66 ft (20,016 m) high and weighs an estimated 143 t, still stands on its original pedestal in the temple precinct (Fig. 3), while the other survives only in fragments. Thutmose I was succeeded after the short reign of his son (Thutmose II) by that king's "royal wife" (and half sister) Hatshepsut (1473–1458 BCE). Hatshepsut erected no less than four large obelisks at Karnak, in two pairs. Of these, only one still stands intact today (Fig. 4). This great obelisk, which rises to a height 96.78 ft/29.5 m and weighs some 323 t, is one of the pairs set up here on the occasion of her Jubilee. The lower part of its companion stands nearby on its original base, and some fragments can also be seen on site and in various museums. Of the second pair that Hatshepsut erected at the beginning of her reign in the eastern section of the temple, only fragments survive today. But a visual record of their transport is preserved in the relief decoration in the Queen's funerary temple at Deir el-Bahari. Here, the obelisks are shown loaded end to end on a large ship pulled by three rows of boats for their

journey "down" the Nile from Aswan to Thebes (Curran et al., 2009, pp. 20–21; Habachi, 1984, pp. 56–72).

Hatshepsut's successor Thutmose III (1479–1425) was responsible for the production of at least nine obelisks, including seven erected at Karnak and two at Heliopolis. Of these, only the Lateran colossus (see above), the Heliopolitan pair – which was transferred to Alexandria in Augustan times and is now in London and New York City (for the latter, see Fig. 2) – and the Hippodrome obelisk in Istanbul – which stood before the seventh pylon at Karnak until it was removed by Constantine and raised in Constantinople by Emperor Theodosius (379–395 BCE) – survive today (Curran et al., 2009, pp. 21–23; Habachi, 1984, pp. 72–77). During the 19th or Ramesside dynasty, the Pharaohs Seti I (1294–1279 BCE) and Rameses II (1279–1213 BCE) erected obelisks in a number of locations, including Luxor, Heliopolis, and Piramesse. One celebrated survivor is the so-called Flaminian obelisk



Obelisks in Ancient Egypt, Fig. 5 Flaminian obelisk of Seti I and Rameses II, Piazza del Popolo, Rome



Obelisks in Ancient Egypt, Fig. 6 Solarium obelisk of Psamtek II, Piazza di Montecitorio, Rome

(ca. 75 ft/22.84 m, 263 t), which was quarried by order of Seti I and completed and erected in Heliopolis by Rameses II. It was transported to Rome and set up in the Circus Maximus by Augustus and reerected in the Piazza del Popolo by Pope Sixtus V in the late sixteenth century (Fig. 5, and see more below).

During later dynasties, obelisks continued to be made, sometimes out of different types of stone and in some cases on a smaller scale. The largest surviving specimen from the later periods is the so-called Montecitorio obelisk (21.79 m, 230 t in its present, reconstructed form), which was one of the pairs raised by the 26th dynasty Pharaoh Psamtek II (664–610 BCE) at Heliopolis and also later taken to Rome (see Fig. 6). The last surviving obelisks commissioned by a native Egyptian pharaoh were a much small pair carved from hard black schist for Nectanebo II (360–343 BCE) of the 30th dynasty. They were dedicated to the Egyptian god Thoth and presumably set up at that god's temple in the city of Hermopolis. At the end of the Napoleonic campaign in Egypt,

two fragments of these obelisks were turned over to British forces by the French and sent to the British Museum, where they may be seen today. A third fragment is in Cairo (Habachi, 1984, pp. 101–103; Iversen, 1968–1972, Vol. 2, pp. 51–61).

During the rule of the Macedonian Ptolemaic dynasty (332–30 BCE), temples and monuments continued to be produced in the traditional Egyptian mode. Among the embellishments for these was the pair of smallish obelisks erected at the Temple of Isis in Philae by Ptolemy IX (107–80 BCE). One of these obelisks (22 ft/6.7 m tall, 6 t) was discovered in 1815 by the British nobleman and scholar William John Bankes (1786–1855). In 1819, Bankes discovered the lower part of its mate and hired the famous Italian strongman turned explorer-excavator, Giovanni Belzoni, to help remove the obelisks and their bases (inscribed in Greek) to his Kingston Lacy estate in Dorset, England. In 1839, Bankes erected the intact obelisk on its pedestal in the garden of the estate. Its hieroglyphic inscriptions and the Greek

Obelisks in Ancient Egypt, Fig. 7 Unfinished obelisk, Aswan



ones on its base were among the key documents in the decipherment of the Egyptian hieroglyphic script by Egyptologist Jean-François Champollion (1790–1832) in 1822 (Curran et al., 2009, pp. 32–33; Habachi, 1984, pp. 105–108; Iversen, 1968–1972, Vol. 2, pp. 62–85).

Manufacture and Installation

The methods the Egyptians used for the manufacture, transport, and erection of obelisks are not fully understood (for what follows, see Arnold, 1991, pp. 36–40, 47–52, 57–73; Curran et al., 2009, pp. 23–32; Engelbach, 1922, 1923; Habachi, 1984, pp. 15–37; Klemm and Klemm, 2008, pp. 233–267; Sorek, 2010, pp. 17–27). Most of the evidence we have comes from the study of extant monuments, investigation into Egyptian building and stone-cutting techniques, and a few visual representations that survive from pharaonic times. But the richest source of information has come from the archaeological study of a large unfinished obelisk, believed to be of Thutmosid (New Kingdom) date, that still lies in one of the granite quarries at Aswan (Fig. 7). This obelisk, which was originally laid out at a height of 41.75 m (ca. 137 ft), would have weighed about 1,168 t if extracted. It was abandoned – after

an attempt to reduce its length – when it developed irreparable cracks in its upper section. Excavation of the monument by Engelbach in 1921–1922 revealed that the ancient workmen began by cutting test shafts into the rock. Then, after laying out the obelisk’s shape on the surface, they began removing the upper layer of uneven stone to expose a suitable piece for excavation. Then came the arduous task of digging trenches on all four sides to provide work areas for the quarrymen to form and separate the block (see Fig. 8). From the evidence of surface marks and tools found on the site, it seems clear that this work was done with ball-shaped tools of ultra-hard dolerite stone (Fig. 9). When the trenches reached the required depth, the workers had to undercut the shaft to extract the obelisk from the bedrock. Then the obelisk had to be pulled or lifted from the quarry bed, smoothed and polished on site (in at least one case, parts of the hieroglyphic inscription were added at this phase), and prepared for transport. At all stages of work, including the carving of hieroglyphic inscriptions, the work was done with stone tools and abrasives like emery, since the copper and bronze tools of the time were not strong enough to cut the hard granite.

Visitors to the site may be surprised to discover that the unfinished obelisk was carved at



Obelisks in Ancient Egypt, Fig. 8 Trench of unfinished obelisk, Aswan



Obelisks in Ancient Egypt, Fig. 9 Dolerite hand-tool, Aswan

a considerable angle longwise, with the pyramidion at the highest point on the east side and the bottom much lower on the west. By removing the deposit of granite at the opposite (bottom) end, it seems that the workers could have pulled the great stone out of the quarry with the help of its own massive weight. But

Engelbach has argued that the failure to remove the rock from the west end, coupled with the removal of stone from the area of the pyramidion on the east side, suggests that the workers planned to lift the obelisk from the bed with the help of large wooden levers and remove it from the front end of the trench (Engelbach, 1923: pp. 41–51).

Once the obelisk had been removed, the workmen loaded it onto a large sledge, which was pulled by a team of laborers on a track or ramp to the riverbank for transfer to a specially constructed transport ship. Upon arrival, it was rolled off and dragged in the same manner to the site where it was to be erected. At this stage, the builders faced the difficult (and potentially dangerous) task of raising the monument to an upright position on its pedestal block. Direct evidence for how this was done does not survive, but a number of plausible hypotheses have been put forward. We know that Egyptian builders used three main methods for raising large stones – levering, pulling with ropes, or drawing them up a ramp-like incline. It was the opinion of Engelbach that the workers dragged the monument bottom end first up a ramp-like incline to a point some height above the base, after which it was pulled upright by ropes and lowered onto the pedestal, where it was positioned by levers and the gradual removal of sand. A version of this method was represented in suitably dramatic terms in the 1956 film, *The Ten Commandments*. A series of attempts to duplicate this method with a modern obelisk finally succeeded in 1999 (see Handshouse Studio, 1999; Nova Online: Mysteries of the Nile, <http://www.pbs.org/wgbh/nova/egypt/raising/>).

Rome and the First Afterlife of the Obelisks

Obelisks continued to be erected, moved, and, in a few cases, manufactured anew during the Roman era, which followed the defeat of Cleopatra VII (51–30 BCE) and her ally Marc Antony by Octavian, who became known as Emperor Augustus in 28–27 BCE. Egypt became

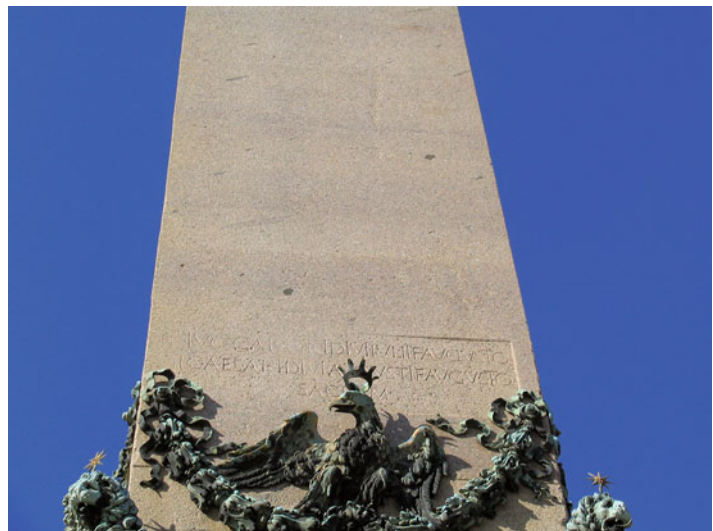
a province of the Roman Empire, and the granite quarries at Aswan came under Roman control, providing a rich supply of monolithic columns and other products for the great building projects of Rome and its empire. The first prefect of Egypt



Obelisks in Ancient Egypt, Fig. 10 Vatican obelisk, Rome

under Augustus, Cornelius Gallus (30–26 BCE), was responsible for laying out a new forum complex, called the *Forum Julium*, at a site near the Ptolemaic capital of Alexandria. As an ornament to this space, Gallus ordered the erection of the so-called Vatican obelisk – the big, 331 t, 83 ft (25.31 m) colossus that now stands in the Piazza di San Pietro in Rome (Fig. 10). Since it lacks a hieroglyphic inscription, it is not known when or by whom this most celebrated of obelisks was originally quarried. Pliny the Elder reports that it had been originally raised in Egypt by the Pharaoh “Nencoreus, the son of Sesostris,” but it has been persuasively argued (Alföldy, 1990) that it was originally quarried by Cleopatra VII as a monument to Julius Caesar and appropriated by Gallus, who added an inscription in bronze letters to the lower end of the shaft that essentially dedicated the obelisk to himself. The letters were removed after Gallus was forced out of office on charges of corruption and took his own life to avoid prosecution (the fastening holes for the inscription were discovered during analysis of the obelisk’s surface in 1959). Sometime after this, presumably during the reign of Emperor Tiberius (14–37 BCE), a second inscription, now eroded but still visible, was carved on the lower east and west faces of the monument (Fig. 11) which rededicated the monument to Augustus, “son of the divine Julius,” and to

Obelisks in Ancient Egypt, Fig. 11 Latin inscription, Vatican obelisk, Rome



Tiberius himself (for the Vatican obelisk, see Alföldy, 1990; Curran et al., 2009, pp. 44–46; D’Onofrio, 1992, pp. 97–185; Iversen, 1968–1972, Vol. 1, pp. 19–21; Sorek, 2010, pp. 60–69).

In 13–12 BCE, Augustus ordered a pair of obelisks originally raised by Thutmose III (with later inscriptions of Rameses II) in Heliopolis to be transferred to Alexandria, where they were set up – facing the sea – before the so-called Caesareum, a complex dedicated to the cult of Julius Caesar. These had apparently been begun as a mausoleum for Marc Antony toward the end of Cleopatra VII’s reign. The obelisks were set on their bases with their corners bronze, crab-shaped astragals – one of which, now in the Metropolitan Museum in New York – was inscribed in both Greek and Latin to commemorate its dedication by Publius Rubius Barbarus, prefect of Egypt. In the later nineteenth century, these obelisks, one of which had fallen but remained intact, were presented as “gifts” from the Egyptian authorities to the British and American governments and transported to London and New York City (Fig. 2), respectively (Curran et al., 2009, pp. 257–281; D’Alton, 1993; Gorringe, 1882; Habachi, 1984, pp. 165–182; Iversen, 1968–1972, Vol. 2, pp. 90–147).

In 10 BCE, 20 years after the defeat of Antony and Cleopatra, Augustus ordered the transport of two large obelisks from Heliopolis. By this time, according to contemporary reports, this great Egyptian city had fallen on bad times, and its marvelous temple had fallen into disrepair. The first, originally carved by order of Rameses II and his father Seti I (and now in the Piazza del Popolo; see Fig. 5), was erected on the *spina* of the Circus Maximus (see D’Onofrio, 1992, pp. 260–266; Iversen, 1968–1972, Vol. 1, pp. 64–75). The second, the aforementioned obelisk of Psammetichus II (now in the Piazza di Montecitorio; see Fig. 6), became the *gnomon* of a gigantic sundial in the Campus Martius (Curran et al., 2009, pp. 36–42; D’Onofrio, 1992, pp. 369–421; Iversen, 1968–1972, Vol. 1, pp. 142–160; Sorek, 2010, pp. 45–56). Both were capped by gilt-bronze spheres with obelisk-shaped pointers and

provided with identical inscriptions on their red granite bases:

IMP. CAESAR. DIVI. FIL. AVGVSTVS. PONTI-
FEX. MAXIMUS. IMP. XII. COS. XI. TRIB.
POT. XIV. AEGVPTO. IN. POTESTAM.
POPVLI ROMANI. REDACTA. SOLI. DONVM.
DEDIT.

When Emperor for the twelfth, consul for the eleventh, and tribune of the people for the fourteenth time, Emperor Augustus, son of the divine Caesar, dedicated this obelisk to the sun when Egypt had been brought under the sway of the Roman People. (Iversen, 1968–1972, Vol. 1, pp. 65, 142)

As the inscription makes clear, Augustus’ obelisks were intended to commemorate his conquest of Egypt. In both cases, the new installations corresponded to the original Egyptian dedication of these monuments to the sun, but gave this theme a new and distinctly Roman spin. In the case of the Circus Maximus, which was traditionally associated with the solar cult, the obelisk took its place on the *spina* or median strip as an embodiment of the sun’s power, while the chariots that raced around it came to be considered symbols of the planets moving around it. In the Campus Martius, the Psamtek obelisk was put to use as a solar instrument, as described by Pliny the Elder (1938–1963) (*Natural History*, Ed. Rackham and Eichholz, 10:55–57).

The one in the Campus Martius was put to use in a remarkable way by Augustus of Revered Memory so as to mark the sun’s shadow and thereby the lengths of days and nights. A pavement was laid down for a distance appropriate to the height of the obelisk so that the shadow cast at noon on the shortest day of the year might exactly coincide with it. Bronze rods let into the pavement were meant to measure the shadow day by day as it gradually became shorter and then lengthened again. This device deserves to be carefully studied and was contrived by the mathematician Novius Facundus. He placed on the pinnacle a gilt ball, at the top of which the shadow would be concentrated, for otherwise the shadow cast by the tip of the obelisk would have lacked definition (Pliny, *NH* 36.14.69–72).

It is unclear from Pliny’s description whether this device was designed as a *solarium* (which

measured the daily length of the sun's shadow on a meridian) or a *horologium* (a more elaborate device capable of measuring the length of the hours of the day), but his admiration for the device was undiminished by his observation that "the readings thus given have for about 30 years past failed to correspond to the calendar." During the fifteenth and sixteenth centuries, pavements with "lines of gilt metal" and mosaics representing the winds were thought to be remains of the device described by Pliny (Iversen, 1968–1972, Vol. 1, pp. 144–149). In 1979–1981, a section of travertine pavement, with a meridian strip with Greek inscriptions in bronze letters (denoting signs of the zodiac and the Etesian winds), was discovered in the area immediately north of the obelisk, confirming the basic veracity of Pliny's account, although problems of interpretation and function remain (Buchner, 1982; Schütz-Tübingen, 1990). As for the obelisk itself, it was still standing in the eighth century but was thrown down and broken at some later date and discovered (and reburied) in about 1512. It was finally excavated in 1748 and, after several abortive attempts, repaired (with fragments of a large granite column) and reerected in the Piazza di Montecitorio in 1789 by order of Pope Pius VI. It was intended to lay a modern meridian to track the obelisk's shadow at this time, but the idea was not realized until 1998, when the pavement was restored to designs by the architect Franco Zagari (see Zagari, <http://www.francozagari.it/HOME/Piazza%20Montecitorio/montecitorio.htm>).

But impressive as these installations undoubtedly were, it was the feat of transporting them across the Mediterranean to Rome that impressed Roman commentators on the subject. Pliny reports that the ship that was specially constructed to carry Augustus' obelisks to Rome was considered such a wonder in its own right that it was placed on display in a "permanent dock" at Puteolis (modern Pozzuoli) to commemorate the achievement – although it was later destroyed by fire. He adds that the ship used by Gaius (Caligula) to move the third (Vatican) obelisk to Rome was likewise preserved until it was filled with concrete and sunk as part of the

Claudian harbor works at Ostia. Excavations in 1957–1960 near Rome's Fiumicino airport near Rome Ostia in 1957–1960 uncovered the concrete core of the Vatican obelisk ship, which preserved a partial "impression" of the vessel that once had borne it. From a reexamination of this and other evidences from Egyptian and Roman sources, Wirsching (2000) has proposed reconstructions of both Egyptian and Roman obelisks and column-carrying ships and has concluded that both riverine and seagoing vessels used a ballasted double hull to control the level of the ship for loading and unloading the monoliths (see also Curran et al., 2009, pp. 29–30, 42; Sorek, 2010, pp. 17–22).

When it came a time to transport and raise the obelisks on land, the Romans were able to use a variety of techniques that had not been available to the Egyptians, including iron tools and heavy lifting cranes employing ropes and pulleys. The most extensive description of the Roman procedure is provided by the fourth-century historian Ammianus Marcellinus, in his account of the transport and erection of the Lateran obelisk (Fig. 1) in the Circus Maximus under Constantius II in 359. He reports that upon its arrival in Italy, the obelisk was put on a *chamulcus* (a kind of sled or cradle) and "carefully drawn" through the Ostian gate to the Circus Maximus, where it was raised using a device resembling a "veritable grove" of beams and derricks and powered by an army of men turning wheels "that resembled millstones" (Ammianus, 17.4.14–15; Ammianus, Rolfe, 1950–1952, 1:325–327). The great stone was gradually raised and lowered on its base on the *spina* of the circus, where it joined (and to a certain extent upstaged) the obelisk erected by Augustus over three and a half centuries earlier. Ammianus' description of the Roman "obelisk-raising" machine corresponds in general terms to the equipment depicted on the base of the Hippodrome obelisk in Constantinople, erected by Theodosius I, 379–395 (Bruns & Krauss, 1935, pp. 47–53; Iversen, 1968–1972, Vol. 2, pp. 15–16; Killerich, 1998, pp. 69–72). It is also the same basic method that was successfully employed by Domenico Fontana to move the Vatican obelisk in 1586 (see below).



Obelisks in Ancient Egypt, Fig. 12 San Macuto obelisk of Rameses II, Piazza della Rotonda, Rome

As the story above illustrates, later Roman emperors emulated Augustus' taste for transporting obelisks. The next to be moved to Rome after Augustus (that we know of) was the one in the *Forum Julium* at Alexandria, which was shipped to Rome and raised on the spina of the Vatican Circus by order of Gaius Caligula (37–41 BCE; see more below). These were followed by some 45 others in the three and a half centuries that followed. Among them were at least six small obelisks of 19th and 26th dynasty vintage that were installed (at an unknown date) in the Roman sanctuary of Isis in the Campus Martius: the Iseum Campense (Iversen, 1968–1972, Vol. 1, pp. 93–114, 174–177; Lembke, 1994, pp. 202–210-cat nos. 48–53; Rouillet, 1972, pp. 35, 72–77-cat nos. 73–80). These include the obelisk now in the Piazza della Rotonda in front of the Pantheon (Fig. 12), which was originally raised in Heliopolis by Rameses II and set up at the beginning of the fifteenth century in the nearby Piazza di San Macuto (which marked the northernmost section



Obelisks in Ancient Egypt, Fig. 13 Capitoline obelisk of Rameses II, Villa Celimontana, Rome

of the Isis sanctuary). Its fragmentary counterpart, now in the gardens of the Villa Celimontana in Rome (Fig. 13), had been restored and set up even earlier, during the twelfth to thirteenth centuries, on the Capitoline Hill. Other obelisks from the Iseum, discovered in the sixteenth to nineteenth centuries, can be seen in other locations in Rome, Florence, and Urbino. The last obelisk to be transported out of Egypt by a Roman emperor was raised in the Hippodrome of Constantinople by Theodosius I in 390 BCE. Originally one of the pairs set up at Karnak by Thutmose III, this 30 m, nearly 400 t colossus (it apparently broke during transport and now stands some 19.5 m (65 ft)) was one of at least five obelisks that once stood in the city. Most of these have disappeared without a trace.

In addition to importing obelisks from Egypt, the Romans also produced their own new obelisks when the circumstances required it. Two that may have been produced directly for Roman use are the pair of uninscribed obelisks that were placed before the mausoleum of

Augustus in Rome. They were erected at an unknown date (probably the first century BCE) and fell into the debris of the city sometime during the middle ages. In the sixteenth century, one of them was excavated and, after years of neglect, was erected by Pope Sixtus V on the Esquiline Hill. In the eighteenth century, the second was discovered and installed in the Piazza del Quirinale by Pope Pius VI (Curran et al., 2009, p. 46; Iversen, 1968–1972, pp. 47–54, 115–127; Sorek, 2010, pp. 84–86).

A more certain case of Roman manufacture is the so-called Pamphilian obelisk, which was inscribed with vignettes and hieroglyphic inscriptions of Emperor Domitian (81–96) in honor of the Egyptian gods. During the fifteenth and sixteenth centuries, this medium-sized and exceptionally slender obelisk (16.54 m tall) lay broken in the ruins of the Circus of Maxentius on the Via Appia outside the walls of Rome. It remained there until the middle of the seventeenth century, when it was repaired and erected as the centerpiece of Bernini's Fountain of the Four Rivers in the Piazza Navona (Fig. 14). It has been proposed that the Pamphilus was originally raised in the central entrance court of the Iseum Campense when it was rebuilt by Domitian after a fire in 80 BCE, but this is by no means certain. The inscriptions mention Isis and allude to the emperor's restoration of "that which had been destroyed," but the principal dedication is to the sun god Re-Harakhte. It is possible that it was made for another Roman site or even – as seems to be the case with the obelisk of Antinous (see below) – for dedication in an Egyptian setting and only later found its way to Rome (Curran et al., 2009, pp. 46–48; D'Onofrio, 1992, pp. 288–301; Iversen, 1968–1972: Vol. 1, pp. 76–92; Preimesberger, 1974; Sorek, 2010, pp. 79–84).

During the reign of Hadrian (117–138), a smaller obelisk was carved in honor of the emperor's late companion Antinous, who drowned in the Nile during an imperial visit to Egypt and was deified as a kind of modern Osiris in Egypt and elsewhere in the empire. This obelisk was originally manufactured – and probably set up – in Egypt, near the site of the unfortunate



Obelisks in Ancient Egypt, Fig. 14 Pamphilian obelisk of Domitian, Fountain of the Four Rivers, Rome

boy's tomb (Boatwright, 1987, pp. 239–260). A more recent proposal that it was installed as part of a memorial complex at Hadrian's Villa in Tivoli (Mari & Sgalambro, 2007) seems less likely, at least to this author. In either case, the obelisk was eventually brought to Rome and erected, during the third century, in the Circus Varianus near the Via Labicana, where two fragments of its broken shaft were visible in the fifteenth and sixteenth centuries. These pieces were excavated and partially reerected by the Saccocius brothers, who owned the property, in 1570. Then, after a period of neglect, the obelisk was purchased by Cardinal Francesco Barberini in 1632 and, after some further peregrinations, was installed in Rome's Pincian gardens by Pope Pius VII in the early nineteenth century (Fig. 15). (For more on the long and tangled history of this obelisk, see Curran et al., 2009, pp. 48–49, 203; D'Onofrio, 1992, pp. 435–445; Grimm, Kessler, & Meyer, 1994; Iversen, 1968–1972, Vol. 1, pp. 161–173; Sorek, 2010, pp. 96–80).



Obelisks in Ancient Egypt, Fig. 15 Obelisk of Hadrian and Antinous, Monte Pincio, Rome

Obelisks from the Middle Ages to Modern Times

During the middle ages, the obelisks continued to attract their share of interest from learned observers, even while many of them were toppled and otherwise neglected or vandalized in Egypt and Rome. They also acquired new names that continued to emphasize their needlelike shape. The common medieval (and modern) Arabic word for an obelisk is *mislah* or *missala*, which refers to a “patching needle,” and thus, like the Greek *obeliscos*, emphasizes the slender, needlelike shape of these monuments. During the middle ages, the obelisks of Senusret at Heliopolis (along with the Alexandrian pair) were popularly known as *Messalat Far’un* (Needles of Pharaoh). Medieval Arabic scholars, whose studies of Egyptian history, monuments, and inscriptions have begun to attract more attention in recent studies, called the hieroglyphic carvings on the obelisks and other Pharaonic monuments by a variety of names, including

“bird’s script” (*qalam al-tayr*), “temple-script” (*al-qalam al-birbawi*), and “hieratic” script (*al-qalam al-kahini*) (Curran, 2007, pp. 34–36; Curran et al., 2009, pp. 61–62; El-Daly, 2003, 2005; Haarmann, 1996; Habachi, 1984, pp. 3–5, 48).

In Egypt, then, it is clear that the obelisks, like the pyramids and other monuments, retained their Pharaonic associations into the medieval period. But the situation was more complicated for the “obelisks in exile” in Rome. It is true that, thanks to the writings of scholars like Isidore of Seville, the Egyptian origins and traditional name of *obeliscus* were never entirely forgotten in the Latin west (Isidore of Seville, *Etymologiae* 18.28–31). But in the ancient capital itself, as the obelisks fell victim to the indignities of neglect, earthquake, and vandalism, the memory of their Egyptian origins also began to fade and was superseded by new or alternate associations with Roman history and legend. By the middle of the twelfth century, the only obelisk of great size that was still standing in Rome was the *Vaticanus* (Fig. 10), which by this time was believed to mark the site of the Apostle Peter’s martyrdom in the Vatican Circus. According to a second tradition set out in the *Mirabilia urbis Romae*, an influential twelfth-century guide to the antiquities of Rome, the obelisk had originally been raised as the monument and tomb of Julius Caesar, whose ashes were believed to be interred in the bronze globe at the monument’s summit. Although other texts of the time referred to this and other monuments in Rome as pyramids or obelisks, the preferred name for the Vatican monument, and later for other Roman obelisks, was the *guglia* or “needle” of Caesar (variants of the term include *agulia* and *aguglia*). Derived in part from a misreading of a passage in Suetonius’ *Life of Caesar* and the Latin inscription on the monuments’ shaft, the association with the “Divine Julius” and the name *guglia* persisted in common parlance long after both the true origin and function of the monument had been established by Renaissance admirers (Curran, 2007, pp. 27–49; Curran & Grafton, 1995; Curran et al., 2009, pp. 61–73; Iversen, 1968–1972, Vol. 1, pp. 22–28).

By the middle of the fifteenth century, Italian humanists had identified the obelisks in Rome as the Egyptian monuments “in exile” described by Pliny and Ammianus and had already embarked on the earliest stages of a long and complicated effort to understand and decipher their hieroglyphic inscriptions. In the early 1450s, builders working for the “humanist” Pope Nicholas V (1447–1455) conducted the first archaeological investigation of the Vatican obelisk in relation to the Pope’s plan to move the great stone from the remains of the circus on the south side of St. Peter’s basilica to the piazza in front of it – a distance of some 275 yards. Accounts of the papal architects’ claims to have devised machines capable of lifting and moving the great stone spread as far as the northern court of Ferrara and inspired a host of imaginative obelisk projects – most of them quite impossible to realize, on the part of Renaissance artists and architects (Curran, 2007, pp. 51–87; Curran & Grafton, 1995, pp. 242–244; Curran et al., 2009, pp. 69–101). But this and other plans to move the obelisk or erect other ones that were discovered in the ruins of Rome were delayed for many years, until 1586, when the transport of the Vatican obelisk was achieved, with great fanfare, by Pope Sixtus V (1585–1590) and his architect in charge, Domenico Fontana (1543–1607). To achieve this long-postponed goal, Fontana devised a great obelisk-lifting and lowering machine – called a *castello* – that resembled a wooden siege tower about 92 ft tall – just tall enough to life the obelisk from its base and lower it to a horizontal position, using a system of ropes and pulleys powered by capstans turned by teams of some 900 men and 74 horses. The obelisk was then transported to the piazza on a specially constructed causeway and raised on its original (albeit restored and elevated) base by reversing the lowering process. The obelisk was solemnly rededicated to the Holy Cross and ceremonially exorcized of all pagan and demonic forces, and Fontana himself was lauded as the hero of the moment and showered with titles and gifts appropriate to his achievement. During the next 3 years, Fontana used his obelisk-lifting machine to raise and repair the broken fragments of three

more obelisks – the two large ones excavated from the Circus Maximus (which he raised in the Lateran and the Piazza del Popolo, respectively) and a smaller specimen that had been discovered decades earlier in the ruins of the Mausoleum of Augustus, which was set up on the Esquiline hill, near the apse of the Basilica of Santa Maria Maggiore (for Fontana’s account and later studies, see Curran et al., 2009, pp. 103–150; Dibner, 1950/1970, pp. 21–43; D’Onofrio, 1992, pp. 71–92, 69–101; Fontana, 1978; Iversen, 1968–1972, Vol. 1, pp. 29–40; Parsons, 1939/1968, pp. 155–173).

During the later seventeenth and eighteenth centuries, a series of smaller and/or broken obelisks were repaired and reerected in Rome, including the Obelisk of Domitian (Fig. 14), which was restored under the supervision of the Jesuit polymath Athanasius Kircher (1601/1602–1680) and installed as the centerpiece for Bernini’s richly allegorical Fountain of Four Rivers in 1649 (see Cipriani, 1993; Curran et al., 2009, pp. 161–180; Iversen, 1968–1972, Vol. 1, pp. 76–92; Parker, 2003; Preimesberger, 1974; Rowland, 2001) and the reconstructed fragments of the Campus Martius sundial obelisk, which was repaired with red granite from the damaged column of Antoninus Pius and set up in the Piazza di Montecitorio by order of Pope Pius VI in 1786 (Fig. 6). It was one of three obelisks reerected by this pope, whose projects represented the final chapter in grandiose papal appropriation of these monuments (see Collins, 2001, 2004). During the nineteenth century, the European and American obelisk importers would be shifting their gaze from Rome to Egypt itself, as the monuments of the country attracted new enthusiasm following the Napoleonic campaign of 1798–1801 and the subsequent decipherment of the hieroglyphic script by Jean-François Champollion. The first to arrive in Europe (after the diminutive Philae/Bankes obelisk, see above) was the westernmost of the pair of obelisks inscribed for Rameses II that still stood before the great entrance pylon of the Temple of Amun-Ra at Luxor. Selected as the most beautiful specimen available on the authority of Champollion himself, the 246 t obelisk was lowered using an

elaborate hinged device and loaded onto a specially designed ship for transport to Paris, where it was raised with great ceremony in the Place de la Concorde in 1833; (Curran et al., 2009, pp. 243–255; Habachi, 1984, pp. 153–164; Hassan, 2003; Lébas, 1839; Porterfield, 1998, pp. 13–41). The next to arrive was the fallen one of the pair at the Caesareum in Alexandria, which had been offered to the British by the Egyptian authorities early in the century, but arrived only in 1878, after a tragic and nearly catastrophic voyage in a specially designed barge called the *Cleopatra*. The obelisk was raised on the Thames Embankment on September 13 of that year. The still-standing mate of this obelisk was offered at this time to the United States, and its lowering and transport were supervised by a naval officer and engineer named Henry H. Gorringe, who described his methods in a monumental tome that rivaled the early production of Domenico Fontana (Curran et al., 2009, pp. 257–281; D’Alton, 1993; Gorringe, 1882; Iversen, 1968–1972, Vol. 2, pp. 90–147). This obelisk was raised with great ceremony in New York’s Central Park in the winter of 1881 (Fig. 2).

Obscured by trees and mostly ignored by strollers, joggers, and the throngs who crowd the Egyptian collections of the Metropolitan Museum of Art nearby, the New York obelisk provides a somewhat sobering coda for the colorful history of these monuments, whose unique appeal made them the most admired and desired of Egyptian inventions for some 2,000 years. But the future, as of 2014, may be looking brighter, as the obelisk has been slated for a long-overdue conservation. It may yet claim its place in the sun.

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See Also

► [Pyramids in Egypt](#)

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Observatories in India

Virendra Nath Sharma

India has an ancient astronomical tradition. Information on its observatories is meager, however. It is certain that a number of prominent astronomers, patronized by kings, carried out their own observations, which are mentioned in *karaṇas*, or practical manuals. The places of such observations, if operated for a reasonable period of time, technically could be called observatories. A court astronomer, Śaṅkaranārāyaṇa (fl. 869), mentions such a place with instruments in the capital city of king Ravi Varmā of Kerala. Astronomers of the Islamic school of astronomy, such as ‘Abd al-Rashīd al-Yāqūtī (fifteenth century) report an observatory in the city of Jājilī in India. The Emperor Humayun (d. 1556) is said to have had a personal observatory at Kotah, near Delhi, where he himself took observations.

An ambitious program of building observatories was undertaken by Sawai Jai Singh (Savā’ī Jaya Siṃha), an astronomer-statesman of India. Between 1724 and 1735, Jai Singh built observatories at Delhi, Jaipur, Mathura, Varanasi, and Ujjain. His observatories, except for that of Mathura, still exist today in varying degrees of

preservation. Sawai Jai Singh’s purpose in building observatories was to update the existing planetary tables. Toward this purpose, he designed and built instruments of stone and masonry. These instruments may be classified into three main categories based on their precision which varies anywhere from $\pm 1'$ to a degree. Table 1 presents an inventory of his masonry instruments according to their precision, with the low precision instruments listed first. Table 2 lists instruments added after Sawai Jai Singh’s death.

Jai Singh constructed 15 different types of masonry instruments for his observatories. Of these, the Samrāt yantra, Śaṣṭhāṃśa, Dakṣinottara Bhatti, Jaya Prakāśa, Nāḍīvalaya, and Rāma yantras are his most important instruments.

Observatories in India, Table 1 Inventory of Jai Singh’s masonry instruments

Instrument	No.	Location
Dhruvadarśaka Paṭṭikā (north star indicator)	1	Jaipur
Nāḍīvalaya (equinoctial dial)	5	Jaipur (2), Varanasi, Ujjain, Mathura
Palabhā (horizontal sundial)	2	Jaipur, Ujjain
Agrā (amplitude instrument)	5	Delhi, Ujjain, Mathura
S’aṅku (horizontal dial)	1	Mathura
Jaya Prakāśa (hemispherical instrument)	2	Delhi, Jaipur
Rāma yantra (cylindrical instrument)	2	Delhi, Jaipur
Rāśi valaya (ecliptic dial)	12	Jaipur
Śara yantra (celestial latitude dial)	1	Jaipur
Diḡaṃśa (Azimuth circle)	3	Jaipur, Varanasi, Ujjain
Kapāla (hemispherical dial)	2	Jaipur
Samrāt (equinoctial sundial)	6	Delhi, Jaipur (2), Varanasi (2), Ujjain
Śaṣṭhāṃśa (60° meridian chamber)	5	Delhi, Jaipur (4)
Dakṣinottara Bhatti (meridian dial)	6	Delhi, Jaipur, Varanasi (2), Ujjain, Mathura

Samrāt Yantra

The *Samrāt yantra* or the “Supreme Instrument” is Jai Singh’s most important creation. The instrument is basically an equinoctial sundial, which has been in use in one form or another for hundreds of years in different parts of the world (Figs. 1, 2, 3, and 4).

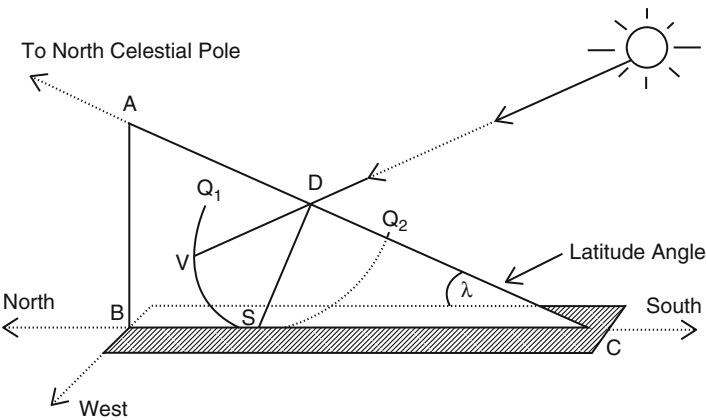
Observatories in India, Table 2 Instruments added after Sawai Jai Singh’s death

Instrument	No.	Location
1. Miśra yantra (composite instrument)	1	Delhi
2. S’aṅku yantra (Vertical staff)	1	Ujjain
3. Horizontal scale (known as the seat of Jai Singh)	1	Jaipur

The instrument consists of a meridian wall ABC, in the shape of a right triangle, with its hypotenuse or the gnomon CA pointing toward the north celestial pole and its base BC horizontal along a north-south line. The angle ACB between the hypotenuse and the base equals the latitude λ of the place. Projecting upward from a point S near the base of the triangle are two quadrants SQ_1 and SQ_2 of radius DS. These quadrants are in a plane parallel to the equatorial plane. The center of the two “quadrant arcs” lies at point D on the hypotenuse. The length and radius of the quadrants are such that, if put together, they would form a semicircle in the plane of the equator.

The quadrants are graduated into equal-length divisions of time-measuring units, such as *ghaṭikās* and *palas*, according to the Hindu system, or hours, minutes and seconds, according to

Observatories in India, Fig. 1 *Samrāt yantra*: principle and operation

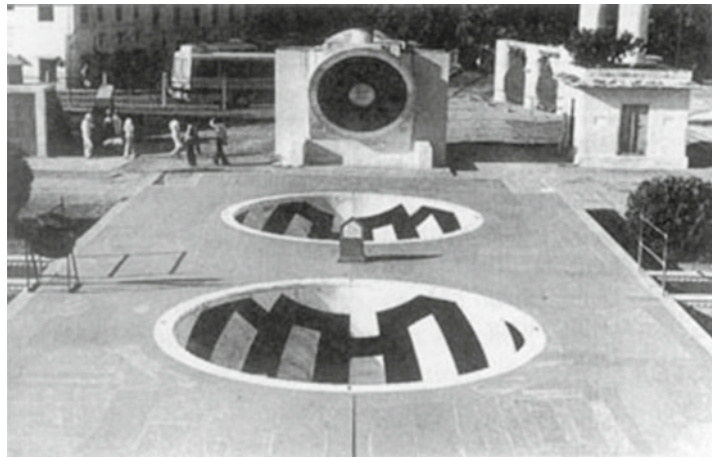
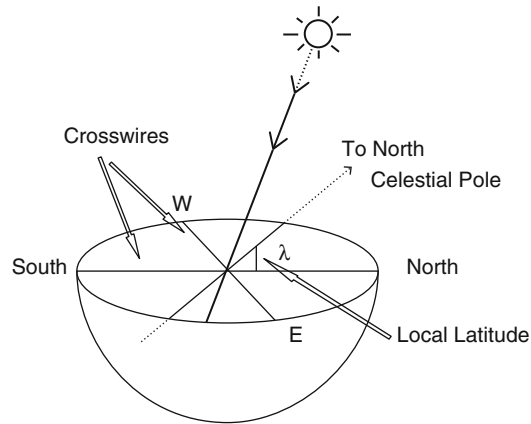


Observatories in India, Fig. 2 Jaipur observatory of Sawai Sai Singh



Observatories in India,

Fig. 3 Jaya Prakāśa at Jaipur. The Nāḍīvalaya is in the background



the Western system. The upper two ends Q_1 and Q_2 of the quadrants indicate either the 15-*ghaṭikā* marks for the Hindu system, or the 6 a.m. and the 6 p.m. marks according the Western system. The bottom-most point of both quadrants, on the other hand, indicates the zero *ghaṭikā* or 12 noon. The hypotenuse or the gnomon edge AC is graduated to read the angle of declination. The declination scale is a tangential scale in which the division lengths gradually increase according to the tangent of the declination.

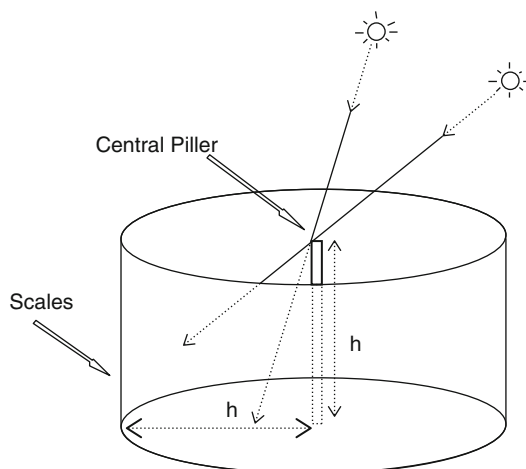
The primary object of a Samrāt is to indicate the apparent solar time or local time of a place. On a clear day, as the sun journeys from east to west, the shadow of the Samrāt gnomon sweeps the quadrant scales below from one end to the other. At a given moment, the time is indicated by the shadow's edge on a quadrant scale.

The time at night is measured by observing the hour angle of the star or its angular distance from the meridian. Because a Samrāt, like any other sundial, measures the local time or apparent solar time and not the "Standard Time" of a country, a correction has to be applied to its readings in order to obtain the standard time.

To measure the declination of the sun with a Samrāt, the observer moves a rod over the gnomon surface AC up or down until the rod's shadow falls on a quadrant scale below. The location of the rod on the gnomon scale then gives the declination of the sun. Declination measurement of a star or a planet requires the collaboration of two observers. One observer stays near the quadrants below and, sighting the star through a sighting device, guides the assistant, who moves a rod up or down along the gnomon

Observatories in India,

Fig. 4 The principle of a *Rāma yantra*



scale. The assistant does this until the vantage point V on a quadrant edge below, the gnomon edge above where the rod is placed, and the star – all three – are in one line. The location of the rod on the gnomon scale then indicates the declination of the star.

enables the observer to measure the zenith distance, declination, and the diameter of the sun. The image formed by the pinhole on the scale below is usually quite sharp, such that at times even sunspots may be seen on it.

Ṣaṣṭhāṃśa

A *Ṣaṣṭhāṃśa yantra* is a 60° arc built in the plane of meridian within a dark chamber. The instrument is used for measuring the declination, zenith distance, and the diameter of the sun. As the sun drifts across the meridian at noon, its pinhole image falling on the *Ṣaṣṭhāṃśa* scale below

Dakṣinottara Bhitti Yantra

Dakṣinottara Bhitti yantra is a modified version of the meridian dial of the ancients. It consists of a graduated quadrant or a semicircle inscribed on a north-south wall. At the center of the arc is a horizontal rod. The instrument is used for measuring the meridian altitude or the zenith distance of an object such as the sun, the moon, or a planet.

According to ► [Jagannātha Samrāt](#), this was the instrument with which Jai Singh determined the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), to be $23^{\circ} 28'$ in 1729.

Jaya Prakāśa

The *Jaya Prakāśa* is a multipurpose instrument consisting of hemispherical surfaces of concave shape and inscribed with a number of arcs. These arcs indicate the local time, and also measure various astronomical parameters, such as the coordinates of a celestial body and ascendants, or a sign on the meridian. *Jaya Prakāśa* represents the inverted image of two coordinate systems, namely, the azimuth-altitude and the equatorial, drawn on a concave surface. For the azimuth-altitude system, the rim of the concave bowl indicates the horizon. Cardinal points are marked on the horizon, and crosswires are stretched between them. On a clear day, the shadow of the crosswire falling on the concave surface below indicates the coordinates of the sun. Time is read by the shadow's angular distance from the meridian along a diurnal circle.

The instrument is built in two complementary halves, giving it the capacity for night observations. In the two halves the area between alternate hour circles is removed, and steps are provided in its place for the observer to move around freely for his readings. The space between identical hour circles of the two hemispheres is not removed, however. The sections left behind in the hemispheres complement each other. They do so in such a way that, if put together, they would form a complete hemispherical surface. For night observations the observer sights the object in the sky from the space between the sections. The observer obtains the object in the sky and the crosswire in one line. The coordinates of the vantage points are then the coordinates of the object in the sky. Jai Singh built his *Jaya Prakāśa*'s only at Delhi and Jaipur. These instruments survive in varying degrees of preservation. The instrument at Delhi has a diameter of 8.33 m and that at Jaipur, 5.4 m.

Nāḍīvalaya

A *Nāḍīvalaya* consists of two circular plates fixed permanently on a masonry stand of convenient height above ground level. The plates are oriented parallel to the equatorial plane, and iron styles of appropriate length pointing toward the poles are fixed at their centers. The instrument *Nāḍīvalaya* is, in fact, an equinoctial sundial built in two halves, indicating the apparent solar time of the place.

The *Nāḍīvalaya* is an effective tool for demonstrating the passage of the sun across the celestial equator. On the vernal equinox and the autumnal equinox the rays of the sun fall parallel to the two opposing faces of the plates and illuminate them both. However, at any other time, only one or the other face remains in the sun. After the sun has crossed the equator around March 21, its rays illuminate the northern face for 6 months. After September 21, it is the southern face that receives the rays of the sun for the next 6 months. Jai Singh built *Nāḍīvalayas* at each of his observatory sites except Delhi.

Rāma Yantra

The *Rāma yantra* is a cylindrical structure in two complementary halves that measure the azimuth and altitude of a celestial object, for example the sun. The cylindrical structure of *Rāma yantra* is open at the top, and its height equals its radius. The accompanying figure illustrates its principle and operation. To understand the principle, let us assume that the instrument is built as a single unit as illustrated.

The cylinder, as in the figure, is open at the top and has a vertical pole or pillar of the same height as the surrounding walls at the center. Both the interior walls and the floor of the structure are engraved with scales measuring the angles of azimuth and altitude. For measuring the azimuth, circular scales with their centers at the axis of the cylinder are drawn on the floor of the structure and on the inner surface of the cylindrical walls. The scales are divided into degrees and minutes.

For measuring the altitude, a set of equally spaced radial lines is drawn on the floor.

These lines emanate from the central pillar and terminate at the base of the inner walls. Further, vertical lines are inscribed on the cylindrical wall, which begin at the wall's base and terminate at the top end. These lines may be viewed as the vertical extension of the radial lines drawn on the floor of the instrument.

In daytime the coordinates of the sun are determined by observing the shadow of the pillar's top end on the scales, as shown in the figure. The coordinates of the moon, when it is bright enough to cast a shadow, may also be read in a similar manner. However, if the moon is not bright enough, or if one wishes to measure the coordinates of a star or planet that does not cast a shadow, a different procedure is followed. To accomplish this, the instrument is built in two complementary units.

The two complementary units of a Rāma yantra may be viewed as if obtained by dividing an intact cylindrical structure into radial and vertical sectors. The units are such that if put together, they would form a complete cylinder with an open roof. The procedure for measuring the coordinates at night with a Rāma yantra is similar to the one employed for the Jaya Prakāśa. The observer works within the empty spaces between the radial sectors or between the walls of the instrument. Sighting from a vacant place, he obtains the object in the sky, the top edge of the pillar, and the vantage point in one line. The vantage point after appropriate interpolation gives the desired coordinates. If the vantage point lies within the empty spaces of the walls, well above the floor, the observer may have to sit on a plank inserted between the walls. The walls have slots built specifically for holding such planks.

See Also

- [Gnomon in India](#)
- [Jai Singh](#)
- [Time](#)

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Observatories in the Islamic World

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The observatory in Arabic/Islamic civilization underwent considerable elaboration, beginning as an imitator of earlier Greek observational posts. The first true observatories were founded under the patronage of the 'Abbāsīd Caliph al-Ma'mūn (198–218 AH/AD 813–833), who also supported numerous translations from Greek into Arabic. The Shammāsiyya (in Baghdad) and Mount Qāsiyūn (near Damascus) observatories each operated for about a year, it seems. Although these sites may have lacked purpose-built structures, both employed permanent observational staff, skilled instrument makers, and technicians. Their purpose appears to have been the collection of accurate observations of sun and moon only, although there is some mention of other observations. The results of these observations were presented in the *Zīj Mumtaḥan*.

Caliph Sharaf al-Dawla (372–378 AH/AD 982–989) built an observatory in the garden of his Baghdad palace. It was housed in a purpose-built structure and equipped with instruments, some of which seem to have been quite large. This institution marks an advance in several respects: (1) it had a specific physical structure;

(2) it had a director/administrator, Abū Sahl al-Qūhī, a well-known geometer and astronomer, in addition to a staff of astronomers and technicians; and (3) its research program involved collecting data on the motions of all planets. Its activities began with great fanfare, but seem to have died out quickly, probably due to the death of the royal patron.

The observatory at Marāgha, founded by the Mongol conqueror-prince, Hūlāgū, was one of the biggest and best equipped observatories prior to the modern era. Founded in 657 AH/AD 1259, the construction was overseen by Muʿayyad al-Dīn al-ʿUrḍī, from whose autobiographical account we learn many details about the observatory and its operation. The physical plant included several purpose-built structures and an extensive collection of instruments, many of them large. There are also reports of an extensive library. The staff, under the direction of Naṣīr al-Dīn al-Ṭūsī, included a number of leading mathematicians and astronomers from all parts of the Islamic world. (There are even reports of Chinese astronomers visiting and assisting at this observatory.) Once again, the purpose was to acquire the most accurate observational data possible in order to correct earlier astronomical tables. The result was the *Zīj Ilkhānī*, completed in 670 AH/AD 1271. After completion of these tables, work on the site seems to have slowed, although the institution continued to exist for at least three more decades.

Another major observatory was founded in 823 AH/AD 1420 in Samarqand by Ulugh Beg, governor of Khurasān, who was himself well versed in mathematics and astronomy. Like the Marāgha observatory, it had a staff of mathematicians, observational astronomers, instrument makers, and technicians, although it seems to have been a more compact operation. The most famous of its instruments was a huge meridian arc enclosed within a large masonry structure. The observatory enjoyed the active support and participation of Ulugh Beg until his assassination in 853 AH/AD 1449. Thus, it functioned for nearly 30 years, during which time the *Zīj-i Jurjānī*, which was widely circulated in Arabic, Persian, and Turkish, was produced. Not only was this one

of the longest lived of all Islamic observatories, it was also the site of the most extensive collection of data on the fixed stars ever attempted in the Arabic/Islamic world.

In 983 AH/AD 1575, Taqī al-Dīn Muḥammad al-Rashīd ibn Maʿrūf, with the support of the Ottoman Grand Vizier, petitioned the Sultan for permission to build an observatory in Istanbul in order to produce a new set of astronomical tables, the older tables being inaccurate and in need of revision. His request was successful, and in 985 AH/AD 1577, the Istanbul Observatory, with Taqī al-Dīn as its head, began operations. Like its predecessors, this institution had permanent building housing observational instruments, a staff of astronomers and support personnel, and a library. Three years after its inception, the observatory was demolished. Contemporary reports differ on whether this action was undertaken with or without the support and encouragement of Taqī al-Dīn. Debate also continues about the possible influence of his account of observatory organization and instrument construction on Europe's greatest naked-eye observer, Tycho Brahe.

With the destruction of the Istanbul observatory, the great premodern period of observatory construction came to an end. The observatories of Jai Singh II, Maharaja of Jaipur (AD 1686–1740), at best represent the dying embers of the tradition. These five observatories (located at Jaipur, Delhi, Benares, Ujjain, and Mathura) contained enormous masonry instruments, many still extant today. Jai Singh's *Zīj-i Muḥammad Shāhī*, named after the emperor to whom it was dedicated, was largely patterned after the earlier work of Ulugh Beg. This has prompted some to conclude that these late observatories mark a period of decadence and derivative astronomy. This judgment is probably too harsh. These observatories, begun nearly a century after the founding of the Paris Observatory (which marks the beginning of a new era in astronomical technique and organization in support of a new interpretation of celestial phenomena), stand today as monuments to a brilliant, but now abandoned, intellectual, and social tradition within the history of science.

The observational instruments used in the observatory were usually larger versions of Ptolemaic (Greek) equipment:

- The meridian armillary, for determining solstice points and the obliquity of the ecliptic
- The plinth, used for the same purposes
- The equinoctial armillary, to determine equinox points
- The “parallactic instrument” (or “Ptolemy’s Rulers”) to measure elevation in relation to the zenith, to determine when heavenly bodies reach culmination
- The armillary or spherical astrolabe, for measuring positions of heavenly bodies relative to fixed or known celestial objects

In the centuries that followed, the physical equipment of observatories underwent continuous evolution. Arabic/Islamic observers sought increased precision in their work and usually endeavored to obtain it by increasing the size of instruments. Large instruments had to be carefully fixed in place and required skilled craftsmen for their construction and maintenance, as well as a staff of observers and mathematicians skilled in reducing the observational data to mathematical models.

In general, observation programs were initiated for correcting or improving the accuracy of existing astronomical tables (*zīj*). The production of a *zīj* was useful for making astrological/astronomical predictions, but by collecting improved data, the observation activity could support the development of alternative cosmographical schemes that avoided the embarrassment of Ptolemy’s equant theory, especially in centers such as Marāgha.

Most observatories, because their operation involved production and use of large and expensive instruments, were supported by state patronage, although there is some evidence that private institutions existed as well, such as the observatory of al-Battānī (d. 317 AH/AD 929) at Raqqa. The majority, however, survived at the mercy of their royal patrons. It was rare for an observatory, such as the institution at Marāgha, to be designated to receive income from *waqf* (donations of property in perpetuity to support charitable institutions) funds. Since it received *waqf* funds, the

observatory at Marāgha (as well as one in Tabriz) must have been seen as providing an essential public service, perhaps through their educational programs.

See Also

- [al-Battānī](#)
- [Al-Ma’mūn](#)
- [Al-Qūhī \(or Al-Kūhī\)](#)
- [Al-’Urḏī](#)
- [Astrology in Islam](#)
- [Astronomical Instruments in India](#)
- [Astronomical Instruments in the Islamic World](#)
- [Astronomy in the Islamic World](#)
- [Jai Singh](#)
- [Marāgha](#)
- [Taqī al-Dīn](#)
- [Ulugh Bēg](#)

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Ophthalmology in Egypt

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We learn about our past from studying its recorded history. Although Egypt is said to have been inhabited since 40,000 years ago, its recorded history, including medical history, is for the most part known from the ten papyri that have survived and by the hieroglyphs or sacred letters that have survived in the tombs of those who have passed away. Of the papyri that have survived, the Ebers Papyrus is the most important for ophthalmology. Edwin Smith discovered it in Thebes in 1862. It is said to have been written in approximately 1500 BCE. It is presently found at the University of Leipzig in Germany. Edwin Smith also found another papyrus that carries his name and is housed at the New York Academy of Medicine in New York City. The papyri were written using hieroglyphics, the translation and the understanding of which have been the subject of academic discussions for hundreds of years. Four hundred plants, minerals, and animal parts were used to create remedies for the various disorders mentioned. Eye diseases comprised a large part of these medical treatments. Surgery was limited at the time, and while cataract couching was common in India, no mention of this is found in any of the papyri.

Ophthalmia or conjunctivitis was a common ocular disorder and was mentioned approximately 40 times in the Ebers Papyrus. Eye stones, perhaps chalazion, meibomian gland disorders, pterygium, entropion, and ectropion as well as trachoma were all described. Blindness was well discussed in Egyptian art as well as in the eye of discovered statues in which the eye of the person was discolored or deformed. The treatment for blindness included attempts to drive out the devil using incantations and prayers as well as using a variety of medicines. The Eye

of Horus, the Egyptian god of health and protection, was widely used as a protective amulet and is often seen in Egyptian art and writings.

Medications used at the time included a variety of pastes or ointments made from antimony. As antimony imparts a dark color to the paste, these pastes were not only used as medicaments but also were used for the cosmetic darkening of the eyebrows or the eyelashes. Malachite which has copper sulfate as a main component was also used to fight off the effects of many disorders. Other medicines that were used included red ochre, alum, copper oxide, or sulfide, which was also made into a paste or a solution. Saltpeter or sodium hydroxide, zinc oxide, and lapis lazuli extract were also used. Animal blood such as from pigs, turtles, and other animals was used as was mother's milk or the urine of a child or of the patient himself.

That trachoma was present in Egypt was clearly recognized by Napoleon when he invaded Egypt in 1799 and his troupes developed serious eye infections and forced him to withdraw from the country. So it is that the history of Egyptian ophthalmology is replete with interest in eye diseases with a variety of medical approaches used to combat them. The treatments that were used have for the most part left us, but not all of the disorders. Trachoma is still found in Egypt today, with trichiasis and entropion being common complications. Pterygium and pingueculum, often mentioned in the papyri, are also common today in part due to solar preponderance in Egypt. The more things change, the more things remain the same.

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Optics in China

Jinguang Wang and Caiwu Wang

Before AD 1911, optics in China went through four stages. The first stage was from remote antiquity to the Spring and Autumn Period (770 BCE), the second ended in AD 220 (end of the Dong Han Dynasty), the third ended in AD 1380 (end of the Yuan Dynasty), and the fourth stage ended in 1911 (end of the Qing Dynasty).

In the first stage, the Chinese began to develop a philosophy of nature. The ideas of optics were in their infancy. In remote antiquity, the Chinese germinated basic knowledge of light sources, vision, shadow formation, and reflection. In addition, there were some inventions such as artificial light sources and reflectors. The artificial light sources or fire source were obtained from striking stones, drilling wood, and focusing sunlight. The reflectors included water mirrors which were plane mirrors (Fig. 1) and bronze mirrors which were plane mirrors and convex mirrors. Even though all these achievements were superficial, they laid foundations for later studies on shadow formation and optical images.

The second stage took place within an important period for Chinese science and technology. During that time, optical technology developed very rapidly. As an example, techniques to make mirrors matured. Numerous studies led to deep understandings of light reflection and rectilinear propagation as recorded in the *Mo Jing* (Mohist Canon), which was written between 450 and 250 BCE. There were eight sections in the book:

1. Processes of shadow formation and vanishing
2. Umbras and penumbras
3. Rectilinear propagation of light and pinhole image
4. Sunlight reflection and formation of an inverted shadow
5. Changes of shadow sizes (length and width)

6. Image formation and symmetries due to plane mirrors
7. Two image variations from concave mirrors (erect image and inverted image)
8. One type of image formed by convex mirrors

These eight propositions systematically described theories in geometrical optics. Technically, *Mo Jing* had achieved a level very similar to that of Euclid's *Optics*.

During the third stage, Chinese scholars discovered various optical phenomena. For example, aspects of atmospheric optics were studied in detail, including halo maps and rainbow formation. Since image formation had been a hot subject in Chinese optics, it was further advanced during this stage. Most of the records can be found in a book called *Mengxi Bitan* (Meng Xi Essays) by the scientist ► [Shen Guo](#) (1032–1096), in the Song Dynasty (960–1279). Among hundreds of sections in the book, there were more than ten dealing with optics. Sections 44 and 330 are the most important. In Section 44, Shen discussed image formation by pinhole and concave mirrors in terms of a terminology called *ai*, or pinhole and focal point. He named such mathematical generalization *ge shu*. In Section 330, Shen discussed light penetrating mirrors, which were also called *tou-guang jian* or “magic mirrors.” There were more than 20 characters inscribed on a magic mirror. When sunlight shone on the mirror, all the characters were clearly projected on to a wall. There were three magic mirrors in Shen's family. He also saw other mirrors in his friends' homes. However, some other extremely thin mirrors did not allow sunlight to pass through. The magic was in the inscription of faint lines on the back side of the mirror. (Based on Shen's descriptions, modern Chinese shops are able to reproduce such magic mirrors by several techniques.) Besides those two sections, Shen presented quantitative relationships between image sizes and curvatures of convex mirrors. He introduced a postmortem examination method in which a red light was utilized. He also attributed rainbows to the shadows of the sun during rain.

Optics in China,

Fig. 1 Water mirror. The water surface was utilized as a reflecting surface. Such a water mirror was called *Jian*



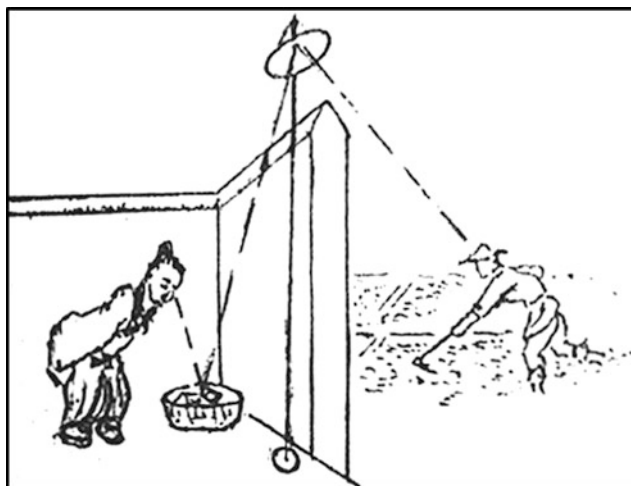
After Shen's work, another scientist, Zhao Youqin, carried out a famous optical experiment. Zhao lived in the thirteenth century, and recorded this experiment in his book, *Ge-Xiang Xin-Shu* (New Astronomy). In a chapter entitled "Pinhole Image," Zhao detailed a systematic study carried out in a two story house. There were two rooms on the first floor, one on the left and one on the right. To make two light sources in these two rooms, two boards were "planted" with thousand of candles. On the top of each light board, an additional covering board was placed. There was a hole in the center of the additional board. If the candles were lit, light could pass through the hole and then was projected on to a screen. The screen was either the fixed ceiling or an adjustable screen suspended from the ceiling so that the distance between the light source and the screen could be adjusted. The following observations were made in the experiment:

1. Shapes of the pinhole images are independent of the shapes and sizes of the small hole in the covering board.

2. The brightness of the image depends on the size of the hole. The larger the hole, the brighter the image.
3. When the source strength (number of candles) increases, the brightness of the image increases.
4. When the distance between the light source and the image screen increases, the image brightness decreases.

Zhao's experiment provided a lot of information on pinhole images. From the experiment, he proposed this idea. On the image screen, there was a light spot corresponding to a single candle. If a thousand candles were lit on a source board, there would be a thousand images of the candles. These images would overlap each other. The final appearance of the image would depend on the distribution of lit candles. In addition to basic optics, Zhao utilized his pinhole image theory to study eclipses of the sun and the moon and other astronomical phenomena.

The fourth stage marked the end of traditional Chinese optics. The new trend both continued the



Optics in China, Fig. 2 Open-tube periscope in Han Dynasty. This illustration is based on a description in *Huai Nan Wan Bi Shu*, a book published in Xi Han Dynasty. By hanging a big mirror on the *top* of a pole and using a water-reflecting surface, one could watch a

neighbor's actions. The object outside of the wall would form the image in the mirror, which in turn would form another image by reflecting. In this illustration, a person inside is watching a farmer outside of the wall. This is actually the earliest periscope in the world

Chinese system and adapted the Western system imported from Europe. During this period, Fang Yizhi (1611–1671) wrote a book called *Wuli Xiaozhi* (Small Encyclopedia of Physical Principles). In the book, Fang pointed out that light travels in wave forms, and he carried out an experiment to study the diffraction of light.

Several books and many articles on optics were translated from Western languages to Chinese languages, such as *Yuan Jing Shuo* (Telescopium) by the Germany Missionary Johanna Adam Schall Von Bell (1591–1666), and *On Optics* by Zhang Fuxi (d. 1862) and Englishman Joseph Edking (1823–1905). Another book entitled *Six Lectures on Light*, written by English physicist John Tyndall (1820–1893), was translated by Card T. Kreyer and Zhao Yuanyi in 1876.

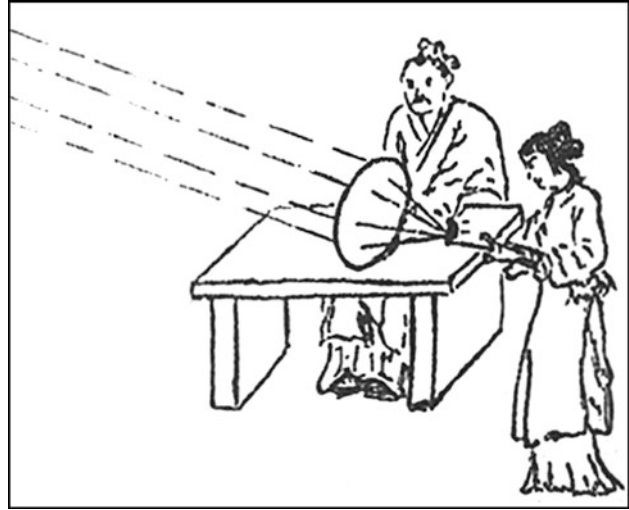
Several monographs on optics were written by Chinese authors. In a book entitled *Jingjing Lingchi* (Treatise on Optics by an Untalented Scholar) by Zheng Fuguang (b. 1780), geometric optics was systematically introduced. In another monograph entitled *Geshu Bu* (Supplement to Geometric Optics) written by Zou Boqi (1819–1869), optical theorems and principles were discussed.

Several different kinds of optical instruments or devices were improved. For instance, an optical expert, Sun Yunqiu (seventeenth century), made spectacles, telescopes, microscopes, and distorting mirrors.

The Chinese achieved high levels of understanding in optics, as illustrated by *Mo Jing*, *Mengxi Bitan*, and *Gexiang Xinshu*. The ancient Chinese paid attention to both theories and applications. A unique characteristic of Chinese optics is related to experimental approaches. All eight propositions in *Mo Jing* were based on experimental observations. Between the Qing and Han Dynasties, the Chinese mastered the concept of “focal distance” when they ignited fires from a spherical mirror. They created several novel devices such as the open-tube periscope and ice lens. Both devices were recorded in a book entitled *Huai Nan Wan Bi Shu*, published in Xi Han Dynasty. The open-tube periscope consisted of a big mirror, a basin filled with water, and a pole. As shown in Fig. 2, by hanging the big mirror on the top of the pole, one could watch the actions of the neighbors with the water surface. To make a spherical ice lens, one would use a piece of ice and grind it into a proper shape. As shown in Fig. 3, one could hold the ice lens toward the

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Fig. 3 Ice lens experiment. In *Huai Nan Wan Bi Shu*, there was a “miracle” experiment using an ice lens. One would make a spherical lens with a piece of ice by polishing both sides. Facing the lens to the sun and placing a piece of *moxa* at the focal point of the lens, one could light this piece of *moxa*



Sun and place a piece of *moxa* (mugwort, or *artemesia vulgaris*) at the focal point. Thus, this piece of *moxa* could be lit. Chinese observed similarities among rainbows, waterdrop dispersion, and crystal dispersion. Several Chinese scientists conducted high level experiments during their times, such as the “spherical mirror images” experiment by ► [Shen Guo](#), and the “pinhole images” experiment by Zhao Youqin. The ancient Chinese optics system was based on empirical observations, which was short of theoretical abstraction and quantitative description. For example, no laws of reflection were proposed even after the phenomena of reflections had been observed for 2,000 years. As Western optics was imported to China, the entire foundation of traditional Chinese optics was changed.

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Optics in the Islamic World

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The science of optics entered the Islamic world primarily through Greek sources, during the ninth century transmission of ancient scientific and philosophical texts. As such, it was unlike other mathematical sciences such as astronomy and algebra, which being based on Indian and Persian sources as well, involved a “non-Western” intellectual and practical dimension, in addition to physical and cultural settings. As further distinct from these and other fields, what emerged as the so-called science of “aspects” or “optics” from a

subdivision of Greek geometry, transformed its parent field quickly and significantly, starting with the translation of the relevant texts (Kheirandish, 1996, 1999, 2001a). Indeed, if one field were to be singled out in the Islamic world for having left the most influential mark on the development of a discipline, this might be *‘ilm al-manāẓir*, as Greek *optika* came to be called in Arabic. During the earliest phases of the discipline, a decisive theory about the nature and manner of vision, which was the main subject of optics for some time, developed after a long period of debate. The domain of the field also expanded from a geometrical study of vision to one into which not only theories of light, mirrors, rainbows, and shadows, but also the psychology of visual perception, were integrated as common subjects of investigation. Some of these added inquiries produced impressive results, but as the field turned from a branch of mathematics into a discipline closer to physics, its methodology also left the purely geometrical world to enter an experimental realm.

Works that represent some highlights of these developments include the *De aspectibus* of Ya’qūb ► *al-Kindī* (d. AD 870) (Adamson, 2006; Rashed, 1997), the *Kitāb al-manāẓir* of Ibn al-Haytham (d. AD 1039), and its rich commentary, *Tanqīḥ al-manāẓir* of Kamāl al-Dīn Fārisī (d. AD ca. 1320) (Sabra, 1989, 1994, 2002; Schramm, 1963).

A supplementary list of optical works by these and other authors, composed in both Arabic and Persian, from the early ninth century all the way to about 150 years ago, are representative of the quantitative developments of the field (Kheirandish, 1998, 2001b, 2002, 2004).

Disciplinary Developments

One would expect the science of optics to have embraced a variety of phenomena from light and shadows, halos and rainbows, mirrors and burning instruments, some observable from the beginning of human history. But this was not always the case even in ancient and medieval times. For ancient Greek scholars, from mathematicians

such as Euclid (ca. 300 BCE) and Ptolemy (second century AD), to philosophers and physicians like Aristotle (ca. 400 BCE) and Galen (second century AD), the focus of what was called *optika* and classified under geometry was vision, not light. Greek optics was primarily concerned with theories of vision, as the close association of the term *optika* with the eye indicates, and in the case of the geometrical tradition in optics – the only tradition treating the subject in independent works with that title – the proposed theories of vision were even expressed in terms of visual rays (*opseis*) extending from the eye to the object. Greek writings did go beyond the realm of direct vision, to include reflection from a polished surface (as in Euclid’s *Optics*, or Hero of Alexandria’s *Catoptrics*) or refraction through a different medium (as added in Ptolemy’s *Optics*). But works titled *Optika* still dealt primarily with vision – leaving the domain of the field largely determined by the relevancy of its subjects to what was long considered the “most noble of the senses.”

Early Islamic scholars inherited this particular orientation, which initially determined the focus of their own optical inquiries, even the classification and study of related subjects concurrently received from ancient sources, from reflection and refraction to shadows, rainbows, colors, sighting instruments, and burning mirrors. But there was soon a considerable change in optics’ scope and profile. With the *Optics* of Ibn al-Haytham (also known as Alhacen or Alhazen, ca. eleventh century AD) the extended disciplinary boundaries left an immediate trace on subsequent developments of a field, now called *Perspectiva*, one that was largely carried over to the seventeenth century when optics acquired its current name and general character.

The change in the scope of *‘ilm al-manāẓir*, which occurred alongside other theoretical and methodological developments, was itself a gradual process. Major works on optics proper, often identifiable by the term *al-Manāẓir* in their titles (corresponding to the *Optika* in the titles of Euclid’s and Ptolemy’s texts), slowly came to expand the meaning of the study of vision. Works from the *De aspectibus* (*Ikhtilāf*

al-manāẓir?) of Ya'qūb ► **al-Kindī** (d. AD 870) and *Kitāb al-manāẓir* of Ibn al-Haytham, to *Tanqīh al-manāẓir* of ► **Naṣīr al-Dīn al-Ṭūsī** (d. AD 1274) and *Tanqīh al-manāẓir* of Kamāl al-Dīn Fārisī (d. AD 1320), spanning a period of about 500 years, well represent the changing disciplinary boundaries. Al-Kindī included in his *De aspectibus* surviving only in Latin a range of related discussions from shadows and mirrors to the clarity of perception, but left a number of others out. Ibn al-Haytham discussed in the seven books of his *Kitāb al-Manāẓir* a wide range of other subjects: the properties of light (and color) (Book I), visual perception and visual illusions (Books II and III), and reflection and refraction (Books 4–7), but wrote separately on burning instruments, halos and rainbows, or *camera obscura*. Kamāl al-Dīn Fārisī's critical study of this same work, supplemented by a few of Ibn al-Haytham's independent optical writings (*On the Quality of Shadows*, *On the Form of the Eclipse*, and *On Light*), together with an examination of his own treatises (*On Burning Sphere* and *On the Rainbow and Halo*), expanded the topical range of his *Tanqīh al-manāẓir* to include all but the study of burning mirrors. The disciplinary developments are also reflected through a variety of related sources. Al-Fārābī's (d. AD 950) *Iḥ al-'ulūm* (Enumeration of the Sciences) describes *'ilm al-manāẓir* as including not only the science of mirrors (*'ilm al-marāyā*), but also such topics as the vision of distant objects and the application of vision in surveying. At the same time as the combination of the subjects of mirrors, or even burning mirrors with that of vision was not so uncommon, treatments of what are now considered optical problems often appeared in their own "proper place." Thus theories of light and perception were treated in philosophical works (following Aristotle), as in the related works of Ibn Sīnā (Avicenna, d. AD 1037), or Ibn Rushd (Averroes, d. AD 1198). Treatments related to the anatomy of the eye appeared in medical treatises (following Galen), as in the works of ► **Hunayn ibn Ishāq** (d. AD 877). Such subjects as burning instruments were more commonly treated as part of the respective traditions of Diocles and Anthemius on *Burning Mirrors*, as

in the case of Abū Sa'd ► **Ibn Sahl** (ca. AD 984). Shadows continued to be treated in books called *kutub al-aẓlāl* (Books on Shadows), as in Bīrūnī's (d. AD 1048) work devoted to this subject, and halos and rainbows often appeared in meteorological and astronomical literature, as in the case of Ibn Sīnā and Quṭb al-Dīn Shīrāzī (d. AD 1311). It was not until the conscious effort of Shīrāzī's student, Kamāl al-Dīn Fārisī, that most of these subjects were integrated into optics (Sabra, 1987a, b, 1989).

Theoretical Developments

At the very beginning of the text which set out to place the science of optics on a new foundation and was instantly recognized and utilized as the most complete work on the subject in Europe, Ibn al-Haytham wrote: "For two opposite doctrines, it is either the case that one of them is true and the other is false; or they are both false, . . . the truth being other than either of them; or they both lead to one thing which is the truth each of the groups holding the two doctrines must have fallen short of completing their inquiry" (Sabra 1989). Here, Ibn al-Haytham was reflecting on a long controversy in visual theory, which had taken shape between the mathematicians and physicists before him and for which he managed to find a lasting solution.

The Greek mathematicians had explained vision through the assumption of visual rays extended from the eye towards the visual object. The best known among these were Euclid, whose *Optics* represents a geometrical approach to the study of vision, and Ptolemy, who had added an experimental and psychological dimension in his own *Optics*. The Galenic version of the visual-ray hypothesis as contained in *De usu partium* included the anatomical aspects of vision and stressed the role of medium through its own physiological approach. So did, Aristotle's language of the reception of forms which was more adopted by the physicists, or natural philosophers, in matters regarding vision. Islamic theorists writing in the tradition of each of the major Greek philosophers on vision did not always fall

strictly into one group or another (Lindberg, 1978). The visual-ray theorists (*aṣḥāb al-shu'ā*) and the upholders of the theory of forms (*aṣḥāb al-injibā'*), to which Ibn al-Haytham repeatedly refers in his search for a systematic solution, often consisted of more than one group. The first included in addition to mathematicians (*ta'limiyyūn*), the followers of Plato or Galen or even theologians (*mutakallimūn*), while its immediate rival, natural philosophers (*ṭabī'iyyūn*) covered both Aristotelians and atomists. The illuminationists (*ishrāqiyyūn*), who proposed an alternative form of perception altogether, had their own forms and variations. Ibn al-Haytham's solution to many complex problems raised by the first two groups was not only an attempt to determine such central questions as the direction of radiation in vision. The significance of his most celebrated work, *Kitāb al-Manāẓir*, goes much beyond treatments of the problems of vision. Having been translated into Latin in the late twelfth or early thirteenth century and then into Italian in the fourteenth century, with a printed Latin version in the sixteenth century, the book had an impact on the epistemology of late medieval Europe, the linear perspective of Renaissance artists, and study of light all the way to the seventeenth century, with a list of figures including Roger Bacon, Witelo, Pecham, Ockham, Oresme, Ghiberti, Snellius, Kepler, Descartes, Barrow, and Huygens. Ibn al-Haytham's contribution to the study of light included the assumption that light requires a body (a medium) for its transmission, that its movement from the object to the eye is not of infinite speed, though too quick to be perceived by sense, and it is "easier" and "quicker" in rarer media. His non-traditional conception of a finite, imperceptible interval of time for the movement of light was defended and advanced by a few in the Latin West, and his appeal to mechanical analogies to explain reflection and refraction were adopted by many later thinkers (Sabra, 1962, 1967). The earlier independent researches of the tenth century mathematician Abū Sa'd ► **Ibn Sahl** and his anticipation of Snell's law have been the subject of a recent study (Rashed, 1993). Earlier developments upon which Ibn al-

Haytham's concepts of light and vision are clearly dependent include a principle now referred to as the "punctiform analysis of light radiation" (Adamson, 2006; Lindberg, 1976). An ancient conception based on rectilinear radiation, it grew on the assumption of a one-to-one correspondence between points on a visible surface and the eye, laying the foundation for the geometry of sight of the Western perspectivists and of Kepler. The principle can already be traced not only in the works of earlier Arabic authors such ► **al-Kindī**, but even in the way Euclidean assumptions were translated into Arabic, thereby stretching the period and importance of theoretical developments to the early ninth century. Immediate preoccupation with crucial questions about the exact nature of visual clarity and the structure of the visual cone (the role of central ray, the shape of its base), goes back to this same early period. Sometimes, concepts were positively affected by the adopted Arabic terminology: the expression for visual "clarity," for example (*kathrā*, also meaning multitude and magnitude), led to questions that were themselves the starting points for many later discussions in medieval Europe. Other times, word choices had an opposite effect: in the case of "refraction", the non-standard adoption of its terminology (in 'itāf) for reflection (in 'ikās), led to a particularly problematic treatment of indirect vision (i.e. vision through mediums), in addition to the poor reception of the relevant parts of the *Optics* of both Ptolemy and Ibn al-Haytham in some parts of the Islamic world (Kheirandish, 1996, 2004). But the limited understanding of concepts such as "refraction" did not provide a major obstacle for important theoretical developments later, including the correct explanation of the theory of rainbow formation. Explanations of the primary and secondary bows in terms of the refraction of light in raindrops were offered by Quṭb al-Dīn Shirāzī and later refined through experimental means by his own student, Kamāl al-Dīn Fārisī in Islamic Persia, almost at the same time as Theodoric of Freiberg's (d. ca. AD 1310) theory of rainbows was being offered. A major obstacle, however, did prevent proper treatment of inverted images within the eye in direct vision

(i.e. vision through air), an obstacle occasioned by physiological shortcomings in Ibn al-Haytham's otherwise "revolutionary" achievements in optics (Sabra, 2002). Kepler's much later treatments provided the necessary breakthroughs in involving upright retinal images and focal properties of lenses; but they are also notable for representing theories of vision and light in a manner that has made their respective treatments viewed as a continuation and break with the past, depending on their perceived stress on vision and light respectively (Lindberg, 1976; Smith, 2004). The earlier Islamic authors, both before and after Ibn al-Haytham, have their own share of historical achievements and contributions: they not only changed the face of the theoretical and disciplinary problems in optics, they also lay new methodological standards for optical inquiries.

Methodological Developments

The historical relationship between the sciences of optics and astronomy had a particularly important effect on the development of the methodological dimensions of the field. Euclid's *Optics* was among the Intermediate books (*mutawassitāt*), studied after his own *Elements* and before Ptolemy's *Almagest*. But optics was also to borrow from astronomy, though in a markedly different form and pace. The notion of *i'tibār* (experiment) was adopted and transformed by Ibn al-Haytham from astronomical works to be used in optics, as a methodological measure to replace geometrical demonstrations related to light and vision with experimental ones (Sabra, 1971, 1994). This, however, occurred only after the old Aristotelian superior-subordinate relationship of disciplines was replaced first by their cooperation (*ishtirāk*) (in the ninth century), and then by their combination (*tarkīb*) (in the eleventh century). So the full service of astronomy to optics came relatively late. The imported experimental dimension was a significant step for the methodological transformation of the science of optics (Sabra, 1989).

Before this transformation, the discipline's methodical guidelines relied heavily on the teachings of Aristotle. For Aristotle, optics was a branch of geometry and one of "the more physical of the mathematical sciences" (*Physics*, 194a 6–11). The method of applying geometrical demonstrations to propositions on vision was adopted by Euclid, and through him more directly by Arabic optical authors. But alternative methodological approaches had already begun with a few early Islamic scholars. ► **Al-Kindī**, who reminded the reader in the preface of his *De aspectibus* that "geometrical demonstrations would proceed in accordance with the requirement of physical things," supplied geometrical demonstrations with experimental ones throughout his text. About the same time, ► **Qusṭā ibn Lūqā** spoke in a text on optics and its application to mirrors about "the cooperation" of natural philosophy (from which we acquire sense perception) and geometry (for its geometrical demonstrations). Even in the early text of Aḥmad ibn 'Īsā, specifically titled as being "in the tradition of Euclid," Euclidean examples were sometimes supplemented by "sense-based examples" – those to be set up (Kheirandish, 2002).

Ibn al-Haytham would continue to regard experimental optics as a mathematical inquiry. But in the course of his attempt to examine the study of vision and its foundations, the methodology of the mathematical science of optics was to be transformed radically. The synthesis (*tarkīb*) of physics (involving questions concerning the nature of light), and mathematics (dealing with manner of its propagation), following his explicit division between physical (*ṭabī'īyya*) and mathematical (*ta'līmīyya*) inquiries as two separate criteria, was at the heart of a new methodology that was to change the discipline. Ibn al-Haytham's contemporary, Ibn Sīnā, adopted a somewhat different methodological approach when he supplemented his critical remarks on previous treatments of rainbows with detailed observations of his own. Kamāl al-Dīn al-Fārisī, acknowledging the guidance of his predecessor, and inspired by his teacher, Qutb al-Dīn ► **al-Shīrāzī**, added an unmistakably modern experimental touch to such observations.

He reproduced an artificial object, such as a spherical globe filled with water to represent raindrops, as part of a conscious shift from traditional explanations of the phenomenon of the rainbow in terms of clouds acting as a concave mirror, to one in terms of the passage of light through a transparent sphere. By this later period, the field not only included subjects and theories more easily associated with optics today; it had also acquired the more modern methodological approach of “controlled” experimentation.

See Also

- [al-Bīrūnī](#)
- [al-Kindī](#)
- [al-Shīrāzī](#)
- [Ḥunayn ibn Ishāq](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn Rushd \(Averroës\)](#)
- [Ibn Sahl](#)
- [Ibrāhīm Ibn Sinān](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Physics](#)
- [Qusṭā ibn Lūqā](#)

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Oracle Bones

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The practice of burning animal bones for divination in China reaches back to the fourth

millennium BCE. It attained increasing levels of sophistication in the preparation and variety of animal bones used under the Shang, beginning in the sixteenth century BCE (Venture 2009). This entry will concentrate on inscribed Shang oracle bones, which date to the late Shang period. A conservative estimate of oracle bone inscriptions places their production to around 1200–1045 BCE (Keightley 1978). They are considered to be the earliest available evidence of the first systematic form of writing in China. Indeed, Shang characters are direct predecessors of some modern Chinese characters (Boltz 1994). Philologists and sinologists have done much to interpret and translate these oracle bones, a significant number of which had been unearthed in the late Shang capital of Anyang, in Henan province (Academia Sinica 2010a; UNESCO World Heritage Centre, n.d; Yin Xu 2007). Although interpretative work with primary material is still ongoing (Chang 1980; Ivanhoe 1996; Keightley 2000, 2001, 2006; Serruys 1974), this entry will present implications that can be drawn from Shang oracle bone inscriptions for conceptions of widespread philosophical import, those of agency and narrative.

Shang characters were displayed in a quite specific organization that reflected the procedure by which the bones and plastrons on which they were inscribed were used in divination and which is highlighted in some translations (Keightley 1978). Inscriptions are structured into what specialists have called preface, charge, and prognostication, other aspects of the structure, such as verification and postface, being here omitted for the sake of brevity. While any one of these positions in the structure might be unfilled in a particular example, the preface recorded the ritual day on which the divination was performed and the name of the diviner, while the charge is thought to have expressed the topic of divination issued by or on behalf of the king. The surface of a turtle plastron or animal bone was cracked by scorching hollows that had been prepared in its underside, and the crack was assessed by the king, whose evaluation, when present, was recorded as a prognostication. We may call the organization

into preface-charge-prognostication, inscribed over a ritually cracked bone or plastron, a configuration (Vicas 2011).

The way these elements are visually organized on a bone or shell is material to understanding the configurational character of the divinatory record (Academia Sinica 2010b). Here is an example, displaying symmetry of presentation around the central axis of a turtle plastron, from around 1240 to 1181 BCE:

(Preface:) [line (4)] Crack-making on <i>xinyou</i> (day 58), Que divined:	(Preface:) [line (3)] Crack-making on <i>xinyou</i> (day 58), Que divined:
(Charge:) “(This season) the king should not follow Zhi Kuo (to attack the Bafang, for if he does, we will not perhaps receive assistance in this case.)”	(Charge:) “(This season) the king should follow Zhi Kuo (to attack the Bafang, for if he does, we will receive assistance in this case.)”
(Preface:) [line (6)] Crack-making on <i>xinyou</i> (day 58), Que divined:	(Preface:) [line (5)] Crack-making on <i>xinyou</i> (day 58), Que divined:
(Charge:) “(This season) it should not be Zhi Kuo that the king follows (to attack the Bafang, for if he does, we will not perhaps receive assistance in this case.)”	(Charge:) “(This season) it should be Zhi Kuo that the king follows (to attack the Bafang, for if he does, we will receive assistance in this case.)”

(Keightley, 1978, pp. 78–79, with adaptations)

The next example is of an oracle bone that contains five 10-day divinations, which were quite typical in the last period of Shang bone divination inscriptions (around 1100–1041 BCE). The bottom-most inscription is translated as follows:

(Preface:) On *guichou* (day 50), the king made cracks and divined:
(Charge:) “In the (next) ten days there will be no disaster.”
(Prognostication:) The king, reading the cracks, said: “Auspicious.”
(Keightley, 1978, Fig. 10)

The other inscriptions, running from the bottom to the top of the bone, record 10-day divinations, the repeated charges and auspicious prognostications made on *guihai* (day 60), *guiyou* (day 10), *guiwei* (day 20), *guisi* (day 30), *guimao* (day 40), and *guichou* (day 50).

The preface provides the time specified with respect to a 60-day ritual calendar, in which dead ancestors received cult names that situated them within recurring cycles of 10-day weeks. The charge is something like a conversation opener, proposed by the ruler (or a diviner on behalf of the ruler) and proffers the matter for consultation with an ancestral spirit or, sometimes, a nature power. The crack was taken to be the mark of an ancestor voicing in response to a charge. Finally, the prognostication conveys what the king understood the voicing to mean (Keightley 1978). Putting this all together, one might say that Shang oracle bone inscriptions present configurations in which a combination involving charge-surface crackings issued in ritual calendar time and calling for interpretation conveyed a dialogical collaboration between ruler and departed ancestor or sometimes nature forces. The presumed conversational exchange was accompanied by lavish sacrificial offerings of animal, and sometimes human, life. Its costliness in communal effort and expense marked the process as one having communal import. The ritual conversation would have been understood as bearing on significant communal matters having to do with the acquisition of resources, the opening of new fields for cultivation, the impact of winds and rains, or the conduct of military campaigns and hunting parties (Chang 1980; Keightley 2000).

Implications for a Conception of Agency

We now tend to think of what a king should do in battle or whether some bad will befall his going about his business as information that can be extracted from the record the Shang provided and placed in causal-linear chains of occurrence. That would be a hasty inference. In the often-repeated charge, “In the (next) ten days there will be no disaster,” the presence or lack of disaster is not linked to any occurrence in the previous 10-day period. It would have been so linked if the Shang conception of agency lent itself to a causal analysis (Bunge 1979; Pearl 2009). On a causal conception of what humans do, some action that the king performed in one of the 10-day cycles

could be extracted from the configuration in which it was presented and tied in a one-way link of dependency to some action performed in later 10-day cycles. We do not, however, find this in Shang records. The auspiciousness of kingly initiatives in any 10-day cycle must be ritually, conversationally, divined anew, every 10-day cycle. In fact, a most striking aspect of Shang divinatory records of any period is their repetitiveness, of which the two examples above give only a small taste.

Indeed, neither one of the examples mentioned above suggests an analysis of events in terms of a one-way dependency traveling over connected chains or forks, in which human or other agents intervene (Pearl 2009). If it had, the divination record would have been organized quite differently. Its formulation in terms of causal relations would have made the repetitions redundant. But they were not redundant. Rather, meaningful action is embedded in blocklike wholes, configurations, which must be reproduced anew in every exercise in divination. These blocklike wholes provide the record of a ritual conversation between king and ancestor – or sometimes a natural power – that was thought to have manifested itself in the presence of communal attention directed to the medium through which the conversation occurred, an oracle bone or turtle shell.

If forms of expression are any indication of patterns of thought at work, then one might propose that the Shang thought of agency as being organized in terms of proffered aspects of copresence that are illuminated by communal focus. Shang oracle bone inscriptions present a conception of human action as embedded in a blocklike configuration, which conveys what lies in attentional focus, namely, a specified combination of ritual time-action-evaluation, understood to have been manifested in the course of ritual conversation. Everything mentioned as part of a configuration simply is, and nothing can be discounted as merely apparent or spurious. The Shang do not seem to have had any use for the assumption that there is an essential, unchanging structure of reality that undergirds variable appearance. Whatever can be attended to is

captured in the organization of a configuration expressed in the oracular record. By implication, there is also no evidence that the Shang thought of divination as being about a fully determinate future contingent action, tied by genetic links to a present action, a view concerning agency reported in Cicero's *De divinatione* (1923), and which came to be prevalent in Western, post-Aristotelian thinking. That is not to say that the way of thinking about agency here imputed to the Shang does not support a conception of change. The conception of change that is implicit in Shang oracular records is that of a juxtaposition of configurations in a series of oracular consultations, indexed with respect to the order of scorching, which was often numbered, and order of occurrence within the ritual calendar.

Thus, human agency is embedded in configurations, which express what is manifested in conversation. Individual action is thought of in terms of a dialogical exchange, which takes place in the purview of communal attention. It is important to note what is missing in this picture, to which we have grown so accustomed. That is the idea that there is an inner structure within individuals, whether they are part of a community or not and whether they engage in dialogue or not, that drives them to act and that can be extracted from some underlying reality standing behind what is apparent in experience (Aristotle 1984a).

Implications for a Conception of Narrative

The view concerning agency that is here attributed to the Shang has direct implications for narrative. The idea that action is produced by genetic factors is widespread. It supports a conception of narrative, which is indebted to Aristotle's discussion of tragedy in *Poetics* (Aristotle 1984b). According to this view, narrative is the representation of causal-linear sequences of agent actions, including inner causes that drive agents to act, organized into a complete whole. This conception is so common that some, today, even take it to be built into human culture by natural selection (Boyd 2009).

If agency is thought of as embedded in configurations rather than in terms of events tied to causal-linear links, narrative would also not be conceptualized in terms of causal-linear links among agent actions. Shang-inscribed oracular material provides records of sequences of configuration-expressing bones or plastrons, which convey a shift from one configuration to another. These sequences are modeled on conversational exchanges in which combinations of charge-cracking-prognostication, issued in ancestral calendar time, are part of a process of dialogical co-completion between ruler and departed ancestor. A Shang conception of narrative that could be inferred is that of an ordering, in the calendar of ancestral time, of responsorial co-completions, recorded as configurations (Vicas 2010). Oracle bone inscriptions mark ritual events that were modeled on conversational exchanges between family members. Oracle bone or plastron cracking was, nevertheless, not likely to be a private affair. It was accompanied by lavish sacrificial offerings (Keightley 1978, 2000). These included many animal and human victims, the marshaling of which must have required substantial community involvement in successful staging, if that is the proper term for what must have been a frightful display. The ritually prepared and scorched bones and plastrons were the objects of community attention. Thus, narrative would not have been construed to be personal, but communal. The call-and-response sequences they were thought to record provide the grounds for the story of a people. Indeed, they are the source of our knowledge of the history of the Shang.

Specialists will continue to debate about how to interpret Shang oracle bone inscriptions. What we gain from the work they have already accomplished is the opportunity to ask questions about cross-cultural concerns: What are the different ways of thinking about what we do and how we talk about it? Shang oracle bone inscriptions are important in their own right. But they also offer a fresh outlook on human agency and narrative that may help us achieve greater flexibility in the ways we are prepared to think about these core concepts.

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Origami

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Origami is the art of folding paper into works of sculpture. No one knows when or where the art of paper folding started, but many scholars believe that the invention of paper in China around 100 BCE (see the Institute of Paper Science and Technology website) had to have coincided with the first attempts at paper folding.

However, while there is evidence of paper folding developing around the world as paper making technology spread, it was the Japanese who embraced the art form as part of their culture. In fact, *origami* is a Japanese word made up of two characters: *oru* meaning “to fold” and *kami* meaning paper. The Japanese language has many homonyms-words that sound the same but mean different things. *Kami* is one such word; in addition to “fold” it also means “god” or “deity.” Some people have conjectured that this is not a coincidence, and that this reflects why the Japanese Shinto religion uses folded paper to symbolize the spirits of deceased relatives. However, the Japanese language simply has so many homonyms that this might actually be a coincidence.

Records of ancient Japanese folding are hard to find. Certainly by the Edo period (1603–1867) in Japan numerous paintings and woodcuts can be found depicting upper class women folding the traditional crane, or *orizuru*. Also in the 1800s a

few books on recreational origami were produced in Japan. Most references historians have found to origami prior to the 1800s are religious and cultural-based. As far back as the 1600s origami butterflies were placed over the stoppers of sake bottles for wedding ceremonies, and folded paper streamers called *go-hei* were hung in Shinto temples to represent spirits of the dead. Such streamers can still be found in modern Shinto shrines (Fig. 1).

The fact that by the 1800s people in Japan were folding paper recreationally, as opposed to only for ceremonies and religion indicates that origami had grown into a standard art form by this time. It is in the Edo period that one finds references to the classic Japanese crane and frog models (Fig. 2). However, there is also evidence that some Edo-era Japanese origamists were exploring the science and mathematics of paper folding-something which modern mathematicians have only been researching in depth for the past 30 years. In Edo-era Japan there was a practice of placing artistically painted geometric problems on small wooden panels in Shinto temples. These tablets, called *sangaku*, were displayed to be read by the temple visitors as challenges to solve. This practice was prevalent throughout Japan, and it indicates some level of public interest and education in geometry-enough to solve such problems recreationally in the same way that people today buy puzzle books for mental challenges. In his book *Japanese Temple Geometry Problems*, Hidetosi Fukagawa describes over 250 examples of *sangaku*, some of which are extremely sophisticated. Two of his examples are based on origami. One, shown in Fig. 3, illustrates how to tie a strip of paper into a pentagonal knot (Fukagawa, 1989, p. 49). The challenge is to prove that this knot makes a regular pentagon (all sides of equal length).

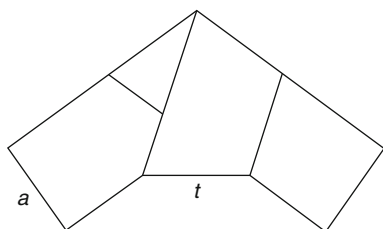
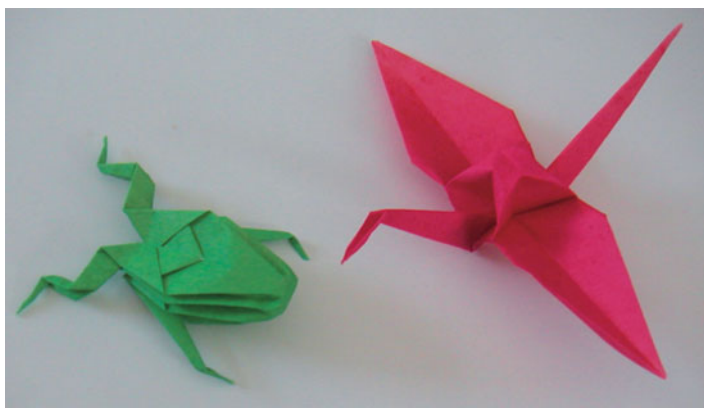
The second example, in Fig. 4, shows a much more complicated instance of paper folding geometry. Here we are asked to take a square piece of paper and fold one corner to an arbitrary point on the opposite side. The text of this *sangaku* is more elaborate.

A square sheet of paper $ABCD$ is folded as shown in the figure with D falling on D' , which

Origami, Fig. 1 *Go-hei* paper streamers at a small Shinto Shrine outside of Tokyo, Japan (Photo by Thomas Hull. Used with permission)



Origami, Fig. 2 The classic Japanese frog and crane (*orizuru*) models (Photo by Thomas Hull. Used with permission)



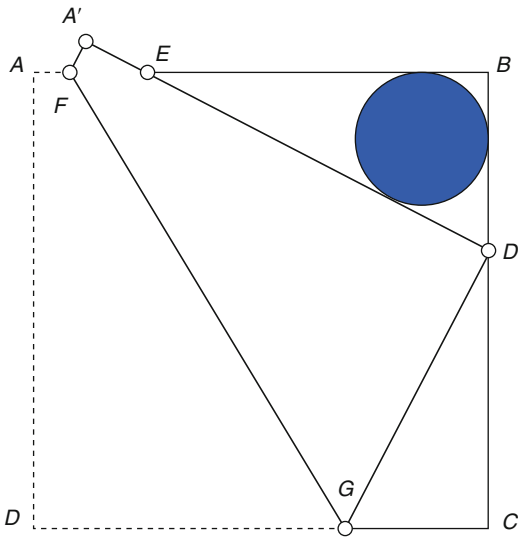
Origami, Fig. 3 The pentagon knot *sangaku*. “Construct a Regular Pentagon by Tying a Knot in a Strip of Paper of Width a . Calculate the Side t of the Pentagon in Terms of a .” (Fukawaga, 1989, p. 49)

lies on BC , with A falling on A' , and $A'D'$ intersects AB at E . A circle is inscribed in triangle EBD' . Show that the radius of this circle is equal to $A'E$ (Fukagawa, 1989, p. 37).

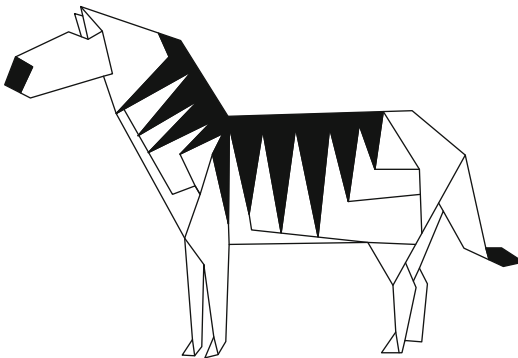
Amazingly, the geometric principles at play in the *sangaku* of Fig. 4 were independently discovered over 100 years later by Kazuo Haga,

a Japanese teacher who specializes in origami geometry. In fact, the geometric property that triangles $CD'G$ and BED' and $A'EF$ are all similar is known as Haga's Theorem. That ancient paper folders were exploring the same kind of origami geometry as modern investigators is a testament to the powerful utility of origami as a device for exploring mathematics.

The Meiji Restoration (1866–1869) and aftermath saw the decline of a number of classic Japanese arts, including origami. But the practice did continue, and after World War II origami emerged again as an art form. The most influential person in this effort was Akira Yoshizawa, who tried to popularize origami in his country by creating hundreds of new models, holding exhibitions, and creating the International Origami Association. He also began important correspondences with people from other countries, in



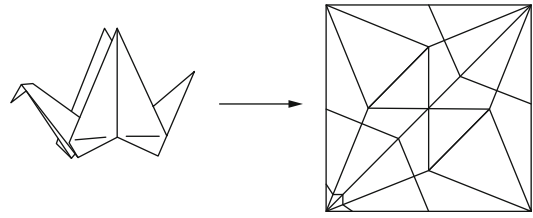
Origami, Fig. 4 A more intricate origami *sangaku*



Origami, Fig. 5 John Montroll's zebra model (Montroll, 1991), folded from a square sheet of paper, *black* on one side and *white* on the other, with no cuts

particular Lillian Oppenheimer of New York, Robert Harbin of the UK, and Gershon Legman of France. This helped spread the art of origami to other countries, and these same people were pivotal in the creation of the organizations Origami USA, the British Origami Society, and the Mouvement Français des Plieurs de Papier.

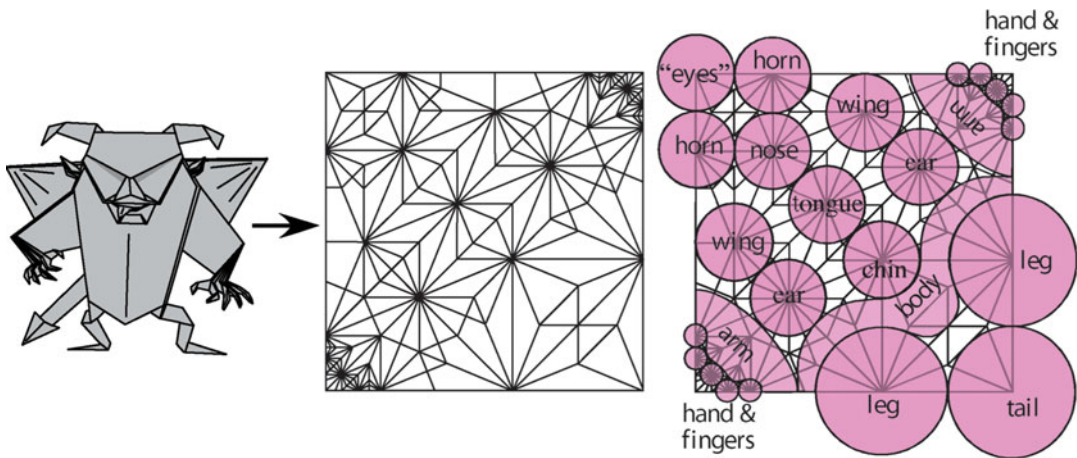
Partly due to the work of these organizations, origami art went through a renaissance in the late twentieth century. In 1979 American paper folder John Montroll published his first book (Montroll, 1979) which contained origami models at a level



Origami, Fig. 6 The crease pattern for the classic flapping bird

of complexity never before seen in the origami world. For the first time, paper folders began to see that it was possible to, for example, fold a grasshopper, complete with six legs, wings, abdomen, thorax, head, and two antennae, all from a single square of paper with no cuts involved. The techniques with which he used to do this, which blended methods from classic Japanese models with brand new approaches, were mined by other origamists, starting a wave of complex-level origami design. Among the artists who emerged during this period was Robert Lang, who began systematically, analyzing the mathematics behind such complex designs. In addition, numerous Japanese folders, like Jun Maekawa, Fumiaki Kawahata, and Toshiyuki Meguro, developed their own methods and raised the level of complex origami to new heights (Fig. 5).

These design methods can be understood by considering the *crease pattern* of an origami model (Fig. 6). This is a diagram of a piece of paper with lines representing the creases used in the final origami model. This can be thought of as a blueprint for the design. In particular, modern origami designers can plan their design by thinking of any appendage that they need, be it the leg of an insect or the head of a horse, as requiring a circle of paper in the square to be devoted to that appendage. In other words, that circle, when folded, can be thought to collapse like an umbrella to create the appendage. This turns origami design into a problem of packing circles of different sizes into a square, and many modern origami designs can be analyzed in this way. Figure 7 shows a model by Jun Maekawa from the mid 1980s with its crease pattern and circle decomposition.



Origami, Fig. 7 Jun Maekawa's winged demon (Kasahara et al., 1983) with its crease pattern and circle. Decomposition

Complex design methods have been developing and becoming more popular in the origami community since the 1980s, culminating in Robert Lang's compendium on the subject (Lang, 2003), where he describes how much of origami design can be done on a computer. Some origami artists have complained that paying such attention to complexity is forcing paper folders to forget the more subtle, artistic expression that origami can achieve. Others have been using computer methods as a quick way to get a design, and then focus on artistry as they try to achieve this design in actual paper. In any case it is clear that origamists today are folding things that people 10 or 20 years ago never would have thought possible.

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Origins of Agriculture in Egypt

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Egyptian civilization has a long history. The artistic genius engendered by the Egyptian craftsmen, the superb condition of many burial chambers, and the dry climate have made it possible to reconstruct a history of agricultural technology. Paleolithic-Neolithic artifacts (flint hand axes, arrowheads, hammers) along the Nile date back 12,000 years. A continuous 6,000-year record exists with a unique and productive agriculture at its base (Asimov, 1967; Darby et al., 1976; Janick, 2002; Singer, Holmyard, & Hall, 1954). From 4000 to 3000 BCE the people of the Nile valley formed a government, constructed the first pyramids, and established a highly advanced agricultural technology. The ancient names for Egypt underscore the relation between the land, the people, and its agriculture (Khattab, 2000). These include *Ta-meri*, the land cultivated by the hoe; *Ta Akht*, the land of flood and fertile soil; *Kmt*, the black soil; *Tamhi*, the land of the flax plant; *Nht*, the land of the sycomore fig tree; and *Misr*, the safe and civilized country. The name

Egypt was derived from the name of the Earth God, *Ge*, or from *Agpt*, referring to the land covered with floodwaters.

Knowledge of the history of Egyptian agriculture and horticulture can be gleaned from the archeological record supported by surviving written Egyptian documents, temple inscriptions, and commentaries from antiquity. The supporting technology can be vividly reconstructed from the artistic record, painted, and carved in tombs and temples dating from before 3000 BC-E. Agricultural activities were favorite themes of artists who drew or sculpted lively scenes of daily life that adorn the tombs of the pharaohs.

The development of Egyptian agriculture was not created in a vacuum. Egypt was an aggressive culture, and, at one time, Egypt ruled from present-day Libya in the west; Syria in the north-east; and Ethiopia and Somalia and, perhaps, portions of sub-Saharan Africa in the south. Egypt continuously incorporated technology as well as new crops from the Fertile Crescent (present day Israel, Jordan, Lebanon, Syria, and Iraq) as well as Africa. In addition there were contacts with the world beyond including Africa, Western Asia, and even China. Strands of silk have been found on mummies of the Pharaohs dating to about 1000 BCE, indicating an ancient exchange of spices and fabrics. A stream of immigrants and captives, as well as invasions by others, such as the Persians in 525 BCE, also contributed to new introductions of germplasm and technology.

To explain the unknown, the Egyptians created a complex and bewildering theology that drew on the sun and the sky as well as every form of life and later included a pantheon of human gods and goddesses. The Egyptian understanding and knowledge of plant and animal life was incorporated into both religious beliefs and art. Thus, papyrus, the symbol of lower Egypt, and the lotus, the symbol of upper Egypt, were incorporated in numerous paintings of hunting scenes, floral offerings, as well as the architectural designs of columns (Fig. 1a, b, e, f). The unification of upper and lower Egypt is expressed not only by the fused hats of the pharaohs but also by the ceremonial intertwining of the two plants (Fig. 1c, d).

Crop Plants

Knowledge of crops of ancient Egypt can be deduced from the artistic record (Manniche, 1989), but definite proof comes from the desiccated remains of plants themselves. Many archeological remnants of both plants and animals can be viewed in the newly reconstructed Ancient Egyptian Agricultural Museum in Cairo.

The chief ancient grain crops, used for bread and beer, were barley and various wheats including the diploid einkorn (AA genome), the tetraploid emmer and durum wheats (AABB), and the hexaploid spelt and bread wheats (AABBDD). One of the ancient cereals of Egypt classified as *Triticum turgidum* (AABB) now marketed as Kamut® has recently been introduced to the United States.

The vegetable crops of ancient Egypt included a number of root crops, leafy salad crops, legumes, and various cucurbits. The ancient root crops such as the pungent alliums, garlic (*Allium sativum*) and onion (*A. cepa*), as well as radish (*Raphanus sativum*) continue to be very popular in modern Egypt. Among the leafy salad crops were lettuce (*Lactuca sativa*) and parsley (*Petroselinum crispum*). There were a number of pulses such as cowpea (*Vigna sinensis*), faba (broad) bean (*Vicia faba*), chickpea (*Cicer arietinum*), and lentils (*Lens culinaris*). The cucurbits included cucumber (*Cucurbita sativa*), melons and gourds (*Cucumis melo*), and later watermelon (*Citrullus lanatus*).

The fruit crops of Egypt were expanded throughout the centuries (Table 1). The date and doum palm as well as the sycamore fig are considered predynastic Egyptian fruits although the sycamore is not indigenous. The jujube, fig, and grape have been known since the Old Kingdom (Table 1); the carob and pomegranate were introduced in the Middle Kingdom; the olive and apple appear in the new Kingdom; and the peach and pear date to the Greco-Roman period.

About 2,000 species of flowering and aromatic plants have been found in tombs. An exquisite bas-relief depicting a visual representation of the fragrance from essential oils being extracted from an herb is found on the walls of the Philae temple



Origins of Agriculture in Egypt, Fig. 1 Papyrus and lotus symbols of upper and lower Egypt. (a) Hunting scene showing lotus and papyrus. (b) Offering of lotus and papyrus to Isis. (c, d) Intertwining of lotus and papyrus symbolizing the reunification of upper and lower

Egypt (Source: (c) Cairo museum, J. Janick photo, (d) Throne of Semusret I. 1900 BCE, Singer et al., 1954, Fig. 28). (d, f) The temple of Khnum (Kom Ombo) at Esna showing columns representing papyrus and lotus (J. Janick photo)

(Fig. 2a). Herb and spice plants important for culinary, cosmetic, medicinal, and religious uses, including embalming, were continually introduced. In the fifteenth century BCE, Queen Hatshepsut recorded the details of her expedition to Punt to fetch myrrh and spices (see Fig. 10). Herbs, spices, aromatics, and medicinal plants include *ami* or Ethiopian cumin (*Carum copticum*), anise (*Pimpinella anisum*), caper (*Capparis spinosa*), coriander (*Coriandrum sativum*), cumin (*Cuminum cyminum*), dill (*Anethum graveolens*), fennel (*Foeniculum vulgare*), fenugreek (*Trigonella foenum-graecum*), marjoram (*Origanum majorana*), mint (*Mentha spicata*, *M. sativa*), mustard (*Sinapis alba*), rosemary (*Rosmarinus officinalis*), safflower (*Carthamus tinctorius*), thyme (*Thymus acinos*), and pomegranate root.

Industrial and fiber crops were also important. Oil of the castor bean (*Ricinus communis*) was used for illumination and also as a medicinal, flax (*Linum usitatissimum*) for linen and oil, henna (*Lawsonia inermis*) for dye, papyrus (*Cyperus papyrus*) for paper and medicinal use, aquatic lotus (*Nymphaea lotus* and *N. caerulea*) for seed and decoration, and acacias (*Acacia* spp.) for gums and oils.

The ancient Egyptians loved flowers as evidenced by murals portraying court ladies wearing Egyptian lotus blooms, container-grown plants, and funeral garlands. Rameses III (1198–1166 BCE) founded pleasure grounds with “wide places for walking with all kinds of sweet fruit trees, laden with fruit, a sacred way, beautiful with flowers of all lands.” Small shrubs were grown in large earthenware pots

Origins of Agriculture in Egypt, Table 1 Evidence for fruit crops in Egypt (Source: Adapted from Darby et al., 1976)

Common name	Scientific name	Earliest record (dynasty or period)	Type of evidence
Date palm	<i>Phoenix dactylifera</i>	Predynastic	Archeological
Doum palm	<i>Hyphaene thebaica</i>	Predynastic	Archeological
Sycamore fig	<i>Ficus sycomorus</i>	Predynastic	Archeological
Jujube (Christ's thorn)	<i>Ziziphus spina-Christi</i>	I (Old Kingdom)	Archeological
Fig	<i>Ficus carica</i>	II (Old Kingdom)	Artistic
Grape	<i>Vitis vinifera</i>	II (Old Kingdom)	Archeological
Heglig	<i>Balanites aegyptiaca</i>	III (Old Kingdom)	Archeological
Persea (<i>lebakh</i>)	<i>Mimusops schimperii</i>	III (Old Kingdom)	Archeological
Argun palm	<i>Medemia argun</i>	V (Old Kingdom)	Archeological
Carob ^a	<i>Ceratonia siliqua</i>	XII (Middle Kingdom)	Archeological
Pomegranate	<i>Punica granatum</i>	XII (Middle Kingdom)	Archeological
Egyptian plum (<i>sehestem</i> , <i>mokheit</i>)	<i>Cordia myxa</i>	XVIII (New Kingdom)	Archeological
Olive	<i>Olea europea</i>	XVIII (New Kingdom)	Archeological
Apple	<i>Malus × domestica</i>	XVIII (New Kingdom)	Literary
Peach	<i>Prunus persica</i>	Greco-Roman	Archeological
Pear	<i>Pyrus communis</i>	Greco-Roman	Archeological
Cherry	<i>Prunus avium</i> ; <i>P. cerasus</i>	5 BCE	Literary
Citron	<i>Citrus medica</i>	Second century CE	Literary

^aA questionable literary reference dates to the first dynasty

(Huxley, 1978, 1998). Plant dyes were an important part of the cosmetic arts (Fig. 2b), and aromatic ingredients from flowers (Fig. 2c, d) were incorporated into oils and fats for use in perfumes, unguents, and ointments (Fig. 2e).

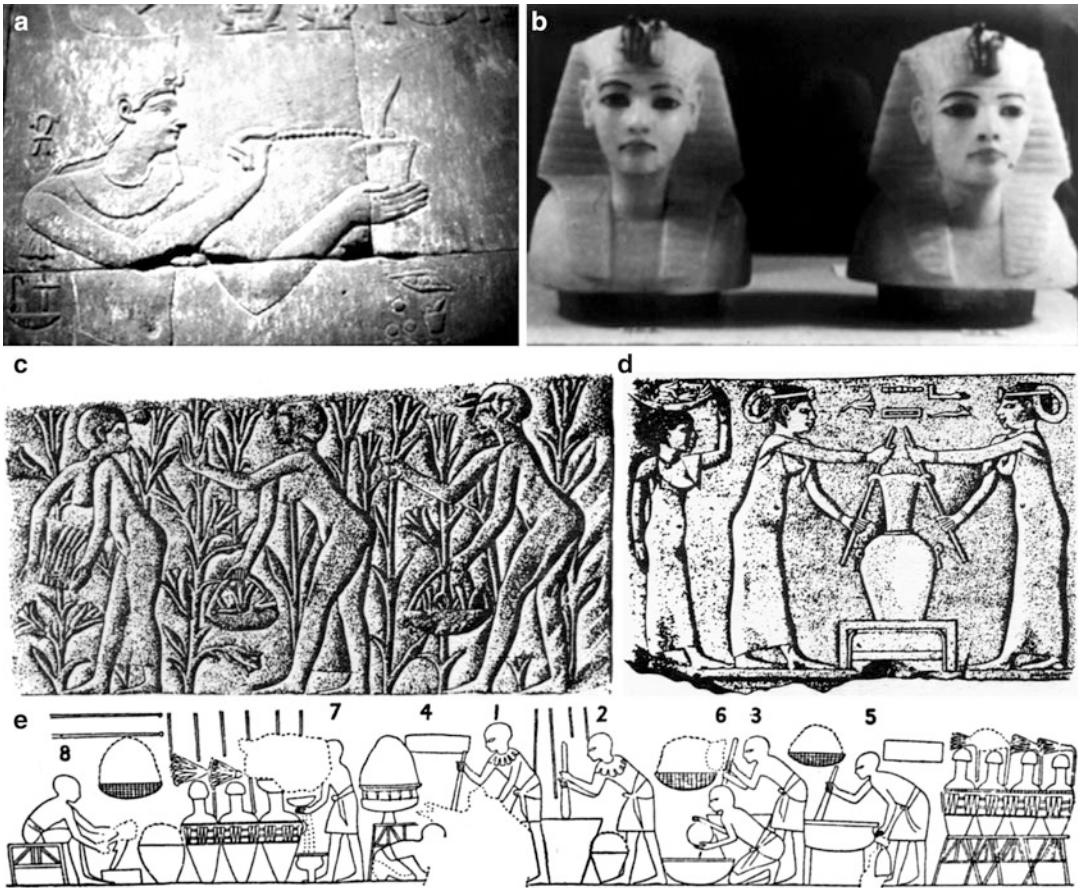
Irrigation and Drainage Technology

The Nile valley dictated the agriculture of ancient Egypt. Long stretches of flat lands were bordered by perpendicular mountains and inundated by constant rhythmic seasonal flooding.

Egypt gave the world the first hydraulic engineering and systematic irrigation (Fig. 3). The Nile rises and falls with regularity, rising in July (canals were opened August 22), and continues to rise until the middle of October, and then rapidly subsides. Crops were sown in November and harvested in April and May (Singer et al., 1954). Basin irrigation, the basic system, consisted of a system of dikes to retain the flood and encourage infiltration of the soil. Earthen banks paralleled the river while intersecting banks

creating a checkerboard of dike-enclosed areas, between 400 and 16,000 ha each. Canals led the water to areas difficult to inundate. The floodwaters ran through a series of regulated sluices into each basin, flooding the land to a depth of 0.3–1.8 m. The water could be held for a month or more; the surplus was drained to a lower level and then returned to canals which emptied into the Nile. The advantage of basin irrigation was that no further irrigation was needed for a winter crop of wheat, barley, or flax, and the silt rich in organic matter and phosphates made fertilization unnecessary.

Irrigation ponds were important for irrigation of fruit trees and for ornamental gardens (Fig. 3d; Fig. 12a–c, e, f). Shallow wells were 4–35 m in depth; deeper artesian wells were dug up to 380 m. Vegetables, flowers, vines, and fruit trees were grown near the rivers, by the banks of canals, and in prized gardens. These horticultural crops required constant and controlled irrigation during the spring and summer drought. At first irrigation was carried out manually with pots dipped in the river, carried



Origins of Agriculture in Egypt, Fig. 2 Perfume and cosmetics. (a) A visual representation of the fragrance from essential oils being extracted from an herb. Philae temple (dismantled and reassembled on Agilika Island, about 500 m from its original home), Aswan (J. Janick, photo). (b) Cover of alabaster canopic vase in Tutankhamon. Note lipstick and painted eyes. (c) Gathering lilies for their perfume (Source: Singer et al., 1954, Fig. 189) (d) Expressing oil of lily (Source: Singer et al., 1954, Fig. 189). (e) Compounding ointments and

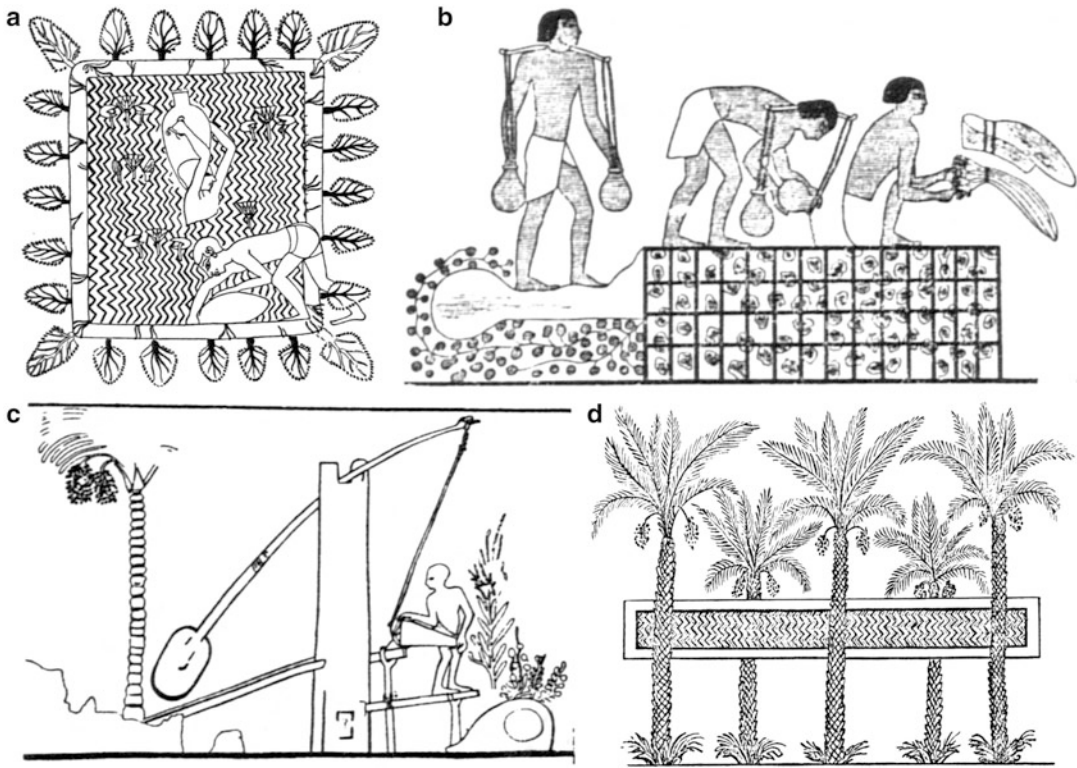
perfumes. Assistants crush dried herbs with pestle and mortar (1, 2, 3, 4). The crushed herbs are added to a bowl of molten fat, stirred (5), and shaped into balls upon cooling (6). Special jars probably containing spiced wine, a useful solvent because of its alcohol content is siphoned and filtered into a bowl (7). At extreme left an assistant shapes a piece of wood beneath a bowl heaped with unguents. Tomb at Thebes, ca. 1500 BCE (Source: Singer et al., 1954, Fig. 190)

on the shoulders with yokes, and poured into field channels (Fig. 3b). By the New Kingdom, the shaduf, a balanced counterpoise, became the irrigating mechanism for gardens (Figs. 1d and 12f).

Cultivation Technology

The basic tools of agriculture, the ax, the hoe, and the plow, are independent Egyptian inventions.

The prototype hoe can be seen as a modification of a forked branch, while the more developed form has a hafted wooden blade (Fig. 4a, b). The plow was at first a modification of the hoe, originally drawn through the ground, perhaps first by a man with a rope, but by the Old Kingdom by a pair of oxen (Fig. 4c, d). Later metal plowshares were added. In the New Kingdom handles were lashed by ladderlike cross pieces and the shaft was bound to a double yoke over the oxen's horns (Fig. 4d).



Origins of Agriculture in Egypt, Fig. 3 Irrigation technology in ancient Egypt. (a) Drawing water in pots from a lily pond (From a tomb at Thebes, Egypt. ca. 1450 BC-E. Source: Singer et al., 1954, Fig. 343). (b) Irrigating and harvesting in a vegetable garden. Gardeners carry pots attached to a yoke and pour water into checkerboard furrows; another ties onions into bundles (From a tomb at Beni Hasan, Egypt. ca. 1900 BCE. Source: Singer et al., 1954, Fig. 360). (c) Irrigation of a palm orchard by

a shaduf, using a water-lifting device consisting of a beam holding a long pole in which a bucket is suspended at one end and a large lump of clay acts as a counterpoise. The water is funneled to a mud basin at the foot of the palm (From a tomb at Thebes, ca. 1500 BCE. Source: Singer et al., 1954, Fig. 344). (d) Date palm with water storage pond in a distorted perspective (Source: E. Hyams, 1971, p. 18)

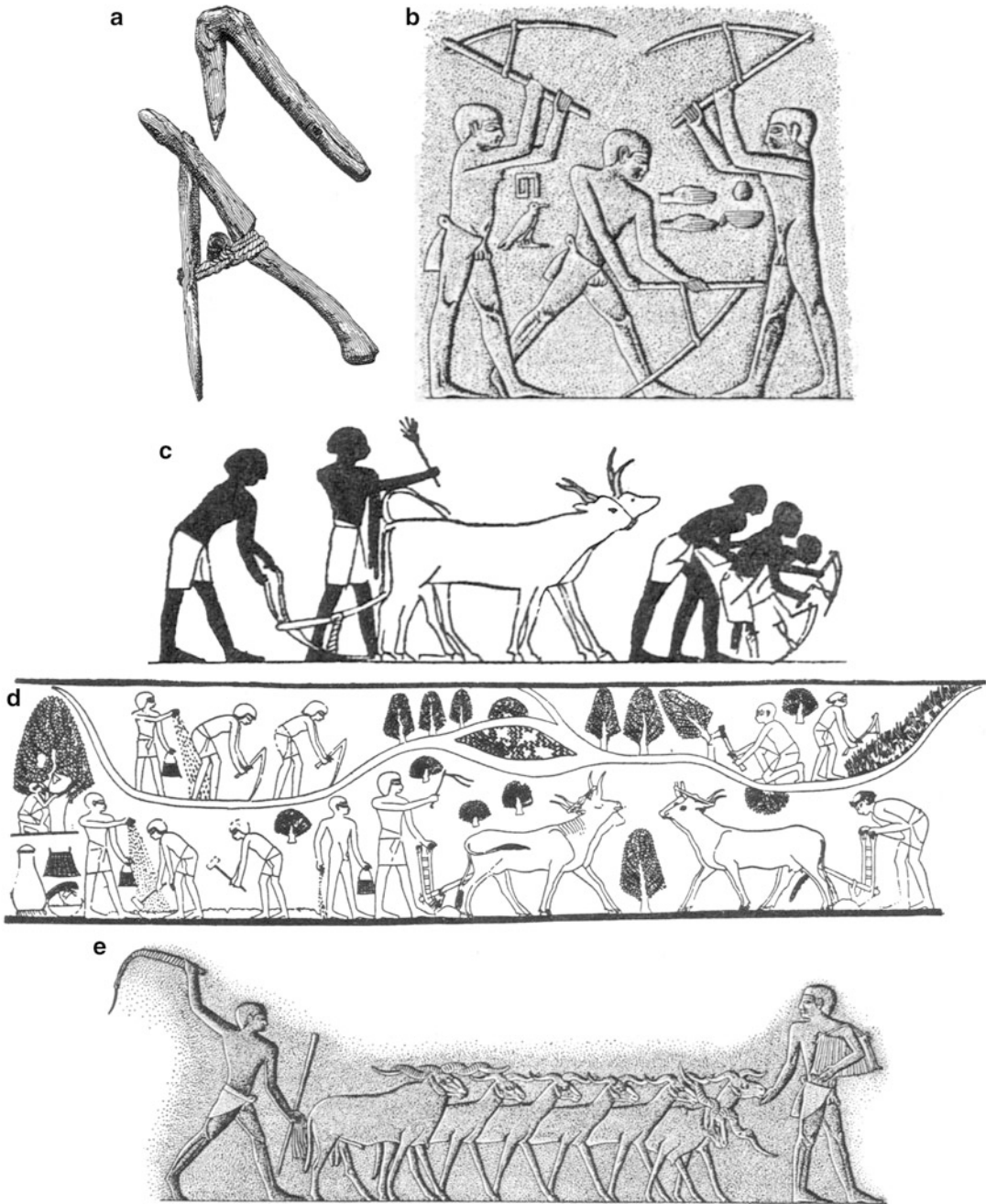
Sowing followed plowing. Often the sower scattered seed in front of the plough, so that the oxen treaded it in while fine seed as flax was shaken directly into the furrows (Fig. 4d). If the seed was sown after flooding, sheep, goats, or swine were driven to tread in the seed (Fig. 4e).

Surveyors measured fields for purposes of tax collection (Fig. 5a). Large stones were used to establish property boundaries (Fig. 3b). Moral teachings included the maxim: "Remove not the landmark on the boundaries of the sown, nor shift the position of the measuring-cord. Covet not a cubit of land, nor throw down the boundaries of the widow. . . Better a bushel that God giveth thee, than five thousand obtained by force."

Harvest and Postharvest Technology

Harvest and postharvest handling of grain were favorite themes in Egyptian art (Fig. 6). Early sickles, used to cut wheat, had flint teeth set in a wooden or bone haft followed by curved sickles with a short handgrip (Fig. 6a, b). Metal sickles were common in the New Kingdom. Wheat was bound into sheaves and loaded onto donkeys for storage (Fig. 6c) or later carried in net baskets. Fruit was collected and packed in shallow baskets, artistically arranged (Fig. 7).

Evidence of grain storage dates to Neolithic times in buried baskets or earthenware jars. Later the storage of grain and other provisions became



Origins of Agriculture in Egypt, Fig. 4 Cultivation technology in ancient Egypt. (a) Development of the hoe. (Top) Primitive hoe cut from a forked branch. (Bottom) A more developed form with hafted wooden blade. Both Middle Kingdom (2375–1800 BCE) (Source: Singer et al., 1954, Fig. 350). (b) Soil preparation by hoeing (From a tomb at Ti at Saqqara, ca. 2400 BCE. Source: Singer et al., 1954, Fig. 350). (c) Plowing and hoeing; from a tomb at Beni Hasan, ca. 1900 BCE (Source: Singer et al., 1954, Fig. 43).

(d) Land reclamation. Trees are being cut in land clearing; clods are broken with mallets; soil is plowed; seed is sown on prepared ground. Note ladderlike cross pieces on plow handle and shaft bound to a double yoke over the oxen horns (Source: Singer et al., 1954, Fig. 351). (e) Seed is treaded by sheep driven across a field. The sower offers them a handful of grain to lure them on while another drives them with a whip (From a tomb at Saqqara, Egypt, ca. 2400 BCE. Source: Singer et al., 1954, Fig. 353)



Origins of Agriculture in Egypt, Fig. 5 Surveying fields. (a) Surveyors measuring a field, probably to determine tax (From a tomb at Thebes ca. 1400 BCE. Source: Singer et al., 1954, Fig. 354). (b) Oath taken on a boundary

stone: *I swear by the great god that is in heaven that the right boundary stone has been set up.* ca. 1400 BCE (Source: Singer et al., 1954, Fig. 355)

a state function and communal silos and granaries were constructed (Fig. 8). In the temple of Abu Simbel built by King Rameses II (XVIII dynasty), the following words are carved: “I (the God Ptah) give to thee (Rameses II) constant harvests, to feed the Two Lands at all times; the sheaves thereof are like the sand of the shore, their granaries approach heaven, and their grain-heaps are like mountains.” (Darby et al., 1976). The Roman world considered Egypt the “bread-basket of the world.”

Viticulture

Grapes were much appreciated in ancient Egypt. There are abundant depictions of grapes, grape culture, and wine making (Fig. 9). Pliny reports that vines were grown directly on the field surfaces, but there are many representations of trellises and arbors (Fig. 9a). The round arbor was a common feature between the New Kingdom and the Greco-Roman period. Greek authors confirmed that various cultivars of *Vitis vinifera* were developed in Egypt. The biblical literature is rich with allusions to grapes and wine.

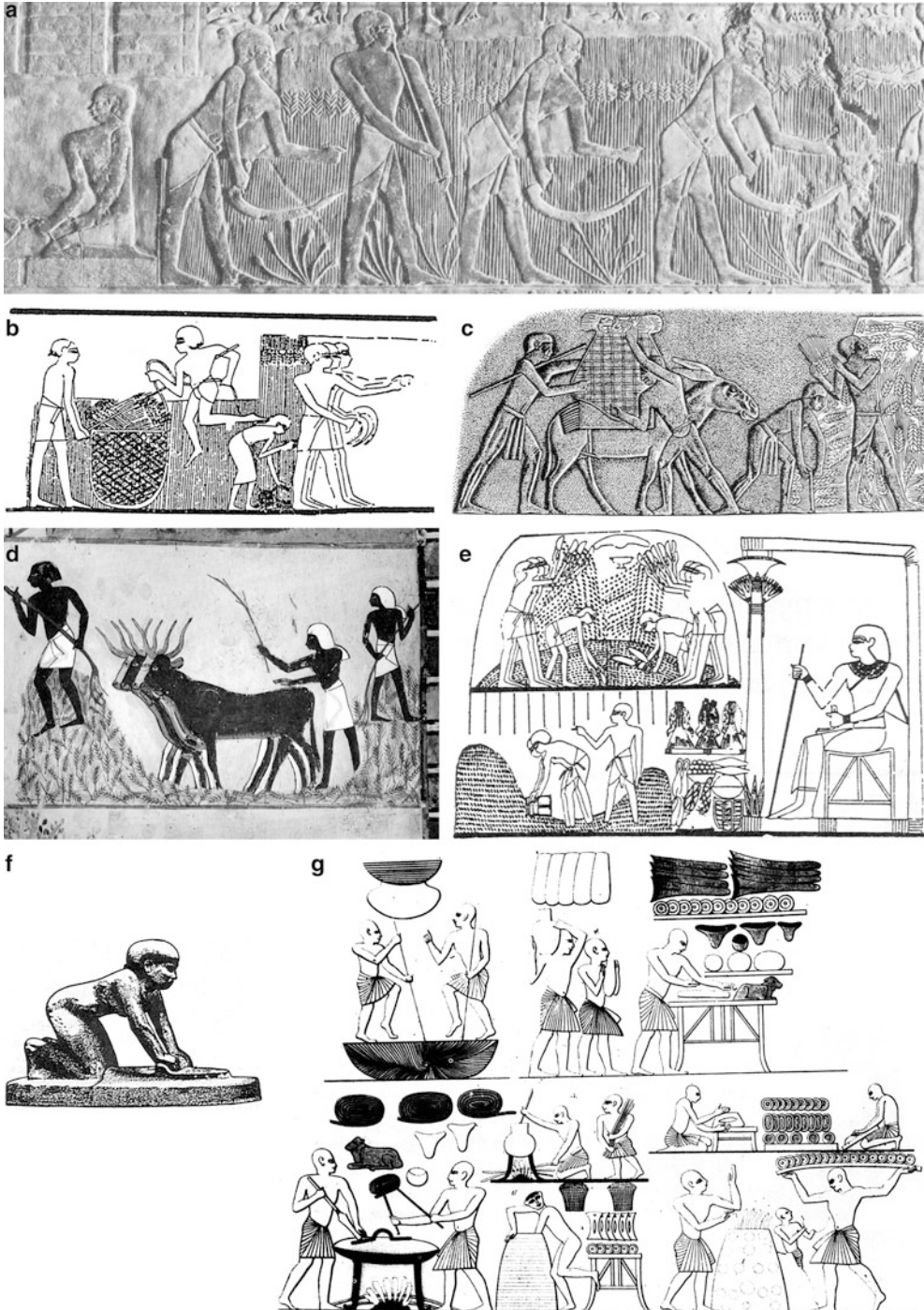
Grapes were preserved by drying. Raisins became favorite foods in cooking, were considered to have medicinal properties, and were at one time used as a drying aid in embalming.

Ripening Induction

One of the most interesting examples of horticultural technologies incorporated by the Egyptians was the promotion of ripening in the sycamore fig. The fig occurs spontaneously in the savannas of eastern Central Africa and in Yemen where they reproduce by seed although propagation is easily carried out by cuttings (Galil, 1968). Fruit set depends on pollination by a wasp (*Ceratosolen arabicus*) which enters the fruit. The sycomores were introduced to Egypt more than 3000 years BCE but not the wasp, so the fruits were seedless and dropped prematurely or if ripened naturally were full of insects and, thus, inedible.

A system of ripening parthenocarpic fruit was developed that involved scraping or wounding of the immature fruit. Gashing of the fruit induces speedy growth in 3–4 days, and the figs increase sevenfold in weight and volume, a process now shown to be an ethylene response. The wounding process yields an induced parthenocarpic fruit that matures before the development of insect pests which makes the fig inedible. Metal scrapers and gashed fruit have survived and are clearly illustrated in a bas-relief in Thebes.

The sycamore tree became highly prized for shade and timber, and the fruit, although not superlative, was esteemed. Commonly used for funeral offerings, the tree became sacred.



Origins of Agriculture in Egypt, Fig. 6 Harvesting and handling grain. (a) Reaping grain and tying sheaves. Tomb at Mena at Thebes, ca. 1420 BCE (Source Darby et al., 1976, Fig. 11.4c). (b) Reaping wheat in New Kingdom. Heads are cut short and cast into a large net, from a tomb at Thebes

ca. 1420 BCE (Source: Singer et al., 1954, Fig. 357). (c) Harvesting wheat in Old Kingdom. Heads are bound into sheaves and loaded onto donkeys (From a tomb at Saqqara, ca. 2400 BCE. Source: Singer et al., 1954, Fig. 359). (d) Oxen threshing grain. Tomb of Mena at Thebes

The fruits reached ancient Israel where they were known as the food of the poor. They are referred to in the Bible in a famous passage referring to the occupation of the prophet Amos. According to the King James Version of the Hebrew Bible, Amos states: “I was no prophet, neither was I a prophet’s son, but I was a herdsman and gatherer of sycomore fruits” (Amos 7, 14). However, this translation is in error as the Hebrew *Boless Shikmim* should be translated as “gasher of sycomores.” In the Greek translation of the Hebrew Bible, known as the Septuaginta (200 BCE in Alexandria), the key words are *Knizon Sycamina* or “piercer of sycomore.” The English translators could not understand the concept of gashing the fruit and stretched the translation. Contemporary Israeli sycomores produce fruit without gashing, but it is likely that in ancient times the same clones were used as found in Egypt.

Pest Control

Predation by insects, rats, birds, and hippopotami in addition to tax collectors is poignantly reported from ancient texts (Durant, 1954):

Dost thou not recall the picture of the farmer when the tenth of his grain is levied? Worms have destroyed half the wheat, and the hippopotami have eaten the rest; there are swarms of rats in the fields, the grasshoppers alight there, the cattle devour, the little birds pilfer; and if the farmer loses sight for an instant of what remains on the ground, it is carried off by robbers; moreover, the thongs which bind the iron and the hoe are worn out, and the team has died at the plough. It is then that the scribe steps out of the boat at the landing-place to levy the tithe, and there come the Keepers of the Doors of the (King’s) Granary with cudgels, and Negroes with ribs of palm-leaves, crying, “Come now, come!” There is none, and they throw the cultivator full length upon the ground, bind him, drag him to the canal, and fling him in head first; his wife is bound with him, his children

are put into chains. The neighbors in the meantime leave him and fly to save their grain.

Use of slingshots to chase away birds is shown in Fig. 7c. The ancient Egyptians also practiced biological control; many insectivorous birds were protected by the state.

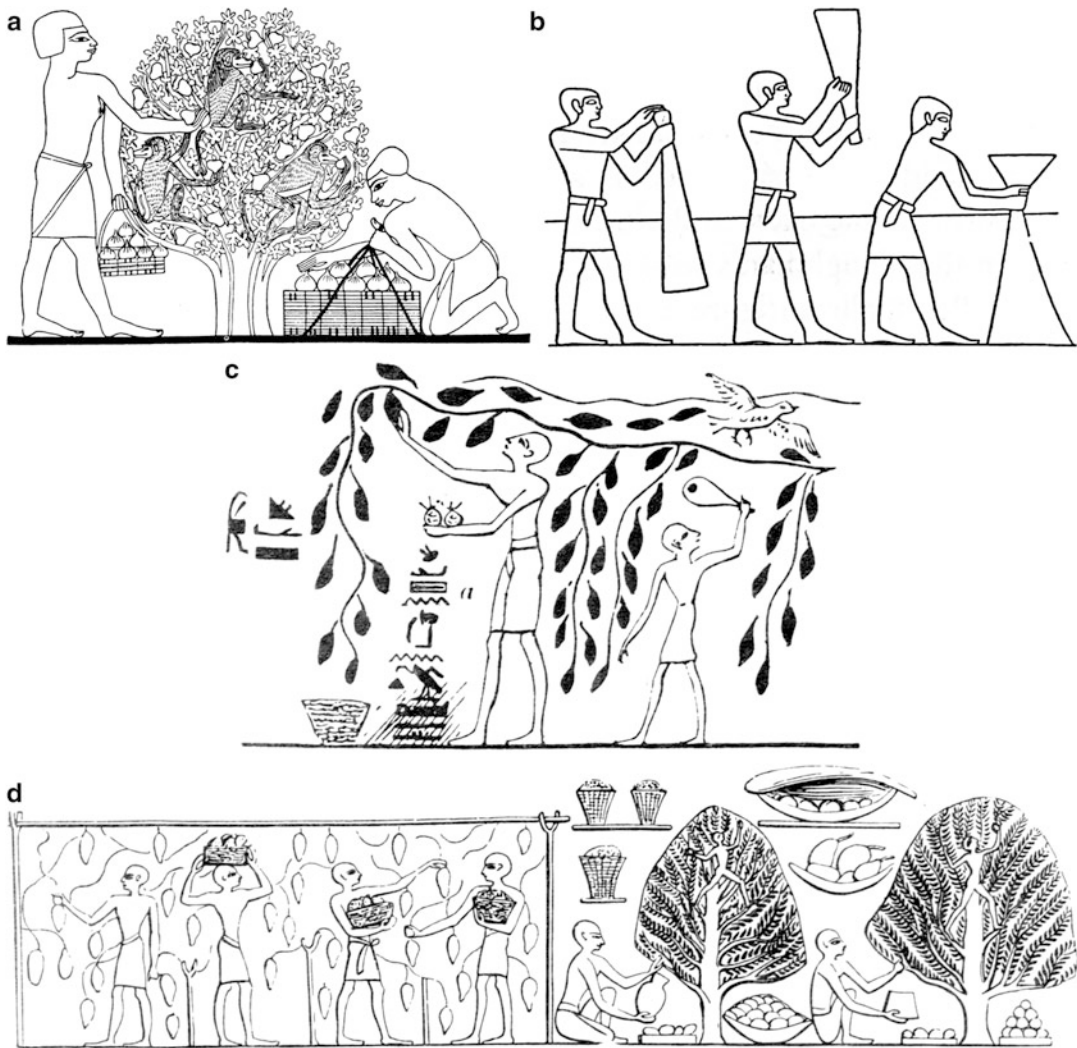
Biotechnology: Bread and Wine

The beginnings of biotechnology are directly traced to the manufacture of bread and wine. The harvesting, threshing, grinding of grain to flour, and subsequent sieving are abundantly illustrated (Fig. 6). Grinding of grain was handled with a hand mill called a saddle quern (Fig. 6f) by the housewife, but millers eventually carried out grinding on a large scale. Fermentation by the use of leaven, a mass of yeast, was a development that changed the making of bread (Fig. 6g). By 1200 BCE, over 30 different forms of bread and cakes were mentioned.

Alcoholic fermentation was carried out in pots with bread or flour to make beer, or sugary fruit juices, particularly grape but also dates and pomegranates to make wine, and with honey to make mead. Wine is specified as early as the first dynasty and was associated with Horus, the falcon-headed god, son of Isis, the Great Mother, loyal sister, and wife of Osiris, god of the beneficent Nile. The first Pharaoh called his vineyard “The Enclosure of the Beverage of the Body of Horus.” About 1200–1500 BCE the complete wine making process is illustrated (Fig. 9), beginning with grape harvest from arbors, treading by workers maintaining their balance by holding hanging cords attached to a frame, and the squeezing of the sediment collected in cloth bags, with fermentation carried out in jars (amphorae). After fermentation wine vessels were sealed with plugs of straw and clay designed to prevent bursting from gas accumulation and

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Origins of Agriculture in Egypt, Fig. 6 (continued) ca. 1420 BCE (Source: Darby et al., 1976, Fig. 11.4b). (e) (Above) Winnowing grain by tossing the grain into the air with wooden scoops. (Below) Husked grain is measured in bushels before storage (From a tomb at Thebes

ca. 1420 BCE. Source: Singer et al., 1954, Fig. 358). (f) Grinding wheat in a saddle quern. ca. 2500 BCE (Source: Singer et al., 1954, Fig. 176). (g) A bakery in Rameses III’s tomb at Thebes showing cakes of various shapes (Source: Darby et al., 1976, Fig. 12.14)

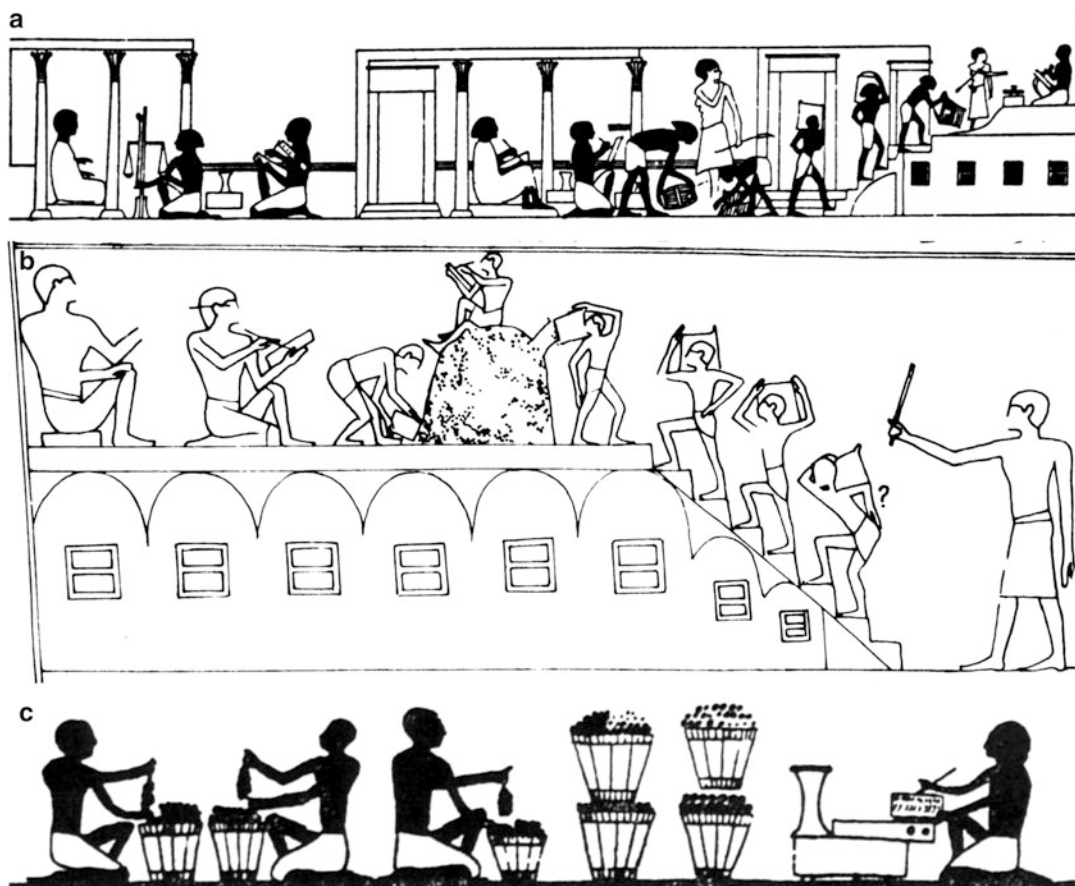


Origins of Agriculture in Egypt, Fig. 7 Harvesting fruit crops and flax. (a) Gathering figs in shallow baskets, while tame baboons cavort in the tree (From a tomb at Beni Hasan, Egypt, ca. 1900 BCE. Source: Singer et al., 1954, Fig. 362). (b) Harvesting and binding flax in sheaves (From the tomb of Hetepet, Old Kingdom.

Source: Singer et al., 1954, Fig. 352). (c) A worker harvests pomegranates, while a boy chases away a bird with a slingshot (Source: Hyams, 1971, p. 13). (d) Harvesting fruit from trellis and freestanding trees (Source: Hyams, 1971, Fig. 14)

impressed with official stamps containing the year of the king's rule, the district, the town, and the name of the wine (Fig. 9f). Wines were mixed by siphoning (Fig. 9g). Taxes were levied

on imported and exported wine. By the Greco-Roman period there were literally hundreds of wine types from grapes indicating intense genetic selection.



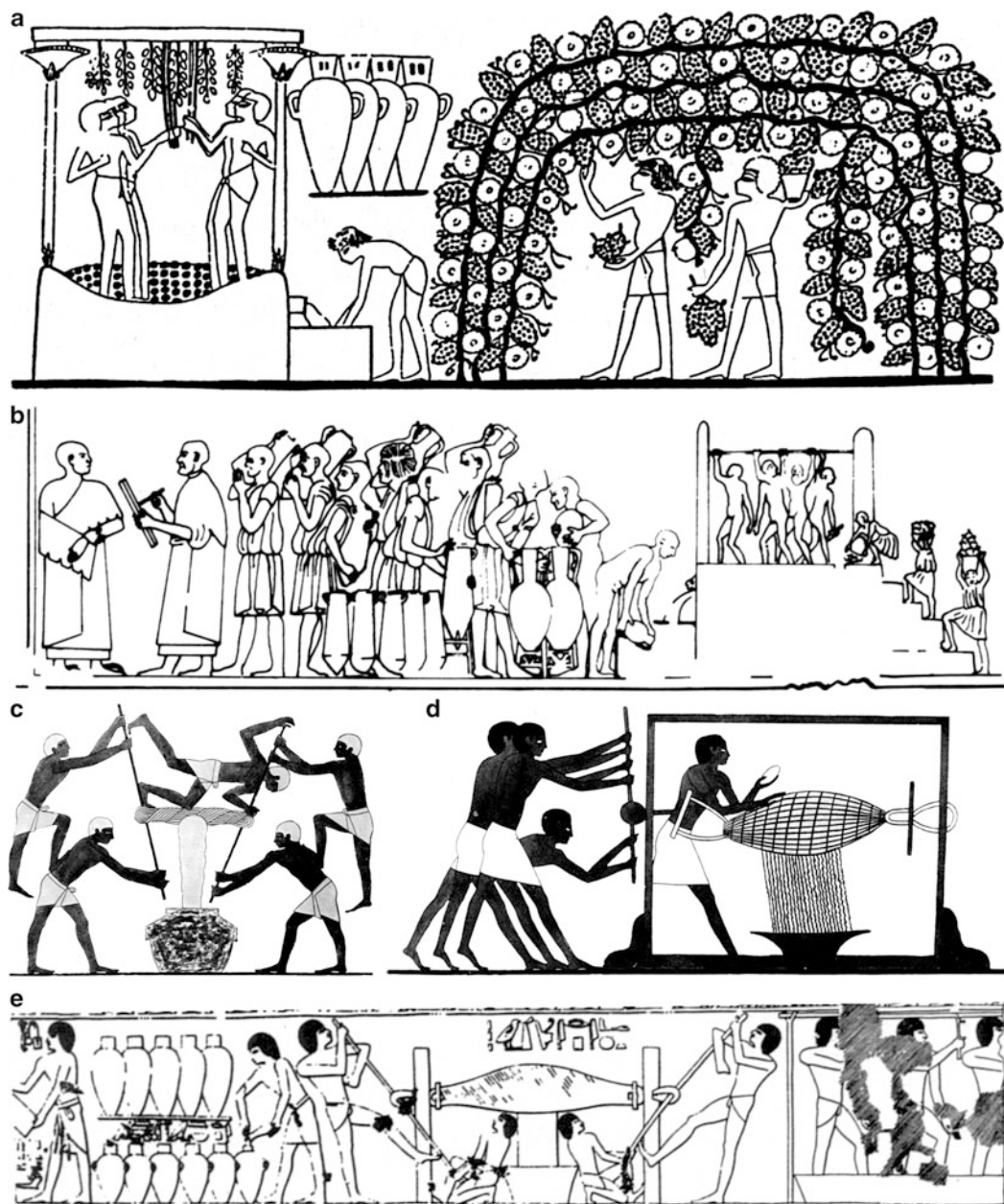
Origins of Agriculture in Egypt, Fig. 8 Storage. (a) Storing the harvest and quality control; note scribe and driver with whip (From a tomb at Beni Hasan, Egypt, ca. 1900 BCE. Source: Singer et al., 1954, Fig. 26). (b) Workers carry grain into silos while scribes register the

amount. Tomb of Antefoker at Thebes, Middle Kingdom (From Darby et al., 1976, Fig. 11.3). (c) A scribe checks the storing of raisins (From a tomb at Beni Hasan, ca. 1900 BCE. Source: Singer et al., 1954, Fig. 26)

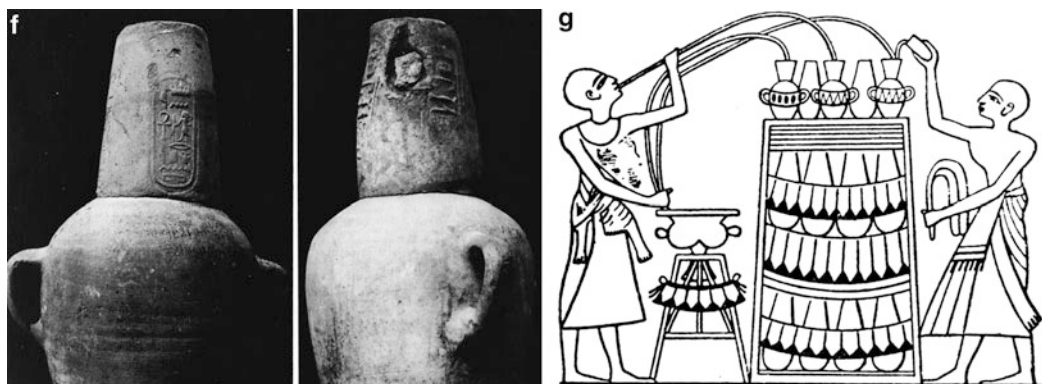
Plant Exploration

Pharaohs were sophisticated horticulturally. From foreign campaigns they brought back exotic trees and plants to be grown in their palace or temple gardens (Fig. 10). Queen Hatshepsut organized a plant expedition delivering living myrrh trees from Punt (northeastern Africa) for

the terraced gardens of her temple at Deir el-Bahri in 1500 BCE (Fig. 10b). Her nephew Thothmes III (1450 BCE) had the curious plants brought from Syria carved upon the walls of the temple of Amun in Karnak (Fig. 10c) from which iris can be recognized. Rameses III (1198–1166 BCE) made “great vineyards; walks shaded by all kinds of sweet fruit trees, a sacred way splendid



Origins of Agriculture in Egypt, Fig. 9 (continued)



Origins of Agriculture in Egypt, Fig. 9 Grape harvest and wine making. (a) Grapes are collected from a round arbor and workers crush grapes by stomping while balancing on cords hanging from a frame. Wine is stored in amphorae (From a tomb at Thebes, Egypt, ca. 1500 BCE. Source: Singer et al., 1954, Fig. 185). (b) Manufacture and registration of wine. Late Pharaonic-Ptolemaic period, Tomb of Petosiris (Source Darby et al., 1976, Fig. 14.15). (c) Pressing grapes in an early Egyptian bag press where the bag is squeezed by poles (From a tomb at Saqqara, ca. 2500 BCE. Source: Darby et al., 1976, Fig. 14.4). (d) Expressing juice of grapes by twisting a bag press in which the ends are held apart in a frame.

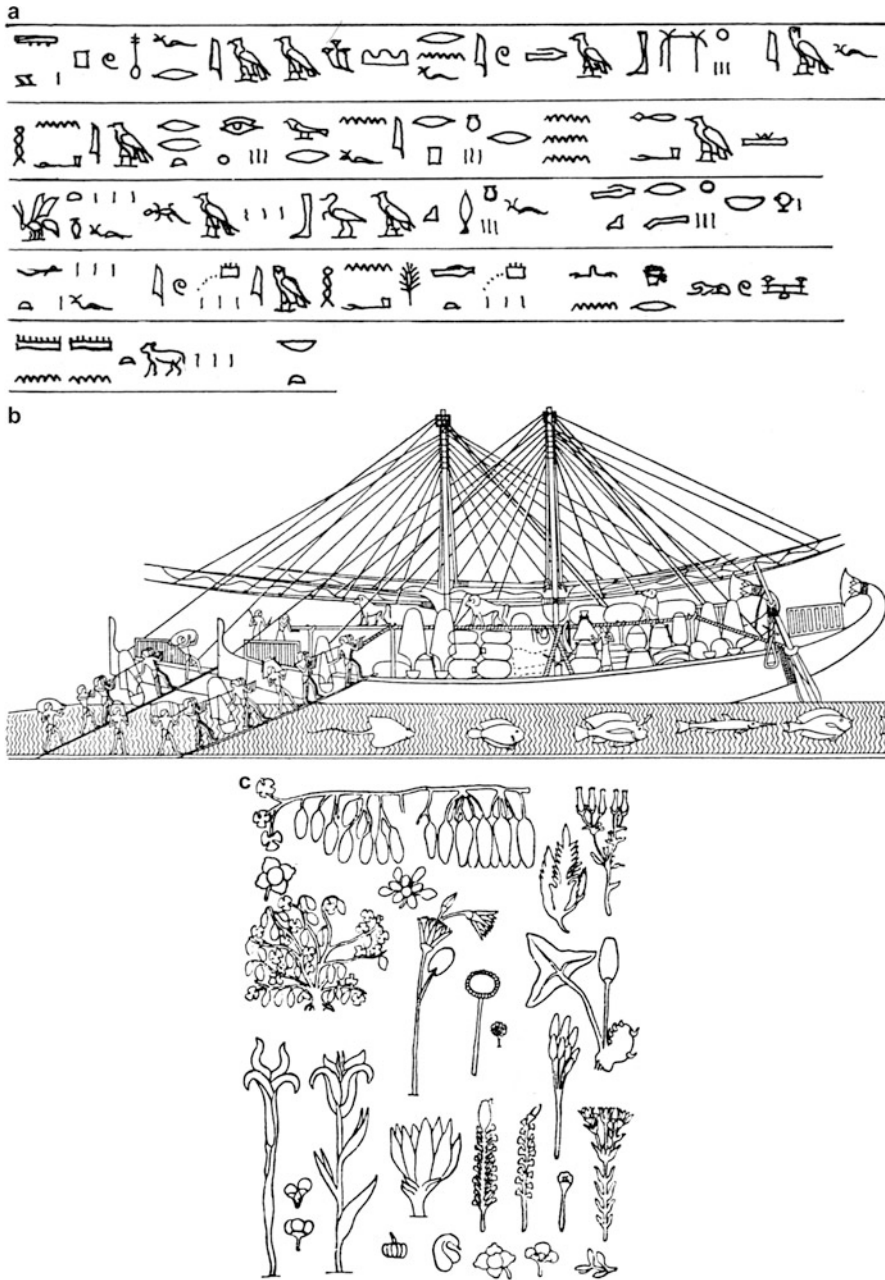
An inspector tests the cloth for holes (From a tomb at Beni Hasan, ca. 1500 BCE. Source: Darby et al., 1976, Fig. 14.3). (e) Preparation of wine showing both foot pressing and a bag press. From a mural in the palace of Thebes of the reign of Amenophis II, 1450–1425 BCE (Source: Goor and Nurock, 1968, p. 20). (f) Wine jars found in the tomb of Tutankhamon. The lid bears the stamp of the pharaoh. In the jar on the right, note the safety opening made in the lid to allow gases out, later closed with a plug of clay (Source: Darby et al., 1976, Fig. 14.8,9). (g) Mixing wines by siphoning, perhaps at a banquet (Source: Darby et al., 1976, Fig. 14.7)

with flowers from all countries, with lotus and papyrus as numerous as the sand” (Huxley, 1978, 1998).

Gardens and Ornamental Horticulture

Gardens in Egypt represent the beginnings of agriculture. They originated on the edge of the desert where the natural vegetation is sparse.

There was no landscape to copy except that of the oasis. Thus, the first garden can be thought of as an artificial, protected oasis and such gardens still exist (Fig. 11). Later gardens surrounded by walls were often terraced, containing enclosed pools to provide the “oasis” feeling and containing water plants (Fig. 12). The gardens were replete with statuary and ornamental columns (Fig. 12e). Plantings became ordered and set in straight rows because of irrigation



Origins of Agriculture in Egypt, Fig. 10 Plant exploration. (a) An epistle in which the Egyptian scribe Sinuhe penned the following description about Yaa, the name for Israel (ca 2000 BCE). *It was a goodly land called Yaa. Figs were in it and grapes, and is wine was more abundant than its water. Plentiful was its honey, many were its olives; all manner of fruits were upon it trees* (Source: Goor and Nurock, 1968, p. 2). (b) Ships of Queen Hatshepsut's fleet lading at Punt (northeastern coast of Africa) with exotic

merchandise for Egypt (From a temple at Deir el-Bahri, Egypt, ca. 1500 BCE. Note the tame baboons, the marine character of the fishes depicted, and the carriage and storage of growing incense plants. Source: Singer et al., 1954, Fig. 32). (c) An early botanical collection. Strange plants and seeds brought back from Syria by Thothmes II, as they were carved on the walls of the temple of Karnak, Egypt, ca. 1450 BCE (Source: Singer et al., 1954, Fig. 32)



Origins of Agriculture in Egypt, Fig. 11 Oasis at El-Tor, Sinai peninsula (Source: J. Janick, photo)

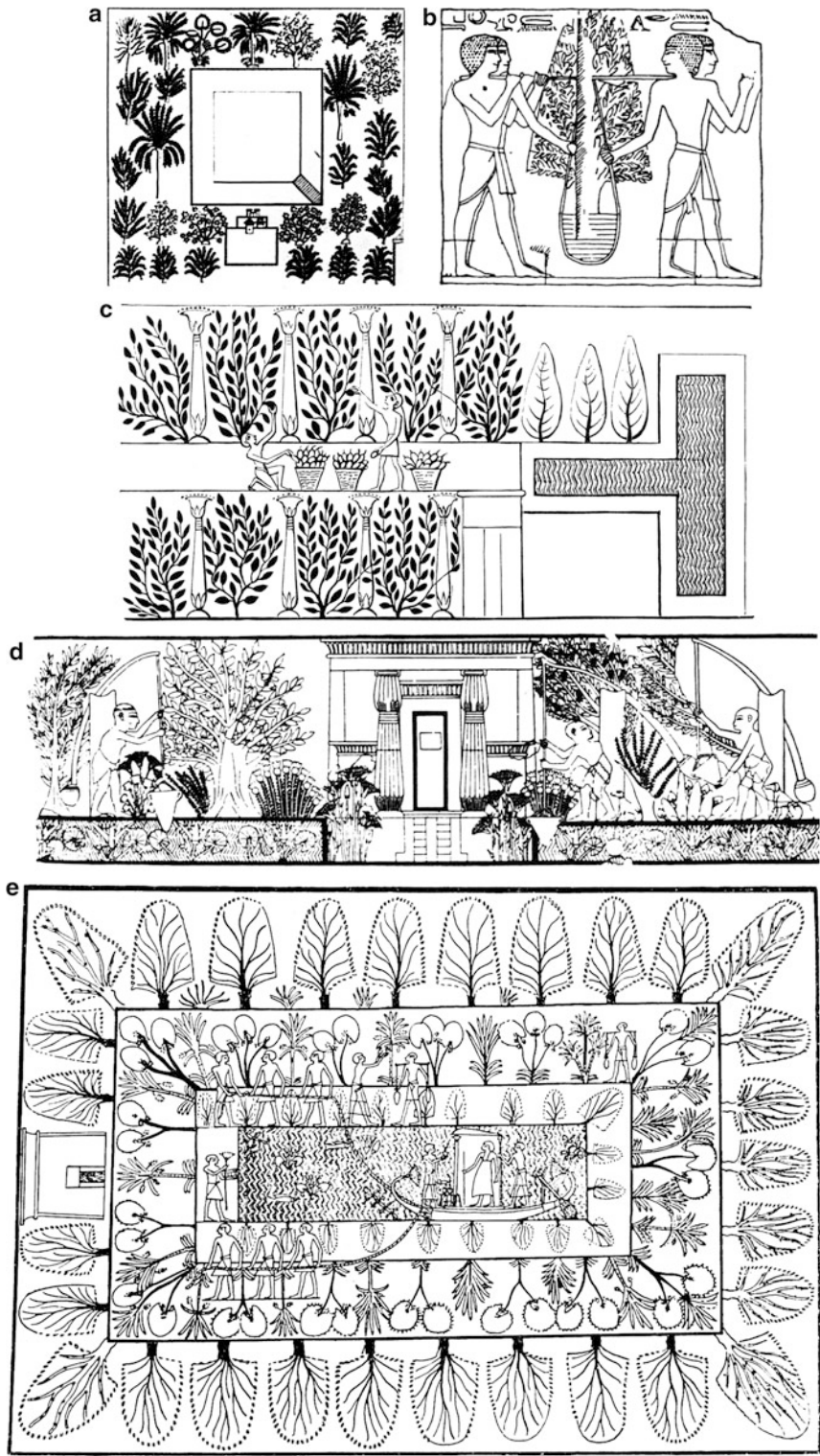
requirements and the flatness of the land (Fig. 12a, b). Irrigation canals were a common feature. Plants were treated architecturally; they were trained on lattice structures to artificial shapes (referred to as arbors, bowers, or pergolas). Fruit trees, palms, and vines in symmetrical arrangements were common garden plants providing food and shade.

The Egyptian gardens are the forerunners of our present-day formal gardens which use plants

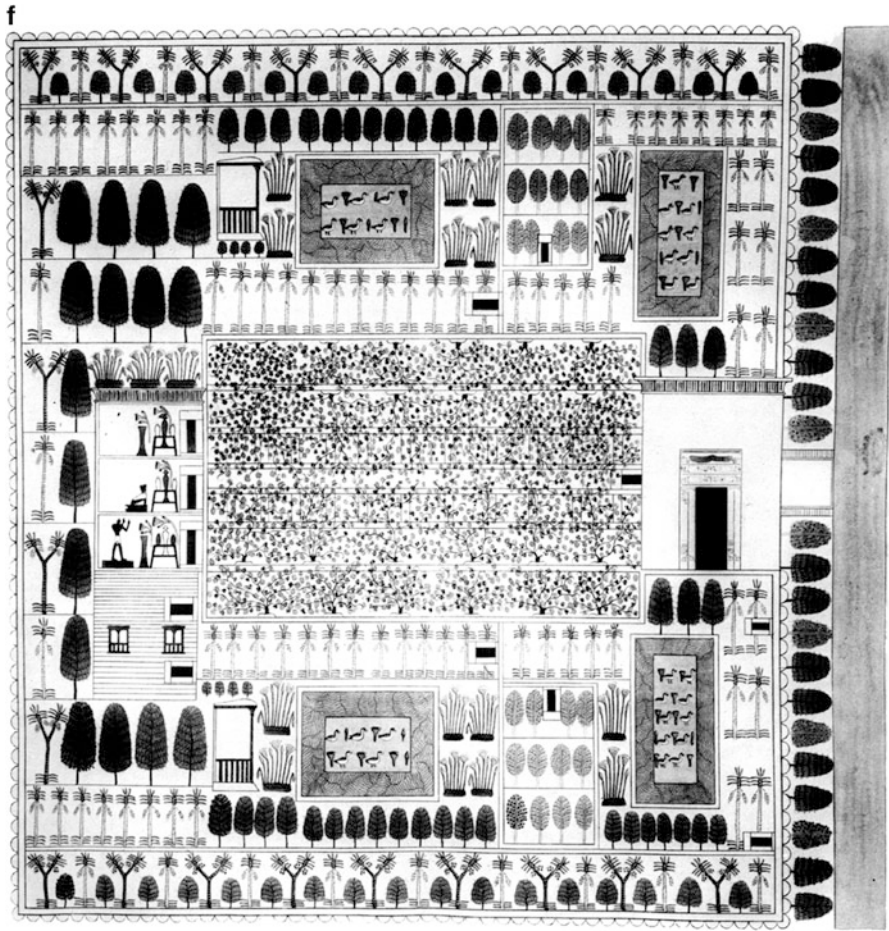
as architectural elements. Because there was essentially no natural landscape, the Egyptians created one based on straight lines and symmetry. They represent human domination over plants and an ordered, artificial environment. It is the antithesis of the naturalistic gardens of Asia which strove to emulate the natural scenery.

Conclusions

A study of the Egyptian history underscores the ancient origins of agriculture; cultivation and irrigation technology and the horticultural arts were all practiced. The ancient Egyptian agriculture provided the resources to enable the construction of vast public works and temples and the basic inspiration to progress from mathematics to chemistry and from medicine to metallurgy. Despite advances in technology, the Egyptian culture became increasingly conservative and traditional, so that continued advances were thwarted. Progress was hampered by the restraints of a rigid society first run by an uneasy alliance between nobles and priests and when racked by internal instability, deteriorating to a stagnant theocracy. The decline was evident about 1000 BCE and Egypt succumbed to pressures from invading cultures: Phoenician, Libyan, Ethiopian, Assyrian, Persian, the armies of Alexander, Roman legions, and Arabian. After the fifteenth century, Egypt was controlled by the Ottoman Turks and later influenced by the colonial power of France and England. These ancient relics, ignored for thousands of years, should be an inspiration to restore the glory in innovation, art, and agriculture that was the hallmark of ancient Egypt.



Origins of Agriculture in Egypt, Fig. 12 (continued)



Origins of Agriculture in Egypt, Fig. 12 The ancient Egyptian garden scenes. (a) Randomly placed trees growing within a square enclosure surrounding a square pool. Carving from the tomb of Akhnaton (eighteenth dynasty) (Source: Thacker, 1979, Fig. 6). (b) Four workers transporting trees for transplanting (Source: Wright, 1934). (c) Harvesting pomegranates in a formal planting interspersed with ornamental columns next to a T-shaped pool (Source: Hyams, 1971, Fig. 13). (d) Garden planted with fig, olive trees, and flowering plants containing a pavilion with steps leading down to the water, being

irrigated by a row of shadufs (From a tomb at Thebes, ca. 1300 BCE. Source: Singer et al., 1954, Fig. 345). (e) Formal Egyptian garden. The lotus pool, on which the statue of the vizier Rekhmire is being towed in a boat, is faced at one end by a pavilion or summerhouse. Around the pool grow doum palms, date palms, acacias, and other trees and shrubs (From the tomb of Rekhmire at Thebes ca. 1450 BCE. Source: Singer et al., 1954, Fig. 361). (f) Garden plant for a wealthy Egyptian estate. Note two types of palms: single trunk = date palm, bifurcated trunk = doum palm (Source: Berrall, 1966, p. 120)

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Ottoman Science

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“Ottoman science” refers to the overall scientific activity carried out within the space and time dimensions of the Ottoman Empire. Scientific activities that took place within the boundaries of the empire over its 600-year history have displayed some characteristic trends. As to historical heritage and tradition, these activities had much in common with those in Muslim societies outside these boundaries. However, they acquired some distinguishing features due to their geographical span and the dynamism of state administration and society. Therefore, though Ottoman science and the science of other Muslim countries shared common elements stemming from a common origin, the former took a leading position with regard to the developments achieved. In its early evolution, the Ottoman scientific tradition drew from the experience of old cultural centers such as Samarkand, Damascus, and Cairo, but not long after, it reached a point where it was capable of influencing these centers in some respects and setting an example for them. On the other side, at an early stage, Ottoman men of science became aware of

scientific developments taking place in Europe; they made selective transfers from the newly evolving Western science. In consequence, from the seventeenth century onward, the impact of Western science started to be felt gradually in the Ottoman world and, through it, in other Muslim countries. This reflects the leading role played by Ottoman men of science. Overall, these developments led the Ottoman state, which had by then come to represent virtually the entire Muslim world, to build a distinctive synthesis between Islam and the modern West.

The Ottoman Empire that was founded as a small principality at the turn of the fourteenth century gradually expanded into the lands of the Byzantine Empire in both Anatolia and the Balkans, while its sovereignty reached the Arab world after 1517. It became the most powerful state of the Islamic world covering a vast area extending from Central Europe to the Indian Ocean and persevered by keeping the balances of power with Europe. Following its defeat in First World War, the Ottoman Empire ended in 1923.

Ottoman science emerged and developed on the foundations of the scientific legacy and institutions of the pre-Ottoman Seljukid period in Anatolian cities and benefited from the activities of scholars who came from Egypt, Syria, Iran, and Turkistan, which were the most important scientific and cultural centers of the time. The Ottomans enriched the cultural and scientific life in the Islamic world by a new dynamism, and the Islamic scientific tradition reached its zenith in the sixteenth century. Besides the old centers of Islamic civilization, new centers flourished such as Bursa, Edirne, Istanbul, Skopje, and Sarajevo. The heritage that developed during this period constitutes the cultural identity and scientific legacy of the present-day Turkey as well as several Middle Eastern, North African, and Balkan countries. This entry aims to give an overview of the formation and development of Ottoman science in Anatolia and the scientific activities that later expanded from Istanbul, the capital of the empire, to the Ottoman lands, with the exception of the scientific activities related to non-Muslims due to insufficient studies and researches at hand.

The Ottomans always searched for solutions to the intellectual and practical problems they encountered in Islamic culture and science. Since the early periods, their attitude toward European science and technology was a selective acceptance. After the scientific and industrial revolutions in Europe, there appeared a gap between the Ottomans and the Western world. However, the Ottomans began to make some selective transfers from Western science, and gradually, the scientific tradition began to change from Islamic to Western. For this reason, Ottoman science should be studied under two headings: classical Islamic tradition and modern Western tradition. Although it is difficult to separate the two traditions in the transition period in a clear-cut way, the demarcation between the two traditions became more evident as their contacts became more frequent.

In the classical period, the *medrese* (in Arabic *madrasa* “college”) was the source of education and science and the most important institution of learning in the Ottoman Empire. The Ottoman medreses continued their activity from the time of the foundation of the state until approximately the turn of the twentieth century. The basic structure of the medreses remained the same within the framework of the Islamic tradition, but in terms of organization, they underwent several changes during the Ottoman period. Starting with the first medrese, established in 1331 in Iznik (Nicaea), all medreses had *waqfs* (charitable foundations) supporting their activities.

Besides the *ulemā* (scholars who were medrese graduates) that provided religious, scientific, and educational services, the medreses also trained the personnel for administrative and bureaucratic posts and the courts. The *ulemā*, who were members of the *ilmiye* (the Muslim learned, cultural, and religious institution), also played an important role in every aspect of the social and official life. With the reign of Mehmed II (Fatih, known as the Conqueror, 1451–1481), the number of medreses increased considerably and they were graded to differentiate them from each other.

Shortly after Mehmed II conquered Istanbul in 1453, he built the Fatih Complex (*külliye*) (1463–1470) which comprised a mosque at the center with other units located around it and also colleges, one hospital, one *mektep* (primary school), and one public kitchen, setting an example for similar institutions that were built by the succeeding sultans and high-ranking members of the ruling class. The Sahn-ı Semān Medreses (Eight Court Medreses) of the Fatih Complex that comprised 16 adjacent medreses represented the structure of an integrated campus. Owing to the political stability and economic prosperity of the Conqueror’s period, distinguished scholars and artists of the Islamic world assembled in the capital of the empire. The Ottomans especially protected the Muslim and Jewish scientists fleeing from the persecution that followed the fall of Granada in 1492 and provided them with shelter in the Ottoman lands. Moreover, as the *waqfs*, which were the financial sources of medreses, grew rich, scientific and educational life further developed. Following the establishment of the Eight Court Medreses by Mehmed II, the rational sciences comprising mathematics and astronomy were included in the formal educational system.

The medrese graduates served as teachers, *qādīs*, *kazaskers* (chief judges), and chief *muftīs*. Several physicians were trained and many patients were treated in the *darüşşifa* (hospital) of the Fatih Complex, which was active until the middle of the nineteenth century. It provided services to the society in the fields of religion, education, science, and health, as well as offered food to the needy in its public kitchens. As of the second half of the nineteenth century, the Fatih Complex gradually became ineffective, its various units, namely, the hospital, *tābhāne* (hospice), *muṣavvakkithāne* (office of the time-keeper), caravanserai, and the primary school, stopped operating. Finally, after all the medreses were discontinued in the Republican period in 1924, its colleges, too, were closed down. The mosque, however, continues its principal function from the time of its establishment until the present day.

The establishment of the Süleymaniye complex (*Külliye*) by Süleyman the Magnificent

(1520–1566) in the sixteenth century marked the final stage in the development of the medrese system where, besides the conventional medreses, a specialized *Dārūtīb* (Medical College) was founded (1550–1557). Thus, for the first time in Ottoman history, in addition to the *şifahānes* (hospitals), an independent institution was established to provide medical education. The other specialized medreses established by the Ottomans were the *Dārülhadīs* and the *Dārülkurrā*. *Dārülhadīs* held the highest grade in the medrese hierarchy.

In addition to the medreses, there were institutions where medical sciences and astronomy were practiced and taught by the master-apprentice method. These were the *şifahānes*, the *muvaḳkithānes*, and the office of the *müneccimbaşı* (chief astronomer of the sultan).

The institutions that provided health services and medical education were called *dārüşşifa*, *şifahāne*, or *bīmāristan*. The Seljukids had built *dārüşşifas* in the cities of Konya, Sivas, and Kayseri. Similarly, the Ottomans built several *dārüşşifas* in cities such as Bursa, Edirne, and Istanbul. Some Western sources mention that in Istanbul they were numerous in number in the sixteenth and seventeenth centuries, which was an indication of the importance attributed to them. The Ottoman *dārüşşifas* were constructed as a section of the *külliyes*.

In the Ottoman palace administration, the *müneccimbaşı* was the head of the astronomers, and this position was established sometime between late fifteenth and early sixteenth centuries. They were selected from among the *ulemā* who were medrese graduates. From sixteenth century onward, they were entrusted with the preparation of calendars, fasting timetables, and horoscopes for the palace and prominent statesmen. Until 1800, the calendars were prepared according to the *Zij* (astronomical handbook) of Ulugh Beg (Uluğ Bey); after that, the *Zij* of Jacques Cassini was used. The chief astronomer and sometimes a senior astronomer fixed the most propitious hour for important events such as imperial accessions, births, wedding ceremonies, launching of ships, declaration of wars, etc., as well as lesser events. Moreover, the chief

astronomers followed extraordinary events such as earthquakes and fires as well as astronomical occurrences such as the passage of comets and solar and lunar eclipses and passed on the information to the palace with related interpretations. The observatory founded in Istanbul was administered by chief astronomer Taqī al-Dīn al-Rāsīd (d. 1585) who was the greatest astronomer of the period. Thirty-seven people held the post of chief astronomer until the end of the empire in 1923. *Muvakkithānes* were also under the supervision of the *müneccimbaşı*.

The timekeepers' offices were public buildings located in the courtyards of mosques or *masjids* in almost every town. They were mostly built after the conquest of Istanbul and administered by the *waqfs*. *Muvakkits* were the officials that worked at the *muvaḳkithānes* and kept the time, specifically the prayer hours. The following major instruments were used in timekeeping: quadrant, astrolabe, sextant, octant, hourglass, sundial, mechanical clock, and chronometer. Depending on the level of the timekeepers' knowledge, the *muvaḳkithānes* also functioned as locations where astronomy was taught and simple observations were made.

The Ottoman scientific literature in the classical period was produced mainly within the milieu of the medrese. Scholars compiled several original works and translations in the fields of religious sciences, mathematics, astronomy, and medicine, besides a great number of textbooks. These works were written in Arabic, Turkish, and Persian, the three languages called *elsine-i selāse*, which were known by the Ottoman scholars. At the beginning, the literature was written mostly in Arabic, but from fifteenth century onward, Turkish was used more often. As of the eighteenth century, the majority of scientific works were written in Turkish, and upon the establishment of the first printing house in Istanbul in 1727, Ottoman Turkish became the most frequently used language in the transfer of modern sciences.

In the last three decades, because of the increasing research and studies due to the published 18 volumes of Ottoman scientific literature, our knowledge of Ottoman literature on astronomy, mathematics, medicine, geography,

and other natural and applied sciences has been greatly enriched. Many new aspects of scientific activities of the Ottoman period were revealed. The results of these studies also illustrate with complete clarity the intensity of scientific activities carried out by the Ottomans. An examination of this literature shows 4897 authors who produced 20,154 works in different sciences. The analytical studies of this literature reveal the different trends of authorship and translation from Islamic languages in the first phase and from European languages in the second phase. It is also clear that Turkish developed as a language of science and acquired the first place as compared to Arabic and Persian in transferring modern sciences not only to the Ottoman Empire but also to other parts of the Muslim world.

Statistics show that the total number of astronomical works is more than the number of mathematical works. This situation stems from the fact that specifically calendars occupied an important place in astronomy literature. A continuous increase is observed in the number of works in these three disciplines until the eighteenth century. The number of works attained their maximum in the eighteenth century and then started to decrease. As for mathematics, the total number of works continued to increase except for the eighteenth century. Works on mathematics, which recorded a major increase especially in the nineteenth century, attained the maximum in the twentieth century. There is also an increase in the total number of works on geography similar to that of mathematics. The rates of increase of the works in these three subjects are close to each other.

Bursalı Kadızāde-i Rūmī, also known as Qādī Zādeh al-Rūmī (died after 844 AH/AD 1440), made the first important contribution to the development of the Ottoman scientific tradition and literature. He was tutored in Bursa, Anatolia, and authored his first work there; then he settled in Samarkand. Qādī Zādeh wrote *Sharh Mulakhkhas fi'l-Hay'a* (commentary on the "Compendium on Astronomy") and *Sharh Ashkāl al-Ta'sīs* (commentary on "The Fundamental Theorems" of Geometry) in Arabic and became the chief professor at the Samarkand

medrese and the director of the observatory founded by Timurid ruler Ulugh Beg (d. 853/1449) in Samarkand. He was also the coauthor of *Zīj-i Jurjāni* (The Astronomical Tables of Ulugh Beg) written in Persian. He simplified the calculation of the "sine of a one-degree arc" in his work *Risāla fi Istikhrāj Jaybi Daraja Wāhida* (Treatise on the Calculation of the Sine of a - One-Degree Arc). Qādī Zādeh's two students from Turkistan, Ali Kuşçu (d. 879/1474) and Fathullāh al-Shirwānī (d. 891/1486), influenced the Ottoman science by disseminating the scientific legacy of the Timurid period in the Ottoman Empire. In the preface of his work *Sharh Ashkāl al-Ta'sīs*, Qādī Zādeh indicated that "the philosophers who ponder about the creation and the secrets of the universe, the jurists (*faqih*s) who give *fetvās* in religious matters, the officials who run the affairs of state, and the *qādīs* who deal with judicial matters should know geometry." Thus, he emphasized the necessity of science in philosophical, religious, and worldly matters. This understanding reflects the general characteristics of Ottoman science in the classical period. In the period of modernization, however, the Western concept of man's domination of nature through science and technology was foreign to Ottoman scholars.

Other astronomy books of this period included *Urjuza fī Manāzil al-Qamar wa Tulu' ihā* (Verses on the Mansions of the Moon and their Rising) and *Manzuma fī Silk al-Nujūm* (Verses on the Orbits of the Stars) written in Arabic by 'Abd al-Wahhāb ibn Jamāl al-Dīn ibn Yūsuf al-Maridānī. Two books titled *Risāla fī'l-Taqwīm* (Treatise on the Calendar) and *Sī Fasl fī'l-Taqwīm* (30 Sections on the Calendar) by Nasīr al-Dīn al-Tūsī, the founder of the Marāgha school, were translated from Persian to Turkish. Ahmed i Dā'ī (d. ca. 825/1421) was the translator of the second work.

During this period, Egypt was another source for Ottoman science. A famous physician of the time, Hacı Paşa (Celaleddin Hıdır) (d. 1413 or 1417) was educated in Egypt. He wrote two books in Arabic titled *Shifā'al-Asqām wa Dawā'al-ālām* (Treatment of Illnesses and the Remedy for Pains) and *Kitāb al-Ta'ālīm fī'l-Tibb*

(Book on the Teaching of Medicine) which played an important role in the development of Ottoman medicine. He had many other works in Turkish and Arabic. The works written by Sabuncuoğlu Şerefeddin (d. ca. 1468) on the subject of medicine have an important place in the development of Ottoman medical literature. His first work in Turkish on surgery called *Jarrāhiyāt al-Khāniyya* is composed of the translation of a section on surgery from the general medical book *al-Tasrīf* by Abu'l-Qāsim Zahrāwī, the famous Andalusian physician and surgeon, and three additional sections that he wrote himself. The work, in addition to the classical Islamic medical knowledge, reflects the influence of Turkish-Mongolian and Far Eastern medicine as well as the author's own experiences. The influence of Sabuncuoğlu was observed outside the Ottoman borders, specifically in Safavid Iran. Miniature paintings that depict surgical operations are one of the most significant features of this work that attained great fame in the history of medicine.

Ottoman science developed further owing to the keen interest of Mehmed II and the educational institutions that he established after the conquest of Istanbul. Consequently, some brilliant scholars emerged in the fifteenth century and made original contributions to science in this period. Mehmed II patronized the Muslim scholars; meantime, he instructed the Greek scholar from Trabzon named Georgios Amirutzes and his son to translate Ptolemy's *Geography* into Arabic and to draw a map of the world. Patriarch Gennadius prepared a book on the Christian belief titled *I'tikādnāme* (The Book on Belief) for the Sultan. The works *Geographia* by Francesco Berlinghieri and *De re Militari* by Roberto Valturio were presented to him by the authors personally. The Sultan's interest in European culture had started while he was still a *şehzāde* (prince) at the Manisa Palace in 1445 where Italian humanist Ciriaco d'Ancona and other Italians taught him Roman and European history. Mehmed II also encouraged the scholars of his time to produce works in their special fields. For example, Hocazāde and 'Alā al-Dīn al-Tusī were both asked to compare

Ghazali's *Tahâfut al-Falâsifa* (The Inconsistency of the Philosophers) which criticized the views of peripatetic philosophers regarding metaphysical matters and *Tahâfut al-Tahâfut* (The Inconsistency of the Inconsistency) written by Ibn Rushd as a response to Ghazali's work.

The most notable scientist of the Mehmed II period was Ali Kuşçu, a representative of the Samarkand tradition. He wrote 12 works on mathematics and astronomy, among them his commentary on the *Zīj-i Ulugh Bey* in Persian. His two works in Persian, namely, *Risāla fi'l-Hay'a* (Treatise on Astronomy) and *Risāla fi'l-Hisāb* (Treatise on Arithmetic), were taught in the Ottoman *medreses*. He rewrote these two works in Arabic with some additions under new titles, *al-Fathiyya* (Commemoration of Conquest) and *al-Muhammadiyya* (The Book Dedicated to Sultan Muhammed). Another noteworthy scholar of the Sultan Bayezid II period (1481–1512) was Molla Lūtfi. He wrote a treatise about the classification of sciences titled *Mawdu'āt al-'Ulum* (Subjects of the Sciences) in Arabic and compiled a book on geometry titled *Tad'īf al-Madhbah* (Delos Problem) which was partly translated from Greek. Mīrīm Çelebi (d. 1525), a well-known astronomer and mathematician of this period and the grandson of both Ali Kuşçu and Qādī Zādeh, contributed to the establishment of the scientific traditions of mathematics and astronomy and was renowned for the commentary he wrote on the *Zīj* of Ulugh Beg.

Some Jewish scholars that found shelter in the Ottoman Empire after the fall of Granada in Spain (1492) also contributed to the Ottoman scientific literature. An example is the Andalusian scholar Ilya ibn Abram al-Yahudī, who after professing Islam changed his name to 'Abd al-Salām al-Muhtadī al-Muhammadi (sixteenth century). He settled in Istanbul during the reign of Bayezid II and authored medical and astronomical works in Arabic. In a treatise that he wrote in Hebrew and later translated into Arabic in 1503, he introduced the instrument of his own invention called *al-Dābid* and stated that it was superior to the *Dhāt al-halaq* (armillary sphere) invented by Ptolemy. This treatise illuminates an aspect of Ottoman scientific literature that is not much

known. Scientific literature developed considerably in the period of Süleyman the Magnificent. We find two major mathematical books in Turkish titled *Jamāl al-Kuttāb wa Kamāl al-Hussāb* (Beauty of Scribes and Perfection of Accountants) and *ʿUmdat al-Hisāb* (Treatise on Arithmetic) by Nasuh al-Silāhī al-Matrāqī (d. 971/1564). His book in Turkish titled *Beyān-ı Menāzil-i Sefer-i Irakeyn* (Description of the Stopping Places of the Campaign to the Two Iraqs) related to geography should also be mentioned. Musā ibn Hāmūn (d. 1554) was another famous Jewish physician of Andalusian descent. He was Sultan Süleyman's physician and wrote the first Turkish book on dentistry. It was one of the earliest independent works on dentistry that was based on Greek, Islamic, and Uighur Turkish medical sources, particularly on Sabuncuoğlu Şerefeddin's works.

In the sixteenth century, the representatives of the Egypt-Damascus tradition of astronomy-mathematics wrote important works on astronomy. Sultan Selim II (1566–1574) appointed Taqī al-Dīn al-Rāsīd as Chief Astronomer; he combined the Egypt-Damascus and Samarkand traditions and wrote about 30 books in Arabic on mathematics, astronomy, mechanics, and medicine. Shortly after Sultan Murad III's (1574–1595) accession to the throne, he started the construction of the Istanbul observatory. This institution was conceived as one of the largest observatories in Islam and was comparable to Tycho Brahe's Uraniborg observatory built in 1576. There is a striking similarity between the instruments of Tycho Brahe and those of Taqī al-Dīn. In his astronomical tables called *Sidrātü Muntehā'l Efkar* (The Lotus Tree of the Extremity of Thoughts), Taqī al-Dīn states that he started the observations in Istanbul in 1573 with 15 assistants. The observatory was demolished on 4 Dhu'l-Hijja 987 corresponding to 22 January 1580. It is estimated that he carried out observations from 1573 until 1580.

Taqī al-Dīn invented new instruments that were added to those already in use for observations in the Islamic world. The instruments that he used were (1) armillary sphere; (2) mural quadrant; (3) azimuthal quadrant; (4) parallel

ruler; (5) ruler quadrant or wooden quadrant; (6) an instrument with two holes for the measurement of apparent diameters and eclipses; (7) *Dhāt al-awtār*, an instrument with chords to determine the equinoxes, invented by Taqī al-Dīn to replace the equinoctial armillary; (8) *Mushabbaha bi l-manātiq*, another of his inventions, the nature and function of which is not clearly explained; (9) mechanical clock with a train of cogwheels; and (10) *sunaydi* ruler, apparently a special type of instrument of an auxiliary nature, the function of which was explained by Alaeddin el-Mansur. Taqī al-Dīn used a mechanical clock that he made himself, as well as a wooden wall dial that he set up in the observatory. He described the clock with the words: "We built a mechanical clock with a dial showing the hours, minutes, and seconds and we divided every minute into 5 s." This was a more precise clock than those previously used, and it was considered one of the significant inventions in the field of applied astronomy that was developed during the sixteenth century.

Taqī al-Dīn found a different method of calculation to determine the latitudes and longitudes of stars by using Venus and the two stars near the ecliptic, i.e., Aldebaran and Spica Virginis. He determined that the magnitude of the annual motion of the Sun's apogee was 63". Considering that the value known today is 61", the method he used appears to be more precise than the methods of Copernicus (24") and Tycho Brahe (45").

Starting with Ptolemy in the second century AD and continuing until Copernicus in the sixteenth century, the Western world used chords for measuring angles. For this reason, the calculation of the value of the chord of (1°) was an important matter for astronomers. Thus, while Copernicus used the method based on the calculation of the chord of (2°) that yielded an approximate value, Taqī al-Dīn used trigonometric functions such as the sine, cosine, tangent, and cotangent to measure the values of angles, in line with the tradition of Islamic astronomy. Inspired by Ulugh Beg, Taqī al-Dīn developed a different method for the calculation of the sine of (1°). Furthermore, he applied decimal fractions to astronomy and trigonometry, which had been previously developed by Islamic mathematicians such as

al-Uqlidīsī and al-Kashī, and prepared sine and tangent tables accordingly and used them in his work titled *Jarīdat al-Durar wa Kharīdat al-Fikār*.

Ottoman scientific tradition reached its highest level in the sixteenth century; meanwhile, the scholars began to follow the innovations that developed in Europe in a selective way. Within this framework, the Islamic world first encountered the Copernican astronomy around the middle of seventeenth century. The earliest work that was translated from European languages on this subject is the astronomical table by French astronomer Noel Duret (d. ca. 1650) called *Nouvelle Théorie des Planètes* that was printed in Paris in 1635. Ottoman astronomer Tezkereci Köse İbrahim Efendi of Szigetvár translated this work in 1660 under the name of *Secenceli'l Eflak fî Gayeti'l İdrak* (Mirror of Revolving Spheres of Heaven on the Limits of Perception) which mentioned Copernicus' heliocentric system of the universe. The first reaction to this book came from the chief astronomer Mehmed Efendi who said, "Such presumptuousness is abundant among the Europeans." However, after learning its application from the translator and comparing it with the *Uluğ Bey Zij* (The Astronomical Tables of Uluğ Bey), he appreciated the work and awarded the translator. The initial reaction of the chief astronomer is a typical example of the cautious approach of the Ottomans who were sure of their own scientific tradition and acquisitions and did not immediately accept the scientific superiority of the West.

The basic concept of the perception of the new astronomy of Copernicus with "the sun at the center of the universe and the earth in motion" which created major disputes in Europe was not taken up as a subject for polemics; for the Ottoman astronomers, there was no religious dogma against it. Until modern astronomy lessons were started at the new educational institutions established in the last quarter of the eighteenth century and the beginning of the nineteenth century, the majority of the works on astronomy translated from European languages were composed of astronomical tables.

The Ottomans needed the knowledge of geography in order to determine the borders of their

continuously expanding territory and to establish control over the military and commercial activities in the Mediterranean, the Black Sea, the Red Sea, and the Indian Ocean. They made use of both the geographical works of classical Islam and works of European origin. By adding their own observations, Ottoman geographers produced original works as well. The first source of the Ottoman knowledge of geography is the Samar-kand tradition of astronomy and geography.

From sixteenth century onward, Piri Reis produced significant geographical works. In 1511, he drew his first world map and presented it to Sultan Selim I in 1517. A section of this map is now preserved at the Topkapı Museum in Istanbul. It was based on a number of Islamic and European maps including Columbus' map of America. This first Ottoman map which included preliminary information about the New World showed southwestern Europe, northwestern Africa, southeastern and Central America; it was a portolano, without the latitudes and longitudes but with lines delineating coasts and islands. Piri Reis drew his second map and presented it to Süleyman the Magnificent in 1528. Only the part which showed the North Atlantic Ocean and the newly discovered areas of the time that comprises North and Central America is now extant. Piri Reis also wrote the book *Kitāb-ı Bahriye* (Book of the Sea) in Turkish in 1521. In this work, he presented drawings and maps of the cities on the Mediterranean and Aegean coasts and gave extensive information about navigation and nautical astronomy. Admiral Seydi Ali Reis (d. 1562) was the author of the work titled *al-Muhīt* (The Ocean) in Turkish; he was a notable figure in maritime geography in his period. This work contains astronomical and geographical information necessary for long sea voyages and his own observations about the Indian Ocean.

Another work of the sixteenth century, which contains information about the geographical discoveries and the New World, is the book titled *Tārīh-i Hind-i Garbi* (History of Western India). This anonymous work based on Spanish and Italian geographical sources was presented to Murād III in 1583. It is important in showing that the

Ottomans knew the geographical discoveries of the West. The work has three parts; the most important is the third part comprising two thirds of the whole book. It relates the adventures of Columbus, Balboa, Magellan, Cortes, and Pizarro within the 60 years that started with the voyage to America between 1492 and 1552.

In the seventeenth century, cartography was organized as a profession in the Ottoman Empire; 15 individuals were occupied with the art of surveying in eight locations in Istanbul.

With the sixteenth century, some European physicians arrived in the major Ottoman cities, mainly Istanbul. Meanwhile, the spread of many infectious diseases of European origin brought new methods of treatment, preventive steps, and ideas. The new medical doctrines of Paracelsus (d. 1541) and his followers, the theories, and applications of treatment with chemical substances which became widespread in Holland in the seventeenth century and the new iatrochemistry appeared in the Ottoman medical literature with the names of “tıbb-ı cedid” (modern medicine) and “tıbb-ı kimyevî” (chemical medicine). Salih b. Nasrullah b. Sellüm (d. 1670), one of the most famous followers of these developments, quoted many European sources in his work called *Nüzhetü'l Ebdan* (Pleasure of Bodies) and noted the compositions of their medicines. Furthermore, he translated Paracelsus' work on iatrochemistry from Latin to Arabic. In the same manner, el-İznîkî (d. eighteenth century) also prepared his work called *Kitab-ı Küniiz-i Hayat el İnsan Kavanin-i Etibba-ı Feylesofan* (The Book on the Treasury of the Life of Humans and the Laws of the Philosophers-Physicians), where he presented the old and the new medicine together by making use of the works of the European physicians along with Arabic, Persian, and Ancient Greek sources. Ömer Sifâî (d. 1742) stated that he translated his work called *el-Cevher el-Ferid* from European languages to Turkish and the medicines in the book were taken from the books in Latin written by European physicians. Thus, in the Ottoman medical literature, the new medical knowledge and methods of European origin were quoted together with the traditional

knowledge of medicine and methods until the beginning of the nineteenth century.

Ottoman medical literature carried both the classical Islamic and the European medical information until the beginning of the nineteenth century when Şânîzâde Atâullah (d. 1826) wrote his work titled *Hamse-i Şânîzâde* (Five Works of Şânîzade) composed of the following branches of medicine: anatomy, physiology, pathology, surgery, and pharmacology. These were based totally on modern European sources without any reference to traditional medicine.

The famous Ottoman scholar and bibliographer Kâtip Çelebi (d. 1658), also known as Hacı Halife, was one of the first Muslim intellectuals to notice the gap between the levels of scientific development in Europe and the Ottoman world. Kâtip Çelebi was able to approach analytically both to classical Islamic culture and modern Western culture. He wrote on a variety of subjects in Arabic and Turkish. In the field of history, he translated the *Chronik* of Johann Carion from Latin under the title of *Târih-i Firengî Tercümesi* (Translation of European History) and compiled his *Ravnak al-Saltana* (Splendor of the Sultanate) on the basis of works by authors such as Johannes Zouaras, Nicetas Acominate, Nicephorus Gregoras, and the Athenian Laonikas Chalcondyle. In the field of geography, he translated the *Atlas Minor* of Mercator and Hondius under the title *Lawamî' al-Nûr fî Zulmât Atlas Minur* (Flashes of Light on the Darkness of Atlas Minor). Furthermore, in his work titled *Mîzân al-Haqq fî İhtiyâr al-Ahaqq* (The Balance of Truth and the Choice of the Truest), Kâtip Çelebi criticized the intellectual life of his period.

The Ottoman Empire expanded into three continents, Europe, Asia and Africa, and had common borders with many European countries. This had been influential in making it the first country outside the Western world where modern science and technology had spread. This proximity also provided the Ottomans with an awareness of the new explorations and inventions that appeared in Europe. The relationship, which was formed within a selective process of transfer, characterized the nature of the Ottomans' attitude vis-à-vis Western science and technology and their

attitude toward the innovations developed in Europe. The adoption of these innovations by the Ottomans differed from those of the Russians, Chinese, and Japanese. In addition, it did not conform to the theories of “central-peripheral” and “exploiter-exploited” interpretation of the spread of Western science outside its cultural environment. The attitudes of the Ottomans toward Western science and technology are better interpreted as “selective attitude adopted by a powerful Empire in response to the developments outside its own sphere and area of influence.” The Ottomans started to transfer European technology, especially in the fields of firearms, cartography, and mining as of the fifteenth century. Furthermore, the Ottomans had the opportunity to become acquainted with the Renaissance astronomy and medicine through the Jewish scholars who took refuge in the Ottoman Empire. In spite of this, the Ottomans considered themselves to be superior to the Europeans, both spiritually and culturally, in addition to their military superiority. Furthermore, their feeling of sufficiency from the aspect of both the educational system and economy was the reason for their being selective in the transfer of science. The following interpretation made by some modern historians that “The Ottomans did not understand that such developments would constitute a danger for them in the future” is anachronistic. The Ottomans, along with the other societies that had deep-rooted civilizations, became aware of the unsurpassable progress made by the Europeans in science and technology after the effects of the Industrial Revolution. The military striking power of the Europeans that resulted from the Industrial Revolution had increased as compared to the past. Their ability to reach swiftly to every corner of the world on land and sea by steam engine and their means to produce an unrivaled amount of goods for the world markets with the new industrial technology established the crushing superiority of the Europeans.

In these periods, the Ottomans required immediate transfers of science and technology to strengthen their military power. Thus, they established the imperial engineering schools at

the end of the eighteenth century and the imperial medical school at the beginning of the nineteenth century. Major reforms known as the *Tanzimāt* (1839) led to a shift in the process of selective transfer to include civilian projects and objectives. In the second half of the nineteenth century, individuals started to establish professional and learned associations similar to those in the West. The new corporate bodies that did not exist in the classical period added a new dimension to Ottoman scientific life with their legal statute and work procedures.

The concepts and information related to both the East and the West appeared side by side in the Ottoman scientific literature in the eighteenth and early nineteenth centuries. An example is the presentation of the heliocentric and geocentric systems of the universe in the same work. It is possible to observe the same situation on the subject of medicine. In the eighteenth century, along with the transfer of the practical medical knowledge of Europe, the classical concepts such as the “ahlat-ı erbaa” (four humors) in physiology and traditional anatomy were still dominant.

The teachers at the Imperial School of Engineering that was established toward the end of the eighteenth century to teach modern sciences to the officers began to prepare their textbooks by translating and adapting the works selected from among the textbooks which were taught at the military technical schools in the West. The first scientific publications that came out at the turn of the nineteenth century were the books prepared by the chief instructor of the Imperial School of Engineering, Hüseyn Rıf kî Tamānî (d. 1817). They were composed of compilations and translations on the subjects of astronomy, mathematics, and geography and were printed many times. These works were followed by 13 volumes comprising the compilations and translations based on the Western and especially French sources prepared by Ishak Efendi (d. 1836) who was Tamānî’s student and later his successor as the chief instructor at the school of engineering. His most famous work is *Mecmu’a-i ’Ulūm-ı Riyāziye* (The Compendium of Mathematical Sciences). This four volume work occupies a special place, because it is the first wide scope

attempt in the Ottoman world in the preparation of a textbook containing many modern scientific disciplines, among which are mathematics, physics, chemistry, astronomy, biology, botany, and mineralogy. Ishak Efendi had a significant role in finding Turkish equivalents for the new scientific terms and disseminating them to the other provinces outside Istanbul.

Obviously, the Ottoman's perception of modern European scientific traditions lacked an overall approach although they followed it closely. It is also clear that their scientific activities concerning research and production of new knowledge and technology – despite various relevant examples – did not have priority in their planning. Research activities conducted by Ottoman scientists inside and outside the empire, particularly in the European countries, did not reach the critical mass as compared to the contemporary Russian and Japanese examples.

During the classical period, the Ottoman scientists and scholars displayed a remarkable success in developing Islamic science and were able to make new contributions to the various branches of science. However, in the modernization period, they were not able to show a parallel performance but were successful in developing the modern scientific terminology of universal Islamic character and the Ottoman Turkish language to a level that would enable them to express their modern scientific and scholarly knowledge on various disciplines. The cultural and scientific heritage of the Ottoman period constituted the scientific and cultural infrastructure of many states founded in the Balkans and the Middle East, with the Republic of Turkey in the lead, and formed the foundations of subsequent activities.

See Also

- Pirī Reis
- Qāḍīzāde Al-Rūmī
- Rationality, Objectivity, and Method
- Taqī al-Dīn
- Ulugh Bēg
- Zīj

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Pakṣa

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Pakṣa (side or position) is a measure of time in Indian astronomy and refers to the lunar fortnight or the 15-day natural intervals in a lunar month. These intervals terminate with the full moon day (*paurṇamāsyā*) or the new moon day (*amāvāsyā*), after which a new *pakṣa* commences. The brighter half is called *śukla pakṣa* (white half) and the darker half, *kṛṣṇa pakṣa* (dark half). A pair of successive *śukla* and *kṛṣṇa pakṣas* constitutes the lunar month. Based on prevailing regional conventions, calendars follow the *pūrṇimānta* system, where the reckoning is between two successive full moons, or the *amānta* system, where two successive new moons form the scale.

The 15 days of the *pakṣa* are called *tithis* (lunar days) and are named in numerical order: *prathamā* (first), *dvitiyā* (second), *tṛtīyā* (third), and so on, up to *caturdaśī* (14), which is followed by *amāvāsyā* or *paruṇamāsyā*. These *tithis* played an important role – and continue to do so – in Indian calendar systems and horoscopes. They were also in use for determining auspicious dates for rites, rituals, religious festivals and other ceremonies. Thousands of land deeds have come down to us from different parts of India in the

form of inscriptions engraved on stones, temple walls, and copperplates. In these deeds, *pakṣa* and *tithi* of the transactions are mentioned invariably, along with the year and the month.

Calendar-makers generally preferred the synodic month to the sidereal month for calculating the lunar month. A synodic month is the period between two consecutive full moons or new moons (*pūrṇimānta* or *amānta*) and has a mean length of 29 days 12 h 44 m 3.84 s, whereas a sidereal month is 27 days 7 h 43 m 14.88 s long and refers to the time taken by the moon to return to its original position after completing one orbit around the earth. The solar month is longer than the sidereal or synodic lunar month, with a mean time-length of 30 days 10 h 29 m 4 s.

The *tithi* is an important component in Indian calendars. It is calculated on the basis of change in the moon's position in relation to the sun across a 24-h day. In the course of its orbit, the moon moves nearly 13° eastwards in a 24-h day. The sun moves a little less than 1° in the same direction in this period. The net displacement of the moon is, therefore, 12°. The sun completes its 360° orbit in 365 days 5 h 48 m 46.08 s, within which time the moon makes 12 such rounds (in 354 days 8 h 48 m 48.08 s) and is already nearly 11 *tithis* into its 13th round. The calendar is rounded off to 354 days. The 11 extra *tithis* add up cumulatively to form an intercalary month or leap month once in a metonic cycle of 2 or 3 years (with a mean of 2 years and 8.4 months). This add-on, known as *adhika māsa* (additional month),

enables calendar-makers to establish correlations between the solar and lunar years.

This mode of reckoning time was known in many parts of the world and was by no means unique to India. It has been in use in India for more than 2,000 years. In the period of the *R̥gveda* (falling broadly between 2,000 BCE and 800 BCE), *pakṣa* was not in use as a measure of time, and *tithi* bore only a lexical meaning without the calendar's technical associations. Their deployment for purposes of orchestrating time was occasioned by the expansion of surplus agriculture and the transformation of small farming settlements into huge peasant localities. The new agrarian cycles necessitated effective ways of understanding and organizing time. This formed the chief impetus behind the development of calendar systems, the earliest of which, like Lagadha's terse *Vedāṅgajyotiṣa*, were already in use by the sixth century BCE.

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Pāṇini

George Cardona

Pāṇini was a grammarian (Sanskrit *vaiyākaraṇa*) who lived around the early to mid-fifth century BCE in the extreme northwest of the Indian subcontinent. He was native to Śālātura (Cardona, 1976, pp. 260–268), and composed a grammar (*śabdānuśāsana*, *vyākaraṇa*, Cardona, 1997, pp. 564–572) of early Indo-Aryan. The main part of Pāṇini's work is the *Aṣṭādhyāyī* ("group

of eight [*aṣṭan*] chapters [*adhyāya*]"). This consists of approximately 4,000 statements called *sūtra* (Cardona, pp. 4, 6) organized in eight chapters, each of which is further subdivided into four quarter chapters (*pāda*). The corpus of *sūtras* is complemented by three ancillaries: an inventory of sounds (*akṣarasamāmnāya*), consisting of 14 sets organized in accordance with the manner in which Pāṇini formulates rules of phonology (Cardona, pp. 80–84); an inventory of underived verbal bases (*dhātu*), divided into ten groups in accordance with the manners of forming present stems (Cardona, pp. 85–129); and groups of items – predominantly nominal bases (*prātipadika*) – associated with particular operations and hence recited together with pertinent *sūtras* (Cardona, pp. 130–135). The rules in question account not only for the language (*bhāṣā*) current in Pāṇini's time and place – conventionally called Sanskrit (*saṁskṛta* "adorned, perfected") – but also for archaic forms proper to earlier stages of Old Indo-Aryan as found in Vedic texts.

Pāṇini accounts for such speech by means of a derivational system from the point of view of a speaker (Cardona, 1997, pp. 136–400; Junnarkar 1977–1988). In doing so, Pāṇini continues a procedure known to him from the earlier procedure followed by grammarians who composed analyzed texts (*padapāṭha*, literally "word recitation") corresponding to the continuously recited versions (*saṁhitāpāṭha*) of Vedic texts (see Jha, 1987). One of these, the *padapāṭha* to the *ṛgveda*, the earliest known Vedic corpus, was definitely known to Pāṇini, who refers to a dialectal feature observed by Śākalya, the author of this *padapāṭha*. In addition, Pāṇini formulates phonological rules but assumes a knowledge of phonetics (*śikṣā*).

Pāṇinian rules serve to account for Sanskrit utterances in terms of their being generated from the point of view of a speaker. The derivational process starts with a weak semantics, particular meanings serving as conditions (*nimitta*) for introducing affixes (*pratyaya*) to bases (*prakṛti*), which are either verbal or nominal bases. The meanings in question are of two general kinds: those which Pāṇini can assume known

to native speakers from their knowledge of the language and those which require explanation. Among the former are notions such as time references, number, and gender; chief among the latter are categories to which are assigned participants in actions, so that they are given class names such as *kartr* (“agent”), *karman* (“object”) (see Cardona, 1997, pp. 137–139). The general scheme for any simple sentence is thus

1. $B^n - A^n \dots B^n - A^n \dots B^v - A^v$,

in which nominal and verbal bases are to be followed by specified affixes. Moreover, the introduction of postnominal affixes is subordinated to that of verbal affixes, and abstract L-affixes are first introduced, later to be replaced by finite verb endings or participial suffixes. For example

1. $B^n - s^1 \dots B^n - am^2 \dots B^v - i$,
2. $B^n - ā^3 \dots B^n - s^1 \dots B^v - i$

are schemata for alternating active and passive sentences such that an L-affix is introduced to signify either (a) an agent or (b) an object, consequent upon which differing nominal affixations apply: if (a), a second-triplet nominal ending is introduced to signify an object but no nominal agent-signifying affix is introduced; if (b), a third-triplet nominal ending occurs to signify an agent but an object signifier is not introduced after a nominal. As noted, L-affixes are abstract elements, subject to replacement by finite verb endings and participial suffixes. For example

1. devadatta-s¹odana-am²pac-ti,
2. devadatta-ā³odana-s¹pac-ta

are strings such that the specific bases *devadatta* “Devadatta,” *odana* “cooked rice,” and *pac* “cook” are used. The verb is followed by the endings *ti* and *ta*, which replace the L-affix *l aṭ* introduced to signify alternately an agent or an object, on condition that the action is referred to current time. Starting with these strings, subsequent operations apply resulting in the final utterances.

1. *devadatta odanam pacati* “Devadatta is cooking rice.”
2. *devadatenaudanaḥ pacyate* “Rice is being cooked by Devadatta.”

In addition, the same types of derivational procedures serve to derive other, related, utterances such as

1. *devadatta odanam pakṣyati* “Devadatta will cook rice.”
2. *devadatenaudanaḥ pakṣyate* “Rice will be cooked by Devadatta.”
3. *devadatta odanam apākṣīt* “Devadatta cooked rice.”
4. *devadatta odanam pakvavān* “Devadatta cooked rice.”
5. *devadatenaudano’ pāci* “Rice was cooked by Devadatta.”
6. *devadatenaudanaḥ pakvaḥ* “Rice was cooked by Devadatta.”

(6a) and (6b) differ in that the former contains the finite verb form *apākṣīt* (third sg. aor. act.) “cooked” and the latter has *pakvavān* (nom. sg. masc.), a form of the agentive past participle *pakvavat-*, itself derived from *pac-tavat-*, with the participial affix *tavat u* following the base *pac*. Similarly, (6c) and (6d) differ in that the first has the finite verb form *apāci* (third sg. aor. pass.) “was, has been cooked” and the second contains the passive participle *pakva-* (nom. sg. masc. *pakvaḥ*), from *pac-ta*, with the participial affix *k ta* (see Cardona, 1997, pp. 144–158, 198).

Further, the selfsame system accounts also for an infinite number of possible correct utterances of Sanskrit. Moreover, this system is recursive in that strings like (1) and constituents within them are the basis for deriving additional elements – derived verbal and nominal bases – which enter into the same derivational system. For example

1. *ātmanah putram icchati* “... wishes a son of his own (*ātmanah* [gen. sg.] ‘self’).”

is related to

1. *putrīyati* “... wishes a son of his own.”
2. contains a form *icchati* (third sg. pres.) of the verb *iṣ* “wish” in construction with the accusative singular *putram* “son.” This sentence is derived from an abstract string
3. *ātman-as* ⁶ *putra-am* ² *iṣ-1*(=*laṭ*).

The constituent *putra-am* of (8) is now allowed optionally to be followed by the affix *k ya c* to form a derived verbal base *putra-am-ya-* with the meaning of *putra-am* in construction with *iṣ*. The nominal ending *am* of *putra-am-ya-* is dropped and an additional operation applies, yielding *putrīya-* – a derived base subject to operations which apply to primitive verbal bases. Again, to a string *rājan-as* ⁶ *puruṣa-s* ¹ operations can apply which result in *rājñāḥ puruṣaḥ* “servant (*puruṣaḥ* [nom. sg. masc.])” of the king (*rājñāḥ* [gen. sg.]), as in.

1. *rājñāḥ puruṣaḥ kutra gacchati* “Where (kutra) is the king’s servant is going?”
2. Derives from an abstract sting
3. *rājan-as* ⁶ *puruṣa-s* ¹ *kutra-s* ¹ *gam-1*(=*laṭ*)

Instead of applying the operations that serve to give *rājñāḥ puruṣaḥ*, the related constituents *rājan-as puruṣa-s* can optionally be combined to form a compound (*samāsa*) *rājan-as-puruṣa-s*, the nominal endings included within which are then deleted to give *rājan-puruṣa-*. The status of the original constituent *rājan-as* as a syntactic word (*pada*) is conventionally maintained, so that the final *-n* of this item is dropped, resulting in the compound *rāja-puruṣa-*. Such a derivation accounts for the fact that anywhere one can use a string such as *rājan-as puruṣa-s* one can alternatively use of form of the corresponding compound, as in

1. *rājapuruṣa-s* ¹ *kutra-s* ¹ *gam-1*

whence is derived

1. *rājapuruṣaḥ kutra gacchati* “Where is the king’s servant going?”

(9) and (12) contain *kutra* “where,” another type of derived nominal base. This is formed from a syntactic constituent *kim-i* ⁷, with the locative singular ending *ni* following the base *kim* (interrogative pronoun). To this complex, the affix *tra l* is optionally introduced, resulting in a derived nominal base *kim-i-tra-*, the ending in which is deleted ($\rightarrow$ *kim-tra-*); the base *kim* is itself then replaced by *ku*. The derivate *kutra* alternates with locative forms, e.g., *kutra nagare* “in which town” is a variant of *kasmin nagare*, with the locative singular masculine-neuter form *kasmin*. There are also derivatives formed from constituents of strings of the type *aupagava-* “descendent of Upagu.” Any form of this derived nominal base alternates with a complex that includes a genitive form of *upagu-* “Upagu” and a term meaning “descendent”; for example

1. *aupagavam ā nagay* “Bring a descendent of Upagu.”
2. *upagor apatyam ā naya* “Bring a descendent of Upagu.”

The derivation of *aupagava-* is comparable to the formation of compounds like *rājapuruṣa-* in that the former is accounted for by introducing an affix *aṇ* after a constituent *upagu-as* ⁶ of a sting

1. *upagu-as* ⁶ *apatya-am* ² *ā* ¹ *nī-loṭ*

from which (14) derives. The complex *upagu-as-a* is a derived nominal base in which the affix *aṇ* is considered to have the meaning of a term denoting a descendent, such as *apatya-*, so that *aupagava-x* is equivalent to *upagu-as* ⁶ *apatya-X*. Since the derived item is a nominal base, the ending included within it is deleted: *upagu-as* $\rightarrow$ *upagu-a-* $\rightarrow$... *aupagava-*.

The Pāṇinian system involves the use of rules of different kinds and these must apply in such a manner as to ensure that they account for the proper results, namely possible correct Sanskrit utterances and no incorrect ones. Moreover, Pāṇini’s grammar is intended to be understood by native speakers of the language it describes.

Accordingly, the metalanguage used is the same as the object language. On the other hand, since he is dealing specifically with grammatical procedures and he must generalize as much as possible, Pāṇini also has both to deviate from established conventions of the object language and to formulate specific practices allowing users to interpret his rules where the native command of usage does not suffice to allow a single unambiguous interpretation. For example, in normal usage a term like *go* “cow, ox” is used to signify its meaning. In addition, Sanskrit has a quotation particle *iti*, which can be used to show that one is referring to a term and not its meaning: *gav iti* (← *go iti*) refers to the term *go*. In his grammar, Pāṇini reverses the normal convention, so that words other than those used as technical grammatical terms are regularly self-referring: *go* refers to the term *go*, not to its meaning. Making use both of the conventions known to any native speaker and of those which Pāṇini states by metarules of his grammar, one can expand and interpret *Aṣṭādhyāyī sūtras* unambiguously (see Cardona, 1997, pp. 75–79).

As noted earlier, Pāṇini had predecessors, including the author of the *padapāṭha* to the *ṛgveda*. There is no doubt that pre-Pāṇinian grammarians had already recognized some important facts and concepts concerning grammatical procedures. The analyzed text of a Veda presupposes a relation between this text and the continuously recited text with which it is associated. In accordance with authors such as Śaunaka, who composed the *ṛgvedaprātiśākhya* – a work that includes rules for converting the *ṛgveda* *padapāṭha* to the *saṃhitāpāṭha* of this text – it is appropriate to consider that one text is theoretically derived from the other by rules of phonological change. Such a system involves recognizing classes of entities with respect to operations as well as relations among rules which state these operations. This also involves recognizing the distinction between the use and the mention of linguistic units. Thus, many of the principles which Pāṇini adopts were recognized before him. Pāṇini nevertheless stands as a major

innovator. His grammar includes not only a complete phonology, but also goes beyond this to account for Sanskrit syntax. He does not begin, as do *padapāṭhas*, with words, but with bases, to which affixes are introduced under given conditions to form words. Most importantly, Pāṇini’s grammar accounts for a language, not merely for a specific corpus.

Pāṇini’s work was the basis of a long commentatorial tradition, including the *Mahābhāṣya* (“great commentary”) of Patañjali (mid-second century BCE), which was the basic work for later commentators. Part of this tradition deals with what is generally called philosophy of grammar. A fundamental work in this sphere is the *Vākyapadīya* of Bhartṛhari (fifth century AD; see Cardona, 1976, pp. 298–299), which was the basis for later work and influenced not only Pāṇinian grammarians, but also scholars in other fields. Thus, Indian scholars of Nyāya (some schools of logic), *Mīmāṃsā* (ritual exegesis and related areas), Buddhism, and Jainism concerned themselves with issues concerning language, semantics, and ontology, and in the course of their discussions make frequent use of Pāṇini’s work and the work of later Pāṇinīyas.

See Also

► Nyāya

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Paper and Papermaking

Pan Jixing

Paper is a felted sheet of plant fibers formed from a water suspension using a sieve-like screen. When water escapes and dries, the layer of interwoven fibers becomes a thin-matted sheet and is called *paper*. It is one of the four great inventions of China, along with ► [gunpowder](#), the compass, and printing. Traditionally, paper was thought to be invented by a eunuch, Cai Lun (ca. 60–121), in the year 105. But according to recent archaeological discoveries, paper made of hemp fibers from rags had already been made in the second century BCE as a new type of writing material. After that papermaking was further improved and popularized in the second to the third centuries in China. During the third to the sixth centuries the raw materials for making paper were expanded. Apart from hemp, paper made from paper mulberry bark and rattan was produced. This marked an important stage in the history of papermaking. Meanwhile, paper converting was developed, such as sizing with starch, coating with white mineral powder, and dyeing with various dyestuffs, especially cork tree bark (*Phellodendron amurens*) which makes paper yellow and moth-proof. Movable types of screens were generally used for making paper. The development of papermaking promoted the flourishing of education, culture, and science. Paper was widely used in daily life to make umbrellas, fans, kites, paper-cuts, toilet paper, and others.

The next important stage (sixth to tenth centuries) was the Tang dynasty (618–907), in which papermaking was greatly developed. In addition to the above-mentioned kinds of paper, some new kinds appeared, such as ► [bamboo](#) paper and bark paper made of *Hibiscus mutabilis* and plants of the Thymelaeaceae family, such as Daphne. Paper coated with colored wax or powder and wax, as well as that decorated with gold or silver dust, gelatin sized, water-marked, embossed, and marbled were also made in this period. Meanwhile, paper was used for clothing, furnishings, visiting and playing cards, lanterns, armor, window posters, and in commercial activities as a medium of exchange. A large amount of paper was used for ceremonies and sacrificial purposes, as was the so-called “fire paper.” The development of block printing also stimulated the manufacture of paper. Another achievement was the production of large-size paper more than 3-m long. The Tang dynasty truly entered the “Age of Paper”.

After papermaking was perfect and popularized in China, it was spread in all directions throughout the world. It arrived first in Korea and Vietnam in the third to the fourth centuries, then in Japan and India in the seventh. Paper reached the Arabian world in the mid-eighth century and Africa in the tenth. The Arabs monopolized papermaking in the West for 500 years. Only in the twelfth century was it manufactured in Spain and France, then in Italy in the thirteenth. In the seventeenth century, paper was made in most European countries and even in America; in Australia it was produced in the nineteenth. Thus it took more than 1,000 years for paper to spread from China to almost every part of the world. Paper and other Chinese inventions played a considerable role in the flourishing of medieval Arabic culture and in the development of European society after that. From the eighteenth century during the Industrial Revolution papermaking itself went through a number of technical reforms in Europe. Chemical pulp appeared in Europe in the mid-nineteenth century, although traditional handmade paper persisted by virtue of its artistic value and elegant appearance. It continues to be produced in China, Japan, Korea, and many

Western countries including the United States. In fact, China remains the biggest supplier of hand-made paper today. Well-known varieties include xuan paper from Anhui, mulberry bark paper from Zhejiang, hemp paper from Shan-xi, and bamboo paper from Sichuan.

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1. *Ḍṛggaṇita* (Computation True to Observation), AD 1431, his magnum opus, a practical manual, in two versions
 2. *Goladīpikā* I (Illumination on Spherics), in 302 verses, on spherical astronomy
 3. *Goladīpikā* II (Illumination on Spherics), in four chapters, on the same subject as above but different from it
 4. *Grahaṇamaṇḍana* (Ornament on Eclipses), in two versions, of 89 and 100 verses
 5. *Grahaṇanyāyadīpikā* (Illuminator on Rationale of Eclipses) in 85 verses
 6. *Grahaṇāṣṭaka* (Octad on Eclipses), on the computation of eclipses
 7. *Vākyakaraṇa*, on methods for the derivation of several astronomical tables

Parameśvara also commented on several standard works on astronomy that were popular in Kerala. These include *Āryabhaṭīya* of Āryabhaṭa, *Laghubhāskarīya* and *Mahābhāskarīya* of Bhāskara I, *Mahābhāskarīya-Bhāṣya* of Govindasvāmin, *Laghumānasa* of Muñjāla, *Sūryasiddhānta*, *Līlāvatī* of Bhāskara II, and his own *Goladīpikā* II. All these commentaries except that on *Līlāvatī* have been published.

Although he was primarily an author of astronomical works, Parameśvara also wrote on astrology:

Parameśvara

K. V. Sarma
Madras, Tamilnadu, India

Among Indian astronomers hailing from Kerala, Parameśvara (ca. AD 1360–1465), promulgator of the Kerala Ḍṛggaṇita School and author of over a score of works on astronomy and astrology, holds a prominent place. He was a resident of Ālattūr, his house being situated on the northern bank of the river Bhāratappuzha, where he conducted his astronomical experiments and observations for over 55 years.

Parameśvara was a prolific writer. Some of his works still remain in manuscript form, while a few are yet to be found. His works on astronomy are

1. *Ācārasaṅgraha*, a popular text
2. *Jātakapaddhati*, in 44 verses
3. Commentary on the *Muhūrtaratna* of Govinda
4. Commentary on the *Jātakakarmapaddhati* of Śrīpati
5. Commentary on the *Praśnaṣ-aṭapañcāśikā* of Pṛhayaśas
6. *Muhūrtāṣṭaka-dīpikā*, *Vākyadīpikā*, and *Bhādīpikā*, mentioned by Parameśvara at the end of his commentary on the *Mahābhāskarīya*

These works are not extant.

In his works, Parameśvara evinces a refreshingly scientific outlook. He avers at the beginning of his *Grahaṇamaṇḍana* that he was setting out to compose the work after closely watching the movements and positions of the planets in the

skies for a long time. At the beginning of his *Dr̥ggaṇita*, he says that in real astronomy, computation should match observation. He enumerates a number of solar and lunar eclipses which he had observed between 1393 and 1432 and gives details about them in his *Grahaṇanyāyādīpikā*. He also points out the error between computed and observed readings and offers corrections and instructs that similar observations should be made at intervals and corrections enunciated for computation and observation to be identical.

See Also

► [Astronomy in Medieval India](#)

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Pauliśa

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Pauliśa, of Greek origin, is the originator of the *Pauliśa Siddhānta*, one of the five systems of astronomy of the early centuries of the Christian era. These were selectively redacted in the *Pañcasiddhāntikā* of Varāhamihira, the prodigious Indian astronomer-astrologer of the sixth century AD. According to a traditional verse attributed to the sage Kāśyapa, Pauliśa is one of the 18 originators of Indian astronomical systems. Al-Bīrūnī, the Persian scholar who sojourned in India from 1017 to 1030, stated that *Pauliśa Siddhānta* was written by Paulus-ul-Yunani, i.e., “Paulus, the Greek.” Probably the Hindus prepared an Indianized Sanskrit *Pauliśa Siddhānta* on the basis of the Greek work. This original Sanskrit work is no longer available, and neither is the commentary on that work by Lāṭadeva, which was referred to by Varāhamihira in *Pañcasiddhāntikā* I.3. However, the redaction of the *Siddhānta* in *Pañcasiddhāntikā* is fairly full and provides ample details about the nature and contents of the work. The Pauliśa system has certain things in common with the *Romaka Siddhānta* and with the *Vāsiṣṭha Siddhānta*, two of the other systems redacted in *Pañcasiddhāntikā*.

The epoch of the *Pauliśa Siddhānta*, which *Pañcasiddhāntikā* says is the same as that of *Romaka Siddhānta*, is the Hindu *caitra-śukla-pratipad* (first day of the bright fortnight of the month of Citrā) in the Śaka year 427 elapsed (*Pañcasiddhāntikā* I.8–10), which corresponds to mean sunset at Yavanapura (modern Alexandria in Egypt) or modern Sunday, March 20, 505. It is interesting that the same moment was adopted by Varāhamihira as the epoch of the *Saura Siddhānta* redacted in the *Pañcasiddhāntikā* (i.e., the old *Śurya Siddhānta*). The Indian time then was 37–20 *nāḍīs* from mean sunrise in Ujjain on Sunday, March 20, 505.

K. V. Sarma: deceased.

(*Pañcasiddhāntikā* III.13). In *Pañcasiddhāntikā* III.13, it is stated that the *deśāntara-nāḍīs* (longitudinal difference in terms of time, expressed in *nāḍīs*) from Yavanapura to Ujjain is 7–20, while that to Varanasi is nine. The actual intervals according to modern calculations are 7–38 and 8–50, the difference being 18 *vināḍīs* and 10 *vināḍīs*, respectively. One minute being equal to four *vināḍīs*, the difference works out only to 4.5 min and 2.5 min, which is remarkable.

At the commencement of the *Pañcasiddhāntikā* (I.4), Varāhamihira gives a pat to the *Paulīśa Siddhānta* for the accuracy of the *tithi* (lunar day) calculated according to it, though he adds that the *tithi* derived through the *Saura Siddhānta* is much more accurate. In fact, it is these two schools, the Paulīśa and the Saura, one representing the Greek and the other the Indian, that Varāhamihira depicts rather fully in *Pañcasiddhāntikā*, allotting them entire sections. Thus, the entire third chapter of *Pañcasiddhāntikā* is devoted to the depiction of planetary computation and allied matters according to the *Paulīśa Siddhānta*, Chapter 5 to the Moon's cusps, Chapter 6 to lunar eclipses, Chapter 7 to solar eclipses, and much of the long Chapter 18 to the motion of the planets. Although the *Paulīśa Siddhānta* was based on a Greek original, the text was painstakingly Indianized, both in the matter of content and presentation.

See Also

- [Al-Bīrūnī](#)
- [Astronomy in Medieval India](#)
- [Deśāntara](#)
- [Varāhamihira](#)

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Pest Control in India

P. Narayanasamy

Field and horticultural crops in India are under threat from many insect pests. Some of them are American bollworm, pink bollworm, spotted bollworm, and white fly on cotton; brown planthopper, green leafhopper, leaf folder, stem borer, and ear head bug on rice; different kinds of stem borers and pyrrilla on sugarcane; red hairy caterpillars and leaf miners on groundnuts; leafhoppers and fruit flies on mangoes; green scale on coffee; tea mosquito bug on tea; thrips on cardamom; fruit borers on vegetables and diamond back moths on cruciferous vegetables.

In storage warehouses, food grains are damaged by varieties of insects and non-insect pests. The majority belong to the orders Coleoptera and Lepidoptera, accounting for 60 and 8–9 % of the total number of pests respectively. In India, pests like the Angoumois grain moth, rice moth, Indian meal moth, khapra beetle, rice weevil, rust red flour beetle, lesser grain borer on rice and wheat, and pulses beetle on pulses are very important.

Metamorphosis of Pest Control

Pest control techniques in India have undergone sequential metamorphoses during the ancient, medieval, British, and modern periods.

Protohistoric Period

Protohistory has been defined as the period of human history between prehistory, when no written records existed, and history in the strict sense, when records are the main source. In India, the term protohistoric period is applied to the post-Mesolithic and pre-Mauryan cultures, between 3,500 or 3,000 and 600 BCE (Singh, 1990).

Following is an account of various kinds of farm pest control practices adopted during the Protohistoric-Neolithic periods.

Grains of primitive wheat species, einkorn, emmer, and spelt have a very tough and sturdy spikelet which does not release the grains in ordinary threshing; such spikelets are beaten to pieces but the grains still remain enclosed in their individual husks. If the spikes are heated however, the solid portion of the spikelet becomes dry and brittle and then it is possible to crush them. Grain drying was a common practice then; it also kept the seed-infesting insects away during storage. The paleoethnobotanical record consisted of mummified and carbonized food grains, imprints of grains on potsherds, silica skeletons, etc.

Harappan Period

Cylindrical pits lined with lime plaster sufficiently wide and deep were likely to have been used for storage of food grains. The lime, besides absorbing moisture, might have deterred the pests.

To the southeast of the pre-Harappan settlement, ploughed furrow marks were still intact in a field with one set of furrows oriented east-west while the other ran north-south. Individual furrows were interspaced at 30 cm in the former and 1.9 m in the latter. Horse gram was grown in short distanced furrows and mustard in the long distanced ones. (A small pulse (legume), which is grown as a crop in India, is used as a food for both human and animal consumption. They are small, thin, and oval shaped, which may be light to dark colored in shades of red, brown, and black. When cooked it provides a slightly strong, somewhat earthy flavor. It is consumed as a whole bean as a sprout, or as whole meal when prepared as a side dish or as a main dish with other ingredients. In some regions, the horse gram is boiled and then

crushed with salt after which it is allowed to ferment in order to produce a sauce that is used in the same manner as soy sauce. Somewhat similar to the moth bean, which is considered the “poor man’s food,” horse grams also have the same connotation.) This prompted the idea of mixed cropping perhaps to manage pest problems.

Terracotta sling-balls were found in all the Harappan excavations. Possibly the farmers used these sling-balls for scaring away pests such as birds, parakeets, or deers. Slings and sling balls are used even now by the farmers of rural India for protecting maize, sorghum, pearl millet, and other crops.

The best evidence of agriculture in the Harappan areas lies in granaries. These granaries, each 50 × 20 ft, were arranged symmetrically in two rows of six, with a central passage, which was 23-ft wide. They were built upon a podium of rammed mud, some 4-ft high, riveted with baked bricks. This kept pest infestation away from the seeds.

Deccan Chalcolithic Period

The wood of *Acacia* spp. was used to fabricate all tillage tools such as ploughs, yokes, and spokes. The wood kept all the timber-infesting pests at bay. This practice existed during 1500–1000 BCE.

Cultivation of two cereals (wheat and barley) and pulses (horse gram, hyacinth bean, lentil, and pea) suggests that the farmers made use of the available water resources very intelligently (Raychoudhary, 1964). There was a guide bund and a diversionary channel to support this. This scheme of growing two different species of plants sequentially is called “crop rotation” and this practice helps to make the next crop free from pest damage.

Storage bins had low mud walls 30-cm high, over which was mud plastered with ► [bamboo](#) screens. The structure contained a number of pit silos and round mud platforms for storing different kinds of grains. In some cases, the sides and the bottoms of the pits were lined with lime whereas in others the bottom was full of sand. In both, insect entry was deterred thus saving the grain from damage.

Straw from threshing floors was mixed with moist clay to make mud bricks, which were used to build multiroomed buildings and storage bins. In the storehouse, the silica content of the straw could have acted as a barrier for pest invasion.

Vedic Period

The Vedic literature quotes various laws and instructions regarding protection of crops from damage by insect pests and diseases. The Atharvaveda (Hymn 50 of book VI) describes the destruction of corn by locusts, mice, and borer.

Following are some pest control practices:

In the Rigveda, the cultivators kept birds away from their cornfields by making noise. In Matravagga, scarecrows were used for the purpose.

In Jataka, cultivators set traps and dug pit falls in their fields to protect the crops from wild animals.

Plastering with the powder of Aragvadha, Arista, Kareniya, Saptaparman, Cinnamon, and Vidanga (*Embelia ribes*) dissolved in cow urine and kept over night would destroy the insects that attacked the trees from outside.

Plaster of Vidanga, white mustard, black pepper, long pepper, and dry ginger, ballata and vaca prepared in cow urine, when applied to branches, kills the stem-boring insects and restores the tree to its natural colour.

Plastering with a paste made of cats, jackals, and pigs along with mustard and cow urine kills tree-boring insects.

Paddy seeds were preserved in receptacles like Kathinya (a storage structure) or in well-baked clay pots or in vessels of strong glass or containers woven of ropes and plastered with mud. In this way, the pests were less able to damage the crops.

A pit was dug in the hard earth and provided with descending steps. People were able to store rice seed in it, taking care that it was safe from damp, thieves, parrots, and rats. The sages advocated that presentation of the best kind of seeds

conscientiously brought prosperity to their cultivators.

The ancient texts of India – *Bṛhat-saṃhitā* of ► **Varāhamihira** (fifth century AD), *Vṛksha Āyurveda* of Lokapakra (ninth century AD) and *Vṛkṣāyurveda* of Sarangadhara saṃhitā (thirteenth century AD) provide instances of plant protection practices based on indigenous knowledge. They provide indication of an integrated approach to control crop pests and diseases through soil, seed, plant, and environmental treatment. Seed treatment with cow dung, milk, juice of *Solanum indicum*, tender coconut water, *Embelia ribes*, and cow ghee were prescribed. Prophylactory pest control measures included soil application of a mixture of *Ferula narthex* Boiss, *Acorus calamus* L., pepper, *Embelia ribes*, cashew seed, *Cheliantes farinosa*, mustard, and cow horn powder in cow urine.

History of Entomology in India

A chronology of events concerning entomological science in India is presented in Table 1 (Atwal & Dhaliwal, 2002; Vasantharaj, 2001).

Pest Eradication Era

There were only a few insect pest problems in India during ancient times and when they occurred, they were exterminated by the “slash and burn” concept. Most of the practices involved were traditional. The reason for the success of these measures was that they were all ecofriendly.

Pest Control Era

When the concept of the green revolution came to be regarded as a solution for the duelling population, Indians used high-yielding crop varieties under intensive and extensive types of cultivation. Misuse of the chemical pesticides damaged the environment, and the pests’ natural enemies were also at risk. In some cases, insect pests in many crops warranted consumption of more pesticides. This led to a change from the pest eradication to pest control. The pest problems could be curtailed or controlled with various strategies

Pest Control in India, Table 1 Events in entomology 1758–1939

Year	Scientist or organization	Contributions
1758	Linnaeus	Included 12 insects from India in his 10th edition of <i>Systema Naturae</i>
	Dr. J. G. Koenig (Tamil Nadu, South India)	Published first scientific work on insects in India
1779	Koenig	Published an account of termites of Thanjavur (Tamil Nadu)
1782	Dr. Kerr	Published a special publication on the lac insect
1785		Asiatic Society of Bengal was formed
1791	Dr. J. Anderson, Physician General to East India Company at Madras	Published a monograph on the cochineal insect
1800	Buchman	Wrote on cultivation of lac in India and silkworms in South India
	Denovan	Published <i>Natural History of Insects</i> , covering insects of Asia (later revised by Westwood in 1842)
1840	Rev. Hope	Presented a paper, “Entomology of the Himalayas and India” in the <i>Madras Journal of Literature and Science</i>
1847	Westwood	Made a cabinet of Oriental Entomology and <i>Arcana entomologica</i>
1875		Indian Museum was founded at Calcutta
1883		Bombay Natural History Society was established
1887	Baltour	Published <i>Agricultural Pests of India and Eastern and Southern Asia</i> and <i>Indian Ants</i> , the first case of biological control in which a small red ant kept away white ants. Government of India commenced the publication of the <i>Fauna of British India</i> series
1889–1903	Indian Museum Calcutta	Published Indian Museum Notes on Economic Entomology
1892	Hampson	Issued four volumes on Moths of India
1905		Imperial Agricultural Research Institute was established at Pusa, Bihar State
	Lionel de Niceville	Appointed as the first Imperial Entomologist
	Indian Tea Association	Commenced entomological work
1906	Prof. Harold Maxwell-Lefroy	Second Imperial Entomologist (1903) Published two books, <i>Indian Insect Pests</i> and <i>Indian Insect Life</i> in 1909. Punjab was first to initiate work on agricultural entomology followed by Tamil Nadu (1906), Uttar Pradesh (1906), Karnataka (1908)
1914		Government of India enacted “Destructive Insect Pests and Diseases Act.” T. B. Fletcher, first Government Entomologist of the then Madras State became the third Imperial Entomologist (1913–1932)
1916	Zoological Survey of India	Founded Indian Museum
1921	Indian Central Cotton Committee	Funded projects on cotton pests in Uttar Pradesh
1925		Indian Lac Research Institute, Ranchi was founded
1926–1932		The Locust Plague led to the establishment of a “Locust Warning organization” in 1939
1937		Entomological Society of India was inaugurated in Calcutta
1938	Dr. T. V. Ramakrishna Ayyar	Published <i>Hand Book of Economic Entomology for South India</i>
1939		Indian Journal of Entomology was launched

including pesticides with economic return. This happened during 1940–1970.

Pest Management Era

In the aftermath of using chemical pesticides for pest control, many pest species became immune to many of the pesticides used. Many actually resisted and resurged which ultimately increased the pest population manifold. This population upsurge became uncontrollable with then available pesticides, thus culminating in complete crop failure. This pest situation existed from 1970 to 1985, forcing Indians to change their efforts from pest control to pest management.

Integrated Pest Management

Integrated pest management (IPM) is a broad ecological approach which employs cultural, mechanical, physical, genetic, and biological methods, including application of chemical pesticides as a last resort, in a harmonious and compatible manner with a view to suppress the pest population below the economic injury level. IPM is a dynamic approach and process, which varies from area to area, time to time, crop to crop, and pest to pest. It aims at minimizing crop losses with consideration to human, animal, and environmental health and safety.

Current Pest Management in India

Herbal Pesticides

Use of plant products has attained importance and practical utility in pest management. More awareness has been created among the farmers to use herbal-based pesticide preparations. Plant species like Neem (*Azadirachta indica* A.), Indian privet (*Vitex negundo* L), (Fig. 1) Adhatoda (*Adhatoda vasica* Nees), Holy basil (*Ocimum sanctum* L), Sweet flag (*Acorus calamus* L), Turmeric (*Curcuma domestica* L), Wild chilli (*Capsicum frutescens* L), Onion (*Allium cepa* L) a conifer, *Cycas revoluta* (Thumb) (Fig. 2) and Garlic (*Allium sativum* L) are used



Pest Control in India, Fig. 1 *Vitex negundo* L

increasingly in pest management. Indian pesticide markets trade in numerous herbal pesticides, especially from plants like neem.

Traditional Knowledge

In recent times, there has been increased awareness of indigenous pest control practices. Concerted efforts are being made to document and revalidate pest control knowledge. Scientific institutions and non-governmental organizations play vital roles in applying the indigenous pest control knowledge with the goal of diminishing consumption of the chemical pesticides. Traditional pest management packages have been created for specific pests in crops such as rice and some vegetables (egg plant) bhendi, and tomato (Narayanasamy, 1999). Application of indigenous tribal knowledge in pest control has enabled us to fabricate rat traps (Fig. 3) for rice and other crops (Kathirvelu et al., 2004).

Pest Control in India,
Fig. 2 *Cycas revoluta*



Pest Control in India,
Fig. 3 Tribal rat trap



Biological Pest Suppression

The Project Directorate of Biological Control at Bangalore has developed strains of an egg parasitoid, *Trichogramma chilonis*, with physiological tolerance to Endosulphan 0.07 % and high levels of temperature.

The Bhabha Atomic Research Center, at Mumbai, has identified a new variety of *Bacillus thuringiensis* var *kenyae*.

Muralirangan, Sanjayan, and Pushkala (1996) recorded new species of microsporidians such as *Nosema locustae*, *N. acridophagus*, *N. cuniatum*, *Perezia dichloroplusae* and a recent discovery of

Cephalogregarine and Gregarine species on nymphs and adults of 15 species of grasshoppers.

Applications of Nucleopolyhedro viruses infecting *Amsacta albistriga*, *Spodoptera litura*, and *Earias vittella* have been standardized for various crops.

Thirty groups of fungal pathogens have so far been recorded on key pests in rice, which included *Pandora delphacis* (Hori). Humber on brown planthopper (BPH) (Fig. 4) and green leafhopper (GLH), *Zoophthora radicans* (Brefeld) Batko on leaf folder and *Nomuraea rileyii* (Farlow) Samson on cutworm. A Mycoinsecticide 70 %

Pest Control in India,
Fig. 4 Rice BPH adult
 infected by *Pandora*
delphacis



Pest Control in India,
Fig. 5 Rice yellow stem
 borer infected by *Fusarium*
moniliformae



wettable powder with sorghum grains as a carrier has been developed with spores of *Pandora delphacis* and found effective against BPH and GLH (Narayanasamy, 2001). Recently for the first time, infection of adult moths of lepidopterous insects of rice ecosystem with certain fungal pathogens including *Fusarium moniliformae* (Fig. 5) has been reported (Yasodha & Narayanasamy, 2004).

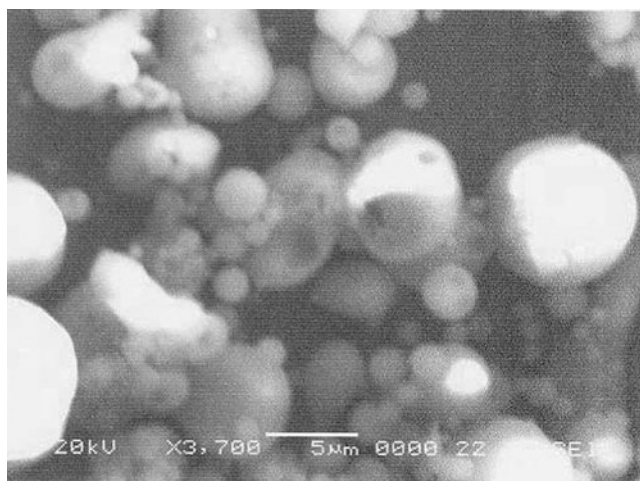
Pheromones

Pheromones act as potential tools for monitoring, surveillance, predicting population threat levels, and thresholds for applications of control measures for pests such as *Helicoverpa armigera*, *Pectinophora gossypiella* in cotton, *Spodoptera litura*, *Plutella xylostella*, *H. armigera* in vegetables, and *Lymantria pomonella* in apple.

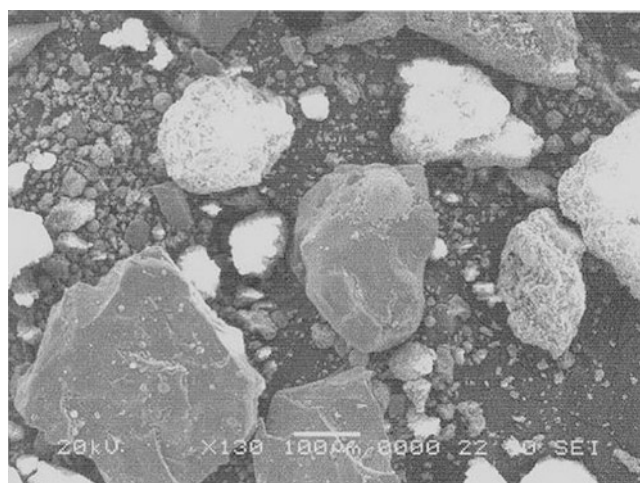
Biotechnological Innovations

- Attempts to develop transgenic maize, wheat, cotton, brassica, mungbean, potato, apple, broccoli, walnut, and alfalfa are underway.
- The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), in Hyderabad is in the process of testing GM pigeon pea, sorghum, pearl millet, and groundnut for the first time (Sharma et al., 2002).
- Transgenic rice with resistance to insect pests and pathogenic viruses are being tested. They include Bt genes like Cry 1 Ab, Cry 1 Ac, conferring resistance against stem borers and leaf folders or GNA (*Galanthus agglutinin*) gene, conferring resistance against sucking pests and potato protease inhibitors for insect resistance (Mishra, 2004).

Pest Control in India,
Fig. 6 Coal flyash



Pest Control in India,
Fig. 7 Lignite flyash



- Entomotoxin gene(s) from *B. thuringiensis* has been transferred to tobacco, rice, cabbage, cauliflower, eggplant, and chick pea (Bhatia, 1996).
- Cowpea trypsin inhibitor (CpTI) gene, which also provides a high degree of resistance against many insect pests, has been isolated and transferred to tobacco (Bhatia, 1996).

Agenda for the Future

If the green revolution is to sustain itself, it is necessary to adapt to the ecology-based IPM

strategy for various crops. In this context, the traditional wisdom of agricultural practices should be the foundation and the modern advancements of science the superstructure to usher in a sustainable food security system. It is of interest to note that flyash (Figs. 6 and 7), a waste from coal or lignite based thermal power plants would be a potential dust insecticide and a carrier in pesticide formulations for tomorrow's agriculture.

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Philanthropy, Medicine, and Health in Colonial India

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The role and contribution of philanthropy to the institutionalization and professionalization of modern medicine and public health in Western societies has been well documented. Modern institutionalized medical philanthropy in India was introduced and shaped by the British colonial state as a part of its colonizing process. The consolidation of colonial rule involved the transfer and transplanting of British political, economic, and social institutions, ideas, and practices. This included the emerging notions of institutionalized and utilitarian philanthropy and associational culture. Even in precolonial India, there was charity that involved individual and religious alms giving or constructing places of worship (Ranganathan, 2012; Sundar, 2000). The British colonial government, however, viewed this traditional mode of charity as superstitious, irrational, ostentatious, ritualistic, and wasteful and believed it encouraged sloth and idleness among Indians. They introduced a new ethic to reorganize and shape Indian charity into a new form of institutionalized philanthropy that was purposive and utilitarian (Sharma, 2001; Watt, 2012). This was in line with the way philanthropy was evolving and being molded in Britain in the nineteenth century (McCord & Purdue, 2007).

As pointed out by one scholar, “Charity was not new to South Asia. Rather it was the partnership with government as mode, the new secular institution as objects, and the restrictions of charity to those who ‘help themselves’ as a guiding ethic that were new” (Chopra, 2011). This ethic was particularly concerned with functionality and usefulness and closely associated with the larger colonization process, the consolidation of British political and economic power, and the challenges emerging from commercialization,

industrialization, migration, urbanization, and the resulting transformation of towns and cities. Calcutta, Bombay, and Madras would be prime examples, but the transformation of Delhi after 1857 and especially after 1911 when the capital of British India was transferred from Calcutta to Delhi necessitated that the colonial authorities direct acts of philanthropy toward promoting “works of public utility” of a permanent nature (Ranganathan, 2012; Sharma, 2001; Nundy, 2014; Watt, 2012). These consisted mainly of secular, public, and modern institutions such as schools, hospitals, courts, police stations, jails, wells, walls, inns, and roads. From the second quarter of the nineteenth century, the British colonial government was engaged in a joint enterprise with Indian philanthropists in the creation of infrastructure (Chopra, 2011), the conduct of welfare activities to address challenges arising from famines, resulting unemployment and migration, and laying the foundations of a medical and public health system to meet threats from disease and epidemics.

Indian princes and the *shetia* (traditional men of wealth and a new rising class of Indian entrepreneurs and businessmen) were encouraged to emulate British philanthropy. However, charitable activities were not state directed alone and other factors motivated private philanthropy. The *shetia* class and Indian princes concerned with issues of moral authority and political legitimacy were engaged in their own philanthropic initiatives to maintain their standing and firm up social relations within their own religious communities or caste groups (Haynes, 1987; Watt, 2012; White, 1991). Philanthropy also had significance as a political strategy as Indian elites sought to ingratiate themselves with the new colonial rulers and fashion a new role for themselves as agents of public welfare. In Bombay at the turn of the nineteenth century, wealthy Indians particularly from the Parsi community (descendants of Iranian immigrants who had arrived on the west coast of India in the ninth century AD) who had acquired wealth from the sea trade in opium and cotton, shipbuilding, and other commercial ventures gradually bought large tracts of land to emerge as the biggest landowners in Bombay.

They reclaimed land from the sea and, on their own initiative, built bridges and causeways for general use and constructed wells, water tanks, rest houses, fire temples, and *dokhamas* (burial wells for the dead) for members of their own community. After 1858, when power was transferred from the British East India Company to the British Crown, the focus shifted to creating and constructing institutions that offered training in or practiced Western education, science, technology, and medicine (Chopra, 2011).

Indian Philanthropy and Western Medicine

In India, medicine was closely aligned with the colonial state and was characterized by political and racial exclusiveness, the primary concern being protecting the health of the army and European residents (Arnold, 1994; Ramasubban, 1982). The emergence and expansion of hospitals and dispensaries were influenced and shaped by ideas of *laissez-faire* and medical philanthropy allied to the voluntary hospital movement in Britain. Sehrawat observes, “Introduction of medical education, institutions and principles of voluntarism by colonial state took place in the heyday of liberal reformism in the early 19th century” (Sehrawat, 2013). The voluntary and philanthropy-based medical care system had its origins in Britain. Responding to threats and challenges to health arising from an expanding overseas commerce and trade, growth of its port cities, industrialization, migration, and urbanization of its manufacturing towns, British governments from the late eighteenth century onward encouraged the establishment of hospitals, dispensaries, infirmaries, and lunatic asylums supported by private philanthropy and public subscriptions. Under the effect of the dominant political and economic ideologies of liberalism and *laissez-faire*, they assigned the state a minimal role in the delivery of medical care and instead placed the initiative and responsibility for it mainly in private hands. A network of charity hospitals funded by public subscriptions and donations for the deserving poor soon

emerged in Britain. The subscriber model associated with the British voluntary hospital system in which subscribers were given privileges in proportion to their subscriptions was the result of this approach (Jenkinson, Michael, & Russell, 1994; McCord & Purdue, 2007; Sehrawat, 2013). Infirmaries for indigents were funded by Poor Law rates. The institutions that formed a part of the voluntary system tended primarily to undertake the treatment of acute but curable diseases.

In India there was a minor divergence in British attitudes toward state provision of medical care (Sehrawat, 2013). European businessmen were encouraged to establish infirmaries for European indigents in India, but this charity was augmented with the aid from the colonial government. This arrangement, Harrison says, was conducive to financial stability (Harrison, 2009), but as Sehrawat points out, the colonial state undertook the administration of medical care representing it as imperial benevolence, a civilizing mission, but most importantly as a case of state charity which, she argues, was a didactic act that was expected to stimulate a spirit of voluntarism and generate a public associational culture among Indians. Thus inspired, Indians would be encouraged to assume responsibility for medical relief and establish through philanthropic acts, charity, and public subscriptions a network of charitable hospitals and dispensaries. Liberal philosophers such as John Mill were proponents of this approach in India. This was to be a provisional and selective intervention that linked government aid to voluntary and public subscriptions, the monitoring of dispensary committees, and devolving to local self-government bodies the responsibility for financing the delivery of medical care for Indians. Government aid would be discontinued once Indians were sufficiently motivated and engaged in the funding of dispensaries and hospitals for medical care (Sehrawat, 2013).

Unwilling to spend from its own resources, the colonial government encouraged Indian princes and the *shetia* to make bequests for the construction of hospitals and dispensaries for Indians. The colonial authorities viewed Indian princes and native aristocracy as natural leaders and hence

felt that they “ought to participate in medical philanthropy” so that “their example would be emulated” (Sehrawat, 2013). There were five significant aspects to Indian medical philanthropy that emerged during this period. First, charitable acts toward the construction of hospitals “served to demonstrate the donors’ benevolence and their credentials as community leaders” (Harrison, 2009; Watt, 2012). Second, it was a manifestation of Indian agency to use “Western-style charity in the service of Indian interests” (Palsetia, 2005). Third, it demonstrated an ability to raise funds through public subscriptions to which even common Indians contributed. Fourth, establishing modern hospitals, the preeminent symbol of Western medicine in non-Western countries, signaled a broadening acceptance of Western medicine by Indians, and, finally, it helped Indian princes and members of the commercial class establish their progressive credentials (Harrison, 2009). Sehrawat comments, “As utilitarian institutionalised philanthropy for projects approved by the colonial state began to play an important role in qualifying for imperial honours and status, princely rulers were eager contributors to projects such as for instance the Dufferin Fund” (Sehrawat, 2013). Several of these philanthropists were in turn rewarded with titles and other awards including membership in the Central Legislative Council (Palsetia, 2005; Sharma, 2012).

The hospitals reduced the alien nature of Western medicine and made it more acceptable (Arnold, 1996). Indian medical philanthropy played a major role in the expansion of Western medicine in India (Ramanna, 2002, 2004). In Calcutta, the Bengali elite, particularly those who believed that Western science was integral to Western culture which they viewed as a modernizing force, extended their patronage to Western medicine. They made liberal donations to set up a hospital and the Calcutta Medical College. Additionally, they provided scholarships to Indians to study Western medicine in Britain (Mukherjee, 2005). In Bombay, the Parsi *shetia* families led the way in supporting the creation of medical facilities (Ramanna, 2000, 2002). The Parsis were among the earliest to take to English

education and European culture and consciously sought to identify themselves with the Europeans. Between 1845 and 1941, some of Bombay's leading Parsi families, the Jeejeebhoy, Wadia, Readymoney, Petit, Cama, Allbless, and Tata, founded large hospitals, dispensaries, and medical colleges both in the city and the presidency. All of them continue to offer care to patients not just from the city but also from all over the country.

Sir Jamsetjee Jeejeebhoy made a donation for Bombay's first general hospital (1845) and set the pattern for others to emulate (Palsetia, 2005; Talwalkar, 1995). This was followed by an obstetric institute to provide specialist medical care for poor women and to which others such as the Maharaja of Baroda also contributed. Sir Cowasji Readymoney's first charity was a hospital (1857) in Surat followed up with the Sir Cowasji Jehangir Ophthalmic Hospital in Bombay. Between 1855 and 1892, the Wadia family, apart from founding several dispensaries in various parts of Bombay and the adjacent district of Thane, bequeathed money for establishing the Bai Motlibai Wadia Obstetric Hospital. The Petit family's chief contribution was the Sir Dinshaw Petit Hospital for Women and Children (1892). After the epidemic bubonic plague that took a heavy toll within the Parsi community, the family made a further donation for the construction of the Parsee General Hospital (1912) for the exclusive use of the Parsis (Boman-Behram & Desai, 1972). In addition, their endowments included a hospital for women in Nasik and a general hospital in Ratnagiri. Byramjee Jeejeebhoy (not related to Jamsetjee Jeejeebhoy) and his family made endowments for medical colleges at Ahmedabad and Poona, a hospital at Matheran, a charitable dispensary at Mehmabad, and the establishment of a charitable institute for children (1928), all of which were named after Byramjee Jeejeebhoy. Some hospitals founded through public subscriptions were memorials to British monarchy such as the King Edward Memorial Hospitals in various towns and cities of the country.

Most of the hospitals had wards that were segregated along class, caste, and religious

lines. For instance, hospitals endowed by Parsi philanthropy when not for Parsis alone had special wards for members of the Parsi community. In 1867, a prominent Hindu Bhatia merchant Goculdas Tejpal contributed toward the building of a hospital in Bombay which was used by Indians alone but with a special ward for members of the Bhatia community. Narottam Harkisandas provided funds to build a hospital that had a ward reserved for members of the Bania caste (Chopra, 2011). By the turn of the century, wealthy Hindus and Muslims had founded hospitals and dispensaries for members of their own communities. For instance, the Haji Saboo Siddick Trust made bequests to open three maternity homes in the city of Bombay (Ramanna, 2004). Class prejudices among members of the ruling regime forced indigent European patients unable to get admission in government-run European hospitals to seek medical care in general hospitals established through Indian philanthropy.

Nationalism, Social Service Organizations, and Public Health

In the early twentieth century, with a shift in medical policy from curative to preventive medicine, the colonial authorities, Indian doctors, and philanthropists collaborated to create awareness about Western notions of sanitation and sanitary science (Ramanna, 2004). Inspired by the *Swadeshi* (national self-reliance) sentiments, India's associational culture and voluntary sector were expanding. The new social organizations were also critical of traditional Indian charity and sought to promote institutionalized philanthropy. Engaged with issues of moral authority, aspects of the "civilizing mission," and political legitimacy with nationalistic overtones, several of these voluntary organizations undertook to diffuse knowledge about sanitation and hygiene with a view to creating educated public opinion on sanitary matters. Most of these social service organizations received generous financial support from industrial and commercial magnates of all communities, business, and merchant

associations reflecting at least partly the nationalist sentiments of the time (Ramanna, 2004).

Among the social service organizations that undertook health awareness activity were the Bombay Sanitary Association (1904); the Bijapur Association (1915); Broach District Sanitary Association (1914) and *Arogya Mandal* (health associations) in Poona, Sangli, and Dhule; and the Servants of India Society (1905). The Bombay Anti-Tuberculosis League (1912) was the recipient of funds from the Western India Turf Club, Grain Merchants' Association, Tata Sons, and Armenian Jew businessman David Sassoon. The League, named after King George V, worked to tackle this disease, while the League for Combating Venereal Diseases (1917) dealt with sexually transmitted diseases. The Social Service League founded in Bombay (1911) disseminated knowledge on hygiene and sanitation, promoted antituberculosis campaigns, maintained an ambulance brigade, conducted first aid classes, and ran a charitable homeopathic dispensary. During the influenza epidemic of 1918–1919, the League was actively engaged in relief work (Ramanna, 2004).

Women and Child Health

Health and medical care for women was promoted by the colonial government as part of its civilizing mission to reform and change the status of local women. This received support from Indian elites and reformists (Nundy, 2014). It received special attention from private philanthropy, Christian missions, and voluntary social service agencies who founded a number of hospitals and dispensaries in various parts of the country. An extension of this concern was the creation of facilities for training women in medicine and maternity care. The early efforts by Parsi philanthropists in Bombay have already been described.

The evangelism and charity approach of the missionaries corresponded with the thinking of the colonial state that wanted private charity to undertake responsibility for Indian health. They had the support of the colonial state and hence the

legitimacy to conduct its activities. They set up *zenana* institutions for maternal and child health care for women in *purdah* (both Muslim and Hindu) and poor women. While evangelism may have been one factor motivating them to come to India, it has been pointed out that the lack of career opportunities for European women medical professionals trained in obstetrics and gynecology in the late nineteenth century in their own countries prompted many of them to look East (Nundy, 2014). From the 1860s, women missionaries from the United States and Britain arriving in India were engaged in providing medical care to women and in the training of local women, both European and Indian, in health care. In 1866 the Church of England *Zenana* Mission Society was founded in Punjab to train *dais*, local birth attendants. Apart from the Church of England were the Scottish and American mission run hospitals spread over various locations in India.

In Bombay, George Kittredge, an American businessman, along with Sorabji Bengali, was responsible for setting up the Medical Women's Fund which raised public subscriptions for promoting medical education among women. The establishment of the Cama Hospital in 1886 for women and children was partly the result of these efforts (Mukherjee, 2005; Ramanna, 2012). The Bombay Presidency Infant Welfare Society (1919) provided aid to infants, expectant mothers, and mothers in childbirth; trained nurses and traditional birth attendants; set up crèches and children's hospitals; and supplied milk (Ramanna, 2004). The Arya Mahila Samaj founded by Pandita Ramabai and the Hind Mahila Samaj founded by Avantikabai Gokhale were engaged in providing medical care to women and children (Ramanna, 2012).

The Seva Sadan Society (1908) founded by associates of Mahadev Govind Ranade, judge of the Bombay High Court, social reformer, and nationalist, for the uplift of women, ran a dispensary for women and children. It was run under the direction of his wife Ramabai. Its Poona branch (1909) had a nursing and medical education committee and maintained a maternity home and an infant welfare center (Ramanna, 2004).

It received funding from Wadia charities, the Western India Turf Club, and individual philanthropists Sheth Mulraj Khatau, Lady Vithaldas Thackersey, Ratan Tata, and the Mysore royal family (Ramanna, 2012). The Women's Zoroastrian Association (1903) worked with women from the weaker sections of the Parsi community. The plague epidemic of 1896–1897 prompted the establishment of this body, which exists today as the Ratan Tata Institute (Ramanna, 2004).

Colonial support, particularly from the wives of the Viceroys who set up foundations to perpetuate their names and rule, was not altogether unknown (Nundy, 2014). In 1885 the Dufferin Fund was established at the initiative of Lady Dufferin the wife of the Indian Viceroy. The Fund received generous donations from the Indian princes and other wealthy Indians both Muslims and Hindus. It had three objectives: to provide medical training to women, to make available female nurses and trained midwives to hospitals and private care, and to organize medical care (Mukherjee, 2005; Ramanna, 2012). The Fund supported both mission- and state-operated *zenana* institutions. It arranged to have European women doctors who had come East in search of career opportunities to work in these institutions (Nundy, 2014). Sehrawat observes that the Fund which was “associated with the colonial improving project of medical philanthropy and represented the colonial ideal of medical philanthropy . . . allowed the state to distance itself from medical provision and to claim that philanthropy and private stimulus ought to provide for the medical needs of Indians” (Sehrawat, 2013).

The Victoria *Zenana* Hospital was a memorial to Queen Victoria, opened in 1906 and managed by women staff trained in the medical schools receiving funding from the Dufferin Fund (Nundy, 2014). The Victoria Memorial Scholarship Fund was initiated by Lady Curzon in 1901 to train *dais* and midwives. Lady Chelmsford launched the All-India Maternity and Child Welfare League (1919) for maternity and welfare centers (Ramanna, 2012).

The Lady Harding Medical College, created as a separate institute for medical education of

women, was founded in 1916 and received support from Indian elites and the state. It was an effort to prevail over cultural barriers and surmount taboos attached to women's education. It was meant to train Indian women in Western medicine. The College received the patronage of many princely states. According to Nundy, the support to this initiative indicates that “reforming the status of women and civilising the society was high priority among the colonizers backed by Indian philanthropists who also echoed similar views” (Nundy, 2014).

Philanthropy and Medical Research

From the late nineteenth century, as the government took the first systematic steps toward organizing medical research and the founding of bacteriological laboratories, government officials and members of the European-dominated Indian Medical Service urged wealthy Indians to donate generously for this purpose. Indian philanthropy generously supported the establishment of the Pasteur Institutes, the Calcutta School of Tropical Medicine, and the Indian Research Fund Association (current Indian Council of Medical Research), all promoted by European members of the Indian Medical Service (Chakrabarti, 2009; Kavadi, 2010, 2011). There were regular appeals to the munificence of Indian princes, the *shetia*, and industrialists to contribute to the advancement of medical science through endowments and donations. The Tata family in the late 1890s, inspired by the German research universities and Johns Hopkins University as the model, proposed a research university in Bombay incorporating an institute for medical research (Harris, 1958; Kavadi, 2011; Lala, 1984; Subbarayappa, 1992). The university materialized as the Indian Institute of Science at Bangalore in the Princely State of Mysore but without a department of medical research (Harris, 1958; Lala, 1984, 1992, 2004; Subbarayappa, 1992). Their subsequent attempts to endow a school of tropical medicine in Bombay and an Imperial Medical Research Institute in Delhi were unsuccessful. This was partly due to the parsimonious attitude

of the colonial government and partly due to the apprehensions among European members of the Indian Medical Service and other government officials about the Tata family's desire, rooted in their nationalist sentiments, to create institutions that would benefit India and Indians. The Tatas, however, went on to set up the Lady Tata Medical Trust (1932) which was the first to offer private funding to individual medical researchers in India, while its London-based Scientific Advisory Committee offered research grants and scholarships to leukemia and cancer researchers globally (Kavadi, 2014). The Trust also established the Tata Memorial Hospital (1941) without government collaboration (Kavadi, 2011; Lala, 1984). This became India's foremost center for cancer treatment and research. Indian nationalism inspired several Indian philanthropists to contribute to the cause of national education and the founding of institutions such as the Seth G.S. Medical College in Bombay (Chakrabarti, 2009; Kavadi, 2010, 2011).

Philanthropy and Ayurveda

In the early nineteenth century, the colonial government which had until then been tolerant of indigenous systems of medicine began to withdraw its support. The Indian elite and princes continued their patronage with the latter retaining practitioners of indigenous medicine as court physicians (Sharma, 2012). With the rise of a new urban commercial class in the second half of the nineteenth century and early twentieth century, indigenous systems found new patrons in the new emerging *shetia* class. They made monetary and land donations to establish charitable ayurveda hospitals. Support for ayurveda also came from the protagonists of Indian culture, several of them associated with the nationalist movement. Hindu revivalists committed to preserving their Hindu identity undertook to revive ayurveda. Ayurveda hospitals and dispensaries were founded, while at the Banaras Hindu University, a medical institute was established that combined both allopathy and ayurveda. The

attempt was essentially to provide a scientific basis to the latter system along the lines of Western medicine. In general, patronage of Indian medicine was largely restricted to individual practitioners. Social service organizations such as the Ramakrishna Mission, Hindu Seva Sadan, and Arya Samaj offered services in all the three main systems of allopathy, homeopathy, and ayurveda and even founded charitable hospitals. The Ramakrishna Mission, for instance, started a TB clinic in Delhi in 1927 and subsequently in 1939 after it received land from the government established a hospital (Nundy, 2014). Initially nationalist support had also been extended to unani [Islamic medicine], but with Hindu revivalism and the movement for a separate Pakistan, support for it declined (Sharma, 2012). In Delhi merchants and businessmen from the Marwari community began to support the establishment of dispensaries of indigenous medicine in the early years of the twentieth century (Nundy, 2014).

The Colonial State's Disengagement with Philanthropy

Wanting to keep its funding low and expecting Indians to raise public subscriptions and make generous donations to replicate the British voluntary hospital system, the colonial authorities began to be critical of the inadequacies of Indian charity and the philanthropic spirit in India (Nundy, 2014). Having originally encouraged medical philanthropy among Indians, gradually the colonial government began to be increasingly less inclined to engage in this collaborative effort. It became less amenable to cooperation or extending financial support. While the authorities persuaded Indians to pay and create medical facilities, government officials expressed both reservations and even outright suspicion about Indian efforts. The government was not even averse to backing out of its own financial commitment whenever possible (Ramanna, 2002). Most hospitals and dispensaries were constructed with Indian donations subject to the government undertaking financial responsibility for essential

maintenance costs, salaries, and medicines. Government officials averred that this placed a heavy burden on the government and suggested withdrawing support. The government sought to justify its position arguing that it would be a retrograde measure if the government was to undertake establishment of medical institutions for it would create dependence on government instead of people relying on themselves to create these facilities. Philanthropic acts of gifting to medical institutions were also looked upon rather cynically by the medical administration which observed that these acts were prompted by a desire for rewards rather than genuine concern for the people for whom these were constructed (Ramanna, 2002; Sehrawat, 2013).

In the years between the world wars and following the recommendations of the Inchcape Committee on Retrenchment created primarily to curtail government expenditure, the government became even less disposed toward supporting philanthropic and charitable ventures. In Bombay, the Tatas faced difficulties in getting government support for their medical research institutes as seen earlier. In Delhi the Shroff Charitable Eye Hospital opened in 1927 by Dr Shroff, a Parsi eye specialist trained in England, received funding from the Municipal Council, from Lady Reading, the wife of the Viceroy who also became its patron and donor. Interestingly it received very generous donations from the Parsis from Bombay. He, however, countenanced problems in getting funds for recurring and maintenance costs from the government. The Delhi Chief Medical Officer was critical of Indians who he said were not disposed toward philanthropic action observing that “the Voluntary Hospital System which is such a feature of civic progress in the UK has as yet attracted little attention among the charitably-minded in India” (Nundy, 2014). The government refused an increase in recurrent grants arguing that most patients who visited the hospital had the capacity to pay. Local bodies, however, continued to give both recurrent and special grants.

In the 1930s, Captain Jamna Das, civil surgeon at Mianwali, and Rai Lala Shri Ram of

Delhi Cloth Mills proposed the founding of a charitable hospital and a charitable maternity hospital, respectively. Both requested land from the government, but their requests were rejected because Nundy notes “by then there was scepticism about individuals who wanted to set up charitable institutions with so much zeal and later requesting for government grants” and more so when both failed to give a definite scheme for maintenance costs to the government (Nundy, 2014).

Rockefeller Philanthropy and Public Health 1920–1947

The early twentieth century witnessed the beginnings of international medical philanthropy. The Rockefeller Foundation was a New York-based private philanthropy established in 1913 with the “well-being of mankind” as its motto and a global vision for public health underscored by a belief in the promotion of preventive care through demonstration and education particularly in regions that were considered to be underdeveloped. It played a pioneering role in trying to shape ideas about health and well-being and in institutionalizing trans-regional networks of information and research (Farley, 2004; Fosdick, 1952). The RF transferred techniques it pioneered in the American south to transform public health ideas and practices globally. It launched a global public health program with the primary objective of creating “a health concept in the minds of people” and “a desire for public health agencies.”

The RF intervention in India occurred at the intersection of two simultaneous processes. First, there was the inauguration of a new chapter in the internationalization of health and medicine in which India was a key node in the generation and transmission of international knowledge about health (Amrith, 2006). Second, colonial medicine in India was making the shift away from its restricted focus on European health to a more inclusive health system. The Government of India Act 1919 devolved public health and medical education to the provinces retaining medical research with the central government.

Indian ministers were placed in charge of portfolios such as health and education. Finance was retained with official European members of the Governor's Council. This decentralization meant to curb government expenditure was in reality not the devolution of real power but administrative responsibilities. The RF's engagement with Indian public health came at an opportune time for provincial governments and local self-government bodies with limited finances struggling to organize and develop public health systems (Arnold, 1994; Kavadi, 1999). The RF programs were alluring for possible gains in preventive care but even more so for the flow of funds and personnel.

In India, education by practical demonstration of sanitary works for the community had been grossly neglected in the rural areas. The RF program which consisted of an anti-hookworm campaign, malaria control, and demonstration rural health units that were to serve as the vanguard of a public health system focused on preventive health, sanitation, health education, and community participation (Kavadi, 1999, 2002, 2007a, b). The RF as a principle worked only with governments. In India, it was primarily engaged with the provincial governments of Madras, Bengal, Bombay, and United Provinces and three princely states. Except for Madras Presidency and the princely states of Travancore and Mysore, nowhere did its cooperation extend beyond 5 years. The RF collaborated with the Government of India in the establishment of the All India Institute of Hygiene and Public Health (AIHHPH) in Calcutta (Kavadi, 1999, 2010).

One commentator has observed that the RF's public health program in India "lacked the intensity and thrust" of its programs in China or Eastern Europe because the RF "understood the local conditions and contemporary politics rather too well and consciously opted for a cautious lukewarm approach" (Kumar, 2009). The fractured and disaggregated nature of colonial administration in India on health policy and decision making had a bearing on the implementation of public health programs (Bhattacharya, Harrison, & Worboys, 2005). Some of the most significant deficiencies in public health administration in

India were (1) the lack of an all-India perspective, (2) its centralization in the central government despite an apparent decentralization to the provinces, (3) lack of uniformity in the provincial public health systems, (4) the hold of the civil service over public health, and (5) the conservatism of the IMS (Kavadi, 2010). The disaggregated structure of the general and public health administration caused priorities, perceptions, and responses to diverge at different levels. Coordination among different government departments varied. Finances and personnel were lacking or inadequate. In a country of sub-continental proportions, regional responses to Rockefeller public health activities were far too varied even where these were seen as having achieved some degree of success. For instance, in the princely state of Travancore, there was much opposition to the continuance of the rural health unit. On the other hand, in Bombay and Madras, health units were desired although these too had to countenance the vicissitudes of administrative and political processes (Kavadi, 1999).

Local official, medical, and popular perceptions about particular diseases were important in determining how and whether a program would be conducted. The purpose of the RF program was to educate people about preventive health and sanitation and not to control disease. It chose a disease, hookworm, that was seen to spread easily and had some consequences for labor productivity but most importantly for the ease with which control techniques could be demonstrated. The RF belief that even simple minds could be convinced of their methods was belied. Even official and medical minds were unconvinced of the necessity for undertaking preventive work for a disease whose gravity was in doubt. High infestation did not necessarily cause severe physical illness.

According to John Grant, RF officer and director of AIHHPH, the RF's major accomplishment in India was in creating a "medical – technical consciousness" and that the chief value of the health units was to "stimulate consciousness among health administrators" for "a more intensive organisation of administration at the periphery" and to provide practice field for health

visitors but pointed out these had “made no contribution to the solution of the fundamental administrative problem of India, and never will as they are now constituted. . .” (Kavadi, 1999, 2010). It appears that the success of some of the health units was more because of the treatment made available to the community members rather than their preventive activities alone. The Health Survey and Development Committee Report (1946) that provided the blueprint for India’s health-care system recommended that the primary health centers introduced in independent India use an integrated curative and preventive approach.

Concluding Remarks

The approach of the Government of India to the provision of medical care has not essentially changed since independence. Although a public health delivery system supported by the government was created, it has failed to displace the dominance of the private and charitable sector in the delivery of medical care and to address the inequities that have characterized India’s health sector since colonial times. If anything, there is clear evidence of a continuance in colonial policy. The Government of India since independence has persisted in a policy of incentivizing private philanthropy to establish hospitals. Additionally, over the last two decades, it has followed a policy of promoting the founding of for-profit corporate hospitals even as its own expenditure remains among the lowest in the world.

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Physics

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Most histories of the exact sciences consider “physics” to have begun with the ancient Greeks, especially with the work of Aristotle (384–322 B.C.E.). Classical physics is usually said to have been developed during the European “Scientific Revolution” by figures like Galileo Galilei (1564–1642) and Isaac Newton (1642–1727), and modern physics is commonly introduced with accounts of the discovery of relativity and quantum mechanics around 1900. Few histories of physics consider developments outside Europe; and of those that do, non-Western physics is often presented as “derivative” of European work.

However, recent scholarship has made it clear that this European view is incomplete, and that numerous non-Western cultures, including those

of China, India, the Islamic world, and others, developed sophisticated physical theories independently of Europe. In this expanded view, physics began in prehistoric times. From its origins in Africa, China, and India, physics developed to a surprisingly advanced level before its incorporation into the European scientific tradition.

Very little historical research into prehistoric African physics has so far been done, but the development of mathematics and astronomy has been dated back to very early times by archaeoastronomers such as Alexander Marshack. The bone tool handles of the Ishango culture of Lake Edward are inscribed with various collections of notches suggesting knowledge of abstract mathematical operations, and knowledge of astronomical events like new and full moons. These bones have been dated anywhere from 8500 to 25000 B.C.E. American physicist John Pappademos argues for a similar early start to African physics. He argues that the earliest dynamical experiments began with prehistoric African inventions like the spear and the bow and arrow, and that “the practical mastery of the principles of mechanics – the oldest branch of physics – grew as man learned to make flint weapons, tools, dwellings, boats, etc.” Similar arguments, of course, have been made concerning the prehistory of physics in other early cultures.

Pappademos further argues, based on archeological, linguistic, and historical evidence, that “ancient Egypt was essentially an African civilization,” and upon this basis he ascribes priority to African cultures for the early development of astronomy, geometry, and measurement. “To the Egyptians,” he concludes, “we owe the concepts of most of the fundamental physical quantities: distance, area, volume, weight, and time. Europe is indebted to Egypt for the invention of standards, units and methods for accurate measurements of all these quantities.” If this view is correct, it sheds new light on the development of the sciences among the ancient Greeks, whose indebtedness to Mesopotamian astronomy and Egyptian geometry has long been acknowledged.

China

A similar “prehistoric origin” may be claimed for physics in China, whose history has been dramatically advanced with the publication of Joseph Needham’s multivolume *Science and Civilisation in China*. Needham argues that traditional Chinese interest in physics was not particularly strong. Yet despite this, Chinese physics developed several interesting and original insights into various physical phenomena.

Chinese physicists, Needham says, were hampered by their lack of an atomic theory, used with great success by both early Greek and Indian, as well as later European scientists. However, their view of the physical universe as a “perfectly continuous whole” rather than as a collection of atoms meant that Chinese scholars were pioneers in understanding action-at-a-distance, and the connection of various forces. Chinese physics tended to emphasize waves rather than particles, and this dominance led to several early discoveries in magnetism, optics, dynamics, acoustics, and many other fields.

Among the earliest Chinese texts on physics are the writings of the Mohist schools of philosophy in the Warring States Period (480–221 B.C.E.). Followers of philosopher Mo Zi (ca. 479–381 B.C.E.), the Mohists made pioneering discoveries in statics and hydrostatics, dynamics, and especially optics, many of which are described in the *Mo Jing* (third to fourth centuries B.C.E.).

One of the areas of physics most successfully tackled by the Mohists was the field of optics. Now while Chinese optics never reached the theoretical level of medieval Arab sources, it is clear that optics in the East was at least as advanced as parallel developments in Ancient Greece.

The propositions of the *Mo Jing* tell us that Mohist physicists made considerable experimentation in their efforts to construct a coherent theory of light and optics. Mohist physicists clearly understood that light travels in straight lines, and by using fixed light-sources, screens with pinhole apertures, and possibly the camera obscura, were able to study the formation of inverted images and the idea of the focal point. The camera

obscura is certainly known from the eighth century A.D. onwards, and is mentioned in the ninth century *Yuyang Za Zi* (*Miscellany of the Yu Yang Mountain Cave*), though the theoretical explanation of its operation is incorrect. By the *Meng Qi Bi Tan* (*Dream Pool Essays*) of Shen Gua in A.D. 1088 we see an active interest in experiments involving pinhole apertures in screens to pass cones of light into darkened rooms.

Back in the Warring States period, by examining combinations of plane mirrors, Mohists also studied the phenomenon of lateral inversion (left becoming right in an image). They measured refraction in different media by examining the apparent bending of a stick in a glass of water. In addition, they used concave and convex mirrors to determine the properties of real and inverted images, and to differentiate between what we now know as the center of curvature and the focal point.

Concave mirrors were also used by ancient Chinese physicists to start fires by sunlight. Bronze mirrors are described as far back as 672 B.C.E.; surviving dated mirrors occur from A.D. 6 to 10, and many exist from later Han times. Multiple reflections were studied in the second century B.C.E., and Han accounts of concave “burning mirrors” in the *Huai Nan Zi* (*Book of Huai-Nan*) of 120 B.C.E. demonstrate they knew of the focal point of a concave mirror. Besides starting fires, concave mirrors were used with the moon in the later Han era to collect dew.

An interesting development of the fifth century A.D. was the use of “light-penetrating mirrors”. These “magic mirrors” were inscribed on their backs with written characters; when held to the light, these otherwise-invisible letters would “shine through” the mirror and become legible. A 1932 investigation revealed these mirrors were made of more than one curvature, with the designs on the back imposing unequal strains on the mirror. The mirror would differ imperceptibly in thickness from place to place, with the convex reflecting surface on the front varying in curvature, and thicker areas having flatter curvatures than thinner areas. They were described in the eleventh century A.D. by Shen Gua.

Alongside mirrors, early Chinese opticians made considerable experiments with lenses. Glass was known to the Zhou dynasty, which began several hundred years before the Warring States period. A glassmaking industry began around 500 B.C.E., and by the A.D. 83 *Long Heng* (*Discourses Weighed in the Balance*) of Wang Chung, there are descriptions of glass lenses used to bring sunlight to a focus to start fires. In the third century A.D. *Bo Wu Zhi* (*Notes on the Investigation of Things*), burning lenses of rock crystal are mentioned. Finally, the 940 *Hua Shu* (*Book of Transformations*) of Tan Qiao describes the various real and inverted images produced by all four types of lenses, the planoconcave, planoconvex, biconcave, and biconvex.

There also appears to be some evidence for an independent Chinese development of the telescope by Bo You and Sun Yun Qiu in the early seventeenth century. However, as for spectacles, though they are often considered a Chinese invention, they in fact originated in Europe, and were imported overland into China soon after their invention around A.D. 1286.

In mechanics, the Mohists performed many experiments to determine the properties of levers and balances. They defined forces and weights, knew the laws of levers, balances, and pulleys, and developed a simple version of what came to be known in Europe as the “Atwood’s machine” (named after English physicist George Atwood in 1780). They also invented the steelyard, and used it in weights and measures. Mohists seem to have been familiar with the “parallelogram of forces”, and may have been in possession of the full theory of equilibrium (ca. 287–212 B.C.E.).

Early Chinese physicists did not discuss theoretical centers of gravity, but they do appear to have done some practical research on centers of gravity in their “trick vessels”, that is, jugs which incline or sway depending on the amount of water they contain. Trick vessels were known to Confucius (551–479 B.C.E.), and were explicitly described in texts of the third century B.C.E. Siphons were constructed since antiquity, and were used for irrigation around the end of the Eastern or Later Han dynasty (A.D. 25–220).

They were later employed (ca. 450 A.D.) by Daoist scientists and inventors like Li Lan in their balanced clepsydra, or water-clocks. Clockmaking is an ancient art among the Chinese, and attained great precision in the eleventh century mechanical and astronomical clocks of Su Sung (A.D. 1090).

As for specific gravity, it was known to the ancient Chinese, and was discussed by the philosopher Mencius (374-ca. 291 B.C.E.), cofounder of Confucianism and one of the students of Confucius' grandson. "Archimedes' Principle" appears to have been known to Han technicians (A.D. 221–264), according to accounts in the *Zhou Li* (Record of the Institutions of the Zhou Dynasty). Han physicists and engineers also knew how to measure specific gravities in liquids, and were familiar with the use of the principle of buoyancy to weigh heavy objects.

Mohists approached the atomic theory in their discussion of the strengths of materials, but never articulated it clearly or developed its consequences. In the explanation of why a fiber breaks under tension, Master Lieh, in the *Lie Zu* book, argues the fiber is composed of unequally strong or cohesive elements, so that a breaking-plane forms somewhere in the fiber. This view is in essence a particulate theory of matter, but Lie uses the example to argue for a continuous universe.

The *Mo Jing* contains some remarkable statements about the study of motion. Though Chinese physics did little theoretical dynamics, they did consider forces in some detail, and appear to have come remarkably close to the principle of inertia as stated by English physicist Isaac Newton (1642–1727) as the first law of motion in his *Principia Mathematica* of 1687. Newton stated that "every body continues in a state of rest, or uniform motion in a right (straight) line, unless it is compelled to change that state by forces impressed on it." According to Joseph Needham, the Mohists argued that motion is due to a kind of looseness [the absence of an opposing force]. . . the cessation of motion is due to the [opposing force] of a 'supporting pillar' [a force that changes the moving body's otherwise-permanent

state of motion]. . . If there is no [opposing force] of a 'supporting pillar', the motion will never stop. . . If there is [some kind of] 'supporting pillar' [some other force interfering with the motion], and nevertheless the motion does not stop [it may still be called motion but it will not be a straight-line motion because there will have been a deflection].

Mohist Chinese physicists also investigated the relativity of motion, and motion along inclined planes or slopes; they also studied particular problems of moving spheres.

As for Chinese acoustics, its history extends back more than two millennia. Second century B.C.E. philosopher Dong Zhongshu studied sympathetic resonance in musical instruments; indeed the entire history of Chinese acoustics is intricately tied up with musical instruments, especially lutes and bells. Chinese physicists first classified sounds based on the four materials (stone, metal, ► [bamboo](#), and skin) which made up the musical instruments producing them; later, they extended their classification to an eightfold scheme tied to the eight directions of the wind. Chinese musicians used resonance phenomena to tune their instruments, and were well aware of the fact that sound was caused by vibrations. Chinese military strategists even used resonance in the fourth century B.C.E. to construct primitive geophones to listen for the tunneling of an enemy besieging a city.

Chinese investigation of magnetism and electricity is similarly ancient, but is better known in the West than acoustics. Almost all physics textbooks note Chinese priority in the magnetic compass. Lodestones and magnets are mentioned in the third century B.C.E. *Lo Shi Chun Qiu* (Master Lu's Spring and Autumn Annals), as well as in the later *Huai Nan Zi* (Book of (the Prince of) Huai-Nan). By the fifth century, Chinese physicists knew of the directive property of the lodestone, and had begun to measure magnetic forces; and by the eighth or ninth centuries, they had discovered both magnetic polarity and variation. Engineer-astronomer Shen Gua discussed both in his *Dream Pool Essays*; his descriptions indicate considerable experimentation on the magnet. As for the

magnetic compass, it is clear that the Chinese were using it for geomancy and divination by the first century A.D. Their earliest use of the compass in navigation is unclear; the first datable references occur in about the eleventh century, but it is certain that Chinese mariners used compasses many years earlier. As in Europe, Chinese physicists used both “wet” and “dry” compasses; the former were made by floating magnetized needles in bowls of water whose rims were inscribed with directions, and the latter by carefully mounting the needle on an upright pivot.

What about the physics of surface phenomena? As in the West, its study was long delayed in China. Of course, knowledge of friction was very old among both cultures. Ancient Chinese, for example, knew how to use friction to make fires; and the friction of wheels was discussed in the *Han Zou Li*. By the Tang dynasty (A.D. 618–906), prince Li Kao studied the fit of smooth surfaces, and in the thirteenth century, Zhou Mi studied monomolecular films. And, during the Sung dynasty (A.D. 960–1279) Zhang Shi-Nan’s 1233 treatise, *Yu Huan Zhen Wen* (Things Seen and Heard on My Official Travels), discusses the ring-test to determine the quality of lacquer. The ring-test was a method of quality control for centuries; it was not until 1878 that it was applied to measuring surface tension by finding the force to break the surface.

In China as in Europe, heat and combustion were a comparatively late interest. Making heat and sparks by rubbing wood and striking flint were techniques known to the ancient Chinese, and medieval texts give priority to the Chinese in the invention of the match (Northern Qi, A.D. 577). Candles were known to the Mohists in the Warring States period, and lamps since ancient times. But by the early eighth century A.D., Chinese lampmakers had cleverly designed an oil-cooling water reservoir below the lamp to reduce evaporation. The use of natural gas for fuel goes back to the first few centuries B.C.E., and Chinese inventors applied this knowledge on an industrial scale.

Some knowledge of the practical principles of steam power may go back as far as the second

century B.C.E., based on a passage in the undated Daoist alchemical and technical recipe book, the *Huai Nan Wan Bi Shu* (Ten Thousand Infallible Arts of the Prince of Huai-Nan). Interest in spontaneous combustion is also very old, and is discussed in accounts of the third century A.D. Chinese physicists also looked at successive boiling phases of liquids (particularly water for tea).

On the theoretical side, Li Shizhen’s sixteenth century *Bencao Gangmu* (Great Pharmacopoeia) of 1596 attempts to classify types of fire. Fire is of two varieties, Yin and Yang, with many subdivisions; in general, it has *qi* (energy) but not *chi* (matter). Shizhen could not classify luminescent “fires” like fluorescence, phosphorescence, electro-luminescence, and piezo-luminescence.

Electro-luminescence was described by Chinese physicists of the third century A.D. The *Bo Wuzhi* (Record of the Investigation of Things), of approximately A.D. 290, describes sparks created by contact with charged objects, such as drawing combs through the hair. As for other electrostatic phenomena, the ability of amber to attract objects when rubbed was known very early. Amber was first described by first century A.D. philosopher ► [Wang Chong](#), and its properties were discussed in more detail around A.D. 500 by alchemist-physician Tao Hong Jing. But there was little progress in electrostatics until the eighteenth century. Meanwhile, piezo-luminescence, caused by rubbing certain types of crystals, was known in the Tang dynasty. Artificial phosphors may have been studied in the Sung period; the eleventh century *Xiangshan Yelu* (Rustic Notes from Xiang Shan) of monk Wen Rong explains the making of a phosphor from oyster shells. Some of these crystals and phosphors may have been imported overland from Arabic cultures, Needham argues; and if so, they may well have similarly influenced Indian physics on the way.

India

There is still much historical research to be done on the growth and development of science in India. Hindu scientists have been justly

celebrated for their early contributions to mathematics (including the Hindu-Arabic number system, the use of zero, trigonometry, series summation, algebraic operations, and so on) and astronomy (elaborate computational techniques to determine the positions of celestial objects), but until recently little has been written on their physics, which is both sophisticated and extensive.

Early Indian physics is concerned with the “doctrine of the five elements” (*pañcamahabhūtas*); that is, the interplay between the elements of earth, water, fire, air, and a nonmaterial substance (*pṛthvī, ap, tejas, vāyu and ākāśa*, respectively). Among the earliest treatises of the ṛgveda period (2000–1500 B.C.E.) we see the emergence of primeval water as the “first cause” of all other elements, rather like the simple cosmologies of ancient Greek scientists like Thales (ca. 624–545 B.C.E.) and Anaximander (ca. 611–575 B.C.E.).

The five element theory was later developed by the Vaiśeṣika School of about 700–600 B.C.E., which also began the study of atomism. The introduction of Buddhism and Jainism brought new inquiries into the problems of atomism, matter, and motion (ca. 600–200 B.C.E.); this was followed by the systematic formulation of atomic theories among Indian physicists between 200 B.C.E. and A.D. 400. Indian science made its greatest advances between the period A.D. 400 and 1200, especially among the Jaina and Buddhist schools, as well as the Nyāya-Vaiśeṣika commentators. These medieval Indian physicists refined atomic theory, and made detailed investigations into gravity, motion, and impetus.

Physicists first began to explain the natural world in terms of atomic theories after 700 B.C.E. For the Vaiśeṣika School, atoms were eternal or indestructible, indivisible, and infinitely small. These atoms (*pramāṇus*) had vibratory and rotational motions, along with inherent impulses to form binary molecules (*dvyāṇuka*). Various combinations of atoms made up all the diverse substances in our world. Interestingly enough, this theory explained chemical reactions by supposing that these

substances were broken up into their original atoms (the *pramāṇu* state) before they could be recombined to make a new material.

Physical and chemical change, meanwhile, was closely linked to the theory of heat. The first century A.D. philosopher Vātsyāyana argued that chemical change occurs as a result of either internal or external heat; moreover, during combustion, heat trapped inside the fuel in a latent form is released, allowing chemical reactions to proceed. The *Kīranāvali* of Udayana ultimately traced all forms of heat back to their source in the Sun.

Ancient Hindus believed that both heat and light were composed of streams of infinitely small particles radiating in all directions from sources like the sun. These particles move at inconceivably high speeds, and, when they strike molecules, break them down into smaller atoms, promoting chemical change. This theory was described in detail in the eleventh century A.D. *Nyāyamañjari* of Jayanta.

Other factors governing matter and physical change included gravity (*gurutva*), fluidity (*dravatna*), viscosity (*sigdha*), and elasticity (*sthitishāpaka*). For the Vaiśeṣika, gravity was seen as a causal factor resulting in the fall of bodies; it is not a force in the modern sense. Moreover, only earth and water possess it. The later Nyāya-Vaiśeṣika school of physicists (ca. 400–1200) add that gravity could be cancelled out by the effects of conjunction (a object supported on a stand) or impetus (an arrow flying through the air). They argued that gravity is eternal for primeval atoms, but temporary for compounds.

Fluidity was of two types, natural and incidental, with the former reserved to water, the latter to water, earth, and fire. Viscosity governs cohesion and smoothness, and is a property of water, preventing particles in it from dispersing. Elasticity is a quality of earthy substances.

How did Indian physicists handle the problem of matter in motion? The Vaiśeṣika held that matter was naturally static or stationary. It could be moved by some physical quality, like gravity in a falling body, but this motion would be temporary; and perpetual motion was impossible.

Interestingly enough, it seems that gravity was only required to set the falling object in motion. Once it had started moving, impetus is generated, which keeps it falling without any additional help from gravity.

The fifth century A.D. philosopher Praśastapāda made a detailed study of motion and impetus in his *Pradārtha dharma saṃgraha*, a revision of the much older *Vaiśeṣikasūtra*. He divided motion into five categories: *utkṣepaṇa*, *avakṣepaṇa*, *prasāraṇa*, *ākuñcana*, and *gamana*, or, respectively, lifting up, throwing down, expansion, contraction, and action (gyrations, evacuations, quivering, and the like). Motion can be caused, says Praśastapāda, by six things: gravity, fluidity, volitional effort, conjunction (such as impact or striking), impetus or unseen causes. His use of impetus (*vega*) is rather close to our modern momentum, and is illustrated by the examples of throwing a heavy shot or firing an arrow. When the shot is thrown, the first impelling push begins its motion; then the shot's internal impetus takes over, and maintains its motion. Once the impetus is exhausted, the shot falls back to the ground.

Praśastapāda also had a relatively modern conception of sound. He realized sound was produced by vibrations in air, and added that these vibrations travel "like a series of water-ripples... or a series of waves" to the ear.

Indian physicists had many contacts with Chinese developments in the East, but they were equally well connected to Arabic work in the West. The relations between Indian and Islamic science in the Medieval period has recently been the focus of much scholarly work (Needham, Chin, Filliozat, Sen).

Islam

Islamic physicists, mathematicians, and astronomers such as Ibn Sīnā, Ibn al-Haytham, ► [al-Bīrūnī](#) and ► [al-Kindī](#) have long been known to Western historians for their influences on scholastic science in the Medieval Latin West. Arabic scientists frequently criticized and extended the physics of Aristotle, Archimedes (ca. 287–212 B.C.E.), and

other ancient physicists and often provided the original roots for many physical ideas, such as force and momentum.

In mechanics and dynamics, Muslim physicists developed several important concepts. Ibn Sīnā or Avicenna (980–1037) invoked the idea of *mayl* (Latin *inclinatio*, or inclination) to explain projectile motion; this theory was further developed by al-Baghdādī before its transmission to the Latin West. Ibn Sīnā and Ibn al-Haytham developed the concept of momentum, and did pioneering research into the theory of gravity. Muslim philosophers knew that falling bodies accelerated independently of their mass, and that the attractive power between two objects increased as their masses got larger, but decreased with their separation.

Arabic physicists extensively studied the theory of weights, densities, buoyancy, and measures. They were familiar with the law of the lever and Archimedes' principle, and developed the balance as a scientific instrument to study topics such as specific weights. Thābit ibn Qurra (836–901) worked extensively on the law of the lever, and his ideas were later quite influential in the West. Meanwhile, al-Khāzinī's (fl. 1115–1130) celebrated *Kitāb mizān al-ḥikmah* (Book of the Balance of Wisdom) developed formulae for the specific and absolute weights of various alloys. Al-Khāzinī's work also discusses centers of gravity, hydrostatics, and other physical concepts.

Many Islamic scientists extended the theory of simple machines. Among these researchers were Baghdad's ► [Banū Mūsā](#), and the many Arabic scientists involved with the development of various mechanical gadgets, automata, trick devices, and other complex machines. This branch of physics, called '*ilm al-ḥiyal*', was developed by the Banū Mūsā, the school of Ibn Sīnā, Ibn al-Sā'ati, and many more. It reached its climax in the famous *Kitāb fī ma'rifat al-ḥiyal al-handasiyyah* (Book of Knowledge of Ingenious Mechanical Devices) of ► [al-Jazarī](#).

Among the most influential researches of Muslim physicists were their pioneering inquiries into light and optics, which virtually established this branch of physics as an organized discipline.

Al-Kindī's (fl. 790–866) early treatises introduced Euclidean optics to the Medieval Latin West. His theories of vision influenced Islamic writers for several centuries, including al-Fārābī (d. 950), al-Ṭūsī (1201–1274), and many more.

Opticians such as Ibn Sīnā and al-Bīrūnī (973–ca. 1050) studied particular problems like the speed of light from ancient sources, usually declaring it to be finite. Meanwhile, doctors like ► [al-Rāzī](#) or Rhazes (ca. 854–935) and ► [Ḥunayn ibn Ishāq](#) inquired into human eye physiology, making their own contributions to the theory of vision. However, the most significant figure in Muslim optics was the Egyptian physicist Ibn al-Haytham (ca. 965–1039), better known in the West as Alhazen.

Many historians consider Ibn al-Haytham to be the most important optician between Euclid and Johannes Kepler (1571–1630). Historian of science David C. Lindberg argues that “Alhazen was undoubtedly the most significant figure in the history of optics between antiquity and the seventeenth century.” This is because Ibn al-Haytham successfully integrated not only competing mathematical and physical approaches to light in his new intromission theory of vision, but also harmonized his views on sight with the anatomical work of earlier Muslim physicians. A prolific writer, Ibn al-Haytham is credited with more than 200 treatises on all branches of the sciences, including almost two dozen dealing with light and optics.

Ibn al-Haytham's most important optical work was his *Kitāb-al-manāẓir* (Book of Optics), which was translated into Latin as *De Aspectibus* or *Perspectiva*. This treatise had a profound effect on optics in the Latin West, influencing the work of Witelo (ca. 1230/5–1275), Roger Bacon (ca. 1220–1292), John Pecham (fl. 1250–1292), and many more. Traces of Ibn al-Haytham's theories are even found in the seventeenth century optical writings of Kepler and Newton.

Alongside his intromission theory, Ibn al-Haytham also studied various celestial and atmospheric phenomena such as twilight,

refraction, atmospheric thickness, and optical illusions. He also contributed to the theory of catoptrics and dioptrics and extensively researched the laws of parabolic and spherical mirrors. “Alhazen's problem”, which he solved geometrically, involved taking a spherical mirror and placing an object before it so that its image was reflected in the mirror; to find the point of reflection, one must solve the equivalent of a fourth degree equation. Ibn al-Haytham also demonstrated various reflection laws, including the significant finding that incident, normal and reflected rays all lie in the same plane. In his study of refraction, he discovered the equivalent of Pierre de Fermat's (1601–1665) “principle of least time”: that a ray of light always takes the shortest and easiest path. Much of Ibn al-Haytham's work in this area was based on direct experimentation; glass cylinders immersed in water revealed refraction laws, and homemade lenses helped him determine the laws of magnification. Ibn al-Haytham even did early research into the camera obscura.

Islamic optics declined after Haytham's synthesis, though there was a revival of interest during the rise of the *ishraq* (School of Illumination) in the thirteenth century. ► [Al-Shīrāzī](#) extended Ibn al-Haytham's account of the rainbow, arriving at essentially our modern understanding that its colors are due to a combination of light reflection and refraction through suspended water droplets. Al-Shīrāzī's explanation was confirmed experimentally by his student, al-Farīsī (d. ca. 1320). But by the fifteenth century, leadership in optics had passed to the West, and by the following century, European scientists were making discoveries in physics, astronomy, and mathematics that were to usher in the “Scientific Revolution”.

See Also

- [al-Kindī](#)
- [al-Shīrāzī](#)
- [al-Rāzī](#)

- [Banū Mūsā](#)
- [Clocks and Watches](#)
- [Geomancy in the Islamic World](#)
- [Ḥunayn ibn Ishāq](#)
- [Li Shizhen](#)
- [Yinyang](#)

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Physics in China

R. A. Uritam

An account of physics, as well as of any other science, in a prescientific revolution era or civilization does not present a meaningful picture without an understanding of the views of nature that are embedded in various natural philosophies that develop in each civilization and that are the most comprehensive account of natural phenomena before “physics” as a distinct discipline existed. In the West most of these natural philosophies had their origins in Greece, and included Pythagoreanism, Atomism, Platonic idealism and dualism, and Aristotelianism, each of which introduced distinct elements into Western science. However, they largely agreed that the final ground for understanding physical reality was substance, or “stuff.” Additionally, in due course, rational proof, Euclidean geometry, reductionism, mechanistic materialism, and atomism became principal determinants of Western science.

In a similar way at about the middle of the first millennium BCE various schools of natural philosophy arose in China. These included Daoism, Naturalism, Mohism, Legalism, and (much later) Sung Neo-Confucianism. The central concept of Daoism, systematized by Laozi (a contemporary of Aristotle) is the *Dao* (the way), the “way the universe works.” It is the unifying principle of the universe, akin to the “One” of Parmenides. This natural, noncoercive, nonanthropomorphic principle encompasses all phenomena, and invites study of all aspects of nature. Human standards are irrelevant in nature; one is to subject oneself to the harmonies of nature (*wu wei*).

Naturalism, represented by its early proponent, ► [Zou Yan](#) (fl. 300 BCE) introduced the doctrines of Yin and Yang and the *Wuxing* (Five Elements or Phases). Yin and Yang are the two fundamental forces, the expression of

the basic dualistic principle, two forces existing not in conflict, but in a balance or a cooperative tension of opposites. Yang represents light, heat, dryness, hardness, activity, heaven, sun, and south. Yin stands for dark, cold, wetness, softness, quiescence, earth, moon, and north. The Five Elements invite comparison with the four elements of Empedocles. In China the five are water, fire, wood, metal, and earth, representative less of substances than of processes of nature. The elements are further arranged into the Mutual Production Order: wood, fire, earth, metal, water, wood, etc., where each element produces the subsequent one. In the Mutual Conquest Order, each element dominates over the subsequent one.

The less prominent school of Mohism introduced more formal, abstract, and geometrical notions such as a dimensionless geometrical point in space and time. Somewhat in the same vein, the Legalists discussed formal logical propositions, paradoxes, and syllogisms. Curiously, modern Chinese writers during the Cultural Revolution were fond of heaping fulsome praise on the Legalists for their supposed kinship to the scientific materialism of Marxism.

Mohism and Legalism waned in importance, and after centuries of evolution indigenous Chinese natural philosophy reached its most mature form in the twelfth century AD in the Sung neo-Confucian synthesis, best represented by the natural philosopher Zhu Xi (AD 1131–1200). This school combined the attention to nature present in Daoism and Naturalism with the heretofore society-centered official Confucianism that governed human conduct and interaction. In this way the human world and the world of nature were unified and investigation progressed at each “level of integration” from inanimate to human. The synthesis introduced two other fundamental principles of *qi* and *li*, roughly similar to Aristotelean matter and form.

The picture or model of nature that emerges is quite different from the Western one. It is not mechanistic, legalistic, geometrical, linear, or even materialistic. The leading twentieth century student of Chinese science, Joseph Needham, described that picture of nature in China as being one of a harmoniously functioning

organism, an interconnected, interdependent whole. Reductionism and analysis into parts will not yield an understanding of nature because each entity is defined by the role it plays in relation to the pattern it fits into, by the web of relationships it has. The principal element of explanation is not substance but relation and pattern. As in Chinese society, so also in nature there is “order without law”. The legal metaphor is absent in statements about nature (“laws” of nature); the order of nature is not as that of citizens subject to universal law but as that of musicians in an ensemble or dancers in a pattern. For these reasons, traditional Chinese thought found no problem in retroactive causality, since temporal succession is unimportant compared to the interdependence of the system as a whole, as a pattern in space and time.

With a world picture so different from the Western one, it is difficult even to match traditional Chinese activity in some realm with “physics”, itself a term that acquired a recognizable meaning only fairly recently. Nathan Sivin has proposed the following divisions for Chinese science: medicine, alchemy, astrology, geomancy, natural philosophy and physical studies, mathematics, harmonics and acoustics, and mathematical astronomy. Present-day “physics” corresponds to parts of “physical studies” and “harmonics.” Also, the strong and weak branches of physics are reversed in China and in the West. There was no Chinese achievement in mechanics, dynamics, or kinematics, nothing at all to rival Aristotle or the medieval precursors of Galileo. This is consistent with the absence in China of geometrical, corpuscular, and mechanistic ideas. Instead the preference was for continuum theories, pneumatic models, waves, vibrations, and resonances, all consistent with interrelation, pattern, and meaning only for a system as a totality. Thus, the highest achievements in indigenous Chinese physics were in the areas of optics, acoustics, and magnetism. Of the three, optics was the weakest, and ironically, its best practitioners were the Mohists, a school generally atypical of Chinese scientific philosophy. Although, lacking Greek geometry, Chinese optics never attained the level of medieval Islamic optics,

it began at least as early as its Greek counterpart, with an account of light-sources, mirrors, and, later, lenses.

The fourth-century BCE Mohist text *Mo Jing* describes shadow formation, the distinction between umbra and penumbra, and discusses the dependence of the size of the shadow on the position of the object and of the source of light. Properties of light passing through a pinhole are discussed, including the definition of a focal plane and the inversion of the image. Reflection from a plane mirror and from a combination of plane mirrors is treated. Refraction of light at the plane boundary between air and water is described, including the resulting phenomenon of the apparent reduction in depth of an object in water. Also, the formation of images by spherical concave and convex mirrors is discussed in some detail.

Of even greater antiquity in China was the practical use of burning-mirrors for igniting fires from the sun's rays. The earliest such mirrors, made of bronze, date from the Chinese Bronze Age, in the seventh century BCE. A more difficult technological achievement was the production of lenses and burning-lenses. Rock-crystal, i.e., pure transparent quartz (SiO_2) was used; glass was produced as early as the sixth century BCE, and lenses were in use from the time of the Han dynasty of the first century AD. By the tenth century AD the four fundamental types of lenses (plane-concave, biconcave, plano-convex, and biconvex) were produced and their properties analyzed. Eye-glasses and spectacles, as well as magnifying glasses were in use by the fifteenth century AD.

Progress in the fields of sound and acoustics followed naturally from the fundamental orientation of Chinese natural philosophy. The alternation between Yin and Yang implies a cyclic, recurring process between opposites, reminiscent of harmonic oscillation or wave motion. Also, sound was likened to waves in a pool, caused by friction, and to a resonance in the fundamental neo-Confucianist substance, *qi*.

In the description and classification of musical sound and in the construction of instruments, the Chinese displayed their characteristic tendency

to emphasize the whole and the complex, instead of isolating the simple. To Western thought the primary attributes of sound are pitch (frequency) and loudness (amplitude). By contrast, Chinese acoustic theory concentrated from the beginning on timbre (the overtone structure) as the primary attribute or parameter describing sound. Sounds were classified according to timbre according to the "eight sources of sound." metal, stone, earth-clay, skin, silk-thread, wood, gourd, and ► bamboo. As can be expected, these timbres were correlated, like the five elements, with seasons, compass points, and, naturally, musical instruments.

The influence of the concept of pattern and organic unity was at work in the ready acceptance of the spontaneous resonances of two musical instruments, this being merely a corroboration of a resonance in the cosmic organism. In a similar vein, sounds were not classified by pitch; rather, the names of notes in the early five-note scale arose from the mutual arrangement of musical instruments in archaic ceremonies.

A distinctive later achievement of Chinese acoustic theory is less closely related to the organic view of nature. In the sixteenth century AD, Zhu Zaiyou (b. AD 1536) provided the earliest solution to the classic problems of rendering melodies in several keys on one musical instrument, without retuning the pitches. The natural scale is one where the frequencies of the sounds, and the associated lengths of strings in a musical instrument are in "just intonation," following Pythagorean ratios (e.g., 2:1 for octave to tonic, etc.). If the ratios are true for one scale they cannot be so for a scale that begins one note higher. Zhu's solution was to have frequencies of all adjacent notes, differing in pitch by half a tone in a 12-note scale, differ by a ratio $2^{1/2}$ to 1. This system of equal temperament, in use on a modern piano, was introduced considerably later in Europe, becoming popular only in the eighteenth century, and is familiar to music lovers from early examples of its use by composers, such as in Johann Sebastian Bach's *Well-Tempered Klavier*.

The most prominent achievement of traditional Chinese physics, however, was in

magnetism. That phenomenon is totally harmonious with a model of the world as organism, with resonances and intangible influences on the parts from the pattern as a whole. Also, China, not knowing the Aristotelian concepts of natural place, natural and enforced motion, did not have to explain magnetic phenomena, as did the West, as deviations from this scheme. Even more to the point, action at a distance, or the concept of a field, was no problem in China, whereas Cartesian mechanicians saw these as throwbacks to scholasticism when used to account for gravitational, electrical, and magnetic phenomena.

Historically, the discovery of every significant magnetic phenomenon – attraction, directivity, polarity, thermoremanence, declination, as well as application to a working compass – considerably antedates comparable advances in the West. Chinese texts of the third century BCE describe the simplest effect, the attraction of iron by natural magnetite (lodestone). The directional, north-south seeking property of the lodestone was observed about the first century AD and first demonstrated by a lodestone placed on a very smooth bronze surface. (Modern replicas of this arrangement have verified that friction can be made low enough to display the effect.) Subsequently, the lodestone was balanced on a pin, or floated on wood in water. In the early centuries of the first millennium AD the directive property of the lodestone was transferred to iron by rubbing. By the eleventh century AD the more sophisticated method of magnetization, thermoremanence, was in use, consisting of allowing a red-hot piece of iron to cool rapidly through the Curie point while it is oriented along the earth's magnetic field.

By about AD 1100, a useful magnetic compass was in use in navigation, although the traditional inward-looking agrarian economy and dependence on river, rather than ocean, transportation did not thereby lead to extensive global exploration. Beginning in the ninth century AD magnetic declination was observed. Subsequent recordings of declination chronicle a variation of declination over time, for example, the declination being to the east prior to about AD 1050, and to the west after AD 1050.

Philosophers of science differ on whether the fundamental concepts of Chinese natural philosophy, such as relation, pattern, and organism could have furnished an alternative but adequate basis for a model of scientific explanation. On this question, in his extensive writings, Needham has probably overstated the case in favor of the Chinese potential for doing this.

In terms of transmissions from China to the West, the technological contributions are well-known; printing, ► [gunpowder](#), and the magnetic compass are always at the head of the list. Many scholars also attribute to Chinese science a role in promoting the development, after Newton, of nonmechanistic concepts in physics, such as field, wave, fluids such as caloric and ether, to say nothing of the loss of distinction between matter and energy in relativity and between wave and particle in quantum mechanics.

See Also

- [Acoustics in Chinese Culture](#)
- [East and West](#)
- [Environment and Nature: China](#)
- [Five Phases \(Wuxing\)](#)
- [Magnetism in Chinese Culture](#)
- [Yinyang](#)
- [Zou Yan](#)

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Physics in India

William T. Johnson

Early Indian thinkers developed a number of theoretical systems which centered around two main themes: elements and atoms. Based upon a relatively broad review of the ancient philosophies, we will discover a rich scientific tradition in India.

Ancient India (2000 BCE–AD 800)

Early Indian explanations about the physical makeup of the universe were religious and philosophical in nature. The oldest literary record of this period, the *ṛgveda*, presents several fundamental concepts related to physical science such as *ap* (primeval water), which was considered the basic element of matter. Gradually, the doctrine of five fundamental elements emerged, as seen in the Upaniṣadic literature of around 700 BCE. The five elements were *pṛthvī* (earth), *ap* (water), *tejas* (fire), *vāyu* (air), and *ākāśa* (a nonmaterial substance). The Sanskrit terms have a wider connotation than the English translation, so it is essential to present the original terms.

Much of this early literature was concerned with the attributes associated with each of these elements. They had both common as well as distinctive attributes, many coincident with the five senses, as follows: *pṛthvī* (earth) sound, touch, color, taste, and odor; *ap* (water) sound, touch, color, and taste; *tejas* (fire) sound, touch, and odor; *vāyu* (air) sound and touch; and *ākāśa* (nonmaterial) sound. Different combinations of these five elements yielded certain products. The human body is a good example. The human embryo has energetic principles which are separated into form by *vāyu* (air). *Tejas* (fire) subsequently transforms the embryo. *Ap* (water) maintains moisture while *pṛthvī* (earth) gives it shape and size. Finally *ākāśa* expands the embryo and develops it.

Many of today's scholars question the notion that scientific inquiry only found fertile ground in the minds associated with the Greek tradition. In fact, a number of diverse systems of scientific inquiry were developing in India coincident with the Greek philosophies by 500 BCE. Those which presented five fundamental elements were the *Sāṃkhya*, *Nyāya*, and *Vaiśeṣika*. The *Jaina*, *Bauddha*, and *Cārvāka* schools, like many of the Greek thinkers, presented four fundamental elements. It is difficult to say with certainty which school or culture developed these ideas first, therefore who influenced whom, or if they developed independently.

The *Nyāya-Vaiśeṣika* school, prominent among early Indian systems, was popularized by an individual who came to be known as Kaṇāda. He and his followers extended the concept of five elements and built a comprehensive theory of atoms. The first four elements of this system (*pṛthvī*, *ap*, *tejas*, and *vāyu*) were material and considered either eternal or temporal. The fifth element, *ākāśa*, was considered eternal only. The eternal form consisted of imperceptible atoms, while the temporal form arose when these atoms joined to create perceptible products. This view of five elements was part of a much larger conceptual picture, that of *dravya* (substance). There were nine types of substances. In addition to the five elements or substances already mentioned, there was *dik* (space), *kāla* (time), *ātman* (self), and *manas* (mind). Each of these substances was considered inseparable from its respective set of attributes. In other words, they were one and the same.

The word used for atom was *aṇu* or *pramāṇu*. The *Nyāya-Vaiśeṣika* school held that the atom was indestructible, indivisible, without magnitude, spherical, and in constant motion. Two atoms of the same substance could join to form a dyad. Atoms of different substances could not join together, yet they could play a supportive role in the combination of materially compatible atoms. The dyad was regarded as too small to be perceived. The smallest visible structure was a triad (three dyads). This structure was referred to as *trasareṇu* or *tryaṇuka* which was about the size of a speck floating through a sunbeam.

The principle of causality was crucial to the *Nyāya-Vaiśeṣika* school. Atoms were the material cause for the dyad, the effect. The dyads were the cause for the production of a triad which was another effect. The individual atoms lost their causative property once the triad was formed. The reason for atoms joining in the first place was attributed to *aḍṛṣṭa*, an unseen force.

Jaina philosophers held that atoms were both cause and effect. They theorized that atoms joined to form aggregates in response to attractive and repulsive forces which were inherent characteristics of the atoms themselves. Jaina atoms were all of one class. There was no distinction, qualitatively, or quantitatively, between types of atoms such as earth-atoms, water-atoms, etc. According to the Buddhists, the atom was indivisible, unable to be analyzed, invisible, inaudible, unable to be tested, and intangible. Neither were these atoms eternal. The Buddhists did not speak of atoms in terms of particles. They thought of them as a force of energy.

The *Nyāya-Vaiśeṣika* school was distinct from other Indian schools in that it placed much more emphasis on the attributes of matter. There were five general qualities possessed by all nine substances: number, dimension, distinctness, conjunction, and disjunction. Other qualities, more closely associated with modern physics included, *gurutva* (gravity), *dravatva* (fluidity), *sigdha* (viscosity), and *sthithāpaka* (elasticity). Gravity, or the cause of falling, was not considered a force but a quality which resided in a whole object. No apparent correlation between gravity and the mass of a particular object was presented. Fluidity was a quality of only three substances – earth, water, and fire – and was of two kinds. Natural fluidity was a specific quality of water. Incidental fluidity was associated with fire in the case of some melted substances. Viscosity was specific to water, causing cohesion and smoothness. Elasticity was only a quality of earthy substances as in the branch of a tree which was caused to return to its original condition if displaced. Another fundamental concept considered by ancient Indian thinkers was that of motion.

The *Nyāya-Vaiśeṣika* concept of karma (motion) was represented by three actions: *utkṣepaṇa* (throwing upward), *avakṣepaṇa* (throwing downward), *prasāraṇa* (expansion), *ākuñcana* (contraction), and *gamana* (going). Only one kind of motion was considered possible at a time and a substance experienced motion only for a moment. This motion was subsequently destroyed or rendered ineffective once completed. The motion of free atoms made possible by *aḍṛṣṭa* (unseen force) caused the material world to be formed.

Among Indian physical concepts, that of *ākāśa* should not be overlooked. Its special quality was sound. Though considered a nonmaterial substance, it was believed to play a role in the formation of material objects. A modern physics concept which some have equated with *ākāśa* is that of ether, which is conceived to be a vast expanse or continuum. Sound moved through *ākāśa* like ripples across the surface of a pond. Unlike the ripples, sound moved through *ākāśa* in a succession of points. The first sound caused the second, and once the second sound was created, the first was destroyed.

Heat and light were understood in relation to one of the five basic elements, *tejas* (fire). When an object was heated it went through a series of distinct changes, each one lasting a prescribed number of moments. A clay pot for example, if heated, would in the first moment experience the production of atomic motion. The second moment would be characterized by the destruction of the clay's original color. In the third and fourth moments one would find that the color red would be produced followed by the destruction of the atomic motion created earlier. A new type of atomic motion, creative in nature, occurred in the fifth moment. A series of two disjunctions between the atoms and *ākāśa* was followed by a conjunction in the sixth through eighth moments. The final two moments consisted of the formation of a red colored dyad followed by a triad. The ultimate source of all heat was thought to be the sun. Light, though often associated with heat in many modern physical systems, possessed many qualities, distinctive from heat, in the early Indian systems.

Light was thought to consist of rays which emanated from the eyes just as a candle casts its light throughout a room. If an obstruction prevented the rays from touching an object, then that object simply could not be perceived. Mirrors were thought to possess particular attributes of color which caused the light rays from one's eyes to return to one's face upon striking the surface.

Medieval India (AD 800–1800)

It is a common misconception that there was a lack of scientific inquiry during the Middle Ages. While India experienced great change during this time, such as the introduction of Islam, there was a continued advance and assimilation of scientific information with an ever increasing number of collaborators. New cultural influences, changing technologies, and language barriers challenged as well as fostered scientific advances.

Physics was viewed as a distinct branch of study during the early part of the Middle Ages. Though experiments were still quite rare, use of this scientific technique began. A large number of texts were translated into different languages. A scholar named ► [Ḥunayn ibn Ishāq](#) translated Aristotle's works into Syriac and his son Ishāq ibn Ḥunayn followed suit, translating Euclid's *Elements*. Ideas were shared, expanded upon, and refined. A number of original inquiries were also initiated.

Among the more notable individuals describing physics research in India as well as Middle Asia at this time was Abū Rayḥān ► [al-Bīrūnī](#). He authored many books devoted to the scientific achievements of the Indian people.

The latter part of this period experienced an influx of European influences. Educational institutions, scientific journals, and professional societies each played a role in the development of what was to become modern India. New political and economic structures, in the face of new language barriers between the educated few and the illiterate masses, threatened to disassemble the rich scientific heritage of the Indian people. Yet India assimilated the old and the new to

emerge strong with an outstanding future of scientific inquiry before it. Much of that future rested in the hands of a few visionaries who understood the significance of science in India's future.

Modern India (AD 1800–Present)

The outstanding efforts of many have contributed to India's rich past and promising future. The following few individuals are some of the physicists who have exemplified the level of achievement found throughout modern India.

Jagdish Chandra Bose (1858–1937) was a biophysicist who explored the response of plants and animals to electrical stimulation. Like many pioneering physicists active at the turn of the century, Bose used instruments of his own design in his work. He was elected a Fellow of the Royal Society of London in 1920. C. V. Raman (1888–1970) investigated optics, including diffraction, molecular scattering of light, and magneto-optics. He was awarded the Nobel Prize in 1930 for the discovery which bears his name, the Raman Effect. This pioneering work described the molecular scattering of light and explained, among other things, why the ocean appears blue. Finally, Jawaharlal Nehru, the first Prime Minister of India, worked hard to foster what he described as a “scientific temper.” He believed that for science to succeed in modern India, as it had in its past, there had to be strong support for the scientific enterprise from all segments of society.

The history of physics in India is a vast subject, offering extensive opportunities for further study. It is hoped that this brief presentation has encouraged some to explore the ancient philosophies, medieval refinements, and modern achievements.

See Also

- [al-Bīrūnī](#)
- [Ḥunayn Ibn Ishāq](#)

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Physics in the Islamic World

Timothy J. McGrew

With the rapid expansion of the Arabian tribes into western Asia and northern Africa in the early seventh century, the Islamic world fell heir to the documentary remains of Greek science and mathematics. Scientific research had grounded to a halt in the Byzantine Empire, and in a very real sense the intellectual center of gravity was transferred to the East, where, despite occasional upheavals, learning flourished

under a series of enlightened patrons for over 500 years.

In contemporary usage, the word “physics” denotes an autonomous and highly specialized branch of science which deals with the behavior of non-living systems, bringing them under the scope of the most general natural laws. There was no parallel to this discipline in medieval Islam, yet from the eighth century onwards there was a profusion of translations, commentaries, and learned writings on topics which would today fall under the broad heading of physics.

The contributions of Islamic thinkers to astronomy and mathematics were of the first importance. Optics, which would today be considered a branch of physics, was studied in close conjunction with both geometry and medicine, since various problems regarding vision remained unresolved in the Greek scientific literature. The contributions of Ibn al-Haytham to the problem of refraction are particularly noteworthy.

Astronomy and optics aside, Islamic scholars wrote profusely on the nature of matter, causality, the theory, and practice of mechanics, and dynamics.

The Nature of Matter and Causal Laws

The dominant philosophical school in Islamic physics was the Aristotelians or *Falāsifa*. Prominent members of this school included al-Kindī (d. 873), al-Fārābī (d. ca. 950), Ibn Sīnā (Avicenna, d. 1037), and Ibn Bājjā (d. 1138). While the *Falāsifa* held Aristotle in the highest respect, their work was somewhat syncretistic. The Greek philosophical corpus was often taken to be an integrated whole, and diverse elements of Plato and the Neoplatonists found their way into the synthesis of the Arabic Aristotelians. Al-Fārābī went so far as to write a book entitled *Jamʿ bayna raʾyay al-ḥakīmayn Aflātūn al-ilāhī wa-Aristūṭālīs* (The Harmony between Plato and Aristotle). Most Arabic scholars who sought to reconcile these strands of thought relied heavily on a work known as the *Theology of Aristotle*, in which Aristotle

himself seemed to provide a bridge between his technical and logically rigorous work and the more literary and imaginative work of Plato. But modern scholarship has established that the *Theology* was wrongly attributed to Aristotle and is actually a compendium of the writings of the Neoplatonist Plotinus.

In physics, the doctrine held that every object could be analyzed as a composite of matter, which is the locus of its potency or possibilities, and form, which is the actualization of some of those potencies. Matter, like space itself, was believed to be infinitely divisible. Physical bodies behaved in qualitatively predictable ways because of their innate tendencies. Hence, a stone falls because it seeks its natural place at the center of the earth, and water seeks its lowest level in lakes and oceans because its attraction to the center of the earth is slightly less strong than that of the stone.

The infinite divisibility of space led to some perplexing dynamical difficulties, first noted by the Greek philosopher Zeno of Elea, which induced some Islamic physicists to question the coherence of the Aristotelian concept of space.

► **Al-Bīrūnī** (d. after 1050), a prominent critic of Aristotelian physics, posed this dilemma in a letter to Ibn Sīnā: If the sun is west of the moon in the sky, with a definite space between them, then even though the moon moves much faster than the sun, it should never be able to catch it. For the space between them can be conceived as divisible into an infinite number of parts; but how can a body moving with a finite speed cross an infinite number of spaces? In al-Bīrūnī's view, this paradoxical consequence reflected poorly on the Aristotelian concept of the infinite divisibility of space. After all, anyone can see that the moon does in fact overtake the sun.

A competing school of thought was inspired by Sunni theology, with its strict insistence on divine omnipotence. In this view, all bodies consist of a finite number of indivisible atoms, and the behavior of these atoms is not the consequence of any causal relations between them but is governed directly by the divine will. What appear to be causal connections are only regularities which we are in the habit of calling laws;

there is no connection discoverable by reason between separate events, and Aristotelian explanations for the behavior of bodies in terms of natural tendencies are therefore hopelessly misguided.

The controversy between the theologians and the Aristotelians came to its climax in the *Tahāfut al-Falāsifa* (Self-Destruction of the Aristotelians) of al-Ghazālī (ca. 1058–1111), in which he maintained that philosophers could not know, for example, that fire causes cloth to burst into flame but only that the combustion of the cloth occurs at the moment that it makes contact with the flame. Ibn Rushd (ca. 1126–1198) responded with a *Tahāfut al-Tahāfut* (Self-destruction of the Self-destruction) in which he claimed that such skepticism regarding the efficacy of reason would undermine itself. In contemporary philosophy of science, a similar controversy is still raging over the nature of causality and our knowledge of causal connections, though the arguments arise not out of theological considerations but rather from Hume's skeptical doubts about induction and the verificationism of the logical positivists.

Mechanics

One of the simplest of mechanical devices, the lever, had been investigated mathematically by the Greek polymath Archimedes, who gave an elegant proof that the forces required to keep the unequal arms of a lever in balance were inversely proportionate to the length of the arms. In the course of his proof, Archimedes assumed that two equal weights located at different points on one arm of the lever produced the same effect as if they were both located at the midpoint between them – an assumption which is intuitively plausible but for which he gave no rigorous justification. ► **Thābit ibn Qurra** (d. 901) provided an intriguing argument for this assumption in his *Kitāb al-qarastūn* (Book of the Balance).

The balance was investigated very thoroughly in Islam. Al-Bīrūnī worked out a general method for determining the specific gravity of an irregular solid which he published in his *Maqala fi'l-ḥisab allatī bayn al-filizzāt*

wa'l-jawāhir fi'l-hajm (Treatise on the Ratios Between the Volumes of Metals and Jewels). In later years, the best-known work on the subject was the *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom) of ► [al-Khāzinī](#) (fl. ca. 1115–1130), a careful though not very original treatise which covers the theory of balances (relying heavily on the work of al-Bīrūnī), the practical details of their construction, and their use for determining proportions of metals in alloys. In the course of his discussion, al-Khāzinī notes that heat decreases the density of metal objects. The *Kitāb* of al-Khāzinī is among other things a source of alchemical lore, and it is no accident that it became a standard text on the construction of equipment among alchemists in succeeding generations.

Islamic scientists were aware of more complex mechanical contraptions, and a few works described windmills, clocks, and other marvelous devices. The most lavishly illustrated volume on this subject, the *Kitāb fī ma'rifat al-ḥiyal al-handasiyya* (Book of Knowledge of Ingenious Mechanical Devices) of ► [al-Jazarī](#), describes some 50 mechanical devices including several different types of fountains. But they made no systematic effort to apply the principles utilized in these devices on a broad scale. The knowledge of the principles of mechanics did not generate a technological revolution.

Dynamics

The Aristotelian theory of motion was a source of considerable difficulty for Islamic thinkers. Apart from the “natural motion” by which objects seek their natural place, the Aristotelians viewed motion as the result of the application of a force. In the absence of the force, motion ceases, as a cart grinds to a halt when the rope connecting it to the horse is broken. But this commonsense theory generates serious problems when applied to projectile motion. Why should a flung stone hurtle through the air when it leaves the hand? Why should an arrow continue to fly when it has left the bowstring? Aristotle’s own suggestion was that somehow the air rushes around to the

rear of the object in a way which prolongs its flight. But this was both vague and apparently irreconcilable with the facts; the flight of a javelin is not appreciably improved by design changes at its back end which would help it to “catch” the air.

In place of this unsatisfactory explanation, Ibn Sīnā and Abū'l-Barakāt al-Baghdādī (ca. 1080–ca. 1165) developed a theory of “violent inclination” which matches very closely the impetus theory first suggested by the Alexandrian Neoplatonist John Philoponus (d. ca. 570) and which was widely held until the seventeenth century. According to this theory, the agent of motion (the hand which flings a stone, for instance) imparts to the object a temporary inclination to continue moving, an inclination which partly counteracts the tendency of the object to seek its natural place and which is gradually dissipated through its flight.

Aristotle’s notions regarding free fall also came under critical scrutiny by Islamic thinkers. According to Aristotle (*Physics*, Book 4, chapter 8), the motion of a falling object is directly proportional to its natural inclination (the tendency it has to seek its natural place) and inversely proportional to the resistance offered by the medium through which it moves, an account which strongly suggests the mathematical formulation

$$M \propto \frac{F}{R},$$

where M is motion, F is force and R is the resistance. Ibn Bājja (better known in the West as Avempace), though working within the broadly Aristotelian framework, criticized this view on the grounds that, if Aristotle’s account were correct, unresisted motion (such as that of the heavenly bodies) would be instantaneous – which it clearly is not. In place of the Aristotelian law of motion, he suggests the formula

$$M \propto F - R,$$

which has the advantages that motion in the absence of resistance need not be instantaneous

but rather proportional to the impressed force, and that when force and resistance are balanced, the result is not motion at all but cancellation of motion. Ibn Bājja's views here closely resemble some arguments advanced earlier by John Philoponus, but it was through Ibn Bājja's writings, preserved in a commentary on Aristotle's *Physics* by Ibn Rushd, that these views were transferred to the west and influenced the early work of Galileo.

Abū'l-Barakāt's reflections on motion in his *Kitāb al-Mu'tabar* (Book of What has been Established by Personal Reflection) are also remarkable as precursors of a radical departure from the Aristotelian view. In explaining the motion of a flung stone, he appeals not only to the dissipation of the violent inclination but also to a compounding of successive natural inclinations which increases the overall strength of the natural inclination during the fall. This idea of the compounding of the force through small intervals represents a serious advance over Aristotle's view that the distance travelled by an object in free fall per unit time is directly proportional to the weight of the object. It appears not to have occurred to Aristotle to consider the question of instantaneous velocity. Abū'l-Barakāt's explanation for free fall is thus one of the first hints that the constant action of a force might produce not merely motion but an acceleration.

See Also

- [al-Bīrūnī](#)
- [al-Jazarī](#)
- [al-Khāzinī](#)
- [al-Kindī](#)
- [Astronomy in the Islamic World](#)
- [Atomism in Islamic Thought](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibn Sīnā \(Avicenna\)](#)
- [Ibn Rushd \(Averroës\)](#)
- [Mathematics in Islam](#)
- [Optics in the Islamic World](#)
- [Thābit ibn Qurra](#)

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Pi in Chinese Mathematics

Lam Lay Yong

In the earliest existing mathematical texts, ► [Zhoubi suanjing](#) (The Mathematical Classic of the Zhou Gnomon) and ► [Jiuzhang suanshu](#) (Nine Chapters on the Mathematical Art), the ratio of the circumference of the circle to its diameter, or π , was taken to be three. Liu Xin, who lived in the first century BCE and was an astronomer and an expert on calendrical calculations, was mentioned in *Suishu* (Standard History of the Sui Dynasty) as being among the earliest to improve on this value. This arose from the construction of a standard measure called *jia lianghu* which he prepared for Emperor Wang Mang.

In his commentary on a problem concerning a sphere in *Jiuzhang suanshu*, Liu Hui of the third century referred to Zhang Heng's (AD 78–139) empirical deduction which implied a value of $\sqrt{10}$ for pi. The eighth century book, *Kaiyuan*

zhanjing (Kai Yuan Treatise on Astrology), expressed Zhang Heng's estimation in the ratio of 736–232. A century later, Wang Fan improved this to the ratio of 142–45.

However, it was Wang Fan's contemporary, Liu Hui, who succeeded not only in attaining a better estimate for pi, but also in writing down the detailed method of how he arrived at the result.

His method commenced with a regular hexagon inscribed in a circle. This was extended to a 12-sided polygon where the length of one side and its area were calculated from the hexagon based on the properties of the right-angled triangle. Next, a polygon of 24 sides was constructed and the length of its side and its area were calculated from the data of the dodecagon. Regular polygons inscribed in the circle were in this manner continuously constructed; the number of sides of one polygon was always double that of the previous polygon and the area of a polygon was formulated as one half the perimeter of the previous polygon multiplied by the radius of the circle. Liu Hui pointed out that if this process was repeated long enough, eventually there would be a polygon whose sides were so short that they would coincide with the circle. He concluded that this explained why the area of a circle was one half the circumference multiplied by the radius. He further pointed out that when the ratio of the circumference to the diameter was taken as 3–1, this value was in fact the ratio of the perimeter of the hexagon to the diameter.

Liu Hui reached a polygon of 192 sides when he calculated pi to lie between 3.14 64/625 and 3.14 169/625. From these figures he deduced an approximate value for pi of 157/50 or 3.14. He gave another value of 3927/1250 or 3.1416 which he said could be verified when calculations reached the polygon of 3,072 sides.

Computations were performed through the rod numeral system which was not only a medium for whole numbers but also one for common fractions and decimal fractions. The knowledge of Liu Hui's method and the rod numeral system would enable the value of pi to be calculated to

any desired degree of accuracy. It was therefore not surprising that ► [Zu Chongzhi](#) (AD 430–501), the most distinguished mathematician, astronomer and engineer of his time, found π to lie between 3.1415926 and 3.1415927 and also gave it a value of 355/113. These values were not surpassed until a thousand years later when al-Kāshī evaluated pi correctly to sixteen decimal places. Zu's values were recorded in *Suishu* but no method was given, and Zu's own work had long been lost.

See Also

- [Computation: Chinese Counting Rods](#)
- [Jiuzhang Suanshu](#)
- [Zhang Heng](#)
- [Zhoubi suanjing](#)
- [Zu Chongzhi](#)

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PI in Indian Mathematics

R. C. Gupta

Undoubtedly π or π is the most interesting number in mathematics, and its history will remain a never-ending story. It occurs in several formulas of mensuration and is variously involved in many branches of mathematics, including geometry, trigonometry, and analysis.

The earliest association of π is found in connection with the mensuration of a circle. The fact that the perimeter or circumference of any circle increases in proportion to its diameter was noted quite early. In other words, in every circle, perimeter/diameter = constant, or $p/d = \pi_1$, where π_1 is the same for all circles.

After knowing the perimeter, the area of the circle was often found by using the sophisticated relation

$$\text{area} = \left(\frac{p}{2}\right) \left(\frac{d}{2}\right) = \frac{pd}{4}.$$

But the earliest rules for determining area were of the form $\text{area} = (kd)^2$, where k is a constant prescribed variously. Both these methods imply that the area of a circle is proportional to the square of its diameter (or radius r), or $\text{area} = \pi_2 r^2$.

We know that π_2 is the same as π_1 , but this was not always known. Similarly, π_3 may be defined from the volume of a sphere. In this article, the symbol π is used to denote all the above three values, as well as for their common value, which is now known to be not only an irrational, but also a transcendental number.

Since the Indus Valley script has not been deciphered successfully, we cannot say any final thing about the scientific knowledge of India of that time (about the third millennium BCE). Some conjectures about the value of π used in the *R̥gveda* (about the second millennium BCE)

have been made. Definite literary evidence is available from texts related to *Vedāṅgas*, especially the *Śulbasūtras* which contain much older traditional material. In the ► *Baudhāyana Śulbasūtra*, the oldest of them, the perimeter of a pit is mentioned to be three times its diameter, thereby implying $\pi_1 = 3$. This simplest approximation is found in almost all ancient cultures of the world. In India, it is found also in classical religious works such as *Mahābhārata* (Bhīṣmaparva, XII: 44), and certain *Purāṇas*, as well as in some Buddhist and Jain canonical works.

Different approximations to π_2 are implied in the various Vedic rules for converting a square into a circle of equal area and vice versa. If r is the radius of the circle equivalent to a square of side s , the usual *Śulba* rule is to take $r = s(2 + \sqrt{2})/6$, which implies the approximation $\pi_2 = 18(3 - 2\sqrt{2}) = 3.088$. Recently, a new interpretation of the *Mānava Śulba Sūtra* has yielded the relation $r = 4s/5\sqrt{2}$, thereby implying $\pi_2 = 25/8 = 3.152$, which is the best *Śulba* approximation found so far.

The ancient Jain School preferred the approximation $\pi = \sqrt{10}$, which they considered accurate and from which they derived the value $\pi = \sqrt{3^2 + 1} \approx 3 + 1/6 = 19/6$. This value ($\sqrt{10}$) continued to be used in India not only by the Jains but also by others, such as ► *Varāhamihira*, ► *Brahmagupta*, and ► *Śrīdhara*, even when better values were known.

With Āryabhaṭa I (born AD 476), a new era of science began in India. In the *Āryabhaṭīya*, he gave a fine approximation of π_1 , surpassing all older values. It contains the rule that the perimeter of a circle of diameter 20,000 is close to 62,832, so that $\pi_1 = 62,832/20,000 = 3.1416$ nearly, which is correct to four decimal places, and he still calls it close and not exact.

This value had a respectful place in Indian mathematics and exerted greater influence. How ► *Āryabhaṭa* obtained it is not known. It was known in China, but evidence of borrowing lacks documentary support. On the other hand, the two typically Indian values $\sqrt{10}$ and

62,832/20,000 appear in many subsequent Arabic works.

In India, the Archimedean value $22/7$ for π first appeared in the lost part of Śrīdhara's *Pāṭī* (ca. AD 750). A Jain writer, Vīrasena, quotes a peculiar rule in his commentary *Dhavalā* (AD 816). It is equivalent to $\rho = 3d + (16d + 16)/113$. If we leave out the redundant dimensionless number +16 in the brackets, this rule will imply a knowledge of the value $\pi_1 = 355/113$ which was known in China to ► [Zu Chongzhi](#) (AD 429–500). In explicit form, this value is found in India much later, e.g., in the works of Narāyaṇa II, Nīlakaṇṭha, and others. The simplified or reduced form 3,927/1,250 of Āryabhaṭa's value of π occurs in the works of Pauliśa, ► [Lalla](#), Bhaṭṭotpala, and the great ► [Bhāskara II](#).

Most significant contributions on the computations of π were made by the mathematicians of the late Āryabhaṭa School of South India. Mādhava of Saṅgamagrāma (ca. AD 1340–1425), the first great scholar and founder of the School, gave the value $\pi_1 = (2, 827, 4, 333, 8, 823, 3)/(9 \times 10^1)$ as known to the “learned men”. This value yields an approximation correct to 11 decimals. Mādhava also knew the series $\pi/4 = 1 - 1/3 + 1/5 - 1/7 + \dots$ which was rediscovered in Europe in 1673 by Leibniz.

In discovering various series for π and in evolving techniques for improving their convergence, a great theoretical breakthrough was attained in sixteenth-century India.

See Also

- [Āryabhaṭa](#)
- [Bhāskara II](#)
- [Brahmagupta](#)
- [Mādhava of Saṅgamagrāma](#)
- [Nīlakaṇṭha Somayāji](#)
- [Pauliśa](#)
- [Śrīdhara](#)
- [Śulbasūtras](#)
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Pirī Reis

Sevim Tekeli

Pirī Reis, Muhyī al-Dīn Pirī (1465–1554), was born in Gallipoli, a naval base along the Marmara coast. He was an important admiral, cartographer, and geographer of his time. His fame depends on two world maps and a book named *Kitāb-i Bahriye*.

The First World Map (1513)

In 1929 a map was found in Topkapi Palace, on a piece of parchment 90 × 60 cm in size. It had

been drawn in 1513, and later presented to Sultan Selim in 1517 in Egypt. This portion shows only the coast of South Western Europe, West Africa, the Middle East, and Central America. On the map, mountains were drawn in outlines, and the rivers marked with thick lines. Shallow places were indicated by red dots, and rocky places in the sea with crosses. Notes were added concerning different regions, and they were decorated with illustrations of special plants, and animals.

This map is a *portolano*, a navigation manual illustrated with charts, with no lines of longitude and latitude. Instead there are two wind roses, one in the North and the other in the South. Each of these roses is divided into 32 parts, and lines are extended beyond these roses; there are two scales indicating mileage. The lines that are extended from the wind roses and the scales are used in measuring the distances between the ports.

Pirî Reis made use of 34 maps in drawing his own. Of these, 20 had no dates. Eight of them were maps that were called *Jaferiyye* by Muslim geographers. Four were new maps drawn by the Portuguese, and one was the map of Christopher Columbus. Since this last is now lost, the only original document we have today is the map of Pirî Reis. When he was drawing the coasts of America, he remained faithful to Columbus' map, and copied it from several points. The Antilles and Cuba are shown as continents on his map, which was what Columbus believed. When Columbus was near the coast of Cuba in 1494, he had the firm belief that Cuba was a continent. As a result, he had his conviction recorded by the notary public on board, Ferdinand Perez de Luna, and asked all the crew to sign it. Columbus had shown South America as a group of islands. Inspired by this, Pirî too drew lot of imaginary islands opposite Trinidad. This map is a very valuable historical map for two reasons. First of all, it was the most correct and scientific map of the time, and secondly it was the only map which was drawn using Columbus' map, of which neither the original nor the copy exists today.

The Second World Map (1528)

Fifteen years after his first map, Pirî Reis drew a second world map. Today we have only a small portion of it, 68 × 69 cm in size. On this portion, there are the northern parts of the Atlantic Ocean and the newly discovered regions of North and Central America.

The map starts with Greenland, in the north. Toward the south there are two pieces of land. The first is called Baccalo; the second one, further down, is called Terra Nova, and it is mentioned that these were discovered by the Portuguese. Further south there is the peninsula of Florida drawn quite correctly. The pieces of land at the side are the peninsulas of Honduras and Yucatan, discovered in 1517 and 1519, respectively.

Cuba and Haiti are drawn quite accurately. The errors on the previous map were corrected on this one.

There is a slight distortion on the map from the true positions as we know them today. This error was committed because of neglect in not taking into consideration the 10–13° of difference in angle on contemporary compasses. This error is true for all Western-originated maps.

In this second map, the drawing of the coastlines shows greater improvement when compared with the inaccuracies of the first one. Only the parts of the world that were discovered were shown; the unexplored areas were left blank.

Kitâb-i Bahriye

Pirî made a book of all his notes, revised and expanded it, and in 1525 presented it to Süleyman the Magnificent. He analyzed the geographic works of his time and, with his sharp faculties of observation, he set down everything he came across in his travels. In the preface of his book, he said that his purpose in writing such a book was to give information about ports, coasts, and islands by drawing them on maps known as *portolanos* in the west. However, he added that no matter how big the scales of maps were, it was impossible to show enough of the vital details on them. This lack of important information made him see the

necessity of writing a book to compensate for this insufficiency. This, then, is the novelty *Bahriye* brought to the science of navigation.

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bodies share the property that they move through the background of fixed stars in a west to east direction, although at vastly different speeds. In addition, all of the planets move through a fairly narrow band of stars, the zodiacal constellations, which lie in a plane tilted about 24° from the celestial equator. Both of these properties, and in addition the fact that the fixed stars and all the planets also share a daily rotation of the celestial sphere in the east to west direction, are plainly visible to the unaided eye and certainly were a significant factor in the interactions of people with their natural surroundings for thousands of years.

Eventually written records of the movements of the planets through the fixed stars began to be kept. For example, we have astronomical diaries from Babylon for much of the first millennium BCE that note the days when some planet is near some bright zodiacal fixed star and the days when some planet became first visible at sunrise and last visible at sunset. Eventually, mathematical models of these occurrences were developed which enabled the prediction of the same events in the future, and astronomy of the planets as we understand it today began to develop. Along with the models of the risings and settings of the star-planets, even more detailed models of the movements of the Sun and Moon were developed that enabled the prediction of events important to establishing the calendar of civil life, namely, the days that mark the first and last appearances of the Moon around the times of new moon and full moon.

The key mathematical ingredients to these early models are the period relations. These are numerical statements that tell the number of years required for the completion of some integral number of some celestial event. An example is the empirical fact that in 83 years Jupiter will pass by some bright reference star, perhaps Regulus, seven times.

Beyond these period relations, which define only average speeds for the planets, is the important realization that the speed of each planet is not, in fact, constant, but rather variable. These variations in speed come in two varieties. First, the speed of a planet as it traverses its path

Planetary Models in India

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For ancient astronomers, the planets were the two luminaries, the Sun and the Moon, plus the five visible wandering stars, Mercury, Venus, Mars, Jupiter, and Saturn. All seven of these celestial

through the zodiac is sometimes faster and sometimes slower. Such a speed variation on the part of the Sun is the cause behind the empirical observation that the length of our four seasons is unequal, and similarly, variations in the speed of the Moon cause some months to be shorter than average while some months are longer. Second, in the case of the five star-planets, the planet from time to time appears literally to stop its forward west-to-east motion, then to reverse and go east to west for some time, and then to stop and resume its normal west-to-east progress through the zodiac. This retrograde motion is also coincident with the time that the planet and the Sun are on opposite sides of the Earth.

Thus, the final stage of planetary model development was to address the two major problems, the variation of speed through the zodiac and, in the case of the star-planets, the correlation of the retrograde motion with oppositions to the Sun. As it happens, this development was not only arithmetical but geometrical, thus enabling the ancient astronomers to predict the future position on the celestial sphere of all planets at any moment in time.

As far as we can tell from the surviving historical record, this final development was begun in the second half of the first millennium BCE and completed early in the first half of the first millennium CE. The surviving records show similar models for planetary motion in Greek (and later Greco-Roman) cultures and later also in the Hindu culture of India.

The Greek planetary models are thoroughly documented in Ptolemy's *Almagest*, written probably around 150 CE, although it is likely that much of the development of these models preceded Ptolemy. The corresponding Hindu models first appear in the *Paitāmahasiddhānta*, probably written in the mid-fifth century CE, and in Āryabhaṭa's *Āryabhaṭīya*, probably written around 500 CE. In the case of these Hindu models, the texts are very terse and contain little or no explanation of the development of the models.

The first step in the determination of the position of a planet is to compute the mean longitude. This is the longitude that the planet would have if

its speed was not varying, either zodiacally or in retrograde. To compute the mean longitude for any moment in time requires knowledge of the mean longitude at some fixed reference (or epoch) time, to which is added the progress from that reference longitude during the time interval. The progress is, of course, just the product of the average speed and the time interval. The average speeds, also known as mean motions, of the planets are generally expressed as ratios of relatively small integers by the Babylonians and Greeks, but the early Hindu texts instead given ratios of very large integers. For example, for Saturn, while the Greeks would give 2 revolutions in 59 years, the *Āryabhaṭīya* gives 146,564 revolutions in 4,320,000 years, and the *Paitāmahasiddhānta* gives the larger pair 146,567,298 revolutions in 4,320,000,000 years.

These huge time periods are known as *yugas*, or Great Year intervals, and are used in a broader sense as the basis for cosmic time that says the universe goes through endless cycles of creation, destruction, and rebirth. At the beginning and end of the cycle and, depending on the details, at various subperiods in between, all of the planets are perfectly aligned.

While either set of larger numbers might suggest a more accurate mean motion than the Greek pair, they are in fact less accurate. The Hindu ratios in fact are based on just two pieces of information: first, an approximation to the Greek ratio and, second, a value of the mean longitude at epoch that is known only to fall within an interval of just over 1° in width for the *Āryabhaṭīya* and $\frac{1}{4}^\circ$ in width for the *Paitāmahasiddhānta*. The result of these approximations is that the mean longitudes can be moderately accurate for a few decades around the epoch time, but their accuracy degenerates quickly with time. Hindu astronomers of the late first and early second millennium CE were aware of these problems, and every few centuries would suggest correction terms to the mean motions to keep the models coordinated with reality.

Having determined mean longitudes, the next step is to determine the correction terms due to nonuniform motion. These terms are added to the mean longitudes to determine the true

(observable) longitudes. In the *Almagest*, the mechanism for achieving the nonuniform motion around the zodiac is an eccentric circular orbit (or the equivalent epicycle model). In such an orbit, although the planet is moving around the circle at a uniform speed as seen from the center of the circle, the Earth is not at the center but at some nearby eccentric position. From this off-center position, the speed of the planet appears to be slower when the planet is farthest from the Earth (at apogee) and fastest when the planet is closest (at perigee). By adjusting the amount of eccentricity, the ratio of minimum to maximum speed can be adjusted to match the observed variation of the planet's speed around the zodiac. The solar model used by the Hindu astronomers was the concentric equant, in which the Earth is at the center of the Sun's orbit and the motion of the Sun is uniform as seen from an eccentric point.

The situation for the Moon is somewhat more involved. When the Moon is near syzygy (new moon or full moon), the Greek model is the eccentric used for the Sun, but with a larger eccentricity, and similarly, the Hindu model uses the concentric equant. But when the Moon is not near syzygy, the effective eccentricity is even larger. This second anomaly due to the varying eccentricity was included by Ptolemy but is missing in the early Hindu texts. However, it does appear in a Hindu text attributed to Muñjāla, probably written around 930 CE, and his version is, in fact, a significant improvement over Ptolemy's treatment.

For Venus, Mars, Jupiter, and Saturn, the *Almagest* model is the equant plus an epicycle. The equant accounts for the zodiacal anomaly. The epicycle center moves around a circle and the Earth is offset from the center. However, the motion of the epicycle center appears uniform not from the center but from an equant point offset from the center. This offset is equal to the offset of the Earth, but in the opposite direction. Then, the planet itself moves counterclockwise around the epicycle so that the radius of the epicycle is always parallel to the direction from the earth to the Sun, thus providing the required retrograde motion and the coordination with the Sun's position.

The Hindu model for the star-planets involves a four-step process. First, a concentric equant is used to compute a zodiacal anomaly for the planet. Second, half of this anomaly is used to compute a solar anomaly for the planet using a simple eccentric model, which is itself subsequently halved. Third and fourth, these two steps are repeated without the halving, giving the final answer. Although it is hardly obvious, detailed numerical and analytic calculations show that for small to moderate sizes of the eccentricity and the epicycle radius, the Hindu four-step model is an excellent approximation to the *Almagest* equant plus epicycle model, but it is definitely not a good approximation to the eccentric plus epicycle model.

There is no evidence that the Hindu astronomers were aware that the four-step method approximates the equant, and the Hindu texts are, as they are on every other subject, completely silent regarding the motivation to use the four-step approximation. One plausible motivation regards the practical computation, which is usually done with tables. For the *Almagest* equant, the anomaly associated with retrograde motion is a function of two variables, and to compute this in the *Almagest* a rather sophisticated interpolation scheme is introduced, and no such scheme is ever mentioned in any Hindu text. However, in the four-step method, both the zodiacal anomaly and the retrograde anomaly are simple functions of one variable, and so practical computation with tables is much simpler. Thus, it is not unreasonable to entertain the idea that not only the equant but also the four-step method is of Greco-Roman origin.

The Greek and Hindu models for the latitude of the Moon simply tilt the orbit a few degrees from the ecliptic. However, the latitude models of the star-planets in the *Almagest* are much more complicated. The planet orbits and epicycles execute various periodic tilting motions that result in changes in latitude so small that they were probably difficult if not impossible to even observe with naked-eye observations. However, Ptolemy also wrote a much shorter exposition of the planetary models called the *Planetary Hypotheses* in which the planetary latitudes are like the Moon's,

a fixed tilt of the orbit from the ecliptic. These are exactly the models found in the Hindu texts. The *Planetary Hypotheses* also gives mean motions in terms of large integers, but those have none of the underlying simple structure of the large number ratios found in the Hindu texts.

An important application of the planetary models was the computation of the time of conjunction or opposition of a pair of planets, for example, the Sun and the Moon for eclipses or Jupiter and the Sun for retrograde motion. To compute the time, the standard method was to begin with the (easily computed) time of conjunction of the mean longitudes and then to determine at that moment the difference of the true longitudes. Then, if you know the true speeds of each planet, as opposed to the mean speeds, it is easy to estimate when they will be in true conjunction. To do this, you need what we call the time derivative of the two anomaly terms, and it is remarkable that we find in the *Almagest* explicit estimation of these derivatives using finite difference approximations. Even more remarkable is the fact that the anomaly terms are functions of a second function, and so the computation of the derivative requires the chain rule of differential calculus, and this is also estimated correctly by finite differences in the *Almagest*. Finally, these same finite difference approximations are found in many later Hindu texts such as the *Sūryasiddhānta* (ca. 1250 CE), but not in the earlier *Paitāmahasiddhānta* or *Āryabhaṭīya*. A badly garbled version might be present in the *Brāhmasphuṭasiddhānta* (ca. 650 CE), but this is uncertain.

Regarding the mathematical astronomy of the planets, it has been widely thought that the sophisticated astronomy of the *Almagest* was not reflected in any Hindu text. Nevertheless, there are a large number of similarities between Greek and Hindu astronomy, many of them technical or linguistic, and so unlikely to be coincidences. Thus, most Western scholars who have looked at the Hindu texts have not hesitated to conclude that Hindu astronomy was influenced by the transmission of Greek astronomy in the centuries following the invasion by Alexander the Great and that Greek astronomy must have

come from pre-Ptolemaic sources that have not come down to us in modern times.

On the other hand, many modern Hindu scholars have argued that since early Hindu astronomy is not influenced by the *Almagest* and that there are many things that are not (they thought) similar to Greek astronomy, there is no good reason to doubt that it was developed in India, and in fact Hindu astronomy might have to some degree influenced both Greek and Babylonian astronomy, thus accounting for the many observed similarities.

It is now clear, however, that both views require some reconsideration. The principal examples of astronomical differences have always been the planetary models discussed above. All of the major elements of the Hindu models were considered by both Western and Hindu scholars to be pre-*Almagest* and not present in Greek astronomy. These include the expression of the mean motions with large integers related to a yuga or Great Year time interval, the treatment of the zodiacal and solar anomalies with the four-step method instead of the equant, the second lunar anomaly, the planetary latitudes, and the true speeds of the planets.

Regarding the Hindu mean motions using the Great Year concept, recent studies have revealed similar schemes in Greek astronomy in the late first millennium BCE, long before the detailed scheme of the *Paitāmahasiddhānta* first appeared in the fifth century CE. Also, regardless of the appearance suggested by the large numbers in Hindu astronomy, they are all constructed from fairly rough approximations that were certainly known in Greek astronomy in the late first millennium BC.

Similarly, the fact that the Hindu four-step models for the star-planets approximate the equant suggests that either the equant was transmitted to India and there modified or the equant was modified before transmission to India and the four-step approximation was eventually transmitted to India. If the transmission to India occurred after the *Almagest*, then the greater question becomes how could it happen that the equant, but nothing else in the *Almagest*, was transmitted to India, and this seems a very hard question to

answer with any respectable degree of plausibility. The same line of argument applies, of course, to both the second lunar anomaly, the latitudes of the star-planets, and the true speeds of the planets. In all of these cases, the most straightforward resolution is that many of the things that were conventionally thought to be of Hindu origin because they seemed pre-*Almagest* are in fact pre-*Almagest* and still Greek.

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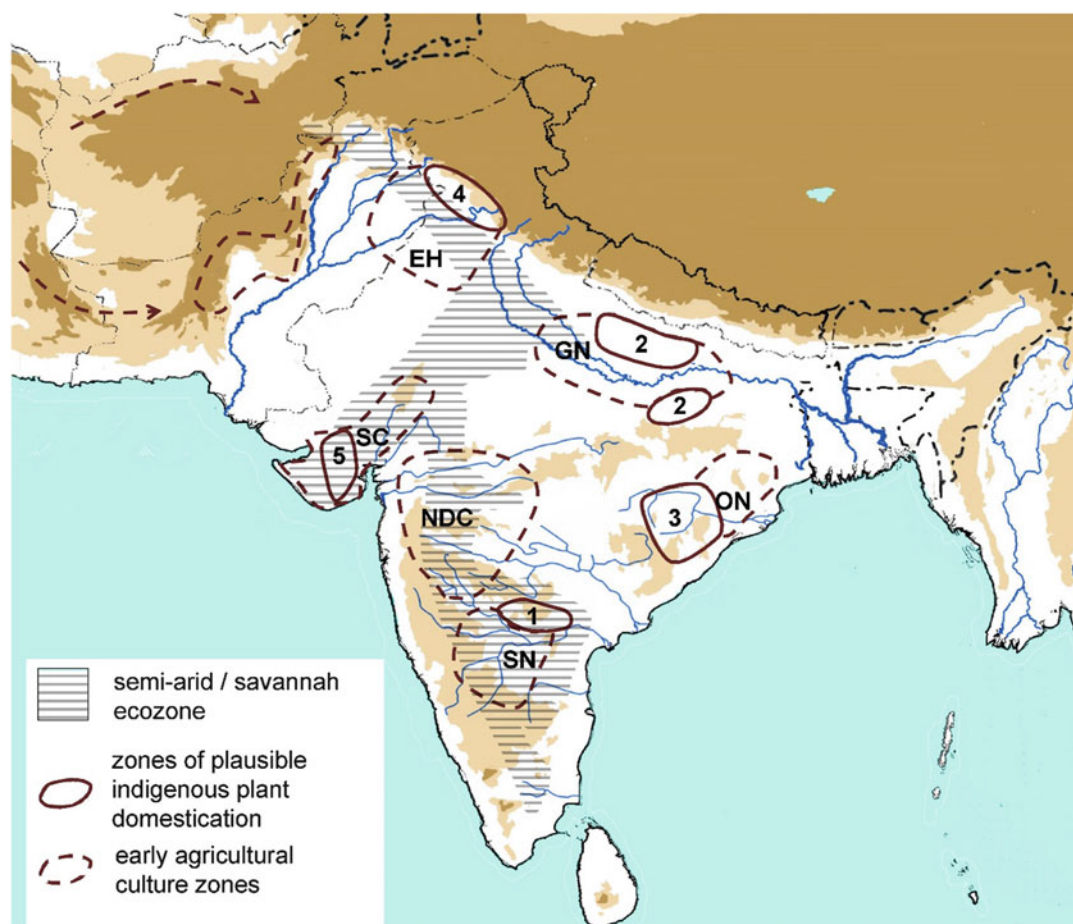
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Plant Domestication in India

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India is believed to possess a unique Neolithic transition toward plant domestication (<http://www.youtube.com/watch?v=FCL0SMbZG6Q&app=desktop>) (Feb 2014 UCL Talk youtube link). It has become increasingly apparent that cultivation preceded sedentary village life in India (Fuller, 2006, p. 52). The beginnings of plant domestication among non-sedentary societies in India have yet to be firmly established as evidence of food production among seasonally mobile societies is difficult to identify in the archaeological record (Fuller, 2006, p. 59). Nevertheless the end of the process, when sedentary villages emerged supported by agriculture, is well established. For most of India this took place around 2500–2000 B.C. It should be noted that this pattern is distinct from that of western Pakistan where preceramic agricultural settlement was established sometime before 6000 B.C., based on crops that had been domesticated earlier in Western Asia, such as wheat and barley (Possehl, 1999, pp. 446–489). Recent archaeological research combined with better botanical documentation of wild crop progenitors in South Asia has provided a basis for postulating several regional foci of plant domestication in India dating to around 3500–3000 B.C.E., based initially on native species.

It has been posited that these foci of plant domestication are mainly located between the savanna and deciduous woodland ecotones which include the South Deccan, Gujarat, and the Western Himalayan foothills, as well as the



Plant Domestication in India, Fig. 1 Map of agricultural origins on the Indian subcontinent. Regions of plausible crop domestication: (1) South Deccan, (2) middle Ganges and/or Vindhyas, (3) upper Mahanadi, (4) foothills of the Indo-Gangetic divide, (5) Saurashtra or southern Aravallis. Zones of early farming Neolithic/Chalcolithic culture areas: (EH) Eastern Early Harappan,

(GN) Ganges Neolithic, (ON) Orissa Neolithic, (SC) Sorath Chalcolithic and Banas culture, (NDC) North Decan Chalcolithic, (SN) Southern Neolithic. The semiarid savanna habitats zone is indicated: this zone and adjacent woodlands were important for most millet and pulse domestications

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Ganges basin (Fig. 1 Fuller, 2006, 2011, 2013, p. 5). The Deccan plateau of South India, a large arid region featuring rich Neolithic period remains, has only recently entered our awareness as a possible center of agricultural origins (Fuller, 2002; Fuller & Korisettar, 2004; Fuller, Boivin, & Korisettar, 2007) (see also Balter, 2007; Bellwood, 2005). This is largely due to recent archaeobotanical sampling which has shown that a number of the earliest staples of the Southern Neolithic were crop domesticates such as horse gram (*Macrotyloma uniflorum*), mung

bean (*Vigna radiata*), and browntop millet (*Brachiaria ramosa*). These are native to the wild flora in the region (Fuller & Korisettar, 2004; Fuller, Asouti, & Purugganan, 2012). Gujarat (the Saurashtra Peninsula) was an early center for the cultivation for additional savanna crops including little millet (*Panicum sumatrense*) and urd bean (*Vigna mungo*). Both Southern India and Gujarat also appear to have cultivated local foxtail grasses (*Setaria* spp.). The Western Himalayan foothills near the Indo-Gangetic divide are poorly documented in terms

of Neolithic cultural remains, but the occurrence of wild progenitors in the region coupled with occurrence of native domesticates on Early Harappan sites suggests that this region may have had a parallel set of crop origins for mung bean, urd bean, and little millet as well as perhaps other millets such as sawa millet (*Echinochloa frumentaceum*) (Fuller, 2006, p. 46). The central Ganges basin has long been regarded as an early center of rice cultivation, along with many cucurbitaceous vegetable crops. Eastern India, around the modern state of Odisha, has also been postulated as a possible focus of early independent rice cultivation and the domestication center of pigeon pea (*Cajanus cajan*) (e.g. Harvey et al., 2006), although evidence that cultivation began here independently of the Ganges Neolithic remains elusive.

The Neolithic faunal resources are dominated by introduced pastoral herds of cattle, sheep, and goats which may indicate an earlier dispersal of mobile pastoral collectors, who may have preceded the development of agricultural economies and later tendencies toward sedentism. There is no firm evidence in the archaeological record for the transition from foraging to farming. Direct archaeobotanical evidence for the processes of initial cultivation and morphological domestication in South Asia is largely lacking at this point.

However, Neolithic deposits do reveal the first evidence of domesticated crops and more intensive sedentary human occupation of the area (Boivin et al., 2008, p. 179). Despite these factors, based upon the archaeobotanical assemblage, it would appear that plant cultivation was independently invented as wild plant species in the local vicinity were brought into cultivation and domesticated locally rather than coming in as introduced crops domesticated elsewhere. Indeed, crops from Southwest Asia and the Indus Valley region do not reach South India until the Neolithic had been well established in the region (Boivin et al., 2008, p. 179). While inspiration through information exchange with distant farmers cannot be excluded, it is clear that local agricultural origins were based on the cultivation and domestication of plants chosen from local wild populations.

The ecological niches of these wild progenitors of the Indian Neolithic varied but in general focused on savanna to deciduous woodland transitions. The wild progenitor of mung bean (*Vigna radiata*) is known to have occurred in the wet and dry deciduous forests on the eastern edge of the Western Ghats in clearings and along the forest edge and sporadically in the Eastern Ghats as well, as the core area of this region of this area was too dry, even in the past, for wild mung beans (Boivin et al., 2008, p. 182; Fuller, 2006, p. 50). Urd (*Vigna mungo*) is distributed in the moist deciduous forests of the northernmost Western Ghats and Western Himalayan foothills of southern Aravallis, Mount Abu in Rajasthan, and eastern Satpura ranges. Urd is absent from the Southern Neolithic until its very latest stages and the most likely zone of domestication was to the northwest in Gujarat or Rajasthan. Wild horse gram (*Macrotyloma uniflorum*) is native to the Acacia thickets ranging from the Aravalli hills in Rajasthan through the savanna zone of the Southern Peninsula. The wild forms of millets, like *Brachiaria ramosa* of the Southern Neolithic, would have also been sporadic patches within the savanna zone as slightly wetter environments like breaks in slope or the distal edges of ponds (Fig. 2). *Brachiaria ramosa* in particular is of interest as it was overlooked in early archaeobotanical and ethnobotanical research but is now evident as having been a widespread cereal crop in Indian prehistory, especially on the Peninsula (Kingwell-Banham & Fuller, 2014). Thus, with the expansion of savanna and a more restrictive dry season as climates dried from 3500 to 2000 B.C., the mung beans of moist woodlands and the wild millets would have become scarcer. Wild horse gram too likely retreated as grasslands expanded. Taken together there were limited watering holes which encouraged the creation of pulse and millet gardens (Fuller et al., 2014).

Thus, these wild progenitors span both the tropical wet to dry deciduous forests on the hills of the Deccan margins and the drier savanna-woodland zones of the Central Peninsula. This is similar to the more Mediterranean habitat of wild pulses found in the Near East and



Plant Domestication in India, Fig. 2 *Brachiaria ramosa* (Photo by C. Stevens 2014)

the drier steppe habitat of wild barley and wheat. A similar scenario may be imaged in each area in which early mobile collectors were combining plant cultivars from across the adjacent habitats which they frequented in their seasonal hunting and collecting strategy.

The South Indian crop domesticates may initially have been cultivated in shifting fields that suited the more seasonally mobile lifestyle of hunter-gatherer-herders. Herd animals such as cattle, sheep, and goat spread through the savanna of Indus from the Indus region and Baluchistan. It remains unclear the extent to which these livestock spread primarily through adoption by local foragers or dispersed with immigrants and which of these groups was primarily responsible for early pulse-millet farming. Nevertheless, established villages based on these crops and

livestock became increasingly widespread in the Southern Deccan after 2200 B.C. Meanwhile in the Northern Deccan, these crops were taken up alongside introduced West Asian wheat, barley, and pulses, mainly after 2000 B.C.

The processes and motivations for domestication may have been similar in Gujarat. A similar combination monsoon-watered millet and pulse were brought into cultivation probably between 3500 and 2500 B.C. This period saw the expansion of the Thar Desert which would have put pressure on the Mesolithic foragers who had lived within the mid-Holocene green desert and savanna-woodlands to its south. Around 3500 B.C. domesticated cattle were adopted and ceramic production began (Patel, 2008). Clear evidence for cultivation derived from later sedentary sites during the Harappan era (from 2600 B.C.), by which time native domesticated crops were well established and dominated the diet (Weber, 1991; Fuller, 2011).

In the Ganges valley, wild rice would have been an important food resource and one which was increasingly managed over the course of the Holocene, eventually providing the genetic background of domesticated *Oryza sativa* subsp. *indica* (Fuller, Allaby, & Stevens, 2010; Fuller & Qin, 2009). Rice is ubiquitous on all archaeobotanically sampled sites of Mesolithic, Neolithic, or Chalcolithic age (Fuller, 2011). The balance of archaeobotanical and genetic evidence suggests a distinct origin of cultivation of ancestral *indica* rice in this region but that full domestication in the morphological sense was not completed until domesticated *japonica* varieties were introduced to North India from China, allowing for hybridization (Fuller, Allaby, & Stevens, 2010; Fuller & Qin, 2009). This can be understood through a “proto-*indica*” model in which abundant and productive annual wild rice (*Oryza nivara*) was harvested and managed in non-intensive way that did not lead to the evolution of domestication traits. Domestication traits were subsequently hybridized into South Asia rices, perhaps first in northern Pakistan, around or after 2000 B.C., with the introduction of highly developed domesticated subspecies *japonica* rice from China that had been exchanged with other

crops westward through Central Asia. Between 2000 and 1600 B.C., fully domesticated rice is evident from Ganges Neolithic sites, such as Mahagara, alongside adopted wheat, barley, lentils, and livestock that had come from the Indus region. At this time, with this mixed economy, agricultural villages of the Ganges Neolithic grew and proliferated. There is also some evidence that some small millets may have been cultivated in the Ganges, including a native fox-tail (Saraswat, 2004, SENUWAR). Among the many native cucurbits, only ivy gourd (*Coccinia indica*) has an early archaeobotanical record. In contrast to Gujarat, South India or West Asia, early Ganges cultivation focused largely or even exclusively on rice, although the Neolithic becomes more widespread as population grows and mixed cropping is adopted. Similar to South India is the rather late emergence of archaeologically visible, widespread, and sedentary agricultural settlement around 4,000 years ago. This points toward more mobile settlement and early cultivation, perhaps a form of shifting agriculture.

Local plant domestication events in India were combined with agricultural dispersals in an interconnected mosaic of cultivation, pastoralism, and sedentism. The Neolithic transition in India is globally among those that emerged in the middle Holocene, with the established sedentary farming village cultures of India mostly evident as the middle to late Holocene transition around 4,000 years ago. The timing of this agricultural emergence is similar to that in parts of Africa and North America, and similar circumstances of grassland expansion and woodland retreat may have been shared (Fuller et al., 2014). This does not, however, preclude the importance of social factors in transition to food production.

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Plant Domestication in the Near East

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Human societies have abandoned their aboriginal hunting-gathering lifeway in favor of economies based on food production independently in several world regions, the Near East included. Major components of this move were the domestication of plants and animals. In this entry, we address the key biological and cultural aspects of plant domestication in the Neolithic Near East (12th–7th calibrated millennia before present) and its bearing on the origins of agriculture as a socioeconomic system. The importance of plant domestication as a central component of agriculture in the Near East and the fact that many of the plants domesticated in the Neolithic Near East still play a significant role in the global economy to this day inspired numerous attempts to find out where are the geographic origins of plant domestication, when were they domesticated, what are the underlying biological and cultural mechanisms leading to plant domestication, and how can all this be explained (e.g., Abbo et al. 2012, 2014a, 2014b; Bellewood 2005; Binford, 1968; Childe, 1951; de Candolle, 1885; Fuller, 2007; Harlan, 1992; Lev-Yadun, Gopher & Abbo, 2000; Purugganan & Fuller, 2011; Redman, 1978; Zohary, Hopf & Weiss, 2012).

Modern, systematic studies on the origin of Near Eastern agriculture and plant domestication combining fieldwork in archaeological sites and the analysis of archaeobotanical finds were pioneered by Robert Braidwood in the late 1940s and the 1950s with the exploration of archaeological sites in Syria, Iraq, and Turkey (Braidwood, 1960, 1975). Developments in archaeological and archaeobotanical

methodology and thinking and in botany, genetics, and plant evolution during the past 50 years yielded enormous amounts of data and a massive volume of literature on the subject, and these enable us to draw an evidence-based reconstruction of plant domestication in the Near East.

Near Eastern agriculture is thought to have started with a crop assemblage including cereals and legumes listed in Table 1. The wild progenitors of these crops were identified based on morphological similarity (botanical criteria) and cytological affinity (genetic criteria) (Zohary & Hopf, 1988; Zohary et al., 2012).

Surveying the literature on the subject, one may easily identify the major issues sitting at the crux of the discussion on plant domestication and on which major disagreements exist. These issues include, but are not limited to, questions such as the geography of plant domestication, the time frame and pace of plant domestication, the scope of plant domestication and the coalescence of the founder package, and the question of human intentionality or consciousness concerning plant domestication.

A summary of plant domestication in the Neolithic Near East focused on these issues, and the scholarly opinions about them are shown in Table 2, alongside a selection of their prominent literature sources. Whether framed as bipolar (either-or) questions or otherwise, the processes related to plant (and animal for this matter) domestication were never simple, unifacial, unidirectional dynamics and the adoption of domesticates was not a simple move. It is clear that opting for domesticates and establishing a rural-agricultural system was a long socioeconomic/cultural process (called Neolithization) involving major changes in lifeways and new structural as well as organizational social systems, all based on a change in human perception of both human-world and human-human relationships. In order to provide an account of such a complex scenario, answers to the basic questions listed above are needed, as well as a detailed cultural reconstruction. The scope of this entry does not allow for

Plant Domestication in the Near East, Table 1 The “founder crops” of the Near Eastern agriculture, after Zohary and Hopf (2000)

Common name	Scientific name	Wild progenitor
Einkorn wheat	<i>Triticum monococcum</i> L.	<i>T. monococcum</i> ssp. <i>boeoticum</i> (Boiss.) A. et D. Löve.
Emmer wheat	<i>Triticum turgidum</i> ssp. <i>dicoccum</i> (Schränk) Thell.	<i>T. turgidum</i> ssp. <i>dicoccoides</i> (Körn.) Thell.
Common barley	<i>Hordeum vulgare</i> L.	<i>H. spontaneum</i> C. Koch
Pea	<i>Pisum sativum</i> L.	<i>P. humile</i> Boiss. et Noë
Lentil	<i>Lens culinaris</i> Medikus	<i>L. orientalis</i> (Boiss.) Handel-Mazzetti
Chickpea	<i>Cicer arietinum</i> L.	<i>C. reticulatum</i> Ladiz.
Bitter vetch	<i>Vicia ervilia</i> (L.) Willd.	<i>V. ervilia</i> (L.) Willd.
Flax	<i>Linum usitatissimum</i> L.	<i>L. usitatissimum</i> ssp. <i>bienne</i> Mill.

Plant Domestication in the Near East, Table 2 A selection of bipolar axes concerning the domestication of plants in the Neolithic Near East and prevalent proponents of each

Geography of plant domestication: The origin of Near Eastern plant domestication was either a highly localized cultural phenomenon or a geographically diffused event sprouting in multiple centers	<i>Highly localized event</i> – Heun et al., 1997; Lev-Yadun et al., 2000; Salamini et al., 2002; Ozkan et al., 2005, Kilian et al. 2009, Abbo et al., 2010a; Gopher et al., 2013
<i>Diffused series of events</i> – Willcox, 2005; Weiss et al., 2006	
Time frame and pace of plant domestication: The domestication of the main Near Eastern crops was a singular, fast (punctuated) move (episode) or a protracted, slow, gradual process unfolding through repeated (multiple) processes/events	<i>Single occurrence</i> – Lev-Yadun et al., 2000; Gopher et al., 2001
<i>Repeatedly recurring processes</i> – Willcox, 2005; Allaby et al., 2008	
<i>Slow and gradual</i> – Tanno & Willcox, 2006; Allaby et al., 2008; Purugganan & Fuller, 2011	<i>Fast changing</i> – Ladizinsky, 1987; Hillman & Davies, 1990; Abbo et al., 2011a <i>Inclusive</i> – Abbo et al., 2010b
Scope of plant domestication and the coalescence of the package: The scale of domestication was an inclusive act of deployment involving most crop plants together or an exclusive act by which domestication of each and every species has occurred independently	
<i>Exclusive, each species selected independently</i> – Willcox, 2005	
Human intention in plant domestication: The process of domestication as a whole was a conscious knowledge-based effort to select and manipulate the various plant species that were eventually transformed or was a product of an unconscious dynamics and natural selection occurring inadvertently either in cultivated fields or via aboriginal resource management operations often perceived as a private case of niche construction similar to adoption of fungi by termites or ants	<i>Intentional, conscious</i> – Ladizinsky, 1987; Abbo et al., 2005; Kerem et al., 2007; Abbo et al., 2009; Abbo et al., 2010b; Tzarfati et al., 2013; Abbo et al., 2014a
<i>Unintentional, unconscious, incident</i> – Harlan et al., 1973; Zohary, 2004; Purugganan & Fuller, 2011	

a detailed discussion; hence, it is focused on the abovementioned aspects.

The Geography of Plant Domestication

To address the geography of plant domestication, evidence from three major independent fields is required: (1) the geobotany and genetics of the living plants, (2) ^{14}C -dated archaeobotanical remains from relevant archaeological sites and contexts, and (3) archaeology – the sociocultural milieu. We offer short comments and conclusions on these three aspects based on evidence known as we write.

Geobotany and genetics – All the wild progenitors of the Near Eastern founder crops (Table 1) are elements of the east Mediterranean oak-pistachio woodland and have different ecological affinities. However, there is only one region in southeastern Turkey and northern Syria where the natural distributions of all the progenitors' taxa coincide (Lev-Yadun et al., 2000; Fig. 1). Genetic analyses using DNA markers (e.g., Heun et al., 1997; Kilian et al., 2009; Salamini, Özkan, Brandolini, Schäfer-Pregl & Martin, 2002) have identified the closest wild genetic stocks of domesticated einkorn and emmer wheats in this geographical region, and the wild stock of lentil to nearby environs (Ladizinsky, 1999). In addition, the wild progenitor of domesticated chickpea is known from this area only. No similar work was done with flax, bitter vetch, and pea. As for barley, Morrell and Clegg (2007) suggest that it has more than one geographic origin.

Archaeobotany – The earliest remains of domesticated cereals (and associated legumes) were excavated from archaeological sites within the same region depicted in Fig. 1 (that we termed the core area) in southeastern Turkey and northern Syria as early as ca. 10,500 cal BP or somewhat earlier.

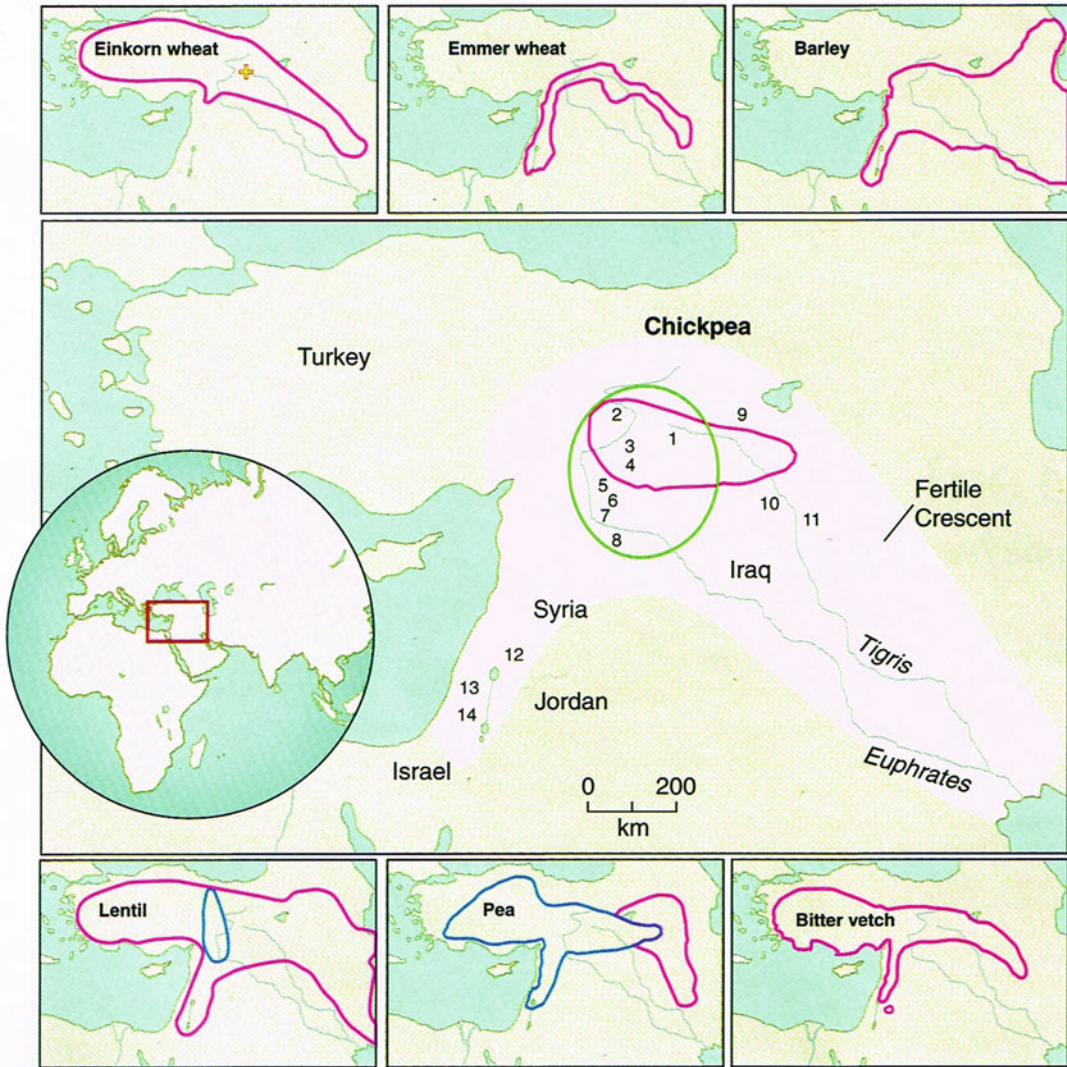
Archaeology – The core area depicted in Fig. 1 was a center of intensive cultural dynamics in the early Neolithic and shows the appearance

of large-scale sites, innovative architectural features, and lithic technology as well as impressive sculpting in stone and a rich array of imagery (symbolic) items, all in the millennium preceding plant domestication. While large-scale sites continue to appear, changes and innovations in architectural design, lithic technology, clay sculpting, burial customs, and in imagery (symbolic) items take place in tandem with the appearance of domesticated plants ca. 10,500 cal BP or somewhat earlier. Some of these innovative aspects spread later to other parts of the Levant and Cyprus.

At present, there is no evidence-based better alternative than the core area reconstruction (Abbo, Lev-Yadun & Gopher, 2010a; Lev-Yadun et al., 2000). This approach is, however, challenged by authors suggesting multiple, genetically and culturally independent domestication processes (e.g., Brown, Jones, Powell & Allaby, 2009; Fuller et al. 2011; Fuller, Willcox & Allaby, 2012; Riehl, Zeidi & Conard, 2013; Weiss, Kislev & Hartmann, 2006; Willcox, 2005), none of which holds up upon careful evaluation of the botanical, genetic, and archaeological evidence (e.g., Abbo et al., 2010a, 2012; Abbo, Lev-Yadun, Heun, et al., 2013; Abbo, Lev-Yadun, Gopher, 2013; Gopher, Lev-Yadun & Abbo, 2013; Heun, Abbo, Lev-Yadun & Gopher, 2012).

Time Frame and Pace of Plant Domestication

A relatively short time frame for plant domestication was suggested in the past (Hillman & Davies, 1990, 1992, 1999; Zohary, 2004). In recent years an opposing view suggesting a protracted, millennia-long process was advanced (e.g., Allaby, Fuller & Brown, 2008; Purugganan & Fuller, 2011; Tanno & Willcox, 2006). To support the protracted reconstruction, diachronic scatterplots showing gradients in the proportion of domesticated vs. wild cereals



Plant Domestication in the Near East, Fig. 1 The geographic distribution of the seven Neolithic founder crops in the Fertile Crescent (yellow) of the Near East. Large map shows the distribution of wild chickpea (red line) in a core area (green line) within the upper reaches of the Tigris and Euphrates rivers (present-day southeastern Turkey/northern Syria). Neolithic sites are numbered as follows: (1) Çayönü, (2) Cafer Höyük, (3) Nevalı Çori, (4) Göbekli Tepe, (5) Djade, (6) Jerf el-Ahmar, (7) Tell Mureybet, (8) Tell Abu-Hureyra, (9) Hallan Çemi Tepesi, (10) Qermez Dere, (11) Mlefaat, (12), Tell Aswad,

(13) Yiftahel, and (14) Jericho. Inset maps show the natural distribution of the wild progenitors of the founder cereal crops; einkorn wheat (cross indicates the putative site of its domestication), emmer wheat, and barley, and founder legumes (lentil, pea, bitter vetch). The blue lines in the distribution maps indicate the area of the identified wild genetic stocks of the domesticated forms, while the red lines indicate the distribution of the wild progenitors beyond that of the founder stocks (Reproduced with permission from Lev-Yadun et al., 2000, *Science* 288, 1602–1603)

remains in various Neolithic sites across the Near East and similarly scatterplots showing increase in seed size of cereals and legumes were presented. In addition, it was hypothesized that

due to the increased workload associated with non-brittle (domesticated) spike phenotypes of wheat and barley, the Neolithic farmers may have selected against the domesticated

morphology, thereby extending the process of domestication over millennia (Fuller, Allaby & Stevens, 2010).

The major underlying assumptions of a protracted scenario are weak from a population genetics perspective (Heun et al., 2012) as well as from ecological, evolutionary, genetic, and cultural perspectives (Abbo et al. 2012, 2013, 2014a, b). In addition, controlled cultivation experiments with wild and domesticated pea (Abbo et al., 2011b) have reaffirmed Ladizinsky's, (1987) hypothesis that domestication of Near Eastern grain legumes cannot be discussed in the context of long-term (protracted) cultivation. Similarly, recent controlled threshing experiments of wild and domesticated wheat (Tzarfati et al., 2013) refuted Fuller et al.'s (2010) workload hypothesis. Thus, when considered together, the available evidence suggests a relatively short domestication episode.

Scope of Plant Domestication

Classical studies suggested that Near Eastern agriculture arose as a crop assemblage (Helbaek, 1959; Zohary & Hopf, 1988; Zohary et al., 2012). This view is based on the archaeobotany of the relevant sites but has agro-economic and economical foundations too (Abbo et al., 2010b). In recent years, various authors suggested that single, different crops were domesticated in isolation (i.e., independently) by different Neolithic communities that relied on additional wild resources for their dietary and other economic needs (e.g., Willcox, 2005, 2012; Weiss et al., 2006).

Taking into account that in ancient times yield stability was more important than yield maximization, and the biology of the founder crops, it was suggested that the Near Eastern crop assemblage was chosen to function within the east Mediterranean climatic regime and precipitation range, in which good rainy years create the “normal surplus” that sustains farming communities during drought years. This was possible because the three cereals provide a maturity gradient (with barley, emmer, and einkorn being early,

middle, and late, respectively), similarly with pea, lentil, and chickpea (Abbo et al., 2010b). In addition, these legumes and the cereals have a contrasting response to the seasonal rain profiles, and therefore, when cereals provide poor yields, the grain legumes are likely to give high yields and vice versa. Therefore, based on agro-economic and economic considerations, as well as on the available archaeobotanical assemblages from the relevant sites, we favor the crop assemblage concept (Helbaek, 1959; Zohary & Hopf, 1988) rather than the hypothetical model suggesting the domestication of single crops at a time *a la* Willcox, (2005). Similarly, from a nutritional perspective, a mixed diet of both cereals and grain legumes is a more sustainable strategy (Abbo et al., 2009) than reliance on a single cereal or legume.

Human Intention (Consciousness)

Harlan et al. (1973) and Zohary (2004) are probably the most prominent advocates of domestication via the “automatic selection” dynamics viewing the emergence of domesticated crop forms as the result of cultivation regimes operated by early Neolithic farmers in their fields. A whole set of related reconstructions conceptualize plant domestication as occurring in the framework of prey-predator coevolutionary process (Rindos, 1984), via a cultural gradient of indigenous low-level food production strategies (Smith, 2001) or as a private case of niche construction (Smith, 2007, 2011). The common denominator of these models is that they do not attribute an important role to human initiative, choice making, intention, and indeed conscious selection (Abbo et al., 2005, 2011a, 2011b, 2014b).

We hold a different view, based on both published models (Ladizinsky, 1987) and our own field and laboratory experience (Abbo et al., 2011b; Tzarfati et al., 2013). As stated above, there is no justification to see the domestication of the three Near Eastern cereals, neither grain legume domestication as an unconscious process nor their subsequent evolution under

domestication, but rather as an intentional, knowledge-based move.

Conclusions

In assuming that Neolithic cultivators were unable to identify plant types that exhibit better taste or aroma, a more nutritious composition, a non-brittle shaft or axis, free germination, or other notable traits, one is likely to advocate for a protracted domestication process (Purugganan & Fuller, 2011). Under such assumptions, one must allow traits of the domestication syndrome to present themselves to the cultivator in such quantities and frequencies that even our presumably incompetent Neolithic ancestors eventually noticed them. Such reconstructions relying on random mutation events rather than on human initiative indeed make more sense in a framework of geographically scattered domestication episodes of single plant species at a time.

However, when evaluated against the ever increasing hard geobotanical, archaeological, archaeobotanical, and genetic evidence, and based on agronomic and nutritional considerations, plant domestication in the Near East emerges as a single, localized event, a relatively fast move initiated by conscious and capable people who used their ingenuity to domesticate a highly successful package of species – the founder crops – comprising a major part of the world's economy to this very day (Abbo et al. 2010b, 2012, 2014a, b; Zohary et al., 2012). It is important to note that similar independent developments including the domestication of crop packages comprising cereals and legumes have taken place in other world areas thousands of years ago, again introducing what are still some of the most important crops to this very day.

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Polycentered History of Science

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It used to be a commonplace in modernist studies and regrettably remains one still in philosophical historiography that modernity is something that happened first, and uniquely, in Europe. Attempts were made to convert the supposition into a tautology through definitions of modernity that exclude non-European histories and geographies (e.g., in terms of capitalist modes of production, the emergence of nation-states and nationalist collective identities, the industrial

revolution, and secularization). Progress of sorts occurred with the acknowledgment of the existence of alternative regional modernities, but the acknowledgment was tied to a center/periphery model and to an associated ideology of European diffusionism. Shmuel Eisenstadt, for instance, is willing to acknowledge “multiple modernities” but only insofar as these new modernities imitate and copy a first modernity centered in Europe (Eisenstadt, 2000). Postcolonial writers such as R. Radhakrishnan have struggled with what they term “the curse of derivativeness” and have sought to find in the interplay between colonized and colonizer, between tradition and modernity, a more dialectical pattern of engagement, finding, for example, a modernizing effect on Europe in the new modernities of Asia (Radhakrishnan, 2002). I will argue that it is better and more correct to think instead of modernity as a happening potentially indigenous to any culture, irrespective of period or place, that like the Indian banyan tree it is “polycentric,” borrowing here Susan Friedman’s very useful term. “The new geography of modernism,” Friedman says, “needs to locate many centres of modernity across the globe, to focus on the cultural traffic linking them, and to interpret the circuits of reciprocal influence and transformation that take place within highly unequal state relations” (cf. Friedman, 2001, 2006, p. 429). It involves a recognition that these modernities are not derivative but different. Modernity, and this is a point that has been made forcefully by Sanjay Subrahmanyam in his use of the term “conjuncturality,” is also characterized by the “intensification of intercultural contact zones... heightened hybridizations, jarring juxtapositions, and increasingly porous borders both characterize modernity and help bring it into being.” Subrahmanyam says, perfectly accurately, that “modernity is a global conjunctural phenomenon, not a virus that spreads from one place to another” (1998, pp. 99–100).

“Modern science” is one of the more manifest embodiments of modernity, and the above observations have equal application to the history of science. Here, likewise, a center/periphery model ought eventually to make way for a polycentric

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understanding, one which acknowledges that scientific practice and scientific modes of inquiry are different if conjuncturally instantiated across the globe. As with modernity in general, the point of departure is to avoid definitions that turn the privileging of Europe into a tautology. In the natural sciences, the standard view is still that a scientific conception of inquiry is a specially European achievement, and the acceptance of that view is what lends continuing significance to a question first posed by Joseph Needham some 40 years ago:

Why did modern science, the mathematization of hypotheses about Nature, with all its implications for advanced technology, take its meteoric rise only in the West at the time of Galileo? ... [The question is] why modern science had not developed in Chinese civilization (or Indian) but only in Europe? (Needham, 1969, p. 16)

Needham, an eminently sympathetic chronicler of the achievements of Chinese intellectual culture, was fully conscious of the fact that “between the first century B.C. and the fifteenth century A.D., Chinese civilization was much more efficient than occidental in applying human natural knowledge to practical human needs,” but he regarded it as uncontroversial that modern science is a uniquely European accomplishment. Needham’s question calls us to ask what Europe had that Asia had not, and there has been a plethora of proposals as to the lacuna, including the Protestant ethic, the application of mathematics in the description of nature, and capitalism’s facilitation of ties between academia and craftsmen (see Cohen, 2011).

If we are to make room for a polycentric history of science, we must begin with a definition that does not presume at the outset that science is in essence an originally European practice. Instead, I will work with a definition that borrows two ideas from recent work in the philosophy of science. The first is Karin Cetina’s idea of “epistemic cultures,” which are “those amalgams of arrangements and mechanisms—which, in a given field, make up how we know what we know ... Epistemic cultures are cultures that create and warrant knowledge, and the premier

knowledge institution throughout the world is, still, science” (Cetina, 1999, p. 1). The second is Philip Kitcher’s idea of science as “a system of public knowledge” (Kitcher, 2001, 2011). Kitcher’s thesis is that what scientific practice should aim for is such public knowledge as would be deemed worthwhile by an ideal conversation *among the whole public* under conditions of mutual engagement. The practice is then, in his phrase, “well-ordered.” It is to Kitcher that we owe the idea that the social values to which scientific endeavor should submit itself are those of a democratic consensus, understood not in the sense of the majority vote but rather in the idea of tutored preferences based on mutual engagement of all human points of view in an ideal conversation. Science, then, in my expanded working definition, is a well-ordered epistemic culture facilitating the production of public knowledge.

Understanding science as a well-ordered system of public knowledge enables us to ask, as Needham could not, whether the epistemic cultures of India or China qualify as genuine modes of scientific inquiry. After describing in a little more detail the role of the idea of well-ordering in the philosophy of science, I will use the remainder of this entry to explore two historical Indian accounts of the ideal conversation whose deliverances seem to govern the aspirations of scientific inquiry. The first is the synthetic pluralism (*syādvāda*) advanced by Jaina thinkers in the second half of the first millennium, and the second is a Buddhist account of balanced deliberation (*vādayutti*) from the time of Aśoka. With a shift in perspective from a center/periphery model of the history of science to a polycentric approach, we can appreciate these contributions as genuine encounters with the emergence of scientific methodologies in India.

Well-Ordered Science

Well-ordered science, another name for which is “properly functioning inquiry” (Kitcher, 2001, p. 118), is science as constrained by goals and values inherent in the pursuit of human goods.

The term “science” here has a broad designation, inclusive of many forms of inquiry that contribute to what Kitcher calls the “system of public knowledge”:

The forms of inquiry designated as “sciences,” where the term is used inclusively to cover studies of art, literature and music, investigations of human behaviour, culture and societies, as well as facets of the physical and organic world, play a central role in our contemporary system of public knowledge, that body of shared information on which people draw in pursuing their own projects. (Kitcher, 2011, p. 114)

A system of public knowledge is defined by norms in the processes of investigation, whose goal is to acknowledge that there is a division of epistemic labor among the contributors to public knowledge, distinguished by their distinctive “trajectories through the habitat” as well as by their various talents and acquired capabilities. Contributors are subject to norms of sincerity and competence with respect to the submissions they make, and there are norms pertaining to submission and transmission. For example, which people are entitled to submit information to the depository and about what? Who is entitled to receive which parts of public knowledge? Fundamentally, there are also norms on investigation, norms that tell us “what types of investigation are viewed as worth pursuing? How are they supposed to proceed? What constraints govern them?” (2001, p. 118, 2011, pp. 85, 90, 91). A properly functioning inquiry, a well-ordered science, is one that proceeds in conformity with these norms, especially the norms on the selection and progress of research agenda.

Kitcher’s radical and distinctive proposal is that the norms bearing on inquiry can be derived from the values and goals of democracy. What the appeal to democracy supplies is a conception of an ideal form of deliberation, inclusive of all perspectives and achieving consensual agreement in matters of significance to all parties concerned. Thus,

Science is well ordered when its specification of the problems to be pursued would be endorsed by an ideal conversation, embodying all human points of view, under conditions of mutual engagement A society practicing scientific

inquiry is well ordered just in case it assigns priorities to lines of investigation through discussions whose conclusions are those that would be reached through deliberation under mutual engagement and which expose the grounds such deliberation would present. (2011, p. 114)

Three ideas are involved in this definition: that of a human point of view, that of mutual engagement in a panhuman conversation, and that of endorsement. Kitcher lacks any general theory of human points of view, their range and variety, of the sort that would ensure that no type of human point of view is left out of the ideal conversation. Mutual engagement, however, is central to his understanding of the account as involving an appeal to democracy more plausible and sophisticated than the “vulgar democracy” of the majority vote which leads only to a “tyranny of the ignorant”. Instead, a mutual engagement requires participants to move beyond their prudential initial preferences in a process of learning about the merits of other points of view and weaknesses of their own, and adjusting their preferences accordingly:

Built into the ideal of discussion under mutual engagement are cognitive and affective constraints: instead of myopic voters choosing in ignorance of the possibilities, and of the consequences for others, completely absorbed in their own self-directed wishes, the ideal conversationalists are to have a wide understanding of the various lines of research, what they might accomplish, how various findings would affect others, how those others adjust their starting preferences, and the conversationalists are dedicated to promoting the wishes other participants eventually form. (2011, p. 186)

What mutual engagement issues in is what Kitcher calls the “tutoring” of the participants, their coming to acquire an understanding of various fields of inquiry, their own preferences revised by a new appreciation of the perspectives of others and by a wish to accommodate others’ preferences as far as possible.

Human Points of View and the Logic of Consensus

This image of the nature of science provides us with a new perspective from which to understand key elements in the philosophical project of Jaina

thinkers in the seventh, eighth, and ninth centuries CE. Situating the Jaina theory in this context will enable us to ask if the extra-European perspective they afford on the concept will itself – in the spirit of mutual engagement – lead to a reformation of contemporary understandings of the requirements of deliberative democracy. For Jaina theory seems exceptionally well targeted on two of the key constituents in Kitcher's depiction of the ideal conversation. These are the classification of all human points of view and the representation of end states of the deliberative process – insofar as it provides extensive and detailed descriptions of any possible human point of view (*naya*) as well as a seven-dimensional structuring of consensual outcomes (*saptabhaṅgī*). These two analyses are jointly constitutive of the celebrated perspectival Jaina theory of conditionality (*syādvāda*).

The Jaina classificatory scheme of human standpoints has it that there is an exact number of distinguishable types. Several interpretations are available in the recent literature (e.g., Balcerowicz, 2001; Ganeri, 2001a, pp. 134–7). In the last section, I pointed to a lacuna in Kitcher's account that he provides no theoretical model that can ensure that *all* human points of view have been taken into consideration in the ideal conversation. The question for any interpretation of the Jaina classification, therefore, if it is brought to bear in the project of understanding how scientific inquiry is constrained by democratic values, is the question of comprehensiveness. Where is the guarantee that excludes the possibility of a human point of view which falls outside the classification? I find this question most fully appreciated in the thinker Malliṣeṇa, who quotes his predecessor Siddharṣigani:

Each preceding viewpoint has larger domain, whereas each subsequent [viewpoint] has [its] province [more and more] determined. The comprehensive [viewpoint] is more extensive in [its] province from the collective [viewpoint], which has as [its] province merely the existent, insofar as it has as [its] scope existence and non-existence. The collective [viewpoint] is larger from the empirical [viewpoint], which reveals an existent [particular] individual, insofar as it shows the amassment (sc. set) of all existent [individuals].

The empirical [viewpoint] has broader reference than the direct [viewpoint], which has as [its] province [only] the present [time], insofar as it rests on the province [made up of] the three times. The direct [viewpoint] has wider reference than the verbal [viewpoint], which shows different things by [reference to] the difference in tense (lit. time), etc., insofar as it comprehends what is contrary to that [scope of the verbal viewpoint]. The verbal [viewpoint] has more comprehensive province than the etymological [viewpoint], which takes separate synonymous expressions as [characterised by] difference of reference (denotata / meaning), insofar as it pertains to what is contrary to that [scope of the etymological viewpoint]. The etymological [viewpoint] has wider domain than the factual [viewpoint], which asserts that an object is different as [something possessed of its] specific activity. Likewise the account [based on] viewpoints, [when] it functions with regard to its province, follows the method of the seven-fold predication of affirmation and negation. (1933, pp. 167.9–18)

It is clear that each of these descriptions relates to a point of view in principle accessible to a human being. There is no mention of anything like a “god's eye” point of view, that is, of a perspective inaccessible to an actual person situated in space and time, following a spatiotemporal path and with restricted perceptual, inferential, and linguistic capacities. It is exactly because of this that the Jaina theory engages with the notion of an ideal conversation in which all human points of view are represented, forgoing any appeal to the transcendental in favor of ideal democratic consensus.

Outcomes of the Ideal Conversation

Kitcher claims that we should recognize three sorts of outcome in ideal conversation: consensus, partially overlapping consensus but agreement on a view as the fair representation of different points of view, and nonoverlapping agreement among the preferences of the participants (2001, pp. 121–2), with majority voting as the course of last resort in the final case.

Conversation may end in one of three states. The best outcome is for the deliberators to reach a plan all perceive as best... Second best is for each person to specify a set of plans he considers

acceptable and for the intersection of these sets to be nonempty. . . . The third option occurs when there is no plan acceptable to all and when the choice is made by majority vote. This is a last resort for expressing the collective will. (cf. 2001, pp. 119–22, 2011, p. 115)

The Jainas whose work I am reviewing add detail and complexity to this analysis. A tripartite scheme arises on the assumption that each participant in an ideal conversation, inhabiting a particular point of view, gives his assent to one range of proposals and dissents from another range. Then we can distinguish the three possibilities identified by Kitcher, that every proposal assented to in any point of view is assented to in any other point of view, that some proposal is assented to from every point of view, and that no proposal is assented to from every point of view. I have elsewhere shown that the Jaina analysis sophisticates this story by introducing the concept of a proposal about which the participant is agnostic, neither giving their agreement nor presenting an objection (see Ganeri, 2002). We might also call such a person tolerant or liberal in their attitude toward the proposal in question, allowing its validity in the conversation without subscribing to it themselves. When the existence of attitudes of toleration, over and above those of assent and disagreement, is introduced into the frame, then possible outcomes multiply, and it is not hard to demonstrate that there is an isomorphism between such possibilities and the seven-dimensional structuring of consensual outcomes (*saptabhaṅgī*) presented in Jaina theoretical discussion (see Ganeri). We might understand the underlying point of this maneuver as follows. Classifying someone's attitude as being one of disagreement forecloses possibilities for compromise and so restricts the opportunities for agreement. What the Jaina theory permits is a more finely grained distinction in the ways that a person might withhold their assent, the distinction between disagreement and toleration. That opens a new range for reaching compromise without unanimous endorsement and so reduces the eventual appeal to the last resort of the majority vote. Understood as a mapping of outcomes in ideal conversation, it is clear that there is no

rejection of the law of contradiction in the Jaina theory (contra Priest, 2008).

The strategy, it might be thought, is especially available under conditions of mutual engagement, when, as a result of sensitive reflection on the priorities and obligations of others, a participant allows space not to be obstructive while not being willing to give his unqualified consent. Yet I do not find an analogue of the idea of mutual engagement in Jaina discussion of the topic, where the presumption seems to be that dialogical positions are fixed and inflexible. For a full appreciation of the virtues of mutual engagement in formulating the deliberative democratic constraints on a well-ordered science, I suggest that we need to look to Buddhist rather than Jaina resources.

Tutoring and Mutual Engagement

Kitcher has this to say about the important notion of tutoring:

In a well-ordered science, a proper verdict would be one achieved by ideal deliberators, well tutored and mutually engaged, who considered the effects both of the proposed experiments and of not undertaking them. . . . Ideal conversationalists form their sympathetic desires by extending mirroring of the desires of others, achieving the desires they judge to be the best balance among the varying assessments (indefinitely iterated) made by fellow participants. If there is complete agreement about how the balancing is to be done, there is no need for further conversation. If there is not, the ideal conversation consists in attempts to support or reject various ways of balancing. (2011, p. 132)

Tutoring involves a revision in one's initial preferences in the light of one's deliberative engagement with others, an appreciation of the virtues of their point of view, and of their perceptions of failings in one's own. It is the idea of a community of suitably tutored participants, rather than raw expressions of self-interest, which distinguishes Kitcher's proposal from the zero-sum rationality of commonplace economic theory. Again, however, I find an absence of depth in Kitcher's description of the phenomenon, and I see in Buddhist Abhidharma a more sophisticated appreciation of the idea in question.

A Buddhist treatise from the third century BCE, the *Kathāvatthu* or *Points of Controversy*, describes for the benefit of adherents to various Buddhist schisms the proper method to be followed in conducting a critical discussion into an issue of doctrinal conflict (*Kathāvatthu*, 1894, 1897). Recent scholarship has largely focused on the question of the extent to which there is an “anticipation” of results in propositional logic. In fact, however, the text offers a particularly clear example of a work whose richness and interest lie elsewhere than in its anticipation of deductive principles and propositional laws. As a meticulous analysis of the argumentation properly to be used in the course of a dialogue of a specific type, its concern is with the pragmatic account of argument evaluation, the idea that arguments have to be evaluated as good or bad with regard to their contribution toward the goals of the dialogue within which they are embedded. The leading concern of the *Kathāvatthu* is with issues of balance and fairness in the conduct of a dialogue, and it recommends a strategy of argumentation which guarantees that both parties to a point of controversy have their arguments properly weighed and considered. There is an important distinction between the global aim of the dialogue as a whole (to rehearse in an even-handed manner all the considerations that bear upon an issue of dispute, to clarify what is at stake even if no final resolution is achieved) and the local aim of each participant (to advocate the stance they adopt with regard to that issue by supplying arguments for it and attacking the arguments of the other parties). A dialogue conducted in accordance with the prescribed method of the *Kathāvatthu* is called a *vādayutti*. The goal of a *vādayutti* is the “reasoned examination” (*yutti*; Skt. *yukti*) of a controversial point in and through a nonconfrontational dialogue (*vāda*). The dialogue is highly structured and is to be conducted in accordance with a prescribed format of argumentation. There is a given point at issue, for example, whether “a person is known in the sense of a real and ultimate fact,” whether there are such things as ethically good and bad actions, and so on. A dialogue is now divided into either sub-dialogues or “openings.” Each such

“opening” proceeds as an independent dialogue, and each is divided into five stages: the way forward (*anuloma*), the way back (*paṭikamma*), the refutation (*niggaha*), the application (*upanayana*), and the conclusion (*niggamana*). In the way forward, the proponent solicits from the respondent the endorsement of a thesis and then tries to argue against it. In the way back, the respondent turns the tables, soliciting from the proponent the endorsement of the counter-thesis, and then tries to argue against it. In the refutation, the respondent, continuing, seeks to refute the argument that the proponent had advanced against the thesis. The application and conclusion repeat and reaffirm that the proponent’s argument against the respondent’s thesis is unsound, while the respondent’s argument against the proponent’s counter-thesis is sound (see further Ganeri, 2001a).

As such, the *Kathāvatthu* is an excellent analysis of the phenomenon Kitcher describes as “tutoring.” Each participant in the ideal conversation comes to understand clearly the embedded commitments, desirable or otherwise, of their own point of view, and each also comes to understand the virtues of the points of view of others. The notion of *vādayutti* constitutes an exact equivalent of the process of mutual engagement and tutoring that Kitcher identifies as essential to ideal deliberation, and the *Kathāvatthu* provides a theoretical framework for understanding the idea unparalleled in any contemporary discussion of deliberative democracy. It provides too what I suggested is lacking in the Jaina analysis of standpoints, namely, an account of the way by which one revises one’s standpoint in the light of an appreciation of the virtues of the standpoints of others. While Jaina discussion presents standpoints as self-formed and static, the supplementation of Buddhist analysis enables us to appreciate their dynamical aspects. With this supplementation, it seems to me entirely right to use the formal tools of dynamic dialogical logic in the modeling of Indian theoretical analysis (dynamic modeling of the mutual revision of each participant’s standpoint within and as a result of the dialogue along with modeling of outcomes).

Conclusion

In answer to Needham, it was not “modern science” which failed to develop in India or China but rather non-well-ordered science, science as unconstrained by social value and democratic consent. What I have argued is that this is not a deficit in the civilizational histories of these countries, but a virtue.

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Potato: Origins and Conservation of Potato Genetic Diversity

Timothy Johns

The Origins and Conservation of Potato Genetic Diversity When the conquistador Francisco Pizarro and his men overran the Inca Empire in the 1530s they stumbled upon the potato, a vegetable with an annual crop value that today far exceeds that of all the gold the Spaniards ever removed from the New World. While the first potatoes that were taken to Europe in 1537 were regarded suspiciously or as just a curiosity, the potato is now the most important tuber crop globally, exceeded only in its contribution to human subsistence by the cereals wheat, rice, and maize.

What global humanity assumed from the Andeans was not just an important nutrient source, but also several millennia of accumulated empirical experimentation through which Amerindian farmers molded wild species of tuber-bearing members of the genus *Solanum* into the domesticated potato. This is a process determined by biological and environmental forces and by the intelligence and cultural traditions of these people in relation to plant biology and ecology. The Andeans made good use of the natural vegetative propagation method of potato plants, and altered it to their own advantage. They chose those tubers that were most favorable, and by

planting the same preferred types year after year maintained their favorable characteristics.

Through time, human selection has resulted in specific changes in the potato plant. In comparing the potato of commerce, *Solanum tuberosum*, with its wild relatives, a botanist might first observe the changes in the length of the underground stems, or stolons, that bear the tubers. These are invariably short in modern cultivars. When wild and primitive plants are pulled up, the stolons are likely to break; tubers from plants with long stolons are more likely to be left in the ground, and less likely to be planted the next year. The result is an unconscious selection for shorter underground stems, and a plant that conveniently produces a mass of easily harvestable tubers close to its base. The typical wild potato is golf ball-sized or smaller. Selection for greater tuber size and plant yield improved the output compared to wild types.

In South America, several thousand different landraces and eight species of potatoes are presently cultivated. Farmers recognize them by differences in color, size, shape, and flavor as well as numerous agronomic traits. Most North American consumers are familiar with two or three colors of potatoes. In the Andes selection by humans has resulted in cultivars in which the skin and flesh color may be black, purple, red, yellow, or white, and spotted combinations of any of these colors. Many wild plants, in order to avoid being eaten by herbivores, produce unpleasant-tasting chemicals. Glycoalkaloids, steroidal nitrogen-containing compounds, are normally found in wild species of potatoes in concentrations high enough to be toxic or potentially fatal to humans or animals. These toxins have posed particular problems for Andean peoples and have been dealt with in various ways, including the selection of genes conferring lower glycoalkaloid content.

Andeans make good use of the knowledge that different potato varieties grow best under different environmental conditions. Even if one type fails due to adverse weather or diseases caused by viral, bacterial, or fungal pathogens, others with specific resistances produce enough tubers to sustain the human population until the next season.

Not surprisingly Andean potatoes are a source of invaluable germplasm from which plant breeders obtain sought after traits such as resistance to frost and disease.

Modern potato fields in the high Andes of Peru and Bolivia exist in the very locale from which wild plants were originally taken (the center of diversity for potatoes) and wild plants, growing around fields, or even within fields, hybridize with cultivated plants. This creates a dynamic situation which produces, from seed, new genetic types. These plants will have valuable traits of the cultivated parent and perhaps valuable traits of the wild parent. Some of them will have a combination of characteristics superior to earlier types; they will often grow as weeds in fields and from them farmers continue to choose new varieties that constantly improve the nature of the cultivars.

Essential to this process of crop evolution is the intimate knowledge farmers have of their potatoes. Andean cultivators recognize clones of potatoes for their various qualities and may grow up to 35 different landraces together in one field. Aymara and Quechua Indians know tubers by name, e.g., *laram imilla* (blue girl), and have detailed taxonomies to describe the multitude of types.

The dynamic situation that created this diversity continues to the present day and is an essential resource both for ensuring human survival in the Andes and for maintaining potato genetic diversity. However, commercial interests which supplant this variation with new high-yielding varieties of potatoes, and introduce modern technologies, are bringing rapid change to the traditional agricultural system in the Andes; it is with alarm that scientists view the loss of potato landraces and the farming systems that guarantee the long-term survival of this crop upon which humankind is heavily dependent.

The conservation of biodiversity of both crop and wild species of plants is of global concern. However, the most obvious beneficiaries of the use of plant genes to produce new pharmaceuticals or improved crops are in the industrialized countries of the world. Fewer of the financial benefits derived from patented products are returned to the countries from which the

germplasm was obtained. More importantly little recognition or compensation is provided to the communities who maintain the essential indigenous knowledge about plant properties. Indeed with economic development the marginalization of indigenous peoples in society is often increased rather than diminished; while indigenous peoples have traditions of conserving natural resources, changing economic conditions force them to adopt practices that are often destructive to their traditional systems.

In addition to the potato, the first peoples of the Americas were the domesticators of numerous crops including tomatoes, maize, and chili peppers. From their knowledge systems humanity learned the use of traditional medicines such as curare and ipecac which have provided valuable pharmaceuticals. Recognition of the true value of the intellectual property of indigenous people is the first step to settle the debt established in 1537; international governments and institutions need to seek in conjunction with these communities means to conserve in situ the valuable resources that are maintained within their cultural traditions.

See Also

- [Agriculture in Africa](#)
- [Environment and Nature in the Andes](#)

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Precession of the Equinoxes

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Precession of the equinoxes, which in Indian astronomy is called *ayanacalana* (shifting of the solstices), refers to the slow but continuous backward movement of the point of intersection of the ecliptic (which is a fixed circle) and the celestial equator (which keeps on moving backward). This effectively means that the first point of Aries, which is the traditional point of the commencement of the Indian year, is really shifting backward continuously. This shifting is, however, so slow, being a meager 50.2 s per annum, that it comes to be noticed only when it accumulates over several years and takes about 25,800 years to complete one circle.

Such a shift seems to have been noticed in India even during the Vedic times, as is evidenced by the Vedic priests changing the beginning of their year backward, from the constellation Mrgaśiras (Delta Orionis) to the next previous constellation Rohiṇī (Alpha Tauri) and again backward to Krittikā (Eta Tauri) in the course of time. But no measurement of it was made. Precession was not apparent during the time of astronomer Āryabhaṭa (AD 499), since at that time the first point of Aries coincided with the equinox. However, later astronomers noted it and also measured its rate. The first Indian astronomer who gave a rule for finding the value of precession seems to be Devācārya, who, in his *Karaṇaratna*, I.36 (AD 689), gives the rate of precession, which works out to 47 s per annum. The magnitude of the precession, called *ayana-amśa* (degrees of precession), of a celestial body would be the angular distance between its

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computed longitude and the first point of Aries on the zodiac (which Hindu astronomy takes as fixed).

Hindu astronomers did not conceive the shifting of the equinoxes as a continuously regressing phenomenon, which it really is. They understood it as an oscillatory motion, with the beginning of the Kali era (3102 BCE) as the “zero-precession year,” when the Sun and other planets were at the first point of Aries (Āśvinī), i.e., at the end of Zeta Piscium (Revatī). According to the *Sūryasiddhānta*, an oscillation of amplitude 27° to and fro would take 7,200 years to complete. Thus, during the first 1,800 years, the equinox moved forward by 27°, and during the next 1,800 years, it moved backward, coming back to the zero position at the end of the Kali year 3,600 (which corresponds to AD 499, when Āryabhaṭa composed his work *Āryabhaṭīya*). It will continue to regress for 1,800 years more, till AD 2299, when its forward motion for 1,800 years would commence, again reaching the zero position at the end of 7,200 years, covering, in all, 108°. Certain other texts, such as the *Karaṇaratna* and *Vākya-karaṇa*, take the amplitude of the oscillation as 24°, the period for one complete oscillation being 7,380 years. Among Indian astronomers, it was only Muñjāla (AD 932) who conceived precession as a continuous motion.

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Prehistoric Copper Mining in Botswana

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Copper has been mined in northeastern Botswana for about 1,200 years with particularly intensive mining during the fifteenth through seventeenth centuries and again in modern times.

Copper chemistry

Element: Cu			
Sulfides: covellite (CuS), chalcocite (Cu ₂ S), chalcopyrite (CuFeS ₂), bornite (2Cu ₂ S·Cu ₃ FeS)			
Oxides: Carbonates, etc.			
Carbonates	Malachite (green)	Cu ₂ CO ₃ (OH) ₂	57.3 % Cu
	Azurite (blue)	Cu ₃ (CO ₃) ₂ (OH) ₂	55.0 % Cu
Oxide	Cuprite (purplish red)	Cu ₂ O	88.8 % Cu
Silicate	Chrysocolla (turquoise)	CuSiO ₃ ·2H ₂ O	37.9 % Cu
Smelting point of carbonates: 700–800 °C			
Melting point of copper: 1,083 °C			
Notes:			
Oxide to copper is like rust to iron			
Sulfides become oxides usually at ground water level			
Prehistoric technology could not smelt copper silicate nor sulfides			
The main copper oxide mined was malachite			
Smelting of malachite: 700–800 °C + reducing agent (carbon from charcoal) + oxygen			
At that temperature, carbon and oxygen produce carbon monoxide (CO), which reacts with malachite to produce copper (solid state):			
Cu ₂ CO ₃ (OH) ₂ + 2CO = 3CO ₂ + H ₂ O + 2Cu			
Copper only melts to liquid at 1,083 °C and can then separate from slag			

Geology

The copper deposits occur in greenstone belts and shear zones of the Zimbabwe Craton. This craton is part of the Archean basement that forms the core of the southern African subcontinent and it stretches across Zimbabwe and northeastern Botswana. Consisting predominantly of granite

and gneiss (c. 75 %), there are also relatively smaller, irregularly shaped areas of metamorphosed volcanic and sedimentary “greenstone” rocks, where hydrothermal fluids coming up through fissures introduced minerals such as copper and gold. Upon cooling, the fluids formed mainly quartz veins on which the metal sulfides precipitated out. A later period of faulting and shearing along the edges of the craton, both within these greenstone belts and the granites, often on contacts, redistributed the minerals and added further enrichment from hydrothermal mineralization. Of the 148 ancient copper workings listed by Summers (1969), all but 16 are found in greenstone belts or shear zone contacts with granite/gneiss. Of these, 59 are located in Botswana and these are the focus here.

Location of the Copper Mines

Summers’ list was drawn up from reports by European prospectors from the 1870s onward for whom the “ancient workings” were important indicators of ore and, with two exceptions, all modern copper prospecting and mining in north-eastern Botswana was initiated by the presence of prehistoric copper mines. Table 1 is an updated list of known prehistoric copper mines in Botswana and their locations are shown in Fig. 1. Apart from the substantial Selkirk Mine, mines in the Tati Greenstone Belt and the Magogaphate Shear Zone were small, but there was a major copper belt between Francistown and the Sua Pan in the Matsitama Greenstone Belt and the Bushman Shear Zone. No ancient workings are known in the rich copper deposits of northwestern Botswana, which were largely covered by Kalahari sands.

Archaeological investigations of the prehistoric copper mines started in the 1990s with impact assessments and mitigation excavations as requirements for modern mine projects. Particularly archaeological mitigations at Thakadu and the Dukwe Mines have increased our knowledge of prehistoric mining and smelting.

The Matsitama Copper Mines

The Matsitama Metasedimentary Group of rocks has a complex history of formation, metamorphism, and deformation, such that the copper mineralization at surface is patchy throughout this large area, which is reflected in the dispersed distribution of small prehistoric mines (Fig. 1; Molyneux and Reinecke 1983).

An exception is the Thakadu Shear System, dominated by a major fold, where copper mineralization is distinctly linear and has been mined by more substantial mines, from southeast to northwest: Thakadu, Peolane, Noko, and Makala Mine, with Logolo and two smaller mines parallel to the north.

Thakadu Mine

Thakadu Mine is at the hinge of the fold, where the sequence of rock formations including the ore zone was folded back on itself. This was mined through, what appeared at surface to be, a double row of pits, overall 180 m long and 10–30 m wide (Fig. 2). After excavation in four pits, Huffman et al. (1995) concluded that these were shafts, but findings at the Dukwe Mines now suggest that they are likely to have been two adjacent, long, narrow open stopes. The other mines west of Thakadu are on the north arm of the fold and consist at surface of a single line of pits, while the south arm is subsurface due to a southward dip and was not mined.

The excavations reached to 3.5–5.75 m into the mine, but it is not known how deep the mine went. The ore was mined away with iron gads and hammerstones, after which the copper oxides, mainly malachite, were cobbled off.

Water Tank Smelting Site

The malachite was smelted in simple pit furnaces away from the mine. A set of four such features was excavated c.130 m from the Noko Mine (Huffman et al. 1995) and the slag analyzed (Eric et al. 1995). They are bowl-shaped pits, 40 × (50–60) cm at surface and dug 25 cm into the pebbly ground with a tuyere port at each end. Tuyeres are trumpet-shaped clay pipes that direct the air from the bellows (itself of wood and/or

Prehistoric Copper Mining in Botswana, Table 1 Prehistoric copper mines in Botswana

Mine name	Type of mine	Number	Size (m)	Depth (m)	Copper minerals	% copper	Associated metals	Lithology	Associated features/artifacts	Associated sites
Tati Greenstone Belt										
Phoenix NiCu (former Mound Struck)	Mine	1			Malachite, chrysocolla	0.8 0.6–0.85	Ni, Ag, Fe Ni 1.1–2.05 % Ni:Cu = 1.7–11.3	Gossan outcrop. Oxides to 18 m BS Strongly sheared amphibolite		2 ore processing sites 4 small smelting sites 2 sites with Cu bangles
Penhalonga [17-B3-84]	Surface pits	>1	Substantial		Malachite, azurite		Au, Pb	Veins to 40 m long. Gossan		1 smelting site
Unnamed [17-B4-39]	Pit	1	4 × 3	1	Malachite		Au		Dump around pit 0.5 m high	1 ore processing site 5 smelting sites
Unnamed [17-B4-59]	Pits	3	8–10 diam	1–3	Malachite		Au, Ni?			1 ore processing site 1 smelting site
Tati Greenstone Belt – Kgarimacheng Formation										
Kgarimacheng West		3						Contact with gneiss		
Kgarimacheng		>1					Ni			
Selkirk Formation										
Selkirk [17-B3-3]	Parallel open stopes; pits	5 3	each (10–23) × (4–5) pit c: 5 × 4 pit e: 10 × 7 pit f: 12 × 7		Malachite, chrysocolla native Cu	To 15 Overall 0.8	Ni 0.9 % Ni:Cu = 1–1.6 Ag; Fe (the latter mined?)	Gossan outcrop on hill, above massive sulfide	Slag, hammerstone	Selkirk Ruin 1 ore processing site 9 smelting sites within 4 km, 1 at 7.5 km
Giraffe [17-B3-67]	Underground workings Pits	3 3	Substantial		Malachite		Au	In quartz vein 20 × 0.3 m		1 ore processing site 2 smelting sites
Motloutse gneiss										
Motloutse		>1						Sheared gneiss		
Motloutse		>1			Malachite			Gossan outcrop		
Magogaphate shear zone										
Tsutsumane S		1								
Tsutsumane E		1								

(continued)

Prehistoric Copper Mining in Botswana, Table 1 (continued)

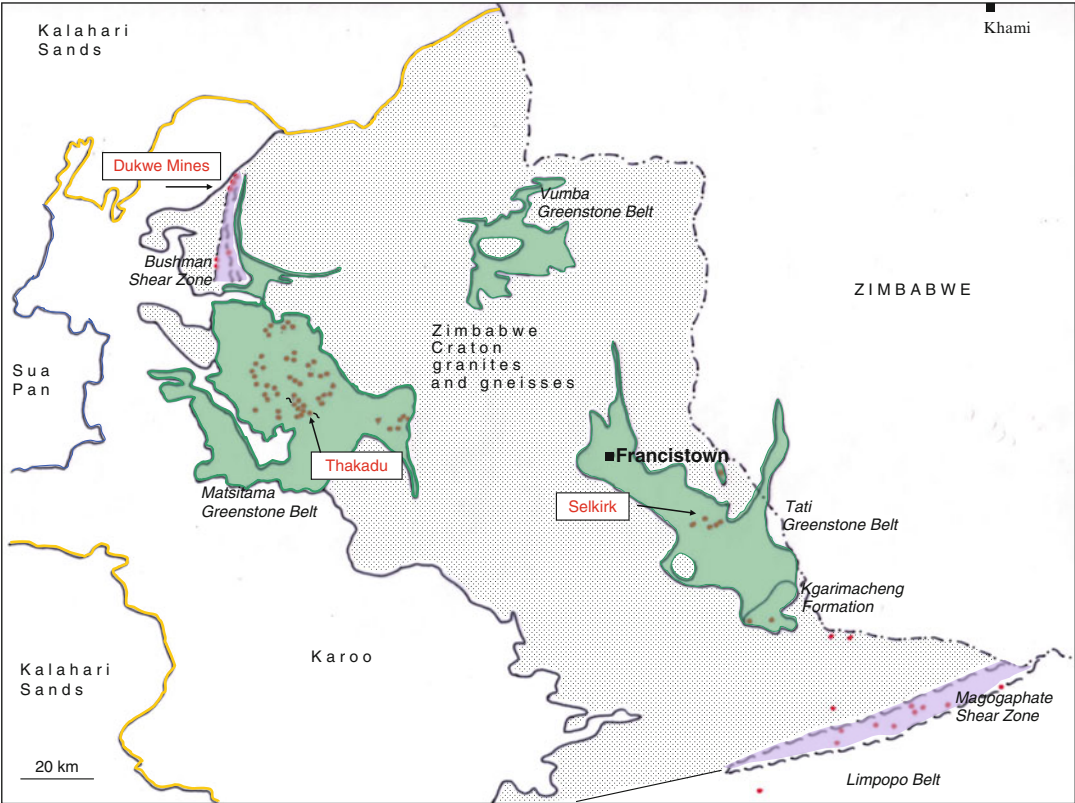
Mine name	Type of mine	Number	Size (m)	Depth (m)	Copper minerals	% copper	Associated metals	Lithology	Associated features/artifacts	Associated sites
Molabe		1						Gneiss		
Mokoswane		1								
Majante		1								
Magogaphate (MO19)		2					Ni 0.7 %, Au	Small gossans; serpentinites, amphibolites		
Magogaphate NW (MO16)	Pits	6	1 at 30m long				Au	Amphibolite and granite		
Maibele N (Group A)	Pits	Many	1 at 4 × 5m 1 at 7 m diam., 1 at 5 m diam.			High	Ni, Au	Gossan outcrop, amphibolite	Low rubble dumps	
Dibete		1								
Motojwane							Ni			
Limpopo Belt – gneiss										
Phikwe		>1	Small			Overall 1.09–1.14 %	Ni 1.13–1.45 %	Gossan outcrops Amphibolite in gneiss		
Matsitama Greenstone Belt – Thakadu shear zone										
Thakadu [16-B2-1]	Large open slope complex (c. 22 surface pits)	1	180 × (10–30)	>6	Malachite chrysocolla, cuprite, tenorite native Cu	Overall 2.5–4.5 %	Fe	Siliceous limestones, quartz-schists, and phyllites	Low rock waste dumps: hammerstones, pot, bloom, gad Cu earring	c. 16 smelting sites (3 registered)
Makala [16-B2-4]	Line of pits	4	50 × 10	Shallow		Overall 1.95–2.1 %	Traces Zn			5 smelting sites
Logolo [16-B2-5]	Pit	1	30 × (5–10)	2		Overall 1.8–2.6 %				1 smelting site
Peolane [16-B2-2]	Line of pits	2 large, 5 small	total 100 × 15	3		–2.61			Rock waste dumps	3 smelting sites, incl. Water tank
Noko	Line of pits	4 pits	total 15 × 5	1.5						furnace site: 4 pit furnaces
Matsitama Greenstone Belt										
16-B2-6	Pit	1	30 × 15	2					Low dump	2 smelting sites
16-B2-20	Pits	2	a. 25 × 15 b. 15 × 10	1 1					Low dumps	2 smelting sites

16-B2-25	Pit	1	10 × 6	2.5	Malachite	<1 %			Malachite	Overall 2 %	Mainly Fe mines specularite, ochre	Quartzites, arkoses, iron formations	Low dumps
Nakalakwana Ridge [16-B2-26]	Pits	>8	Extensive		Malachite				Malachite		Mainly Fe mine	Lower slopes 1	Low dumps
Nakalakwana Hill	Mines	2	Extensive		Malachite				Malachite		Mainly Fe mines specularite, ochre		
Nakalakwana Prospect	Mines	3	Extensive		Malachite				Malachite		Mainly Fe mines		
Dihudi	Mines	3									Ag, Pb, Z		
Lengau	Mines	4			Malachite				Malachite				Pot
Palamela	Mine	1											
Agente	Mine	1											
Lepashe	Mines	3											
Mutsuku	Mines	3											
Mutsuku E	Mine	1											
Kukama	Mines	3											
Kamela	Mine	1											
Dihudi	Mine	1											
Sebotha	a. Surface pit b. Steep narrow open stope	1 1	Big										
Samsongo	Mine	1											
Lengau	Mines	4											
Esoka	Mine	1											
unnamed	Mines	19											
Bushman Shear Zone													
Matokojwe (former Bushman Mine) [06-D1-3]	Large open stope complex (> 23 surface pits)	2 stopes	W stope: 150 × (3–15) E stope: 210 × (2–25) Total: 360 × (2–25)	>34	Malachite, chrysocolla minor: cuprite, azurite, bornite, native Cu	>5 % in places to 34 %	Pb, Fe, some graphite	Quartz-calcite and carbonaceous breccias in limestone Oxides to 20–70 m dip 70–80°	Surrounded by substantial dumps; hammerstones, gad, pot, bone	15 smelting sites 0.4–2.1 km distance			

(continued)

Prehistoric Copper Mining in Botswana, Table 1 (continued)

Mine name	Type of mine	Number	Size (m)	Depth (m)	Copper minerals	% copper	Associated metals	Lithology	Associated features/artifacts	Associated sites
Dukwe Mine South (former Mapanipani) [06-D1-4A]	Large open slope complex (10 surface pits)	2 stopes	E stope: 118 × (2–14) W stope: c.68 × (4.4–10) Total: 186 × (2–14)	>27	Malachite, chrysocolla minor: cuprite, azurite, bornite, native Cu		Fe, graphite also mined	Quartz-calcite and carbonaceous breccias in limestone and argillites	Surrounded by substantial dumps; hammerstones, gads, pot, bone	1 ore processing site 1 smelting site at 0.4 km
Dukwe Mine North (former Mapanipani) [06-D1-4B]	Large open slope complex (14 surface pits)	3 stopes	Main stope: 126 × (3–9) NW stope: 27 × (3–10) SE stope: 19 × (3–4.5) Total: 172 × (3–10)	>8	Malachite, chrysocolla minor: cuprite, azurite, bornite, native Cu	Overall >2 %	Fe, graphite also mined	Quartz-calcite and carbonaceous breccias in limestone and argillites	Surrounded by substantial dumps; hammerstones, pot, bone	7 smelting sites 2.8–7.4 km distance
Matunga (former San Toy claims) [06-D1-10]	Line of pits: main group S group	6 3	Total: 75 long (5–18) × (5–20)	1–3	Malachite, chrysocolla, cuprite, chalcocopyrite	>1 %		Sheared quartzite surrounded by mylonites and siliceous breccias	Surrounded by dumps, 1 m wide, 0.5–1 m high; hammerstone	Malokojwe Ruin + terraced site; 4 smelting sites
Sinti (former Nondu claims) [06-D1-11]	Pits	7	Small	Shallow		Overall <1 %		Brecciated quartzite lenses in limestone and graphitic schists within sheared zone of granitoid mylonites	Surrounded by low dumps	Small walled site; 2 smelting sites
Phudulooga (former Outlaw claims) [06-D1-12]	Main group: pits over 280 m N group: pits S group: pits	17 3 5	a. 40 × 15 b. 30 × 20 c. 10 diam rest 5–10 diam 1 large, 2 small	1 4 4 1–1.5		Overall <1 %		Brecciated quartzite lenses in limestone and graphitic schists within sheared zone of granitoid mylonites		



Prehistoric Copper Mining in Botswana, Fig. 1 Prehistoric copper mines in northeast Botswana



Prehistoric Copper Mining in Botswana, Fig. 2 The east end of Thakadu Mine

leather and not preserved) into the fire. The furnaces were oriented east–west and spaced 1 m apart. They had no superstructure and had become filled with ash, charcoal, tuyere fragments, and slag, while ore, malachite chips, copper wire, some pottery, and animal bones were found in association.

Fayalite-like dendrites in the slag, visible under a scanning electron microscope, indicate that temperatures of 1,200 °C may have been reached in these furnaces, accounting for the presence of almost pure copper beads formed at the melting point of copper (1,083 °C). Some of the copper only reached a semiliquid state, however (Eric et al. 1995).

Four charcoal dates from the mine and two from the furnaces indicate that mining took place in the period c. AD 1480–1670.

Copper Mines in the Bushman Shear Zone

To the northwest of the Matsitama copper belt, a major fault occurred in the granites, visible at surface by a low range of mylonite hills and exposure over about 60 km, trending north-northeast. The associated shear zone includes two relics of metasedimentary rock, which became brecciated and mineralized with copper. In the southern relic are the Phudulooga and Sinti Mines and nearby the Matunga Mine, while in the northern mineralized zone are three large mines, from south to north: the Malokojwe Mine, Dukwe Mine South, and Dukwe Mine North, together referred to as the Dukwe Mines. The three mines consist of a number of features, which when combined are over 700 m long and range in width from 2 to 25 m (Table 1). The ore body was explored underground from 1902 to 1913 by the Bechuanaland Copper Exploration Company, and Malokojwe, then also known as Bushman Mine, was mined from 1914 to 1918. The European miners had encountered prehistoric workings at Malokojwe still at 100' or c. 30 m BS (below surface), going deeper yet, making this the deepest known prehistoric open stope copper mine within the Zimbabwe Craton area.

The Dukwe Mines Project

African Copper Plc was given permission to mine these deposits further through a large open pit which would destroy the three main prehistoric mines, on condition that these would be excavated and documented in detail as mitigation. While major prehistoric copper mines in Zambia, Zimbabwe, and South Africa had already been destroyed by modern mining with little or no documentation, here was a last opportunity to study such a mine complex. This mitigation project has been ongoing in tandem with the deepening of the modern mine, and a number of smelting sites have also been excavated.

The breccias, which host the copper, are largely quartz, calcite, and jasper with varying amounts of graphite; the latter was also mined as pigment to decorate pottery. The ore zone is enveloped in limestone to the east and argillites to the west. Except for presumed surface outcrops of ore, the whole area was covered under a blanket of 1–2 m of black cotton soil, a vertisol, which is loose and crumbly when dry, but sticky when wet. The prehistoric miners removed and dumped this adjacent to the mines along with rock waste, from where it was readily washed back into the mine. As a result the mines were found filled largely with mixed secondary waste deposits with a high black cotton content, with only here and there more packed rock waste that might indicate purposeful back-filling from an adjacent area. Mitigation excavations, therefore, concentrated more on exposing the mine walls rather than analyzing the fill. Excavation of the mines was largely done by backhoe machine with the finer details done manually.

Mining

As the mineralized breccia occurred from surface in elongated lenses with near-vertical dip, the ore was mined through long open stopes (Figs. 4 and 5), although these led also to two underground stopes. Mining was done with iron gads and hammerstones and, where the rock was especially hard, by setting fires and quenching them with water (possibly brought in the pots of which fragments were found in the mines). The long



Prehistoric Copper Mining in Botswana, Fig. 3 Dukwe Mine North, test trench through pit and dump exposed the mine wall and fill

Prehistoric Copper Mining in Botswana, Fig. 4 Dukwe Mine South excavations at 2–5 m below the original surface, viewed from the south



P

stopes were segmented where hard rock with low copper value was left. Backfill and erosion into these segments gave an appearance at surface as shallow pits surrounded by dumps (Fig. 3), similar to Thakadu.

In addition to open stopes and the two underground stopes, there were quite a number of small

prospecting shafts. These were cylindrical, just large enough for one, at most two miners and sunk vertically from surface to depths of 3 to over 5 m BS. They were found especially in areas where the ore seems to have been lost. Where ore was found, this was stoped away and in many cases the main open stope enlarged to incorporate these.



Prehistoric Copper Mining in Botswana, Fig. 5 Plan view of Dukwe Mine South. Brown = surface dumps; blue 2-5 m below surface (BS), green 13-15 m BS, red 25-27 m BS

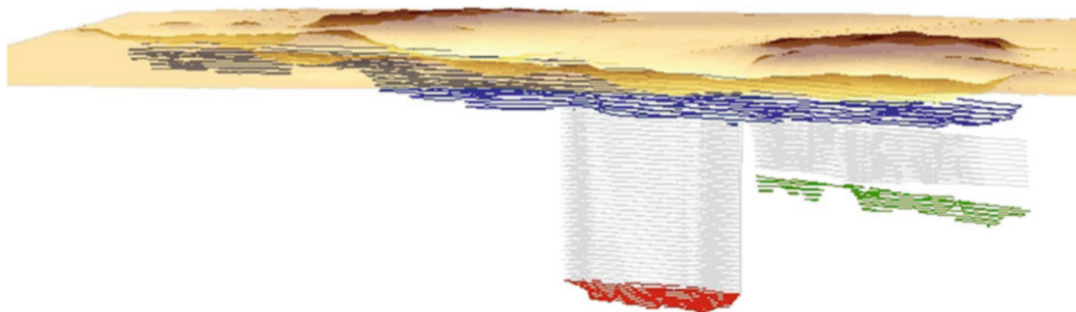
The Dukwe Mine North is known to have been at least 8.5 m deep, but less than 15 m. For Dukwe Mine South, documentation reached a depth of 27 m and the mine was still deeper, but at 35 m BS recent mining had disturbed the area. Figure 6 is a reconstruction of this mine. At Malokojwe the 35 m BS level is still to be tested, but parts of the mine were encountered at 23.5 m BS.

Volumes of ore mined are still to be determined, but initial estimates are given in Table 2. The ore was sorted in the mine and then cobbled further on the waste heap with hammerstones and only high value copper oxides taken to be smelted.

Smelting and Smithing

Smelting sites were located 0.4–7.4 km from the mines outside the black cotton soil area. These typically were in a clearing in the mopane forest near a water hole, with one or more small houses and a livestock enclosure. Ore preparation, smelting, and smithing took place right in the yard.

Small flakes of malachite were chipped off the ore, probably with a knife, and only this concentrated malachite smelted, so little slag was produced. Smelting was done in pit furnaces like at the Water Tank Site at Matsitama, but smaller and simply dug into the soil, not into a stony



Prehistoric Copper Mining in Botswana, Fig. 6 Model of Dukwe Mine South, viewed from the west. Brown = surface dumps; blue 2-5 m below surface (BS), green 13-15 m BS, red 25-27 m BS

Prehistoric Copper Mining in Botswana, Table 2 Preliminary estimates of ore production

Mine	Number	Stope/pit sizes (m)			Estimated volume (m ³)	Approximate tonnes of ore (volume × 2.8 SG)	Total estimated tonnes of ore
		Length	Width	Known depth			
Malokojwe	1	360	2–25	5 ⁺ –30 ⁺	79,560	222,770	
Dukwe Mine South	1	186	2–14	5 ⁺ –27 ⁺	23,800	66,660	
Dukwe Mine North	1	172	3–10	5 ⁺ –8 ⁺	7,220	20,230	
Sub-total Dukwe Mines							309,600
Matunga	1	75	5–20	3 ⁺	2,700	7,500	
Sinti	7	?				?	
Phudulooga	1	14	15	1 ⁺	210	590	
	1	30	20	4 ⁺	2,400	6,700	
	15	5–10	5–10	1 ⁺ –4 ⁺	2,200	6,200	
Sub-total Phudulooga						13,490	
Sub-total Bushman Shear Zone South							21,000
Total Bushman Shear Zone							330,600
Thakadu	1	180	10–30	5 ⁺	18,000	50,400	
Total Matsitama Greenstone Belt							100,000
Total Matsitama-Bushman SZ copper belt							430,600

Assuming average c. 5 % Cu and 2/3 efficiency in extracting the copper, then 430,600 tonnes of ore would be estimated to have produced 14,353 tonnes of Cu

substratum. These are associated with ash, charcoal or charred wood, sinter with prills of copper, tuyere fragments, and domestic waste. Temperatures reached in these furnaces appear to have been high enough to smelt the ore, but not to melt the copper to liquid and separate it from the slag.

One site had a different type of furnace, made with quartz stones, which had been cracked by fire, and many had become coated on one side with slag. These furnaces had been broken open to remove the copper; hence we do not know the size or shape and we found no pit or burnt area associated. Slag-coated stones were also found on two sites near the Matunga Mine further south and on three sites probably associated with the Selkirk Mine east of Francistown, as well as on sites associated with the Messina

copper mines in the Limpopo Valley in South Africa, where such furnaces had been used in the nineteenth century by Lemba smiths who lived among the Venda (Küsel 1974, p. 247; Stayt 1931, Chapter VI).

These two types are both primary furnaces as both are associated with ore and malachite. The stone furnaces may have reached higher temperatures due to heat retention by the stones, so that copper reached the liquid phase; they may also have produced more copper per smelt. Analysis is ongoing.

No ingots or ingot molds were found, but production specialized in the manufacture of wire by drawing heated copper through successively smaller holes in an iron plate. This was made into bangles of fine wire coiled tightly around a grass or hair core, similar to bangles

made of iron, bronze, and even gold in this region.

Dates

No dates are yet available for the smelting sites and the pottery is insufficiently diagnostic to be certain of the time period. Elsewhere Early Iron Age potsherds (c. ninth century) were found associated with ore, tuyeres, and slag. There is also one site with historic glass beads and bottle glass (c. AD 1900), associated with tuyeres and ore, pottery, and stone tools. Charcoal from the lower levels of a dump of the Dukwe Mine North was dated to c. AD 1300, but there are five dates from in situ charcoal associated with fire setting in the mines from the period c. AD 1480–1670.

Culture-Historical Context

The bulk of the mining in the three large Dukwe Mines and at Thakadu took place when this area was part of the Kalanga State Butua and the capital was at Khami, 100 km to the east near modern Bulawayo in Zimbabwe (Van Waarden 2012). The Malokojwe Ruin on the hills of the Bushman Shear Zone, 12 km south of the Dukwe Mines, may date to this period and was likely the residence of a chief who may have controlled the copper industry.

Much copper as well as bronze was found at Khami, and the Dukwe-Matsitama copper belt was the main source within the state at that time (Summers 1969, p. 112; Van Waarden 2012, pp. 229–233). Copper was traded regionally as wire to make jewelry and even ordinary people were found buried with a bangle or two; bronze bangles were reserved for elite and gold bangles only worn by royalty. This reflected prestige and signaled class distinctions.

Who were the miners? Today the area is inhabited by Khoe (80 %), Kalanga (6 %), and Ngwato (12 %). The latter arrived here in the nineteenth century, but the history of coexistence and trade between Khoe from this area and Kalanga further east probably dates back to the tenth century and continued to the 1980s. Research continues to determine whether Khoe and/or Kalanga mined the copper.

At the end of the seventeenth century, the ruler at Khami was overthrown, the palace burnt down, and the new ruler established the capital 100 km further east at Danangombe, extending the state and including in his sphere of influence the copper mines of central and northern Zimbabwe. This coincides with the end of large scale copper mining in Botswana. It is also possible that the mines had been exhausted of suitable copper oxides and the water table reached.

Analysis of the findings at the Dukwe Mines is still ongoing. Particularly the questions around the two types of furnaces and the ethnic identity of the miners are intriguing.

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Printing and Dyeing in India

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Defining India

India as we know it today has existed only since 1947; prior to that date, much of South Asia was part of the British Empire and “British India” (1858–1947) included the modern countries of India, Pakistan, and Bangladesh. The Indian Independence Act (1947) integrated territories under direct British rule and the princely states under the suzerainty of the Crown and established the sovereign states of India, Pakistan, and East Pakistan; the latter subsequently became Bangladesh after secession from Pakistan in 1971. Thus, some of the historical discussion that follows refers to the Indian subcontinent as a whole while more recent material refers to modern India only.

Early Textile Production

Indian textile technology, notably the cultivation, processing and weaving of cotton, and the production of fast colors, led the world from at least the second millennium BCE. The first urban civilization in South Asia developed in the Indus Valley between ca.2600 and 1700 BCE and extended over a region that included parts of northwest India and Pakistan. Named Harappan Culture after the site of Harappa in Punjab Province, Pakistan, this early civilization traded with ancient Mesopotamia and Egypt, and among its exports were cotton textiles. In the early twentieth century, archaeologists retrieved reddish-colored cotton fibers that appeared to have been dyed with madder from the site of Mohenjo Daro in Sindh Province, Pakistan (dated 1750 BCE). As madder requires a mordant, this discovery implies that Harappan dyers were familiar with the technology of using metallic salts, such as alum, chrome, iron, tin, and copper, to permanently fix colors to fiber. Pliny provides the earliest description of mordants in use in Egypt in the first century CE and notes that after boiling in a single dye bath, fabric treated with mordants emerges multicolored and with colors that are fast (1957, p. 283). It is almost certain that the technology had transferred to Egypt from India as a result of trade via the Arab Sea.

Beyond these technical accomplishments, Indian artisans came to excel at patterning cloth using colorfast dyes. Their expert manipulation of mordants and a range of natural dyes that included indigo, madder red, and iron paste (which when used in conjunction with tannin oxidizes to produce black) enabled them to produce a wide spectrum of colors and shades. Apart from the simple dyeing of yarns and fabric, they harnessed the technology to decorative techniques, including resist patterning such as tie-dye and batik, as well as hand painting and block printing. The latter technique required coordination of several engraved wooden blocks or stamps to build up a multicolored pattern on cloth using mordant pastes and resist media such as mud, wax, or lime and gum paste.

International Trade

Indian dyers and printers became adept at responding to the demands of a varied clientele and produced patterns for any market, be they for the refined tastes of royal patrons, ceremonial purposes, or everyday use by the general populace. India was a significant entrepôt for early international trade; a log written by a Greek-speaking Egyptian merchant reports on the scale of maritime trade in the first century CE between India and Egypt, listing indigo, cotton cloth, fine cotton garments, silk, and yarn as among the exports from the port of Barygaza (modern Broach) in western India (Casson, 1989, p. 16). By the medieval period, Indian artisans were supplying dyed, painted, and block printed cottons along with other textiles across a vast network that extended from the Mediterranean to Southeast Asia and China via the maritime trade routes of the Indian Ocean and the overland routes of the Silk Road. The main centers for printing and dyeing were in western India and along the Coromandel Coast.

1. The oldest surviving Indian textiles are fragments of dyed, painted, and printed cotton trade cloths that were exported from western India to Egypt. Numerous pieces were retrieved from Fustat near Cairo, a selection of which have been radiocarbon dated to ninth to sixteenth centuries. Several of the fragments from Egypt show remarkable similarities to ninth to sixteenth century Indian textiles found in Southeast Asia, preserved in Toraja, central Sulawesi, as heirloom cloths used for ceremonial purposes (Guy, 1998, p. 51). Indian textiles were central to the exchange mechanisms of the spice trade. The painted and printed cottons that became known as “chintz” (from a northern Indian term *chint* meaning “to sprinkle or spray”) were bartered for much sought-after spices such as cloves, nutmeg, and mace from the Spice Islands of eastern Indonesia and pepper from Sumatra and Java. It was spice that first lured Europeans to India and Southeast Asia in the early seventeenth century; already highly

organized, the trade was dominated by Indian merchants from Gujarat, Arab, and Chinese traders. Initially, the Portuguese, British, and Dutch merchants were unable to break the existing monopoly, but eventually, a triangular trade developed, led by the English and Dutch East India Companies. The Europeans paid bullion for Indian cottons which they then exchanged for spices in Indonesia. It was this mechanism that introduced chintz to Europe. Designs were adapted to suit European tastes, and the multicolored Indian cottons which were light to wear and far easier to launder than the heavy woollens and linens of local production, gradually became all the rage, used extensively for fashion and soft furnishings. By 1664, textiles accounted for three-quarters of the exports from India (Crill, 2008, p. 15). But despite the evident popularity of Indian chintz, by the late eighteenth century, it had been banned in several northern European countries for fear that indigenous woollen, flax, and silk industries were being fatally undermined. The prohibition and the birth of industrialization eventually led to the decline of Indian chintz in Britain, and by the end of the eighteenth century, the trade had all but vanished. Another notable category of piece goods exported by the East India Companies were tie-dyed handkerchiefs or bandanna (from *bandhana*, the Sanskrit for “tying”). They were a popular accessory in Europe, the USA, and the Caribbean, serving as neckties, scarves, and head wraps (Crill & Murphy, 1991, pp. 125–130).

Domestic Market

Indian dyers and printers catered for global and home markets. Domestic products could be as diverse as those for export, covering the needs of the royal courts, temples, and mosques, as well as the mass populace. During the Sultanate period (1206–1526) and the classic period of the Mughal Empire (1526–1857), legions of craftspeople were employed in the imperial workshops, or *karkhanas*, producing textiles, metal work,

wood carvings, and paintings for the their royal patrons and members of the court. An inkling of the glories of Mughal textiles may be gleaned from the *Ain-i-Akbari* which chronicles the reign of the Emperor Akbar (1526–1605) and includes inventories of textiles and garments held in the *toshkhana* or imperial store (Allami, 1989). Mughal period block prints, many of which survive in museum collections in India and the West, were made for use as floor coverings, tent panels, upholstery, coverlets, drapes, hangings, wrappings for the *Quran*, and of course, dress. Stylistically, they reveal a strong Persian influence marked by a preponderance of small floral and botanical motifs repeated over the cloth. Several types of fabrics were printed, including finely woven cottons and silk which might be further enhanced by “tinsel printing” whereby an adhesive paste known as *rogan* was stamped on the fabric to which gold or silver leaf was adhered (Fig. 1). Block printers also

stamped fabrics for the multifarious communities or castes of India and provided domestic textiles such as floor covers and quilts, as well as votive textiles used in private and communal worship. Block prints and tie-dyes played a role, too, in the creation of individual visual identity; the use of particular designs for dress was determined by caste, gender, age, and marital and even economic status (Edwards, 2007, pp. 179–197). Tie-dyed designs were worked on a variety of fabrics, from robust motifs on a rustic veil cloth or skirt of coarse *deshi* (local) wool to minutely worked patterns on blouses and saris of Chinese silk (Fig. 2). Tie-dyed textiles remain an essential item of women’s wedding dress, in red, green, or yellow, which are deemed auspicious; their popularity transcends caste and class. Although caste dress has largely disappeared from urban India, it still prevails in the rural areas where the pattern tie-dyed on a woman’s skirt or printed on a man’s turban cloth pinpoints their membership of



Printing and Dyeing in India, Fig. 1 Contemporary “tinsel printing” @ Ahmedabad, 2012



Printing and Dyeing in India, Fig. 2 Tie-dyed woollen veil cloth worn by Rabari women in Kachchh, Gujarat



Printing and Dyeing in India, Fig. 3 Faux tie-dye block printed turban worn by a Rabari in Kachchh, Gujarat

a specific hereditary occupational community (Fig. 3). However, the industrialization of textile production in India (late nineteenth century) and innovations in textile and dyeing technologies such as the introduction of synthetic dyes (late nineteenth century) and screen printing (early twentieth century) undermined the market for tie-dyed and block printed textiles, especially those produced using natural dyes. Popular preference for cheaper, screen printed copies of traditional block prints and tie-dyes meant that by the mid-twentieth century, the original crafts were moribund.

Craft Revival

Determined to establish India as a major force in the new world order that had emerged after the

World War II, Jawaharlal Nehru, the country's first Prime Minister (1947–1963), launched a cultural and economic revival in which the resurrection of Indian craft was to be a key component. Regeneration was initially handled by national agencies including the All India Handicrafts Board (founded 1952), the National Crafts Museum (1956), the National Institute of Design (1961), and state-level craft organizations (1970s onward). Initiatives included a rolling program of exhibition-cum-sales in the cities of India and artisans' participation in cultural festivals overseas (e.g., the *Festival of India* in the USA, 1985–1986) and crucially the development of new products suitable for the urban and overseas markets that were a result of collaborations between professional designers and traditional craftspeople. Although the traditional local market has been overtaken by cheap, mass-produced polyester textiles from the factories of Surat and Mumbai, tie-dyeing and block printing have rallied in some areas. From the 1970s onward, clusters of printers and dyers adapted traditional products and found niche markets for them. The use of natural dyes stabilized although it was not widespread, most printers and dyers preferring the convenience of synthetic dyes. More recently, the spending power of India's burgeoning middle class has seen a sharp rise in the domestic consumption of handmade textiles, especially by urban elites; similarly, the influence of the global "slow fashion" movement and consumer concerns about environmentally friendly production have all served to support the viability of tie-dyeing and block printing.

Centers of Block Printing and Dyeing

Historically, block printing was practiced across the breadth of the subcontinent; tie-dyeing was found primarily in western India, notably Jamnagar and Kachchh district in Gujarat, and Rajasthan; this is still the case. Major block printing centers emerged under the patronage of the Mughals, the British, and the regional courts; of note were Jaipur and environs in Rajasthan,



Printing and Dyeing in India, Fig. 4 Detail of block print at Jaipur, showing typical Rajasthani *buti*

Ahmedabad, Deesa, and Kachchh district in Gujarat, Machilipatnam, and other centers in coastal Andhra Pradesh. Jaipuri production was admired for the variety of its small *buti* (bud) motifs, created by printing mordant pastes of alum and iron, followed by dyeing in madder or alizarin, a technique known as *syahi begar*. Rajasthani block prints have enjoyed a revival since the 1970s, largely down to the commercial success of the Jaipur-based company Anokhi which has played a major role in regenerating the craft (Kumar & Ronald, 2005; Fig. 4). Ahmedabad, long one of the most important commercial hubs of western India, was noted for indigo dyeing and the export of *baftas*, plain-dyed cottons, which appear in profusion in East India Company manifests, and also produced an enormous range of prints for local use as well as



Printing and Dyeing in India, Fig. 5 Detail of contemporary *ajrakh*. Kachchh, Gujarat, 2013

servicing the export market. *Saudagiri* (“trade goods” in Persian) textiles which featured small geometric motifs were exported to Thailand until the outbreak of World War II (Guy, 1998, pp. 150–151). The block prints of Kachchh, Gujarat, were made originally for domestic use and dress by the district’s herders and farmers; latterly, they have been adapted for contemporary urban use as fashion and soft furnishings. At the vanguard of the craft revival movement, the printers of Dhamadka and Ajrakhpur villages are known for block printing using natural dyes, notably for the production of *ajrakh* (derived from *azrak*, “blue” in Arabic), a resist-dyed and mordant-printed textile that is printed on both sides with complex geometric patterns (Fig. 5).



Printing and Dyeing in India, Fig. 6 Detail of contemporary *kalamkari*. Machilipatnam area, 2013

Worn chiefly by Muslim cattle herders in north Kachchh, it is related stylistically and technically to the medieval Indo-Egyptian trade cloths, evidence of which was found at Fustat near Cairo (Edwards, 2011, p. 14). Machilipatnam in south India is one of the few remaining centers for *kalamkari* printing. The term means “pen work” and derives from Persian, reflecting the technical roots of these textiles which were originally drawn and painted rather than printed – a tradition that persists in the temple town of Srikalahasti. Machilipatnam became a production and export hub for printed *kalamkaris*, notably to Persia. The trade had ceased by the twentieth century, but the influence of Persian design is evident in the elaborate florals, arabesques, and prayer niches that distinguish *kalamkari* prints. Refashioned as contemporary products, they have found new markets in urban India and overseas (Fig. 6).



Printing and Dyeing in India, Fig. 7 Chippa printer at work in Bagru, 2012

Hereditary Occupation

Like many occupations in India, especially in the craft sector, dyeing and printing are hereditary professions in India. Caste, a hierarchical system based on occupation and notions of ritual purity and pollution, was outlawed in the Indian Constitution (1950); however, it persists as a daily reality especially in rural India. Traditional knowledge was retained by particular castes, passed down from one generation to the next, and the secrets of dyeing and printing were closely guarded. In Rajasthan and Ahmedabad, printing is dominated by the Chippa caste while indigo dyeing is the domain of Chippa converts to Islam who are known as Rangrez (Figs. 7 and 8). Dyeing and printing in Kachchh, Gujarat, and



Printing and Dyeing in India, Fig. 8 Rangrez indigo dyeing cloth at Bagru, 2012



Printing and Dyeing in India, Fig. 9 Khatri printer at work in Dhamadka, 2013

western Rajasthan is a Khatri occupation; in Gujarat, most of the Khatri artisans are Muslims, while in Rajasthan, they are Hindus (Fig. 9). In contrast to this pattern of hereditary occupation, block printing in Machilipatnam, Andhra Pradesh, is carried out by a caste of former weavers who took up the craft in the 1970's because of the decline of the handloom industry from the nineteenth century onward (Fig. 10).

Dyestuffs and Printing Blocks

Indian dyers were famous for their ability to produce fast blues, reds, and blacks. The classic Indian dyes were derived from plants and minerals, the foremost being indigo (*L. Indigofera*

tinctoria) and madder (*L. Rubia tinctorum*); *chay* (*L. Oldenlandia umbellata*) was an important source of red on the Coromandel Coast. Indigo, which still grows wild in many areas of the sub-continent, was a significant export for nearly two thousand years. From the seventeenth century onward, the British gradually assumed control of the export trade from the Mughals, supplied from the major processing centers at Biana near Agra and Sarkhej in Gujarat. Nowadays, production is much reduced and is limited mainly to south India where the chief sites are Tindivanam, Tamil Nadu, and Vallur district, Andhra Pradesh (Fig. 11). A good deal of contemporary indigo dyeing is actually done with the synthetic form (chemically identical to the real thing) which is widely known as "German indigo" in India,



Printing and Dyeing in India, Fig. 10 Printer at work near Machilipatnam, 2013



Printing and Dyeing in India, Fig. 11 Indigo harvest at Tindivanam, 2007

a legacy of its development and global marketing by the German company, Badische Anilin und Soda Fabrik (BASF), in the early twentieth century. Similarly, madder has been largely replaced by synthetic alizarin (Balfour-Paul, 1998, pp. 81–87).

Printing blocks are customarily made from seasoned hard wood. Formerly, locally grown varieties of teak were used but imported hard woods now supplement local supplies. The wood is cut to approximate size; the surface is planed and sanded by hand until it is perfectly smooth, after which it is painted white; and then, the design is marked out. Blocks are engraved by hand using specialist tools including pre-formed

punches and dies, a bow drill, and small chisels. The number of blocks required is determined by the number of colors and pattern elements featured in a textile design; a complex textile like *ajrakh* requires up to twenty-four individual blocks. Some blocks have a wooden base into which brass or copper strip is hammered to form the outlines of the design, allowing for a finer line to be printed; this type of block is used especially for silk printing. Enclaves of block carvers are used to be found at all the block printing centers, but as that craft has shrunk, they are clustered at Farrukhabad and Pilkhuwa in Uttar Pradesh, Jaipur in Rajasthan, Pethapur in Gujarat, and Pedana in Andhra Pradesh (Fig. 12).



Printing and Dyeing in India, Fig. 12 Block engraver at Pedana, 2013

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Probability in Non-Western Cultures

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The mathematical theory of probability begins with the theory of permutations and combinations, needed to calculate probabilities in games of chance, such as dice or cards. The earliest account of this theory is found in India. This theory is tied to the theory of the Vedic meter (and the theory of Indian music, in general).

The Vedic and post-Vedic composers used combinations of two syllables called *guru* (deep, long) and *laghu* (short). The earliest written account of this theory of meter is in Piṅgala's *Chandaśśūtra* (third c.CE), a book of aphorisms (*śūtra*-s) on the theory of meter (*chanda*). To calculate all possible combinations of these two syllables in a meter containing n syllables, Piṅgala gives the following rule (which explicitly makes use of the symbol for zero) (*Chandaśśūtra*, 1840): “(Place) two when halved;” “when unity is subtracted then (place) zero;” “multiply by two when zero;” “square when halved.” In a worked example, Dutta and Singh (1962) show how this rule leads to the

correct figure of 2^6 possibilities for the Gāyatrī meter with six syllables.

Piṅgala's commentator, the tenth century CE Halayudha, clarifies that this involves the binomial expansion. Thus, in a 3-syllabic meter with two underlying syllables, *guru* and *laghu*, 3 *guru* sounds will occur once, 2 *gurus* and 1 *laghu* will occur twice, as will 1 *guru* and 2 *laghus*, while 3 *laghus* will occur once. Symbolically $(g + l)^3 = g^3 + 3g^2l + 3gl^2 + l^3$. To generalize this to the case of n underlying syllables, Halayudha explains the *meru-prastāra* (pyramidal expansion) scheme for calculation (Bag, 1979), which is identical to "Pascal's" triangle which first appeared in Europe over a thousand years after Piṅgala and about a century before Pascal (on the title page of the *Arithmetic* of Apianus) and in China in the fourteenth century (Needham, 1981). An example, using the Gāyatrī meter is also found in Bhaskara's *Līlāvātī* (Bhaskara, *Līlāvātī*, trans. K. S. Patwardhan, S. A. Naimpally, and S. L. Singh, p. 102. The verse is numbered differently in different manuscripts. K. V. Sarma, in his critical edition of the sixteenth-century southern commentary *Kriyākramakarī* (VVRI, Hoshiarpur, 1975) on the *Līlāvātī*, gives this as verse number 133, while the other cited source has given it as verse number 121). Stock Western histories of mathematics (such as that by Smith, 1958) are unreliable and wrongly state that no attention was paid in India to the theory of permutations and combinations before Bhaskara II (twelfth century CE).

Although this theory of permutations and combinations is built into the Vedic meter, the earliest known written account actually comes from even before Piṅgala and is found in the fourth-century Jain *Bhagvatī Sūtra*. Permutations were called *vikalpa-ganita* (the calculus of alternatives) and combinations *bhanga*. The text works out the number of combinations of n categories taken 2, 3, etc., at a time.

From the earliest Vedic tradition, there is a continuous series of manuscripts linking the first accounts of permutations and combinations with those of Bhaskara II (twelfth century) and later

commentaries on his work up to the sixteenth century CE, such as the *Kriyākramakarī*. (It is these latter texts which arrived in Europe and first brought the mathematical theory of probability to Europe, as detailed later on, through Pascal, Fermat etc.) Thus, (Bag, 1979) the surgeon Suśruta (second century CE) in his compendium (*Suśruta-samhitā*) lists the total number of flavors derived from six flavors taken 1 at a time, 2 at a time, and so on. Likewise, Varāhamihira (sixth century) states the number of perfumes that can be made from 16 substances mixed in 1, 2, 3, and 4 proportions. Similar examples are found in the *Pāṭiganīta* (Slate Arithmetic) of Śrīdhar (tenth century), a widely used elementary school text, as its name suggests, Mahavira's (eighth century) *Gaṇita Sāra Saṃgraha* and Bhaskara II (*Līlāvātī*), etc. Bhaskara mentions that this formula has applications to the theory of meter, to architecture, medicine, and *khaṇḍameru* ("Pascal's triangle"). In these later texts, one finds explicitly stated formulae for permutations and combinations.

For example, to calculate $\binom{n}{r}$ values, Śrīdhar, in his text on slate arithmetic (*Pāṭiganīta*, 1959), gives the following rule.

एकाद्व्युत्तरविधिना रस विन्यासे विलोमतो गुणयेत् ।
पूर्वेण परं क्रमशो रूपादिचयेर्हरेर्विभजेत् ॥

This translates as follows (*Pāṭiganīta*, 72, Eng. p. 58):

Writing down the numbers beginning with 1 and increasing by 1 up to the (given) number of savours in the inverse order, divide them by the numbers beginning with 1 and increasing by 1 in the regular order, and then multiply successively by the preceding (quotient) the succeeding one. (This will give the number of combinations of the savours taken 1, 2, 3, ..., all at a time respectively.) (*Pāṭiganīta* of Śrīdhar, trans. K. S. Shukla. As he points out, similar articulations are found in the *Gaṇita Sāra Saṃgrah* of Mahavira, vi.218, *MahāSiddhānta* of Āryabhaṭa 2, xv, 45–46 etc.).

Thus, in the case of six savours, one writes down the numbers 1–6 in reverse order:

6, 5, 4, 3, 2, 1

These are divided by the numbers in the usual order, to get the quotients:

$$\frac{6}{1}, \frac{5}{2}, \frac{4}{3}, \frac{3}{4}, \frac{2}{5}, \frac{1}{6}.$$

Then, according to the rule, the number of combinations of savors taken 1 at a time, 2 at a time, etc., up to all at a time is, respectively,

$$\frac{6}{1}, \frac{6}{1} \times \frac{5}{2}, \frac{6}{1} \times \frac{5}{2} \times \frac{4}{3}, \text{ etc.}$$

Bhaskara II illustrates these formulae by asking for the total number of five-digit numbers whose digits sum to 13 (*Līlāvātī* of *Bhāskarācārya*, trans. Patwardhan et al., p. 181. They give the number of this verse as 276, whereas, in K. V. Sarma's critical edition of *Kriyakramkarī*, a commentary on the *Līlāvātī*, this is at 269, p. 464).

पंचस्थानस्थितैरंकैर्यद्योगसंख्योदश ।
कतिभेदा भवेत्संख्या यदि वेत्सि निगद्यताम् ॥

Almost all Western histories of probability incorrectly state that the mathematical theory of probability began with a European dispute over gambling in the seventeenth century CE. This account intrinsically lacks credibility because, given that gambling is so ancient, it is hard to understand why a mathematical theory related to it should have developed so late. One readily understands why this happened late in Europe, since Greek and Roman numerals are not suited to anything beyond elementary arithmetic and cannot even represent fractions, and arithmetical skills became widespread in Europe only after elementary Indian arithmetic was first introduced in the Jesuit syllabus ca. 1572.

But mathematics related to games of chance did develop elsewhere. In fact, elementary Indian mathematical texts give us accounts of gambling strategies and methods of calculating gain or loss. The relevance of these weighted averages to gambling was understood. For example, the *Gaṇita Sāra Saṃgraha* (1963) (268.5, 273.5) gives the example of “Dutch bets” mentioned

by Hacking (1975) (Hacking uses the English translation of *Gaṇita Sāra Saṃgraha*, trans. M. Rangacharya (1912), pp. 162–163). This is “a rule to ensure profit (in gambling) regardless of victory or loss,” a method of riskless arbitrage, in short. The text illustrates the rule with an example, where “a great man knowing mantra and medicine sees a cockfight in progress. He talks to the owners of the birds separately in a mysterious way. He tells one that ‘if your bird wins, you give me the amount you bet, and if it loses, I will give you $\frac{2}{3}$ of that amount’”. Then he goes to the owner of the other bird where on those same conditions he promised to pay $\frac{3}{4}$ of the amount. In either case, he earned a profit of only 12 pieces of gold. O mathematician, blessed with speech, tell me how much money did the owner of each bird bet.”

It is also interesting to note that this involves the formula for “mixtures” or weighted averages, exactly the formula used to calculate mathematical expectation (or, say, the expected value of a lottery ticket) in probability theory today. There are other more complicated betting strategies showing that standard Western accounts that the mathematics of gambling began in Europe in the seventeenth century are completely misplaced. That is, when it began in Europe, whereas it began in the world a few thousand years earlier.

Needless to say, the game of dice itself is very ancient in India. The earliest known textual account of gambling is found in the *akṣa sūkta* or hymn on dice in the *R̥gveda* (10.2.34). The long hymn begins by comparing the pleasure of gambling with the pleasure of drinking soma!

There is enjoyment like the soma in those dice
(*R̥gveda*, 10.2.34.1). (सोमस्यैव मोज्ज्वतस्यमद्यो)

It goes on to describe how everyone avoids a gambler, like an old man avoids horses, even his mother and father feign not to recognize him, and he is separated from his loving wife. Many times the gambler resolves to stay away, but each time the fatal attraction of the dice pulls him back. With great enthusiasm he reaches the gambling place, hoping to win, but sometimes he wins and sometimes his opponent does. The dice do not obey the wishes of the gambler, they revolt.

They pierce the heart of the gambler, as easily as an arrow or a knife cuts through the skin, and they goad him on like the ankuṣ, and pierce him like hot irons. When he wins he is as happy as if a son is born, and when he loses, he is as if dead. The 53 dice dance like the sun playing with its rays, they cannot be controlled by the bravest of the brave, and even the king bows before them. They have no hands, but they rise and fall, and men with hands lose to them. The gambler's wife remains frustrated and his son becomes a vagabond. He always spends his night in other places. Anyone who lends him money doubts that he will get it back. The gambler who arrives in the morning on a steed leaves at night without clothes on his back. [Such is the power of dice!] O Dice, I join the ten fingers of my hands and bow to the leader among you!

The mathematics of probability was not restricted to games of chance in India: at a very early stage, it was linked to statistics or sampling theory, used, for example, to count the number of fruits in a tree. The first account of it is found in the Mahabharata epic, traditionally dated to the beginning of the Kali era (–3,102 or about 5,000 years ago). The Mahabharata war, itself, is precipitated when the heroes (Pandava-s) lose their kingdom and dignity during a game of dice (दुत क्रीडा). Yudhishtira, the Pandava leader, who loses the game of dice, realizes that the game is not fair, and says so: निक्तिर्देवनं पापं न चाश्रोत्र पराक्रम (Mbh, Sabhā Parva, 59.5). That is, “Deceitful gambling is sinful, there is no Kshatriya valor in it.” Nevertheless, he continues to play, since he cannot prove the dice are loaded, and, as a Kshatriya, he would be dishonored if he refuses to participate in an enterprise involving risk.

When Yudhishtira is banned to the forest, and ruining his condition, a passing sage consoles him by telling him the romantic story of Nala and Damayanti. Nala, too, loses his kingdom in a deceitful game of dice and loses even his last clothes in a forest where he abandons his wife Damayanti, since he is unable to support her.

Someone advises him to go to R̥tuparṇa, king of Ayodhya, knowledgeable in the science of dice. Accordingly, Nala disguises himself and takes up a job as a charioteer with R̥tuparṇa. Damayanti somehow finds her eventful way home and sends out search parties for Nala. Eventually, she locates him, and to test whether he really is Nala, she announces her second marriage through a *swayamvara* (ceremony to choose a husband). R̥tuparṇa wants to wed Damayanti and rushes to Vidarbha. The distance from Ayodhya to Vidarbha being so large, only an accomplished charioteer like Nala can reach in time, so R̥tuparṇa naturally turns to him.

On the way they stop for a moment under a Vibhīṭaka tree – it is significant that the nuts of this very tree, with five faces, were used in the ancient Indian game of dice (Mahabharata, 1883–1896). R̥tuparṇa cannot resist showing off his knowledge of mathematics and says: the number of fruits in the two branches of the tree is 2,095; count them if you like. Nala wants to know how this was done and threatens to stop and count. He also offers his knowledge of horses in return. Under tight time pressure, R̥tuparṇa succumbs and explains that it is done by counting a portion of one branch. (The story has a happy ending and Nala gets back both his wife and his kingdom). However, what it tells us is that this knowledge of the mathematics of dice, though very ancient, was regarded as valuable and kept a secret to be passed on from one person to another, and not put in common texts.

Lastly, there is the question of continuous probabilities, which are today defined using Kolmogorov's axioms or measure theory. This approach is not really satisfactory since our empirical understanding of probability is based on relative frequency and the so-called law of large numbers. If a coin is tossed 100 times and comes up heads 48 times, the relative frequency of heads is $\frac{48}{100} = 0.48$. On the next 100 tosses, the relative frequency may change to 0.47. However, relative frequency is not the probability, which could be 0.5 if the coin is unbiased. The belief is

that, as the number of coin tosses becomes large, the relative frequency will be closer to the “true” probability. But “closer” in what sense? Suppose, after a 1,000 tosses, the relative frequency is 0.49. Can we be sure that after 2,000 tosses it would not be 0.47? We cannot. In fact, it can even happen that the next 1,000 tosses all result in tails. All we can say (and all that the “law of large numbers” enables us to say) is that it is *unlikely* that this will happen. That is, the probability that this will happen is small. This state of affairs means that empirical relative frequency cannot be used to define axiomatic probability. The issue of the failure of this frequentist interpretation of probability and the way it is resolved by zeroism are taken up in a more advanced article (Raju 2011).

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Proofs in Indian Mathematics

M. D. Srinivas

Alleged Absence of Proofs in Indian Mathematics

Most of the scholarly works on history of mathematics assert that Indian Mathematics, whatever its achievements, does not have any sense of logical rigour. For instance, we may cite the following as being typical of the kind of opinions commonly expressed about Indian mathematics:

As our survey indicates, the Hindus were interested in and contributed to the arithmetical and computational activities of mathematics rather than to the deductive patterns. Their name for mathematics was *gaṇita*, which means “the science of calculation”. There is much good procedure and technical facility, but no evidence that they considered proof at all. They had rules, but apparently no logical scruples. Moreover, no general methods or new viewpoints were arrived at in any area of mathematics. (Kline, 1972, p. 190)

While modern scholarship seems to be unanimous in holding the view that Indian mathematics lacks any notion of proof, even a cursory study of the source works that are available in print reveals that Indian mathematicians place much emphasis on providing what they refer to as *upapatti* (proof, demonstration) for everyone of their results and procedures.

Some of these *upapattis* were noted in the early European studies on Indian mathematics in the first half of the nineteenth century. For instance, Colebrooke notes the following in the preface to his widely circulated translation of portions of *Brāhmasphuṭasiddhānta* (ca. AD 628) of ► [Brahmagupta](#), and *Līlāvātī* and *Bījagaṇita* of Bhāskaračārya (ca. AD 1150):

On the subject of demonstrations, it is to be remarked that the Hindu mathematicians proved propositions both algebraically and geometrically:

as is particularly noticed by Bhāskara himself, towards the close of his algebra, where he gives both modes of proof of a remarkable method for the solution of indeterminate problems, which involve a factum of two unknown quantities. (Colebrooke, 1817, p. xvii)

Around the same time, Whish (1835) pointed out that infinite series for π and the trigonometric functions were derived in texts of Indian mathematics much before their discovery in Europe. It would indeed be interesting to find out how the currently prevalent view, that Indian mathematics lacks the notion of proof, obtained currency in the last 100–150 years.

The Tradition of *Upapattis* in Mathematics and Astronomy

A major reason for our lack of comprehension, not only of the Indian notion of proof, but also of the entire methodology of Indian mathematics, is the scant attention paid to the source works so far. Much of the methodological discussion is usually contained in the detailed commentaries, whereas modern scholarship has concentrated almost exclusively on translating and analysing the original works, without paying any heed to the commentaries. Traditionally, the commentaries have played at least as great a role in the exposition of the subject as these original texts.

Among the source works available in print, there are about 25 commentaries which present detailed *upapattis* of results and processes in mathematics and astronomy (see References, Primary Sources). Amongst these, the earliest expositions of *upapattis* are to be found in the *Bhāṣya* of Govindasvāmin (ca. 800) on the *Mahābhāskarīya* of Bhāskarācārya I, and the *Vāsanābhāṣya* of Caturveda Prthūdakasvāmin (ca. 860) on *Brāhmasphuṭasiddhānta* of Brahmagupta. We find a very detailed exposition of *upapattis* in the works of Bhāskarācārya II (ca. 1150): his *Vivaraṇa* on *Śiṣyadhīvṛddhidatantra* of Lalla (ca. 800) and his *Vāsanā* on his own *Bījagaṇita* and *Siddhāntaśiromaṇi*. Bhāskarācārya notes that the exposition of *upapattis* goes back to the

ancient teachers and is handed down by the teaching tradition (Bhāskarācārya II, *Vāsanā* on *Bījagaṇita* 1949, pp. 125–127).

Mathematical Results Should Be Supported by *Upapattis*

The following passage from Kṛṣṇa Daivajña's commentary *Bījapallava* (ca. 1600) on *Bījagaṇita* of Bhāskarācārya, clearly brings out the basic understanding of Indian mathematical tradition that citing any number of instances (even an infinite number of them) where a particular result seems to hold, does not amount to establishing that as a valid result in mathematics. Only when the result is supported by an *upapatti* or a demonstration, can the result be accepted as valid:

How can we state without proof (*upapatti*) that twice the product of two quantities when added or subtracted from the sum of their squares is equal to the square of the sum or difference of those quantities? That it is seen to be so in a few instances is indeed of no consequence. Otherwise, even the statement that four times the product of two quantities is equal to the square of their sum, would have to be accepted as valid. For, that is also seen to be true in some cases. For instance take the numbers 2, 2. Their product is 4, four times which will be 16, which is also the square of their sum 4. Or take the numbers 3, 3. Four times their product is 36, which is also the square of their sum 6. Or take the numbers 4, 4. Their product is 16, which when multiplied by four gives 64, which is also the square of their sum 8. Hence, the fact that a result is seen to be true in some cases is of no consequence, as it is possible that one would come across contrary instances (*vyabhicāra*) also. Hence it is necessary that one would have to provide a proof (*yukti*) for the rule that twice the product of two quantities when added or subtracted from the sum of their squares results in the square of the sum or difference of those quantities. We shall provide the proof (*upapatti*) in the end of the section on *ekavarṇa samīkaraṇa*. (Kṛṣṇa Daivajña, *Bījapallava* 1958, p. 54)

Upapatti for the *Kuṭṭaka* Process

To understand the nature of *upapattis* in Indian mathematics, we have to analyse some of the lengthy demonstrations which are presented for the more complicated results and procedures.

We also have to analyse the sequence in which the results and the demonstrations are arranged to understand the method of exposition and logical sequence of arguments. For instance, we may refer to the demonstration given by Kṛṣṇa Daivajña of the celebrated *kuṭṭaka* procedure, which has been employed by Indian mathematicians at least since the time of ► *Āryabhaṭa* (ca. AD 499), for solving first-order indeterminate equations of the form $(ax + c)/b = y$, where a, b, c are given integers and x, y are to be solved for integers. The *upapatti* is rather lengthy (Kṛṣṇa Daivajña, *Bījapallava* 1958, pp. 85–99; Srinivas, 1987), and we merely recount the essential steps here.

Kṛṣṇa Daivajña first shows that the solutions for x, y do not vary if we factor all three numbers a, b, c by the same common factor. He then shows that if a and b have a common factor, then the above equation will not have a solution unless c is also divisible by the same common factor. Then follows the *upapatti* of the process of finding the greatest common factor of a and b by mutual division, the so-called Euclidean algorithm. He then provides an *upapatti* for the *kuṭṭaka* method of finding the solution by making a series of transformations on the *vallī* (column) of the quotients obtained in the above mutual division, based on a detailed analysis of the various operations in reverse (*vyasta-vidhi*). The last two elements of the *vallī*, at each stage, are shown to be the solutions to the *kuṭṭaka* problem for the successive pairs of remainders (taken in reverse order from the end) which arise in the mutual division of a and b . Finally, Kṛṣṇa Daivajña explains why the procedure differs depending upon whether there are odd or even number of coefficients generated in the above mutual division.

Yuktibhāṣā Proofs of Infinite Series for π and the Trigonometric Functions

One of the most celebrated works in Indian mathematics and astronomy, which is specially devoted to the exposition of *yukti* or proofs, is the Malayalam work *Gaṇita-yuktibhāṣā* or *Yuktibhāṣā* (ca. 1530) of Jyeṣṭhadeva. Jyeṣṭhadeva states that his work closely follows

the renowned astronomical work *Tantrasaṅgraha* (ca. 1500) of Nīlakaṇṭha Somasutvan and is intended to give a detailed exposition of all the mathematics required thereof. The first half of *Yuktibhāṣā* deals with various mathematical topics in seven chapters and the second half deals with all aspects of mathematical astronomy in eight chapters. The mathematical part includes a detailed exposition of proofs for the infinite series and fast converging approximations for π and the trigonometric functions, which were discovered by Mādhava (ca. 1375); it also includes proofs of Brahmagupta's results concerning the diagonals and the area of a cyclic quadrilateral. Some of the proofs in this part have been studied in recent times, after the pioneering work of Rajagopal and his collaborators over 50 years ago (John, 2002; Katz, 1995; Marar, 1940; Paramesvaran, 1998; Rajagopal, 1949; Rajagopal & Aiyar, 1951; Rajagopal & Venkataraman, 1949; Raju, 2001; Saraswati Amma, 1979; Srinivas, 2005). The proofs of *Yuktibhāṣā* have also been expounded in the form of Sanskrit verses (*kārikas*) by Śaṅkara Vāriyar in his commentaries *Kriyākramakarī* (ca. 1535) and *Yuktidīpikā* on Līlāvati and *Tantrasaṅgraha*, respectively.

Upapatti and “Proof”

The Raison D'être Of Upapatti

The notion of *upapatti* is significantly different from the notion of “proof” as understood in the Greek and modern Western traditions of mathematics. The ideal of mathematics in the Greek and modern Western traditions is that of a formal axiomatic deductive system. This ideal of mathematics is intimately linked with another crucial philosophical presupposition that mathematics constitutes a body of infallible eternal truths. It is this quest for securing absolute certainty of mathematical knowledge, which has motivated most of the foundational and philosophical investigations into mathematics and has shaped the course of mathematics in the Western tradition, from the age of Greeks to contemporary times.

Indian epistemological position on the nature and validation of mathematical knowledge is very different from that in the Western tradition. This is brought out for instance by the Indian understanding of what indeed is the purpose or *raison d'être* of an *upapatti*. In the beginning of the *golādhyāya* of *Siddhāntaśiromaṇi*, Bhāskarācārya says (Bhāskarācārya II, 1981, p. 326):

Madhyādyaṃ dyusadāṃ yadatra gaṇitaṃ
tasyopapattiṃ vinā
prauḍhiṃ prauḍhasabhāsu naiti gaṇako
niḥsaṃśayo na svayam
gole sā vimalā karāmalakavat pratyakṣato
drśyate
tasmādasmyupapattibodhavidhaye
golaprabandhodyataḥ

Without the knowledge of *upapattis*, by merely mastering the *gaṇita* (computational procedures) described here, from the *madhyamādhikara* (the first chapter of *Siddhāntaśiromaṇi*) onwards, of the (motion of the) heavenly bodies, a mathematician will not have any value in the scholarly assemblies; without the *upapattis* he himself will not be free of doubt (*niḥsaṃśaya*). Since *upapatti* is clearly perceivable in the (armillary) sphere like a berry in the hand, I therefore begin the *golādhyāya* (section on spherics) to explain the *upapattis*.

Thus, as per the Indian mathematical tradition, the purpose of *upapatti* is mainly (a) to remove confusion and doubts regarding the validity and interpretation of mathematical results and procedures; and (b) to obtain assent in the community of mathematicians. Further, in the Indian tradition, mathematical knowledge is not taken to be different in any “fundamental sense” from that in natural sciences. The valid means for acquiring knowledge in mathematics are the same as in other sciences: *Pratyakṣa* (perception), *Anumāna* (inference), and *Śabda* or *āgama* (authentic tradition).

The Limitations of *Tarka* or Proof by Contradiction

An important feature that distinguishes the *upapattis* of Indian mathematicians is that they

do not generally employ the method of proof by contradiction or *reductio ad absurdum*. Sometimes arguments, which are somewhat similar to proof by contradiction, are employed to show the non-existence of an entity, as may be seen from the following *upapatti* given by Kṛṣṇa Daivajña to show that “a negative number has no square root”:

The square-root can be obtained only for a square. A negative number is not a square. Hence how can we consider its square-root? It might however be argued: ‘Why will a negative number not be a square? Surely it is not a royal fiat’... Agreed. Let it be stated by you who claim that a negative number is a square as to whose square it is; surely Not of a positive number, for the square of a positive number is always positive by the rule... not also of a negative number. Because then also the square will be positive by the rule... This being the case, we do not see any such number whose square becomes negative... (Kṛṣṇa Daivajña, Bṭjapallava 1958, p. 19)

Such arguments, known as *tarka* in Indian logic, are employed only to prove the non-existence of certain entities, but not for proving the existence of an entity, whose existence is not demonstrable (at least in principle) by other direct means of verification.

In rejecting the method of indirect proof as a valid means for establishing existence of an entity whose existence cannot even in principle be established through any direct means of proof, the Indian mathematicians may be seen as adopting what is nowadays referred to as the “constructivist” approach to the issue of mathematical existence. But the Indian philosophers, logicians, etc., do much more than merely disallow certain existence proofs. The general Indian philosophical position is one of eliminating from logical discourse all reference to such *aprasiddha* entities, whose existence is not even in principle accessible to all means of verification (Srinivas, 1986). This appears to be also the position adopted by the Indian mathematicians. It is for this reason that many an “existence theorem” (where all that is proved is that the non-existence of a hypothetical entity is incompatible with the accepted set of postulates) of Greek or modern Western mathematics would

not be considered significant or even meaningful by Indian mathematicians.

Upapatti and “Proof”

We now summarise the classical Indian understanding of the nature and validation of mathematical knowledge:

1. The Indian mathematicians are clear that results in mathematics, even those enunciated in authoritative texts, cannot be accepted as valid unless they are supported by *yukti* or *upapatti*. It is not enough that one has merely observed the validity of a result in a large number of instances.
2. Several commentaries written on the major texts of Indian mathematics and astronomy present *upapattis* for the results and procedures enunciated in the text.
3. The *upapattis* are presented in a sequence proceeding systematically from known or established results to finally arrive at the result to be established.
4. In the Indian mathematical tradition, the *upapattis* mainly serve to remove all ambiguity and doubts and obtain assent for the result among the community of mathematicians.
5. The *upapattis* may involve observation or experimentation. They also depend on the prevailing understanding of the nature of the mathematical objects involved.
6. The method of *tarka* or “proof by contradiction” is used occasionally. But there are no *upapattis* which purport to establish existence of any mathematical object merely on the basis of *tarka* alone.
7. The Indian mathematical tradition did not subscribe to the ideal that *upapattis* should seek to provide irrefutable demonstrations establishing the absolute truth of mathematical results. There was apparently no attempt to present the *upapattis* as a part of a deductive axiomatic system. While Indian mathematics made great strides in the invention and manipulation of symbols in representing mathematical results and in facilitating mathematical processes, there was no attempt at formalisation of mathematics.

The classical Indian understanding of the nature and validation of mathematical knowledge seems to be rooted in the larger epistemological perspective developed by the Nyāya school of Indian logic (Bhattacharya, 1987; Mohanty, 1992). Some of the distinguishing features of Nyāya logic, which are particularly relevant in this context, are:

1. That it is a logic of cognitions (*jñāna*) and not “propositions”.
2. That it has no concept of pure ‘formal validity’ as distinguished from “material truth”.
3. That it does not distinguish necessary and contingent truth or analytical and synthetic truth, that it does not admit, in logical discourse, premises which are known to be false and terms that are non-instantiated.
4. That it does not accord *tarka* or “proof by contradiction”, a status of independent *pramāṇa* or means of knowledge, and so on.

Towards a New Epistemology for Mathematics

Mathematics today, rooted as it is in the modern Western tradition, suffers from serious limitations. First, there is the problem of “foundations” posed by the ideal view of mathematical knowledge as a set of infallible eternal truths. The efforts of mathematicians and philosophers of the West to secure for mathematics the status of indubitable knowledge has not succeeded, and there is a growing feeling that this goal may turn out to be a mirage.

Apart from the problems inherent in the goals set for mathematics, there are also other serious inadequacies in the Western epistemology and philosophy of mathematics. The ideal view of mathematics as a formal deductive system gives rise to serious distortions. Some scholars have argued that this view of mathematics has rendered philosophy of mathematics barren and incapable of providing any understanding of the actual history of mathematics, the logic of mathematical discovery and, in fact, the whole of creative mathematical activity. There is also the growing awareness that the ideal of mathematics

as a formal deductive system has had deleterious consequences on the teaching of mathematics.

Notwithstanding all these critiques, it is not likely that, within the Western philosophical tradition, any radically different epistemology of mathematics will emerge and so the driving force for modern mathematics is likely to continue to be a search for absolute truths and modes of establishing them, in one form or the other. This could lead to “progress” in mathematics, but it would be progress of a rather limited kind.

If there is a major lesson to be learnt from the historical development of mathematics, it is perhaps that the development of mathematics in the Greco-European tradition was seriously impeded by its adherence to the cannon of ideal mathematics as laid down by the Greeks. In fact, it is now clearly recognised that the development of mathematical analysis in the Western tradition became possible only when this ideal was clearly given up during the heydays of the development of “infinitesimal calculus” during sixteenth, seventeenth and eighteenth centuries. As a historian of mathematics notes:

It is somewhat paradoxical that this principal shortcoming of Greek mathematics stemmed directly from its principal virtue – the insistence on absolute logical rigour . . . Although the Greek bequest of deductive rigour is the distinguishing feature of modern mathematics, it is arguable that, had all the succeeding generations also refused to use real numbers and limits until they fully understood them, the calculus might never have been developed and mathematics might now be a dead and forgotten science. (Edwards, 1979, p. 79)

It is of course true that the Greek ideal has gotten reinstated at the heart of mathematics during the last two centuries, but it seems that most of the foundational problems of mathematics can also be perhaps traced to the same development. In this context, study of alternative epistemologies, such as that developed in the Indian tradition of mathematics, could prove to be of great significance for the future of mathematics.

See Also

Nyāya

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Printing can be described as a process by which texts and images prepared on a master form are transferred by being impressed onto a receiving surface. Thus, characterized printing is an extremely ancient process that includes the cylindrical seals from the fourth millennium BCE used in Mesopotamia as well as later seals and a wide variety of methods that could produce a three- or two-dimensional impression by inks, dyes, or pigments. Both the master form, prepared in relief or intaglio, and the receiving surface could be made from many different materials. The printed text or image could be used for different purposes – to record information, to disseminate information, to assert authority, to indicate confidentiality, or to convey religious or talismanic power. Printing therefore is not synonymous with publishing or the broadcasting of information. This entry focuses on the technological aspects of woodblock printing (xylography) and traditional movable-type printing (typography), the two methods of printing for publishing that were most important in China until the nineteenth century, when other printing methods, such as lithography and Western typography, were introduced.

Woodblock Printing

The idea for block printing follows easily from using seals to make impressions, a practice known as early as the Shang period (ca. 1500–1050 BCE). The earliest extant seals from the late Zhou (ca. 1050–256 BCE), Qin (221–206 BCE), and Han (206 BCE–220 CE) Dynasties were made of stone, earthenware, metals, or horn and could be used to make impressions on clay, silk, and other surfaces (Tsien, 2004, pp. 57–61). Most of the surviving seals were used to authenticate the identity and

authority of an individual or organization, but there are also some from the first or second century CE that served religious and magical purposes. Textual accounts suggest they were meant to protect occupants of tombs. We also have records about the apotropaic [preventing evil] use of seals carved from peachwood from the first century CE and descriptions of Daoist seals from the fourth century. Buddhist texts, such as one from the fifth century, describe “devil-subduing seals” as well as impressions of the Buddha’s image for devotional purposes. Moreover, the impressions were not necessarily made on silk or paper but on soft clay, sand, or even human skin (Strickmann, 2002). A different application of block printing in China was its use in dyeing textiles, for which we have brass blocks from the second century BCE and one anecdotal account describing a dye-resist method using woodblocks in the eighth century CE (Barrett, 2001).

Equally important for multiple replication of text and image by printing is the availability of a pliant, absorbent surface that could be cheaply produced – paper. Although the earliest extant paper dates to the first or second century BCE (Tsien, 2004, p. 146), historical tradition attributes a Han Dynasty official in the second century CE named Cai Lun with developing high-quality paper suitable for writing and painting.

Although the physical process of block printing may easily be inspired from earlier technologies that applied ink or dye on a given material, they differed sufficiently from the xylographic process so that the latter may not have been immediately obvious as a means of replicating text and image on paper for the purpose of making multiple copies for publication. What was required was a combination of political, religious, or cultural purpose and economic advantage afforded by bringing these techniques together – a vast topic that has received increasing scholarly attention in the last several decades (Brokaw, 2005, 2007; Chia & De Weerd, 2011; McDermott, 2006; Twitchett, 1983).

Woodblock printing developed in China probably by the late seventh century CE and was first used to produce religious materials,

including Buddhist and Daoist scriptures and charms. Although we know of crudely produced woodblock imprints of school primers, “character books” (lists of Chinese characters for students), calendars, and books for fortune-telling from the late ninth century, it was only in the mid-tenth century, just prior to the establishment of the Song Dynasty (960–1279), when the ancient Confucian classics were first printed. In the Song, however, the state, schools, private individuals, and commercial publishers all began to print books, ranging from the Confucian Classics to dictionaries, histories, geographies, medical texts, encyclopedias, collections of anecdotes, school primers, poetry anthologies, plays and ballads, and historical novels. By the beginning of the eleventh century, woodblock printing was a technology that was some 400 years old, so it is no surprise that Song-period imprints should have reached very high level of technical and aesthetic quality. Thereafter, block printing became the dominant printing technology in China, used for producing books, broadsheets, legal and business documents, calendars, pictures, and paper money. By the late seventh to early eighth century, xylography was also introduced into Korea and Japan, where Chinese characters had been adopted for writing these languages. Later on, Korean printing also used movable type, both for Chinese characters and Hangul, the native alphabet devised in the fifteenth century. The Japanese also used both xylography and typography, for Chinese characters and the native *kana* script. In China, it was not until the late nineteenth century when Western technologies, such as lithography and modern movable-type printing, were introduced into China and began replacing xylography. Woodblock printing of books finally died out some time in the first half of the twentieth century, but it is still used as an artistic medium.

The process of woodblock printing is quite simple (Edgren, et al. 1984, pp. 16–21; Tsien, 1985, pp. 196–201; Pietzcker, 2003). The text (and/or picture) is first written or painted by ink brush on a piece of paper. This sheet is then

placed facedown on a previously prepared block of wood and a wet brush is used to rub the ink from the paper to the woodblock. Next, a blockcarver takes the appropriate knives and gouges to carve out the characters and images (Barker, 2005, pp. 26–42; Tsien, 1985, pp. 196–200; Pietzcker, 2003) as well as the frame around the leaf (folio), if there is one. Once the woodblock is carved, a water-based ink is applied, and a blank sheet of paper is pressed down and rubbed against the block to transfer the text onto the sheet. For monochromatic printing, usually the text and image (s) are all carved on one block; for polychromatic printing (Barker, 2005, pp. 48–52; Pietzcker, 2003; Tsien, 1985, pp. 277–292), different blocks are used, each corresponding to a specific color. The complete contents of a sheet require printing off the entire set of blocks, a process that requires careful registration, which could be achieved in different ways, such as using the traditional Chinese printing table (Barker, 2005, pp. 58–60). (We should note that in addition to wood, printing blocks made of bronze were also used, mainly for printing paper money and some official documents, and we have a few extant examples from the Song, the Jurchen Jin (1127–1234), and the Mongol Yuan (1279–1368) Dynasties.)

For monochromatic woodblock printing in particular, with the exception of the time-consuming step of engraving the characters and/or picture on the woodblock, which requires the service of skilled carvers, the rest of the process is quite straightforward. In fact, one of the great advantages of woodblock carving is its simplicity and portability. This may explain why the Chinese and other East Asians who used woodblock printing did not talk of a “printing revolution” in the same way that the Europeans in the mid-fifteenth century did when typography developed or the way writers today talk about a “computer revolution.” In a sense, xylography was a transparent technology – more like photocopying in the ease of its acceptance and widespread use, so that people simply took to using it without the fanfare surrounding other technological revolutions.

Materials and Tools Used in Woodblock Printing

Paper (Tsien, 1985, esp. pp. 42–96; McClure, 1986; Hunter, 1947/1978)

The kinds of paper used in woodblock printing were either the same or similar to those used for handwritten texts and hand-drawn images and for painting and were made from different materials, including fibers of tree barks (mulberry and paper mulberry), bamboo, and basts (hemp, jute, ramie, rattan). Papers composed of mixtures of different fibers were common. The quality of the paper depended not only on the kinds of fiber used but even more on the treatment of the pulp in the many steps of the papermaking process. For example, while untreated bamboo pulp would yield papers with a yellow or tan color, it could be bleached to varying degrees of whiteness. Sizing to control the paper’s absorbency of ink and dyes using various materials (gelatin, gum, gypsum, starch) also was essential. The same pulp could be used to make sheets of different thicknesses. Papers could be dyed either for artistic effect or infused with an insecticidal liquid from the Amur cork tree that gave the sheets a yellow tinge. The quality of papers ranged from very fine – smooth, lustrous, and white – to just adequate for printing but often with a yellow or brown tinge due to the lignin or gray from dirt remaining in the pulp. Many of these different papers had distinct names, which varied from place to place. Table 1 gives a very brief listing of just some of the papers used in block and movable-type printing in imperial China.

Because printing paper for traditional Chinese books and pictures is generally much thinner than that used in Western books, the paper is printed on one side only, and for books, the sheet is then folded in half (see below). Thus, the problem of the text from one leaf showing through another is not significant, even with cheap imprints. The thinness of the book paper does cause problems in taking an impression from the woodblock. Some care must be exercised not to tear the sheet when rubbing the back of it on the inked woodblock, but if the rubbing is too lightly done or the block is worn, the resulting impression will not be sufficiently dark. Yet another problem is

Publishing and Printing in China, Table 1 Chinese papers for printing: a brief sample (fibers of tree barks (mulberry and paper mulberry), bamboo, basts (hemp, jute, ramie, rattan))

Kind of fiber	Kind(s) of paper
Bast	
Hemp (<i>da ma</i> ; <i>Cannabis sativa</i>)	<i>Ma zhi</i>
Rattan (<i>teng</i> ; <i>Calamus rotang</i>)	<i>Youquan zhi</i> , named for Youquan in Hangzhou, Zhejiang province
Jute (<i>huang ma</i> ; <i>Corchorus capsularis</i>)	
Ramie (<i>zhu ma</i> ; <i>Boehmeria nivea</i>)	
Flax (<i>ya ma</i> ; <i>Linum perenne</i>)	
Tree bark	
<i>Tan tree (Pteroceltis tatarinowii)</i>	<i>Xuan zhi</i> : soft, white, fine paper made from the bark of the <i>tan</i> tree and straw; named for Xuancheng, Anhui – for printing and artwork
Paper mulberry (<i>chu</i> or <i>gu</i> or <i>gou</i> ; <i>Broussonetia papyrifera</i>)	<i>Gupi zhi</i> , Guangdu zhi (from Guangdu, Sichuan province)
Mulberry (<i>sang</i> ; <i>Morus alba</i>)	
Bamboo (<i>zhu</i> ; many species and varieties used)	“Cotton paper” (<i>mian zhi</i>) <i>Lianshi zhi</i> Both made from bleached bamboo pulp and/or paper mulberry bark Bamboo paper (<i>zhu zhi</i>); “book paper” (<i>shuji zhi</i>): yellowish, from unbleached bamboo fibers, generally for commercial printing “Document paper” (<i>gongdu zhi</i>): heavy, sturdy paper made of fine bamboo for official documents, but its back sometimes used for printing books

that with age the paper becomes increasingly brittle because of the substantial amount of lignin as well as other chemical changes. The resulting decrease in fold strength is obvious in the many books whose leaves are wholly or partially split along the centerfold, which receives the brunt of handling by the reader. Yet another problem is

that the impressions of mediocre imprints are not black but gray. Although this difficulty is blamed chiefly on the use of poorer inks (see below), the varying ability of different kinds of paper to absorb ink is also a consideration. The same ink may appear more pallid and duller on inferior bamboo paper than it does on better-quality paper.

Ink

Like paper, the ink used for printing was generally of a lower quality than that for calligraphy and painting. Although the making of highly prized ink cakes has been described appreciatively and in great detail and the names of master inkmakers recorded (Tsien, 1985, pp. 240–251), little is known about the production of cheaper inks. Printing ink was most likely made from pine soot (Song, 1637/1966, p. 287), which is cheaper than the lampblack made from various oils (tong, sesame, etc.), and results in an ink with a flat, dark black color. Moreover, since printing ink need only be sufficiently dark and adhere to the paper without smudging but need not fulfill the aesthetic requirements of ink for painting, it was composed of far fewer ingredients. Two descriptions from the eighteenth and early twentieth centuries are quite similar. After being beaten and sifted through a sieve, ten parts of the soot were mixed with one-part cowhide glue and added to water and wine to form a thick paste. To dispel its bad odors and improve its qualities, the paste was stored in a jar for at least three summers. When it was to be used, it was mixed with enough water to make a liquid and strained again. Judging from Chinese block-printed books in general, this ink was adequate for printing. The main noticeable defect, evident in many commercial imprints from all periods, is the pale color – dark gray rather than black – of the impressions, which probably resulted from overdiluting the ink paste with water as a cost-cutting measure.

Cutting Woodblocks

Traditional Chinese woodblocks are made from plankwood (cut along the grain), which, for a given tree trunk, yields larger pieces than the

end-grain wood (cut against the grain) and allows the cutter to avoid the problematic knotty heartwood (Tsien, 1985, pp. 196–201). The unplanned blocks are then seasoned up to several years, until they have dried and shrunk and warped as much as they are likely to. Finally, the blocks are planed, oiled, and polished. The actual process differs from place to place. In one procedure, woodblocks are boiled (to remove the sugar and other substances) and then left to dry. Drying, ideally in a cool, airy place away from light and heat, is the essential step in the seasoning process. Carved blocks should be stored under the same conditions, standing upright, with a slight gap between adjacent blocks to allow the circulation of air. Vertical storage allows moisture and heat to penetrate the two carved surfaces equally and renders a block less liable to mechanical abrasions than if it were lying flat.

Generally, an even, close-grained, and relatively hard wood is preferred because it allows for the cutting of finer lines and more impressions. An extremely hard wood like maple that is very difficult and slow to cut, however, is neither practical nor economical for the quantity of blocks required in book production. The choice of wood also depends on the kind of material being printed (text or pictures) but more often on the availability and cost of the wood. The woods used for block printing in China include camphor, catalpa, boxwood, Chinese honey locust, and fruitwoods such as pear and Chinese date (jujube), as listed in Table 2 below. The Manchurian catalpa was so widely used that the Chinese character (*zi*) acquired a second meaning – woodblock printing. Pearwood is a relatively hard wood and can be used for general-purpose woodblock printing.

Of the various processes required for producing a Chinese woodblock book, the one calling for the most skill is the carving of the characters and images. Thus, the majority of the terms that have come to mean publishing a woodblock imprint refer to the engraving process. These words are also quite fitting since once the woodblocks for a book are carved, they are permanent in a way that movable type composed in a frame is not. For woodblock imprints, the idea of an

Publishing and Printing in China, Table 2 Some Chinese woods for block printing

Kind of wood	Description
Pearwood (<i>li</i> ; <i>Pyrus sinensis</i>)	Medium-hard surface; normal printing block use; used for carving text
Jujube (<i>zao</i> ; <i>Ziziphus vulgaris</i>)	Normal printing block use; harder
Manchurian catalpa (<i>qiu</i> or <i>zi</i> ; <i>Catalpa bungei</i>)	Normal printing block use; very hard, for cutting delicate lines as in pictures for illustration
Little leaf boxwood (<i>huangyang</i> ; <i>Buxus sempervirens</i>)	Also used today; softest, used for carving regular text; now only available in small surfaces
Ginkgo (<i>yinxing</i> ; <i>Ginkgo biloba</i>)	Also used today; more absorbent; excellent for block making
Honey locust (<i>baitao</i> or <i>zaojiamu</i> ; <i>Gleditsia sinensis</i>)	Also used today; very hard, for cutting delicate lines as in pictures for illustration; now only available in small surfaces
Maple/Chinese sweet gum wood (<i>fengmu</i> ; <i>Liquidambar formosana</i>)	Excellent for block making
Manchurian ash (<i>shuiuliu</i> ; <i>Fraxinus mandshurica</i>)	Strong, linear grain

“edition” and its date more properly relates to when the blocks were carved rather than to the date when the impressions were made, which could be at any time after the blocks have been cut. Thus, a work described in library catalogues and bibliographies as a *Song kanben* is printed from blocks carved in the Song. In the absence of any evidence such as repairs that can be dated, materials added subsequently (including owners’ seals), or possibly the printing paper, it would be hard to know when an impression was made from the blocks. In fact, many extant copies of old Chinese books are late impressions made from woodblocks engraved earlier.

The recording of the engravers’ names in an imprint is useful to scholars for several reasons. First, it is possible to date an imprint approximately if the name(s) of engraver(s) match those of another imprint with a known date. Second, in much the same way, the provenance of an imprint may be determined if it has the same group of

carvers as another imprint whose place of origin is known. Finally, by knowing how many different carvers worked on a given text, it is possible to estimate the minimum time required for producing the imprint, since the carving is the slowest step in the overall process. For example, in one set of the Confucian Classics produced in the sixteenth century, each work had over 110 different carvers. Since each carver can cut 100 characters a day, the shortest period that a work with 300 characters per leaf and 200 leaves could be carved would be about 6 days. Actually, the time required was much longer, since the evidence indicates that not all the carvers worked at the same time, and errors in the text had to be corrected.

The technique of carving both text and image on woodblocks changed very little for the thousand or more years that Chinese books have been produced. Block carving is the rate-determining step in the physical production of imprints and probably the costliest in terms of material and labor. Thus, that block printing was never supplanted by another technique for most of the late imperial period shows that it was an economically viable method for commercial book production for all this time. Of the two developments that became widespread in the Ming Dynasty (1368–1644), color printing and the use of the calligraphic style known as craftsman style (*jiangti*), the former was an extension of the potential of woodblock printing and the latter made carving more efficient and allowed more text to be packed onto a page without seeming too cramped or illegible. In fact, these modifications in block-carving techniques can be seen largely as responses to the pressures of a rapidly expanding book market in the mid- and late Ming and even more so into the Qing.

Making Impressions

The number of “acceptable” impressions made of a woodblock varies wildly depending on the source consulted, which almost never specifies the specific wood or paper used. The blurry nature of many cheaper imprints is much more likely due to printing too many copies from a woodblock and/or printing more than

200–300 copies without letting the woodblock “rest” from several hours to a day. Without a pause, the block would swell up as it absorbed the water-based ink and to a lesser extent from the continual rubbing to transfer the impression to the paper. (Printers using wooden movable type had to deal with a similar problem; see Chia, 2002, pp. 30–31.) This was probably a widespread problem among commercial printers anxious to print as many copies of a book as quickly as possible but remains almost unmentioned in the traditional literature on rare books and printing, since presumably such a flaw would not have afflicted the higher-quality books valued by bibliophiles.

The number of satisfactory impressions that can be pulled off a woodblock depends on the hardness of the wood, its water absorbency, weather conditions, and the standards of the printer. According to two modern publishing houses, 2,000–3,000 copies can be made from pearwood blocks before minor repairs need to be made. Actually, the equivalent of a “press run” usually was a much more modest number – between 20 and 200 copies. Since woodblocks lend themselves easily to printing on demand, it made better economic sense not to use ink, paper, and labor producing more copies than can be sold at a given time. An excellent example is the use of blocks in a Buddhist temple’s possession to print one or more copies of a sutra on a donor’s request. Finally, although woodblocks may seem permanent once carved, they are all too subject to the ravages of insects, fire, water, changes in humidity and temperature, as well as damage by humans. Woodblocks are thus far more liable to destruction long before they wear out from too many impressions. At the Rongbao Studio art shop in Beijing today, frequent repairs are made even within 30–50 years, with about 10–20 % of the blocks having to be replaced during that period of time. Finally, a certain amount of care and time is required to obtain clear pages even from new blocks. For example, often in a poor imprint, part of the impression on a sheet would come out quite clearly, whereas another part would be faint or blurred, indicating a problem with either the printing block itself and/or with the impression.

A commercial printshop either in a hurry to beat its competitors to the market with a cheap edition or unable to pay for repairing old blocks or engraving new ones would ignore such considerations and might simply keep making impressions until they were nearly illegible.

Bookbinding (International Dunhuang Project; Martinique, 1983; Tsien, 1985, pp. 227–233)

It is probably safe to say that all the different kinds of bookbinding used for imprints in imperial China had already been used for manuscript works, but those formats that were more convenient for printing grew in popularity with the advent of print (Table 3). Nevertheless, convenience was not always the deciding factor in choosing the format of a printed work. For example, the Buddhist *Kaibao Canon*, compiled and published by the state in the early Song (972–83) and the largest single printed work from the dynasty, was produced in the more traditional scroll format, probably because of the momentous circumstances of the work.

Movable-Type Printing

The Chinese also developed movable-type printing (Edgren et al., 1984, pp. 22–23; Tsien, 1985, pp. 201–222) by the mid-eleventh century at the latest, when Shen Kua, a Song scholar, wrote a vivid description of the process using earthenware type by a craftsman named Bi Sheng. Other materials used for making types of individual Chinese ideographs and other symbols included enamel ware, wood, and various kinds of metal such as bronze and tin. In the late thirteenth century, Wang Zheng described in some detail the procedure by which he produced, organized, and used wooden movable type (Tsien, 1985, esp. pp. 206–207) to print his treatise on agriculture. By the early Ming Dynasty, bronze type was also used by government offices, schools, and private and commercial printers to produce books. During the Qing Dynasty in the early eighteenth century, one of the largest printing projects was that of the huge encyclopedia of 5,020 volumes, *Gujin tushu jicheng* (Compendium of texts and

Publishing and Printing in China, Table 3 Chinese bookbinding formats

Name of binding	Description	Notes
Scroll (<i>juan</i>)	One continuous roll made by pasting together separate sheets	
Whirlwind (<i>xuanfeng zhuang</i>)	A number of sheets, each successive sheet longer, all bound together by paste and a split bamboo rod at one edge	No extant example of printed work in this format
Concertina (<i>jingzhe zhuang</i>)	Sheets pasted together, then each sheet folded	Mainly used for religious works; convenient for reading, as each fold flips very easily
Butterfly (<i>hudie zhuang</i>)	Sheets written/printed only on one side facing in, folded in half, and pasted together	Became popular by Northern Song (10th c. onward)
Backwrapped (<i>baobei zhuang</i>)	Each sheet folded in half, with written/printed sides facing out, sheets attached by paper twists forced into holes on one edge of the sheets	Popular starting in the Song Dynasty (ca. 12th c onward)
String bound (<i>xian zhuang</i>)	Each sheet folded in half, with written/printed sides facing out, sheets sewn together with thread	Popular starting in the mid-Ming Dynasty onward

images old and new), compiled and published by the imperial court at Wuying Hall.

There are, however, a number of reasons why xylography was dominant in China for over a thousand years. First, it was more efficient to carve the contents of an entire leaf on a woodblock than to compose the type for the text with so many different Chinese characters.

Even a simple text may require several thousand different characters, unlike that in an alphabetic language, with only 26 or so letters in lower and upper cases. As Tsien Tsuen-hsuei pointed out (Tsien, 1985, p. 220), a fount of at least 200,000 Chinese types would be required to include enough characters (with 20 or more of the more popular ones of each size). Second, the process of woodblock printing is relatively simple and economical, and printing facilities could be easily set up wherever the materials (paper, ink, wood, brushes) were available or could be produced.

We should not, however, think of woodblock and movable-type printing in China as two entirely separate or competing technologies. Sometimes they were used in combination to produce certain works. For instance, because of the somewhat formulaic nature of texts in family/lineage genealogies that required a relatively limited variety of characters, it was feasible for printers to use movable types for printing them. These texts set in movable type could be placed in a large form together with block-carved images and tables, for example, with drawn portraits of family members and some family tree diagrams (Xu, 2005).

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There is no other cylindrical tower known within the great Maya region. Some buildings can be compared in morphology, such as Mayapan's round temples or the cylindrical building at Chichén Itzá, best known as "El Caracol." But there is an elementary difference between them: Puerto Rico's tower has a solid core, and the others have interior spaces and vaults.

Few studies have been carried out at Puerto Rico (Andrews IV in Aveni, 2005, p. 383; Benavides, 1999) and the tower has been mentioned in some other papers (Andrews, 1989; Kelly & Kelly, 1982). But the first archaeological research was carried out by archaeologist Antonio Benavides Castillo (1999). The results on the excavations showed that previous researchers used incomplete data about the morphology of the cylindrical tower.

Several studies focused on the astronomical function of the tower because it has some ducts going through the solid core of the cylinder (Andrews IV, in Aveni, 2005, p. 383; Benavides, 1999), but the interpretations on the nature of this building remained incomplete. Because of this, some authors mentioned that the function of cylindrical tower must remain as a "mystery," at least for now (see Aveni, 1991, pp. 306–308, 2005, p. 383).

Recent researches have proceeded on the interpretation of this "enigmatic" Maya building and a preliminary interpretation can be found at Higón Calvet and May Castillo (2011), but it is not the last word on the nature of this beautiful and unique sample of Maya architecture (Fig. 1).

P

Puerto Rico Tower

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Puerto Rico's cylindrical tower represents a unique case in Maya typologies of architecture.

Description

The tower is located in the municipality of Xpujil, Campeche, Mexico. The name of the site comes from the nearest community, called Puerto Rico. The tower is an architectural monument within an ancient Maya settlement (maybe a city-ceremonial center). The cylindrical tower is located at the center of a square (in Yucatec: *Chúumuk kaaj*), and other buildings can be found at the surroundings, but they remain still buried.



Puerto Rico Tower, Fig. 1 Puerto Rico's tower (Modified from Higón Calvet and May Castillo 2011)

No archaeological researches have been made in order to learn the nature of the other buildings; the only interest is in conservation of the tower. It is currently within an agricultural area (*milpas*) in the middle of the jungle. There are no guards at the site; nevertheless people from the community keep it safe.

Form

The morphology of this building can be divided, for purposes of analysis, into two parts: the main cylindrical body and the rectangular basement. The cylindrical body has 12 small ducts; some of them pierce its solid core. The cylinder has an elliptical section of 2.90 m at its main axis. The base is a rectangular prism, with curved corners and four elements added at each side; all of them resemble staircases. The base measures approximately 4.32 and 4.54 by side. The overall height of the tower is 7.45 m approximately, although originally it was higher. Benavides found the tower partially collapsed, and he only restored and consolidated the part still standing (Fig. 2).

Constructive System

The constructive system is in Rio Bec style. It consists of small ashlar [hewn or squared stones]

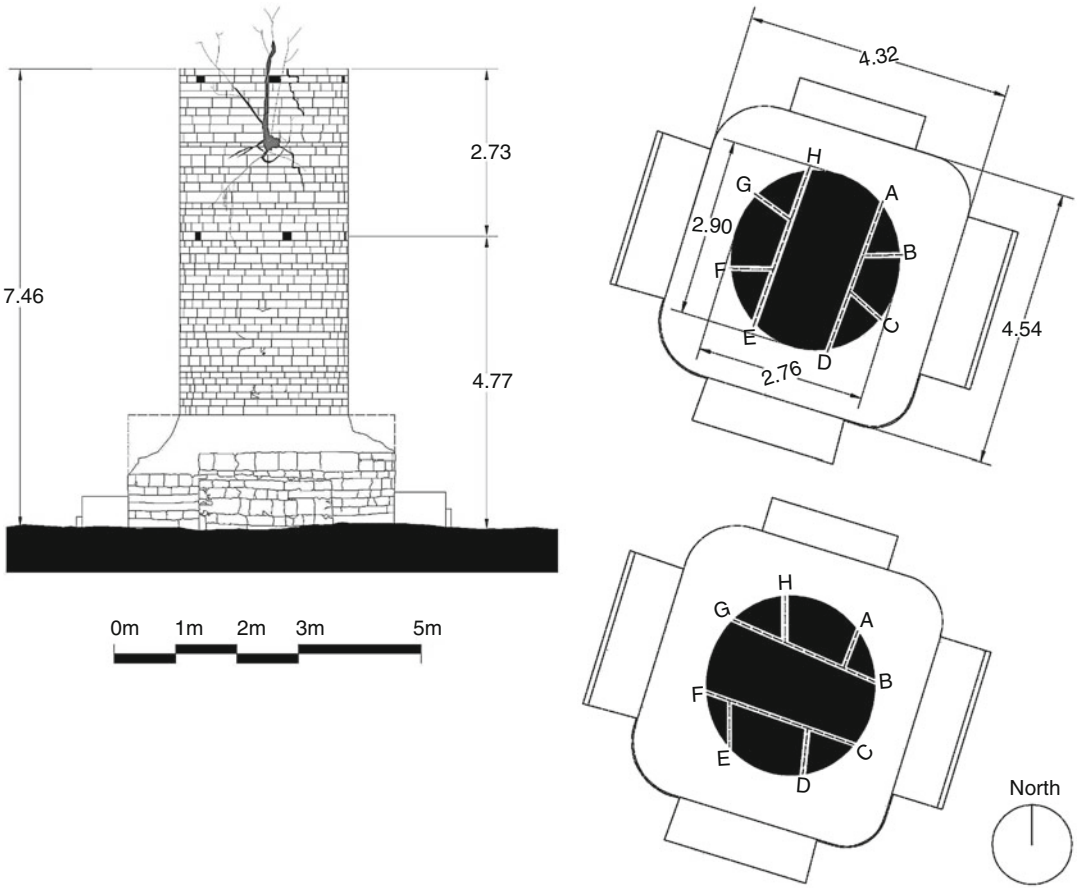
finely carved in the curved section, covering a solid core of masonry and calcium mortar. The tower is apparently a masterpiece of Rio Bec style. Previously, there were cylindrical columns of Hormiguero's structure II and the squared towers of Xpujil, Rio Bec, and Hormiguero sites, which are curved at the corners, similar to the base of Puerto Rico's tower. If we visit the sites of the Rio Bec region, we can find several beautiful samples of architecture which confirm the existence of master architects within a small area, who were using their creativity and experience in order to create unique masterpieces, such as the cylindrical tower at Puerto Rico.

Since carved ashlar were also found within the solid core (Benavides, 1999), we can confirm the ancient tradition of Maya builders: old buildings are reused to build a new one. In most cases, the old building is covered by the new one, as a first constructive layer. Of course, other cases only use parts of an ancient building, as in the Puerto Rico tower, at least in the cylindrical solid core.

The ducts are also made following Maya traditions; the ashlar are displaced some few centimeters in a certain row, but not in the next row, so we have a kind of small window made only by variation of separation between ashlar. At the interior of the solid core, two rows of ashlar are aligned and parallel to the axis of the duct. Horizontal slabs are placed at the top of the ashlar, shaping the ducts and also contributing to the mortar which fills out the core. Horizontal slabs are found not only in the Maya region but also in Mesoamerica, where we can find some tombs covered with horizontal slabs. As an example, we can mention the Monte Alban tombs.

Understanding

In the recent past, some scholars stated that one of the functions of the tower had to do with astronomical observations (Andrews IV in Aveni, 2005, p. 383; Benavides Castillo, 1999; Higón Calvet & May Castillo, 2011). But before continuing with this argument, we have to refine the statement of the astronomical function. First of



Puerto Rico Tower, Fig. 2 Map of Puerto Rico's cylindrical tower (Modified from Higón Calvet and May Castillo 2011)

all, we are not dealing with an astronomical observatory as it is understood in Western cultures. We are dealing with a building which integrated astronomical knowledge in order to transmit a set of deep messages related to the Mesoamerican cultural context. The minimalist concept of architectural design is the opposite of its symbolic complexity, as we will see below.

Continuing with the astronomical argument, the ducts were the evidence on which previous studies based their hypotheses of the tower's astronomical function. Since 1969 some authors argued that these were part of an astronomical system of observation. Nevertheless Aveni (1991, pp. 306–308, 2005, p. 383), after his field-work, argued that there were no reasons to consider the ducts as astronomical apparatus. Later

Benavides (1999), after his restoration, reported new ducts in a second level (which apparently were not detected by Andrews IV, Aveni, and others) and argued that there were some ducts pointing to positions of the Moon, the Sun, and other celestial bodies on the horizon line. Higón Calvet and May Castillo (2011), after revisiting the site, made new analyses considering their own data and Benavides' data. The authors confirmed some statements of Benavides, and they added that one of the ducts (C-F) points to a certain position of the Sun on the horizon, which marks the sunrise on the days when it passes through the zenith.

But, the tower is more than a building for astronomical ducts. Excavations of Benavides showed that the base of the building was not

conical as previous researchers thought. The base is squared and includes four altars like small staircases at each side. The base is oriented to the Four Directions of the Maya World. This means that deep symbolism is embedded in the architectural plan of the tower.

The Maya and Mesoamerican World have four main directions, related to four colors, and several deities are located at those four regions of the World. The regions of the World and their deities can be seen on pages 75–76 of the Maya codex at Madrid and also at page 1 of codex Fejérváry-Mayer from Central Mexico. The Maya (and Mesoamerican) World also has four corners which have sacred trees and birds. In the center of the diagram of codex at Madrid, we can see a central element which resembles a tree or central axis. The central axis of the World is a recurrent topic in several cultures around the world (see Eliade, 1974, pp. 269–271), and within the Maya worldview, the *Ya'ax che'* (ceiba tree) is, in a certain way, related to the *axis mundi*.

So, the base and altars can be related to the Four Directions and their deities. The cylindrical element appears as a central axis in this composition. At this point, we have to review the interpretations of the ducts.

Andrews IV suggested that the ducts were a sort of “psychoducts” similar to those found on the funerary monuments at Andean culture. “Psychoducts” would be open channels to communicate with the spirits of the people buried underneath the tower. But, Aveni argued that there is not enough archaeological evidence to consider the tower as a funerary monument. Actually, there were no excavations in the solid core of the base, but archaeological evidence points to ritual activities at the tower (Benavides Castillo, 1999). Additionally, the directions of the ducts seem to point to the Four Directions of the World and its corners, where deities are located. I agree with Aveni that there is no evidence for relating the tower with a funerary monument, but the idea of communicating with spiritual levels of the World (suggested slightly by Andrews IV) seems to be appropriate. If we are with contemporary Maya peoples, we can see

that ancient traditions are still alive, and the deities of the Four Directions are called to take part at contemporary rituals. So, the ducts could materialize the communication channels towards the spiritual level (a wider interpretation on the ducts can be seen at May Castillo 2014, pp. 379–382).

Since Higón Calvet and May Castillo state that the duct C-F points to zenith passages, we cannot reject the astronomical function of the cylindrical tower, but must always keep in mind the cultural context where the observations of the Sun are carried out. In other words, if the zenith passages were observed by the duct C-F, the meaning of this astronomical event has to do with Maya dates on the ancient calendar. The date has significance in terms of agriculture, because it indicates the beginning of the rainy season (see also Broda, 2004), and the religious rituals performed at the tower could be related to agricultural activities. But other religious rituals could be performed as well; we have to remember that there are more ducts than C-F and they are pointing to deity's localities.

Other towers in Tabasqueño, Chenchán, and Nocuchic have been related to zenith passages in the Maya region (Tichy, 1992), but the mechanism proposed for registering this astronomical event is by projecting shadows of stone “ledges.” Franz Tichy's hypothesis is very interesting, but it is based only on astronomical phenomena, and he does not link his argument with the ancient and contemporary Maya worldview. Those towers are squared in their horizontal section, so there are no similarities between them and Puerto Rico's cylindrical tower. Puerto Rico's tower remains a unique case where it is apparently pointed to the sunsets when the Sun passes through the zenith.

On the other hand, Benavides and Higón Calvet and May Castillo argued that other ducts are related to equinoxes and solstices, but there are enough reasons to believe that equinoxes and solstices were concepts of a Western worldview imported during colonial times (see May Castillo, 2014, pp. 167–171). Of course, there are some architectural orientations to the extreme positions of the Sun, but I believe they are pointing towards the corners of the Maya World. The ducts E and

F of the first level are pointing towards the center of the east and west directions, where two deities are located at each center.

State of Preservation

The fieldwork at Puerto Rico's tower in 2010, carried out with Félix May (a guard from the Instituto Nacional de Antropología e Historia and an expert on Maya culture), allows us to register the state of preservation of the tower, having in mind that it was consolidated and restored in 1999. Almost 11 years after Benavides intervention, the tower has been affected by natural agents; rainy and dry seasons stress the surface of the building, and this probably has destroyed some stucco remains which Benavides found. In 2010 there was a tree rotting at the top of the tower. Because of this, some cracks have appeared at the surface, and they were heading towards the solid core. Additionally, the forest surrounding the tower is often burnt during the dry season, when the temperature is about 40 °C.

Final Words

Puerto Rico's cylindrical tower is a unique masterpiece of Maya architecture. It has embedded both the fundamental symbolism of the Maya worldview and also some astronomical knowledge. Nevertheless its nature is still not completely understood. Future researches on the tower will shed more light on the understanding of Maya culture and its technologies.

Unfortunately the cylindrical tower remains endangered. It is attacked every day by natural phenomena and also by pathologies which must be stopped as soon as possible. If this does not occur in the near future, the building will collapse (at least partially) as has occurred with one of the Nocuchic's towers, which completely collapsed. And of course we, the scholars, will miss a unique opportunity to do research on an exceptional sample of Maya architecture.

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Putumana Somayāji

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Putumana Somayāji (ca. 1660–1740), author of the work *Karaṇapaddhati* (Methodology for Astronomical Manuals), was a *nampūtiri* (the appellation of the Brahmin community of Kerala in South India) who belonged to a family which bore the name Putu-mana (New House). He was of ṛgvedic denomination and secured the surname Soma-yāji by having performed the Vedic *Soma* sacrifice. His real name remains unknown.

K. V. Sarma: deceased.

The date of Soma-yāji is surmised on the basis of the chronogram which gives the date of completion of his *Karaṇapaddhati* (as 17,65,653) of the Kali era, stated in the *kaṭapayādi* notation of expressing numerals, which is in the year AD 1732. Again, in the concluding verse, Somayāji states that he hailed from the village named Śivapura, which has been identified as Covvaram in Central Kerala, where his descendants still reside.

Somayāji was a prolific writer mainly on astronomy and astrology, his only work in a different discipline being *Bahvṛcaprāyaścitta*, a treatise which prescribes expiations (*prayāścitta*) for lapses in the performance of rites and rituals by Bahvṛca (ṛgvedic) Brahmins of Kerala. In addition to his major work, Somayāji is the author of several other works. In *Pañca-bodha* (Treatise on the Five), he briefly sets out computations at the times of *Vyatipāta* (an unsavory occasion), *Grahaṇa* (eclipse), *Chāyā* (measurements based on the gnomonic shadow), *Śṛṅgonnati* (elongation of the moon's horns), and *Mauḍhya* (retrograde motion of the planets), all of which are required for religious observances. His *Nyāyaratna* (Gems of Rationale), available in two slightly different versions, depicts the rationale of eight astronomical entities: true planet, declination, gnomonic shadow, reverse shadow, eclipse, elongation of the moon's horns, retrograde motion of the planets, and *Vyatipāta*. Three short tracts on the computation of eclipses, including a *Grahaṇāṣṭaka* (Octad on Eclipses), are ascribed to Somayāji. He also composed a work called *Veṇvārohāṣṭaka* (Octad on the Ascent on the Bamboo), which prescribes methods for the computation of the accurate longitudes of the moon at very short intervals. A commentary in the Malayalam language on the *Laghumānasa* of Muñjāla is also ascribed to him. On horoscopy, Somayāji wrote a *Jātakādeśa-mārga* (Methods of Making Predictions on the Basis of Birth Charts), which is very popular in Kerala.

The *Karaṇa-paddhati*, in ten chapters, is his most important work. The work is not a manual prescribing computations; rather, it enunciates the rationale behind such manuals. Toward the

beginning of the work, the author states that he composed the book to teach how the several multipliers, divisors, and R sines pertaining to the different computations and the like are to be derived. Thus, the work is addressed not to the almanac maker but to the manual maker. All the topics necessary to make the daily almanac are not treated in *Karaṇapaddhati*, whereas several other items not pertaining to manuals are dealt with. The work takes as its basis the parameters and postulates of the Parahita system of astronomy promulgated by Haridatta, except for the section on eclipses, where the more accurate system from the *Dr̥ggaṇita* of Parameśvara is taken as the basis.

In Chapter I, the *Karaṇapaddhati* sets out the planetary parameters, the computation of the mean planets, and the corrections to be applied thereto. Chapter II is devoted to the derivation, by means of pulverization (*kuṭṭaka*), of the multipliers and divisors necessary for planetary computations. Chapter III is concerned with various aspects of the computation of the moon, and Chapter IV deals with miscellaneous matters relating to the determination of suitable epochs for commencing computations. Chapter V mentions methods for correlating observed results with computed results, while Chapter VI depicts such matters as the circle and the circumference and the R sines pertaining to various entities for different purposes. Chapter VII is devoted to the rationale of the derivation of the mnemonics relating to the epicycles, their R sines, and allied matters. Chapter VIII describes varied derivations using the gnomonic shadow. Chapter IX is devoted to stellar declination and latitudes. The last chapter is concerned with certain derivations from the shadow of the gnomon.

As a work on astronomical rationale and exposition of the logic of several practices, the *Karaṇapaddhati* is highly important. A very significant statement made by the Putumana Somayāji, toward the close of Chapter V, is that the conception of eons and eras, the measures therefore, and the various derivations based on them are not really true; they are only a means to compute the positions of celestial bodies and matters related to them. What is really important

is the correlation of computation with observation, and to effect the same, a practical astronomer is authorized to make changes as necessary. This is a highly significant statement, maybe even revolutionary, which was made in a forthright manner by an orthodox Hindu astronomer.

See Also

- [Eclipses: Calculating and Predicting Eclipses](#)
- [Haridatta](#)
- [Parameśvara](#)

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Pyramids in Egypt

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The pyramids of ancient Egypt still stand overlooking the Nile, bearing mute testimony to the civilization that constructed them nearly 5,000 years ago. Considering the magnitude of the effort expended, it seems surprising that no information about their planning or construction has been preserved. Such mysteries have generated an incredible array of hypotheses and suppositions concerning both construction techniques and cultural implications of the pyramid.

History

The origins of pyramid construction are obscure. The Step Pyramid of Third Dynasty Pharaoh Djoser (ca. 2667–2648 BCE) at Saqqara appears to be an elaboration of earlier funerary architecture, combining First Dynasty *mastaba* forms (low, flat mud brick, or stone superstructure above a subterranean burial vault and storage compartments) with the large, mud-brick-walled funerary enclosures of the Second Dynasty. Djoser's pyramid appears to be a first experiment in large-scale stone construction. Beginning as a mastaba, it was enlarged horizontally several times before building upwards, perhaps because the original low mastaba was not visible behind the wall surrounding the complex. A passage on the north led to a subterranean burial chamber with 11 subsidiary burial chambers. The adjoining storage chambers and corridors were decorated with blue faience tiles and relief sculptures of Djoser.

The Step Pyramid is only the most obvious structure on the site. Also inside the enclosure wall are temples, pavilions, mastaba-like tombs, chapels, as well as extensive storage structures. Most important of these was the mortuary temple placed on the northern side of the pyramid in imitation of the offering chapels attached to archaic mastabas, where offerings on behalf of the dead Pharaoh might be made. Early mortuary orientation to the north is taken to indicate a focus on the undying circumpolar stars in the northern sky. (In later pyramid complexes, the mortuary temple would be placed on the eastern side, facing the rising or reborn sun.)

The experiment in stone construction must have been regarded as a success, for the pyramid was rapidly developed in the Fourth Dynasty. The Pharaoh Sneferu (ca. 2613–2589 BCE) erected two pyramids at Dahshur, south of Saqqara. The Bent Pyramid's distinctive outline, with its shift from 54° to 43°, showed the necessity for a solid foundation. Built with much larger stones than the Step Pyramid of Saqqara and placed directly on the desert surface, subsidence, combined with less stable inward-sloping core blocks, soon introduced internal stresses that

caused fissures to appear in the structure. Apparently hoping to relieve some of the internal stresses, the builders changed the slope of the pyramid, but the damage to the structure was beyond repair. Learning from experience, Sneferu's architects then constructed the Red Pyramid a kilometer to the north of the Bent Pyramid. Here, although they retained the relatively shallow 43° angle, the builders first laid a solid stone foundation and then built on it with horizontal courses of stone to produce the first completely successful true pyramid. These early Fourth Dynasty pyramid complexes reveal the basic features characteristic of later pyramids. The pyramid is typically the focal point of an east–west oriented rectangular enclosure, containing an offering temple on the east side of the pyramid and often one or more subsidiary pyramids. A causeway, usually covered, led from the pyramid complex down to a valley temple near the banks of the Nile.

Following on these early experiments, the great pyramids of Giza were constructed. The largest was created by Sneferu's successor, Khufu (ca. 2589–2566 BCE). Two somewhat smaller pyramids belong to his son, Khafre (ca. 2558–2532 BCE) and grandson Menkaure (ca. 2532–2503 BCE). These pyramids mark a high point in terms of sheer physical size and engineering prowess. The Fifth Dynasty pyramids at Abu Sir are often held to represent the highest development architecturally of the pyramid complex and associated valley temple, although the pyramids themselves are distinctly smaller in size. They also reveal a significant decline in workmanship, perhaps paralleling the decline of centralized authority in the state. Their interior blocks were scarcely shaped, and the removal of the limestone casing blocks has left most of them looking like little more than piles of rubble.

Royal burials between the Sixth and Twelfth Dynasties largely abandoned the pyramid form. When it was revived in the Twelfth Dynasty (ca. 1895–1795 BCE), both construction material and construction techniques had changed considerably. The interior structure often consisted of little more than stone cross walls to give solidity

and rigidity to a mud brick or rubble-filled structure. The pyramids continued to be faced with high-grade limestone, however, and so would externally have looked very similar to earlier pyramids. They would have been more economical to build, however, since they require a considerably smaller workforce, as well as utilizing cheaper building materials.

By the end of the Thirteenth Dynasty, pyramids had once again been abandoned for royal burials. In the Nineteenth and Twentieth Dynasties (New Kingdom), however, small pyramidal structures often surmounted the funerary chapels of nonroyal burials. Important examples appear in the cemetery associated with Deir el-Medina, the town housing the workers who constructed the rock-cut tombs in the Valley of the Kings and Valley of the Queens, the new royal necropolis on the west bank of the Nile opposite Thebes.

Nearly 1,000 years passed before the pyramidal form was reclaimed for royal burials by the Nubian kings. Their pyramids are constructed from blocks of local sandstone. They have steep sides (approximately 70°) and are relatively small. Their apex is often flat. The burial chamber was not constructed inside or underneath the pyramid. Rather, the burial chamber, often decorated in Egyptian style motifs, was constructed, and then the pyramid was erected above it. The pyramid fields at Nuri and el-Kurru (above the fourth cataract) were constructed mainly between 770 and 400 BCE. Meroe (between the fifth and sixth cataracts) was an active necropolis until nearly 350 AD. These sites contain more pyramids than have been discovered in the Nile Valley.

Construction Techniques

The pyramid of Khufu involved quarrying nearly 2.5 million blocks of limestone weighing on average between 2 and 3 t, transporting them to the building site, and raising them into place. If the report of Herodotus, that the pyramid was completed in 20 years, is to be believed, this would require moving a block into place approximately every 3 min – a remarkable achievement indeed.

Although no documentary evidence has ever been found, there is ample circumstantial evidence to suggest that Khufu's pyramid was carefully planned, taking into account what had been learned in earlier construction attempts. The builders constructed a level foundation directly on the bedrock. The early suggestion that the site was leveled by surrounding the entire site with a low mud wall, filling the enclosure with water, and digging a series of trenches at uniform depth below the surface of the water (the intervening material could easily be removed later) no longer appears credible, but the precise technique remains rather mysterious. Most probably it was done by adjusting the foundation stones to provide a flat plane on which to build, a process that might be accomplished by using a simple A-frame tool to assess the leveling of the surfaces.

These pyramids are also remarkable for their accurate alignment with the four cardinal directions. This alignment must have involved some sort of astronomical technique. One suggested procedure involved bisecting the angle between the rising and setting point of a star in order to determine true North. Although this method sounds simple, it would require the construction of an artificial level horizon and very precise observations in order to obtain the observed accuracy of alignment. A somewhat easier technique would require erecting a gnomon perpendicular to the surface of the earth and constructing a circle about it with some convenient radius. It is then necessary to mark the two points during the day when the tip of the gnomon's shadow touches this circle, connect these two points to the gnomon, and bisect the angle so produced in order to determine true North. Although requiring simpler equipment, the observations must still be made with careful accuracy in order to produce the orientation we observe in Khufu's pyramid.

Large quantities of stone had to be quarried and transported to the building site. Extracting blocks of relatively soft local limestone for use in the core of the structure posed no technical difficulty for the ancient Egyptians. The stone block could be defined using traditional flint axes and

separated from the rock matrix with wedges. The quarries for the bulk of the stone lie on the Giza plateau almost below the pyramid building site itself. Facing blocks of high-grade limestone were brought from Tura, on the other side of the Nile. Granite, used in facing the corridors and chambers within the structure, had to be quarried in Aswan and transported to Giza by boat or barge. A very hard Plutonic stone, it required the use of dolerite mauls to work, since copper and even bronze were too soft to be effective. Recent experiments have shown that heating the stone using fire and then rapidly cooling the area with water causes the granite to fracture much more easily.

Once separated from the bedrock, the limestone core blocks were transported to the building site on wooden sledges pulled by teams of 15–20 men – more if massive blocks needed to be moved. The sledges could travel across firm surfaces using sets of wooden rollers as a kind of primitive wheel. If it were necessary to transport the blocks over sand, friction might be reduced by constructing a primitive roadway, embedding timbers in the desert surface on the pattern of railway ties or sleepers. When wet, the wooden sledge would slide quite easily across these wooden beams. There is still no conclusive evidence to indicate whether dressage occurred at the quarry sites or at the construction site.

Once at the pyramid site, the blocks had to be raised into position. The most prevalent view is that this involved recourse to a system of ramps, although there is no agreement on straight or helicoidal ramps spiraling around the exterior of the pyramid. Either proposal requires considerable construction of an ancillary structure that would later need to be removed. Opponents of ramps question where the evidence for removal of such large-scale ramps is. (Perhaps it was simply dumped into the quarries.) The most common alternative suggestion has been the use of some form of jacking mechanism, either directly through levering or indirectly through the use of "cradles" equipped with rockers that could be pushed to one side or the other while wooden planks were placed under the elevated side to raise the structure. (Examples of such rocker

cradles have been found near construction sites.) In practice, however, raising blocks to the level of about a meter using jacking techniques is difficult because the supporting structure rapidly becomes less stable with increased height.

More recently, a suggestion has been made that the “cradles” were not intended for rocking the stone upward, but that four cradles, attached to the faces of the block, might function as a kind of primitive wheel. A few preliminary tests indicate that such a configuration might work to move stones up a ramp. Another recent suggestion does away with both jacking and ramps, arguing that the blocks were simply pulled up the side of the pyramid mounted on their sledges and lubricated with water. This hypothesis would explain why there is little evidence of ramps surviving at the work site. It would also presuppose that the finished casing blocks must have been put in place immediately on completion of each course of core blocks. It also leaves open questions about the upper courses, where men would have had less room for maneuvering while raising the blocks a longer distance. Each theory has some merit to recommend it, as well as practical difficulties in application. It is likely that there was no single method used in every pyramid; probably an array of techniques was employed to solve these technical problems in various contexts.

In addition to the physical problem of raising sizable limestone blocks to a considerable height, it was necessary to control the shape of the pyramid in order to avoid deformations. Once again, we do not know exactly how the ancient Egyptians solved such problems. One simple-sounding technique would be to measure the sides at each course of stone to make sure they are still square (assuming that one had successfully laid out a square base), or perhaps each course was checked by sighting across the pyramid on the diagonals. But actually carrying out such operations might prove difficult. Measurement would require either the repeated application of a rigid measuring rod, which could allow small errors to cumulate over long distances, or use of a measuring rope, which would be subject to stretching or sagging and so also allows for

incursions of significant error. In this case, too, it is possible that various techniques were tried in various combinations on each pyramid that was constructed.

From very early dynastic times, there was a clear concern for security of tombs (including burial chambers within or below pyramids). Considerable treasure was interred with royalty, and wealth inevitably attracts robbers. Already at the construction of the Fourth Dynasty Bent Pyramid, we find the use of a portcullis system by which large (usually granite) blocks could be lowered to block passages leading to the burial chamber. Sometimes these portcullis blocks came with a kind of locking device to prevent robbers from lifting them with levers: a short rod would be placed in a small shaft at the side of a portcullis channel just above the height of the portcullis block and angled so that when the portcullis was lowered, the wooden rod would protrude into the channel, thus blocking any attempt to raise the portcullis using levers. In practice, such devices rarely delayed robbers long. They simply tunneled around or over the portcullis. Equally ineffective were the efforts to provide a means to block entrance tunnels with great blocks of granite drawn into the passage from the side or the use of gravity to slide granite blocks into a passageway, blocking access to the door to the burial chamber. Again, robbers were likely simply to tunnel past these obstacles. The lure of riches left no pharaoh undisturbed for long.

Pyramid Workforce

Herodotus, the Greek traveler who visited Egypt about 450 BCE, was told by his informants that it had required 100,000 slaves laboring for 20–30 years to build the pyramids of the Giza Plateau. Modern scholarship has painted a quite different picture. Mark Lehner has excavated a large urban complex on the Giza Plateau, separated from the pyramid worksite by a massive stone wall. This urban complex contained what appear to be barracks for workers, bakeries, and fish-processing installations big enough to produce

food for several thousand workers. It is believed that a contingent of about 5,000 skilled stoneworkers, together with a contingent of support personnel, were in residence in this center all year round. During the inundation period, there would be an influx of several thousand unskilled workers to provide the basic manual labor of cutting and moving stones from the quarries and from the harbor. These estimates coincide reasonably well with those made by a modern engineering firm who attempted to estimate the workforce based on application of techniques used to plan modern large-scale construction projects.

Zahi Hawass excavated the tombs of workers associated with the pyramid building process. These tombs imply that the builders were not slaves, for no slave would be able to construct a tomb out of rock nor would slaves have the financial means to decorate their tombs with inscribed and painted hieroglyphs. Analysis of the skeletal remains from the tombs shows distinct signs of heavy toil but also shows a level of medical care that would have been highly unusual for a slave population. Further, DNA analysis shows that these workers were certainly Egyptian, not enslaved foreigners or military prisoners.

This workforce was highly organized. A “crew” of about 2,000 was subdivided into two gangs, each of about 1,000 men. Each gang was further subdivided into five phylae (*zaa*), each containing 200 men. Each phyle was subdivided into 10 groups of 20 men each. Evidence for such a division of workers comes from graffiti left behind by members of the various groups. This hierarchical organizational plan was copied whenever large groups of people needed to be organized efficiently – for example, in the staff of the large cult temples.

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Pyramids of Mesoamerica

Geoffrey Mccafferty

The construction of monumental architecture is one of the archaeological hallmarks of social complexity. It involves the ability to mobilize and coordinate labor; it requires surplus manpower and material; it implies sophisticated knowledge of architecture and engineering; and it assumes a fair degree of administrative control. In evolutionary terms, monumental architecture appears when there is a fairly high degree of complexity, with multitiered political organization in what can be characterized as “chiefly” or “stratified” society. In pre-Columbian Mesoamerica, this level of complexity first appeared in the Early Formative period, ca. 1200 BCE, among the Olmecs of the southern Gulf Coast. In time other cultures also adopted monumental architecture for primarily religious purposes but also as a legitimization of political authority.

The most typical form of monumental architecture used in Mesoamerica was the pyramid. Pyramids were often perceived as artificial mountains, and they represented attempts by the ruling elites to construct a symbolic landscape. Most pyramids were built to correspond to cosmological principles, such as astronomical orientation. They also represented the recreation of an axis

mundi, a world axis where the pyramid became the cosmic center around which the rest of the universe revolved both vertically and horizontally. Mesoamerican pyramids were literally a “stairway to heaven” where a select few could rise above the mortal plane to communicate with deities of the multitiered heavens in temples on top of the pyramid platforms. Similarly, many pyramids were constructed over natural springs, caves, or artificially created portals into the underworld for access to the deities residing there. A pyramid, therefore, was a conduit linking the three planes of the cosmos, where powerful ruler/priests could communicate with the gods and petition them for supernatural assistance. In part because of this symbolic centrality, Mesoamerican pyramids were often rebuilt by encasing the old structure within new layers of fill and façade to enhance the cosmic significance with a connection to the ancestral past, and thereby adding a temporal dimension as well.

Pyramids were fairly basic in their architectural form, with simple mounds of packed earth as the most simple style. Others were made of mounded earth and rubble, sometimes segregated in cells for internal integrity. The most elaborately built pyramid was the Great Pyramid of Cholula, where the internal structure is made up of stacked adobe bricks to create a remarkably stable interior. Note that with very few exceptions the interior of pyramids was solid, lacking inner chambers. The importance of a Mesoamerican pyramid was as a platform for one or more temples located on top.

Despite the relatively simple internal construction, however, Mesoamerican pyramids were often elaborately decorated on the exterior. The staircase was a natural focus of the building program, since it was the means of ascending to the temple. Staircases were often quite steep, making a direct vertical climb difficult, particularly for heavily robed priests. One speculation is that ascent was made in a serpentine fashion, moving up diagonally. Priests in colorful robes and elaborate feathered headdresses, climbing in procession, would appear to spectators below as a polychrome feathered serpent undulating up to the inner sanctum of the temple. As will be

discussed below, the Feathered Serpent god was a unifying theme of Mesoamerican religion, particularly as it relates to political legitimation and priestly knowledge.

Pyramid façades were generally finished in cut stone and covered with layers of stucco. Particularly in the Maya area they were often elaborated with symbolically significant carvings, often depicting powerful deities. The temples themselves were occasionally decorated with the image of the earth monster whose open mouth formed the temple entrance, a portal into the underworld. Maya temples also featured elaborate roof combs of stone rising high above the temple itself, created in lattice format to depict further cosmological images visible from great distances (Fig. 1). The Maya temples were constructed using the corbeled vault technique so that the weight of the roof and roof comb was transferred to the thick walls, in what was the crowning achievement of Maya structural engineering.

Mesoamerica, consisting of central and southern Mexico, Guatemala, Belize, Honduras, and parts of El Salvador, Nicaragua, and Costa Rica, is a culturally complex region that, during the pre-Columbian era, was often characterized by overarching similarities. Religious beliefs were one of these, and the use of pyramids was common to Mesoamerican cultures for over 2,500 years. Other commonalities included the calendar system, ritual ballgame, maize/beans/squash as dietary staples, and human sacrifice to appease the gods. Nevertheless, due to the cultural diversity some regional and temporal variations arose. The following is a brief survey of some of the important pyramids of Mesoamerica within their cultural contexts.

The earliest clear pyramid is known from La Venta and corresponds to the Olmec culture of the Middle Formative period (900–500 BCE). The pyramid itself is just one manifestation of a massive landscape modification as the ruling elite transformed the ceremonial center into a cosmogram that constructed their capital as the center of the universe. The pyramid itself is made of packed earth, and has been compared to an effigy volcano. The Olmec heartland is in the



Pyramids of Mesoamerica, Fig. 1 Example of a Maya temple with roof comb (Palenque)

swampy lowlands of the Gulf Coast, so this pyramid may be a reference to the volcanic Tuxtla Mountains to the north, from which much of their building stone was imported. A more revealing monumental construction was intentionally buried beneath the plaza in front of the pyramid, where thousands of imported jadeite bricks were formed into a mosaic image of the jaguar-like earth monster and then covered by layers of imported, colored clays to symbolize the layers of the underworld. Taken as a meaningfully constructed building program, the La Venta ceremonial center represents the symbolic relationship between the three levels of the cosmos, as well as a major investment in labor and resources.

In the Maya lowlands, sites such as Uaxactun, Nacbe, and El Mirador demonstrate monumental architecture during the Late Formative period. El Mirador features the El Tigre pyramid complex, one of the earliest Maya pyramids that was also the largest in terms of volume at 380,000 m³. Another early Maya pyramid is found at Cerros, where elaborate building façades are interpreted as representations of astronomical passages as the

sun traveled from east to west on its daily journey. A symbolic reading of this again suggests that the universe revolved around the Cerros pyramid. This probably relates to both religious beliefs as well as political propaganda, as jadeite jewelry cached at the site has been interpreted as an indication of the creation of a Maya *ahaw*, or king, suggesting a new level in political complexity.

Monte Albán, located in the southern highland valley of Oaxaca, represents another example of monumental architecture that was begun in the Late Formative period (500 BCE–200 CE), though modifications continued through the Classic period (200 CE–800 CE). Located on a ridge high above the valley floor, Monte Albán's acropolis was created first by flattening the ridge top to form a level surface, then by building numerous large buildings around a rectangular plaza (Fig. 2). The largest pyramid is the South Platform, that in its final manifestation consisted of a massive platform with a smaller pyramid located on top. While religious practices were probably paramount on this structure, numerous carved stone slabs depict political scenes



Pyramids of Mesoamerica, Fig. 2 Acropolis of Monte Albán

including captives and an emissary from Teotihuacan, emphasizing the interwoven nature of Mesoamerican religion and politics. The North Platform is even more massive, but probably had a more secular function. A wide staircase leads to a plaza where public rituals were likely held, before smaller passageways lead to a more restricted area that may have been the royal residence. Other smaller pyramids delimit Monte Albán's plaza, which is clearly outlined on the horizon and visible from the valley floor as a sort of "Big Brother is watching" political message.

In central Mexico the great urban center of Teotihuacan arose in the Late Formative period, and around 100 CE embarked on a major urban renewal program that included a rigorous grid system based on its Avenue of the Dead. The Avenue is oriented at 16° east of North, with a pecked cross marker in the bedrock of Cerro Gordo mountain as a datum point for aligning the Avenue. At the northern end of the Avenue is the Pyramid of the Moon, framed by Cerro Gordo behind it and actually designed to mimic

the form of the mountain (Fig. 3). To the south is the Pyramid of the Sun, the largest of Teotihuacan's pyramids, and it too mimics the shape of Otumba mountain in the distance. A third pyramid in the western part of the city is similarly set in relation to the natural landscape, perhaps as an intentional cosmogram in which the hills and the pyramids represent the three hearth stones symbolic of symbolic centrality.

Excavations beneath the Pyramid of the Sun discovered a long passageway, excavated into the volcanic bedrock for building materials but then modified into an artificial cave where rituals were performed. The form of the inner chamber resembles the flower shape of Chicomoztoc, the cave of origin from later Aztec mythology, suggesting that later peoples may have continued to worship in the artificial cavern at Teotihuacan. The entrance to this tunnel is beneath the west facing staircase onto the Avenue of the Dead, and therefore faces 16° north of west, the orientation of the setting Pleiades constellation which marks the beginning of the rainy season. It is possible,



Pyramids of Mesoamerica, Fig. 3 Teotihuacan's pyramid of the moon

therefore, that the entire urban renewal program around the Avenue of the Dead makes Teotihuacan an elaborate celestial almanac relating to the all-important rains.

Recent investigations into Teotihuacan's Pyramid of the Moon, as well as the Pyramid of the Feathered Serpent, have discovered sacrificial burials of warriors, perhaps as dedicatory offerings to the lords of the underworld. These burials are clustered in groups of 9, 13, and 20, numbers symbolic of cosmological principles including the sacred 260-day calendar. The stone façade of the Feathered Serpent Pyramid features a long rattlesnake body (covered in feathers) undulating in profile but with a front-view head surrounded by more feathers (Fig. 4). This image is generally identified as a "feathered serpent" but is also similar to the *axolotl*, a species of salamander that lives in the lakes of central Mexico and has feathery gills that encircle the head. On the back of the serpent is an elaborate mosaic headdress representing political office (a similar scene adorns the mosaic façade of the Nunnery Compound at the Maya site of Uxmal). Curiously, the west façade of the Pyramid of the Feathered Serpent was covered over by later construction to obscure, and thereby unintentionally preserve, this iconographic program.

Pyramids dot the Classic Maya landscape where, because of the prevalence of textual

evidence on carved stone markers, they can occasionally be related to the particular ruler who commissioned their construction. Some of the most impressive pyramids come from Tikal, the capital of a Maya "superpower" of the sixth through ninth centuries. For example, Temple I reached 52 m in height, with its temple structure and roof comb reaching above the current jungle canopy (Fig. 5). Contemporaneous with these is the Temple of the Inscriptions from Palenque, where extensive hieroglyphic texts record the lineage history of King Pakal. A trapdoor in the floor of the temple led to a passageway down through the pyramid itself to a subterranean chamber where Pakal's sarcophagus was found (Fig. 6). This use of a pyramid to enshrine a ruler is unusual in Mesoamerica. Other pyramids at Palenque include the Cross Group, where three small temples represent the three hearth stones, a Mesoamerican metaphor for the cosmic center. Another major Maya center was Copán, located in modern Honduras. It is famous for its elaborately decorated architecture and the many carved stone stelae that recount dynastic histories. Its largest pyramid was Temple 26, known for its hieroglyphic staircase representing the longest known text in the Mayan language; unfortunately early explorers stripped the carved stairs from their original position before randomly replacing them out of order so attempts at decipherment are still furtive.



Pyramids of Mesoamerica, Fig. 4 Serpent/Axolotl on façade of Teotihuacan's feathered serpent pyramid

**Pyramids of
Mesoamerica,
Fig. 5** Tikal temple I





Pyramids of Mesoamerica, Fig. 6 Palenque's temple of the inscriptions, indicating passage to a subterranean crypt

Following the collapse of Teotihuacan and Monte Albán at the end of the central Mexican Classic period (ca. 700–800 CE), Maya influences in the central highlands of Mexico resulted in architectural innovations that affected pyramids at sites such as Xochicalco, Cacaxtla-Xochitecatl, and Cholula. Similar to Monte Albán for the scale of modifications to the natural hilltop, Xochicalco is best known for its Temple of the Feathered Serpent. Large feathered snakes curl around the walls of the pyramid base, with Maya-style lords seated within the curves of the serpent's body (Fig. 7). Glyphic inscriptions in a non-Maya – and as yet undeciphered – script likely describe conquests and/or political alliances. Cacaxtla boasts beautiful polychrome murals, again in Maya style, on the walls of Building B at the north end of its acropolis. The murals depict the aftermath of ethnic conflict between an army with Maya costume and physiological traits, who have been defeated by another group. As a result of this battle the female war-chief of the Maya group is captured, perhaps to become the founding queen of a new, united lineage. On the adjoining hill of Xochitecatl, the Pyramid of the Flowers was likely dedicated to a

goddess cult. The staircase is made up of basalt grinding stones, an artifact closely associated with female domestic practice. On top of the pyramid, caches contained dozens of female figurines depicting different phases of the female life cycle, especially motherhood, and also hundreds of clay spindle whorls, another characteristic of female practice.

The largest pyramid in Mesoamerica is at Cholula, located in the Puebla/TLaxcala valley east of Mexico City. It was built in successive stages over a period of over 1,000 years (Fig. 8), and it remains an important religious site with its Colonial church dedicated to the Virgin of the Remedies perched on top and attracting tens of thousands of pilgrims annually. The Great Pyramid of Cholula is known as *Tlachihualtepetl*, literally an artificial mountain. Its construction history has been studied using 8 km of tunnels cut through the adobe brick construction to reveal at least four major construction stages. The final stage measured at least 400 m on a side, and 65 m in height (although the construction of the Colonial church undoubtedly destroyed the uppermost levels). The Great Pyramid was oriented toward the setting sun at summer solstice,



Pyramids of Mesoamerica, Fig. 7 Temple of the feathered serpent at Xochicalco



Pyramids of Mesoamerica, Fig. 8 Great pyramid of Cholula with church to the Virgin of the remedies on *top*



Pyramids of Mesoamerica, Fig. 9 Puuc architecture at Chichen Itza

the longest day of the year, so that the temple on top of the pyramid would have been the last place illuminated by the setting sun.

The relationship between Maya and central Mexican architecture is particularly strong at the sites of Chichen Itza, in northern Yucatan, and Tula, located far to the west. Chichen Itza features Puuc style architecture with elaborate stone mosaic work to create geometric patterns and visages of deities (Fig. 9). But it also has other architecture with distinctive features that have traditionally been labeled “Mexican” following ethnohistorical accounts that Toltecs from central Mexico invaded the region. This interpretation has been challenged, however, with new dates that suggest that Chichen predates Tula, the highland capital of the Toltecs. Numerous decorative features from both Chichen Itza and Tula are virtually identical, including the use of reclining Chacmool thrones, feathered serpent columns, and colonnaded areas. The close similarities between the two sites has led many to suspect that the two were eastern and western capitals of an extensive Toltec empire, but a near total lack of related elements in the intervening territory adds to the enigmatic status of the two sites. The large pyramid at Chichen Itza is

notable because of the feathered serpents that flank the radial staircases (Fig. 10). The pyramid is oriented so that, at the spring equinox, shadows formed by descending serpents appear to undulate down to earth; this phenomenon is a popular tourist attraction drawing thousands to witness the illusion, including living Maya who continue to revere the site. At Tula, north of modern Mexico City, the ceremonial center has a nearly identical plan (albeit 90° off from Chichen Itza). Pyramid B closely resembles Chichen Itza’s Temple of the Warriors, with stone warriors as building columns that must have supported the roof (Fig. 11).

The Gulf Coast site of El Tajín does share some iconographic characteristics with Chichen Itza, especially in the use of elaborately carved columns and ball court. Narrative qualities of the carvings seem to relate to political legitimization and alliance building, again emphasizing the ideological content of the built environment. The major pyramid at El Tajín is known as the Pyramid of the Niches, named for 365 empty niches that decorate the façade (Fig. 12). Conceivably these would have originally held idols of gods associated with different days of the solar year. Large slabs at the base of the pyramid were



Pyramids of Mesoamerica, Fig. 10 The Castillo pyramid from Chichen Itza



Pyramids of Mesoamerica, Fig. 11 Pyramid B from Tula, showing warrior columns

drilled with holes where banners representing conquests or forged alliances would have been raised.

The final pyramid to be discussed is also the best known, though ironically it is almost

invisible today. When the Spanish entered the Aztec capital of Tenochtitlan in 1519, the Great Temple was the ceremonial center of the Aztec empire. Spanish conquistadors described the temple and associated rites of sacrifice, and artists in



Pyramids of Mesoamerica, Fig. 12 Pyramid of the niches at El Tajin



Pyramids of Mesoamerica, Fig. 13 Depiction of great temple in Codex Duran

the early Colonial period illustrated the Temple. Typical of Aztec pyramids, the Great Temple featured two temples atop a single pyramid base. These were dedicated to Huitzilopochtli, the patron god of war, and Tlaloc, god of storms and rain (Fig. 13). However, shortly after the

Spanish defeated the Aztecs they tore down the Great Temple to build their own Colonial capital. Fortunately for later archaeologists the lowermost levels of the pyramid were preserved beneath the rubble (Fig. 14). When utility workers dug at the site in the 1970s they chanced upon a



Pyramids of Mesoamerica, Fig. 14 Excavated great temple of Tenochtitlan

massive carved stone representing the dismembered moon goddess Coyolxauhqui, and based on this discovery a monumental excavation project was begun by the Mexican government to expose the remains of the Great Temple. According to Aztec myth, the Great Temple represented the serpent mountain, Coatepec, where Huitzilopochtli killed his sister, Coyolxauhqui, while defending his mother, Lady Serpent Skirt/Coatlicue. This mythico-historical drama was played out at the Great Temple, which featured serpent head iconography to make it “Serpent Mountain,” while the dismembered moon goddess lay at the base of the staircase. Archaeologists have found hundreds of ceremonial offerings at the Great Temple that further emphasize the symbolism of the site. For example, stone boxes contain layered dioramas of the three-tiered cosmos represented by successive layers of sea, land, and sky creatures. Sacrificial victims climbing the steps of the pyramid, only to have their hearts removed and their bodies hurled back down the bloody steps, were themselves participating in the mythic drama of creation and rebirth.

The Pyramids of Mesoamerica are among the most visible monuments of the ancient cultures of the region, and the stories that they tell are important clues to the belief systems of the people. Modern tourists marvel at the grandeur of these structures, built using Stone Age technology and without the benefit of draft animals or complex engineering. In fact, the pyramids of Mesoamerica are relatively simple mounds of rock and rubble, albeit decorated with often elaborate stucco façades. What is truly remarkable about these monuments is the meaning content that they embody, as cosmograms reenacting and centering cosmic forces, and as political narratives to legitimize the ruling elite. These pyramids encode important messages about Mesoamerican belief systems, and the critical yet imaginative interpretation of these monuments reveal the mythstories of the Mesoamerican world.

See Also

- [Calendars in Mesoamerica](#)
- [Cosmology in Mesoamerica](#)
- [Time](#)

Q

Qāḍizāde Al-Rūmī

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Qāḍizāde al-Rūmī (Ṣalaḥ al-Dīn Mūsā b. Muḥammad b. al-Qāḍī Maḥmūd), one of the founders of Ottoman science and philosophy, was born in Bursa, in Turkey, about 765 AH/AD 1364. His talent for scholarship was early recognized, and his teacher, Mollā Fenārī, recommended that he continue his studies of mathematics and mathematical astronomy among the scholars of Transoxiana (a portion of Central Asia straddling the borders of present-day Uzbekistan and Kazakhstan), then a major center of scholarship and patronage. Consequently, about 814 AH/AD 1410, he migrated to the court of Ulugh Beg, governor of Samarqand (in what is now Uzbekistan) and serious amateur astronomer, and joined his retinue. He quickly gained favor with the court, in part because he dedicated his commentaries on al-Samarqandī's *Ashkāl al-ta'sīs* and on al-Jaghminī's *Mulakhkhaṣ fī'l-hay'ah* to Ulugh Beg.

In 824 AH/AD 1421, 4 years after establishing a major *madrasa* (school of advanced studies), Ulugh Beg decided to establish an observatory in Samarqand in order to complete and improve the data collected by Naṣīr al-Dīn al-Ṭūsī and his

assistants in the *Zīj al-Ilkhānī*. Al-Rūmī, along with his younger contemporary, Ghiyāth al-Dīn Jamshīd al-Kāshī (d. 832 AH/AD 1429), played an important role in both institutions. When al-Kāshī died, al-Rūmī succeeded him as director of the observatory. The work was still incomplete at the time of al-Rūmī's death (after 844 AH/AD 1440). It was finally completed by Alī Kushjī under the title *Zīj-i Jurjānī*.

Al-Rūmī also authored an influential commentary on Umar al-Jaghminī's (d. ca. 745 AH/AD 1345) compendium of cosmography, *Sharḥ mulakhkhaṣ fī'l-hay'a* (Summary Commentary on Hay'a/Mathematical Cosmography). In the field of mathematics, he is best known for his commentary on al-Samarqandī's *Ashkāl al-Ta'sīs* (*Fundamental Theorems*) [De Young, 2001]. These treatises had special appeal for al-Rūmī because they resonated with his Platonizing approach to mathematics [Fazlıoğlu, 2008]. His commentaries became standard texts to be read at the intermediate (*iktisar*) level in Ottoman madrasas. The influence of these two commentaries is also attested by the existence of numerous super-commentaries in Arabic, Persian, and Ottoman Turkish. Both commentaries were disseminated in lithograph editions during the nineteenth century.

Al-Rūmī's *Risālat al-jayb* (Treatise on the Sine) displays a greater independence of thought, but even here he relies on the iterative

techniques developed by al-Kāshī in order to find the sine of one degree.

See Also

- [Al-Kāshī](#)
- [Al-Samarqandī](#)
- [Hay'a](#)
- [Naṣīr Al-Dīn Al-Ṭūsī](#)
- [Observatories in the Islamic World](#)
- [Ulugh Bēg](#)
- [Zīj](#)

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Qanat

Arnold Pacey

The *qanat*, invented in Iran, is a tunnel that allows a well in hilly country to supply water to users on lower ground by gravity flow.

Once the well has been sunk and has proved to be a good source of water, the route of the tunnel is carefully surveyed, and a series of further wells or guide shafts is dug, each one about 300 m from the next. Excavation of the tunnel begins at the intended outlet and proceeds from the foot of one guide shaft to another. The depth of these shafts has previously been set, so that when the tunnel links them all together, it will have an even gradient of about 1:500. The head well may be anything from 15 to 100 m deep, and tunnels are frequently 2,000 m or more in length (Fig. 1).

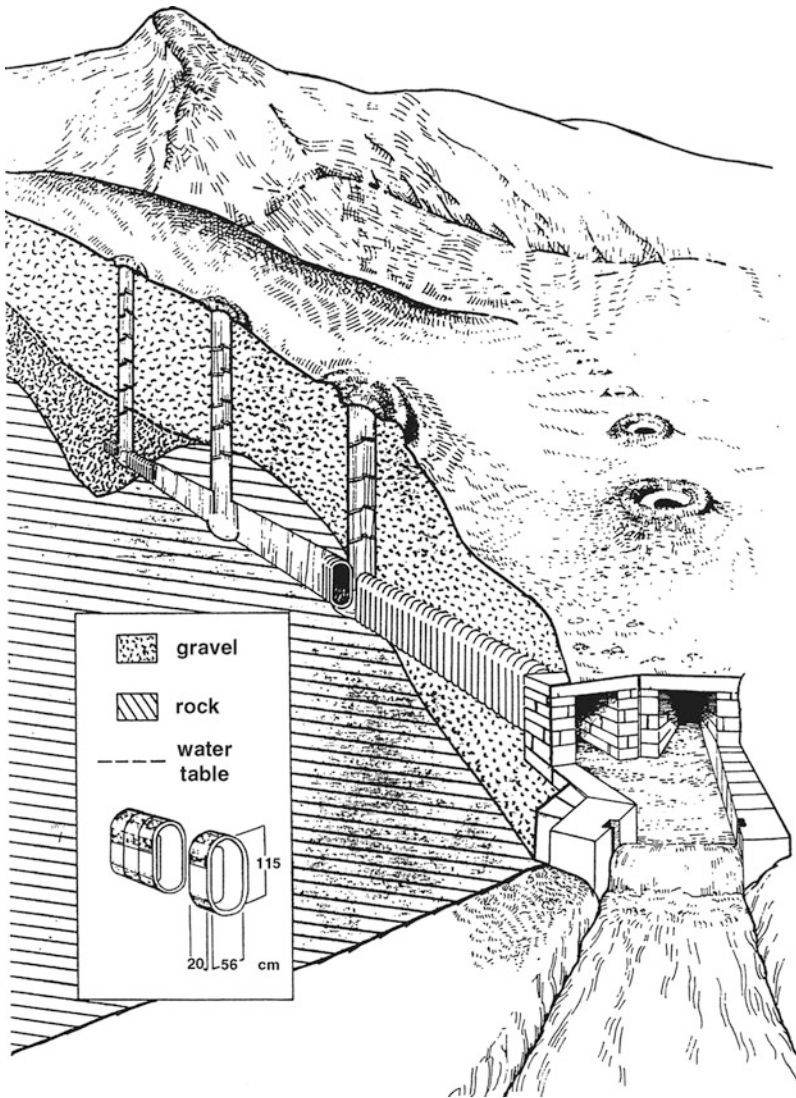
As Andrew Watson points out, the history of the qanat can be clearly illustrated by a distribution map showing where water supplies of this kind are to be found. Before the time of Alexander the Great, i.e., before 330 BCE, about the only qanats known to have existed were in Iran. A thousand years later, around AD 700, qanats had been constructed in the Arabian Peninsula and Syria as well as in Persia. But then the Islamic people took up the qanat in a big way. Books were written on the subject in AD 840, and by al-ḥasan al-ḥāsib around AD 1000. Knowledge of the technique spread east to Afghanistan and west through North Africa to Morocco, Mauritania, and Spain.

Qanats continued to be developed in later centuries. By the sixteenth century, potteries were making earthenware rings for lining the tunnels where they passed through soft ground. In 1960, three-quarters of all water used in Iran came from qanats, with Tehran alone having 36 of them bringing water from hills several miles away.

The word “qanat” in Arabic is said to be the source of the English word “canal,” which was initially used to mean a pipe or tube or tunnel carrying liquid; it retains that usage in anatomy – hence, alimentary canal.

See Also

- [Agriculture in the Islamic World](#)
- [Irrigation in the Islamic World](#)
- [Technology in the Islamic World](#)



Qanat, Fig. 1 Two qanat tunnels in a typical landscape, where rainwater running off mountains replenishes groundwater beneath the sand and gravel of the lower slopes. (Water-bearing gravel is shown darker than the dry gravel layer above.) The ground penetrated by one of the qanats is shown in cut-away section to demonstrate how the tunnel gives access to water trapped by impervious rock. The section also shows how the tunnel is lined with earthenware rings when passing through sand or

gravel layers which might otherwise cave in. Qanat tunnels were excavated from the bottoms of a series of well shafts, with the “mother well” at the upstream end dug first to prove the existence of water. The tunnels were sometimes several kilometers long with their route evident on the surface from the line of well shafts, as on the right of the picture (Illustration by Hazel Cotterell based on sketches by Arnold Pacey. Reproduced from Pacey, 1990, p. 86)

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Qasba in the Maghrib

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Qasba-s as fortifications fall into the broad category of power, status, and security artifacts. *Qasba* (*qaṣaba*, pl. *qaṣabāt* (Std. Arabic); dialectal pl. *qṣābī*) is usually rendered as castle, fort, fortress, château, or citadel – terms that in their own cultural setting are fully as generic as *qasba*. Such terms, however, evoke images and institutional frameworks (European, medieval and feudal) that do not really suit *qasba*-s. The mystique and appeal of *qasba*-s is a product of the same colonial-era art and literature that popularized the blanket use of *qasba* to label fortified places in the Maghrib (western North Africa) rather indiscriminately. The usage and the associated romantic flavor spilled over into nineteenth- and twentieth-century European historiography and anthropology.

In Arabic sources going back to the third AH/CE eighth century to seventh AH/CE thirteenth century, the fortification terms *ḥiṣn*, *qaṣr*, *qal'a*, and *ma'qil* (refuge, base) are far more common than *qasba* (Benhima, 2008). Moreover, if and when used, *qasba* often conveyed specific nuances: (a) keep, as core (*jawf*) of a fortification (the command post and residence), and (b) the political and economic central place of an area, a collective space. The latter sense resonates in the pre-Saharan Maghrib to this day, even though meanings have shifted compared to what they were before c. 1600 CE: *qasba* now tends to denote a private elite residence with quarters for a retinue/garrison, while the defensible collective and economic space usually is a fortified village, a *qaṣr* (*ksar*, pl. *ksour*).

The term *qasba* as commonly used and misused covers a wide range of structures differing in design, building materials, structural engineering, topographic setting, and date of origin. At one end of the spectrum, we find walled encampments (*amṣār*, sing. *miṣr*) (mostly long destroyed, overlaid by later works, or absorbed

into urban fabric), palace precincts, or urban citadels (freestanding or tied into the defenses). At the other end, *qasba*-s comprise modest local forts, the fortified habitat of kin groups, collective emergency refuges, fortified granaries shared by multiple stakeholders under customary law, and even old caravan way station enclosures (*nzāla*-s) maintained by local lineages as guarantors of travelers' safety. The array of *qasba* types does not represent, however, any straightforward sequence from "primitive" to "advanced." Regardless of date, different kinds of *qasba*-s were adapted to needs, means, and context.

Qasba-s are not easily reduced to a military dimension alone. They fulfilled diverse political, socioeconomic, ideological, propagandistic, and socially differentiating functions. Military aspects were intertwined with the other ones often, but not always. The *qasba* as a palatial precinct, even when designed as a fortification or nestled inside outer defenses, was laid out to stage the ceremonial discourse of power. *Qasba* quarters welded to or embedded in historic town cores (*médinas*) constitute a later development. Almost any type of *qasba* – if urban, large enough, and eventually overrun by private or kin group houses forced into high-density patterns by constraining fortifications – could give rise to a *qasba* quarter. Parallel urbanization during the colonial/Protectorate period (*médina* complemented by a separate *ville nouvelle*/colonial town) – a conservation-minded process but also one imbued with colonial ideology – favored the persistence of *médina/qasba* pairs in the Maghrib.

In various well-preserved Maghribī *qasba*-s, the visually dominant parts often date to c. 906 AH/CE 1500 and later. Key components range from Sa'did or 'Alawid (Morocco) and Ḥafṣid (Tunisia and Algeria) to Ottoman (across the Maghrib). At coastal locations formerly occupied by Europeans, mainly in the sixteenth century, prominent elements tend to be Portuguese (Morocco) or Spanish (Morocco, Algeria, Tunisia). Remnants of pre-1500 CE walls, gates, or towers may be embedded deep within later works (e.g., at Ceuta or Safi) – an aspect highlighted especially in recent historical and archaeological



Qasba in the Maghrib, Fig. 1 The *qasba* of Agadir from the air, before its destruction in 1960 (View adapted and enhanced from an early colonial-era photograph)

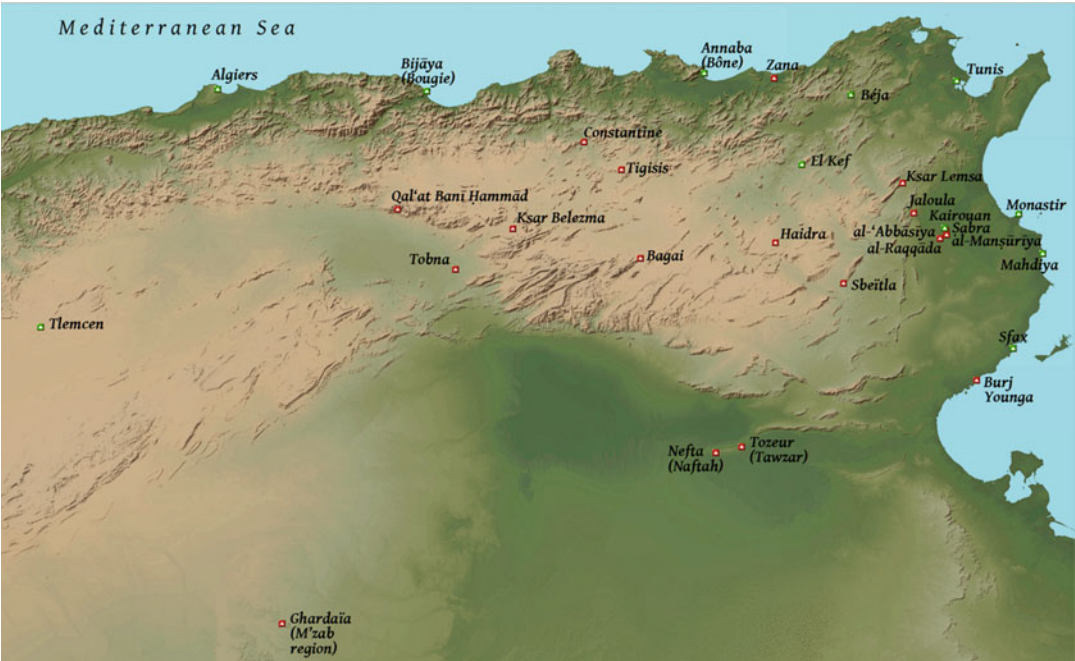
research (Ceuta or Tangier) (Elbl, 2012). Some seventeenth- to nineteenth-century *qasba*-s or associated defenses were partly designed by hired foreign experts, mostly European or Ottoman, e.g., at Essaouira (Mogador/Amagdūl (Morocco), basic layout by Théodore Cornut, 1764) or at Agadir (Morocco) (hilltop *qasba* destroyed in 1960 by earthquake) (Fig. 1).

Extensive gaps remain in data regarding Maghribī *qasba*-s. Closely related settlement patterns, auxiliary defensive systems, and hydraulic installations, especially those dating to the immediately pre-Islamic and early Islamic periods (late sixth century CE to the early fourth AH/CE mid-tenth century), have not been explored in detail. This affects our comprehension of the dynamics of past land use, the politics of water, community organization, landscape change, and collective defense (Benhima, 2008). This is especially true in Algeria, in eastern Morocco, along the pre-Saharan desert edge, and also at various oases west of the Fazzān region of southwest Libya. One of the exceptions is the old urban core of Sijilmāsa, to which al-Muqaddasī, for

instance, referred as *qasabat al-bilād* (i.e., the central place or *qā'ida*) of its district (Tafilālt oasis, southern Morocco; key archaeological campaigns from 1988 to 1998) (Messier, 1997a) (Figs. 2 and 3).

Qasba as a Spatiotemporally Hybrid Concept

What stands out readily for most observers is the contrast between *qasba* as a citadel or a palace/administrative precinct, the size of an urban quarter, and “kasba(h)” as the fortified village or collective granary (a *qṣar*, *agadīr*, or *ighrem*) that constitutes a widely recognized identity icon of pre-Saharan Morocco (Nijst, Kasba 64 Study Group, et al., 1973). This icon has now become a hospitality industry marketing tool, in the shape of neo-kasbah and post-kasbah pastiches designed to hint at Amazigh (Berber) heritage (e.g., the ecolodge Atlas Kasbah in the Sūs). The kasba(h) is commonly associated with the use of *ṭābiya* (replaced by concrete in modern



Qasba in the Maghrib, Fig. 2 Important *qasba* and related sites in the Central and Eastern Maghrib. Locations shown cover all periods mentioned in the article. *Green icons* indicate urban sites; *red icons* indicate sites at least initially rural in character or remote



Qasba in the Maghrib, Fig. 3 Important *qasba* and related sites in the Western Maghrib. Locations shown cover all periods mentioned in the article. *Green icons* indicate urban sites; *red icons* indicate sites at least initially rural in character or remote

imitations), unbaked brick (adobe), and mixed materials. This style confronts the traveler mainly in parts of the western High Atlas, along the pre-Saharan slopes of the Middle Atlas and eastern High Atlas, in the eastern Anti-Atlas, the Siroua, the Dadès, the Dar'a Valley, and the Tafilālt. Even in these areas, however, and certainly elsewhere, competing and less publicized fortifications feature dry stone or rubble masonry (as did various Almoravid *qaṣba*-s).

The indiscriminate use of *qaṣba*/kasba(h) to designate disparate defensive structures is relatively recent. By the late 1930s the attention of the public and of colonial/Protectorate authorities was being drawn to the “kasba berbère” of the Dadès and Dar'a valleys as an architectural type, to the “route des kasbas” as a tourist itinerary, and to the area from Ouarzazate to Kelaa Mgouna as a heritage zone, in order to fund the exploration of Amazigh architecture (Terrasse, 1938 (2010)). An earlier trend, from the 1850s onward, had seen various *qā'id*-s of the Moroccan *makhzen* and later on *qā'id*-s cooperating with France to label their bases kasba(h) – i.e., *chef-lieu*, central place. The two trends blended, and the term kasba(h) spread to the settlements of various *amghar* (leaders) and kin groups. For the casual visitor, the *Amazigh ighrem* (dim. *tighremt*) and *agadīr* (pl. *igudār*) thus became a romanticized kasba(h). A similar drift affected functionally equivalent structures – the Rīfī *aqrār* (or *hrī*), the *guella* (*guela'a*, *gual'a*) (Algeria (Aurès)), and the *gṣar* or *ksar* (pl. *gṣūr*, *ksour*) of southern Tunisia and Tripolitania (De Meulemeester, 2003). The trend proved enduring. In Morocco, new rural heritage surveys (1980s to present) started by showcasing the iconic kasbas and ksour of the south.

The *qaṣba*/kasba(h) dichotomy was compounded, from the late 1970s, by critical study of historic settlement patterns and organization of rural space in al-Andalūs and in the early Islamic Mashriq (East). Research relating to the Maghrib lagged by comparison (Cressier, 1995). Conceptual filters focusing on al-Andalūs, readily available and methodologically more advanced in the 1980s, were thus prone to obscure the Maghribī specifics of terms such as *qaṣba*, *hiṣn* (a larger freestanding fortification

dominating interlaced rural settlements (*qarya*-s)), *qal'a* (usually a mountain fortress), *ṣakhra* (or *ṣukhayra*, mostly a collective refuge, often on a naturally defensible crag), *burj* (detached auxiliary fort or redoubt), and *ṭālī'a*, *nāḏūr* (dial. *nāḏūr*) (watch tower), or *maḥras* (pl. *maḥāris*) (a blockhouse with observation post). The ambiguities were aggravated by the fact that historic derivatives of *qaṣba* in Iberian languages – *alcazaba* and *alcáçova* – had drifted their own way, over centuries, entrenching definitions and concepts that did not necessarily match Maghribī situations.

The Origins of the *Qaṣba*

Local solutions, technological borrowing, invention, and adaptation intersect in *qaṣba*-s. Reassessments of the “siècles obscurs” (dark ages) of Maghribī history (fifth to ninth centuries CE) suggest that Late Antique and Byzantine defenses, bearing an imprint of emergencies and already incorporating salvaged materials, represent one of the inputs. Another strand was local Late Antique and subsequent nucleation: the shift to compact fortified rural settlements that altered parts of Roman Africa's landscape of open farms and large export-oriented estates (Fenwick, 2013). The third strand presaged the *qaṣba* as *extra muros* walled camp (a *miṣr* or *maḥalla* (Berber *āfrāg* or *tagrārt*)) or the inner core of such a camp. The type emerges by the second AH/CE eighth century, e.g., at Walīla (Volubilis (Morocco)), as a segregated settlement for eastern (not always Arab) newcomers (Fentress & Limane, 2010). Such *miṣr*-s reflect the parallel urbanization documented in the Mashriq from as early as 29 AH/CE 650, e.g., at Byzantine Aila/Umayyad Ayla in the Gulf of 'Aqaba or at the twice-besieged Sāsānian Iṣṭakhr in the Fārs (Iran) (23 AH/CE 643–29 AH/CE 649–50) (Martínez Enamorado & García Alfonso, 2002). The fourth strand was palace/administrative precincts insulating key power players from the urban populace and from the fractious Arabo-Persian *jund* military. The trend is highlighted in Ifrīqiya (Tunisia) by 185 AH/CE 801, with the founding by *amīr*

Qasba in the Maghrib,

Fig. 4 The Byzantine walls of Tebessa in the later nineteenth century. Note the reuse of salvaged components, such as drum sections of columns (Early photograph (c. 1850–1890))



Ibrahīm b. al-Aghlab of the *al-‘Abbāsīya* precinct south of Kairouan (Qayrawān). Later precincts, nearby, presaged the model’s persistence: Aghlabid *Raqqāda* (263 AH/CE 876) and Fāṭimid *Ṣabra al-Manṣūrīya* (337 AH/CE 948–9) (Cressier & Rammah, 2006; Martínez Enamorado & García Alfonso, 2002).

In the case of *qaṣba* as camp, fortress, or palace precinct, layouts defined or inspired by local Late Antique and Byzantine works at first meshed with equally culturally mixed Umayyad models from the east. These blended later on with ‘Abbāsīd architectural formulas (Martínez Enamorado & García Alfonso, 2002). Texts as well as archaeology suggest that many of the urban sites in Paul-Louis Cambuzat’s mid-1980s study of seventh AH/CE eleventh century Ifrīqiya incorporated Byzantine forts later held by Muslim garrisons (Cambuzat, 1986). Solid evidence for continuity comes, e.g., from Tocrā (Taucheira) in coastal Cyrenaica, where a Byzantine emergency intramural fort, basically a *qaṣba*, was built ca. 21 AH/CE 642. After Tocrā’s capitulation in 23 AH/CE 644, the fort remained in use, only with a new garrison. Similar reuse is attested at Ksar Lemsā, Haïdra, Béja, Tebessa, Jaloula, Zana, Tigisis, Ksar Belezma, Bagai, Tobna, at the Aghlabid Burj Younga, and elsewhere. How one should interpret fortified forums, amphitheaters, and small seventh- to ninth-century CE forts at town not walled during the Byzantine era, such

as Sbeïtla (Sufetula) – whether as discrete *quṣūr* or as *qaṣba*-s – remains debatable (Fenwick, 2013; Martínez Enamorado & García Alfonso, 2002; (Fig. 4).

The rural evidence is even more complex. Private fortified estates (*centenarium*, *turris*) prevailed, for instance, in Tripolitania (e.g., Jabal Tarhūna and the Sahara edge) after the decommissioning of the forward Severan *limes* in 259–63 CE. From the fourth century CE – a period blighted by early Christian sectarian strife – settlements clustered around redoubts resembling later *quṣūr* (sing. *qaṣr*, vernac. *ksar*). The outermost perimeter might be fortified, forming a kind of *ḥiṣn* around the core/*qaṣba*. The process is assumed to reflect a shift from dominance by great Roman-era landowners to a more socially flat organization, with control of agriculture and of desert trade by local lineages and long-entrenched Amazigh populations (e.g., the Luwāta or the Infūsen in Tripolitania). At present, confirmation is lacking for a general hiatus between such settlements and the second to third AH/CE ninth to tenth century expansion of villages and tower granaries, many of them newly founded. A notable obstacle to the dating of sites is the imperfect sequence of seventh to ninth-century ceramics (Benabbès, 2005; Fenwick, 2013).

The founding of *ribāt*-s intended to boost coastal defense and communications in Ifrīqiya

(Tunisia) before and after c. 184 AH/CE 800 (i.e., before and after the establishment of the hereditary Aghlabid governorate) blurs the origins of *qaṣba*-s further. Just like *qaṣba* could partly be a function and not so much a thing, so *ribāṭ* too was a function: at first a plain guard post, squad (*rābiṭa*) base, or staging point for cavalry, it was not necessarily wrapped in the shroud of prestige associated with holy war. Early sources refer to the prominent *ribāṭ* of Monastir (Munastīr (Tunisia), founded (180 AH/CE 796) as a *ḥiṣn*, a *qaṣr ribāṭ*, or *qaṣr li-l ribāṭ* – a humble fort serving *ribāṭ* purposes (Khalilieh, 1999). Functions and structures accreted through time. Several *quṣūr* were added to the Monastir *ribāṭ* by c. 973 CE, and the whole, enclosed in a larger enceinte, was now a citadel (*ḥiṣn*) comprising discrete *qaṣba*-s (*qiṣāb*). Tactical nesting thus marked *qaṣba* design and terminology from early on.

Qaṣba Patterns: General Observations

No adequate model of a typical *qaṣba* exists, mainly because of the wide range of types. The most frequently evoked characteristics reflect (a) research relating to al-Andalūs (Cressier, 1995), (b) Jean-Claude Garcin's post-eleventh century and explicitly pan-Mediterranean concept of the “ville des cavaliers” (horsemen's town) (Garcin, 2000), and (c) constructs such as André Raymond's contrast between a tactically closed private (upper) town or quarter and tactically open public (lower) town or quarter (Raymond, 1984). Viewed through this filter, a *qaṣba* (or *qal'a*) is a citadel dominating an urban core (*madīna*). The two are so interrelated that one seems unthinkable without the other. Inside the *qaṣba*, the palace/keep (ostensible site of legitimate power (*al-mulk*)) and other elite establishments may rank as *quṣūr*. Stables (*riwā*, pl. *arwiya*, vernac. *rwīya*, *rwāyāt*; western equivalent of the Mashriqī *iṣṭabl*) are typically adjacent to or part of the *qaṣr* nucleus. A large open space for ceremony and for cavalry exercises – the *maidān* (pl. *mayādīn*) – tends to buffer *qaṣba* from *madīna*, functionally evoking

a Late Antique/Byzantine hippodrome, just like the *qaṣba* and its core *qaṣr* faintly evoke a Roman camp with its *praetorium* or *principia*. Andalūsī usage suggests that if ranking as a seat of *mulk* – a casa real/crown residence – the entire *qaṣba* might take the label *qaṣr* (Sp. *alcázar*) to denote political status. In such a case, lesser (often earlier) inner precincts became *qaṣba*-s – quite properly, given the term's range of meanings (Martínez Enamorado & García Alfonso, 2002). This tentative model does not fit all settings, however, and is rather static.

There was a variation in what came first – core keep or outer enceinte – unless a preexisting *madīna* constrained choices. The first stand-alone *ribāṭ* at Monastir (180 AH/CE 796), for instance, devolved into a *qaṣba* inside a larger *ḥiṣn* only by the later tenth century CE. At al-'Abbāsīya (Kairouan), the *Qaṣr al-qadīm* (or *Qaṣr al-abyaḍ* (185 AH/CE 801)) – the core (*qaṣba*) of the Aghlabid precinct – was built first. Surrounding cantonment and enceinte followed. Similarly, most parts of 'Ubayd Allāh al-Mahdī's Fāṭimid *ḥiṣn* of Mahdiya (Tunisia) (isthmus barrier wall, enceinte, and two palaces/*quṣūr*) were built in a coherent building push, even though it lasted a decade (300 AH/CE 912 to 308 AH/CE 921). Inside the initial Almoravid camp at the future site of Marrakech (1060s AD), however, the *Dār al-Ḥajar* (the Stone House *qaṣba*, c. 463 AH/CE 1070) was set up first. A town enceinte had to wait until c. 520 AH/CE 1126.

Construction sequences at the partially excavated Qal'at Banī Ḥammād (Hodna, Algeria; founded 398 AH/CE 1007–8) are still not clear (Bourouiba, 1975). The *qaṣba*-like enclosure that comprises segments of a Roman wall, the *Qaṣr al-Manār* palace, and the signals *burj* may have been the original core. A nearby simple mountain refuge, Kiyāna, preceded it, dating back to the 332 AH/CE 943 Khārijī revolt of Abū Yazīd, the *ṣāhib al ḥimār* (Man on a Donkey). At Rabat (Ribāṭ al-Faṭḥ), an Almohad *qaṣba* furnished the first core (built 545 AH/CE 1151, under 'Abd al-Mu'min), holding inside its c. 4 ha a fort/palace (*qaṣr*) and a *khuṭba* mosque, among others. Documented use of adjacent terrain to lodge troops bound for al-Andalūs followed only in

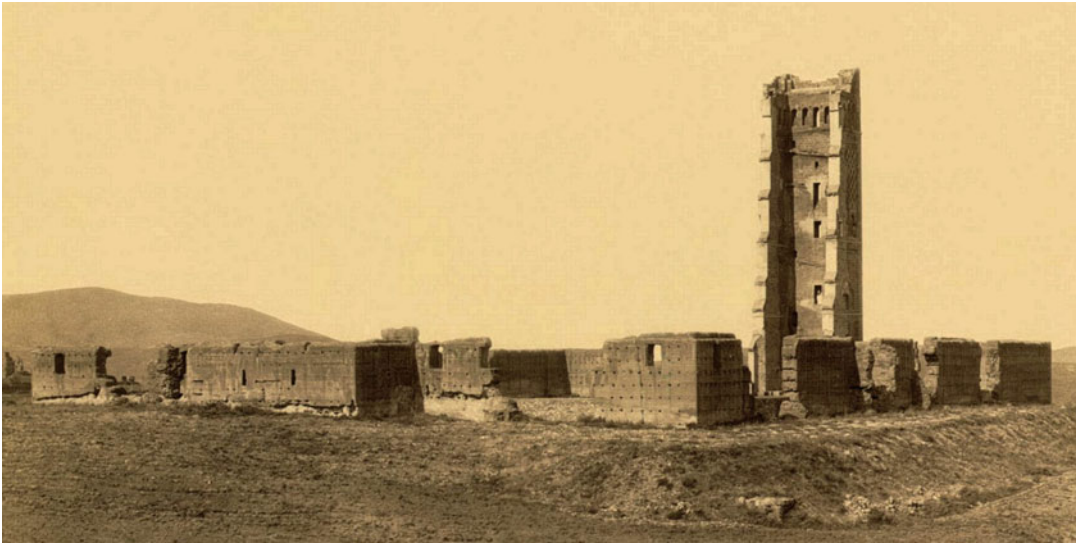
560 AH/CE 1165. Walls enclosing a large *maḥalla/ribāṭ* area and suitable for a proper *madīna* were started only in 566 AH/CE 1171 under Abū Ya'qūb Yūsuf b. 'Abd al-Mu'min and completed under Abū Yūsuf Ya'qūb al-Manṣūr (1184–1199 CE). (Sedra, 2008). At quickly built new Marīnid strategic camp towns such as *Āfrāg* (1328 CE), outside of Ceuta, enceinte and embedded *qaṣba/qaṣr* rose mostly in tandem (Villada Paredes & Gurriarán Daza, 2013), but at organically developing towns such as ninth- to thirteenth-century Tunis, the *madīna* enceinte and successive *qaṣba*-s and palaces/*quṣūr* sought adjustment to each other over centuries.

It was not only spatial and chronological nesting as both design and process that patterned the history of *qaṣba*-s. Parallel urbanization did its share, as did the serial founding of new palace/administrative precincts to mark the rise of new dynasties and their altered political order. The gesture of forsaking, even ruining, earlier rival sites often went hand in hand with new *qaṣba* construction. Salvage of materials was common. To this we must add other pattern-setting determinants, at least in terms of location choice: coastal defense, surveillance of trade and military arteries, creation of strategic reserves, and segregation of rivals, of dissidents, and of outlying or rugged-terrain districts difficult to control fully. These factors relate mostly to *qaṣba* building by an established or rising central regime. Other dynamics at regional and lineage level shaped the number and location of rural *qaṣba* refuges, granaries, and staging posts along trade or seasonal migration corridors habitually claimed by diversified lineage groups (Acién & Cressier, 2009; Benhima, 2008).

Historic towns with a complex past, e.g., Marrakech, Fez, Meknès, Tlemcen, Algiers, Bône, Bougie, or Tunis, embody long sequences of the relevant patterns. At Meknès (Miknās al-Zaytūn) (Morocco), early settlements such as Qaṣr Tūrziḡuīn were complemented by an Almoravid *tāgrārt* (a *maḥalla* enclave dubbed a *hiṣn*), with at least one *qaṣba* nucleus. The extent of Tāgrārt's reuse by the Almohads is unclear (by the 1190s AD, some twelve new *quṣūr*, military and residential, some with *qaṣba*-like enclosures of their

own, were dotted around Tāgrārt, now a *madīna*). After the final Marīnid takeover (645 AH/CE 1247–8), a separate new *qaṣba* was built under Abū Yūsuf Ya'qūb (from 674 AH/CE 1276) (El Khammar, 2005). Under Mawlāy Ismā'īl (1082–1139 AH/CE 1672–1727), components of the Almoravid and Almohad *qaṣba*-s embedded in the *madīna* were remodeled, and the Marīnid *qaṣba* largely razed to create a palace precinct with spacious gardens, structured around the *quṣūr* of Dār al-Kbīra, Dār al-Madrasa, and Qaṣr al-Mhansa. Lesser *qaṣba*-s were scattered around the *médina* proper (Hadrās, Barrīma, Sīdī Sa'īd, Gnāh al-Aman and Qā' Warda) (Barrucand, 1985; El Khammar, 2005). Numerous decorative components were extracted from the opulent sixteenth-century Sa'did *qaṣba* of Marrakech (*Qaṣr al-Badī'*, 1002 AH/CE 1578–1593), plundered and almost entirely dismantled by AH/CE 1698–1119 AH/CE 1707.

At Tlemcen (Algeria) a similar sequence presents itself. The small Roman colony of Pomaria grew in c. 122 AH/CE 749–AH/CE 950–967 into a roughly rectangular Amazigh *maḥalla*-type settlement (Agadir) with a *qaṣba* in the southwest corner. In 473–4 AH/CE 1081–2, a separate Almoravid *tāgrārt* sprang up west of Agadir, at first only a large empty *hiṣn* with a *qaṣba* core (Qaṣr al-Qadīm), like at Meknès or at the stone-and-brick Almoravid *qaṣba* atop Jbel Amargū (Amargō (Amargou), 50 km northwest of Fez; reused as late as the 1270s CE). The Almohads created around 540 AH/CE 1145 a separate precinct (a palace/*qaṣba*) in the area of the later Mashwar citadel. Agadir and Tāgrārt fused into a dual fortified town by 581 AH/CE 1185 (main enceinte construction under 'Abd al-Mu'min), and Tāgrārt had become the upscale administrative sector (Dahmani, 1983). The Marīnid Long Siege of Tlemcen (699–707 AH/CE 1299–1307) saw the founding of a third separate *maḥalla* called *al-Manṣūra*, a town-size camp 2 km west of Tāgrārt, with a palatial *qaṣr/qaṣba*, *khuṭba* mosque, hospitals, baths, markets, and caravan-serais. Ruined in 1307 CE, *al-Manṣūra* was rebuilt in 1337–1344 and ruined again in 1348 and 1361. The old Mashwar *qaṣba* was repurposed as an 'Abd al-Wadid residential *qaṣr*



Qasba in the Maghrib, Fig. 5 Partial view from within the ruined Marīnid *maḥalla* of *al-Manṣūra*, showing the state of structures next to the minaret in the late nineteenth century (c. 1860–1890). A remnant of fosse runs around

the corner and along one side of this block. Most of the walls, with the exception of the minaret, are made of *ṭābiya* erected on rubble masonry foundations (Early photograph)

Qasba in the Maghrib, Fig. 6 The Mashwar of Tlemcen in the nineteenth century (Lithograph from a sketch by Genet, 1836)



(633–81 AH/CE 1236–83) and later adapted for use as *qaṣba* once again by *ghulām/oghlan* (Kouloughli) Turkish troops (after 962 AH/CE 1555) (Figs. 5 and 6).

At Fez, the commonly cited sequence starts with the dual eighth- to ninth-century CE settlements of Fās and al-'Āliya (the latter became the al-Qarawiyyīn quarter), each with their own *qaṣba*, defensively flanked by other forts.

The two urban cores were amalgamated under the Almoravids and to the west a new *qaṣba* was built at Bū Julūd (*Qaṣba al-Filāla*). Torn down (540–1 AH/CE 1145–6) and rebuilt by the Almohads, the Bū Julūd *qaṣba* was then reused by the rising Marīnid dynasty, at first, only to be supplanted by a new Marīnid palace/administrative precinct even further west, laid out in 674 AH/CE 1276 – al-Madīnat al-Bayḍā' or Fās

Qasba in the Maghrib,

Fig. 7 Main entrance to the Ismāʿīlian *qasba* at El 'Aioun Sidi Mellouk (1679 CE) on the road from Oujda to Taza. Under Mawḷāy Ismāʿīl it held a garrison of 500 Zirāra cavalry and was under the orders of regional headquarters at Oujda. State of the structure c. 1914–20. Note the more modern service sheds lining the walls. Early colonial-era photograph in the author's collection



al-Jadīd. In the sixteenth century CE, this *qasba* was reinforced with artillery emplacements (Barrucand, 1980). Other instances of spatiotemporal drift in the location of urban *qasba*-s can be found at Taza (Morocco) and Bougie (Bijāya) (Algeria) or Tunis. Nineteenth- and early twentieth-century sources document similar patterns for rural *qasba*-s, particularly in Morocco. Time and again ruins of old *qasba*-s, sometimes in serial clusters reaching back through time, are mentioned close to recently built fortifications (1850s–1910s).

For many rural *qasba*-s, encompassing micro-regional contexts based on both historic and archaeological data remain to be established. This applies, for instance, even to the c. 80 listed and for the most part well-identified government *qasba*-s built or restored in Morocco under Mawḷāy Ismāʿīl (1082–1139 AH/CE 1672–1727) (Chapelle, Lt. F. de la, 1931) (Fig. 8). Collective rural defenses are often lumped by the dozen in the sources, in clusters located simply by subregion, mountain range, or lineage territory – thus the cluster of *Qulūʾ Jāra* in the Rīf of the Banī Wartadī, the *ḥuṣūn Waṭṭāṭ* on the Moulouya taken by the Almoravids in 463 AH/CE 1070–71, even more generically the Moulouya *ḥuṣūn* taken by the Almohads under ʿAbd al-Muʿmin, the *ḥuṣūn* of the Ghumāra, those of the Taza area, those of the Sūs and the Tafīlālt, the *quṣūr* of the Maṣmūda around Aghmat (Benhima, 2008), and so on all the way

east to Ifrīqiya and southeast into the Tuat and Gourara (Tigurārīn) (Sahara). By contrast, fortifications built by successful centralist regimes during their rise as well as in decline stand out more distinctly as individual structures, in the sources as well as in the emergent archaeological record. The lists of such *qasba*-s are not always reliable, however. They often bear the imprint of propagandistic narratives of dynastic origins (e.g., al-Baydhaq's list of Almoravid forts built to contain the rising Almohad movement) (Benhima, 2008) (Figs. 7 and 8).

Qasba Research and Heritage Issues

As of March 2014 no unified, open access spatiotemporal GIS database was available that would cover all known Maghribī *qasba*-s and related or precursor sites from Late Antiquity to the colonial/Protectorate period. Even in compact areas such as the Rif (northern Morocco), for instance, site data remain to be refined. Surveys in the Rif and in adjacent areas since the late 1970s and then more systematically from 2000 onward, accompanied by targeted excavations at Bādīs, Nakūr, Maṣṭāsa (a *qasba*/hilltop refuge, Jbel Tiroubai), and al-Mazamma (2010) (Project PAC Rif central), have established a baseline (Cressier, 1981–1982; Touri, Bazzana, & Cressier, 1988). More work, however, needs to be done. The historic context is reasonably clear at certain sites,



Qasba in the Maghrib, Fig. 8 Spatial distribution of key well-documented Ismā'īlian *qasba*-s. The map represents a recent snapshot from an evolving GIS database

whose underlying core was originally constructed around raw data in Chapelle and assorted colonial travel sources (Chapelle 1931) (Cartographic rendering by author)

such as the Marīnid *qasba* of Tāzūṭa (pre-1213 AD-1293 AD; reused in the sixteenth century), the Marīnid *qasba* at Debdou, the Dār Sulṭān *qasba* at Targha, or the Ismā'īlian *qasba*-s of Seluan and Snāda (the latter replacing an earlier Sa'did *qasba*) (Barrucand, 1980; Cressier, 1981–1982; El Boudjay, 1996). Elsewhere, puzzles remain: the small artillery *qasba/burj* on the beach of Targha (deemed to be Sa'did), the hilltop ruined fortified village (thirteenth century CE or earlier) and European-style fort at *Qal'at Sanhāja/Torres de Alcalá* (El Boudjay, 2003), or the enceinte fragments of Sūr al-Qasaba at the Iharounen-Boukrat confluence (El Boudjay, 1996) (Fig. 9).

Prominent urban *qasba*-s are covered quite extensively in the literature, but gaps persist. Conservation and meaningful integration into



Qasba in the Maghrib, Fig. 9 Marīnid *qasba* of Debdou. Corner tower and section of main curtain with a large swath of weather sealant topcoat still partly in place. All sections shown are ṭābiya on stone rubble foundations

modernizing urban textures progressed rapidly in 2000–2013, but whether or not a *médina* with its *qaṣba*(s) figures on the UNESCO World Heritage Site list is not always an indicator of satisfactory solutions. A case in point is the *qaṣba* of Algiers, listed since 1992 – or more specifically the top part of the historic upper *casbah* (al-Gabal (*Jabal*)) (the lower town or the *Quartier de la Marine* (*Quartier de l’Ancienne Préfecture*)) had changed drastically starting in 1830–1849). After the serial crises affecting the *qaṣba* ever since the 1931 colonial urbanistic blueprint and the stalled projects that followed, a thorough new plan was tabled in 2011, but the *qaṣba* remains a fragile environment in 2014. A fundamental salvage archaeology project in the Place des Martyrs area started in 2009, spurred on by subway (Métro) construction. In general, it remains difficult to model trends in the role and evolution of urban *qaṣba*-s throughout Maghribī history or to present them to the public as de-romanticized and properly contextualized components of *médina* architecture. The tourist appeal of the *qaṣba*/kasbah concept continues unabated. Redevelopment and gentrification driven by cultural tourism have entered a new phase since c. 2003 with a proliferation of authentic *riad*/*maison d’hôte* hotels and residences (Elbl, 2013) (Fig. 10).

The rural *qaṣba* has become a factor in new approaches to writing Maghribī history, even though archaeology of the fortified rural habitat lags behind. As Yassir Benhima stressed (2000, 2008), without studies of rural defenses, in context, it is difficult to decode past regional patterns of climate change, landscape evolution, land use, demographics, shifts between transhumance and sedentarization, rural vs. urban dynamics, and, ultimately, state formation and its failures. The issues go beyond inventorying and excavating discrete sites. A broadly based archaeology of the *qaṣba* can potentially become a tool to cut through biases embedded in the written sources of Maghribī history – above all in propagandistic narratives of dynastic origins or of social and political movements. It offers a valuable auxiliary key to sources ranging from al-Muqaddasī (aka al-Bashshārī) and Ibn Ḥawqal to al-Bakrī, al-Baydhaq, *al-sharīf* al-Idrīsī, the anonymous



Qasba in the Maghrib, Fig. 10 View of a steeply sloping street in the *qaṣba* of Algiers, nineteenth century (c. 1870–1895). Upper floors on timber structural supports extend into the airspace above the street. Minimal street width was typically governed by custom, precedent (in principle, seven cubits (c. 3.5 m) for a pedestrian passageway (*ṭarīq al-mushāl*)), and legal opinion – sometimes respected more in breach than in observance, depending on circumstances

Kitāb al-istibṣār, and onward to Ibn Abī Zar‘a, Ibn Khaldūn, Leo Africanus, al-Nāṣir al-Salāwī, and colonial-era records.

On the conservation front, much has been achieved, thanks to dedicated individuals and institutions. In the Moroccan south, for instance, the thrust has been spearheaded by CERA (Centre d’Études et de Recherches Alaouites (Rissani, Tafilālt), key project: Ksar al-Fida, now the Musée archéologique et ethnographique de Sijilmasa-Tafilalt since 2003) and by architects and anthropologists like Salima Naji (e.g., the restoration of Aguelluy (2004–2006), Inoummar (2005), Amtoudi (2006–2008), Id Issa (2007), Ksar Assa (2006–), the 1810 CE Kasbah Aghenaj (2008–2011) (now the Museum of Tiznit), Aīt Kin (completed 2012–2013), Agadir n’Issergine (ongoing), and other sites) (Naji, 2006, 2013).

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Qi

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In Chinese culture, *qi* is the common denominator that underlies all being and all behavior

and that allows for their interaction and their interpenetration. *Qi* enables seeds, air, and soil to become plants, a mountain range to produce good fortune, or a human being to cultivate wisdom and human kindness. It is what makes possible the processes of chemistry and the researches of the alchemists. *Qi* is the fundamental Chinese articulation of what underlies the universe, what is the universe, and what is the reality of the universe.

Given the key position the concept of *qi* holds in explaining the process of change in Chinese scientific, medical, psychological, and spiritual thought, one is tempted to assume that it is one of the oldest and most central concepts in the Chinese world view. A look at the history of both the character and the concept shows otherwise.

The oldest inscriptions in Chinese, the bones used in the Shang dynasty oracle, are concerned with understanding the process of change in such uncertain areas as agriculture and illness. Nowhere in the more than 200,000 known extant oracle bones can one find the character *qi* or anything which might be its close antecedent or relative. Throughout the oracle bone inscriptions we see that, in Shang culture, change was brought about by the actions of spirits rather than by naturalistic forces.

The character *qi* is composed of an element which signifies vapors which rise to form clouds and another element which means grain. The character may mean vapors arising from cooked food or simply steam. At this level of the character's history *qi* is a simple notion. *Qi* is what makes the lid on a pot of boiling water rattle.

In the course of its development Chinese thought began to look for the origins of change in sources other than the spirits. For a time change, especially illness, was understood to come from the winds of the eight directions, each of which was responsible for causing particular diseases at particular seasons and each of which was personified as a deity. Although this model of change brought about by wind is a step toward a world of naturalistic causality and away from a world of spirit causality, it still has a strong component of the latter. It is probably,

however, a major step in the development of the concept of *qi* which later comes to permeate all of Chinese thought.

By the time of Confucius (551–479 BCE), the word *qi* appears in literature but it is rare and its meaning is confined to purely human qualities. The *Analects*, the record of Confucius' teachings, use the word four times, each of which is distinctly related to some aspect of human behavior, such as appetite, tone of voice, breath, and physical stamina. In none of these does it refer to anything beyond a specific physical quality of human life. At this stage in its history *qi* still shows its origin as a common, ordinary term.

The several centuries following Confucius were a critical time of change in Chinese culture. One of the key concepts to emerge at this time was *qi*. Mencius (371–289 BCE), the follower of Confucius, refers to *qi* 19 times and each time it is a concept of major philosophical import. *Zhangzi*, between 399 and 295 BCE, a major Daoist text, refers even more frequently to *qi*. In this text we see one of the earliest and clearest uses of *qi* to refer to a natural force, something which, although an attribute of human beings, is also a power which makes things happen in the world. We see this conceptualization of *qi* (although still connected to wind) as a moving power in the universe in a famous passage from the *Zhangzi*.

The great clod belches out breath (*qi*) and its name is wind. So long as it doesn't come forth nothing happens, but when it does, the 10,000 hollows begin crying wildly.

Here *qi* is a conceptual model for explaining and understanding the process of change in the observable world. The Shang world of a supernatural spirit causality which had developed into the world of semisupernatural wind causality has now become a world of natural causality. The *qi* model explains the process of change and development in a naturalistic way which is conducive to the expansion of philosophic and scientific thought and inquiry.

By the late third century BCE we see *qi* becoming a concept used throughout Chinese thought. This conceptualization/experiential

model is used to explain the qualities of plants and animals, the uses of herbs, and the influences of climate, weather, and geographic location on people. From its use to explain the process of disease and illness comes psychological insights into character and personality types. Eventually, through philosophers such as Wang Yangming (1472–1529), *qi* becomes an essential quality which enables all change since, no matter how they seem to differ, all things share the same *qi*. It also becomes a moral spiritual quality allowing for the oneness of all being.

In recent times, possibly under the influence of Western thought, *qi* has frequently been identified with the Western concept of energy. Westerners are by no means the only ones to make this equation. To characterize *qi* as energy is to invoke a worldview which the Chinese never had, a worldview in which matter and energy are different things. While it is true that modern scientific theory no longer holds that matter and energy are separate entities the words have come, through several centuries of use, to connote, in common parlance, distinct, and separate entities. To the Chinese matter was never inert; it always had dynamic and teleological properties.

As Western concepts of physics have caused some to think of *qi* as energy, nineteenth century western concepts of vitalism have caused it to be identified, especially in medicine, as some form of vital force, distinguishing living things. Historically, however, *qi* has been as much an attribute of a rock or river as of a person or animal. To call *qi* energy or life force is as erroneous as it is to call it matter. It is all and it is neither. *Qi* is the fundamental Chinese articulation of the interconnectedness of the universe, of what the Chinese call the 10,000 things. *Qi* is the cause, process, and outcome of all activity in the cosmos.

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Qianjin Yaofang

Richard Bertschinger

The *Qianjin Yaofang* (Remedies Worth their Weight in Gold), and its sequel the *Qianjin Yifang* (More Remedies Worth their Weight in Gold), were written by the physician and alchemist Sun Simiao (also called ► [Sun Simo](#)) in 652 and 682, respectively, during China's Tang dynasty.

These books are especially valuable for the breadth of their content. They described the medicine of the day, both the systematic acupuncture and herbal tradition, and the less organized folk tradition. Unfortunately neither has as yet been translated into a Western language.

Sun built on the work of Zhang Zhongjing's earlier ► [Shanghan Lun](#), especially in advocating the careful selection, picking and preparation of herbs. In acupuncture he devised the system of *ahshi!* (ow! that's it!) points, or needling at the tender muscle nodules. These books also contained the author's newly verified and drawn charts of the channels and points on the body, with front, side, and back views – the earliest-known point charts to have been produced. The 12 channels were shown in five colors, while the eight extraneous channels were depicted in green.

Many of Sun's ideas were closer to Western notions of common sense. For instance he put disease down more to incorrect diet than to the influence of evil ghosts and spirits. He advocated general cleanliness to protect against the development of sores and ulcers, and he urged rinsing the mouth out several times after a meal to keep the teeth healthy and the breath fresh. During childbirth he said not more than two or three people should be allowed into the delivery room, to keep the mother quiet and the atmosphere calm, and he excluded anyone who had recently survived a fatal illness. He thus showed an awareness of complications arising in labor through the nervousness of the mother, and of infection spreading to the mother or newborn child. He also advocated the use of gentle

exercise in imitation of animals in order to prevent disease and combat the process of aging. He introduced the treatment of night-blindness with goat or ox liver (which is rich in Vitamin A), the use of the thyroid glands of sheep or deer (equally rich in iodine) for a swollen thyroid, and abstaining from salt in cases of edema.

He innovated a clear ethical stance on medical practice, urging the doctor to be vigorous in investigating the disease and finding a suitable treatment. Many of his methods are in line with modern thinking. His work was equally valued in both Japan and Korea and works in these countries quote extensively from his tracts.

See Also

► [Sun Simo](#)

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Qibla and Islamic Prayer Times

Mohammad Ilyas

Ṣalāt (prayer) is one of five pillars of Islam. Islam requires all adult sane, healthy, and able-bodied Muslims to perform five daily prayers. The corresponding time intervals are commonly known as "Islamic prayer times."

Muslims are enjoined to face the *Ka'ba* in Mecca during their prayers. It is believed that *Ka'ba*, the cubical shaped edifice, was built by the Prophet Abraham. The direction to the *Ka'ba* from a place is known as its *qibla* direction. Mosques are built with a clear pointer in the qibla direction. Knowledge of the qibla direction is also important for certain other acts, including the call to prayer (*Adhān*), the ritual slaughter of animals for food, and burial of the dead. Muslim astronomers from early times dealt with the

determination of the *qibla* and produced highly sophisticated trigonometric and geometric solutions.

The time intervals of the specified daily prayers are clearly specified. The intervals are exclusive of each other; the end of one time interval marks the beginning of the next. Besides regular prayers, there are supplementary prayers, and some of these follow specific time intervals. There are also certain periods of the day during which prayers are prohibited. All this reflects the need for a clear understanding of diurnal phenomena and the proper determination of the time of day. The way in which the various Islamic prayers are distributed throughout the day further emphasizes the treatment of day and night as a single time unit, in contrast to the practice of earlier civilizations in treating them separately. Also, the mutually exclusive time intervals for each regular prayer, which depend upon the specific (local) positions of the sun, introduced a new way of dividing the day.

The Islamic prayer times are so defined that they can be easily ascertained by observation on a clear day. However, under cloudy conditions, one has to resort to some sort of a time clock and mathematical computation. Since the performance of regular prayers within the specified time intervals is a most serious matter, advance determination of the intervals is of great importance. From the very beginning, Muslim scientists were engaged in mastering the techniques of positional and observational astronomy, including instrumentation, and went on to develop this and allied fields. It is not surprising to find that almost all major astronomical works during that period of 500 years incorporated a discussion relating to the Islamic prayer times, which came to be known as *ʿIlm al-mīqāt* or the times of “fixed positions” of the sun. Closely associated with the Islamic prayer times is the matter of determining the direction of Mecca. Elaborate tables showing the direction of the *Kaʿba* from different parts of the world became an integral part of Islamic astronomical works.

The demarcation of various time intervals is based on the guidelines contained in the *Qurʿān* and elaborations given in the *Ḥadīth* (Traditions)

of Prophet Muḥammad. Based on these, the time intervals were subsequently translated into more precise definitions by the theological jurists of the early centuries of Islam. Muslim astronomers helped to translate these into equivalent astronomical definitions.

In Islam, the day begins at sunset and the time for the first prayer (*maghrib*) begins after the sun has set. The second (*ʿishāʾ*) and third (*fajr*) prayers then follow, the latter ending before the sun begins to rise. The fourth prayer (*Zuḥr*) is performed after midday and is followed by the fifth and last obligatory prayer (*ʿaṣr*) in the afternoon. The optional prayers performed after midnight (*tahajjud*) and a little after sunrise (*chasht*) have special importance. The time durations during which the sun rises, sets, and crosses the local meridian are prohibited times and no prayers are generally allowed during these periods. Thus, one has to determine the various portions of the day in a sequential and somewhat symmetrical way.

As we know, the “true” solar day-length keeps changing through the seasons. Therefore, on a 24 h civil clock, the solar phenomena, such as midday and midnight, keep moving backward and forward. However, as the Islamic time intervals are related directly to the true natural (solar) phenomena and not to the day length, it simply boils down to the daily determination of the times of various astronomical phenomena according to whatever day-time system is used, e.g., time-hours or time-degrees would be equally applicable. This situation obviously laid down strong foundations for mathematical-dynamical astronomy. Also we can recognize that the “day-time” length depends upon the season and the latitude and varies from a winter minimum to a summer maximum. For Islamic fasting, which is done from dawn to sunset, some countries are favored (shortest duration) in one season and others in a different season. In Islam, this situation has been fully taken care of through the rotation of the Islamic (lunar) months through the seasons.

Muslim astronomers during the medieval period made considerable efforts to construct tables of Islamic prayer times according to the defined solar positions. The data on the solar

position (azimuth) at different altitudes was also used for observationally determining the direction of the *qibla*. It was important to present the prayer times in the form of basic universal tables which would remain unchanged over a long time. These tables could then be used through secondary and smaller tables which could be recomputed if necessary.

These tables were universal, since the Muslims used a purely lunar calendar independent of solar calendar dates. For each new day/date, one simply needed to ascertain the solar longitude by direct measurement or through the simultaneous measurement of positional parameters at meridian passage.

Muslim astronomers' interest in regulating daily time went beyond the determination of prayer times to include overall time measurement. Their tables contained information on various time parameters, such as length of daylight and duration of the fasting period (from morning twilight to sunset), auxiliary tables on various functions needed in computations, and special tables on parameters such as the solar azimuth and solar altitude in certain azimuths for use in *qibla* determination, besides supplementary information on such parameters as horizontal refraction. The prayer tables were generally produced with great computational skills and care and in a comprehensive way. A study of Cairo's tenth-century astronomer Ibn Yūnus' *Kitāb Ghayat al-intifa' fi ma'rifat al-da'ir wa-faḍlihi wa-l-samt min qibal al-irtifā'* (Very Useful Tables for Finding the Time since Sunrise, the Hour Angle, and the Solar Azimuth, from the Solar Altitude), one of the major *mīqāt* tables, shows that Ibn Yūnus' values were, in general, very carefully computed. The tabular works incorporating *ṣalāt* times and other auxiliary tables were prepared for various major localities of the Muslim world, such as Cairo, Mecca, Medinah, Jerusalem, Damascus, Tripoli, Aleppo, Tunis, Istanbul, Baghdad, and towns in West Africa, Andalusia and the Indian subcontinent. Later work by a Damascus astronomer, al-Khalīlī (fourteenth century), greatly expanded the dimension of *mīqāt* tables by latitude and longitude degree of the globe. David King's

comparison of al-Khalīlī's data with modern calculations shows his work to be remarkably accurate. Al-Khalīlī's tables may thus be considered to present the first global data set on the *qibla*.

We noted how, through the ingenious use of solar longitude, the Tables were made time-invariant and independent of the solar calendar, and the computational system was further expanded to determine the solar altitude for a specific solar azimuth, giving the direction to Mecca. In this way, an accurate astronomical method was developed to meet an additional need. The remarkable achievements in mathematical astronomy mark the high points of Islamic astronomy.

In the period after the introduction of the mechanical clock, a 24-equal-h civilian day took over from the 12-h daytime and 12-h nighttime day which had dominated civilian timekeeping systems well into the fourteenth century. Although Muslim scientists had started to utilize an Islamic equal hour day, the use of true solar time and sundials prevailed in non-European and Islamic countries for quite a while. The detailed tables of Islamic prayer times constructed for specific localities of the Muslim world in the early centuries have remained in effective use right into modern times.

We are aware that as we go toward the higher latitudes, the usual cycle of daylight, twilight, and night begins to change during certain parts of the year. First, the night gets shorter and shorter with the increasing latitude, until the evening twilight merges with the morning twilight. In other words, the clear distinction of the end of the evening twilight from the beginning (or end – depending how one looks at it) of morning twilight no longer exists, and the determination of times for the beginning of *ishā*, *fajr*, and fasting cannot be done through the conventional solar position basis. As one moves toward the higher latitudes, even the twilight period gets shorter, to the extent that the end of the day merges with the beginning of the day, so that the sun does not set (or rise) but remains continuously above the horizon. In a situation like this, with 24 h of daylight, how is one to determine the times of *fajr* and *maghrib* prayers and how is one to fast a “nonending

daylight” day? This is one of the questions that needs to be tackled within the theological rather than the scientific arena.

See Also

- [Al-Khalīlī](#)
- [Ibn Yūnus](#)
- [Religion and Science in Islam I: Technical and Practical Aspects](#)

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Qin Jiushao

Ulrich Libbrecht

Qin Jiushao is one of the few mathematicians in China of whom we have fairly detailed

biographical data, since he held subsequent positions in government administration. Although not mentioned in the biographies of the official Song dynasty historical annals, numerous references to Qin Jiushao can be found in local monographies or writings by his contemporaries.

Qin was in all probability born in 1202 in Puzhou (now Anyue in Sichuan province). In his youth he was commander of the “patriotic soldiers”, an armed force outside the regular military establishment, in his native place. In 1224–1225 his father was given an appointment in the capital of Southern Song, Hangzhou. In the preface to his ► [Shushu Jiuzhang](#) he says, “In my youth I was living in the capital, so that I was able to study in the Board of Astronomy; subsequently, I was instructed in mathematics by a recluse scholar.” According to analysis of his mathematical work he must have studied the *Jiuzhang suanshu*. In 1226 he was staying with his father in Tongchuan (now Santai in Sichuan province). When the Mongols began their conquest of Sichuan and destroyed its capital Chengdu in 1235, Qin was at the frontier as a military official.

According to his own preface it was during this period of distress that his mind went back to the mathematical studies started in his youth. He escaped calamities by going to the southeast. He was appointed subprefect in Qizhou (now Qichun in Hubei), where he behaved badly, causing a military revolt. Later he was appointed prefect in Hezhou (now Hexian in Anhui), where he was responsible for the salt trade and sold salt illegally to the people, so that he left the southeast as a rich man, settling in Huzhou in Zhejiang. In 1244, he was named Court Gentleman for Comprehensive Duty in the prefecture of Jiankang (now Nanjing in Jiangsu). After 3 months he resigned because of his mother’s death and returned to Huzhou. It was during this 3-year mourning period that he wrote his mathematical work, which appeared in 1247. As a consequence he was recommended to the throne on account of his calendrical science, and he was allowed to take part in the examinations. We can only suppose that something went wrong, as we find him as consultant of the Directorate of Military

Affairs in Jiankang from 1253 until 1259. However, after that he resigned and went back to his native place. He paid a visit to chancellor Jia Sidao, and he got an appointment as prefect of Qiongzhou (now Qiongsanxian) in far Hainan. But after a few months he had to leave Qiongzhou because he was impeached for corruption and exploitation of the people. He followed his friend Wu Qian, who was a naval officer in the district of Yin in Zhejiang, and in 1259 he was appointed assistant in the Court of the National Granaries there. Wu Qian subsequently became a minister, but when he was disgraced in 1260, chancellor Jia Sidao also collected data about Qin, and put him away in Meizhou (now Meixian in Guangdong), where he died in 1261 at the age of 60.

See Also

- [Jiuzhang Suanshu](#)
- [Salt](#)
- [Shushu Jiuzhang](#)

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Quadrant

Richard P. Lorch

The quadrant is an instrument which was used for measuring angles and for making astronomical calculations. Apart from those for the accurate observation of altitude, known to us almost entirely from written descriptions, the quadrants of the Arabic Middle Ages were portable. They fall into three categories: those carrying a projection, or two-dimensional representation, of the celestial sphere (the imaginary sphere containing the stars and celestial circles); those designed for astronomical calculations; and horary quadrants, i.e., those used specifically for telling the time by the altitude of the Sun. Most have a thread fixed at the vertex carrying a movable bead for transferring distance from the vertex from one point of the instrument to another. Of the first type the best known is the astrolabe quadrant, invented before 1100. These are essentially the plate and rete of a standard astrolabe overlaid on one another. The motion of a star (or the Sun) is imitated by the motion of the bead, which has been set by putting it over the representation of the star, about the vertex. In the *shakkāzīya* plate associated with the name of 'Alī ibn Khalaf (eleventh-century Toledo) and taken over by al-Zarqāllu (Arzaquiel), celestial coordinates may be converted (e.g., ecliptical coordinates into equatorial) either by moving one projection over another or by using one twice and transferring one set of coordinates to the other by means of the thread and bead.

The second type of quadrant is closely related to graphical solutions of astronomical problems by ruler and compasses, the function of the compasses being taken over by the string and bead (or ruler) fixed at the vertex. Many astronomical calculations involve the use of sines of arcs in a standard circle (a sine is half the chord spanning double the arc) and these may be drawn as lines parallel to one side of the quadrant.

Multiplication may be achieved by the help of scales and the thread and bead. The sine quadrant is well attested in the tenth century and was probably known in ninth-century Baghdad.

The horary quadrant was a quadrant on which “hour-lines” were represented on the face of the instrument by circular arcs issuing from the vertex. The altitude of the Sun is taken by using sights on one side of the instrument and seeing where the thread, weighted with a plumb-bob, falls on the markings. When the position of the bead has been set for the day (e.g., by the noon altitude and the corresponding hour-line), the time can be read off from its position among the hour-lines. In some forms of the instrument a ruler or alidade takes over the functions of the thread and bead. The hours measured by the instrument are “seasonal” hours, for which $1 \text{ h} = 1/12$ time of daylight. The instrument, which is universal, is inaccurate in high latitudes. Underlying the instrument is an approximate formula, which probably came from India, used for calculating tables and also applied to a type of sine quadrant. Horary quadrants and related instruments were often provided with a cursor, or sliding plate carrying markings to facilitate the initial placing of the bead.

There were several further varieties of quadrant – e.g., horary quadrants for fixed latitudes – and also numerous mixed forms. Much of our knowledge of the rarer forms comes from the encyclopedic treatises of al-Marrākushī (thirteenth-century Cairo) and Ibn al-Sarrāj (fourteenth-century Aleppo). The “new” quadrant of Jacob ben Machir (thirteenth-century France), with its combination of horary quadrant and astrolabe projection, appears not to be of Arabic origin.

See Also

- [Astrolabe](#)
- [Astronomy](#)
- [Celestial Vault and Sphere](#)
- [Ibn Al-Zarqāllu](#)
- [Time](#)

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Quarries in Harappa

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Flint was the most important raw material exploited by the third millennium BCE Bronze Age inhabitants of the Indus Valley and its related territories. Although the importance of this siliceous stone, apart from very few exceptions (Cleland, 1987; Hoffman & Cleland, 1977; Inizan & Lechevallier, 1997; Kenoyer, 1984), has rarely been pointed out even in the most recent publications on the subject (see, for instance, Lahiri, 1992, 2005; Possehl, 2002; Ratnagar, 2004; Wright, 2010), nevertheless, the research carried out mainly during the last 30 years in the Rohri Hills in Upper Sindh (Biagi, 1997), Ongar and the neighboring hills (Biagi, 2005; Biagi & Nisbet, 2011), and Jhimpir (Biagi & Nisbet, 2010; Biagi 2011; Ozcelik, Közem, & Kartal, 2011) in Lower Sindh and also in the artisan workshops of the metropolis of Mohenjo-daro



Quarries in Harappa, Fig. 1 A Harappan flint workshop mainly composed of debitage flakes

(Bondioli, Tosi, & Vidale, 1984; Vidale, 2000; Vidale, Siviero, Sidoti, Guida, & Priori, 2013) has shown the fundamental role played by flint in the wider context of this highly developed urban civilization of the Indian subcontinent.

Although the Rohri Hills have been known since the end of the 1970s as a raw material source (Allchin, 1976), systematic surveys and excavations in the region were undertaken only in the 1990s, after the discovery of impressive clusters of Indus age flint mines in the limestone terraces east of the Shrine of Shadee Shaheed made in 1986 (Biagi & Cremaschi, 1991), by the Ca' Foscari University of Venice (Italy) and the Shah Abdul Latif University, Khairpur (Sindh, Pakistan: Biagi & Starnini, 2011; Biagi & Shaikh 1994; Starnini & Biagi, 2011). The first to report the presence of flint artifacts from this region was Blandford (1880, p. 103), who, in his *Geology of Western Sind*, describing the flat tops of the Rohri Hills south of Rohri, wrote, "The surface of the limestone consists in general of a series of low slopes, corresponding in direction to the dip of the rock. The flints weather out and cover the surface throughout a large area; cores and flakes split from them being scattered about

Quarries in Harappa, Fig. 2 The Indus at Rohri



Quarries in Harappa,

Fig. 3 Fishermen flat-bottomed boats in the Indus at Sukkur

**Quarries in Harappa,**

Fig. 4 The hill to the east of the Shrine of Shadee Shaheed where the first Harappan flint quarries were discovered in 1986



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in abundance in some places” (Fig. 1). The same author mentions the recovery of “some flint cores, from which flakes have been chipped, obtained from Lieutenant Twemlow, R. E., in the bed of the Indus. The cores were remarkable for their regularity” (Blandford, 1880, p. 20), although the same author suggested that the cores found in the Indus were manufactured from people different from those who had chipped their tools on the hills around it. These latter cores were first illustrated by Evans (1866

p. 434) who was “superintending excavations connected with a canal, near Shikarpoor, in Upper Scinde.” Furthermore, Blandford (1880, p. 20) reports that “large quantities of flint cores have been found near Sukkur and Rohri, and there is a good collection in the Geological Museum Calcutta” (Figs. 2 and 3).

Apart from the rediscoveries made by Cousens (1929) and De Terra and Paterson (1939), Allchin (1976, p. 477) of the University of Cambridge visited the northernmost edge of the hills, near



Quarries in Harappa, Fig. 5 A concentration of debitage flakes along the edge of a Harappan flint quarry-pit on the Shadee Shaheed Hills

Rohri, in December 1975. Here she noticed “extensive Harappan working floors on the top of several of them,” which were illustrated by the same author in some of her papers (Allchin, 1979, 1999, pp. 291–292), where she describes each of them as “an area large enough for a man to sit cross-legged,” which “had been completely cleared of stones” (Allchin, Goudie, & Hedge, 1978, p. 276).

Before the complete destruction of this important archaeological area, due to industrial quarrying (Biagi, 2007), I visited the limestone mesas south of Sukkur in April 1985 and again in January 1986, when groups of large flint mines were discovered by me and Professor M. Cremaschi of Milan University in the Shadee Shaheed terraces (Figs. 4, 5, and 6).

The Rohri Hills

The Rohri Hills, which are some 40 km long and 16 wide, extend in a north–south direction between the course of the Indus and the cities of Sukkur and Rohri, in the north, and the westernmost fringes of the Thar Desert, in the south (Fig. 7), which, in this part of the country, is

Quarries in Harappa, Fig. 6 The circular appearance of a flint quarry-pit at Shadee Shaheed



Quarries in Harappa,

Fig. 7 The southwestern fringes of the Rohri Hills partly covered by the Thar Desert sand dunes

**Quarries in Harappa,**

Fig. 8 A salt-lake basin near the caravan city of Thari, south of the Rohri Hills



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very rich in salt-lake basins (Figs. 8 and 9). The hills consist of fossiliferous limestone rocks of the Brahui formation attributed to the Middle Eocene/Early Oligocene period, very rich in seams of good quality flint (Blandford, 1880, p. 103), which attracted the prehistoric populations at least from the Early Paleolithic Acheulian period onwards (Biagi & Cremaschi, 1988; Biagi, Kazi, & Negrino, 1996; Biagi, 2008; Fig. 10). They separate two very different

environmental regions, the Indus Valley to the west and the Thar Desert to the east. Their eastern fringes are lapped by the Nara Canal, which flows inside the old bed of the Hakra–Ghaggar River. The hills are limestone mesas (Fig. 11), dissected by erosion and deeply incised by old river courses (Fig. 12).

As mentioned above, the surveys carried out in 1986 led to the discovery of groups of Indus flint mines and workshops in the Shadee Shaheed area

Quarries in Harappa,

Fig. 9 The high sand dunes surrounding the salt-lake basin of Sāin Sim



Quarries in Harappa, Fig. 10 Acheulian bifaces on the surface of a workshop near the tomb of Ziarāt Pir Shabān on the Rohri Hills

of the hills (Biagi & Cremaschi, 1991). Here, the most impressive structures were located along the edges of the limestone plateau (Fig. 13). From the surface the mines consisted of almost circular empty areas, representing the mine pits, filled with aeolian sand, blown from the Thar Desert dunes, and heaps of limestone block, deriving from prehistoric mining activity (Fig. 14). All around these structures, flint workshops were noticed (Fig. 15), represented by scatters of flint flakes and blades among which were typical Indus-elongated blade cores and characteristic bullet cores with very narrow bladelet detachments (Fig. 16). During the same survey,

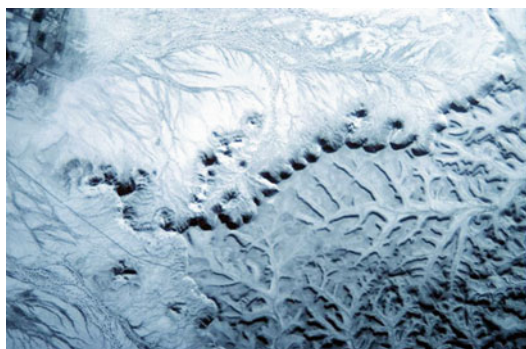
it was possible to observe that large areas of this part of the hills had already been highly damaged by illegal activities carried out by limestone quarriers (Figs. 17 and 18) and that even wider devastations were in progress by modern industrial limestone quarrying (Fig. 19). Nevertheless, it was possible to notice that the area covered by the presence of groups of prehistoric mines was very wide and extended all over the central–western region of the hills. Indus Civilization mines were discovered also in the valleys of the internal mesas (Fig. 20).

The Excavation of Mine RH862

The excavation of mine RH862 was carried out between 1995 and 1998 (Starnini & Biagi, 2011). This mine lies along the western edge of the Shadee Shaheed Hills, some 3.5-km south of the shrine that bears the same name (Fig. 21). “The site is part of an impressive, wide ring-shaped group of features, some 120 m in diameter, related to a Harappan flint mining activity area” (Starnini & Biagi, 2005, p. 1). The mine was surrounded by several flint scatters and workshops (Negrino, Ottomano, Starnini, & Veesar, 1996), one of which was connected with the production of narrow bladelets from typical bullet cores (see Fig. 16). As mentioned above,

Quarries in Harappa,

Fig. 11 The western fringes of the central part of the Rohri Hills



Quarries in Harappa, Fig. 12 An aerial view of the Rohri Hills at Shadee Shaheed and their very corrugated system

the excavation was carried out during four fieldwork seasons. It was aimed at understanding the mining techniques employed by the Indus Civilization workers and the understanding of its chronological attribution. Thanks to the discovery of two small pieces of *Zyzyphus* cf. *nummularia* charcoal it was possible to obtain an AMS radiocarbon date of the excavated pit. It gave the result of $3,870 \pm 70$ uncal BP (GrA-3235), which attributes the structure to the mature Indus Civilization (Biagi, 1995). The excavation covered an area of some 60 m^2 down to a depth of 1.5 m, where the floor reached by the Indus workers was found (Fig. 22), inside which dozens



Quarries in Harappa, Fig. 13 Professor Cremaschi positioning the first Harappan flint quarries at Shadee Shaheed in January 1986

of extractive holes containing flint nodules still in situ (Figs. 23 and 24) were discovered (Starnini & Biagi, 2005, Fig. 4). The excavation did not yield any metal or other extractive tool which might have been employed for breaking the fissured limestone and reaching the flint seam. In contrast, it produced a huge amount of flint debitage



Quarries in Harappa, Fig. 14 Aerial view of part of the main system of Harappan, flint quarry-pits on the hills near Shadee Shaheed

(Fig. 25) and several hammerstones and cores from the same material. On the basis of the field observations, “the preparation of the precore rough-outs was most probably performed inside the quarry trench, or along its edge, as many decorticating flakes, pre-forms and typical crested blade-like-flakes found inside the ditch fill should indicate” (Starnini & Biagi, 2005, p. 5).

The Ongar, Daphro, and Bekhain Hills

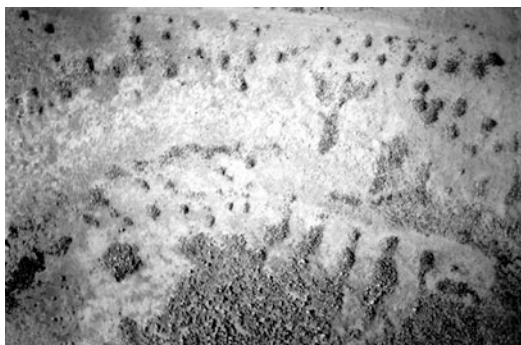
The surveys carried out on the Ongar, Daphro, and Bekhain Hills, south of Hyderabad, some 8 kms north of Jhikar, in Lower Sindh, led to the discovery of other flint-extractive mines also in this region (Biagi, 2005; Biagi & Franco, 2008; Biagi & Starnini, 2008). Indus flint extraction trenches were discovered mainly along the edges of a narrow hill still intact that elongates between Ongar and Daphro. Also a few points of Daphro Hill revealed the presence of flint-extractive systems similar to those observed along the western mesas of the Rohri Hills in Upper Sindh (Figs. 26 and 27). Apart from

Quarries in Harappa, Fig. 15 Very wide, circular concentration of Harappan debitage flakes near Shadee Shaheed





Quarries in Harappa, Fig. 16 Harappan bullet cores with very narrow bladelet detachments



Quarries in Harappa, Fig. 17 Large area cleaned by the quarries. The modern heaps of flints are clearly visible

Quarries in Harappa, Fig. 18 Modern handmade quarrying along the fringes of the Rohri Hills mesas



ditches excavated along the edges of the limestone mesas, the surveys revealed the systematic recurrence of flint workshops (Fig. 28), undoubtedly attributable to the Indus Civilization, as indicated by the presence of characteristic elongate, subconical, flint cores with long blade detachments (Fig. 29). A similar situation has been noticed also along the sides of Bekhain, a low hill, located just to the south of the abovementioned two, where most of the Indus flint mines had already been destroyed at the time of their discovery. At Bekhain Hill, the occurrence of large-sized pre-cores (Fig. 30), already prepared for being transported, is of major interest. Single pre-core specimens have been found also at Mohenjo-daro, the Rohri Hills, and Kahi Bhandari near Badin (Khan, 1981), close to the Rann of Kutch. This discovery is particularly important because it indicated that not only the final products, such as well-defined types of blades and bladelets, were transported to the major centers of the Indus Civilization for being transformed into instruments for craft production around the middle of the third millennium BCE, but also complete, large blocks of flint already prepared for their transport. It is highly regrettable that most of the above important third millennium BCE extractive areas were

Quarries in Harappa,

Fig. 19 Machine quarrying in the central part of the Rohri Hills as it was in 1999



Quarries in Harappa,

Fig. 20 An internal region of the central part of the Rohri Hills rich in groups of Harappan flint quarries and workshops



devastated during the last 50 years by illegal limestone quarrying and that they are also “exploited to produce flint cores and blades, seemingly to decorate private residence walls” by a Karachi enterprise (Biagi & Nisbet, 2011) without any interest by both local- and national-appointed authorities.

Jhimpir

The presence of a flint source in the Ranikot bed northwest of Jhimpir railway station had already

been reported by Blandford (1880, p. 153). Although a survey conducted in the area in 2010 did not reveal any important flint seams in situ in the limestone deposits, further investigation conducted south of the above small town led to the discovery of two distinct flint outcrops in two limestone terraces oriented in an east–west direction (Biagi 2011; Biagi & Nisbet, 2010). Further investigations in the area undertaken the following year showed that the same flint seam, although interrupted, continues further to the west, following the same direction. The most evident traces of prehistoric exploitation were

Quarries in Harappa, Fig. 21 The beginning of the excavation of the Harappan flint quarry-pit 862 in the Rohri Hills



Quarries in Harappa, Fig. 22 The flint seam reached by the Harappan miners during the mid-third millennium BCE with many nodules still in situ, ready for extraction at quarry-pit 862



Quarries in Harappa, Fig. 23 A large flint nodule discovered in the bottom layer of the excavation carried out at quarry-pit 862



Quarries in Harappa, Fig. 24 A small flint nodule prepared for its extraction in the bottom layer of the excavation carried out at quarry-pit 862



Quarries in Harappa, Fig. 25 Concentration of flint debitage flakes discovered during the excavation of quarry-pit 862



Quarries in Harappa, Fig. 26 A large, Harappan flint workshop discovered in the Daphro Hill in 2006

Quarries in Harappa, Fig. 27 Three parallel, Harappan flint extraction trenches opened along the edge of the Daphro Hill



recorded on a flat terrace that elongates close to the Larinadi riverbed. Here, the westernmost part of the mesa is marked with extraction trenches surrounded by workshops marked by the presence of blade cores, debitage flakes, crested blades, and bifacial picks made from the same flint. Good-quality flint seams were observed also at the top of an inclined terrace located about one mile south of the abovementioned one. At present, this seam is exploited on a small scale for industrial purposes.

Considerations

The discoveries made in the Rohri, Ongar, Daphro, and Bekhain Hills and Jhimpir have demonstrated that flint was still extremely important during the flourishing of the third millennium BCE Indus Civilization. Flint was extracted not only from the Rohri Hills quarries but also from other mining areas which were unknown to archaeologists until a few years ago and most probably also from other outcrops still to be discovered (Biagi, 2010, p. 13). During this period, they were traded over long distances at least as far as Harappa, to the north (Law, Baqri, Mahmood, & Khan, 2002–2003), and the Indus cities located along the north Arabian Sea coast, to the south

Quarries in Harappa,

Fig. 28 A long Harappan flint extraction trench excavated along the edge of the Daphro Hill



Quarries in Harappa, Fig. 29 Harappan elongated core for the production of long, narrow flint blades with parallel edges



Quarries in Harappa, Fig. 30 Harappan flint pre-core already oval-shaped for its exportation to one of the Harappan urban centers of the Indus Valley

(Gadekar, Ajithprasad, & Madella, 2013). The complicated extractive system, which undoubtedly involved a great number of workers and knappers (flint shapers), and the extraordinary great number of mines discovered on the Rohri Hills indicate that this was undoubtedly a main extractive center and that flint was of primary importance at least during the mid-third millennium BCE mature Indus Civilization. Although the extraction systems have not been fully understood and the trade routes are still poorly known,

there is no doubt that the role played by this raw material has so far been underestimated by archaeologists.

Furthermore, as already remarked on many occasions, the damage to a more comprehensive knowledge of the Indus Civilization caused by the systematic devastation, for illegal industrial activities, of most of the aforementioned archaeological areas of Upper and Lower Sindh is remarkable (Dar, 1991; Allchin, 1999, p. 298; Biagi, 2007).

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Quarries in Tunisia

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Since antiquity, stones have played an important role in Mediterranean civilizations. Thanks to the surveys and the studies of both geologists and archaeologists, the extraction quarries are partly identified. Tunisian quarries are numerous, and since the Punic period they have provided several types of sandstone and limestone of good quality for construction. The stone extraction techniques employed by the quarry workers have undergone great changes from antiquity to the present.

This present study deals with the geological features of the cut stones, a view of the location of most of the Tunisian quarries, and finally the stone extraction techniques which have been used since ancient times.

Geological Features of Tunisian Stones

Tunisia has many useful mineral resources, particularly in phosphates, clays, extra-siliceous sands, charge substances, raw materials for mineral binders (gypsum, limestone, calcareous clay, etc.), and stones. These last have been exploited for more than 2000 years because of their good mineralogical, physical, and chemical features. Indeed, these stones reveal a good structural resistance mainly linked to their mineralogical composition; they have calcites, dolomites, and sometimes a very low proportion of quartz. Their long use, from the Libyc dynasty to now, is real proof of their strength. Furthermore, the presence of these stones in wide-scale geological areas situated not far from urban centers both with

their attractive appearance (color, texture, and homogeneity) encouraged the quarriers to exploit them for different uses.

Tunisian stones, with their great variety of colors ranging from light to dark, allowed them to meet all the architects' and town planners' requirements from all over the world (Fig. 1).

The Tunisia geological map shows sedimentary outcrops ranging from the Upper Permian age to the Quaternary except for a few sporadic outcrops made of metamorphic and magmatic rocks, most of them situated in the far northwest of the country (Fig. 2).

These stones belong to six geological periods characterized by completely different sedimentology and paleogeographic conditions: Jurassic, Cretaceous, Eocene, Miocene, Pliocene, and Quaternary.

Jurassic

The stones that come from this period are:

- Gray and black dolomites and dolomitic limestone veined by white calcite. They are found in the Jurassic massifs of the Tunisian ridge.
- Yellow, orange, red, green, and gray low metamorphosed dolomites in Jebel Chemtou and Jebel Ichkeul (northern Tunisia).
- Beige and punctuated with red in the region of Ghomrassen where the thick dolomitic limestone bar stands as a landmark all over southern Tunisia.

Cretaceous

This period produced stones with the following features:

- Black limestone with occasional red veins filled with oxide of iron from Albian-Aptian outcrops. These stones are present in the regions of Boulahneche (Governorate of Kasserine) and of Bou Arada (Governorate of Siliana).
- Yellow, beige to grayish carbonated rocks of the so-called bar of Gattar from Turonian age. These types of stones outcrop mainly in the south of Tunisia and particularly in the regions of Gabes and Matmata.

- Reddish and whitish biolithite calcareous from Cenomanian age which are present in Jebel Keddel (around 20 km south of Tunis).
- Beige, gray, and reddish calcareous (Thala type) from Abiod formation of Campanian-Maastrichtian central Tunisia and more particularly in the region of Thala (Governorate of Kasserine in center-eastern Tunisia).

Eocene

When it is a nummulitic facies, the Lower Eocene is used as varicolored marble stones such as the Kesra type. Indeed, the colors are the most varied: black, gray, beige, yellow, red, and whitish.

Miocene

Yellowish bioclastic sandy limestone with lamellibranchs has been identified especially in the region of Mahdia.

Pliocene

The Pliocene stones consist of bioclastic sandy limestone which have revealed very good physical and chemical features. They are essentially located in the region of Monastir and Nabeul.

Quaternary

Tyrrhenian Dune Line

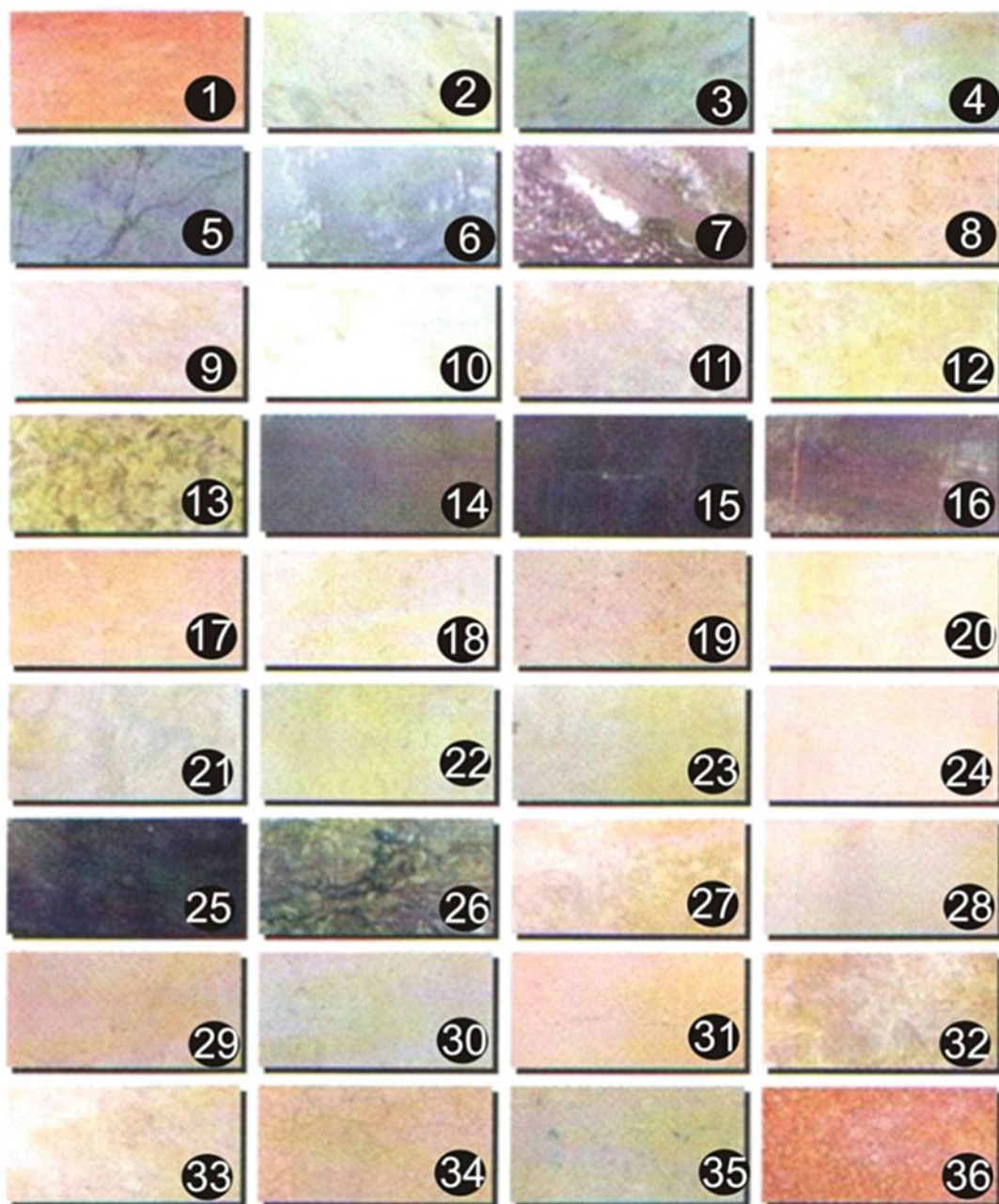
The Tyrrhenian dune line, ranging from a few meters to a few kilometers wide, outcrops all along the Tunisian coastline and provides carbonated sandstones, most often bioclastic (lamellibranchs, gasteropoda, and strombes).

The Holocene Dune Line

This dune line is an ancient beach constituted of lamellibranch sandstones whose color ranges from red to yellowish. They are found at El Haouaria in the Governorate of Nabeul.

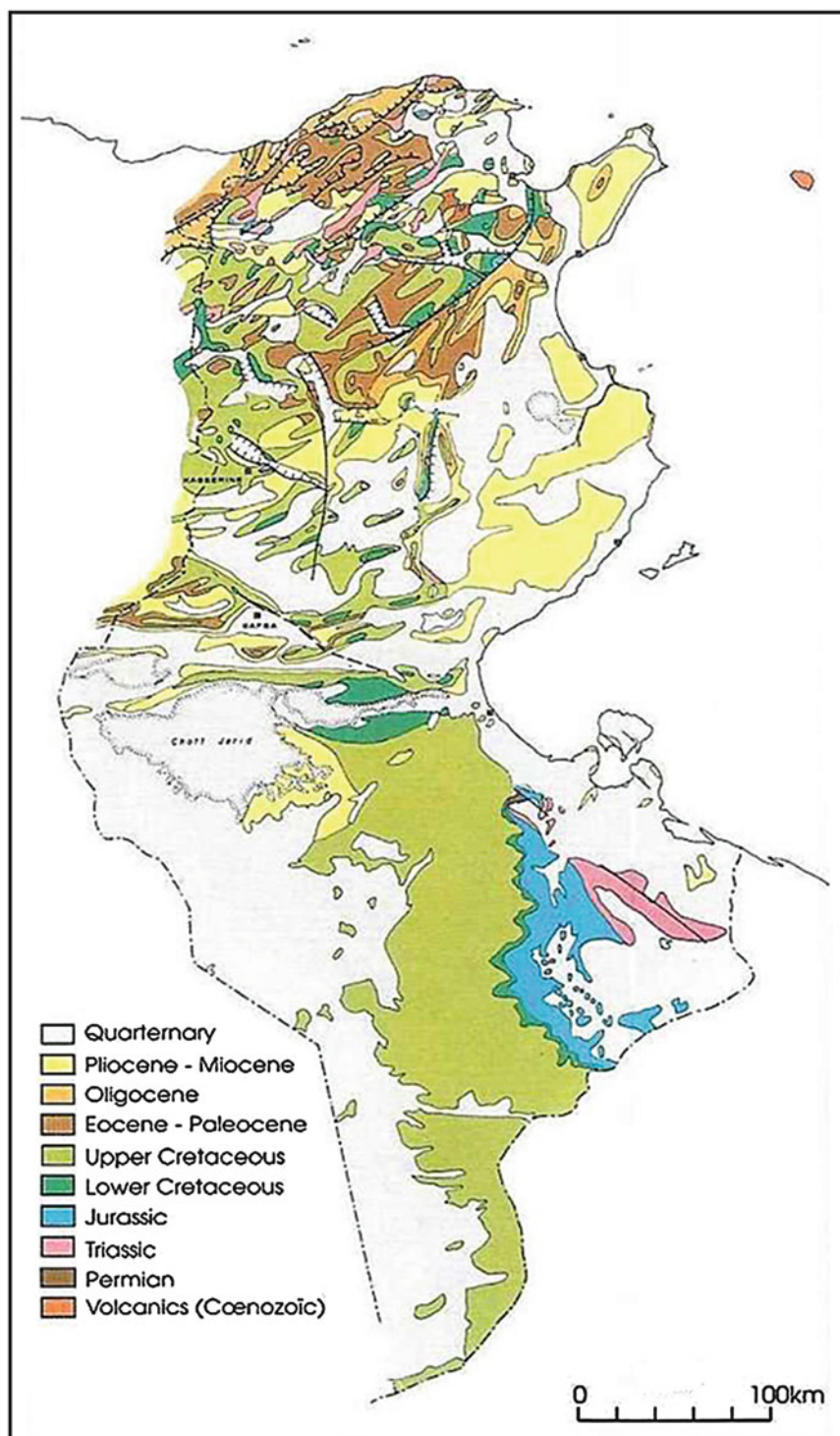
Location of the Quarries

According to current data, Tunisian quarries have been known since the Punic period. They are situated essentially in the sedimentary outcrop belonging to six different geological periods in



Quarries in Tunisia, Fig. 1 Colored range of Tunisian stones (Mohamed Essghair Gaied). 1, pink of Chemtou; 2, yellow of Chemtou; 3, gray of Chemtou; 4, green shale of Hairech; 5, Aziza black; 6, Aziza Berber; 7, Aziza brown; 8, Ghomrassen type; 9, 10, 11, 12, and 13, limestone reef (type Keddel); 14, 15, and 16, Boulahneche type or black Thala; 17, Matmata type; 18 and 19, Thala imperial; 20,

Thala royal; 21, Thala gray; 22, Thala veined or fissural; 23, Thala flowery or shelly; 24, Thala pink or Gabes stone; 25, Kesra black; 26, Kesra gray; 27, 28, and 29, Kesra beige; 30, Kesra gray-beige; 31, Kesra red or pinkish stone Mateur; 32 and 33, Kesra beige or Dahmani stone; 34, Foussana stone; 35, El Hamma or Gabes stone; 36, Chebika or Kairouan stone



Quarries in Tunisia, Fig. 2 Geological map of Tunisia (Mohamed Essghair Gaied), (ETAPE, 2010)

northern, central, and southern Tunisia. This type of outcrop has most often provided a good quality building stone.

In northern Tunisia, two quarry areas can be distinguished: the coastal quarries and the inland ones. The first ones are mainly located in the regions of Cap Bon (Holocene sandstones), Bizerte (Tyrrhenian or Würmian sandstones, Jurassic dolomitic limestone), and Tabarka (Eutyrrhenian sandstones, Eocene limestone) (Fig. 3). Concerning the inland quarries, they have been found in the regions of Beja (Eocene limestone), Jendouba (Eocene limestone, Jurassic dolomitic limestone), Kef (Eocene limestone), and Zaghuan (Jurassic limestone and travertine) (Fig. 3).

In central Tunisia, the quarries are found both in the Sahil region (Pliocene and Miocene sandstone-limestone, Tyrrhenian carbonated sandstones, Holocene biolithite sandstones) and inland in the regions of Thala, Siliana, Kasserine, and Kairouan (Eocene limestone) (Fig. 3).

In southern Tunisia the quarries identified are less numerous and less preserved than those in northern and central Tunisia. They have been found in the regions of Gabes (Cretaceous recrystallized limestone, Tyrrhenian sandstones), Tataouine (Trias dolomitic limestone, travertine), and Djerba (Tyrrhenian shelled limestone) (Fig. 3).

Extraction Techniques

It is mainly thanks to archaeological evidence that the quarrying techniques are well known nowadays. Indeed, the best-preserved quarries from sandstone and limestone rocks provide precious information concerning the different exploitation techniques used by the quarriers from antiquity to now.

Ancient Extraction Techniques

Two types of exploitation have been identified: open-air exploitation and in galleries.

In open-air exploitation, the quarry worker starts to choose the good quality rock for

construction by taking off the sand and the vegetation layer which cover this rock. Then, following the natural planes of weakness in the bedrock (joints, stratigraphic levels), he outlines the block to be cut by making slits in the three non-detached sides with a pick or *escoude*. Afterwards, he widens and deepens these slits using different tools such as pick, *escoude* and/or sledgehammer, awl, and chisels in order to get extraction trenches wide enough for the tool to be easily moved in. The length and the width of these extraction trenches correspond to the size (or volume) of the block to be cut (Fig. 4).

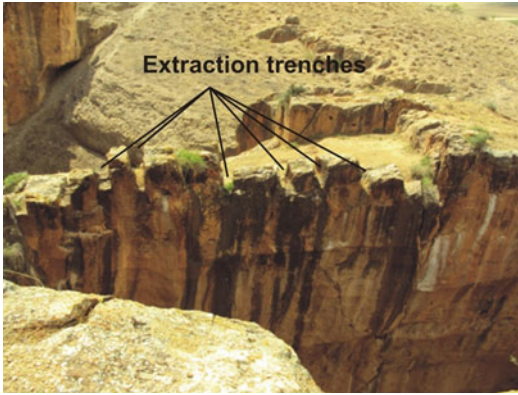
The sizes (length $\times$ width $\times$ thickness) of the well-preserved extraction trenches on the quarry faces range from $0.25\text{--}2.50 \times 0.08$ to $0.15 \times 0.15\text{--}0.75$ m. Finally, in order to extract the block, the quarry worker makes a line of rupture at the lower forward side where holes are made to insert metallic wedges on which two or three quarriers hammer. When this last step is not successfully done, the lower part of the block remains attached to the rock.

The coastal quarries are often separated from the sea by a non-detached straight line of the rock in order to prevent water from entering which would interrupt all activities. The extracted blocks give to the quarry faces either a beveled edge or stepped profile. When the thickness of the pumice stone upper layer becomes of poor quality for building, the quarry worker gives up open-air exploitation and opens up a gallery. The underground quarries known under the name of *ghar* consist of at least one room and one or two entrances situated to the eastern or western sides providing the rooms with daylight and fresh air.

The technique of block extraction in galleries is the same as in the open-air quarries. Yet, inside the gallery, in order to strengthen the ceiling of the quarry, a kind of natural pillar is cut into the rock which is not the case in the open-air quarries (Fig. 5). Most of the rooms in the underground quarries are medium and small sized, so they are rather well ventilated and lit during the day. In the scarce large-sized ones which are poorly lit since they have not got lighting shafts, the quarry workers have to light the far end of the gallery with oil lamps.



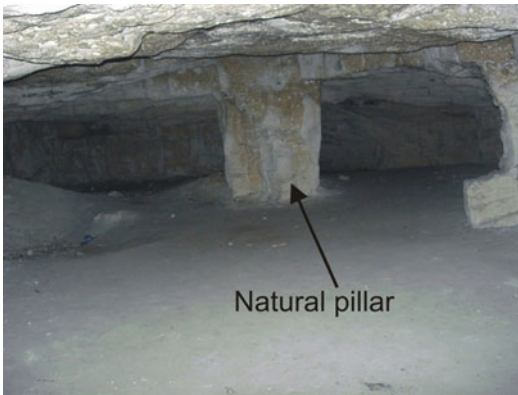
Quarries in Tunisia, Fig. 3 Location map of the identified quarries (Ameur Younès)



Quarries in Tunisia, Fig. 4 Extraction trenches in Simitthus Roman quarry (Ameur Younès)



Quarries in Tunisia, Fig. 6 Modern extraction techniques of sandstone blocks in Rejiche quarry (Ameur Younès)



Quarries in Tunisia, Fig. 5 Natural pillar in the underground Roman quarry in Ksour Essaf (Ameur Younès)

The cutting marks left on the gallery faces give them a beveled edge profile. The extracted blocks are small and medium sized, but with an occurrence of the small ones. These small-sized blocks are easier to move in the galleries than the medium- and large-sized ones.

Though the extraction technique in the galleries has not changed since ancient times, the open-air exploitation has undergone great changes.

Modern Extraction Technique

The ancient open-air extraction technique was used until the second half of the twentieth century. Then, the mechanization of the quarry

exploitation changed from the ancient extraction techniques. Today, the quarry men follow two different techniques according to the type of the rock to be extracted.

For sandstone rocks, the quarry men take off the upper layer of the soil, and then a driver operates a disk saw machine to cut uniform square sandstone blocks (Fig. 6). These blocks are then picked up and loaded into trucks to be transported to building sites.

For extracting marble limestone, the quarry men take off the sand and vegetation layer covering the limestone banks to be extracted, and then they outline the blocks to be cut following the natural planes of weakness in the bedrock. Afterwards, using a diamond thread saw machine, the technical driver cuts up large-sized marble limestone blocks which are finally carried and transported from the quarries into marble stone factories where they are cut, polished, and sculpted (Fig. 7).

Conclusion

Geologists and archaeologists have located most of the Tunisian stone quarries. These quarries have provided several types of good quality stones for construction thanks to their different geological formations. Exploitation techniques



Quarries in Tunisia, Fig. 7 Modern extraction techniques of marble limestone blocks in Chemtou quarry (Ameur Younès)

have remained the same since the Punic period until the second half of the twentieth century when the quarry men began to use machines in order to cut stones in the open-air quarries. Both the ancient and modern extraction techniques of blocks in Tunisia are similar to the exploitation techniques identified in the quarries situated in the Mediterranean countries. Yet, because of scarce documents available on the administration of many quarries, it is not possible to know exactly how they were administered.

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Quinoa. A Millenary Grain in Northern Argentina

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Quinoa (*Chenopodium quinoa*) is a plant of South American origin able to flourish in poor soils and conditions often regarded as marginal for other crops. Its panicles contain a large number of grains basically composed of starch and rich in protein, mineral nutrients, and oils (Ayala, 2004; Repo-Carrasco, Espinoza, & Jacobsen, 2003).

Since the first information collected by Armando Hunziker between the 1940s and 1970s, the background for pre-Hispanic cultivation and use of the quinoa in what is today Argentina has been considerably enlarged. The renewed interest in this plant in the last decade

Quinoa. A Millenary Grain in Northern Argentina, Fig. 1

West side of Argentina. From west to east in the Northwest region there are the High Puna, mesothermal valleys, mountainous rainforest, mountainous Chaco forest, and Chaco plain

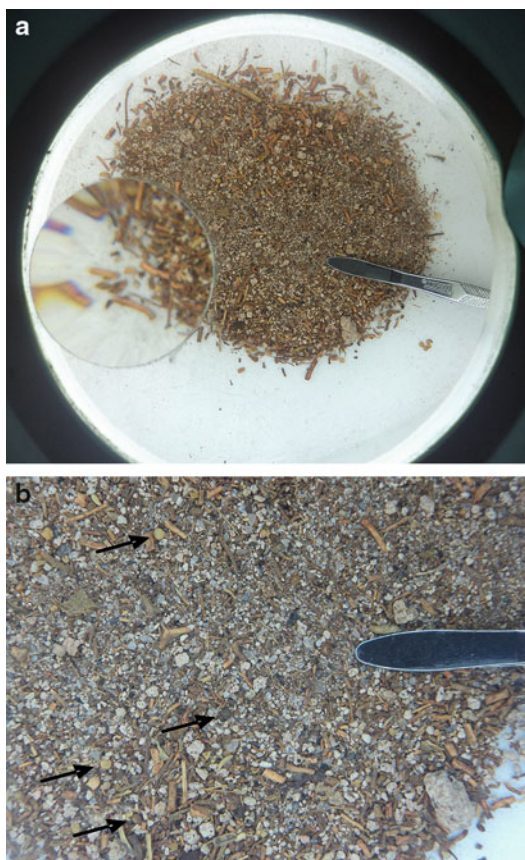


has drawn a more precise, though still fragmented, panorama of the millenary use of this South American grain. Even though the southern Andes has been traditionally considered marginal regarding agricultural development in the Central Andes, the new discoveries indicate that, quite to the contrary, a long tradition exists in the local use of this plant.

Numerous seeds and fragments of both panicles and stalks, as well as microscopic remains of this plant on ancient tools, are widely distributed in the western part of Argentina, from the northern locations in Jujuy province to the Cuyo area

in Mendoza province to the south (Fig. 1). These findings resulted from the careful implementation of field and laboratory archaeobotanical techniques focused on the recovery of ancient botanical material from site sediments (Fig. 2) as well as from the objects yielding microscopic residues of plant manipulation.

In the Northern region, available information indicates the use of quinoa by the societies inhabiting several archaeological sites in the Puna but also in the hillsides and valleys of arid or semiarid climates, the mountainous rainforests, and the Chaco environments nearby,



Quinoa. A Millenary Grain in Northern Argentina, Fig. 2 Dry sieving is an archaeobotanical technique to separate sediment fractions that contain archaeological plant material, according to the size of a series of sieve meshes. Sediment fractions obtained are scanned under a magnifying glass, and plant material is picked up with a pin. (a) Sieved sediment fraction, from 1 to 1.99 mm, under the magnifying glass. (b) Detail of different color quinoa seeds, before being picked up from the sediment

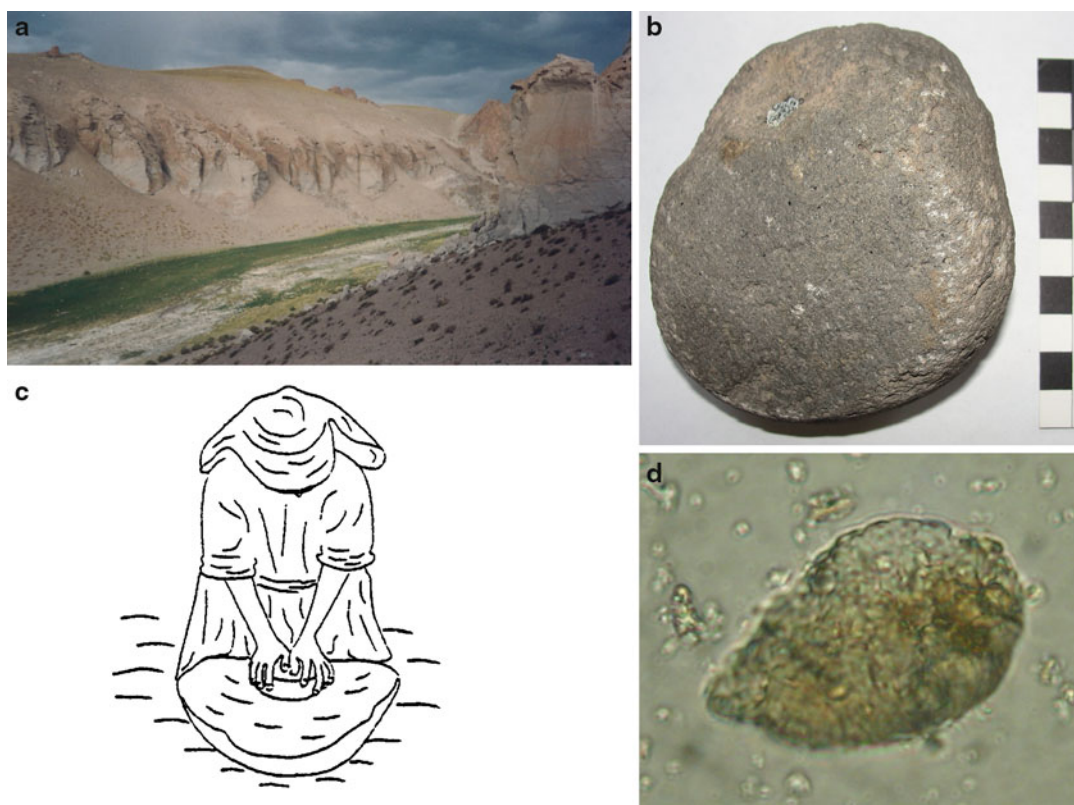
far before the arrival of the Inca and European populations. Historical chronicles as well as travelers' tales give hints about its cultivation even in later Colonial and Republican times.

A number of references for the use of quinoa were recovered at some archaeological sites in the Punilla river basin (Puna of Catamarca), a high-elevation desert environment some 3,500 masl. The earliest date for quinoa manipulation corresponds to hunter-gatherer groups who occupied the area some 4,500 years ago. These societies seem to have been responsible for the

beginning of camelid husbandry practices and their eventual evolution into llamas (Aschero, Izeta, & Hocsmán, 2014). It may be possible that, at the same time, they would have engaged in small-scale experimental cultivation of some plants to collaborate with the food provision to the familiar unit. Both activities would be complemented by hunting, plant gathering, and exchange of some products with other areas. Thanks to these mechanisms, even in those early times, the societies inhabiting the whole Argentinian Puna manipulated a wide spectrum of plants and animals for food, crafting, habitat accommodation, illness treatment, and ritual practices (Babot, 2011; Fernández Distel, 1986).

Many of the plants used, particularly the ones intended for food, did not survive in the archaeological sites of early dates. Nevertheless, they are known by microscopic remains called microfossils, which are preserved on the surface of grinding stones and projectile points/knives of the Quebrada Seca 3 site (Antofagasta de la Sierra, Catamarca), for instance (Fig. 3). These microfossils are testimony to the preparation previous to the consumption of several tubers and roots, cactus fruits (*Opuntia* sp.), wild grass seeds, maize grains (*Zea mays*), and pseudocereals such as quinoa and *kañiwa* (*Chenopodium pallidicaule*, a plant of the same genus as quinoa) (Babot, 2011; Babot et al., 2013). Some of the plants manipulated at the time, like maize and Cactaceae, would have originated in warmer and more humid ecological zones than the Puna. However, species prone to Puna climate, such as quinoa, may have been locally produced and harvested. This idea is supported by the evidence of manipulation of a seed similar to quinoa by Puna societies, who used to know and consume wild amaranth grains (*Amaranthus hybridus*) some 8,000 years ago (Arreguez, Martínez, & Ponessa, 2013).

The next milestone in the history of quinoa use in the Punilla river basin may be placed about 3,500 years ago. This is the date for the earliest quinoa stalks remains found so far. It is estimated that, at that date, the small agricultural fields and the spaces for postharvest activities



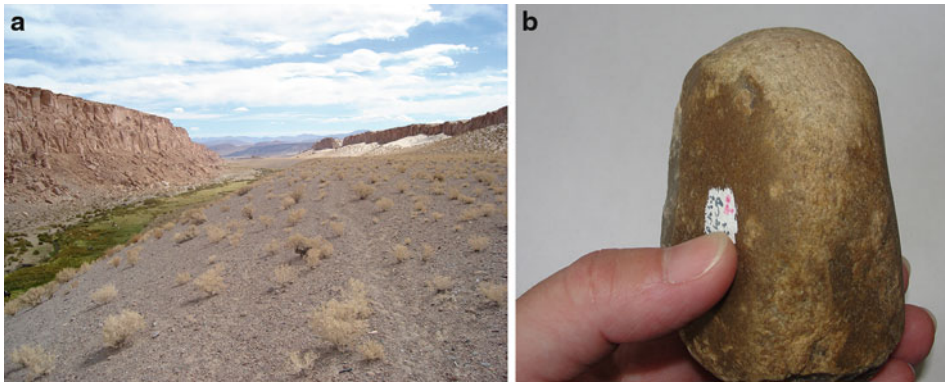
Quinoa. A Millenary Grain in Northern Argentina, Fig. 3 (a) View of Quebrada Seca Gorge at 4,000 masl in the Punilla river basin (Southern Puna of Argentina). (b) Handstone from Quebrada Seca 3 site – the scale bar is in centimeters. (c) Drawing showing the way of using a

handstone on a lower grinding tool. (d) Microscopic starch grain of *Chenopodium* cf. *quinoa* (approximately 20 μ m length) recovered from a handstone from Quebrada Seca 3 site (4,500 years old)

would be nearby the residential areas, where the different parts of the plant were consumed. One of these residential sites is the Peñas Chicas 1.3 rock shelter in the Las Pitas middle river basin (Antofagasta de la Sierra, Catamarca) (Hocsman, 2006; Fig. 4). This place yielded a fragment of stalk morphologically related to a quinoa with ancient features (Aguirre, 2007), testifying to the harvesting of the plant. A few meters from this site, the Peñas Chicas 1.1 rock shelter, of a similar chronology, provided microscopic starch grains corresponding to the remains of quinoa ground into flour (Babot, 2011). Local populations would have incorporated other plants into their food repertoire, such as *oca* (*Oxalis* cf. *tuberosa*), common potato (*Solanum* cf. *tuberosum*), edible canna (*Canna* cf. *edulis*), algarrobo (*Prosopis* spp.),

and wild native walnut (*Juglans australis*) (Babot, 2011).

The distance between spaces for quinoa cultivation and their related residential sites seem to have remained unaltered throughout time at least until 1,400 years ago, as indicated by the desiccated remains of stalks and panicles recovered in residential sites of different chronologies: Cueva Salamanca 1, El Aprendiz, and Punta de la Peña 9 (Arias, Aguirre, Luque, & Escola, 2014; Babot, Aguirre, & Hocsman, 2013; Pintar, 2014). Then, when agricultural intensification increased toward 1,000 years BP in several locations in the Punilla river basin (Olivera & Tchilinguirian, 2000; Salminci, Tchilinguirian, & Lane, 2014; Tchilinguirian & Olivera, 2000), quinoa was still being locally produced as is proved by quinoa seeds and panicle fragments at Punta de la



Quinoa. A Millenary Grain in Northern Argentina, Fig. 4 (a) View of gorges at 3,600 masl in the middle basin of Las Pitas River (Southern Puna of Argentina).

In the *center* of the image, there is the archaeological area of Peñas Chicas. (b) Pestle from Peñas Chicas 1.1 site (3,500 years old)

Peña 4 and Punta de la Peña E sites until 600 years before now (Rodríguez, Rúgolo de Agrasar, & Aschero, 2006; S.M.L. López Campený, personal communication, November 22, 2013). Such findings, spread throughout time, indicate the presence of a local and uninterrupted tradition of quinoa cultivation covering three and a half millennia in the southern Argentinian Puna.

The agricultural instruments used to manipulate quinoa are still unknown for the early moments of its cultivation before 2,000 years BP. However, between 1,700 and 1,200 years BP, herding and horticultural societies are known to have used large lithic objects with cutting edges related to modern knives or sickles for these tasks, to the point of making them blunt (Escola, Hocsman, & Babot, 2013; Fig. 5). These pieces were recovered in different sites in the Punilla river basin (Punta de la Peña 9, Punta de la Peña 12, and Casa Chávez Montículos 1). Knives would have been useful in the many activities implied in the agricultural cycle, including thinning or desuckering the green plant and reaping the mature panicles of the different pseudocereals. Consequently, their cutting edges have preserved microscopic residues of quinoa, *kañiwa*, and some amaranth plants such as *kiwicha* or *chaclión* (*Amaranthus caudatus* and *Amaranthus mantegazzianus*). Cultigens are known to have been attacked by pests as well,

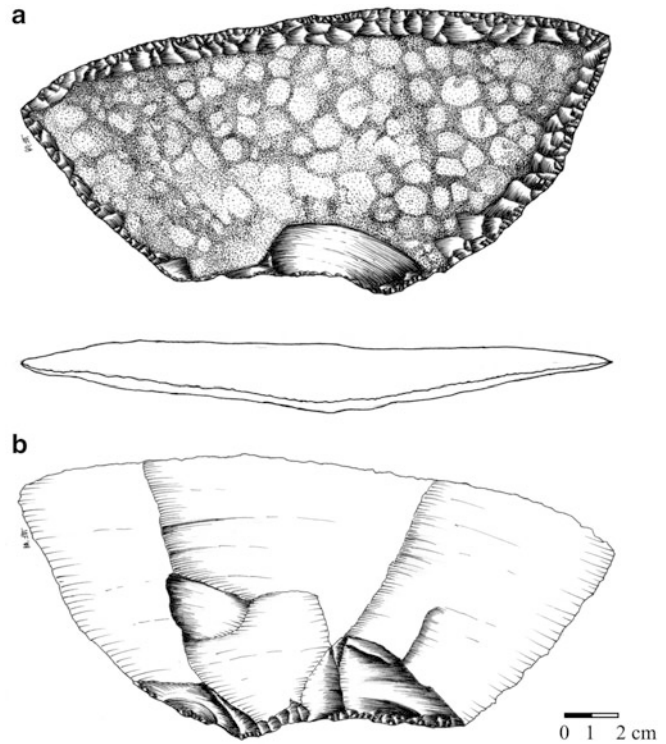
as tiny moth scales were identified among the remains. Some of these ancient instruments were recovered from storage places, carefully arranged, in both residential and de-kernel and threshing areas. Additionally, knives were found close to spaces which may have been devoted to the highland cultivation of quinoa, particularly next to river margins where water was available for irrigation. Currently, it is cultivated in small orchards with a large diversity of floral examples, where edible plants alternate with ornamental and medicinal species (Fig. 6).

Both the knives and the severed stalks found in Antofagasta de la Sierra cover a wide chronological range and suggest a common tradition of harvesting the pseudocereal by cutting the stalk instead of uprooting the complete plant.

Similar lithic knives were also located in many valley sites in Catamarca province beyond the Puna region: El Bolsón, La Ciénega, Hualfín, El Cajón, and Yocavil (Escola, Hocsman, & Babot, 2013). Microfossil studies on the materials from El Bolsón documented that the knives were used with a similar purpose to the ones recorded in the high Puna (Maloberti & Mauri, 2013).

The process followed by quinoa seeds after harvest can be tracked from the findings in ancient kitchens, rubbish middens, or small deposits of plants and vessels in caches inside several archaeological sites in the Punilla river basin such as Cueva Cacao 1 or the locations

Quinoa. A Millenary Grain in Northern Argentina, Fig. 5 Knife/sickle used in harvesting quinoa in the Southern Puna of Argentina from between 1,700 and 1,200 years before the present day

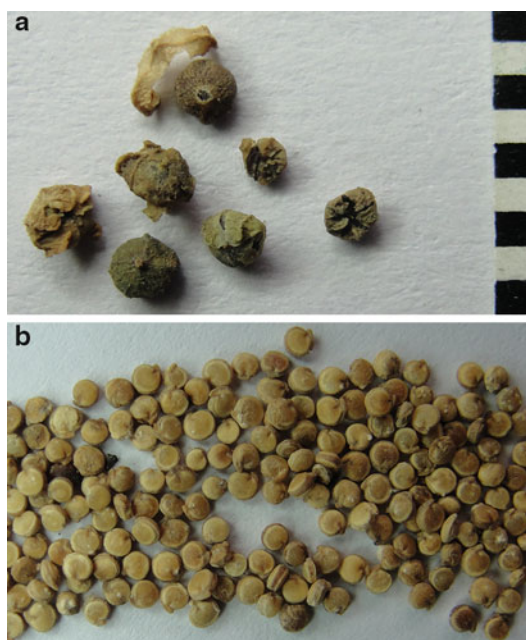


Quinoa. A Millenary Grain in Northern Argentina, Fig. 6 (a) Location of high-elevation orchards next to Las Pitas River, in the Punilla River basin (Southern Puna

of Argentina). (b) Local varieties of quinoa in the Morales Family's high-altitude orchard at Las Pitas River

aforementioned (Babot, Aguirre, & Hocsmán, 2013; Olivera, 2006; Fig. 7). Archaeological seeds are somewhat more recent than stalk remains, dating to 3,000 or 2,500 BP, but they were present until Colonial times. Grains are occasionally recovered together with the terminal

fragments of panicles, constituting the earliest record of the postharvest quinoa treatment stage (Fig. 8). Similar to modern times, dry panicles would have been de-kerned by carefully patting and rubbing. After that, the detached material would have been threshed and winnowed to



Quinoa. A Millenary Grain in Northern Argentina, Fig. 7 Archaeological quinoa seeds from the Punilla River Basin (Southern Puna of Argentina). (a) Unhusked seeds from Punta de la Peña 9 site (1,500 years old) – the scale bar is in centimeters. (b) Dehusked seeds from Punta de la Peña 4 site (700 years old)

separate the grain from the remaining tiny residues. The recovery of the waste from these activities in some archaeological sites such as Punta de la Peña 9 indicates that the stages of detachment and dusting were carried out near residential places. At least a threshing enclosure, with a mortar-and-slab floor and simple *pirca* walls resembling pre-Columbian and modern so-called *kayanas* in the Bolivian Altiplano, was recorded in this archaeological site (Escola, Hocsman, & Babot, 2013).

Beyond the northern area of Catamarca, Puna records of quinoa are less frequent, but they may increase with the advance of research in progress. Available evidence indicates that in the Puna highlands of Salta and Jujuy provinces, this Andean grain was among the first plants cultivated by local societies, as also happens in Antofagasta de la Sierra. Coat removal and grounding of quinoa seeds were included in the daily activities carried out in the residential areas of the



Quinoa. A Millenary Grain in Northern Argentina, Fig. 8 Endings of the quinoa panicles, from Punta de la Peña 9 site (1,500 years old) in the Punilla River basin (Southern Puna of Argentina). They are waste from the quinoa cleaning – the scale bar is in centimeters

early agricultural and herding human groups living in El Aguilar area (Puna of Jujuy), as evidenced in the microfossil plant remains found on grinding stones dated between 3,000 and 2,600 years ago (Babot, Hocsman, Piccón Figueroa, & Haros, 2012). The grain was incorporated into several culinary recipes whose ingredients accumulated on some ceramic sherds from the Cueva de Cristóbal archaeological site (Babot, Hocsman, Piccón Figueroa, & Haros, 2012), one of the earliest pottery records in the southern corner of South America. In the case of El Aguilar, the use of quinoa was documented as a living practice even in Spanish Colonial times some 400 years ago, exemplified by the seeds found in Cueva El Portillo rock shelter.

Some seeds morphologically similar to quinoa were located in the Puna of Salta. Due to charring, their identification has to be restricted to the genus *Chenopodium*. The seeds were recovered in a garbage midden at the agropastoral village of Matancillas 2 (San Antonio de los Cobres), dated toward the beginning of the era (Muscio, 2004). Not far from this site, in the northern head of the Calchaquí Valleys, which provides a natural access to the Puna, Dr. Verónica Lema also recorded quinoa with a chronology approximately 450 years earlier than the former site, in the Puente del Diablo Cave (La Poma) (V.S. Lema, personal communication, November 22, 2013).

So far, the southernmost finding of ancient quinoa in the Puna region as well as in all of northwestern Argentina took place in Tinogasta, Catamarca province. In this case, quinoa seeds were part of the grave goods of an adult male who died some 600 years ago (Ratto, Lema, & López, 2014).

Going down the eastern border of the Puna, between 3,500 and 2,400 masl, the landscape presents numerous valleys and hillsides. Due to natural conditions, which are usually adverse for the preservation of organic materials, these environments are poorer in archaeobotanical findings than the Puna desert. However, some sites characterized by peculiar conditions have provided valuable information about the ancient use of quinoa and other plant resources, shedding light on the trajectory of this grain in the lowlands for the last two millennia, simultaneously with its production and consumption in the Puna.

In the valleys, the outstanding recovery of *Chenopodium* seeds morphologically similar to quinoa in the village of Cardonal (El Cajón Valley, Catamarca province) is unique in the area due to their early chronology, dating back to the first centuries of the era. Quinoa was one of the useful plants villagers manipulated in their ancient kitchens, among which maize, potatoes, and common beans should be also mentioned (Calo, Bugliani, & Scattolin, 2012). Toward the east, the Pampa Grande contexts in Las Pirguas Hills (Salta province) are testimony to other exploitations of this grain, represented here in mortuary rites (Hunziker, 1943). This custom is indicated by the presence of quinoa seeds in a vessel, together with other plants accompanying human burials dated to 1,200 AP. Hunziker's was one of the pioneer case studies of archaeological quinoa in the country, developed as early as the 1940s in collaboration with Francisco de Aparicio. As much as quinoa, *kiwicha* and other wild *Chenopodium* and *Amaranthus* grains were identified (Hunziker, 1943). Once in the mountainous rainforests of northwestern Argentina, Las Pirguas is the westernmost enclave where archaeoquinuas were found.

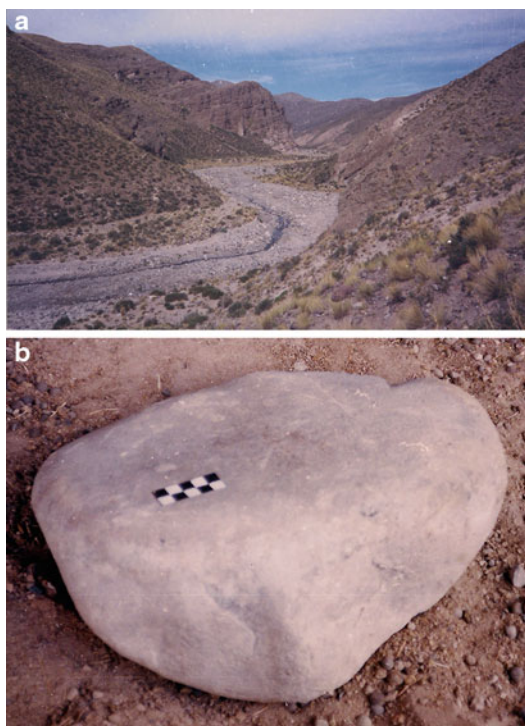
Toward the last centuries before the arrival of the Inca to the territories in Northern Argentina,

the quinoa "trace" seems more defined in the archaeological sites of the temperate valleys, which in turn presents different environmental conditions. In the pre-Puna locations in the El Bolsón Valley (Catamarca province), two cases may be mentioned, both of them dated to some 1,000 years before today: Cueva de las Máscaras and Alero Los Viscos, two nearby shelters in the Los Viscos Gorge (Korstanje, 2007). The latter yielded quinoa and amaranth seeds in a garbage midden located inside the residential place.

At a lower altitude and near the border with the eastern mountainous rainforests, Cueva de Los Corrales Cave site, in the Tafi Valley (Tucumán province), constitutes another hillside location where quinoa, *kiwicha*, wild *Chenopodiaceae*, and wild *Amaranthaceae* seeds were discovered in a full-use context, as part of a larger repertoire of native plants (Arreguez, Martínez, Oliszewski, & Ponessa, 2015; Fig. 9). To the north, on the border between Argentina and Bolivia, the Río Grande de San Juan basin is also informative regarding quinoa consumption and the disposal of charred grains in the garbage middens of the Finispatriae site (Nielsen, Angiorama, Maryaňsky, López, & Ávila, 2013). All these hillside sites as well as the large urban conglomerates in the Calchaquí Valleys (Salta), where this Andean grain was abundant, suggest that quinoa must have been a key resource for the native societies in the valleys of northwestern Argentina between the centuries after 1,000 years BP and the Inca arrival.

The situation does not seem to have changed under Inca control. The finding of numerous charred grains similar to quinoa and their wide distribution in the valley (Puerta de La Paya, Cortaderas Bajo, Valdez, and Potrero de Payogasta sites in Salta province) suggest that the regional production and use of the grain were not interrupted and that the different social groups living in the area had access to this plant (Lennstrom, 1992).

Summing up, the remains of seeds, stalks, and panicles and microscopic remains of quinoa plants cover a wide geographical range in northwestern Argentina: from the current political border with Bolivia in the Río Grande de San Juan



Quinoa. A Millenary Grain in Northern Argentina, Fig. 9 (a) Los Corrales Gorge in the mesothermal valleys area of Northwest Argentina. (b) Lower grinding tool from Cueva de los Corrales 1 site that contained microscopic remains of grinded pseudocereal seeds – the scale bar is in centimeters

river basin to the north to Tinogasta, in Catamarca, to the south and from Antofagasta de la Sierra, near the border with Chile to the west, to Pampa Grande, Tafí Valley, and the Chaco area near the eastern mountainous rainforest in Jujuy to the east. Besides this region, the Sierras de Córdoba area, at the center of the country, also reported the pre-Hispanic cultivation of this Andean grain. This is the current picture of the range covered by the ancient use of quinoa in this part of Argentina from its beginning some 4,500 years ago until Colonial times.

Hence, the enclaves located in the Puna, pre-Puna, and mesothermal valleys, as well as those close to the rainforests in the Northwest, outline a long-time regional counterpoint which accompanied the initial agricultural developments and continued until the Inca Empire. Such chronological continuity and the



Quinoa. A Millenary Grain in Northern Argentina, Fig. 10 Various pseudocereals sharing the same space within the high-elevation orchard of Rita Salva at Antofagasta de la Sierra, in the Punilla River basin (Southern Puna of Argentina)

geographical range of the ancient quinoa production in the region illustrate the presence of a rich and varied ancestral knowledge regarding variations in the agricultural and postharvest cycles and the seed in itself, which were adapted to the requirements of such differing landscapes. Further studies will prove if these statements are also true for the other geographical nodes in the western area of the Central-South Andes where quinoa was also in use: San Juan and Mendoza provinces in the Cuyo region.

Recent studies suggest that in northwestern Argentina, ecotone landscapes which define the transition between the typical highland and lowland environments would have been favorable for vegetal diversification. In the pre-Hispanic horticulture modes characterized by an open and flexible management of the flora, wild and domesticated plants, as well as weeds, may have shared the same agricultural fields, and their hybridization would have been accepted for different purposes (Lema, 2010). Quite possibly, quinoa would have been included in these production modes, as happens in some places nowadays (Fig. 10). At the time, there may not have been such a conclusive difference among plants producing panicles with edible grains as there is today. This situation is evident in the numerous

findings of diverse varieties of quinoa seeds mixed with *kiwicha* and grains of other plants classified as associated weeds.

To round off, wider knowledge is currently available regarding the pre-Hispanic chronology and geographical distribution of the cultivation, treatment, and consumption of quinoa in the modern Argentinian territory. However, a more precise knowledge of the insertion of these local practices in the larger panorama of the Central-South Andes is still pending, as is incorporating these data to the area where this grain was domesticated and intensively used. It is also necessary to study the historical reasons which led to the abandonment in its cultivation in most of the Argentinian territory, relegating it to the marginal position it has held until the recent past, a situation which nowadays seems to be improving.

Box 1: Quinoa Cultivation in the Past in Northwestern Argentina

Both cut stalks and panicles, as well as the large knapped knives used for reaping quinoa panicles in southern Puna, suggest that this plant was cultivated in the high-elevation desert at least some 3,500 years ago. It further seems to have followed a process similar to the modern one, with the exploitation of the spaces near permanent water sources (Hocsman, 2006). The plants would be managed through thinning or desuckering, and the ripe grains would be harvested by cutting the stalk. It is possible to make an analogy between the cut stalks and panicle fragment from Puna sites and the techniques still in use to harvest quinoa in some sectors of the Bolivian Altiplano. When the grain is in the appropriate maturity stage, the plants are cut at a certain distance from the soil. Panicles are removed from the fields after harvest, whereas roots and the basal part of the stalks remain planted. This strategy prevents soil loss, favors the manipulation of the panicles, and avoids the contamination of the unthreshed grain and later tasks with soil sediment (Escola, Hocsman, & Babot, 2013).

Desuckering is also optimal for harvesting the green leaves which can be used to cook warm or cold dishes such as soups or salads. This is what could have happened between 3,000 and 2,600 years ago in the Puna of Jujuy according to microscopic remains of leaves and the left-overs of food cooked in the now fragmented vessels from Cueva de Cristóbal site. As green leaves can only be harvested from growing plants, quinoa must have been cultivated near the residential areas in this Puna region of Jujuy (Babot, Hocsman, Piccón Figueroa, & Haros, 2012).

These many indications help reconstruct the pre-Hispanic production practices for quinoa. However, it is in the study of the ancient agricultural fields where the most direct evidence of this task can be found. In northwestern Argentina, the spaces devoted to seeding and harvesting in the past have turned out to be particularly elusive or badly defined, particularly due to the fragility and low recovery potential of quinoa remains from archaeological agricultural structures (López & Capparelli, 2010).

Fortunately, the study of diverse microscopic evidence such as pollen and other microfossils – started a little more than a decade ago – identified the first archaeoquinoas fields, dated to the beginning of the era. These fields are located in diversified environments in northwestern Argentina. One of them can be found in the hillsides of the high Catamarca valleys, testified by the microfossils identified in the soils of Morro Relincho site, where quinoa cultivation seems to have alternated with potatoes (Korstanje & Cuenya, 2008). A second enclave is the Chaco forest area bordering the eastern mountainous rainforest of Jujuy, topographically falling to 550 masl. There, quinoa cultivation was identified from the pollen recovered in Moralito site (Echenique & Kulemeyer, 2001). Beyond the geographic borders of

northwestern Argentina, pollen records indicative of the cultivation of quinoa and *kiwicha* extend to the late pre-Hispanic occupations in the Sierras Centrales, Córdoba, with a strategy similar to the one referred in seventeenth-century colonial documents (Medina, Grill, & López, 2008).

Corroborating the local cultivation of quinoa is important to clarify that at least some of the grain used in northwestern Argentina was self-produced, resulting from a three-millennium-old practice, rather than assuming that the seed came from the exchange of products with other areas of the Central-Southern Andes.

Box 2: The Ancient Uses of Quinoa

The traditional uses of quinoa plant in the pre-Hispanic past are found in the roots of practices still in use in some areas of northwestern Argentina (Storni, 1942). Studying the traditional postharvest treatment performed by modern Altiplano societies (López, Capparelli, & Nielsen, 2011), aimed at “improving” the grain and at the preparation of different products based on quinoa, has provided some analogical clues to recognize such treatments in archaeological contexts. It is also possible to record the modifications suffered by the seeds and other parts of the plant at both macroscopic and microscopic levels during these processes, as they leave identifiable traces on the archaeological material (Babot, 2003; López, Capparelli, & Nielsen, 2011). Hence, we know that, together with the first uses of this grain, procedures to eliminate the bitter compound (“saponins”) adhered to the seed pericarp or coat were implemented. This stage, which implied removing and winnowing the grain coat to later soak the grain in water and polish it with a piece of cloth, is fundamental for human consumption of quinoa.

Toasting may be further needed for certain extremely bitter varieties.

The grain prepared in this way would have served multiple purposes. Flour was obtained by grounding raw or cooked grains and may have been later used to knead dough or to thicken foods such as cold or warm soups or beverages, identified in the presence of microscopic seed remains. A substance similar to quinoa and *kaniwa* seed flour was preserved in the mills, pestles, and mortars used by the people living in the Punilla river basin and El Aguilar, in Catamarca and Jujuy provinces, respectively, from some 4,500 to 3,000 years ago (Babot, 2011; Babot, Hocsman, Piccón Figueroa, & Haros, 2012). Such preparations were also frequent in the nearby valleys and mountains, where flour remains were found on grinding stones of the agricultural societies inhabiting Tafí Valley and Amaicha del Valle, in Tucumán province (Babot, 2009). The propensity to pop of some of the grains also suggests that the seeds may have been placed among wild grasses near the hearths to produce a kind of popcorn. Popped quinoa was found in some sites of the Punta de la Peña location, in the Punilla river basin, at dates as early as 1,500 years BP (Babot, Aguirre, & Hocsman, 2013; Rodríguez, Rúgolo de Agrasar, & Aschero, 2006; Fig. 11). In this place, they were used both as a nutritive foodstuff and as an offering, embedded in ancient rituals. According to these records, the practice of toasting the seeds in straw beds with the occasional popping of the grain is rather old in the region, much prior to the arrival of the Incas.

Boiled grain preparations were also common in the Puna of Catamarca, seen in the agglutinated remains of seeds disposed in the garbage middens of the area (Babot, Aguirre, & Hocsman, 2013). However, it is in Cueva de Cristóbal (El Aguilar, Puna of Jujuy) where the exceptional



Quinoa. A Millenary Grain in Northern Argentina, Fig. 11 Pop quinoa from the Rockshelter 1 in the Punta de la Peña 9 site (1,500 years old), Punilla River Basin – the scale bar is in centimeters

preservation of an assemblage of fragmented pottery provided the most accurate evidence of food preparations or recipes based on quinoa at such an early date as 2,800–2,600 years BP (Babot, Hocsman, Piccón Figueroa, & Haros, 2012). These preparations included the use of quinoa grains as the only ingredient or, alternatively, their preparation as stews, porridges, or thick soups together with maize and tubers. Green leaves were probably used in soups or salads as well. In this way, wet culinary preparations with quinoa were routinely incorporated into the daily life of the groups inhabiting northwestern Argentina together with the first ceramic ware, supplementing the earliest consumption of this pseudocereal after toasting and grinding.

Together with the culinary uses of quinoa plants, the production and consumption of *llipta* was also frequent, at least from the beginning of the era. The *llipta* is an alkaline substance derived from the reduction of the plant to ashes. It is typically placed with coca leaves in the *acullico*. Its use during the past in northwestern Argentina seems to be indicated by the starch remains affected by heat and mixed with charred bone found in a small milling stone in the Los Viscos site, in El Bolsón Valley



Quinoa. A Millenary Grain in Northern Argentina, Fig. 12 Small lower grinding tool with calcined and grinded remains of bone and quinoa, probably to be used as *llipta* together with *coca* leaves – the scale bar is in centimeters

(Babot, 2009; Fig. 12). Microscopic remains of *llipta* and coca were also recorded in the dental calculus of the people living in Antofagasta de la Sierra during the first millennium AD, indicating that the *coqueo* was practiced by the time (González Baroni & Babot, 2013).

Other applications of the quinoa plant, such as using the stalks and roots for livestock fodder or fuel, as well as its reduction to ashes to prepare bleaches to wash wool, have not been deduced from archaeological materials so far. However, these uses may have been common in the past and could be identified in archaeological sites in the future.

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Glossary

Chenopodium Genus which includes domesticated plant species such as quinoa, weeds such as “ajara” (*Chenopodium quinoa* var.

melanospermum), and wild species like “paico” (*Chenopodium ambrosioides*). Plants of this genus have small seeds of a similar morphology. Their appearance can be modified by several postharvest and charring treatments, making the precise identification of the species difficult during archaeological research and sometimes restricting it to the *Chenopodium* genus.

Microfossil Microscopic particle of animal or vegetal origin which constitutes a product of the metabolism of a living creature or a fragment of its tissues. It can survive after the decomposition of the individual they derive from, being useful as evidence when the complete specimen is absent. Microfossils include opal silica particles and crystal bodies of calcium salts (phytolites), starch grains, microcharcoal, pollen, and spores.

Panicle Quinoa inflorescence which presents a central axis as well as secondary and tertiary axes where the flowers of future seeds are inserted.

Pseudocereal Term used to designate the species of the genus *Chenopodium*, which includes quinoa and “ajara,” and *Amaranthus*, represented by *kiwicha* (*Amaranthus caudatus*) and other amaranths. The pseudocereal category discriminates these South American grains from maize and the cereals domesticated in the Old World, such as wheat and barley, by the place the starch is deposited in the seeds.

Thinning or desuckering Practice which consists in controlling the density of a crop by eliminating the excess of quinoa plants in the field, particularly the weak or small specimens, to gain much needed space for the better growth of the ones which remain.

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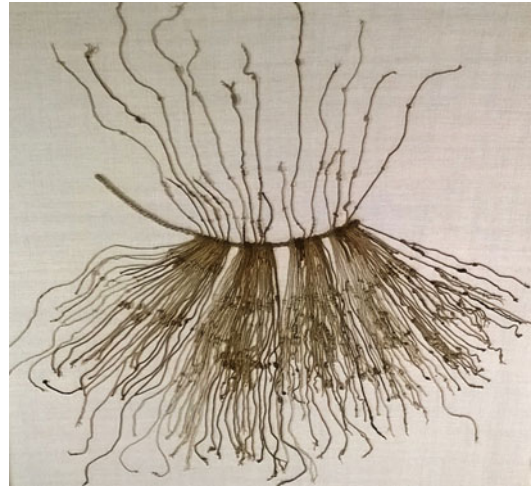
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Quipu

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The quipu is most commonly known as the numeric recording system of the Inca Empire, which extended across Peru and parts of Chile, Argentina, Ecuador, Bolivia, and Colombia during the fifteenth and sixteenth centuries (see Fig. 1). This device is the result of a long tradition of Andean textile production and string patterns in pre-Inca civilizations, and its use extended well into the colonial period (and is still used to some extent in various present-day communities). Over the years, these knot records have been interpreted as mnemonic devices, numeric



Quipu, Fig. 1 An Inca quipu from the southern coast of Peru (Courtesy of the Milwaukee Public Museum)

accounts, narrative histories, binary codes, and various classifications of writing systems.

Colonial chroniclers described their awe and inability to perceive how the Incas manipulated the colored cords with such ease to denote both numerical and historical information related to the tribute of goods and money, labor obligations, censuses, laws, past leaders, and deposits. The Jesuit missionary José de Acosta writes,

They are quipus, memorials or events registered in strings, on which diverse knots and diverse colors, meant different things. It's incredible what they achieved this way, how much books can say about history, and laws, and ceremonies, and business accounts. The quipus supply all this so promptly that it's admirable. In order to have these quipus or memorials there were official representatives that today are called *quipocamayo*, who were obligated to give accounts of everything, like the public scribes here, and as such they have to be given full credit. For diverse genres like war, government, tribute, ceremony, land, there were diverse quipus or strings. And in each handling of these, so many knots and intricacies, and strings were attached. Some were colored, some green, some blue, others white, and so many differences, that just as we form 24 letters in different ways and make such an infinity of words, these knots and colors make innumerable meanings of things (VI. c. viii. 2008, p. 210 my translation)

Colonial accounts such as this one, however, cannot be taken as verbatim descriptions of Inca



Quipu, Fig. 2 Images of quipus and quipucamayocs from the *Nueva coronica y buen gobierno* by Guamán Poma de Ayala (1615), folios 202r, 335v, 348r, 358r, 360r, 773r, and 700r



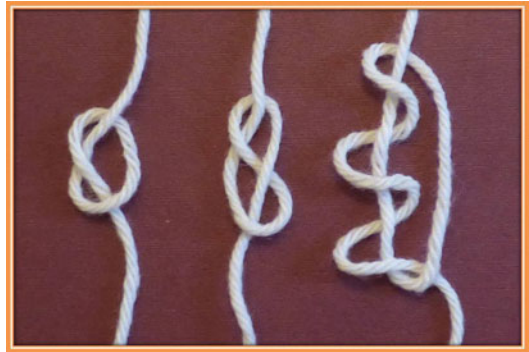
Quipu, Fig. 3 Images of quipus and quipucamayocs by Martín de Murúa, folios 76v and 124v from *Historia y Genealogía de los Reyes Incas del Perú*, Galvin Manuscript (1590), and folio 51v from *Historia General del Piru* (1616) Getty Manuscript, Ms. Ludwig XIII 16 Los Angeles, J. Paul Getty Museum

Quipu, Fig. 4 This is a contemporary replica of a quipu composed of commercial yarns. Its cords contain the information regarding the final grades submitted to the registrar of the past 15 courses taught by the author at the University of Minnesota in the past 5 years (Photo by author)

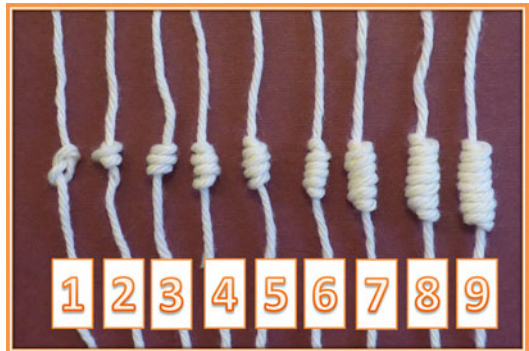


accounting as this practice and the very nature of quipus were greatly transformed after Spanish intervention (Curatola Petrocchi & de la Puente Luna, 2013). To my knowledge, there are ten known images of quipu from the colonial period, seven from the *Nueva corónica y buen gobierno*, two from the *Historia General del Piru* (Galvin Manuscript), and one from the *Historia General del Piru* (Getty Manuscript) (Figs. 2 and 3). These visual sources provide additional clues regarding the system including the connection between quipu records and the Spanish letter: *carta*, the Inca messengers; *chasquis*, the Inca deposits; *collca*, the Inca abacus; *yupana*, astronomy, the Spanish book; and more.

On a descriptive level, the quipu is a system of cords and knots in which information is conveyed through the varied use of knot patterns, materials, and structural indicators (Fig. 4). In its most basic and common form, the quipu is composed of a thicker primary cord from which pendant cords are attached in a downward direction and top cords extend upward, sometimes even uniting various pendant cords. Each cord is at least two ply with one looped end and one finished with a knot. Subsidiary cords can be affixed to any top or pendant cords or even to other subsidiary cords. This structure of main, pendant, top, and subsidiary cords of distinct colors and adornments is



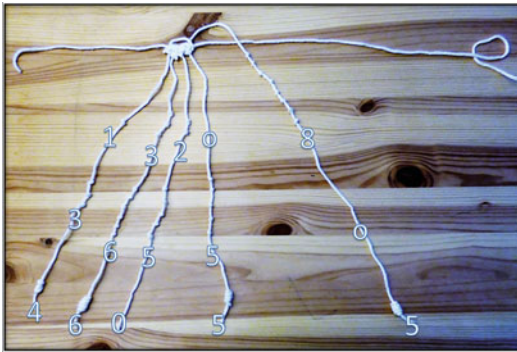
Quipu, Fig. 5 Details of the single knot, figure-eight knot, and long knot with three turns (Photo by author)



Quipu, Fig. 6 Figure-eight knot and long knots #2-9 (Image by author)



Quipu, Fig. 7 Single knots #1-9 (Image by author)



Quipu, Fig. 8 A replica of the knot pattern described by Locke, illustrating cord summation, $134 + 366 + 250 + 55 = 805$ (Image by author)

created before knots are tied into the medium (Ascher & Ascher, 1981, p. 21). The figure-eight knots (representing #1) and the long knots (representing #2-9) are used in the units position, and the single knots (representing #1-9) are used in all other place values (tens, hundreds, thousands, etc.) (Figs. 5, 6, and 7). This positional system locates the highest place values closest to the primary cord with the units position toward the end of the cord, and 0 is represented by a blank space in any of these positions. The use of the numbers 0–9 is indicative of a base-10 counting system, and this conjecture was confirmed in 1923 by Leland Locke, who showed that a decimal reading of the knots of four pendant cords revealed that their summation was

located on the top/summation cord that united them, a logical and common relationship of quipu cords (Fig. 8).

After reading knots as numeric values in base 10, various scholars have attempted to correlate their numeric values with qualitative data registries. After examining quipus from burial sites, Erland Nordenskiöld (1925) claimed that only quipus reflecting the cosmos with mysterious religious, astronomical, and calendrical data could be buried alongside the deceased, and Day's analysis of quipus 14–3866 (“the astronomer’s notebook”) also suggests the astronomical data such as lunations and synodic revolutions of Mercury, Venus, and Jupiter were recorded on the quipus. “Such efforts have not, however, proved convincing to succeeding researchers, since the ‘proofs’ characteristically involved a careful sifting and arranging of both astronomical and quipu numbers until coincidences were formed, with the remaining bulk of numbers unexplained” (Conklin, 1982, p. 263). More recently, Robert and Marcia Ascher, Tom Zuidema, and Gary Urton identified quipus whose cord values resemble calendrical data (Ascher & Ascher, 1978; Urton, 2011b; Zuidema, 1988). This decimal interpretation of the knots has been widely accepted, although not all quipus found have this same pattern of knots (Adawi Schreiber, Ortegá Izquierdo, Mejía Pérez, & Rojas Leiva, 2011).

The first effort to centralize quipu descriptions on a large scale is that of Robert and Marcia Ascher, who recorded the following categorical data from 206 quipus (from 1970 to 1988): knot type and placement, cord type, placement, length, color and attachments, and numerical interpretations (<https://courses.cit.cornell.edu/quipu/contents.htm>). The Ascher model has been used and modified in subsequent data collection projects, including that of Gary Urton (2002–2009), who also examined twist and knot direction and cord attachment (<http://khipukamayuy.fas.harvard.edu/>), Hugo Pereyra (2006), who initiated a Peruvian database, and the National Museum of Archaeology, Anthropology and History in Lima, Peru (Adawi Schreiber et al., 2011), which began Project Quipu in 2007 with the objective of describing their quipu archive (of over



Quipu, Fig. 9 Quipu-keepers from Tupicocha, Perú (Photo reproduced with permission of the Archive of the Ministry of Culture, Peru)

200 samples). Gary Urton and Carrie Brezine used software programs to comb through the Harvard database, looking for matching quipus that shared a similar external structure; they found that some of the Puruchuco quipus displayed the summation values of other local quipus, concluding that information was assimilated throughout the empire, either being funneled and synthesized upward or subdivided and distributed downward. Urton and Brezine also suggest that the introductory cords on the local quipus served as location identifiers used when moving information throughout the empire (Urton & Brezine, 2005).

In addition to archival research, scholars have carried out fieldwork in communities that use “modern” quipus in order to illustrate the great variety of quipu manifestations that exist and possibly have some connection to ancient traditions (Mackey, 1970; Ruiz Estrada, 1981; Uhle, 1897). Frank Salomon, together with the Ministry of Culture (Peru), has made available a documentary entitled *Tierra de Quipus* in order to illustrate these contemporary quipu traditions in the



Quipu, Fig. 10 Sabine Hyland with a quipu board from Mangas, Peru (Photo reproduced with her kind permission)

Peruvian village of Tupicocha: <https://www.youtube.com/watch?v=xjEzFW4IUBs> (Fig. 9).

The enigmatic nature of this particular accounting tool stems ultimately from the difficulties inherent in preservation of the quipus themselves as well as the ability to read their encoded messages. The number of quipu samples identified to be in existence is estimated to be around 800 (Urton, 2011a, p. 65), the majority of these being cotton samples from the arid coastal region of Peru where preservation conditions are maximal; far fewer samples of camelid knots from this central region of Peru have been traced. But perhaps even more consequential to our understanding of this medium is the loss of the knowledge that would allow scholars to decode and “read” the knot messages. While the loss of this ancient counting practice is oftentimes attributed to destructive colonial policies and the introduction of alphabetic writing in the Andes in the sixteenth century, one colonial document suggests that the destruction of this

medium actually commenced during the civil war of the Inca Empire when the captains of the aspiring Inca leader Atahualpa “killed all the quipucamayos that they could get their hands on and burned their quipus saying that they had to start over again” (Collapiña & y otros quipucamayos, 1974, p. 20 my translation) in order to erase the memory and record of previous Inca leaders. In spite of the difficulties, scholars continue working to uncover the lost legacy and past entwined in the quipu cords – a task that might be accomplished through further analysis of the quipu boards that juxtapose the colored cords and alphabetic print, exhibiting the distinct mediums side by side (see Hyland, Ware, & Clark, 2014) (Fig. 10).

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Qusṭā ibn Lūqā

E. Ruth Harvey

Qusṭā ibn Lūqā is one of the important figures in the transmission of Greek scientific writings to the Muslim world and subsequently to the Latin west. The ancient Arab biographers say that he was a Christian of Greek origin from Baalbek (Heliopolis) in Lebanon; he visited the Byzantine empire and brought back Greek texts which he then translated into Syriac and Arabic. He worked for the Caliph al-Mustaʿīn (862–866) in Baghdad, where he may well have known ► [al-Kindī](#) and Thābit ibn Qurra; he died in Armenia (ca. AD 912/300 AH) where he had been an honored guest of the ruler Sanharib.

Qusṭā is important both for his translation and for his original works. The transition of Greek science and philosophy into the Arab world resulted in the development and preservation of traditions largely lost to the west. Most western medieval science owes a great debt to the Arab scholars who kept alive this vital link with ancient learning. Qusṭā provided versions of Diophantos' *Arithmetica*, Hypsicles' *Liber... de ascensionibus*, Autolycus' *De ortu et occasu*, Theodosius of Bithynia's *De sphaeris*, and Hero of Alexandria's *Mechanics*; Qusṭā's Arabic version of this last work is the only text extant today. He is credited with other translations, notably some of the works of Aristotle with the commentaries of Alexander of Aphrodisias and John Philoponos, but they do not appear to have survived.

The biographers provide a list of over 60 original works by Qusṭā; the titles suggest that most are medical, but some are clearly works on mathematics, astronomy, logic, and natural science. Sezgin provides a list of the medical works of Qusṭā which are known to survive in manuscript. Very few of them have been printed, although interest in Qusṭā's treatises is increasing. His little monograph on infection (*Kitāb fī al-īdā'*) explains in terms of the medicine of the day how some diseases are contagious, and his *Viaticum*, explaining various principles of health and hygiene for travelers are both now available. His work on sex has been published in Germany, but is not readily obtainable. A work on the efficacy of amulets is extant only in the Latin translation of Arnald of Villanova (called both *De physicis ligaturis* and *De incantatione*); the Arabic text of his work on the celestial globe still exists and there are in addition medieval translations of the treatise in Latin (*De sphaera solida*), Hebrew, Spanish, and Italian.

Probably the most famous and influential of all Qusṭā's works is the short treatise on the difference between the spirit and the soul (*Kitāb fī 'l-farq baina 'l-nafs wa 'l-rūh*), which,

in the Latin translation of John of Seville, was used as an authority by almost all medieval Western physicians and by some of the philosophers. It distinguishes carefully between the immortal soul and the bodily "spirit of life" within man. The idea that a material but gaseous substance existed inside the human frame and made possible the functions of life, sensation, and motion was an essential part of medical doctrine in the days before the discovery of electricity. Qusṭā's lucid explanation was received as a kind of gloss or commentary on Aristotle's *De anima*. It was frequently misattributed to Constantine the African.

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Rainwater Harvesting

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Throughout history people have lived in areas where there are few rivers and where the direct collection of rainwater from roofs, paved courtyards, hillsides, or rock surfaces is one of the best available methods for securing a water supply. By extending this principle to provide water for crops, early civilizations practiced agriculture much further into the semidesert areas of Arabia, Sinai, North Africa, India, and Mexico than has been possible in modern times – and this is not explicable by changes in climate.

Agriculture in the Old World originated in climatically dry regions in the Middle East and may have depended to some degree on rainwater running off nearby slopes almost from the start. Evidence is lacking until a later period, however, when some of the most striking applications of rainwater harvesting were related to crop production in the Negev Desert between 200 BCE and AD 700. One technique would be to dig a channel across a hillside to intercept water running downslope during storms. The water would be directed onto fields which, in the Negev, were carefully leveled and enclosed by bunds (an embankment or dike). Further west, steeper hillsides were used in Morocco, with cultivation on flat terraces formed behind stone retaining walls. In Tunisia,

French travelers in the nineteenth century noted fruit trees being grown at the downslope end of small bunded rainwater catchment areas or microcatchments.

In India, one common technique is simply to build a bund across a gently sloping hillside, so that runoff flows originating from rainfall collect behind the bund, where water is left standing until the planting date for the crop approaches; then the land is drained, and the crop sown. This land behind the bund which is seasonally flooded and then later planted with a crop is known as an *ahar* in Bihar, or a *khadin* in Rajasthan. Although some *ahars* may be only 1 ha in extent with a bund 100 m long, others are very large and account for 800,000 ha of cultivation in Bihar state. In desert areas of Rajasthan, there are many *khadins* of 20 ha or more, some of them having been first constructed in the fifteenth century AD.

In North America, research on the modern potential of runoff farming methods has been stimulated by the realization that people living in what is now Mexico and the southwestern United States prior to European settlement had methods of directing rainwater from hillsides on to plots where crops were being raised, thereby making productive agriculture possible in an otherwise unpromising semiarid environment. On lands occupied by the Hopi and Papago peoples in Arizona, fields were predominantly on alluvial valley soils below hillsides or gullies from which water could flow to the crops during rainstorms.

Sites were chosen so that only minimal earth-works were needed to spread the water over the fields. These were short lengths of bund referred to as spreader dikes.

See Also

► [Irrigation in India and Sri Lanka](#)

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Raja Ratan Singh

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From the reign of Emperor Akbar (1556–1605), when a common syllabus for rational sciences for madrasas was introduced, the madrasas in India became institutions in which Muslim and Hindus together acquired their higher education without any prejudice. In this article, India denotes Medieval India. Raja Todar Mal, the minister of Emperor Akbar, was directed to promulgate in 1582 the decree by which the local language Hindi was replaced by Persian as the official language of administration and thereby motivated the Hindu officials (*Munshīs*) and scholars to learn Persian. In fact the learning of Persian among Hindus had already been promoted by Sultan Zainul 'Ābidīn (r. 1423–1474) in Kashmir and Sultan Ibrāhīm Lodhī (r. 1517–1526) during the Sultanate period in North India. Both Muslim and Hindus attended *madrasas* and also joined

instruction (*Darāsāt*) offered privately by famous Muslim scholars and poets, in order to learn Persian and to study other disciplines ('*Ulūm*'). Later arose a whole Hindu caste, *Kāyesth*, which became gradually expert in both the Persian language and literature. Actually the *Kāyesth* community in Medieval India contributed to many disciplines: poetry, history, anthologies of poets (*Tadhkirah*), epistles (*Inshā*), philosophy, Islamic medicine, mathematics, astronomy, and lexicography. Evidently this writer-caste, *Kāyesth*, became very influential in the courts of Mughal emperors, predominantly during the reign of Muḥammad Shāh (171–1749) and his successors and even in the administration of local rulers. Hindu *Munshis* gradually dominated the Persian-knowing community of Mughal officialdom. In this article, I wish to present the scientific contributions of the Hindu poet, writer, historian, and particularly astronomer, Raja Ratan Singh Zakhmī (d. 1851).

Biography

Raja Ratan Singh (1782–1851) s/o Rai Balk Ram Kayesth, born in Lucknow, belonged to an illustrious family of servicemen of the *Nawābs* (rulers) of Awadh (modern *Uttar Pradesh*). His grandfather, Raja Bhagavan Das, was the *Dīvān* (prime minister) of Āṣaf-ud-Daulah (r. 1775–1797). Ratan Singh began as a servant of the East India Co. at Calcutta (ca. 1803), and after 1815, he joined the court of the Awadh rulers: Ghāzīuddīn Ḥaidar (r. 1814–1827), Naṣīruddīn Ḥaidar (r. 1827–1837), and Muḥammad 'Alī Shāh alias Naṣīr-ud-Daulah (r. 1837–1842). This last Nawāb bestowed on the Raja the title, *Fakhr-ud-Daulah Dabīrulmulk Hoshyār Jang* (Pride of his Kingdom, Secretary of Administration and Intelligent Veteran).

Ratan Singh was a scholar of many languages: Arabic, Persian, Turkish, Sanskrit, and also English. He studied the traditional disciplines ('*Ulūm-i Naqliya*) and the rational sciences ('*Ulūm-i 'Aqliya*). He is known as a *litterateur*, with his *nom de plume* *Zakhmī* (the wounded), a historian, and an excellent scholar of astronomy.

In this article, we report on two of his astronomical works. For his poetic compositions, historical works, etc., see Storey (1972), Vol. I (pt. 1), p. 709, and Ansari (2004) pp. 130.

Mi'yār al-Azmān

Mi'yār al-Azmān is a short tract on chronology completed in ca. 1819, which deals with calendars (*Tawārīkh*) of different nations: Arab/Hijrī, Christian, Roman, ancient Persian (*Yazdijird*), Jalālī or Malikshāhī, ancient Indian, Chinese, Greek, Coptic, and Khānī. The various epochs, i.e., beginning date of each era, are explained clearly. Moreover, he gives comparative tables for various eras for the year 1234 AH/1819. According to our preliminary survey, four manuscripts of this tract are extant, one each in the Asiatic Society (Calcutta, modern Kolkata), Khuda Bakhsh Library (Patna), and the Library of Urdu Promotion Board (*Anjuman Taraqqī-i Urdu*), Karachi. The manuscript copy at Raza Library (Rampur) is ascribed by Ghulām Hussain and dated 1822. No study of this tract is known so far.

Hadā'iq al-Nujūm (Gardens of Astronomy)

Hadā'iq al-Nujūm: Gardens of Astronomy is a comprehensive compendium in Indo-Persian on nineteenth-century European astronomy, which includes its mathematical treatment; it will be referred to hereafter as HN. Ratan Singh completed this treatise in 1837 by the order of Nawāb Muḥammad 'Alī Shāh alias Naṣīr-ud-Daulah. It was lithographically printed and published in a few editions, 1837, 1841 (Lucknow), and 1843 (Storey II (1) p. 99; Rahman p. 350). Four manuscript copies of the treatise are extant in M.A. Library (AMU, Aligarh), along with a copy of the Lucknow edition. This systematic treatise consists of nine chapters (*Hadīqa*, Arabic for garden) with 1158 pages and comprises 180 tables (*Lawḥ*) and 129 diagrams (*Shakl*). The author states in the beginning that he “describes in this book the celestial bodies,

solution of their astronomical problems according to the past Islamic scholars and present European scholars and also some researches of his own” (p. 8). The European scholars are Copernicus (1473–1543), Tycho Brahe (1546–1601), Galileo (1564–1642), Kepler (1571–1630), and Newton (1642–1727). He also describes recent works of Hevelius (1611–1687), Flamsteed (1646–1720), Herschel (1738–1822), Cassini (1625–1712), and Lalande (1732–1807), to name just a few. Ratan Singh's collection of these sources is remarkable indeed in nineteenth-century India. Modern instruments treated in HN are the telescope (*Dūrbīn*, *Sitārahbīn*), the micrometer (*Raizah-i Paimā*), and cross wires (p. 154). Ratan Singh gave a short history of the telescope. He stated that Johann Lippershey invented and constructed a telescope of 15 in. in 1590; the telescope of Zakaria Jansen was of 18 in. in length and was made in 1605. He mentioned also in this connection Simon Marius, Galileo, and Kepler (p. 152). He describes the establishment of the Greenwich observatory in 1676 and the Paris observatory in 1664 (p. 156). Ratan Singh treated in detail in a chapter/section the following salient features of European astronomy, which are cited here in Ratan Singh's own words:

1. The Sun is a member of fixed stars, it is a source of light (*Nūr*) and heat and gives its light to all planets and comets (HN p. 181).
2. Proof that the Sun is stationary (pp. 188–190). Besides the gravitational attraction, Ratan Singh discusses the phases (i.e., the variation in shape) of Mercury and Venus and also their transits across the disk of the Sun as the proof of the heliocentric system. See the data for transit of Venus and Mercury in Table 1.
3. The orbits of all planets, satellites, and comets are all elliptical. . . with the Sun at one focus. He deals with gravitation, true, and mean anomaly (HN pp. 135, 188, 222).
4. In a diagram of the solar system, he draws the orbits of planets around the Sun including orbits of satellites (*qamar*) of major planets in this sequence: Mercury, Venus, Earth (1 satellite), Mars, the minor planets (Vesta, Juno,

Raja Ratan Singh, Table 1 Data for transits of Venus and Mercury

Table no.	Page no. ^a	Concerning	Remark/period/sources
58	363–367	Obliquity (60 values)	As determined by Ancient Indian (1), Greek (5), Islamic (13), and European (41) astronomers
49	298–305	Transits of Mercury	AD 1605–1894
51	310–315	Venus	AD 902–2984 ^{b1}
	312	Venus	7 June 2004, 5 June 2012, 10 Dec. 2117 ^{b2}
109	709–722	Lunar and solar eclipses	AD 1837–1900
112	776–799	Comets	AD 835, 1231–1835 ^c
120	889–893	Catalogue of stars	al-Šūfī (d. 986), al-Ṭūsī (d. 1774), Ulugh Beg (d. 1449)
133	1,000–1,004	Planetary revolutions in a <i>Kalpa</i>	Sanskrit sources: <i>Brahāmasiddhānta</i> , <i>Pancasiddhānta</i> , <i>Sūryasiddhānta</i> , etc.

^aRefer to Ratan Singh's Treatise: *Hadā'iq al-Nujūm*

^{b1}Source: de Laland, *Astronomie* (Paris), probably the first edition of 1764. He also mentions that "Ibn Sīnā (d. 1037), Abū 'Imrān in Baghdad, Muḥammad abī Bakr observed Venus on the face of the Sun, [while] Ibn al – Māja and Ibn al – Haitham (d. 1039) observed *Venus* and *Mercury* each as black dot on the disk of the Sun" (p. 309), cf. Goldstein (1985), Kapoor (2013)

^{b2}Venus transit occurs in pairs. The dates of the first pair are correct. Of the second pairs, Ratan Singh has given only one correct date, the second date is Dec. 2125; see www.wikipedia.org/wiki/Transit_%20of_%20Venus, accessed on 26.8.14

^cThis is the Halley comet for which he mentions its earlier sightings and his own observation first on 15 Oct. 1835 near *Corona Borealis* (in Persian *Ikhlī Shimālī*) with the length of its tail between 29° and 30° and its period being 76 years and 248 days (p. 805). For more tables, see Ansari (2006)

Ceres, and Pallas), Jupiter (4), Saturn (7), and Uranus (6), the last one he calls *Jarjīs*. F. W. Herschel discovered Uranus in 1781. He named it *Georgium Sidus* after the King of England George III. The name *Jarjīs* is derived from George. The German astronomer J. E. Bode named this seventh planet of our solar systems Uranus, which name gained currency in about 1850 (*HN*, p. 180). Ratan Singh named these in the correct order of ascending heliocentric distances. See Fig. 1, which is the reproduction of his diagram No. 85.

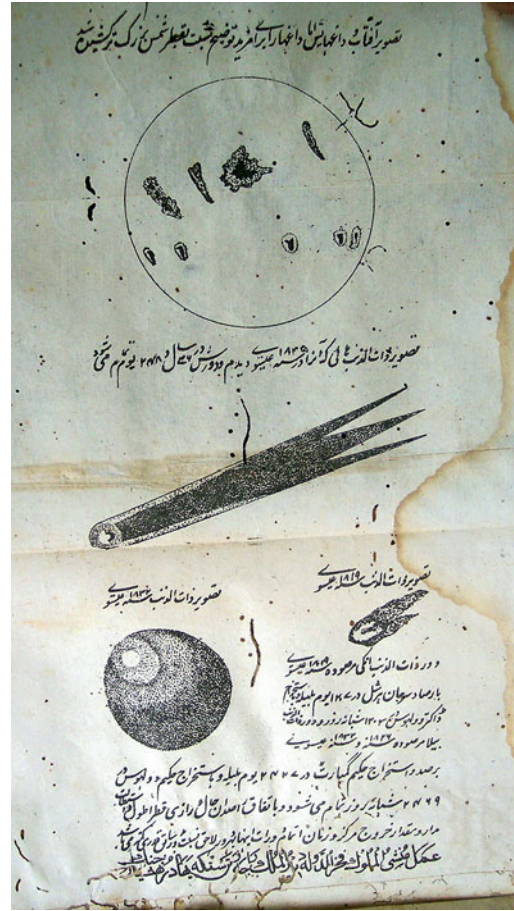
- On comets. I reproduce here in Fig. 2 Raja Ratan Singh's observations of sunspots furnished with umbra and penumbra and drawings of three comets (*HN*, diagram No. 57, p. 178). The Persian text reads in Fig. 2 as follows: The first diagram of the comet below the solar disk is the picture of Halley's comet, which he observed in 1835 AD, and he found its period of revolution (*Dawr*) as 76 years and 248 days. Raja Ratan Singh gives two further drawings of comets: one with a small tail observed in 1819 by Sir John Herschel, who calculated its period as

1,207 days, but according to Dolhaus was only 1,203 days, and the third comet without a tail was observed actually by Biela in 1826 and again in 1832. Raja Ratan Singh gives the period of this comet as 2,427 and 2,469 days, citing the calculations of Gambart and Dolhaus respectively. The chapter on comets is very detailed one (*HN* p. 730–829). There is a full section on Halley's comet (*HN* pp. 805–810); see Table 1 (row 5).

Raja Ratan Singh's *Treatise* in Persian of 1157 pages is in fact a unique comprehensive compendium of nineteenth-century European practical astronomy, in which elements of traditional ancient Indian and particularly of Islamic astronomy are *not* overlooked. The important discoveries of eighteenth-nineteenth centuries have been particularly well treated, for instance, about asteroids, planetary configurations, or the solar system according to Ptolemy, Tycho Brahe, Regiomontanus, and Copernicus and even about nebulae after Herschel (*HN*, pp. 1006–1027). The treatise was printed in three editions (1837, 1841, and 1843) and published in Lucknow, the capital



Raja Ratan Singh, Fig. 1 Diagram of heliocentric system. Orbits of major and minor planets: Mercury, Venus, Earth (1 satellite), Mars, Vesta, Juno, Ceres and Pallas, Jupiter (4), Saturn (7), and Uranus (6), the last one is named *Jarjīs*. Cf. Text, section 2.4, (HN, p. 180)



Raja Ratan Singh, Fig. 2 Solar disk with sunspots and three comets: Halley (1835), Herschel (1819), Biela (1832). Cf. Text, section 2.5

of the rulers of Awadh state, which was then bustling with the confrontation of traditional and modern scientific culture. As evidence the following instances are noteworthy.

The Frenchman Claude Martin (d. 1800), who was in the service of the Awadh ruler (*Nawāb*), Aṣaf -ud-Daulah (r. 1775–1797) at Lucknow, was extremely interested in European scientific pursuits and devices, e.g., steam engine for raising water out of wells and telescopes for his private observatory, one of which he bought from the astronomer royal, William Herschel. He had been a major general in the French Army initially and later shifted his allegiance to the British East India Co. Inspired by Martin's observatory, the geographer Khaliluddīn Khān built an observatory in 1820 to teach practical astronomy (Khan, 2003, pp. 288–289; Liewellyn-Jones, R. (2004)).

Nawāb Naṣīruddīn Ḥaidar (r. 1814–1827) founded the Royal Observatory at Lucknow.

Maj. Richard Wilcox (d. 1848) was appointed in 1835 as the director, whose observational work on minor planets during 1840–1846 became well known internationally. Unfortunately that observatory was abolished in 1849 by Nawāb Wājīd ‘Alī Shāh (r. 1847–1856), cf. Ansari (1985), pp. 385–389.

From 1815, when Ratan Singh joined the service of the Nawab of Awadh, he had been a witness to all this development. It is therefore not surprising that Nawāb Naṣīr-ud-Daulah alias Muḥammad ‘Alī Shāh (r. 1837–1842) commissioned Ratan Singh to write a treatise on mathematical and practical astronomy which I consider the culmination of the “Awadh scientific

renaissance” (Khan, 2003, pp. 287–292). Unfortunately that nascent reawakening was stifled in the bud, when Persian and Urdu languages were banished from the curricula of schools and replaced by English as the medium of instruction by the British Colonial Government.

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Ramanujan

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Srinivasa Ramanujan was born on 22 December 1887 in the home of his maternal grandmother in Erode, India, a small town located about 250 miles southwest of Madras. Soon thereafter, his mother returned with her son to her home in Kumbakonam, approximately 160 miles south-southwest of Madras. Ramanujan’s father was a clerk in a cloth merchant’s shop, and his mother took in local college students to augment the family’s meager income.

Ramanujan’s mathematical talent was recognized in grammar school, and he won prizes, usually books of English poetry, in recognition of his mathematical skills. At the age of 15, Ramanujan borrowed G. S. Carr’s *Synopsis of Pure Mathematics* from the local Government College in Kumbakonam. This unusual book, written by a Cambridge tutor to teach students, contained approximately 5,000 theorems, mostly without proofs, and was to serve as Ramanujan’s primary source of mathematical knowledge.

With a scholarship, Ramanujan entered the Government College in Kumbakonam in 1904. However, by this time, he was completely absorbed with mathematics and would not study

any other subject. Consequently, at the end of his first year, Ramanujan failed all of his exams, except mathematics. He lost his scholarship and therefore was unable to return to college.

For the next 5 years, working in isolation, Ramanujan devoted himself to mathematics. He worked on a slate, and because paper was expensive, recorded his mathematical discoveries without proofs in notebooks. During this time, he attempted once more to obtain a college education, at Pachaiyappa College in Madras, but his singular devotion to mathematics, and illness, deterred him again.

Having married Janaki in 1909, Ramanujan sought employment in 1910. For over a year, he was privately supported by Ramachandra Rao, as he gradually became known in the Madras area for his mathematical gifts. In 1912, Ramanujan became a clerk in the Madras Port Trust Office, and this was to be a watershed in his career, for the manager, S. Narayana Aiyar, and the Chairman, Sir Francis Spring, took a kindly interest in Ramanujan and encouraged him to write English mathematicians about his work.

On 16 January 1913, Ramanujan wrote to the famous English number theorist and analyst, G. H. Hardy. He and his colleague J. E. Littlewood examined the approximately 60 mathematical results communicated by Ramanujan and were astounded by his many beautiful and original claims. Hardy strongly encouraged Ramanujan to come to Cambridge, so that his mathematical talents could be fully developed. At first, Ramanujan was reluctant to accept the invitation, because of orthodox Brahmin beliefs that crossing the seas makes one unclean, but on 17 March 1914 Ramanujan sailed for England.

During the next 3 years Ramanujan achieved worldwide fame for his mathematical discoveries, some made in collaboration with Hardy. However, in the spring of 1917, Ramanujan became ill and was confined to nursing homes for the next 2 years. Tuberculosis, lead poisoning, and a vitamin deficiency were among the many diagnoses made, but a more recent examination of Ramanujan's symptoms points to hepatic

amoebiasis. In 1919, he returned to India with the hope that a more favorable climate and more palatable food would restore his health. However, his condition worsened, and on 26 April 1920, Ramanujan passed away.

After Ramanujan's death, Hardy strongly urged that Ramanujan's notebooks be edited and published with his *Collected Papers*. Two English mathematicians, G. N. Watson and B. M. Wilson, devoted over 10 years to proving the approximately 3,000–4,000 theorems claimed by Ramanujan in his notebooks, but they never completed the task. It was not until 1957 that an unedited photocopy edition of Ramanujan's notebooks was published. In 1977, Berndt, with the help of Watson and Wilson's notes, began to devote all of his research efforts toward editing the notebooks, and in 1998 he completed the task with the publication of his fifth volume on the notebooks. In 1976, Andrews discovered a sheaf of 140 pages of Ramanujan's work, now called the "lost notebook," in the library at Trinity College, Cambridge. In 2005, Andrews and Berndt published their first volume on Ramanujan's lost notebook.

Ramanujan made many beautiful discoveries in several areas of number theory and analysis, in particular, the theory of partitions, probabilistic number theory, highly composite numbers, arithmetical functions, elliptic functions, modular equations, modular forms, q -series, hypergeometric functions, asymptotic analysis, infinite series, integrals, continued fractions, and combinatorial analysis. His influence can be traced to many areas of contemporary mathematics; this is evident in the proceedings of major conferences commemorating Ramanujan on the 100th anniversary of his birth. Although much of Ramanujan's work is quite deep, many of his original discoveries can be understood with a background of only high school mathematics. In particular, his several results on solving systems of equations, representing integers as sums of powers, and approximating π are elementary. In the past few decades, as more of Ramanujan's results have been unearthed, his already great reputation has soared even more.

Most biographical sketches of Ramanujan's life rely chiefly on the obituaries written by Seshu Aiyar and Ramachandra Rao, and the writings of Hardy. However, Robert Kanigel's biography is by far the most complete and detailed description of Ramanujan's life. Much can also be learned from Ramanujan's letters to Hardy, his family, and friends.

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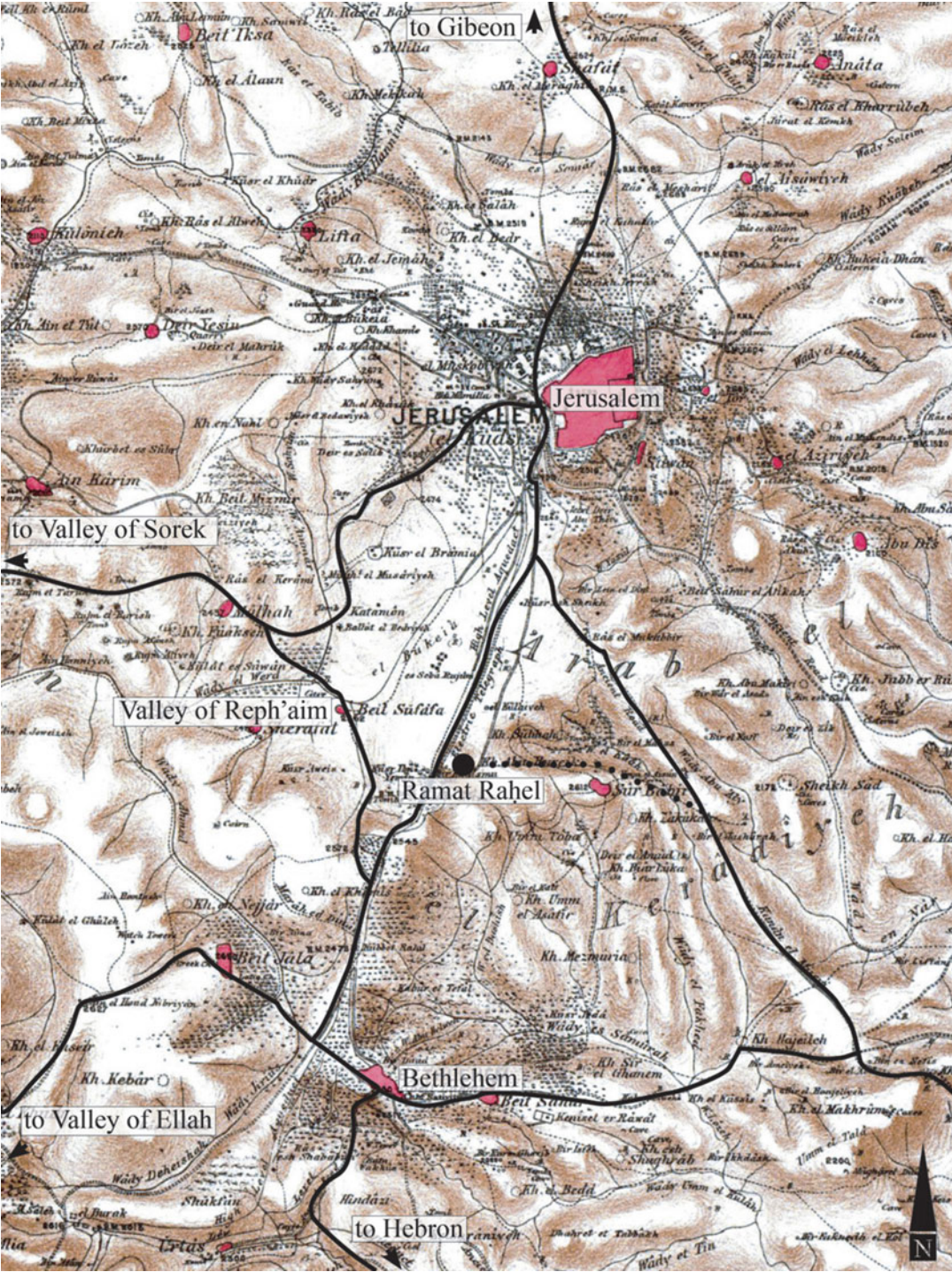
Ramat Raḥel

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Ramat Raḥel (Heb. רַמַּת רָחֵל) is an ancient site located on a hilltop (818 m above sea level), about midway between the Old City of Jerusalem and Bethlehem. It is inside Israel's international 1947–1948 borders in the western part of Kibbutz Ramat Raḥel. The site is located in one of the highest peaks to the south of Jerusalem, a location that offers a superb view to the north (Mount Zion and modern-day western Jerusalem), to the west (the Rephaim Valley), and to the south (Mount Giloh, Bethlehem and the northern Judean hills). This is also a prominent strategic place, controlling the important junction between the "King's Road" leading from Jerusalem southward, in the direction of Bethlehem, Hebron, and Beersheba, and the road leading from Jerusalem westward, in the direction of Beth Shemesh in the Shephelah, through the Rephaim Valley. Furthermore, Ramat Raḥel has complete control over the Rephaim Valley, with its rich alluvium soil and moderately terraced slopes, one of the prosperous agricultural districts in the Jerusalem landscape, vital to the economy of the city, a valley that probably should be identified with the Biblical "Valley of the King" (Fig. 1).

The Arabic name of the site is Khirbat Ṣāliḥ, but the name and the identification of the site during the Biblical period are still an enigma. Based on the LXX supplement to Joshua 15: 59a and on Nehemiah 3: 14, Yohanan Aharoni identified Ramat Raḥel as the Biblical Beit Hakerem. He hypothesized that the site was built on a previous vineyard of the king and this is the source for its name. This suggestion was accepted by most scholars, even though Benjamin Mazar suggested identifying the site with Netofah, a site mentioned in the Old Testament near Bethlehem (2 Sam 23: 28; 1 Chr 2: 54, et al., and cf. Ez 2: 22; Neh 7: 26; 12: 28), and Gabriel



Ramat Raḥel, Fig. 1 Map of the area of Ramat Raḥel (Ido Koch, based on the PEF Map)



Ramat Raḥel, Fig. 2 Reconstruction of Ramat Raḥel and its edifice as seen from the southwest (Drawing by Nirit Kedem)

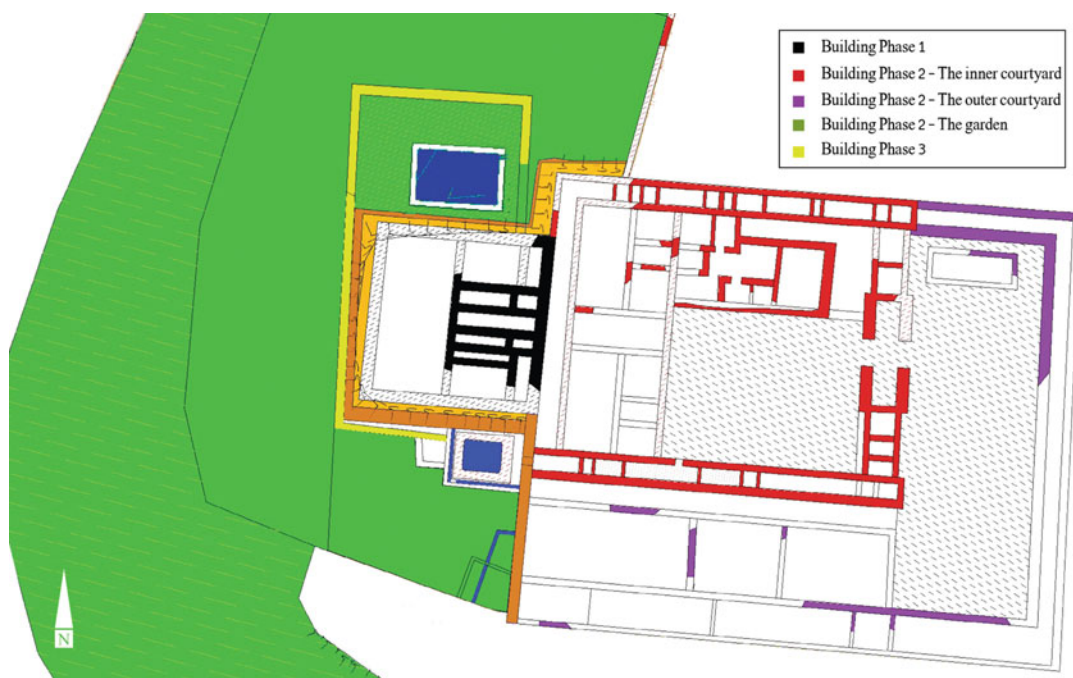
Barkay identified the site with MMŠT [the Hebrew letters Mem-Mem-Shin-Tav] – one of the places mentioned on the LMLK stamp impressions [LMLK, in Biblical Hebrew, “belonging to the king,” are stamp impressions on jar handles, identified as part of the royal system of jars in Judah, mainly from the time of King Hezekiah. See below an image of this stamp impression as well as other types of stamped jar handles from Judah].

In 1930–1931, B. Mazar and M. Stekelis excavated a Jewish burial cave some 200 m to the south of the site’s hilltop on behalf of the Israel Exploration Society. Y. Aharoni excavated the hilltop in 1954 and again in four successive seasons between 1959 and 1962 on behalf of the Israel Department of Antiquities and Museums, the Israel Exploration Society, the Hebrew University of Jerusalem, and the University of Rome. G. Barkay made a few soundings at the site in 1984 on behalf of the Institute of Archaeology of Tel Aviv University, the Israel Exploration Society, the Israel Department of Antiquities and Museums, and the American Institute of Holy Land Studies on Mount Zion. In the framework of the site’s restoration and reconstruction as an Archaeological Park, Gideon Suleimanny, on behalf of the Israel Antiquities Authority, made trial excavations. Excavations on behalf of the Institute

of Archaeology of Tel Aviv University and the University of Heidelberg resumed in 2004, under the direction of O. Lipschits, M. Oeming, and Y. Gadot, as part of a major excavation project. Between 2005 and 2010, six excavation seasons were conducted in the site by hundreds of students and volunteers. In addition, a comprehensive survey of underground spaces, a survey of agricultural installations and a comprehensive study of the agricultural terraces on the slopes of the mound were carried out.

Based on the results of the Renewed Expedition and the careful study of the previous excavations conducted at the site, it seems that at Ramat Raḥel there are nine separate phases of construction and development and additional phases of destruction and desolation (Figs. 2 and 3).

Prior to the late eighth century BCE, the hill was rocky and desolate, with no evidence of human habitation. **The first building phase** should be dated to the late eighth to early seventh centuries BCE. The main structure from this early phase is the “western tower.” In its plan and building method, the tower belongs to the array of fortresses built on high hills around Jerusalem in the late Iron Age. Other structures from this building phase were later either incorporated into structures of the following phase or dismantled to their foundations, and it is difficult to understand the architectural plan of this phase. However,



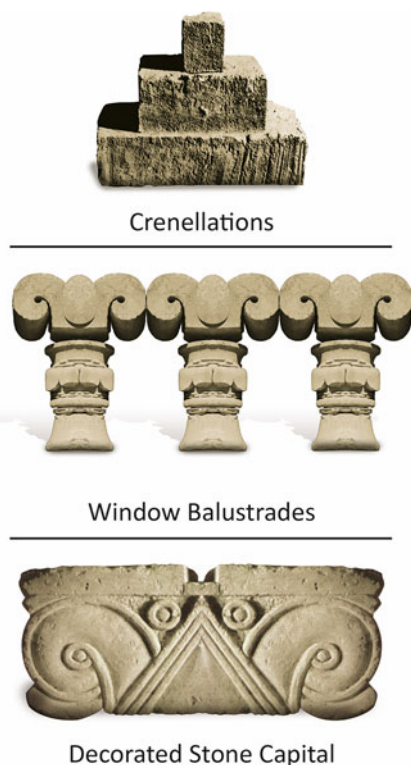
Ramat Raḥel, Fig. 3 General plan of Ramat Raḥel (Benjamin Arubas and Shatil Emmanuilov)

unique architectural features from this early phase are the volute capitals (the so-called Proto-Aeolic capitals, a type of stone capital characteristic of palaces and public buildings in Israel and Judah), relief in the line of small stone columns, a series of small carved stone columns with tiny palmette capitals that had been part of a window balustrade (similar to those that appear in the reliefs known as “the woman in the window”), and pyramid-shaped stones (crenellations). All these items continued into the second building phase. There is no other site in Judah with so many one-of-a-kind and high-quality architectural items (Figs. 4 and 5).

Many small finds and a lot of pottery that was discovered in the fill beneath the second-phase floors should be also assigned to the first building phase. It includes about 70 jar handles with LMLK and “private” stamp impressions, representing all the known varieties dated from the late eighth to the mid-seventh centuries BCE. The unique architectural elements, the many stamp impressions, as well as the ceramic assemblage confirm that already in the early phase the site served as an

administrative and governmental center. Since Judah was under the rule of the Assyrian empire, it might be that Ramat Raḥel was the main center for collecting wine and oil jars, probably as a levy (Fig. 6).

To implement the comprehensive planning concept of **the second building phase**, dated to the second half or even the last quarter of the seventh century BCE, significant logistical and operational groundwork was required. A large quantity of material was extracted from the natural hill on its western side in order to create a garden sunk into the bedrock. All the quarrying waste was used as fill, removed, and poured over the eastern slope. This fill created a large level base upon which palace units and courtyards were constructed. As a result, the edifice was constructed in an east to west orientation despite its location on a hill that faced southeast–northwest. This indicates that this complex was built according to a predetermined architectural plan that intentionally disregarded the area’s topography. The tower fortress of the first phase was integrated into the new, enlarged plan. At the



Ramat Raḥel, Fig. 4 Architectural features from the Iron Age (Adapted by Ido Koch)

time of the construction of the sunken garden, the fortress was isolated on three sides – south, west, and north – and stood upon a prominent rock cube projecting westward out of the palace complex.

The garden extended around the western tower on its northern, western, and southern sides, on a lowered, leveled surface covering 1.5 acres (0.6 ha, 6 dunams) and possibly more. In creating the sunken garden, the planners removed the *nari* rock from the natural surface and created a leveled and unified rock surface. This surface was covered by a 17.7 in. (45 cm) deep layer of amalgamated brown garden soil, free of stones and sherds, that was artificially placed upon the leveled limestone surface. Other features incorporated into the flattened area related to water: at least three and possibly four plastered pools with three rock-cut and roofed tunnels, two exceptionally well-built drains, channels, gutters, and a large underground water reservoir (Fig. 7).

A rectangular palatial complex was constructed at the top of the mound, surrounded by casemate walls on its northern, eastern, and southern sides, with a 6,458.3 ft² (600 m²) inner courtyard in the center and an approximately 4,843.8 ft² (450 m²) outer courtyard to the east.

The palace of the second building phase was not destroyed in the late Iron Age and probably continued to function during the sixth century BCE. Hundreds of broken pottery vessels; ten restored jars, some of them bearing stamp impressions on jar handles of the early YHWD [YHWD is the Aramaic name of the province of Judah] types and some with sixth-century “private” stamp impressions, together with lion stamp impressions on body sherds, were unearthed in a huge pit to the south of the edifice. This assemblage stands as a clear marker for sixth-century BCE pottery, administration and economy, a clear indication for the existence of an unbroken economy and administration in Judah from the end of the seventh to the fifth and fourth centuries BCE.

The profusion of artifacts found at Ramat Raḥel shows a significant presence at the beginning of the Second Temple period – **the third building phase**. Of special importance are the 365 YHWD stamp impressions of the Persian and Hellenistic periods (out of a total of about 640 known to date), a clear indication that during the Persian and early Hellenistic periods the edifice at Ramat Raḥel was used in an administrative/governmental capacity for collecting wine and oil jars in Judah, probably as a levy. During this period, a large, sturdy building was added to the northwestern side of the second-phase palace complex covering an area of about 6,458.3 ft² (600 m², about 65.6 by 98.4 ft [20 by 30 m]). It probably served as a northward expansion of the fortress tower extending west of the line of the palace.

The garden that surrounded the palace continued to exist during the Persian period and went out of use in the third century BCE. Pollen research conducted at the site enabled a first attempt at answering the riddle of what flora had grown in the garden and the function it had served during the Persian period. According to the

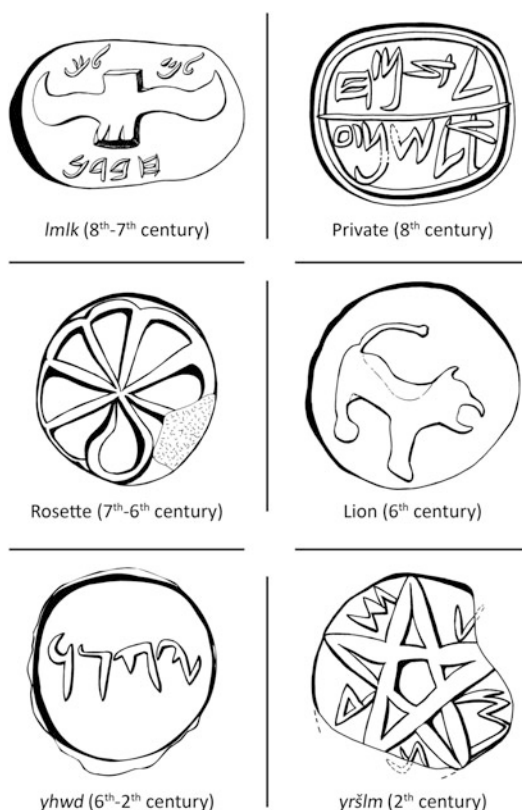
Ramat Raḥel,**Fig. 5** Window balustrade and example of “the woman in the window” motif

pollen, besides the native Mediterranean maquis/forest taxa, fruit trees and ornamentals, which had certainly been planted specifically for aesthetic and symbolic reasons, were grown in the garden. The most surprising fossil pollen found was the citron (*etrog* in Hebrew, a word with a Persian precursor). This tree apparently arrived in the area from India via Persia and is the earliest botanical evidence of its presence in the southern Levant. Also, the Persian walnut originated in northern Iran, northeastern Turkey, and the Caucasus, and its Hebrew name, *éḡôz*, is also a word with a Persian precursor. Other imported trees identified in the pollen assemblages of Ramat Raḥel are cedar of Lebanon and birch. The pollen evidence of these exotic trees in the palatial garden suggests that they were brought by the ruling Persian authorities from remote parts of the empire as a royal extravagance.

The presence of local garden plants like myrtle, grapevine, and the common fig completes the

picture of the garden. Willow and poplar, which were also identified, are common to riverbank vegetation and therefore probably required irrigation; to these one can add the presence of pollen belonging to the water lily. All these flora species and their origins point to the fact that the garden was in bloom during the Persian period. Its imported trees from far-off lands, aromatic plants, and impressive fruit trees, together with its aesthetic architectural features, symbolized the power and affluence of the Persian-period rulers. It seems that with this combination of magnificent edifice and luxurious garden during the Persian period, Ramat Raḥel was not just an administrative center but served as the edifice of the imperial governor in the province, side by side with Jerusalem, which renewed its status as the lone cultic site, the location of the Temple, and the seat of the priests.

Following the end of the Persian period, Ramat Raḥel lost its prominence and some of



Ramat Raḥel, Fig. 6 Stamp impression types found at Ramat Raḥel (Illustration by Rodika Penchas)

the walls of its complex were robbed. Its status during the early Hellenistic period is cloaked in obscurity, but it seems to have regained its standing as an administrative center at the beginning of the second century BCE. This is mainly evidenced by the distribution of *yehud* and YRŠLM [Hebrew letters for Jerusalem] stamped handles. Remains of the citadel from this period were located on the eastern edge of the site, and it was probably a fortifying wall that was built upon the eastern wall of the former complex. The plan and exact location of this citadel are, however, not clear.

A drastic change in the history of Ramat Raḥel occurred during the late Hellenistic period, probably in the second half of the second century BCE, when the fortified edifice was completely obliterated. Its walls were robbed and the stones removed from the foundation trenches. The

thoroughness with which the stones were excised from the foundation channels, the furnaces constructed next to the water pool in the southern section of the garden, and the entire area covered over with fill suggest that it was an intentional act of annihilation carried out in order to eradicate the ancient garden and the buildings at the western front of the site. Demolishing the royal complex in this way was probably meant to obliterate from the landscape, and consequently the social memory, any reminder of the base that had for centuries served as the administrative center of imperial rule in Judea.

The character of the settlement that developed in the area during the late Hellenistic and the early Roman periods (late second–first centuries BCE and during the first century CE to the Great Revolt, 66 CE) can only be understood from its rock-cut installations since in most cases the walls of the buildings were dismantled or robbed for secondary use during the late Roman and Byzantine periods. Such installations include at least 13 ritual baths and two columbaria [a cave used to grow pigeons]. The pottery vessels and the many coins unearthed all over the site demonstrate that it became a Jewish settlement that existed up until the Great Revolt.

As a direct result of the suppression of the Judean rebellion and the destruction of Jerusalem, Ramat Raḥel, like other villages in the Jerusalem area, ceased to exist. The numismatic evidence clearly shows the lack of Judean coins later than year two of the rebellion. Furthermore, there is a very pronounced lack of evidence that can substantiate the existence of a settlement or any other Judean activity at the site during the period between the two Judean revolts.

Following the two revolts against the Romans the ethnicity of the Ramat Raḥel population changed. The site was abandoned for a short period and then reoccupied as a Roman village. A Roman country villa (of the kind known as *villa rustica*), equipped with a typical bathhouse, was built during the second half of the second century or in the early third century CE as part of a new settlement model that developed, at least in the area south of Jerusalem, and was based on an array of private estates. It seems reasonable to

Ramat Raḥel,

Fig. 7 Aerial view of the garden area (Photo by Sky-View)



assume that all these sites were the private estates of the high officials of provincial rule or Roman veterans who had close connections to the military units that were camped in the area.

From this period and up to the Umayyad period (eighth century CE), an organic development can be detected in various areas of local community life. Over a long period of time, no significant changes occurred in the nature of the settlement, yet it is still possible to track the physical expression of the changes that took place in accordance with the spatial–functional division. Thus, for example, in some cases, agricultural production facilities survived and continued to function, with some modifications, from the Roman period through the Umayyad period.

The process of Christianization of the Roman Empire had a profound effect on Ramat Raḥel, and this was expressed in the appearance of the church within the plan of the existing settlement. The church had already been uncovered in 1954, during Aharoni's salvage excavations in the northeastern sector of the site, together with a structure identified as a monastery on the other side of a stone alley. The church, it appeared, had been "planted" on the northeastern outskirts of the settled area, on top of earlier industrial

facilities and dwellings. It was a simple rural church, probably meant to serve the local population. The apse on the east was made of finely cut ashlar stones with remains of a fresco that was painted over the inner side. The pottery and coins unearthed from beneath the foundations confirm that the church was built during the sixth, possibly the seventh, century CE, much later than the Kathisma Church, just a few hundred meters southwest of the summit of the tell, on the third mile of the main road between Jerusalem and Bethlehem, just as the location of the Kathisma is described in the New Testament.

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Rangoli: Versatile Domestic Art

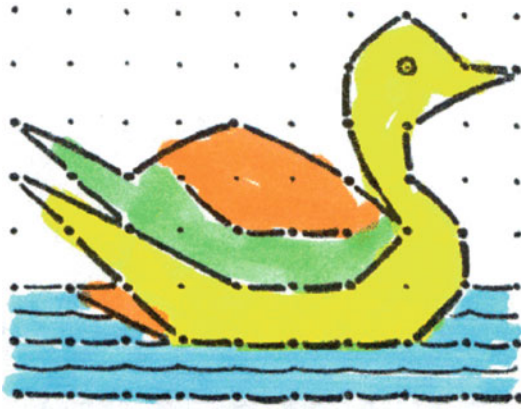
Jyotsna Kamat

The art of rangoli (also known as alpana, saaz, muggu, kolam, zuti, mandana, and by many other names in India) is a traditional art of decorating courtyards and walls of Indian houses, places of worship and sometimes eating places as well. The powder of white stone, lime, rice flour, and other cheap paste is used to draw intricate and ritual designs. Each state of India has its own way of painting rangoli (Fig. 1).

Women's Art

One characteristic of rangoli is that commoners paint it, without much background in geometry, fine arts or mathematics. Women use their bare fingers or a homemade brush to create various designs from sandstone powder or grain flour. Sometimes colors and petals are used in addition to flour paste. Some women are so skilled with their fingers that they can create figures of deities, chariots, temples, etc., on the finely layered floor. Petals of various flowers, such as oleanders, cosmos, zinnia, chrysanthemums, and green leaves provide the artist with the ability to work out various patterns and colors. Most of the rangoli designs are motifs of plants, flowers, leaves such as coconut, lotus, mango, and ashwath (peepal), animals such as cows, elephants, and horses, and birds like eagles and swans. There are geometrical designs as well. When drawn with the fingers, these acquire different dimensions of their own (Fig. 2).

The rangoli art is practised as a ritual to welcome the goddess of prosperity, Lakshmi, into the home. Hence the first duty for housewives and young girls in the morning is to sweep the courtyard clean and draw rangoli patterns. Old and young alike participate in this ephemeral domestic art which changes every day.



Rangoli: Versatile Domestic Art, Fig. 1 Example of a Rangoli design (Illustration by K. L. Kamat)

We see that rangoli is predominantly a ritual performed by women. Men draw rangolis in temples and in public places.

History of Rangoli

The history of rangoli is quite ancient. Early rock paintings have symbols and figures of wild animals, hunting scenes, etc., to ward off evil and wish success in hunting expeditions. By the time of the Indus valley civilization (3000 BC), symbols like triangles, circles, and *swastikas* were used to represent supernatural powers. During the Vedic period, places to seat guests and sacrificial altars were decorated with floral designs. By the use of the hand and deft movement of the figures, rangoli has developed into a fine art over centuries. At times, a simple home-made brush is used (Fig. 3).

Complex Geometry and Philosophy for Common Folk

Almost all of the rangoli patterns involve dots (*bindu*) and lines (*rekha*); joining these creates innumerable patterns. A spot suggests power or life. A line suggests the flow of life. A circle represents the universe and a triangle signifies woman's power or fertility. The swastika stands



Rangoli: Versatile Domestic Art, Fig. 2 Rangoli to welcome God (Photograph by K. L. Kamat)

for the sun's movement. Some interpret that it represents fourfold achievements for householders as laid down by sacred texts. These are *dharma* (virtuous life), *artha* (earning livelihood), *kama* (creature comforts), and finally *moksha* (renunciation in old age). The four corners of the swastika are supposed to symbolize these ideals.

The sun, the moon, the stars, conches, and lotus are considered sacred figures in rangoli. Animals like elephants, cows, horses, tortoises, and birds like parrots, peacocks, and swans, along with plants and creepers, are often included in this art that combines geometry with philosophy and devotion with beauty.

Rangoli in Contemporary India

Festivals dedicated to different gods provide change in the daily routine of rangoli. During Naga panchami, symbols of serpents will appear.

Rangoli: Versatile Domestic Art,

Fig. 3 Women joining dots to make complex designs (Photograph by K. L. Kamat)



On Deepavali, the festival of lights, small earthen lamps will be drawn. On Sankranti festival day, sugarcane, paddy, and wheat sheaves, which are fresh at that time, will find a place of honor in the front door rangoli. Usually every Hindu house has a platform built round the sacred plant of Tulasi. On festival days, this place will also get a special design in addition to the daily ones. Patterns of flowers are popular. Innovative artists paint Christmas and New Year's greetings also in the form of rangolis, depicting Santa Claus and nativity scenes.

During Car festival, the entire village or townspeople will decorate the paths with colorful rangoli designs through which the deity's car (chariot or *ratha*) will pass.

With smaller flats in cities, this temporary and renewable art is disappearing. More and more households find it convenient to decorate their houses with permanent paints; however, they continue to use traditional rangoli designs.

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Rationale in Indian Mathematics

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Rationale in Hindu mathematics and astronomy is expressed by the terms *Yukti* and *Upapatti*, both meaning "the logical principles implied." It is characteristic of the Western scientific tradition, from the times of Euclid and Aristotle up to modern times, to enunciate and deduce using step-by-step reasoning. Such a practice is almost absent in the Indian tradition, even though the same background tasks of collecting and correlating data, identifying and analyzing methodologies, and arguing out possible answers have to be gone through before arriving at results. However, in the final depiction, only the resultant formulae would be given, and that too in short, crisp aphoristic form, leaving out details of all the background work. Commentaries generally content themselves with explaining the text of the formulae and adding examples. This tendency toward selective depiction of results has resulted not only in blacking out the background but also in not understanding the mental working of the

K. V. Sarma: deceased

Indian scientist. It also throws into oblivion the methodologies that had evolved. For this reason, many Indian advances have been branded as unoriginal and borrowed.

The situation is, however, relieved to some extent by the presence of a few commentaries which took pains to explain elaborately the methodologies adopted by the original author and also set out the rationales of the formulae he enunciated. Among such commentaries might be mentioned

- *Siddhāntadīpikā* on Govindasvāmī's *Mahābhāskarīya-Bhāṣya* by Parameśvara (1360–1465)
- *Āryabhaṭīya-Bhāṣya* by Nīlakaṇṭha Somayāji (b. 1444).
- *Yuktidīpikā* on Nīlakaṇṭha Somayāji's *Tantrasaṅgraha* by Śaṅkara Vāriyār (1500–1560)
- *Vāsanābhāṣya* on Bhāskarācārya's *Siddhāntaśiromaṇi* by Nṛsiṃha Daivajña (1621)
- *Marīcī*, again on Bhāskarācārya's *Siddhāntaśiromaṇi* by Munīśvara (1627)

A few texts devoted solely to the depiction of rationale are also known, such as the *Yuktibhāṣā* (Mathematical “Rationale in Language” Malayalam) by Jyeṣṭhadeva (1500–1610), *Jyotirmīmāṃsā* (Investigations on Astronomical Theories) by Nīlakaṇṭha Somayāji (b. 1444), *Rāśīgolasphuṭānīti* (True Longitude Computation on the Sphere of the Zodiac) by Acyuta Piṣāraṭi (1600), and *Karaṇapaddhati* (Methods of Astronomical Calculations) by Putumana Somayāji (1660–1740).

However, what is more significant is the occurrence of a number of short tracts giving mathematical and astronomical rationale which are available, some in print and several others in the form of manuscripts. These tracts take up individual topics of importance, analyze the technical principles involved therein, compare the procedures adopted in different texts, and often suggest revisions. To cite an example, the work *Gaṇitayuktayaḥ* (Rationales of Hindu Astronomy) contains a set of 27 tracts providing

rationalistic exegeses on several topics, including parallaxes of latitude and longitude, elevation of the moon's horns, constitution of epochs for new astronomical manuals, planetary deflections, and equation of the center. It is also noteworthy that some of these exegeses establish the originality of the methodologies and formulae depicted by Indian scientists.

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Rationality, Objectivity, and Method

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Rationality, objectivity, and method are three words that capture the essence of science and at the same time provide its mythic structure. Science has become the authoritative form of knowledge in the world today. The proof of its

superiority lies in the ever-expanding body of knowledge we have about reality. We can predict where, when, and how meteorites will collide with Jupiter, and we can build interplanetary spacecraft to send back signals recording the event. We can explore the atomic structure of chemicals and design new ones to suit whatever purpose we have in mind, ecstasy or health. We can map the human genome. We can explain the origins of everything in the universe down to the first few nanoseconds. The source, according to the myth, of this unparalleled success lies in science's embodiment of the highest form of rationality and objectivity in the scientific method. This mythical underpinning of science also provides the rationale for the celebration of modernity and the current domination of the West. This view is unselfconsciously exemplified by the philosopher Ernest Gellner who claims, "If a doctrine conflicts with the acceptance of the superiority of scientific-industrial societies over others, then it really is out" (cited in Salmond, 1985).

Therein lies the first set of intrinsic problems and contradictions the myth conceals. Modernity is supposedly synonymous with development and social improvement, but it has become apparent in recent times that science and technology are no longer unalloyed agents of progress. They now seem to contribute significantly to the difficulties we are facing in environmental degradation, pollution, climate change, and waste disposal. The other equally difficult emergent problem for the mythological account of science is that it has been seen as quintessentially Western and as absent in the developing countries or an undeveloped possibility in the Islamic, Chinese, and Indian cultures. This can no longer be accepted as a simple fact, but has now to be seen as an ideological marker in the creation of the "other." We have then a joint problem. On the one hand "the future is not what it used to be," courtesy of the negative effects of science and technology, but we will nonetheless have to call on them for their problem solving capacities. On the other hand it is becoming apparent that the grand project of modernity – a universal scientific culture – has failed and ought to be

relinquished in favor of encouraging cultural diversity. Just as biological diversity has become recognized as an ecological necessity so too has our cultural survival come to be seen as dependent on a diversity of knowledge (see knowledge systems). Consequently "the central problem of social and political theory today is to decide the nature of communicatory reason between irreducibly different cultures" (Davidson, 1994). Given this double difficulty we need to ask ourselves if science can be reconstituted.

Rationality

It is in trying to explicate rationality, objectivity, the scientific method and the nature of science that the myth of science's transcendental supremacy really comes undone. Rationality is a deeply problematic concept. It is profoundly embedded in the hidden assumptions of late twentieth century occidentalism about what it is to be a knowing, moral, sane individual. Indeed it is so embedded that to be anything other than rational is to be ignorant, immoral, insane, or a member of an undifferentiated herd. Hence rationality cannot be treated as simply an epistemological concept about the conditions under which one can know something; it also carries ideological overtones, privileging certain ways of knowing over others. Rationality is a constitutive element in the moral economy.

Yet despite, or perhaps because of, this central role of rationality, there are no fully articulated rules or criteria for being rational in the acceptance of beliefs or in the pursuit of knowledge, nor is there a single type of rationality. This sense of incoherence in the concept reaches total intransigence in the recognition that ultimately there can be no rational justification for being rational. Nonetheless critical rationalism as advocated by Karl Popper has a primal persuasiveness in contemporary Western society. Mario Bunge has captured some of that self-evidentiality and variability in his seven desiderata for rationality:

1. Conceptual: minimizing fuzziness, vagueness, or imprecision

2. Logical: striving for consistency, avoiding contradiction
3. Methodological: questioning, doubting, criticizing, demanding proof, or evidence
4. Epistemological: caring for empirical support and compatibility with bulk of accepted knowledge
5. Ontological: adopting a view consistent with science and technology
6. Valuational: striving for goals which are worthy and attainable
7. Practical: adopting means likely to attain the goals in view

Indeed seeing them set out like this makes their denial seem irrational.

From a relativist's perspective there are no universal criteria of rationality, and even if the claim for rationality's governing role is weakened to talk of desiderata as Bunge does, Wittgenstein's and Godel's point prevails: all formal systems are necessarily incomplete, no body of rules can contain the rules for their application. Rationality consists in the application of locally agreed criteria in particular context or as Foucault puts it, forms of rationalization are embedded in systems of practices (Foucault, 1979, p. 47). Hence it should be acknowledged that science, rather than exemplifying some transcendental rationality, has developed its own rationalities that have in turn served to create a great divide between science and traditional beliefs. There is of course a middle ground, the so-called bridgehead argument which calls for the recognition that all humans have some minimal forms of practical rationality in common. Though this recognition has produced no universal truths and no universal criteria, it nonetheless provides the grounds for a commonality sufficient for partial communication and understanding across linguistic, ontological, and cultural differences.

There is a philosophical tendency to talk of rationality as if it were a problem with no historical or sociological dimensions. This is to ignore the fact that the concept of the individual as a rational actor that is now so basic to Western ways of thought is not derived from first

principles; it arose in conjunction with the development of modern science in the seventeenth century. This was a period which saw great debates over the appropriate forms of rationality between the Cartesian rationalists and the Baconian empiricists. Whether true knowledge was to be derived deductively from self-evident first principles or by observation and experiment, it had already been accepted that the acquisition of such knowledge was within the capacity of human individuals. The recognition that human reason and experience was not inherently limited and could be a source of knowledge re-emerged in the twelfth and thirteenth centuries in the West with the separation of the church from the state and with the development of secular law from the accompanying canon law (Berman, 1983). The development of this conception of rationality was not universal. For example it was not paralleled in Islamic society where men were denied rational agency; they were held to lack the capacity to change nature or to understand it. Knowledge was instead to be derived from traditional authority. This is not to claim that there has been no Islamic science or any Islamic discussion of rationality (Huff, 1993). On the contrary, there have been major achievements in Islamic science but in a radically different moral economy.

While the notion of the rational actor as unconstrained by circumstance or authority and moved only by logic and evidence has become embedded in our legal, economic, and scientific presuppositions, such an idealized conception is at variance with our lived reality both at the societal and the individual level. At the societal level, modern Western capitalism has become a bureaucratic system that, as Weber pointed out, relies on a calculative rationality (Weber, 1979). The administration and perpetuation of this system is crucially dependent on a system of rules from which legal and administrative calculations can be derived by professional, objective, experts. Hence modern science and capitalism are interdependent; they were coproduced on the basis of a calculability derived in part from rational structures of law and administration. In Weber's view it is the specific and peculiar rationalism of western culture that makes science

unique to the west. Even if Weber was right, what needs further examination is how specific and peculiar that calculative rationalism is. That form of rationality has a number of interwoven components, for example the acceptance of written documents as evidence as opposed to oral testimony. This transition also occurred in the twelfth and thirteenth centuries but required the development of a “literate mentality” before it became self-evident that records and archives were more worthy of belief than the word of “twelve good men and true” (Street, 1984). Some, like Goody, have further argued that the accumulation of knowledge and the possibility of criticism and hence rationality are only possible in a literate culture. Similarly vision had to be rationalized to provide grammar or rules for the relationship between the representation of objects and their shapes as located in space. Yet another component of the form of rationality we equate with science was the acceptance of the validity of experimental evidence. Shapin and Schaffer have argued in *The Leviathan and the Air Pump* that Thomas Hobbes was able to dismiss Robert Boyle’s experiments on the vacuum as private, local, and artifactual until Boyle was able to introduce a range of social, literary, and technical practices that enabled the knowledge produced in the isolation of the laboratory to be “virtually witnessed” and reproduced for other audiences and in other laboratories (see Knowledge Systems).

Rationality is not a particular human capacity. Rather there are forms and compounds of rationality which at the societal level, as Foucault has shown, are dependent on particular social and historical institutions, constituted through the interwoven practices, techniques, strategies, and modes of calculation that traverse them. However, at the individual level we do not behave like the ends/means optimization calculators that economic rationalism would have us believe we are. We are at least as interested in meaning, significance, and personal values as we are in economic concerns. Nor are we quite the rational agents basing our knowledge on direct experience that the legal and philosophical theorists claim. A vast preponderance of our knowledge derives not from personal experience but

from books, newspapers, journals, teachers, and experts. In other words our knowledge comes, directly or indirectly, from the testimony of others, in particular from those we trust. Thus our individual lived rationality is based in a range of social practices, traditions, and moralities that are suppressed and concealed in the portrayal of rationality as an ahistorical, universalistic form of reasoning exemplified by science.

Objectivity

Much the same can be said of objectivity. Objective knowledge is held to be the product of science that has established methods to ensure that individual, institutional, and cultural biases are eliminated. On closer examination objectivity is not characteristic of one special kind of knowledge – science. Rather it is the result of whatever institutionalized practices serve in a particular culture to create self-evident validity. Objective knowledge, in modern terms, is held to contrast with subjective knowledge. It is knowledge that is not local, that is not contingent on the circumstance, authority, or the perspective of the individual knower. However, the concept of objectivity, like that of rationality, is not immutable; it is an historic compound. In the seventeenth century objectivity meant “the thing insofar as it is known.” The concept of aperspectival objectivity emerged in the moral and aesthetic philosophy of the late eighteenth century and spread to the natural sciences only in the mid-nineteenth century as result of the institutionalization of scientific life as a group rather than an individual activity.

This characterization of objectivity as the “view from nowhere” (Nagel, 1986) represents one of the essential contradictions of scientific knowledge production. Knowledge is necessarily a social product; it is the messy, contingent, and situated outcome of group activity. Yet in order to achieve credibility and authority in a culture that prefers the abstract over the concrete and that separates facts from values, knowledge has to be presented as unbiased and undistorted, as being without a place or a knower.

Objectivity, like democracy, is at best a worthy goal but one that is never capable of achievement. Since knowledge is the product of social processes it can never completely transcend the social. Objective knowledge cannot, for example, simply be knowledge which is unaffected by nonrational psychological forces, since scientists always have motivations even if they pursue knowledge for its own sake. Nor can objectivity be restricted to the avoidance of dogmatic commitment, because there have been scientists like Kepler whose obsession with regular solids and cosmic harmony led to his derivation of the laws of planetary motion. While it may be possible to avoid personal idiosyncrasy this can only be achieved through the establishment of communal or public knowledge. If knowledge is a communal product, then the question of how the community should be constituted arises. Should the scientific community be an essentially western institution? Consequently objective knowledge cannot simply be “value free” knowledge because what is counted as knowledge is itself a value. Similarly the criterion of practical effectiveness cannot determine objectivity since it too is based in community standards.

The only remaining possibilities for objective knowledge lie in the notions of correspondence with reality and experimental verification. There are well known difficulties here, since correspondent theories of truth and verification are dependent on empiricism and the scientific method, both of which have been subject to powerful criticism in the last half century or so. Essentially, what philosophers like Duhem, Quine, and Wittgenstein have argued is that our ways of knowing about the world are riddled with indeterminacies; which is to say that there is no set of procedures sufficiently powerful to determine which knowledge claims are absolutely true and certain, nor is there a certain way of grounding such claims. There are uncertainties inherent in all our ways of knowing that have to be bridged by a variety of practical and social strategies. Popper and Kuhn have argued that neither deduction nor induction is capable of providing true and certain knowledge. Furthermore observations and theories are interrelated and hence

neither can be an independent foundation for the other. Both Popper and Kuhn recognize that observations have point and meaning within the context or framework of a theory: we do not simply observe natural phenomena, we observe them in the light of some theory we already have in mind, or minimally with some set of expectations about what is interesting or what to look for. In this sense our observations of the world are “theory dependent” or “theory laden.”

As Duhem points out, all theories are enmeshed in a web of other theories and assumptions. The apparent conflict between an experimental result and a particular hypothesis cannot conclusively lead to the rejection of that hypothesis, since the strongest conclusion that can be drawn is that the hypothesis under test and the web of theories and assumptions in which it is embedded cannot both be true. Since the experimental result by itself is insufficient to tell us where the flaw lies, we can always maintain a theory in the light of an apparently falsifying experiment if we are prepared to make sufficiently radical adjustments in the web of our assumptions. Conversely it is the case that for any given set of facts there is an indeterminably large number of possible theories that could explain them.

In addition to the problematic relationship of theory and observation there is a difficulty concerning the language in which our claims about the world are expressed. All propositions or observation statements contain descriptive predicates which imply a classification or categorization of the world based on postulated essences or natural kinds. We are stuck with some degree of circularity since we gain our knowledge about natural kinds from theories which are in turn based on observations. There is no neutral observation language; our only option is to recognize and acknowledge the conventional character of our linguistic classifications.

Scientific Method

Despite all these difficulties scientists are able to reach firm conclusions about the natural world.

How is this possible? Many would claim that even though it may be logically true that there are an indefinite number of possible explanations for a given body of facts, in a given case there are typically a very restricted set of alternatives and there are adequate means of selecting the right theory, or at least the best possible theory in the circumstances, given the application of certain criteria. For example, we obviously desire theories which are internally coherent, consistent with other accepted theories, and simple rather than complex. However coherence, consistency, and simplicity as well as other criteria like plausibility have all proved notoriously difficult to express in a way which can be used to measure all theories in all circumstances. It is, none the less, very tempting from our twentieth century standpoint, imbued as we are with the scientific ethos, to suppose that there must be a particular set of rules, procedures, and criteria to which all scientists adhere. Taken together they should constitute the scientific method, and by diligent application of this method we should be able to arrive at all the scientific discoveries of our age. However, Paul Feyerabend in *Against Method*, for example, argues that no proposed set of rules and procedures has survived criticism or has been universally adopted by all scientists in all circumstances. Likewise he claims that in no case can it be shown that the success of science can be solely attributed to its adherence to the scientific method.

There can of course be endless debates about such claims, but so far no one has been able to identify the one scientific method which has been adopted in all the sciences. Compare for example theoretical physics (mainly mathematical) and biology (mainly observational). Nor is there a method which has been unilaterally accepted in a particular discipline. Compare again, Newton's espoused methodology ("I feign no hypotheses") with Einstein's (bold hypotheses and deductive tests). Further, particular instances of scientific practice under close examination reveal a pragmatic willingness to suspend or modify any particular version of the scientific method if necessary, as Feyerabend has shown in his analysis of Galileo and Copernicus. It seems then that

there is no "single, invariant methodology of science." Instead there are series of complex interactions between method and practice. As science and technology develop, so the practitioners develop and negotiate the rules for doing them in a local and contingent fashion. New methodologies are propounded in order to provide support and credibility to a newly preferred scientific theory.

Scientific Practice

It could be argued that the indeterminacies of science and the lack of a specific scientific method are merely philosophical and theoretical problems, and that science is firmly grounded in experimental practice. The best way to know whether a particular knowledge claim about the world is true or false is to subject it to experimental test and then have somebody else repeat the experiment.

There are two kinds of related difficulties with this empirical approach. Experiments are inevitably performed on a simplified, artifactual, and isolated portion of reality. Hence the universal generalizations drawn from them are not indubitable. Cartwright (1983) goes so far as to claim that the Laws of Physics are, in effect, lies. Equally the effectiveness of experimental replication as the litmus test of truth is somewhat undermined by the role of skill or tacit knowledge in scientific practice. "The problem being that, since experimentation is a matter of skillful practice, it can never be clear whether a second experiment has been done sufficiently well to count as a check on the results of the first. Some further test is needed to test the quality of the experiment – and so forth" (Collins, 1985). This result in what Collins calls "the experimenter's regress." In the normal course this is resolved by social processes in which the judgment about whether to accept a particular result is based on the relevant community's evaluation of the skills of the experimenter in question. It becomes deeply problematic when the existence of the phenomenon itself is at issue, as in the case of gravity waves. An experiment showing the

existence of such waves was followed by others seemingly denying their existence, or at least failing to detect them. Which was correct? The existence of gravity waves turns on the judgment of the community about competently performed experiments, and those judgments of competence are based on the accepted community knowledge about the nature of gravity waves. Replication then is not the test of their existence; rather it reflects the ability of the experimenter to achieve community standards of experimental practice.

Thus it would seem that conceptions of rationality, objectivity, and the scientific method cannot be derived from self-evident epistemological principles. They are instead embedded in the historically contingent processes of scientific practice, whereby the resistances and limitations of reality are encountered and accommodated. Science is a social activity that is essentially dependent on community and tradition, and the practice of science is governed by concrete, discrete, local traditions which resist rationalization.

The notion of a great divide between Western and so-called primitive knowledge systems has turned crucially on the question of rationality of science. If, as the arguments above suggest, science has a rationality of its own, but not one that is especially privileged, how do we both account for and deal with similarity and difference between cultures? How is it, on the one hand, that the peoples of the world are sufficiently alike to have universally developed complex languages, and yet those languages and their accompanying knowledge systems have produced profoundly different cultures? On the other hand, how are we to ensure communication and preserve cultural diversity?

In the entry on local knowledge it is claimed that the common element in all knowledge systems is their localness, and that their differences lie in the way that local knowledge is assembled through social strategies and technical devices for establishing equivalences and connections. It is no small reflexive irony that this entry on rationality and science and the encyclopaedia itself are dependent on unspoken assumptions concerning their credibility and authority which

constitute a form of rationality. The encyclopaedia is based on the assumption that widely disparate knowledge can be meaningfully assembled into a volume without loss of coherence due to incommensurability. Furthermore it is assumed that the individual articles, dependent as they are on evidence, analysis, and argument, are capable of being read, understood, and utilized by readers from all cultures. In other words there is a strong resemblance between this encyclopaedia and the practice of science. Science is dependent on the assemblage of heterogeneous inputs, but that assemblage is not achieved by the application of logical and rational rules or conformity to a method or plan. Indeed it is not even dependent on a clearly articulated consensus. Rather the assemblage results from the work of negotiation and judgment that each of the participants puts in to create the equivalences and connections that produce order and meaning. Perhaps then it has to be acknowledged that there is a minimal rationality assumption, and that links between rationalities can either be created or ignored by common human endeavor. So, given the lack of universal criteria of rationality the problem of working disparate knowledge systems together is one of creating a shared knowledge space in which on the one hand equivalences and connections between differing rationalities can be discursively constructed; and on the other hand where no common ground can be created, agreement can be sought to work with the creative tension of difference. A good example of such competing rationalities in tension is the irrigation system of Bali. Stephen Lansing's analysis shows the crucial role of the symbolic system of water temples in managing the flow of the waters, a role that classic Weberian forms of rationality have in the past simply dismissed as irrational (Lansing, 1991). Yet the role of the water temples was revealed by Lansing's anthropological and computer-based analysis. Communication, understanding, equality, and diversity will not be achieved by others adopting Western information, knowledge, science, and rationality, it will only come from negotiating ways to work together in joint and multiple rationalities.

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Religion and Science in China

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“Religion and science in China” is a controversial topic which requires some clarification before the discussion can begin. Because the first serious efforts to bring Chinese classical study to the Western academic world were initiated by Jesuit missionaries in the seventeenth century, it became a Western tradition to look at many Chinese cultural phenomena from a religious point of view and categorize them accordingly. For a long time in the West, the three main *Jiao* (systems of teachings and beliefs) of Chinese traditions, Confucianism, Daoism (Taoism), and Buddhism, were called three religions. However, since the reconstruction of Chinese classical study early in this century, Chinese scholars generally consider Confucianism and Classical Daoism philosophies, popular Daoism a religion, and

Chinese Buddhism both a religion and a philosophy. Today in the West there is no consistent way of using these terms. All three are called either religions or philosophies or both, according to the idea or method or focus of the researcher. Furthermore, it is common practice to include other beliefs and activities in the study of religion, such as myths, rituals, customs, popular superstitions, and court divination rediscovered through mythological, linguistic, or archeological findings. These new studies are in fact turning the topic of “religion and science” into a much broader topic of “culture and science.”

On the other hand, the concept of “Chinese science” is even more uncertain. There is a strong tendency both in the West and in present-day China to question the possibility of a different kind of science. The underlying implication is the belief that there is only one science for one universe – The Science, which is objective and universal. With this belief in mind, explicitly or implicitly, historians of science generally consider Western modern science as the best approximation of The Science, and use it as a measure to search for relevant materials in Chinese ancient relics and texts. By using the same measure, Chinese ancient ideas, theories, studies of nature, and activities dealing with nature are accordingly classified into “scientific subjects” and thereby evaluated. The same belief also provides criteria for distinguishing nonscience from science. The danger of this viewpoint is that it will miss many of the real merits in cultures other than Western ones. One example is that the deep-set dichotomy of “body and soul (mind)” in the Western culture is typically a Greek tradition and may not be shared by other cultures. This difference will show itself especially in the different medical traditions.

For those who do not accept the idea of The Science, it becomes crucial to establish a reasonable or practical criterion for nonscience and science. Research efforts in this regard have not been successful either. Another confusion comes from the fact that in ancient China achievements in technology and in science are not easily distinguishable. There are doubts about if it makes sense or even if it is possible to define these two

concepts separately in the context of Chinese ancient culture.

With all these ambiguities in the main concepts and differences in the basic positions, the interaction between religion and [science in China](#) has not been formed into a regular study subject. In this article we will acknowledge that the concepts “religion” and “science” are both Western concepts used in a Chinese context. “Religion” means a system of beliefs and “science” means knowledge, especially theoretical or systematic knowledge about nature, human beings, and life, but not about human beliefs, activities, and relationships. Thus we will be able to achieve some clarity in our discussion.

The question of why the scientific revolution did not take place in China has drawn much attention during recent decades. A generally accepted conclusion is still far away, and may not even be important. In this article we will explore the influence exerted by the main Chinese ideologies on the nature and development of Chinese science. Here “main Chinese ideologies” means Confucianism and Daoism. Also, “Chinese science” means and includes Chinese ideas, theories, and knowledge about nature (including humans as natural beings) which were accepted by Chinese scholars or professionals in corresponding historical periods.

In the West in ancient times, science was under the strong influence of religions, and in modern times, religions were under the influence and pressure of the development of science. In China, science went along a different road; it started under the decisive influence of early Confucianism and philosophical Daoism. These two traditions governed the development of Chinese science. There were no serious conflicts between these governing ideologies and Chinese science until China began to bring in Western science on a large scale in the late nineteenth century. The conflict between Confucianism and Western science at that time has been a much studied topic.

After Buddhism was introduced into China around the first century, it gradually became the primary organized religion. However, little can be found in the development of Chinese science that was affected by the development of Chinese

Buddhism. One explanation of this phenomenon is that the characteristics of Chinese science, its subject matter and method, had been firmly established before the Qing dynasty (221–206 BCE). The nature of that science is quite compatible with the philosophy and practice of certain kinds of Indian Buddhism. On the other hand, together with Confucianism and Daoism, Chinese science might have exerted a strong influence upon the development of Chinese Buddhism, especially the Chan sect (the origin of the Japanese “Zen”). Little research has been done on this topic.

Our main concern will be the influence of ancient Confucianism and Daoism on Chinese science. We will begin with ancient cosmological beliefs and the methodology associated with these beliefs. As Confucianism and Daoism are the two schools that have been most influential in the making of Chinese culture, have preserved a great quantity of texts and historical records for their teachings, and have been thoroughly studied, the common features of these two schools will provide a good starting point in searching the origin of Chinese science. After this, we will also discuss how the difference between these two schools influenced the development of Chinese science in their own way.

Chinese Ancient Cosmological Beliefs

It is important to examine the basic concepts that were used in both Confucian and Daoist texts. Those that concern Chinese science are the concepts of Heaven, Earth, Human, *Dao*, *Te*, and Fate. Though Chinese classics do not provide definitions for these concepts, we can study the way they were used in their textual contexts and interpret their meaning approximately by using Western concepts as follows: Heaven and Earth form the natural world that Human lives in. Heaven is the part that is farther away from Human but is more fundamental in the sense that it ultimately governs and decides everything that happens to Earth and Human. Earth is the part of the natural world that surrounds and interacts

with Human directly. Human is the concept for every human being, who has a life that has a beginning, a growing process, and an end. The distinction between Heaven and Earth is of great importance in the interactive mechanism between Human and Nature. Human can act directly on Earth and change it and use it for his own purposes, but not on Heaven. Earth is governed by Heaven and not by Human; therefore, the way Human deals with Earth (e.g., agriculture and irrigation) can either be right or wrong according to whether it follows or violates Heaven’s way. This sounds quite like the Western idea of natural law and it seems compatible with modern scientific views, but there is a crucial difference. The Chinese “Heaven’s way”, which is called *Dao*, governs not only Earth, but also Human’s life and society, and therefore it is a moral matter whether one follows or violates it. To follow the *Dao* is not only a matter of what to do to achieve a certain purpose, like what science tells us in the West, but also what purposes one should have in all his/her activities including governmental, social, familial, and individual activities. Thus, *Dao* as the most fundamental principle or cosmological law is objective and natural, and governs the whole world which in Western categories splits into the natural world, society, and individual life.

To know *Dao* and therefore to act according to *Dao* is the goal of ancient Chinese study. The result of this study is to gain *Te*. *Te* is both knowledge in the sense of knowing what is right, and virtue in the sense of practicing what is right. Like knowledge and virtue in the West, *Te* can be both innate and acquired. That is, people are born with *Te*, to a greater or less degree, and can acquire and accumulate *Te* through study and practice in their lives. However, unlike the Western concepts of knowledge and virtue, *Te* can neither be defined by a general relationship, either functional or quantitative, nor be abstracted or theorized from its special context – the human conditions which define the reality of the individuals concerned.

The reality of an individual is his/her Fate, which is basically determined by Heaven.

That means it is out of human reach to change or control it. On the contrary, Fate is the realization of *Dao* in each individual's life. It can be known either through study and practice, or by divination. Ancient Chinese divination, like a certain kind of Greek oracle, does not tell what will happen in the future but answers if actions are right or wrong according to Heaven's way. Therefore, the concept of "good fortune" is not defined by positive results to individual purposes, nor satisfaction of natural or whimsical human desires, but by the realization of the *Dao*. Therefore, ancient Chinese divination, typically represented by the Yijing (I Ching, Book of Changes), has a close relation with the ancient Chinese value system and moral principles as well as understandings of *Dao*, and thus exerts great influence on the development of Chinese science.

Now when we look back at these beliefs, the following conclusions are apparent:

1. Because of the wide variety of its governed phenomena, and because of its moral nature, *Dao* is not a deterministic regularity which decides in every detail what happens in the world. Maybe it is, on the whole and in the long run, but certainly not in the form of an instant causal relationship in everyday phenomena which are available for measurement and observance. *Dao* is not a natural law which is impossible to violate.
2. If *Dao* is ultimately deterministic, it can be seen in history. Therefore, to keep historical records is tremendously meaningful and important for the Chinese, and to study these records, what is called historiography in Western terminology, is especially so.
3. If *Dao* is indeterministic in details, and can be violated by people for their wrong purposes, then it makes no sense to study *Dao* by mechanical experimenting, nor by searching underlying regularities in the observable movements of stars in heaven and things on earth. In other words, one cannot study *Dao* through instant causal relationships, because in these relationships there are no observables
4. Chinese divination has a nature of empirical knowledge which comes from generalization of phenomenological and historical observations, and a nature of theoretical knowledge which employs mathematical representation to calculate functional relations in the change of affairs. Not only does it exert great influence on the later development of Chinese science in its conceptual system and methodology, but also it could be looked upon as the earliest achievement of Chinese science.

Confucianism

Confucianism is the English word for *Ru Jia* (the School of Scholars), which was founded by Confucius (551–479 BCE), the first private teacher in China. Confucius is the Latinized form of *Kong Fuzi*, a respectful way of addressing the master. *Kong* was his family name. He lived in a time when the empire was being broken up into numerous feudal states. It was a time of change, disorder, and degeneration of the old moralities. When he started as an officer and political reformer, Confucius' ideas of personal cultivation and moral government failed to attract the rulers of his time. So he turned to teaching and taught a large number of private students, preparing them to be good court ministers as well as good teachers. Thus, he managed to exert an influence by establishing a tradition of individual learning and private education. In the second century BCE his ideas and teachings were made authoritative by the Han emperors, and the Classics Confucius edited and used in teaching became the only official textbooks in China until the beginning of the twentieth century.

Confucianism is *the* Chinese ideology. From the second century BCE to the beginning of the twentieth century, it has been the orthodoxy. In a way, it is the Chinese religion, because it provides a system of beliefs (or disbeliefs) and values which calls for faith and acceptance from

students, and also because it is more a way of life for students to follow than a body of knowledge for them to master. There are always scholars who spend their lives studying the text of Confucian Classics, but it is not through these studies that Confucianism exerts its influence on Chinese society and culture. In this regard, Confucianism is more comparable to Western religions than philosophies.

However, Confucianism is not a religion in the Western sense, because it has neither doctrine nor reference to the supernatural. It gives no promise, no reward, and no consolation to its followers either in or beyond this life. It has no God, no church, and no organization. It is only a teaching. It teaches the follower how to be a noble man (a *Junzi*) living a noble life in his special social context.

The ultimate goal of Confucius' teaching, and therefore the goal of Confucian learning, is the benefit of the people. The essence of Confucianism lies in these two doctrines (1) a moral government, i.e., governing by moral examples and education instead of by rules, law, and punishment, is the solution to social disorder and is to the highest benefit of the people; and (2) the cultivation of a group of *Junzi* (noble men) in a society is a practical road toward moral government.

A *Junzi* is an elite scholar. He is elite because he has higher moral standards and is therefore a better person than a common man (*Xiaoren*, the small men); but he is not an elite in the Western sense, because his higher moral standards require that he has no social privileges but only duties and obligations. To be a *Junzi* is both to lead a noble life and to have a noble personality; it is a lifelong task of self-cultivation without personal gains. One will choose to be a *Junzi* because he knows it is his fate.

To be a *Junzi* is the immediate goal for a Confucian. Because Confucians believe that people's benefit will be served best by bettering the government, people are left alone to deal with their own material needs, their production, and their struggle with the natural surroundings. Confucians take it for granted that common people are

naturally wise enough to deal with all that and take care of their own needs, and it is not *Junzi's* task to learn and develop knowledge and ability in this regard. Confucians believe that a moral society would naturally become prosperous.

The *Analects*, a basic Confucian classic, recorded that Confucius once refused to teach his student agricultural knowledge, saying the elder farmers and gardeners were better than he in this regard. This shows that *Junzi's* learning should be limited to the scope of human relationships, and science or scientific knowledge has no value to *Junzi's* task of self-cultivation.

This Confucian attitude toward scientific knowledge has its roots in the belief that the world Human lives in is governed by the *Dao*, and the best thing Human can do is to follow the *Dao*. In Chinese cosmology it is a Human choice, therefore a moral matter, to follow or to go against the *Dao*. Therefore, the Western task of changing the world according to man's ideas, or reforming the world to suit man's needs, would sound absurd and dangerous to the ancient Chinese, for it advocates going against the *Dao*. Human is a part of the universe, and not the governing part. Man is not the lord of the earth and cannot give orders to Nature. This is not to say that ancient Chinese did not make efforts to better their living conditions, but it does mean that they did not give these efforts high priority on the scale of social urgencies.

After Confucianism was made authoritative by Chinese emperors in the second century BCE nearly all Chinese intellectuals became Confucians, who formed an elite class in Chinese society. Generally speaking, Confucians looked down on technical and scientific knowledge and achievements because these neither had any use in self-cultivation, nor helped in turning the government into a moral one. This attitude left the development and preservation of scientific knowledge in the hands of professionals, many of whom were illiterate and kept their skills and knowledge as a family tradition. With the exception of astronomy, mathematics, and medicine, Chinese ancient technological and scientific achievements were seldom recorded or their

records preserved. When the British scientist and historian of science Joseph Needham started to search extensively through the extant texts for these records, and began to publish the results of his search in the multivolumed *Science & Civilization in China* (1954-), it shocked the world to see that Chinese themselves did not remember what they had achieved. Certainly the ancient Confucians would not value these “achievements” as much as modern Westerners do.

There is no doubt that this Confucian devaluation of scientific activity, knowledge, and achievements has been a significant hindrance to the development of Chinese science. However, Confucians did value the study of astronomy, mathematics, and medicine, though the former two were not necessarily as urgently needed by the people as the knowledge for agricultural production. The reason Confucians accepted them as a proper scholarly study is for their use in divination. Confucianism included divination in the basic teaching of *Li* (rites). Astronomy and mathematics were needed in making calendars, which were important for the agricultural economy. Medicine was an early tradition and developed into such a complicated system that it became an intellectual profession even before Confucianism gained its orthodox position.

Confucianism did allow for scientific and technological knowledge to grow among the professionals. The Confucian attitude toward science is to leave it alone. Science and technology are not Confucians’ proper concerns, but they never go against them. Under the reign of Confucianism there were no known cases in which scientists and innovators were persecuted because of their ideas or inventions. Confucianism created unfavorable social attitudes and conditions for scientific and technological development in China, only because Chinese rulers made Confucianism orthodox and turned the intelligentsia into Confucians. But we cannot oversimplify this situation and accuse Confucianism of smothering a scientific revolution which would otherwise have happened in China. When we study the three branches of science Confucianism valued, and compare them to Western

ones, it can be seen that they are metaphysically and methodologically different. What Confucianism did to Chinese science was external and only confined to social factors.

Daoism

The term Daoism in English has several meanings. In its basic meaning it is a translation of the Chinese *Dao Jia* (the School of *Dao*), which was represented by two Daoist classics: the *Lao Zi* and the *Zhang Zi*. In this sense, Daoism (also called Classical Daoism or Daoist philosophy) is an ancient philosophical tradition. In its second meaning Daoism is a translation of the Chinese *Dao Jiao* (the religion of *Dao*, or Popular Daoism). It includes a variety of later organizational developments of the Daoist religion, mostly imitating the form of imported Buddhism but incorporating the ideas of the *Lao Zi* and *Zhang Zi*. It was often involved in political issues, sometimes was used to organize and mobilize peasants’ uprisings, occasionally was used to seek favors from the court, and was thereby supported by Chinese emperors. It was a folk religion and Confucians looked down on it as low culture and superstition. In its third and very broad meaning, it is a vague concept that includes Classical Daoism, Popular Daoism, and some other schools that were similar to Classical Daoism. These other schools include the School of [Yinyang](#) and the School of *Huang-Lao* (the School of the Yellow Emperor and *Laozi*). It is in this last sense that we are now using the term Daoism.

Generally speaking Daoists emphasize individual happiness rather than social welfare. They believe in *Dao*, in cutting down one’s desires and wants, in living a simple, secluded, and natural life, and in cultivating spiritual as well as physical immortality. In the last aspect it is mysticism from a modern scientific point of view, but the method it uses in seeking the way of immortality, which according to Daoism should be realized in this life on earth, is very much empirical and congenial with the Western development of geography, health care, and elixir

alchemy. Thus, the influence of Daoism on the development of Chinese science is substantial.

The central idea that exerts a strong impact on the development of Chinese science is the search for immortality in this life on earth. We do not know what the origin of this idea is and when its practice started. There are three approaches: the first is by cultivating one's *Qi*, the second by making special drugs such as the elixir of life, and the third by going deep into mountains or on the seas to find living immortals to learn from. The concept of *Qi* is one of the most ancient Chinese concepts about nature and life. It was used, in the sense of vitality, in the works of the warring-states philosophers, such as Mencius, Xun Zi, Zhuang Zi, and Lüshi Chunqiu in the fourth and the third centuries BCE. The earliest extant text that mentioned elixir drugs is *Hanfei Zi*, which was in the third century BCE. *Shi Ji* (Records of the Historian, compiled during the second and the first century BCE) recorded that in the fourth and third century BCE the rulers of Chu and Yan states sent envoys sailing to learn about the ways of immortality.

These three approaches led to three developments of Chinese science. The first is Chinese medicine, including health care techniques and Qigong. *Qigong* is an Eastern exercise which is based on the theory of interaction between body and spirit and the possibility of controlling one's mental state by manipulating one's body. The second is somewhat connected with the development of Chinese pharmacology, but more so with that of chemistry which led to the invention of ► [gunpowder](#). The third helped to preserve ancient myths and legends, and initiated the need to exploit the outside world which Confucians neglected. The earliest Chinese geographical work, *Shan Hai Jing*, is basically the result of this effort.

The Daoist influence on Chinese science is more congenial with the criteria of modern science. Daoists believe in the power of true knowledge for their own purpose of immortality and that knowledge can be sought by experimenting or by learning from those who know. They accept that the truthfulness of that knowledge should be tested by the results of its applications. With their

beliefs of *Yinyang* and Wuxing (Five Phases), which are not religious but ontological and methodological, Daoism is the Chinese system of belief that led to the flourishing of Chinese medical theory and health care practices, which might be considered the highest achievements of Chinese science.

See Also

- [Alchemy in China](#)
- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [East and West: China in the Transmission of Knowledge from East to West](#)
- [Five Phases \(*Wuxing*\)](#)
- [Gaitian](#)
- [Geography in China](#)
- [Geomancy in China](#)
- [Gunpowder](#)
- [Huntian](#)
- [Magic and Science](#)
- [Medicine in China](#)
- [Qi](#)
- [Yinyang](#)

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Religion and Science in Islam I: Technical and Practical Aspects

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In Islam, as in no other religion in human history, the performance of various aspects of religious ritual has been assisted by scientific procedures. The organization of the lunar calendar, the regulation of the astronomically defined times of prayer, and the determination of the sacred direction toward the Ka'ba in Mecca are topics of traditional Islamic science still of concern to Muslims today, and each has a history going back close to 1,400 years. But the techniques advocated by the scientists of medieval Islam on the one hand and by the scholars of religious law on the other were quite different, and our present knowledge of them is based mainly on research conducted during the past 30 years on one small fraction of the vast literary heritage of the Muslim peoples. To understand Muslim activity in this domain we must realize that there were two main traditions of astronomy in the Islamic Near East, folk astronomy and mathematical astronomy.

The Regulation of the Lunar Calendar

The Islamic calendar is strictly lunar. The beginnings and ends of the lunar months, in particular of the holy month of Ramadan, and various festivals throughout the 12-month "year," are regulated by the first appearance of the lunar crescent. Since 12 lunar months add up to about 354 days, the 12-month cycles of the Islamic calendar begin some 11 days earlier each year, and the individual months move forward through the seasons.

For scholars of the sacred law, the month began with the first sighting of the crescent moon. This observation is a relatively simple affair, provided that one knows roughly where and when to look and the western sky is clear. Witnesses with exceptional eyesight were sent to locations that offered a clear view of the western horizon, and their sighting of the crescent determined the beginning of the month; otherwise they would repeat the process the next day. If the sky was cloudy, the calendar would be regulated by assuming a fixed number of days for the month just completed. Also, the crescent might be seen in one locality and not in another. Unfortunately the historical sources contain very little information on the actual practice of regulating the calendar.

Medieval astronomers, on the other hand, knew that the determination of the possibility of sighting on a given day was a complicated mathematical problem, involving knowledge of the positions of the sun and moon relative to each other and to the local horizon. The crescent will be seen after sunset on a given evening at the beginning of a lunar month if it is far enough away from the sun, and if it is high enough above the horizon not to be overpowered by the background sky glow. Conditions required to assure crescent visibility on most occasions can be determined by observations, but the formulation of a definitive set of conditions has defied even modern astronomers. The positions of the sun and moon must be investigated to see whether the assumed visibility conditions are satisfied, but, even if they are, the most ardent astronomer can be denied the excitement of sighting the crescent at the predicted time if clouds or haze on the western horizon restrict his view.

The earliest Muslim astronomers adopted a lunar visibility condition which they found in Indian sources. It was necessary to calculate the positions of the sun and moon from tables and then to calculate the difference in setting times over the local horizon. If the latter was 48 min or more, the crescent would be seen; if it was less, the crescent would not be seen. In the early ninth century the astronomer ► [al-Khwārizmī](#) compiled a table showing the minimum distances

between the sun and moon (measured on the ecliptic) to ensure crescent visibility throughout the year, based on this condition and computed specifically for the latitude of Baghdad. During the following centuries Muslim astronomers not only derived far more complicated conditions for visibility determinations but also compiled highly sophisticated tables to facilitate their computations. Some of the leading Muslim astronomers proposed conditions involving three different quantities, such as the apparent angular separation of the sun and moon, the difference in their setting times over the local horizon, and the apparent lunar velocity. Annual ephemerides or almanacs gave information about the possibility of sighting at the beginning of each month.

The Regulation of the Five Daily Prayers

The times of the five daily prayers in Islam are defined in terms of astronomical phenomena dependent upon the position of the sun in the sky. More specifically, the times of daylight prayers are defined in terms of shadows, and those of night prayers in terms of twilight phenomena. They therefore vary with terrestrial latitude, and unless measured with respect to a local meridian, also with terrestrial longitude.

Because the months begin when the new moon is seen for the first time shortly after sunset, the Islamic day is considered to begin at sunset. Each of the five prayers may be performed during a specified interval of time, and the earlier during the interval the prayer is performed, the better. The day begins with the *maghrib* or sunset prayer. The second prayer is the *ishā'* or evening prayer, which begins at nightfall. The third is the *fajr* or dawn prayer, which begins at daybreak. The fourth is the *Zuhr* or noon prayer, which begins shortly after astronomical midday when the sun has crossed the meridian. The fifth is the *ʿaṣr* or afternoon prayer, which begins when the shadow of any object has increased beyond its midday minimum by an amount equal to the length of the object casting the shadow. In some medieval circles, the *Zuhr* prayer began when the

shadow increase was one-quarter of the length of the object, and the *ʿaṣr* prayer continued until the shadow increase was twice the length of the object.

In the first few decades of Islam, the times of prayer were regulated by observation of shadow lengths by day and of twilight phenomena in the evening and early morning. Precisely how either the daylight or the nighttime prayers were regulated is unfortunately not clear from the available historical sources. Muezzins who performed the call to prayer from the minarets of mosques were chosen for their piety and the excellence of their voices, but their technical knowledge was limited.

On the other hand, the determination of the precise moments (expressed in hours and minutes, local time) when the prayers should begin, according to the standard definitions, required complicated mathematical procedures in spherical astronomy, that is, the study of problems associated with the apparent daily rotation of the celestial sphere. Accurate as well as approximate formulae for reckoning time of day or night from solar or stellar altitudes were available to Muslim scholars from Indian sources and these were improved and simplified by Muslim astronomers. Certain individual astronomers from the ninth century onward applied themselves to the calculation of tables for facilitating the determination of the prayer times. The earliest known prayer-tables were prepared in the ninth century by ► [al-Khwārizmī](#) for the latitude of Baghdad. The first tables for finding the time of day from the solar altitude or the time of night from the altitudes of certain prominent fixed stars appeared in Baghdad in the ninth and tenth centuries. The extent to which these tables deriving from mathematical procedures were used before the thirteenth century is unknown. The earliest examples are contained in technical works which must have had fairly limited circulation; the muezzins certainly had no need of them. Only a professional astronomer could use the tables, together with some kind of observational instrument for measuring the sun's altitude and reckoning the passage of time.

It was not until the thirteenth century that the institution of the *muwaqqit* appeared in mosques and madrasas. These professional astronomers associated with a religious institution not only regulated the prayer times, but constructed instruments, wrote treatises on spherical astronomy, and gave instruction to students. In thirteenth-century Cairo, new tables were available, and these set the tone for astronomical timekeeping all over the Islamic world in the centuries that followed. In medieval Cairo there was a corpus of some 200 pages of tables available for timekeeping by the sun and for regulating the times of prayer; in numerous copies the tables are associated with Ibn Yūnus.

Impressive innovations in astronomical timekeeping were made in other medieval cities, especially Damascus, Tunis, and Taiz, although by the sixteenth century Istanbul had become the main center of this activity. Highly sophisticated tables of special trigonometric functions were compiled to solve problems of spherical astronomy for any latitude. Tables for finding the time of day from the solar altitude at any time of year were compiled for Cairo, as we have mentioned, and also for Damascus, Tunis, Taiz, Jerusalem, Maragha, Mecca, Edirne, and Istanbul. Medieval tables for regulating the times of prayer have been found for a series of localities between Fez in Morocco and Yarkand in China. Such tables have a history spanning the millennium from the ninth century to the nineteenth.

Astronomical tables for regulating the prayer times had to be used together with instruments; only in this way could one ascertain that the time advocated in the table had actually arrived. The most popular of these instruments were the astrolabe and the quadrant. Hundreds of Islamic astrolabes and several dozen quadrants are preserved in the museums of the world, only a small fraction of the instruments actually made by Muslim astronomers. An alternative means of regulating the daytime prayers was available to the Muslims in the form of the sundial. Many mosque sundials from the later period of Islamic astronomy survive to this day, though most are now nonfunctional.

The Determination of the Sacred Direction

The Ka 'ba in Mecca was adopted as the focal point of the new religion since the *Qur'ān* advocates prayer toward it. For Muslims it is a physical pointer to the presence of God. Thus since the early seventh century Muslims have faced the Sacred Ka 'ba in Mecca during their prayers. Mosques are built with the prayer-wall facing the Ka 'ba, the direction being indicated by a *mihrāb* or prayer-niche. In addition, certain ritual acts such as reciting the *Qur'ān*, announcing the call to prayer, and slaughtering animals for food, are to be performed facing the Ka 'ba. Also Muslim graves and tombs were laid out so that the body would lie on its side and face the Ka 'ba. (Modern burial practice is slightly different but still Mecca-oriented). Thus the direction of the Ka 'ba – called *qibla* in Arabic and all other languages of the Islamic commonwealth – is of prime importance in the life of every Muslim.

During the first two centuries of Islam, when mosques were being built from Andalusia to Central Asia, the Muslims had no truly scientific means of finding the qibla. Clearly they knew roughly the direction they had taken to reach wherever they were, and the direction of the road on which pilgrims left for Mecca could be, and, in some cases, actually was used as a qibla. But they also followed two basic procedures, observing tradition and developing a simple expedient. In the first case, some authorities observed that the Prophet Muḥammad when he was in Medina (north of Mecca) had prayed due south, and they advocated the general adoption of this direction for the qibla. This explains why many early mosques from Andalusia to Central Asia face south. Other authorities said that the Quranic verse quoted above meant standing precisely so that one faced the Ka 'ba. Now the Muslims of Meccan origin knew that when they were standing in front of the walls or corners of the Ka 'ba they were facing directions specifically associated with the risings and settings of the sun and certain fixed stars. They knew that the major axis of the rectangular base of the edifice points

toward the rising point of Canopus, and the minor axis points toward summer sunrise and winter sunset. These assertions about the Ka 'ba's astronomical alignments, found in newly discovered medieval sources, have been confirmed by modern measurements.

In addition Arabic folklore associates the sides of the Ka 'ba with the winds and rain. These features and associations cast new light on the origin of the edifice, and in a sense confirm the Muslim legend that the Ka 'ba was built in the style of a celestial counterpart called *al-bayt al-ma' mūr*: indeed it seems to have been an architectural model of a pre-Islamic Arab cosmology in which astronomical and meteorological phenomena are represented. The religious association was achieved first by a number of statues of the gods of the pagan Arabs which were housed inside it. With the advent of Islam, these were removed, and the edifice has for close to 1,400 years served for Muslims as a physical focus of their worship.

The corners of the Ka 'ba were associated even in pre-Islamic times with the four main regions of the surrounding world: Syria, Iraq, the Yemen, and "the West." Some Muslim authorities said that to face the Ka 'ba from Iraq, for example, one should stand in the same direction as if one were standing right in front of the north eastern wall of the Ka 'ba. Thus the first Muslims in Iraq built their mosques with the prayer-walls toward winter sunset because they wanted the mosques to face the north eastern wall of the Ka 'ba. Likewise the first mosques in Egypt were built with their prayer-walls facing winter sunrise so that the prayer-wall was "parallel" to the north western wall of the Ka 'ba. Inevitably there were differences of opinion, and different directions were favored by particular groups. Indeed, in each major region of the Islamic world, there was a whole palette of directions used for the qibla. Only rarely do the orientations of medieval mosques correspond to the qiblas derived by computation. Recently some medieval texts have been identified which deal with the problem of the qibla in Andalusia, the Maghrib, Egypt, Iraq and Iran,

and Central Asia. Their study has done much to clarify the orientation of mosques in these areas. In order that prayer in any reasonable direction be considered valid, some legal texts assert that while facing the *actual* direction of the Ka 'ba (' *ayn*) is optimal, facing the *general* direction of the Ka 'ba (*jiha*) is also legally acceptable.

In various texts on folk astronomy, popular encyclopedias, and legal treatises, we find the notion of the world divided into sectors about the Ka 'ba, with the qibla in each sector having an astronomically defined direction. Some 20 different schemes have been discovered recently in the manuscript sources, attesting to a sophisticated tradition of sacred geography in Islam.

The earliest schemes of Islamic sacred geography date from the ninth century, but the main contributor to its development was a Yemeni legal scholar named Ibn Surāqa, who studied in Basra about the year 1000. Ibn Surāqa devised three different schemes of sacred geography, with the world arranged in 8, 11, and 12 sectors around the Ka 'ba. Each sector of the world faces a particular section of the perimeter of the Ka 'ba. Simpler versions of his 12-sector scheme occur in such popular geographical works as the *Taqwīm al-buldān* of Yāqūt al-Rūmī (ca. 1200) and the *Āthār al-bilād* of al-Qazwīnī (ca. 1250) as well as the encyclopedia *Ṣubḥ al-a' shā* of al-Qalqashandī (ca. 1400). From the fifteenth century to the nineteenth, we find a proliferation of schemes with different numbers of divisions between 8 and 72 divisions of the world around the Ka 'ba.

Muslim astronomers from the eighth century onward concerned themselves with the determination of the qibla as a problem of mathematical geography. This activity involved the measurement of geographical coordinates and the computation of the direction of one locality from another by procedures of geometry or trigonometry. The qibla at any locality was defined as the direction of Mecca along the great-circle on the terrestrial sphere.

Muslims inherited the Greek tradition of mathematical geography, together with Ptolemy's lists of localities and their latitudes

and longitudes. By the early ninth century observations were conducted in order to measure the coordinates of Mecca and Baghdad as accurately as possible, with the express intention of computing the qibla at Baghdad. Indeed, the need to determine the qibla in different localities inspired much of the most sophisticated activity of the Muslim geographers (see below).

Once the geographical data are available, a mathematical procedure is necessary to determine the qibla. The earliest Muslim astronomers who considered this problem developed a series of approximate solutions, all adequate for most practical purposes, but in the early ninth century, if not before, an accurate solution by solid trigonometry was formulated. The accurate formulae derived by the Muslim astronomers from the ninth century onward are impressive, and are mathematically equivalent to the modern formula. Muslim astronomers also compiled a series of tables displaying the qibla for each degree of latitude and longitude difference from Mecca, based on both approximate and exact formulae, the first of these being prepared in Baghdad in the ninth century.

Over the centuries, numerous Muslim scientists discussed the qibla problem, presenting solutions by spherical trigonometry, or reducing the three-dimensional situation to two dimensions and solving it by geometry or plane trigonometry. They also formulated solutions using calculating devices. But one of the finest medieval mathematical solutions to the qibla problem was reached in fourteenth-century Damascus: a table by al-Khalīlī displays the qibla for each degree of latitude from 10 to 56° and each degree of longitude from 1 to 60° east or west of Mecca, with entries correctly computed according to the accurate formula. This splendid table (rediscovered only in the early 1970s) was not widely known in later Muslim scientific circles. *Muwaqqits* of later centuries wrote treatises about the determination of the qibla but did not mention this Syrian table. By the fourteenth century the correct values of the qibla of each major city had long been established (correct, that is, for the medieval coordinates used in the calculations). Simple

qibla-indicators fitted with a magnetic compass and a gazetteer of localities and qiblas became common, and the modern variety represents a continuation of this tradition.

Some of the most important Muslim contributions to mathematical geography are to be found in a series of treatises by the early eleventh-century scientist ► [al-Bīrūnī](#). In one treatise he set out to determine for his patron the qibla at Ghazna (in what is now Afghanistan), first establishing the necessary geographical coordinates and then calculating the qibla by different procedures. Since 1989 three Persian qibla-indicators, made in Isfahan about 1675, have become available for study. They bear a cartographic grid so devised that one can read the direction and distance to Mecca directly. Mecca is at the center of the grid and one has only to lay the diametrical rule over any city marked on the map (between Spain and China, Europe and the Yemen) to read off the qibla on a circular scale around the grid and the distance on the diametrical rule. The origin of this remarkable device is still under investigation; but the underlying mathematics is described in two treatises on conic sections, one from tenth-century Baghdad and the other from eleventh-century Isfahan. The tradition behind the Isfahan world maps represents the most sophisticated contribution to mathematical geography known between Antiquity and the Renaissance.

The alignment of medieval mosques reflects the fact that the astronomers were not always consulted on their orientation. But now that we know from textual sources which directions were used as a qibla in each major locality, we cannot only better understand the mosque orientations but also recognize numerous cities in the Islamic world that can be said to be qibla-oriented. In some, such as Taza in Morocco and Khiva in Central Asia, the orientation of the main mosque dominates the orientation of the entire city. In the case of Cairo various parts of the city and its suburbs are oriented in three different qiblas. The new Fatimid city of al-Qāhira, founded in the tenth century, faces winter sunset, which was the qibla of the Companions of the Prophet who

erected the first mosque in Egypt in nearby Fustat some three centuries previously. The later Mamluk "City of the Dead" faces the qibla of the astronomers. The predominant orientation of architecture in the suburb of al-Qarāfa is toward the south, another popular qibla. The splendid Mamluk mosques and madrasas built along the main thoroughfare of the old Fatimid city are aligned externally with the street plan, and internally with the qibla of the astronomers: one can observe the varying thickness of the walls when standing in front of the windows inside the mosque overlooking the street outside. This is an area of the history of urban development in the Islamic world which has only recently been studied for the first time, not least because, prior to the discovery of the textual evidence, it was by no means clear which directions were used as qiblas; even if a qibla at variance from the true qibla was clearly popular, it was not known why. The first accurate longitude values of localities in the Islamic world become available only with the systematic scientific cartographic surveys of the eighteenth and nineteenth centuries. Thus most of the accurately computed qiblas of the medieval astronomers could be judged as being in error by a few degrees anyway.

Other Applications of Science to Daily Life

The Islamic laws of inheritance, based on prescriptions in the *Qurʾān*, are complicated, and their application involves some skill in arithmetic. Both legal scholars and certain mathematicians wrote on this subject, but only two or three simple works by legalists have been studied and until recently no research of consequence had been conducted on the large number of available sources. There is also a vast corpus of literature on weights, measures, and arithmetical techniques.

Muslims also developed geometric designs for the decoration of religious architecture and also secular artifacts. The acceptability of such ornamentation is discussed by various legal scholars,

but their writings have yet to be properly studied. Only two Muslim mathematicians are known to have included remarks on geometric design in their writings, a fact which confirms the suspicion that this was an art passed down amongst the practitioners. Some years ago a manuscript of an artisan's manual with guidelines for generating numerous patterns is now published.

The legal scholars of medieval Islam used methods for regulating the calendar and prayer times and for finding the sacred direction which were simple and adequate for practical purposes. Their ingenuity in coping with differences of opinion never lost sight of the basic purpose of Quranic and Prophetic injunctions. Some of the greatest of the Muslim scientists dealt with the calendar, prayer times, and the qibla, and in these areas, as in others, their mathematical creativity and their quest for greater accuracy was impressive. In later centuries (after the thirteenth), competent astronomers were appointed to the staffs of major mosques in order to advise on these specific subjects. But the solutions developed by Muslim scientists were invariably too complicated for widespread application in the medieval milieu. Although the scholars of the sacred law and the scientists proposed different solutions for the same individual problem, there are few records of serious discord between the two groups in the medieval sources. The legal scholars criticized mathematical astronomy mainly insofar as it was used by some as the handmaiden of astrology, which was an anathema to them. The scientists seldom spoke out against the simple procedures adopted by the legal scholars.

See Also

- [al-Bīrūnī](#)
- [Al-Khalīlī](#)
- [al-Khwārizmī](#)
- [Astrolabe](#)
- [Astronomy](#)
- [Calendars in Islam](#)
- [Geometry](#)

- [Ibn Yūnus](#)
- [Maps and Mapmaking: Islamic Terrestrial Maps](#)
- [Ottoman Science](#)
- [Qibla and Islamic Prayer Times](#)
- [Quadrant](#)
- [Weights and Measures in Islam](#)

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Religion and Science in Islam II: What Scientists Said About Religion and What Islam Said About Science

Anton M. Heinen

The interaction between religious life and scientific enterprise in the culture that evolved under the impact of Islam is one of the predominating themes in today's discussions and writings of Muslims all over the world. It has continued to be such ever since the beginning of the last century, when European forces, with their newly developed technological means, extended their rule over large areas with Muslim populations until then concerned only with the traditional values of their preindustrial communities. Today's revivalist Muslim leaders, themselves often engineers or trained scientists and not theologians, fight for a new society based on a harmonious practice of Islam and science. Or governments build mosques with technological showpieces (e.g., minarets with laser beams as indicators of the *qibla*, the direction of Mecca, as recently in Morocco), and museums and universities dedicated to the "Islamic sciences". The scientific achievements of the West are considered to be the inheritance of great Muslim sages of the Middle Ages. Thus modern technology cannot be a dangerous evil because it belonged to the Muslims first. But it has been alienated by the West, truncated from its heart, which is the recognition of Allāh, the Creator of all beings. This was the view of the influential leader of the Muslim Brothers, Sayyid Qutb (1906–1966). Although he was executed under Nasser's government in Egypt in 1966, his brief sermon on *This Faith, Islam* is still representative of some sections of opinion in the Muslim community.

Observers from the outside world, where the dispute between religion and science has largely turned into a relic of the past, if it does not lead into ethical discussions about the effects of

scientific and technological progress on human values, find it difficult to do justice to this preoccupation of their Muslim neighbors, which they usually interpret in analogy to apparently similar ideologies in their own realm, such as fundamentalism in America's "Bible Belt". However, the religious as well as the scientific realities involved differ greatly on both sides. Instead, the insights of the history of science as well as that of religion should be drawn upon when the relationship between the two fields is to be treated objectively. As the history of science has brought to light a whole spectrum of changing methods and conceptualizations that over the centuries have been interpreted as "science", so also "religion" has been described by its historians as being practiced variously by just about every people, culture, time, or even individual. Generalizations about the religious factor in human activities, in the West always identified with dogmatic teachings, are just as false as those about an unhistorically monolithic science, but even more widespread. The surprisingly bitter reaction to the attack of some European powers and individuals will be more readily understood if the interaction of science and Islamic religion, from the outset centered on increasing knowledge, is rightly appreciated.

The case of scientific technology probably was chosen as a favored battlefield because the Western critics, proudly flying the flag of enlightenment, had previously used it as a weapon against the Islamic religion. Thus, cultural and technological backwardness became a religious issue for Muslim intellectuals. Curiously enough, it was the philosophical and scientific work of Ibn Rushd (Latin Averroes, 1126–1198), who as "the Commentator" (namely of Aristotle) had been accepted as master by the European scholars throughout the Middle Ages, which stood in the center of this modern attack on Islam. That he had not been able to influence his co-religionists in the Islamic world to the same extent as the Jewish and Christian schoolmen in Europe was the main reason that Islam in the last century was made responsible for the worst obstruction against scientific progress. The main exponent for this attack was Ernest Renan's *L'Islam et la science*,

written in 1883; the Arabic writings of Farah Anṭūn in the journal *Al-Jāmi'a* (Cairo, 1902–1903), easily accessible for Egyptian intellectuals, made this attack on Islam even more effective. From then on, the relationship between science and religion, both seen in the crystallized and almost ahistorical notions of that time, was turned into the most crucial question for any global view of Islam in human history. The question was raised on more general grounds: "Why did the Muslims fall back, while the others made progress?" The more general and fundamental questions have stood in the foreground; the more particular ones, e.g., the Islamic position *vis-à-vis* alchemy, astrology, geocentric vs. heliocentric astronomy, or such consequential medical questions as anatomical dissections, preventive measures against epidemics, abortion, birth control, etc., have been strangely pushed into the background, although numerous treatises over the centuries have been written on them.

In defense, the beginnings of the spread of scientific activity in Islamic culture, and then its high period, were chiefly taken for reference, not the obvious stagnation in the later Middle Ages. The latter phenomenon has hardly been studied, and almost no convincing explanations have ever been proposed. But it is revealing that no responsibility for such an intrusion into scientific development has been assigned to the Islamic religious authorities, as has been the case of the Inquisition trials in Christian countries.

But, in confrontation with medieval historians centered on Europe, it was not easy to reclaim the scientific heritage for the Muslims, for this heritage was primarily seen as that of the ancient Greeks whose works had been translated into Arabic. And since these works, some centuries later, were again translated from Arabic into Latin, the Arabs apparently were assigned the humble role of transmitters only, like the merchants in an import and export business. For Renan, the cultural role of Islam was actually limited to the preservation of ancient culture for and transmission to Europe, where it would be revived. That such translations from pre-Islamic Hellenistic culture involved a heavy indebtedness was not denied by Arab historians. However,

in their view this ancient heritage was integrated into an already established Islamic society. As it is today, with more sources to judge by, the roots of the scientific movement in Islam itself are more generally recognized as having exerted a stimulating influence on the introduction of the more complete scientific heritage of pre-Islamic cultures: the *Qur'ān* and its exegesis, jurisprudence, philology, etc.

The first line of defense was taken up by such rationalist reformers as Shaykh Muḥammad 'Abduh (1849–1905). He argued that Quranic religion was in no way opposed to, but on the contrary totally in harmony with science. The guidelines of his argument were taken from the apologetic discussions about the necessity of miracles as testimonials for the true prophet: miracles supposedly revealed the divine nature of Jesus, the Son of God, while the Prophet Muḥammad had only referred to the factual evidence of the Arabic *Qur'ān* in support of his divine message. (Miracles like the splitting of the Moon by the Prophet, as they were described in popular literature, were apparently not considered in this argumentation of modernist theology.) That the fact of revelation, divine speech entering the limits of creation, or the *Qur'ān* as an inimitable revealed book, were proposed by the Prophet as the decisive miracle, or that creation and recreation after death were described as miracles permeating the whole of human existence, all these truly “miraculous” events apparently were not considered to interfere with the course of nature.

Unfortunately, 'Abduh's apologetic argumentation was later exaggerated by his disciple Rashīd Riḍā (1865–1935) who claimed science for Islam. In his commentary of the revealed book, all knowledge was traced to the *Qur'ān*, even modern technological and medical inventions. For example, the Arabic *Jinn* were identified with the microbes of contemporary medicine. But progress soon let such hasty identifications appear outdated, and today this unhealthy spirit of “Islamization” is much less prevalent.

More common, and truer to the revealed Quranic texts, is the derivation of an original

Muslim science from the so-called “sign-verses,” i.e., those verses that prescribe the inquiry into such signs in creation as the sun, moon, stars, earth, and sea, life in all its forms, in fact whatever enters the realm of human experience. Corresponding texts can be found in the works of Muslim scientists throughout Islamic history, in the *Taḥdīd nihāyāt al-amākin* (The Determination of the Coordinates of Positions for the Correction of Distances Between Cities) of the mathematician and astronomer ► [al-Bīrūnī](#) (973–1051), in the *Faṣl al-maqāl* (On the Harmony of Religion and Philosophy) of the philosopher Ibn Rushd (1126–1198), or the interviews of the living Nobel prize winner Abdus Salam. Such an inquiry, as should be noted against a frequent misunderstanding of Western scholars, was not to lead to higher developed proofs for the existence of God, for it would be contrary to the faith of Islam that such proofs should be needed. But Muslims of all times have interpreted the Quranic counsels of “considering the wonders of creation” as the most effective promotion of scientific research. The results were not predetermined; not even the existence of the Creator was imposed as the logical consequence of a binding argument. But the faithful scientist was to find himself placed in the more overwhelming presence of a personally approachable God Almighty. The inner spiritual motivations for an Islamic science, not the passing discoveries, were of the greatest significance.

How far along the way of an open and progressive science a Muslim scholar could be led by the sign-passages of the *Qur'ān* is best illustrated by Ibn Rushd's treatise *Faṣl al-maqāl*. Even though he was a high functionary of Islamic law at the court of the strict Almohad administration, Ibn Rushd wrote this work as a legal defense of objective and universalist scholarship. Beginning from the Quranic injunctions to respond with thought and inquiry to the wonders of creation, he gradually moved on to the defense of gradual progress beyond incomplete scientific results, relying in the process on the heritage of pre- and non-Islamic sages. Hence, the great lawyer could even accept preliminary results, teachings known to include errors. To tolerate such partially

erroneous theories, while always proceeding toward deeper insights, was for him a basic consequence of the human condition. While not denying prophetic revelation as the source of the Islamic religious movement, Ibn Rushd with this open system may be said to have reached the highest peak of the Islamic scientific worldview.

It cannot be surprising that natural research on the background of the Quranic finding of the Creator, whose inner nature is above all human speculation, in the signs he had placed for humanity into his creation, has sometimes been understood along Pantheistic lines. Knowledge did seem to acquire a higher character for salvation, or even a certain participation in the unitarian nature of the One God. Influential theologians like al-Ghazālī (1058–1111), but also leading scientists up to Abdus Salam in present times, insisted on Allāh's personal nature as Creator. Scientific disciplines, therefore, were to be used only for specific human purposes, and no one but God himself granted his highest blissful knowledge to the faithful who had clung to the fulfillment of his revealed will. Since God himself as Creator was also the author of all instruction, the growth of knowledge and the production of new inventions were not really possible for man restricted to his own created capacities.

But, as heir to a tradition of scholars who already had worked at filling a still Hellenistic science with Islamic spirit, al-Ghazālī also proposed the method of *Tafakkur*, a kind of meditation on the various phenomena of creation, which could lead to greater insights and more extensive knowledge, under the constant guidance of the Almighty. Such a method may have been at the root of the widespread mysticism of nature in Islam. As S. H. Nasr has observed, some of the greatest scientists in Islam (e.g., Quṭb al-Dīn ► al-Shīrāzī, AD 1236–1311) are known to have practiced Sūfism as well. But *Tafakkur* also presents a corrective for the unitarian view of Islamic science described above, Muslim thinkers asserted God's unity in all spheres of reality, thus reducing the multiplicity of created phenomena into a forced monism. The contrary can also be said, because by always keeping the spiritual goal of *ta'ẓīm Allāh* (Magnification of

God) in mind, the Muslim researcher, instead of closing it, would instead turn more and more leaves of Allāh's grand book of nature. The linguistic particularity of the Arabic language, always concentrating on individuality (*shawādh*), naturally could enforce this tendency.

It has become a standard argument that Islam needed such sciences as astronomy, mathematics, and geography for ritual obligations like the pilgrimage to Mecca, the establishment of the *qibla* (direction to Mecca) of new mosques, or even any prayer according to the traditional prescriptions. But some scholars feel this point should not be overstressed: even a legal authority like Abū Hanīfa (d. 767) warned that spatial orientation was not essential for the submission of the worshipper to the Creator, and numerous religious leaders maintained a quite relaxed attitude when confronted with greater mathematical exactness in the setting of the *qibla*. On the other hand, quite simple devices were sufficient for these needs. The number of treatises on the mathematical problems of the *qibla* are not necessarily in proportion to its importance for the Muslim community.

Of greater significance, and easily demonstrable, is the promotion of mathematical works by the theological principles of Islamic law. As the mathematician and astronomer in the Biblical tradition was encouraged by the saying that God had created the whole world with numbers (Wisdom 11,20), so the Muslim was convinced that the divine lawgiver had left nothing to the arbitrary decisions of sinful mankind, not even the shares of inheritance to be distributed among the members of a family: "...the male shall receive the portion of two females..." (Sūra 4, 175 ff). The natural consequence was the discovery and perfecting of algebraic rules which future lawyers had to learn for the administration of bequests; in other words, some mathematical instruction even entered legal schools usually blamed for having marginalized the rational and natural sciences. There it achieved full recognition as the respectable "science of shares" (*ilm al-farā'id*).

The most characteristic and generally applied argument in support of orthodoxy and

orthopraxis in Islamic intellectual history has certainly been the principle of *Sunna*. With carefully examined traditional reports it had to be established that questionable teachings or practices were sanctioned by words or actions/omissions of the Prophet himself or his Companions, or, in the case of Shiite Islam, the Imams. As this had already been done for the concepts and arguments of the theologians and jurists, the procedure did not stop at science, where it would seem to have been singularly inappropriate. Thus one of the most copied treatises of the Middle Ages, an indicator of its popularity, was the *al-Hay'a al-sanīya fī al-hay'a al-sunnīya* by al-Suyūṭī (1445–1505), a cosmographical work totally made up of well-attested traditional fragments of early theories.

The apparently simplistic view that truth can only be what has been taught or practiced by respected members of the Muslim community, testified to by an interrupted chain of trustworthy witnesses, may have been grounded in the deeper conviction that all values are sanctioned by the harmony with the laws of a well-established community. Scientific progress cannot be judged good and sane if it does not fit into the proven structures of a justice-oriented society or a healthy environment. In Islam this social order and the harmony with a God-created nature are directly derived from religion; hence, their demands on the work of the scientists belong to the religious, not the ethical or secular, realm.

Jurisprudence, no doubt, has been the most important discipline in the intellectual formation of the Muslims throughout their history. Some historians, considering the numerical superiority of law teachers and their students at the colleges and universities in Muslim lands, have blamed the lawyers for having pushed the sciences to the margins of academic institutions. On the other hand, hardly any other religious community has been so deeply formed by the ideal of realizing all its vital functions according to the principles of justice. The work of the scientists has not remained unaffected by this ideal. Thus long before Simon Stevin in his *Weeghconst* (Theoretical Statics, 1586) prepared the “democratization of science”, which eventually gave it a

special measure of vitality in Western nations, his Arab predecessor ► [al-Khāzinī](#) (fl. first half of the thirteenth century) had published in the *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom) a remarkable memorandum on science's being rooted in an all-encompassing justice. This is, however, an aspect of the interaction of science and faith in Islam which has hardly been studied, in spite of its significance for the appropriation of technology by widely spread popular organizations, guilds, and Sūfī brotherhoods, or the stagnation up to modern times.

See Also

- [al-Khāzinī](#)
- [al-Suyūṭī](#)
- [Hay'a](#)
- [Ibn Rushd \(Averroës\)](#)
- [Religion and Science in Islam I: Technical and Practical Aspects](#)
- [Science as a Western Phenomenon](#)
- [Qibla and Islamic Prayer Times](#)

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Religion and Science in the Native Americas

Åke Hultkrantz

If science may be said to be concerned with "observation, description, definition, classification, measurement, experimentation, generalization, explanation, prediction, evaluation, and control of the world," as it is in the *International Encyclopedia of the Social Sciences*, it is easy to conclude that all these practices have occurred among American Indians, mostly within a religious and mythological perspective. Some scholars presuppose that American Indians have lived in a natural-supernatural continuum where the distinction between this and the other world (however we care to define it) practically falls down. Others, including this author, are under the impression that the indigenous people postulated two experimental worlds, the natural world around them in everyday life, and the mysterious world of myth and religion which occasionally breaks into the natural world, for instance in dreams and rituals. In the long run this mysterious (supernatural) world seems to constitute the real, true world; at least some religious Native thinkers believe this is the case. It is not impossible that many Indian visionaries believed this without verbalizing their beliefs.

In any case, Indian observations and explanations have, in their own thinking, been linked to

religious evaluations. Everyday reality was mostly experienced from a profane point of view where experiences followed each other in a foreseen way. Where this was not the case, or uncertain courses of events and unknown places are met, the other dimension is resorted to. Since the latter dimension is the most difficult to understand, and rules humankind's life, the interpreters of that world, medicine men, shamans and priests, and artisans that catch symbols and spiritual realities, are more important than experts on the everyday world. We can state that in Native America the range of spiritual experts has been much wider than that of technological experts.

The anthropologist Paul Radin has shown that there exists what he calls "two general types of temperament" among, in particular, American Indians: "the man of action and the thinker, the type which lives fairly exclusively on what might be called a motor level and the type that demands explanations and derives pleasure from some form of speculative thinking." It is characteristic that in order to describe the thinkers and their accomplishments he turns to the specialists on religion (and then a bit arbitrarily joins "historians," i.e., mythological raconteurs, with such specialists of experimental religion as medicine men and shamans). American Indians are on the whole not skeptics, since dreams, hallucinations, and traditions of visits to the other world by eminent spiritualists give strength to their religious beliefs. Collective rituals give these beliefs a realistic stamp. Only when different religions collide and a relativism of values ensues do religious brooding, skepticism, and indifference take over. There is thus little space for other than religiomythical incitements in penetrating the marginal recesses of the empirical world.

The dominance of religious thinking in what science today would call secular matters is obvious in the fields of cosmology and medicine. There are two great world pictures in America. One is certainly the older one, with Paleolithic-Mesolithic origins and connections with the hunting tribes in the Old World. It depicts a Universe where the world pillar or the world tree forms the axis which connects heaven and earth. It is often said that this pole or tree is situated in the middle

of the world; its roots are fixed in the underworld and nourished by subterranean rivers or a well. Its top reaches the sky that rests on it. Sometimes the world column stretches through several skies until it reaches the highest sky. Symbols of the different species of animals living on different levels are supposed to dwell on the tree: lowest down snakes or fishes, on the earth level deer and buffalo, highest up birds like eagles and falcons. Some tribes relate that unborn souls inhabit the crown of the world tree. Other tribes believe that the world tree, that often has a forked top, is identical to the Milky Way which is "the backbone of the sky" and the road taken by the souls to the hereafter. The world has also formed the passageway downward for the gods when they cared to visit the ground and upward for the shamans when in their séances their souls went to the supernatural world to receive information of the gods (and, in some cases, to release a diseased person's captured soul from the realm of the dead). The world tree is ritually modeled in the middle pole of ceremonial structures, such as the Plains Indian Sun Dance hall, which is itself a ritual reproduction of the cosmos. The Sun Dance ceremony is a repetition of the cosmic creation.

The world tree expresses an inclination for a heavenly world. American high culture supplants the tree or pillar symbol with a temple mound, mostly a pyramid. On the top of this pyramid the gods have their habitats (read: statues), and many pyramids enclose the bodies of deceased princes. The sacred temple areas in Mexican pre-Columbian cities are modeled after the supposed heavenly geography.

The other world picture which has been distributed in agricultural areas has its parallels in the agrarian civilizations of the Old World. In this case the attention on the supernatural world is, at least partly, directed downward, to the underworld. Here is the place from which man, like the plants, once in mythic time came up, often climbing on a reed. Myths even talk of four successive underworlds, one darker than the other, or qualified through different colors. Inundating waters or other difficulties started the evacuation. Myths tell us that valuable animals, like the buffalo in North America, also came up from the

nether world. Men and animals appeared from a grotto which ever since has been said to be the center of the world. After death the living beings returned to the underworld, like the plant returns to it when it withers. The underworld realm of the dead is mostly the place to which shamans send out their soul to retrieve the lost soul of a sick patient. Some divinities, be it the lord-lady of the dead or the spirits of vegetation, may be found in the underworld.

These world pictures are supposed to be stable, as when the Lenape (Delaware Indian) Supreme Being with his hand holds the upper part of the world pole. However, in earthquake areas this is not the case. According to anthropologist Lowell J. Bean, the Cahuilla of Southern California believed

that all matter was subject to unpredictable change . . . For example, dramatic changes in topography are vividly and frequently recalled. . . This instability was true from the beginning. Creation of the earth and life itself was fraught with indecision, mistakes, and conflicts of power between the creator brothers.

This is a neat example of how environmental changes are referred to mythical incidents.

Also in another topic, medicine and medical practice, religion outbids what we might consider a more "scientific" approach. Certainly, there is, even behind supernatural gestures, the beginning of a systematic and naturalist treatment of sick persons in a simple hunting milieu. The herbalists who supply herbs, cobwebs, sap, or leaves for wounds, or handle internal medicine for the patient, follow what they have learnt or what their own experiences have taught them. Observation and practice over the years thus guided their use of natural medicine, and today's science of laboratory medicine can sometimes corroborate the positive medical properties of these medicines. If anything the choice of useful medicaments points out the scientific endeavors of American Indians.

However, there are other doctors as well, and their curing is considered more important. Medicine men and shamans invoke supernatural powers in order to deliver the sick from a serious disease (or a disease which they comprehend as

serious). Gods and spirits are then thought to be the active medical powers, and the disease itself may be a demoniac being. In other words, the more serious the disease is, the more frequently supernatural powers have to be invoked. Of course, even simple herbalist methods may be accompanied by religious blessings.

Such a continuum between this world and the other world may, superficially seen, seem to make the distinction between them invalid, but this is not so. American Indians have had recourse to systems which would not satisfy Western logic; their logic is often created from the needs of the situation. In religion, completely reciprocally exclusive belief chains may be resorted to, depending on the situation. In the same manner, Indians may interpret phenomena as derived from this world or the other world, but also, in single cases, see a continuous line between them.

As a further example of such thinking the hierarchy of biological masters may be mentioned. In many places in both Americas animals and plants are supposed to be controlled by masters who rule over them and own them. These masters may be animals of some sort, or supernatural beings. The Mataco in Argentina and Bolivia believe that herbs and trees are subordinated to their "owners," certain animals and birds. Thus, the wild red pepper is owned by the red-eyed dove. The dove in its turn obeys a lord of the forest who is also the lord of honey. We learn that the latter is a supernatural being, whereas the dove is a natural bird. In this connection it should be pointed out that in many places, scholars have observed a folk classification of natural plants and animals. Indian tribes have constructed taxonomies with a series of hierarchical levels. In these cases it seems that only natural species have been segregated. It is another matter when Plains Indian medicine men arrange their guardian spirits, which appear in animal disguise, in an order according to their efficiency: they are ranked as spirits, not as animals, and may be included in a hierarchy. It is a remarkable fact that this hierarchical thinking occurs in societies which are otherwise characterized by their equality.

We have seen how the world picture, or the view of the Universe, is arranged according to religiomythical models in original Native American thought. In addition to what was said above it can be noted that stars and planets are also included in these models. The sun and moon may be understood as divinities or symbols of divinities; the sun is often a manifestation of the Supreme Being, the moon a manifestation of Mother Earth, or the god (goddess) of vegetation. The planets and stars incarnate other supernatural beings, often the culture hero and hunting spirits. The Blackfoot and other tribes tell myths according to which the main actors are transformed into well-known stars when their adventures have finished. Among the Pawnee all dominant gods are stars, the chief one among them being the high god Tirawa who is identified as the North star. Thus, the stars are supposed to be living, spiritual beings, something which is also demonstrated in their movements over the sky. Such a portrait of the star charter is the presupposition of astrology. In the classical antiquity of the Old World some supreme power, or fate, ruled the star movements; in America, the prime movers could be the stars themselves, or some power behind the stars. In both worlds omens and policies were dictated by these powers, and thus what some call a pseudoscience, astrology, took form to find out the nature of these dictates.

Among the high civilizations, such as the Maya of Southern Mexico and Guatemala, parts of the clergy made observations of the sky for astrological purposes. It has been said that in Mesoamerica and South America people tracked the positions of the stars in order to know how they themselves should behave, when they should plant, and when they should perform sacrifices, whereas in North America the signs from the heaven were an aid to good living, not frightening information. This distinction is probably too exaggerated. In North America there was great fear when, during eclipses of the sun or the moon, the celestial body was supposed to be swallowed up by some monster.

Astrology has, all over the world, paved the way for astronomy; this is also true in North and South America. The great annual festivals,

the fertility ceremonies, and other occasions for ritual celebrations could begin when star constellations were favorable. The Tapirape Indians of the Amazonian forest know that when the Pleiades disappear in the west the rainy season is over. The prehistoric northern Plains Indians constructed ► [medicine wheels](#) on mountain tops (or, if there were no mountains in the area, on the open plains) which archeologists and astronomers interpret as calendar monuments, used for the determination of the summer solstice. For instance, the famous Medicine Wheel on the ridge of the Bighorn Mountains in Wyoming has the form of a wheel with a central cairn united with the peripheral stone ring through 28 spokes of stone. Other cairns are situated close to the periphery. From one of the latter cairns one can perceive the sun over the central cairn on Midsummer's Day. There are reasons to assume that the structure also had cultic functions. Its ground plan mirrors the world picture with the world pillar in the middle of the world, as was described earlier. Among other things, the 28 spokes correspond to the 28 roof poles of the Sun Dance lodge. This might also correspond to the 28 lunar mansions in Chinese, Islamic, and Indian astronomy.

In the matter of astronomical calculations the Maya were the masters. In order to arrive at exact computations they developed mathematics, used multiplication tables, and calculated the days of the year. With these means the Maya priest-astronomers managed to bring the Venus cycle into relation with the year, and they were also able to construct a table for predicting solar eclipses (although the latter were not always visible in the Maya area). Such eclipses were considered to be dangerous. The foreknowledge of the times they would appear made it possible for the priests to take action to help the threatened human beings.

Thus it appears that the beginning of science was motivated by its use for religious and ritual purposes. The Maya scholar, Eric Thompson, has this to say about the Maya intellectual achievements:

It is remarkable that the intellectual successes of the Maya were not (from our point of view) practical; they were the outcome of spiritual needs.

The Maya astronomers strove for knowledge, not as an end in itself, but as a means of controlling fate, a kind of astrology. There was, he felt, an orderliness in the heavens to which the gods conformed; once that was learned, he could predict the future through exact knowledge of which gods held sway at any given time, and influence it by knowing when and whom to propitiate.

It is also possible that the Maya writing with its multivalent hieroglyphs was first developed to serve sacerdotal ends. In any case, during the Classic Period, the Maya texts deal with astronomy, the connections between stars and gods, and associated ceremonies.

We could of course argue that there was in aboriginal America an appreciation of knowledge and learning that had no religious causation; but it can be scarcely understood as a scientific ambition. Skills in technology, and inventions (Inca road building, Maya corbelled vaults, Mexican wheel toys, etc.), rarely deserve this designation either. Inuit coast maps are a wonder of precision and may pass for art. Truly profane science was not part of the American Indian world.

See Also

- [Astronomy](#)
- [Eclipses in the Americas](#)
- [Magic and Science](#)
- [Mathematics](#)
- [Medicine in Native North and South America](#)
- [Medicine Wheels](#)

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Reproduction in Japan

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This entry focuses on reproduction, the process by which human generations succeed each other, in Japan during the early modern period. This period is also known as the Tokugawa era that began in 1603 and ended in 1868. Reproduction concerns the number of surviving children, taking into account not only the number of children born to each woman or couple, known to demographers as fertility, but also infant and childhood mortality. In contrast to historical Europe in which births were in general recorded without omission in parish registers, annual local household registers called *ninbetsu-aratame-cho* or *shumon-aratame-cho*, which are the major data sources for demographic studies of Tokugawa Japan, only recorded infants who survived to the first enumeration after birth (Smith, 1977, pp. 59–64; Tsuya & Kurosu, 2010). Since this partial omission of births distorts nearly all conventional fertility measures, when we look at reproduction, we have to consider both fertility and infant mortality due to under-registration.

Although seemingly a data problem, differences in recording births between the historical West and preindustrial Japan reveal different perceptions of what constituted “life” in the context of different reproductive cultures. Because Christianity regards the moment of conception as the beginning of life, intervention in procreation was deemed unacceptable in the historical West (Lee, Wang, & Tsuya, 2010). Furthermore, since the

bond between a husband and a wife was the foundation of the Western family and the conjugal bond was legitimated by procreation, interference in reproduction was probably inopportune from the perspectives of couples as long as procreation did not limit their economic situations seriously. In contrast, in preindustrial Japan a life in a fetus or a newborn was viewed as flux and therefore not considered fully human (LaFleur, 1992). The view of liquid life coupled with the collective orientation of families as a lineal entity allowed and even encouraged direct intervention in reproduction through infanticide and induced abortion (Derosas & Tsuya, 2010; Taeuber, 1958, pp. 29–30).

Reproduction in preindustrial Japan is characterized by relatively early and universal marriage, especially among women, and tightly controlled reproduction within marriage. The mean age at first marriage among women in different parts of rural Japan in the eighteenth and nineteenth centuries is estimated to have ranged from around 15–16 in the northeast to around 25–26 in the southwest (Kurosu, Tsuya, & Hamano, 1999; Tsuya & Kurosu, 2010). Though varied widely by region and time period, the timing of female first marriage in eighteenth- and nineteenth-century Japan was earlier than in preindustrial Western Europe where the mean age at first marriage typically ranged from women's late 20s to 30 (Dupaquier, Helin, Laslett, Livi-Bacci, & Sogner, 1981; Flinn, 1981). Marriage was also universal in early modern Japan. The proportion of women who never married was below 5 % at age 50 (Tsuya, 2001; Tsuya & Kurosu, 2010), posing a clear contrast to historical Western Europe in which a considerable proportion (roughly 10–30 %) of women stayed unmarried until the end of their reproductive years. Clearly, a relatively early and universal female marriage pattern prevailed in preindustrial Japan.

Marital reproduction was tightly controlled in early modern Japan although there were considerable regional and temporal variations (Hayami & Kurosu, 2001; Saito, 1998). Studies found that the level of marital reproduction in Tokugawa Japan was in general lower than those in many preindustrial European communities.

For example, the total marital fertility rates (TMFR) for women age 20–49, which is a common indicator of the level of marital fertility used in historical demography, ranged from 2.8 to 5.9 in farming villages in northeastern and central Japan during the eighteenth and nineteenth centuries (Tsuya & Kurosu, 2010). The TMFR was in the range of 7.3–8.7 in nineteenth-century rural communities in eastern Belgium, southern Sweden, and central Italy (Lee, Wang, & Tsuya, 2010). The relatively low level of marital fertility in Tokugawa Japanese villages may have been due in part to the above mentioned under-registration of births, which is estimated to be around 18 % of all births (for specifics, see Tsuya, Campbell, & Wang, 2010). Even taking this under-registration into account, however, the level of marital reproduction in early modern Japan seems to have been still lower than in many parts of historical Europe.

Using the two parameters – M and m – derived by Coale and Trussell (1974, 1978a, b), we can quantify the degree of age-specific control of reproduction within marriage and the level of marital reproduction. The M parameter indicates the level of marital fertility relative to the natural fertility standard, and the m parameter indexes the extent of deliberate control of marital fertility depending on family size. Studies found that the level of marital reproduction was indeed low in rural communities in Tokugawa Japan (Tomobe, 1991; Tsuya & Kurosu, 2010): as measured by M , it was roughly 30–60 % lower than the natural fertility standard. On the other hand, the estimated values of m for these communities indicate a moderate degree of reproduction control depending on family size. These studies therefore suggest that couples in early modern Japan controlled reproduction not only by limiting their family size but also by spacing children.

A consensus emerging from accumulated evidence covering a variety of Tokugawa Japanese villages is that marital reproductive control was done primarily through infanticide, and the way it was used was influenced by family-related factors such as the number of surviving offspring, their sex, and the timing of birth (Derosas & Tsuya, 2010). Some studies suggest that infanticide was practiced only after couples achieved their desired family size

(i.e., parity specific) and primarily against female infants (i.e., sex selective) (e.g., Hanley & Yamamura, 1977, pp. 226–232; Taeuber, 1958, p. 30). However, other studies found that infanticide was not always parity specific or limited to female infants. Rather, it was practiced flexibly to achieve the desires of couples and their households in terms of the size, sex composition, and sequence of progeny (Derosas & Tsuya, 2010; Smith, 1977, pp. 59–85; Tsuya & Kurosu, 2010).

Although a general agreement has not yet been reached as to whether or not deliberate control of marital reproduction was specific to family size or sex selective, empirical studies generally agree that infanticide was practiced in all classes of the Tokugawa peasant population and that it was used not only in times of economic difficulty but also in good times (Hanley & Yamamura, 1977, pp. 226–266; Saito, 1992; Smith, 1977, pp. 59–85; Tsuya & Kurosu, 2010). These studies therefore suggest that deliberate reproductive control by rural couples in early modern Japan was not a desperate response to the inexorable pressure of poverty and starvation at the time of economic hardships caused by famines and crop failures. Rather, it seems to have largely been couples' calculated behavior intending to improve the living standards and well-being of their progeny and household. The traditional Japanese term referring to infanticide – *mabiki*, literally the culling of seedlings – clearly indicates such intentions. Just as farms yield a better crop if certain seedlings are removed, couples might have desired to cull some infants to ensure the overall better quality of their surviving offspring. A trade-off existed between the benefits of having additional children and the alternative of conserving wealth to maintain or improve the family's living standard, and couples in preindustrial Japan often chose to control the size and composition of their offspring.

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Rice Fields Reclamation in Southern India

K. T. Rammohan

Backwaters are large water bodies that are receptacles of rivers but contain saline water as they are connected to the sea. The Vembanad backwater system in far southern India covers an area of over 21,000 ha, measures 96.5 km in length, and is 3–8 m deep. Designated as a Ramsar site in 2002, the Vembanad is the largest estuarine system on India's western coast and as a transitional ecotone between land and sea, offers protection to innumerable living organisms, including clams and waterfowl (Nair, 2003). Population expansion and economic pressures of commercial agriculture and tourism, however, have put pressure on the backwater causing it to considerably dwindle over time (Narayanan, 2003).

While reclamation of Vembanad backwater for habitation and cultivation has a history that dates back many centuries, the scale of operation was small until the nineteenth century. From this period, Travancore was rapidly drafted into the world economy as a source of varied goods: coffee, tea, coconut oil, coir, and later rubber. It was crucial for the export economy to be price-competitive in the international market. Export production was labour intensive. To keep prices low, wages had to be kept low. This in turn required keeping food prices under check. However, the demand for rice was rising and its supply was falling. Besides normal demographic expansion, the immigrant workforce in the plantations

marked new demand. The relocation of agricultural workers to coir weaving factories in the coastal urban centres also possibly raised the demand for rice. Earlier, in the countryside, their food comprised some rice and a large share of tubers. In the town, lacking access to tubers that were not a marketed commodity, people substituted rice. As demand for rice rose, its supply fell. This was mainly due to the decline of hill cultivation of rice consequent to the setting up of plantations (Rammohan, 1996).

The princely government of Travancore sought to address the growing mismatch between supply and demand of rice in three ways: import of rice from Bengal, Burma, and Siam; propagation of cassava as a rice substitute; and encouraging the creation of new rice lands by reclaiming the Vembanad backwater. Large-scale reclamation began towards the late nineteenth century, with the princely government granting short-term exemption from tax on reclaimed lands and extending loans at concessional rates to the cultivators. Even with cheap and servile labour, reclamation was expensive. Usually one person was given permission, but he carried out reclamation by forming partnerships with a few others. Networking was mostly confined within a caste or community or among castes and communities of similar social status. Nayars and Christians, jointly and severally, floated most of the partnerships. Lower castes and communities lacking financial resources and influence in government could not undertake reclamation. Workers of Pulaya and Paraya castes, considered 'untouchable' by their higher caste landlords, did most of the work. The technology of reclamation also is indebted to these castes, especially Pulayas, who had long resorted to reclaiming shallow backwaters for cultivation, as they owned no land themselves.

Reclamation occurred during the summer when water level in the lake dipped. It involved two major operations: building a circular dyke (outer main dyke or ring dyke or *mata*) to enclose the backwater area proposed to be reclaimed and draining water out from the enclosed area. Dykes had to be built where water was 8–10 ft deep. This involved several stages. First, coconut palm trunk

piles in two parallel lines were driven into the bed of the backwater area to be reclaimed. These were fenced with ► **bamboo** screens on either side. The space enclosed by the bamboo screens was then tightly packed with clay, sand and brushwood. Clay had to be lifted from the lakebed at a depth of 10–12 ft and transported by country boats to the site. The dyke-enclosed area was then drained by using an array of waterwheels of different sizes, mounted one upon the other, operated day and night. After draining the area, usual agricultural operations could be commenced. With high water levels surrounding the field and the lake being prone to tides, constant vigil had to be maintained against any breach in the dyke. Land and water management was central to cultivation. All operations, including ploughing, sowing, weeding and harvesting, were dependent on timing and any delay could ruin the crop.

Rice cultivation in reclaimed lands was highly labour-intensive and its success depended on the availability of a captive workforce round the clock. Male workers built and maintained the dykes, and ploughed the field; the rest of the operations were mostly done by women. These workers were initially slaves and their masters were mostly members of upper castes like Brahmins and Nayars and communities like Syrian Christians. From the mid-nineteenth century, with the abolition of slavery, they were partially liberated but were still attached to the masters and their land. As land changed hands they had new masters. Some of them were settled in thatched mud huts in the master's homestead so that their services could be had anytime in the day or night. Others were settled on or near the dyke so that they could keep vigil over the dyke in times of heavy rains and act immediately if a breach occurred. The ring dykes demarcated individual fields while most fields were protected by outer dykes, built and maintained jointly by the farmers.

During the early years of reclamation, water was drained by using waterwheels made of wood. With the introduction of mechanical pump sets towards the end of the nineteenth century reclamation activity received a further boost. While earlier, only small blocks of 40–60 acres used to

be reclaimed, large blocks of hundreds of acres could now be reclaimed. Over 5,000 acres were newly reclaimed. The first pump sets that were introduced during the late nineteenth century were worked by producer gas and those introduced in the early decades of the twentieth century were run by kerosene or diesel. A British engineering firm based in Cochin, Geo Brunton Company, boat builders and operators of steamboats, introduced the first pump sets. The company hired these out to farmers. The company's men, many of them Anglo-Indians, operated the pump sets. With increase in demand, new suppliers like Marshall Sons and Company of Edinburgh operating through its branch at Madras also entered the scene (Rammohan, 1996).

Agricultural operations in the reclaimed tracts began in January or February. The field was ploughed using bullocks or oxen as draught animals. The soil of the reclaimed backwater was acidic and to neutralise it, lime was applied. The field was then flooded by opening the sluices in the dyke. The field remained submerged throughout the south western monsoon (June to August). By August when the water receded the field was again ploughed. This was a difficult operation as the worker had to wade through waist-deep and muddy water with the draught bullock or buffalo. Following this, the outer dykes were repaired and waterwheels set up at different points. The wheel was mounted vertically on a horizontal axle. The wheels were of different sizes; the number of spokes was usually in multiples of 6 and ranged from 6 to 36. To drain large areas an array of waterwheels, arranged in ascending order of size was used. The wheels were operated by gangs ranging from eight to ten workers, who perched themselves on ► [bamboo](#) scaffolding and pedalled the water away. This was hard labour and work was carried out in four shifts. The workers ascertained the time by looking at the sun, moon and stars. Alternatively, a half shell of coconut with a fine hole pierced at its bottom was used like an hourglass with water substituting for sand. The shell was placed in water and when water entering from below filled it entirely it was reckoned as a unit of time. Drainage operations were conducted for many fields at a time. As water

levels receded, the inner dykes and irrigation channels were repaired. The soil was then raked with a harrow, weeded and worked into a soft puddle. Water was then let into the field up to knee-depth. Sowing was done in October or November after the monsoon subsided. Seeds, sprouted in screw-pine bags, were broadcast in water. The field was then completely drained and kept dry for a week. Water was then let in, and when seedlings were about a month old, some transplanting was done to reduce the unevenness resulting from broadcast sowing. The field was completely drained after transplanting and manure – cow dung, green leaves, hay, and ash – applied. Pesticides were not used. The most common pest was a worm. As water level in the field rose, the worm crawled up and positioned itself on the edge of the leaf-blade. The worms were swept away into a basket using a stick or a broom. Water was let into the field at regular intervals till the harvest, which occurred in February or March. The ear heads were garnered with sickles and threshed with feet. The grain was winnowed and sun-dried on the threshing floor and conveyed to the granaries in country canoes. The grain was boiled, sun-dried and pounded by hand into rice. In certain parts of reclaimed areas, a deep-water variety of rice was cultivated. Its ear heads floated on the surface of water and were harvested from the canoes (Pillai and Panikar, 1965; Tharamangalam, 1981).

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Rice in Africa

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Introduction

Rice and wheat are the most important food crops of humankind. Both contribute about 21 % each of the total energy consumed by humans (Food and Agricultural Organization [FAO], 2009). However, between the two crop plants, rice is the more important one. It is the staff of life of humans, as it constitutes the staple food for more humans than any other crop.

Among all the crop plants, rice shows the widest adaptability. It is grown in more diverse environments than any other crop plant – from 4 m below sea level to the snowbound regions of Japan and Central Asia – from 53° North latitude to 35° South latitude (Lu & Chang, 1980). It shows a wide range of maturity also, from 65 to 70 days up to 330 to 360 days (Nayar, 2014).

Cultivated rice consists of two species, the universally cultivated Asian rice, *Oryza sativa* L. and the African rice, *O. glaberrima* Steud., whose cultivation is limited to tropical west Africa. The two rices belong to the genus *Oryza* L., tribe *Oryzeae* Dumort., subfamily Ehrhartoideae Link., family Poaceae Barnhart (synonym, *Gramineae* L.), order Poales Small, division Monocotyledonae, and class Magnoliopsida (Angiosperm Phylogeny Group [APG], 2009; Grass Phylogeny Working Groups [GPWG], 2001).

Rice is not a major crop in Africa, when the continent is considered as a whole. It ranks only fifth in the area under cultivation in the continent after maize, sorghum, millets, and cassava (cf. Nayar 2014). It occupied in 2013 only 6.6 % of the net cropped area in Africa and produced only 3.9 % of the global production with 29.3 M t rice paddy (FAO, 2007, 2009; FAOSTAT, 2014) (Table 1). At the same time, the rate of increase in rice production has been the highest in Africa since 1961 – with CAGR (compound annual growth rate) of 31.2 % versus 22.2 % globally (Nayar, 2014). The consumption rate of rice is also increasing most rapidly in the continent. For this, it imports as much as 60 % of its annual requirements of rice.

The present rice supply in Africa is only 23.3 kg/head/year (vs. 54.0 kg/head/year in the world) in 2011 (FAO, 2014). There is however much variation in rice consumption patterns in different regions of the continent. They are (in kg/head/year) as follows: Africa, 23.3 kg; Eastern, 15.3 kg; Middle, 13.9 kg; Northern, 16.3 kg; Southern, 16.1 kg; and Western, 39.5 kg (data for 2011, FAOSTAT; cf. Table 2 for latest data.).

Even within different regions, there is considerable variation in consumption patterns among countries (Tables 1 and 3).

Rice constitutes the staple/secondary staple food (a food item that provides 10 %/5 % energy/head/day) in 26/40 countries/entities in the continent (FAOSTAT, 2014). The daily percapita energy consumption varied from 101 kcals (5.4 % Middle Africa) to 1,038 kcals in Madagascar (102.1 kg annually, 48.1 % energy/day) (Nayar, 2014).

Egypt is the only country in the continent that produces more rice than it consumes. Cameroon in West Africa is almost self-sufficient in its rice requirements. All the other countries depend on imported rice to meet their requirements.

History

The earliest record of rice in Africa is that of Alexander the Great in 332 BCE, who had

Rice in Africa, Table 1 Trends in area and production of rice paddy in Africa, 1961, 1991, & 2013^a

	Year		
	1961	1991	2013
Area (M ha)			
World	115.8	146.7 (+127 %)	164.7 (+112 %)
Africa	2.8	6.6 (+236 %)	10.9 (+165 %)
Eastern Africa	1.00	1.76 (+176 %)	2.9 (+165 %)
Middle Africa	0.15	0.56 (+373 %)	0.93 (+166 %)
Northern Africa	0.23	0.47 (+204 %)	0.71 (+151 %)
Southern Africa	0.004	0.001 (-269 %)	0.001 (nil)
Western Africa	1.41	3.80 (+269 %)	6.4 (+168 %)
Production (M t)			
World	215.7	518.7 (+240 %)	745.7 (+144 %)
Africa	4.3	13.7 (+319 %)	29.3 (+214 %)
Eastern Africa	1.7	3.3 (+194 %)	7.0 (+212 %)
Middle Africa	0.13	0.56 (+430 %)	0.96 (+171 %)
Northern Africa	1.2	3.5 (+292 %)	6.8 (+194 %)
Southern Africa	0.007	0.005 (-71 %)	0.003 (-60 %)
Western Africa	1.3	6.4 (+492 %)	14.5 (+227 %)

^aSource: FAOSTAT. Downloaded 08 October 2014**Rice in Africa, Table 2** Food balance sheet of rice in Africa, 1961, 2011^a

Country/region/year	Production, 10 ⁶ t	Import, 1,000 t	Domestic Supply, 10 ⁶ t	Waste, 1,000 t	Food, 10 ⁶ t	Food supply, kg/cap/year	Food supply, kcal/cap/ day
World							
1961	141.2	6,159	138.3	7,013	116.0	37.9	390
2011	481.2	34,107	465.7	26,375	371.7	54.0	544
Africa							
1961	2.8	470	0.003	297	2.5	9.3	94
2011	17.0	10,549	26.8	1,879	22.6	23.3	233
Eastern Africa							
1961	1.1	116	1.2	138	0.86	10.7	108
2011	5.0	1,659	6.1	542	4.98	15.3	153
Middle Africa							
1961	0.04	0.01	0.34	2	0.04	2.7	28
2011	0.28	0.95	1.10	54	0.88	13.9	139
Northern Africa							
1961	0.78	0.02	0.81	52	0.68	9.6	101
2011	3.8	4.4	4.0	232	34	16.3	171
Southern Africa							
1961	0.005	0.05	0.05	Nil	0.05	2.6	26
2011	0.002	1.00	0.96	Nil	0.96	16.1	158
Western Africa							
1961	0.88	0.27	1.1	105	0.90	10.5	103
2011	7.9	6.50	14.6	1,051	124	39.5	390

^aSource: FAOSTAT FBS. Downloaded 08 October 2014

Rice in Africa, Table 3 Countries in Africa where rice is used as staple/secondary staple^{a,c} food (2007)^b

Continent/region/country	Production (2009) rice paddy 000 t	Food rice supply		Supply
		Total kcals	kcals/cap/day	kg/cap/year
World	^c	2,796	532 (19.0 %)	52.9
Africa	^c	2,445	167 (6.8 %)	19.6
Eastern Africa	^c	2,045	138 (6.7 %)	13.7
Comoros	19	1,884	595 (31.6 %)	59.5
Djibouti	Not available	2,291	387 (16.9 %)	39.2
Madagascar	4,738	2,160	1,038 (48.1 %)	102.1
Mozambique	180	2,067	198 (9.6 %)	20.3
Seychelles	Not reported	2,463	296 (12.0 %)	29.8
Tanzania	1,105	2,032	194 (9.5 %)	18.9
Cameroon	175	2,269	223 (9.8 %)	22.4
Gabon	1	2,755	375 (13.6 %)	37.5
Middle Africa	^c	1,860	101 (5.4 %)	10.0
Northern Africa	^c	3,016	168 (5.6 %)	16.0
Egypt	4,330	3,195	388 (12.1 %)	37.0
Southern Africa	^c	2,918	181 (6.2 %)	18.3
Mauritius	Nil	2,965	503 (17.0 %)	49.9
Swaziland	<1	2,292	204 (8.9 %)	20.7
Western Africa	^c	2,649	324 (12.2 %)	32.8
Benin	167	2,533	326 (12.9 %)	32.6
Cape Verde	Not reported	2,572	462 (18.0 %)	46.2
Cote d'Ivoire	723	2,528	552 (21.8 %)	61.0
Gambia	100	2,385	580 (24.3 %)	57.6
Ghana	492	2,907	273 (9.4 %)	28.2
Guinea	1,499	2,561	961 (37.5 %)	128.2
Guinea-Bissau	177	2,306	848 (38.5 %)	84.7
Liberia	296	2,204	734 (33.3 %)	73.0
Mali	2,308	2,614	540 (20.7 %)	54.4
Mauritania	134	2,841	302 (10.6 %)	30.8
Sierra Leone	1,027	2,170	898 (41.4 %)	92.4
Togo	110	2,161	198 (9.2 %)	20.3

^aStaple food: A food that provides 10.0 % or more food energy^bComputed by author from FAO Food Balance Sheets (2007)^cSecondary staple food: A food that provides 5.0–10.0 % food energy

brought it to Africa after his conquest of India, but rice did not get established then. Later, the Arabs introduced rice cultivation into Egypt in the seventh century CE. Rice cultivation became widespread with the increase in the Arab and Muslim influences from the tenth century CE (Nayar, 2010).

There is some prehistoric evidence about the introduction of rice into the Cyrenaica (Sudan) in 332 BCE, as mentioned by Pliny, the Greek geographer and historian (64 BCE–24 CE) (Lewicki, 1974). But this has not been confirmed by archaeological evidences.

The earliest archaeological record of rice in Africa has been obtained from the Roman ports of Berenike and Myos Hormos, both, in the Egyptian Red Sea. This is dated to the first century CE. These were entrepôts for goods required for the Roman Empire. Goods from India and East Africa used to be exchanged here with those from Rome.

There are three other archaeological reports of rice from Africa, all from Inland Niger Delta (IND) in tropical west Africa. They are all dated between 1000 BCE and 50 CE. One site yielded wild rice, and the other two were claimed to be of

O. glaberrima, the African cultivated rice. But there have been various problems in their identification (Nayar, 2014, for full details).

The east coast of Africa in general, and Madagascar in particular, has had a long history of maritime contacts with south and southeast Asia from prehistoric/early historic times. In Madagascar, there is an overwhelming influence of oriental contacts, particularly with present-day Indonesia. Even the language that is spoken there is Malagasy, which is a variant form of an Indonesian language. Most of the southeast Asian crops including rice have been cultivated there from very early times. Portères (1955) recorded that names of several rice landraces of the Island resemble those of south and southeast Asia.

The situation prevailing in tropical west Africa is comparable to that in Madagascar, but to a much less extent. This is so especially in the coastal regions of south and southwestern tropical Africa. Part of this coastal region is even known as the Rice Coast. Here, oral history and traditions indicate that this region might have had various Asian influences from very early times. Some of the ethnic or language groups of the region have a long history of rice culture. The traditional rice landraces of the region here possess red pericarp, and the local people traditionally prefer parboiled rice. Both these customs are widely prevalent in some regions of south Asia, such as in Kerala, the Konkan Coast, and parts of southeast India adjoining Bangladesh (Nayar 2014). Some authors have even proposed that rice was introduced into this region in very early times either overland across tropical Africa from Madagascar, or by sea round the Cape (Carpenter, 1978, Nayar, 1973 for instance). It was from this region that African rice *O. glaberrima* was first discovered and named.

Portères, the noted botanist from France, spent his career working and writing on both the African rice species. When Linnaeus first described the genus *Oryza* in 1753, he had identified only one *Oryza* species, the universally cultivated Asian rice, *O. sativa* L. Then Ernest von Steudel (1783–1856) described the African rice, *O. glaberrima* Steud. in 1855 AD, from a specimen collected by a French navy commander

Edelstan Jardin during 1845–1848 from the West African coast – actually, from Loess Island, off the coast of Conakry (in present-day Guinea). Jardin had identified it as *O. sativa* (Portères, 1955). Prior to Jardin, Leprieur, a French navy pharmacist had collected some rice specimens during 1824–1829 from Cape Verde, near Dakar (in present-day Senegal). Jardin prepared a herbarium sheet of his rice collection with two rice panicles and identified them as *O. sativa*. Portères (1955) found that one panicle was actually of *O. glaberrima*. This has become thus the first herbarium specimen of *O. glaberrima*, the African rice.

As the Latin name of the African rice implies, *O. glaberrima* is characterized by glabrousness of the spikelet, leaf, and some other plant parts. Typical African rice also possesses short ligules and red pericarp, and secondary branches are nearly absent in the panicles. In all other aspects of gross morphology, African rice looks similar to Asian rice.

At present, it is difficult – almost impossible – to find typical African rice. Most parts of tropical West Africa were in the possession of various European powers until the 1960s. After the end of the First World War (1914–1918), all these powers were promoting only Asian rice in their various agriculture development programs in their respective colonies. Thus, Asian rice got substituted for African rice. Second, natural crossings take place between the two cultivated rice species, which has all but eliminated pure forms of African rice.

Portères published early in his career that African rice arose in the Inland Niger Delta (IND) 3,500 years ago from the locally widely occurring annual species, *O. barthii* (then known as *O. breviligulata*) (Portères, 1962). He proposed further that African rice had two secondary centers of origin, the upper Guinea highlands and the region between the Casamance and Gambia rivers, both in tropical West Africa. He based his proposition partly on linguistic grounds and partly on archaeological evidences. Portères associated the time of origin of African rice with the time of installation of the giant stone structures, commonly known as Senegambian megaliths.

Portères (1962) papers have been severely criticized by both archaeologists and linguistic scientists. The age of these megaliths has since been determined to be between 200 BCE and 800 CE (Gray, 1962; Posnansky & McIntosh, 1976).

Unfortunately, all the literature that mentions African rice origins have been quoting only Portères (1962), oblivious of the criticisms that have been raised by numerous authors and scientists beginning with Gray (1962). Likewise, an alternative proposition on the origin of African rice from Asian rice and of *O. barthii* being the hybrid derivatives of *O. sativa* and *O. glaberrima* (Nayar, 1973) has not also received much attention including any repudiation of this proposal. Nayar (2010, 2012) has provided further evidence in support of this contention and also with the closely related annual wild rice species, *O. barthii*. Semon et al. (2005) have provided experimental evidences for this situation, albeit in another context (cf. Nayar 2014).

Current Rice Research in Africa

Most of the research on rice in Africa is now being carried out by either the International Rice Research Institute, Los Banos, The Philippines, which operates some cooperative programs with some countries in Africa, or the African Rice Center Cotonou, Benin (AfricaRice). Both are constituents of the CGIAR (Consultative Groups on International Agriculture Research). AfricaRice presently operates in over 24 countries in Africa. It is now primarily engaged in improving African rice. NERICA rice is the acronym for NEW RICE for Africa. It was the result of interspecific hybridization between African rice and Asian rice. However, the NERICA rice carries less than 10 % of the genetic material of African rice (Nayar, 2010). The newer series of rice are expected to contain higher levels of genetic material.

Egypt possibly is the only country in Africa having its own rice research program. Incidentally, Egypt is the largest producer and the only rice exporting country in Africa.

Rice Introduction into the New World

An important aside is the finding that rice was first introduced into the Americas not by the Europeans from Europe in the sixteenth to seventeenth centuries, but earlier by the African slaves of west Africa. Many of the slaves had carried rice with them for their personal use and/or for cultivation (Carney, 2001). West Africans carried rice not only to the present-day USA, but also to South America, especially the Guyanas.

Rice in Africa: The Future

We stated in the beginning that both the rates of increase in production and of consumption of rice have been the highest in Africa. Presently, it is importing almost 60 % of its annual requirements. The present yield levels in Africa are dismally low. We can only hope that with the intensification of R&D efforts on rice by the IRRI and AfricaRice, the continent will soon be in a position to be self-sufficient in its requirements in the medium term. This requires a considerable infusion of capital, for capacity building of both humans and infrastructure and also for meeting the recurring expenditure.

Africa is very rich in natural resources. Unfortunately, because of various social and political issues, these resources are not being put to productive uses. We can only hope this situation will improve in the future.

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Rice in China

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Rice is a staple food for half of the world's population, and it has been a significant icon of Chinese culture for thousands of years. So far

the earliest written Chinese character of “wild rice” (秼) was recognized as  on an oracle bone of the Shang dynasty (1600–1046 B.C.), and the first “rice” (稻) was identified as  or  inscribed in a bronze of the Western Zhou dynasty (1046–771 B.C.). Long prior to any written records, archaeological evidence indicates the earliest harvesting of wild rice can be traced back to more than 10,000 years ago in southern China. The origins and developments of rice cultivation in China have a very deep root and a long process of evolution, closely linked with technological advances and the unique characters of Chinese life and cultures.

Origins and Early Developments

Rice is a cereal crop that produces edible seeds of grain. The seed can be eaten in its natural “wild” form, but rice potentially can be more productive and reliable as a staple crop in its domesticated form. Fully domesticated morphologies of Asian rice emerged in China as *Oryza sativa* var. *japonica* through multiple stages of crop processing (threshing, winnowing, sieving, dehushing, and hand selection) and over the course of many generations. In a natural condition, the seeds are easily shattered as part of their dispersal for regrowth, but over time, people selected for nonshattering varieties that could be stored safely for long periods such as the seasons between harvests. Additionally, people learned how to manage a well-watered environment for healthy growth and then eliminate the water supply for an artificially induced production of the edible seeds. These manipulations led to genetic transformations of rice, as well as to opportunities for various technological, economic, and social developments among rice-growing people.

Archaeological evidence so far reveals plentiful examples of wild and domesticated rice in several parts of China, but an exact point of origin (or multicentric origins) for domestication has been uncertain. The oldest preserved specimens are dated about 12,000–8000 B.C. in several

limestone caves in the foothills of the Nanling mountain range, but these specimens probably were wild *Oryza*. The middle-lower Yangtze River traditionally is viewed as the heartland of domesticated rice in China, where accordingly evidence of rice cultivation has been dated to about 8000–5000 B.C. The ancient origins may have been more complex, as morphologically domesticated rice has been found at comparable early dates elsewhere outside the Yangtze Basin, for instance, about 7000–6000 B.C. in sites of the middle Hanshui Valley and Huai Valley, located between the Yangtze and Yellow Rivers.

Regardless of debates about the point(s) of origin, the middle-lower Yangtze region contains several sites that together represent different stages in a long sequence of rice domestication. Here, rice farming can be seen as having developed in close integration with social life over a few thousand years. In the lower Yangtze, the abundance of rice is hinted at by the considerable quantities of rice husks incorporated into the clay of earthenware pottery as early as 8000 B.C. at Shangshan. Very dense concentrations of rice phytoliths have been found in the cultural layer of Xiaohuangshan, c. 8000–6000 B.C. Thousands of rice husks were found at the site of Kuahuqiao dated 6000–5000 B.C. In the middle Yangtze, as early as 7000–6000 B.C., preserved rice specimens are numerous at Pengtoushan. Nearly 20,000 rice husks and grains were collected from one small excavation at Bashidang, identified as an archaic type of cultivated rice, but the morphology differed from the present-day *indica* and *japonica* varieties (Zhang & Pei, 1997, pp. 36–41). Although those ancient rice grains unearthed from 8000 to 5000 B.C. appear to be wild-like (Crawford & Chen, 1998, Fuller et al., 2009) rather than fully domesticated, the impressive quantities found in the sites suggest that deliberate food production already was beginning at this time.

Definite nonshattering domestic forms of rice were prevalent by 4000 B.C. (Fuller et al., 2009). The oldest known traces of actual rice fields have been identified in the middle and lower Yangtze, at least as early as 4500–4200 B.C. These small fields probably were used by individual households, as

they typically enclose only 3–5 m² each, surrounded by low earthen banks. Examples in the lower Yangtze are found at Caoxieshan (Zou et al., 2000, pp. 97–113) and Chuodun (Ding, 2012), dated about 4200–3000 B.C. (Fig. 1). In the middle Yangtze, similar small rice fields have been reported at Chengtoushan, dated about 4500–4000 B.C. (Nasu, Gu, Momohara, & Yasuda, 2012). Large numbers of spades made of bone or wood come from other similar-aged sites in the lower Yangtze.

Increasing Productivity

Stone implements of plow cultivation first appeared about 4000–3300 B.C. and became well developed by 3300–2400 B.C. in association with the Liangzhu culture of the lower Yangtze, known for its marvelous artworks of jade, silk, and lacquerware and complex social structure. In a practical sense, plow cultivation enabled people to work in much larger fields than previously was possible by use of wooden and bone spades, and the total harvest output in theory could support a larger population. At the Maoshan site, more than 55,000 m² of ancient rice paddies has been documented (Fig. 2). At least as early as 3000–2600 B.C., the individual rice plots varied in size, as small as 1–2 m² but remarkably as large as 30–40 m², in rectangular or irregular rounded shapes. After 2600–2400 B.C., the rice fields were designed to incorporate river courses and embankments, irrigation channels, and paddy embankments (Fig. 3). So far, nine embankments between the paddies have been identified in this later stage of Liangzhu culture at the Maoshan site, and each unit enclosed about 1,000 m². Judging by the characteristics of rice phytoliths and spikelets, an estimated 221 kg of rice could be produced for each 1,000 m² area in the later stages of the Maoshan site, about 2.2–2.5 times higher than the yields in earlier Hemudu phase (c. 5000–3000 B.C.; Zheng et al., 2014). The large quantity of rice output very likely was one of the main factors in the Liangzhu culture's transformation into an elaborate social structure with ranked status and overt displays of wealth

Rice in China,

Fig. 1 Ancient rice paddy field in Chuodun, Jiangsu Province (After Ding, 2012)



Rice in China, Fig. 2 Archaeological excavation at the Maoshan site in Zhejiang Province

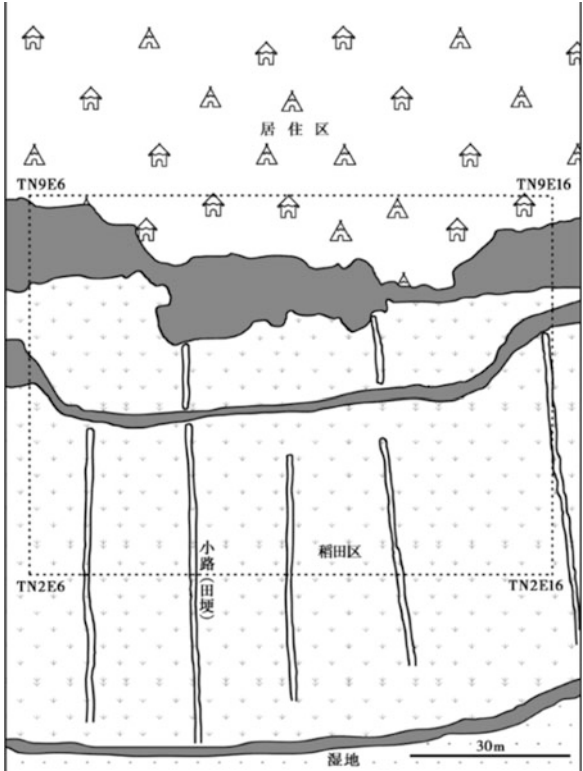
through artworks. Today, many Chinese scholars regard Liangzhu as the earliest kingdom in China.

With larger rice fields, irrigation systems developed for controlling flows of water. Since the Spring and Autumn Period (770–476 B.C.),

several national-level irrigation systems and water conservancy projects were developed for rice farming in China. The Dujiangyan (都江堰) irrigation system in Sichuan, an infrastructure was built in 256 B.C. during the Warring States

Rice in China,

Fig. 3 Partial paddy fields of the late Liangzhu period at Maoshan, showing housing area, river, rice paddy fields, and paddy embankments (After Zheng, Chen, & Ding, 2014)



Rice in China, Fig. 4 A piece of Han dynasty portrait stone, unearthed from Mizhi of Shaanxi Province, showing a farmer with a cattle-driven plow



period, and it still is used today to irrigate over 5,300 sq km of farming land in the region. Many of these irrigation infrastructures meanwhile facilitated transpiration in ancient China.

By 700–600 B.C., iron tools and animal-driven devices vastly increased farming productivity, chiefly for rice. Some bronze implements already had made significant impacts at least as early as

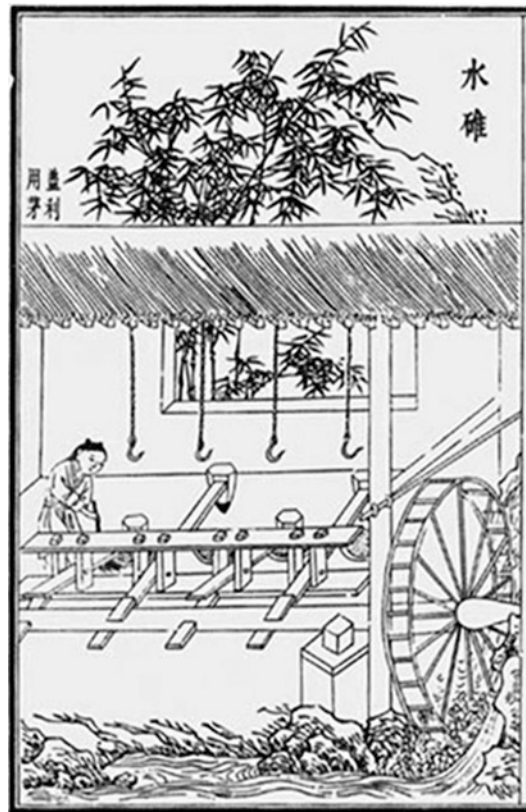
Rice in China, Fig. 5 A ceramic funerary object, depicting a grain-processing workshop, unearthed from Sijangou, Jiyuan, Henan, showing a rice pestle and a winnowing device with two workers of Western Han attire, dated more than 2,000 years ago (Henan Museum)



1700 B.C., but iron tools were much more effective after the Spring and Autumn Period and best documented during the Han dynasty period of 206 B.C.–A.D. 220. Detailed scenarios of rice farming were recorded in Han period mural tombs, portraits on stones and bricks (Fig. 4), funerary objects, and ancient Chinese documents. *Si Sheng Zhi Shu* (汜勝之書, *Book of Si Sheng Zhi*) is the oldest known book about agriculture in China, presenting the details of the principles, methods, and timing of cultivation, as well as strategies of harvest and hoarding for 13 types of crops, including rice. The same book documented the techniques of water temperature control for rice paddies. Notably during the Han dynasty period, various new technologies were being developed to improve agricultural pursuits, such as a multiple tube seed drill for tilling soil and snowing seeds simultaneously, water lifting devices for irrigation, and winnowing devices and a water-driven pestle for grain processing (Hsiao & Yan, 2014; Figs. 5 and 6). Since then, technological inventions have continued to characterize much of Chinese history.

Dispersals to Other Regions

After 3000 B.C., rice cultivation was introduced into most parts of China and farther into



Rice in China, Fig. 6 Water-driven pestle for grain processing, illustrated in the book of *Tiangong Kaiwu* (天工開物, *The Exploitation of the Works of Nature*, by Song Yingxing in Ming dynasty). This type of pestle can be traced back to the Han dynasty

Rice in China, Fig. 7 A modern Vietnamese farmer with her plow and cattle working in a rice paddy field



neighboring regions, in some cases involving migrations of people and lifestyle along with the materials, knowledge, skills, and mechanisms of rice farming and processing. From the middle-lower Yangtze River, southern-moving routes were coastal into Fujian and Guangdong about 3000–2500 B.C., as well as inland into Guangxi and Sichuan by 3000 B.C. and into Guizhou and Yunnan by 2500 B.C. These southern movements led farther into Taiwan and into Southeast Asia (Zhang & Hung, 2010; Fig. 7). From the lower Yellow River, where rice farming had been well established since 6000 B.C., dispersal routes went northward to the Shandong Peninsula by 3500–3000 B.C., then much later into Korea and finally Japan about 300 B.C. via the Liaodong Peninsula.

Conclusion

Rice in China is more than a staple food. Hundreds of recipes make use of rice for worship at special events, enjoyment at particular feasts, ceremonies, and daily life. Beyond just the edible seeds, the by-products of rice have multiple functions, such as rice straw for making ropes, sandals, hats, mats, and raincoats. For thousands of

years, Chinese traditions of year cycle and philosophy centered around rice farming, as in the phrase “plowing in spring, weeding in summer, harvesting in autumn, and hoarding in winter.” Rice has raised generations of people, and it supported the development of countless perspectives of Chinese culture, such as the living landscape, scientific inventions, transportation systems, astronomical knowledge, supernatural beliefs and religions, and lifestyle that characterize the foundations of Chinese civilization.

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Rice in India

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Rice, a member of the grass family, feeds two thirds of the human population. Rice is decisively an Asian crop. 90 % of world yields are grown and consumed in monsoonal Asia (East and South East Asia) where rice is the staple because of its ability to tolerate excessive water conditions, both cold and warm climates. Maize and wheat fail to do so. It has adjusted itself to cool, dry land conditions and saline, alkaline, and acid sulfate soils. It has earned epithets as “grain of life” and “rice is life.”

Debates over the origin and domestication of the rice plant continue and will perhaps never be known as the crop is ancient. Archaeological and molecular studies still fail to give an exact picture.

Vavilov in 1908 considered India as the place of origin of rice on the basis of the wealth of rice varieties in the southwest of the Himalayas (Framji, 1977). Of the 150,000 estimated rice varieties of the world, more than 50,000 occur in India (Rani & Krishnaiah, 2001). On the basis of the pantropical distribution of 20 wild species of *Oryza*, Chang (1976) proposed that rice

originated in the early cretaceous period before the Gondwana breakup. This view has found support from recent discoveries at Pisdura, Maharashtra. Plant remains found in the dung of dinosaurs in Pisdura, Chandrapur district, in Maharashtra revealed that dinosaurs ate this grain much before humans. It may give a new turn to the controversy. This pushes the origin of rice 35 million years back during the late Cretaceous period and raises the possibility of rice having an Indian parent. Until now, it was believed that rice originated about 30 million years ago in China (Pallavi, 2011).

Early rice cultivation followed two pathways toward domestication in India and China, with selection for domestication traits in early Yangtze *japonica* and a nondomestication feedback system inferred for proto-*indica*. The protracted domestication process finished around 6,500–6,000 years ago in China and about two millennia later in India, when hybridization with Chinese rice took place (Fuller, 2011).

Genus *Oryza* has only two cultivated species, *Oryza sativa* Linn (Asian cultivated species) and *Oryza glaberrima* Steud (confined to West Africa). *Oryza sativa* is grown on every continent throughout the world, with the exception of Antarctica. Domestication of Asian rice, *O. sativa*, diversified to form two ecological major subspecies groups, *Indica* and *Japonica*. Other studies indicated that the two groups were derived independently from the domestication of two divergent wild rices in China and India, respectively (Second, 1982, 1986), or from three different populations of *O. nivara* (wild rice) existed then in different regions. The hill rices of southeast India, the japonica-like types of southwest China, and the hill rices of Indo-China are said to have directly evolved from the annual wild species in their respective regions. The *aus* ecotype of West Bengal seems to have directly evolved from the upland rices of southeast India, whereas *aman* type came from the introgression of *rufipogon* genes into *aus* type somewhere in the lower Gangetic Valley. The *sali* type of Assam possibly evolved from the introgression of *O. rufipogon* genes into *japonica*-like type somewhere in the Brahmaputra Valley (Sharma, Dhua, Agrawal, et al., 2000).

Rice is grown in almost all the states of India, covering more than 30 % of the total cultivated area. Rice extends from 8 °C to 35°N latitude, from sea level in river deltas, in areas below sea levels in Kerala, 4–6 m deep water in Assam and West Bengal, and at altitude (in meters) of 900–1,500 and even more in Kashmir and on slopes of Coorg (700–900) and Assam (600) (Framji, 1977).

Rice is grown under varied ecosystems on a variety of soils under varying climatic conditions. The climatic factors affecting the cultivation of rice are rainfall, day length, and temperature. Soils capable of holding water for a longer period such as heavy neutral soils (clay, clay loam, and loamy) are most suited for its cultivation. The most important groups of soils for successful rice cultivation include alluvial soils, red soils, laterite soils, and black soils. It is grown normally in soils with pH ranging from 5 to 8. Because of its better adaptation, it is also grown under extreme soil conditions such as the acid peaty soils of Kerala (pH 3) and highly alkaline soils (pH 10) of Punjab, Haryana, and Uttar Pradesh (Tripathi, Govila, Warriar, & Ahuja, 2011).

Rice Ecosystems

No other country in the world has such diversity in rice ecosystems than India with four distinct types of ecosystems: irrigated, rainfed lowland, rainfed upland, and flood prone. More than half of the rice area (55 %) is rainfed, and 80 % of the rainfed rice areas are in eastern India, making its cultivation vulnerable to the vagaries of monsoons (Tripathi et al., 2011).

- (i) **Irrigated ecosystem:** Irrigated rice is grown in bunded (embanked), paddy fields; this accounts for approx. 50 % of the total rice area in the country.
- (ii) **Rainfed upland:** Upland rice fields are generally dry, unbunded, and directly seeded. Land utilized in upland rice production can be low lying, drought prone, rolling, or steep sloping.

- (iii) **Rainfed lowland:** Farmers in the rainfed lowland are typically challenged by poor soil quality, drought/flood conditions, and erratic yields. This area accounts for approx. 32 % of the total area under rice.
- (iv) **Flood prone:** These areas are characterized by periods of extreme flooding and drought. Yields are low and variable. Flooding occurs during the wet season from June to November, and rice varieties are chosen for their level of tolerance to submersion.

Diverse ecological situations in areas of rice cultivation have given rise to the following major eco-specific rice varieties with specificity for season, situation, and system.

- **The aus group:** Early maturing, photoinensitive types can be grown across the seasons except in the winter.
- **The aman group:** Late types mostly photoperiod sensitive and flower during specific time regardless of when they are sown or transplanted.
- **The boro group:** Perform best as a summer crop. When sown during winter, they tolerate cold temperature in the early vegetative stage better than the other groups.
- **The gora group:** Only in short duration, it can withstand a certain degree of moisture stress during its growing period.
- **The basmati group:** Specific to regions in the northern parts of Indian subcontinent, possessing extremely valuable quality traits like elongation, aroma, and flavor.
- Aromatic rices other than basmati are found in different states of the country.

Diverse management systems for rice cultivation are practiced in each of the ecosystems. However, the management of irrigated rice is most diverse. Most rice cultivation is done through transplanting manually, and the use of machines is low. Weeding is done by herbicides and manually. Harvesting is done manually or by machine. In the rainfed lowland, rice is primarily transplanted, and weed control and harvesting are done manually as is threshing through small

threshers. Upland rice is generally broadcast sown on dry soil or dribbled in slash and burn situations. It is harvested and threshed manually. Deepwater rice is broadcast, sown in dry soil with very little weeding as most of the weeds do not survive in deep water. Harvesting and threshing is done mostly manually (Khush, 2005).

Like its cultivators, rice comes in different shapes, sizes, colors, qualities, and tastes. Rice is eaten only after processing (shelling of husk). It is eaten as white rice or parboiled (steamed rice). Rice grains are long, short, medium, thin, or plump. The colors vary from white to black with shades of beige, bronze, russet, purple, and red. People in different parts of India differ in their preference for long or small, glutinous, or nonglutinous, white (raw) or parboiled rice, and scented fine or coarse grained rice.

Discussion on rice cultivation in India would be incomplete without reference to specialty rices. These include colored, aromatic, soft, and wild varieties. Of these, red and aromatic rices are important in India. Colored rice has been preferred in the past for its special features such as medicinal value and exclusive taste. Black rices were the favorites of the royals of China. Red rices are preferred by people in many parts of India, Sri Lanka, and Bhutan. Red rices in Chhattisgarh and Jharkhand of *Bhama*, *Danigora*, *Karhani*, *Kalmdani*, *Ramdi*, *Muru*, *Hindmauri*, and *Punaigora* varieties are more nutritious, and their consumption provides enough energy for whole day's work without feeling hungry (Rahman, Sharma, Sahai, et al., 2006). People in Maharashtra during *Hal Shashti* and *Rishi Panchami* rituals abstain from taking food grown with the help of animals and take wild rice (*Oryza nivara*) and other self-grown plants. Brahmins and tribals eat wild rice during fast days (Ahuja, et al. 2001, 2007; Watt, 1891; Vaughan, 1994).

Before the advent of high yielding varieties, about 300 scented varieties exclusive to their respective areas were grown for the rich and noble classes. Of the various scented rices, basmati of Haryana and Punjab; *Ambemohar* of Maharashtra; *Dubraj* of Madhya Pradesh; *Joha* rices of Assam; *Kamod* of Gujarat; *Badshahbhog*

and *Radhunipagla* of Bengal; *Katrini* of Uttar Pradesh; *Kalanamak* of Uttar Pradesh, Bihar, and Nepal; *Jeera samba* of Tamil Nadu; *Gandhasambha* of Kerala; *Kalajira* and *Badshahbhog* of Orissa; and *Chakhao* rices of Manipur are some that are more well known. Basmati rice surpasses all in its size, shape, grain size, exquisite aroma, cooking quality, and taste which has made it the prince of rices (Ahuja, Ahuja, Thakrar, Shobha Rani, et al., 2008).

The rice crop provides a number of by-products such as straw, husk, bran, and broken rice. Part of the straw is used in preparing cardboard and paper for newsprint, in addition to its traditional use for thatching, grain storage structures, packing material, and religion (Hamilton, 2003; Ahuja, et al. 2013). The husk constitutes the largest by-product and one fifth of the paddy by weight. It has a considerable fuel value and is widely used as boiler fuel in the industry. Rice husks are also a rich source of silica. Rice bran is the most valuable by-product of the rice milling industry. It is obtained from the outer layers of the brown rice during milling. Rice bran consists of pericarp, aleurone layer, germ, and a part of endosperm. Rice bran is utilized in various ways as cooking oil, cosmetics, feed, and fertilizers. Rice bran oil is considered one of the healthiest oils for human consumption. Two interesting uses of rice mentioned in *Jatakas* and *Garud Puran* are the use of sour rice gruel in preparation of arrows and that of boiled rice in cleaning and perforating pearls (Kumar, 1988).

Rice is also converted into a number of alcoholic beverages, known to have medicinal value and to increase palatability in addition to their use as gifts and in personal, social and religious ceremonies (Ahuja, Thakrar, Ahuja, et al. 2001).

In addition to being the basic food of millions, rice is attributed with many medicinal uses. Rice meets most of the requirements of a good and healthy food. This is the only cereal eaten as a whole grain, which according to Ayurvedic texts is more easily digestible than flour (Ahuja, Uma, Ahuja, Thakrar, Rashmi, & Singh, 2008). The French traveler and diamond merchant who visited India in 1646 observed that wheat-eating people had more strength while rice eaters (red rices)

had more stamina (Ahuja, Uma, Ahuja, Thakrar, Rashmi, & Singh, 2008; Vir, Singh, & Tomar, 2005). The editor of the *Rice Journal* in 1938 recorded similar observations on sturdy Japanese and Chinese races and speculated, “May be our people would have better health and more energy if they ate more rice” (Anonymous, 1997). Rice is the main constituent of the life-saving oral rehydration solution (ORS). Ancient Ayurvedic treatises laud the *Raktasali* red rice as a nutritive food and medicine. The medicinal value of shashtika, Sali, and parched rice was documented in *Carakasamhitā* (c. 700 BC) and the *Suśrutasaṃhitā* (400 BC), in the treatment of various ailments such as diarrhea, vomiting, fever, hemorrhage, chest pain, wounds, and burns. Even today, certain varieties are used to treat skin diseases, blood pressure, fever, paralysis, rheumatism, and leucorrhea, as well as being used as a tonic for lactation. The famous *Nivara* rice of Kerala is widely employed in Ayurvedic practice as a body-enriching item, to exclude toxins and delay premature aging. Colored rice (black and red) is rich in minerals (iron and zinc) and polyphenols and possesses antioxidant properties. Traditional varieties such as basmati have a low glycemic index and are useful in weight-reducing diets. Rice-based ORS is known to be better than glucose-based ORS and has been included in World Health Organization recommendations (Ahuja, Uma, Ahuja, Thakrar, Rashmi, & Singh, 2008).

Rice in Indian Folklore

The ubiquity of rice is evident in all forms of folklore, myths, legends, stories, and folktales (Ahuja & Ahuja, 2010). However, its position in Indian folklore is unmatched elsewhere. Its perpetuity is evident in a mélange of ancient texts, proverbs, poetry, and sayings.

There are special transplanting songs in most Indian languages. *Romani* songs of Himachal Pradesh and *Ropani* songs of Bengal are quite interesting. Rice has a respectable place in riddles and proverbs of many Indian languages:

“Flattened rice, fried rice: but nothing like Boiled rice: mother paternal, mother maternal, but none like one’s own mother.” (a Bangla

proverb, Bhattacharyya, 1978) “No charity is greater than feeding the hungry stomachs with rice. It is surest way of getting the blessings from angels.” (a Malayalam proverb) (Ahuja, et al., 1997).

Surnames of some powerful Japanese are derived from rice such as Toyota, Honda, Nakasone, Sawada, Tanaka, and Narita (Huggan, 1995). Names of some important states and countries are based on rice, i.e., Nellore in South India (town of rice), Java, Sikkim, and Japan. Even names of many rites/ceremonies owe their names to this tiny grain as *Dhanpan*, *Bhat*, and *Tilchauli* (Ahuja & Ahuja, 2010; Ahuja, et al., 1997).

Fairs, Festivals, and Rituals Associated With Rice Cultivation

Many Asian festivals are tied to the agricultural cycle, and in many cultures, months are named according to the activity of the rice field. New Year starts with either the sowing or harvesting of rice. Cultivation of rice is hard work and must be carried out at the correct time for sowing, transplanting, weeding, and harvesting. To follow a strict timetable, people became accustomed to working in groups, leading to celebrations in the form of festivals and ceremonies at all crop growth stages, turning the hard job of rice production into joyous affairs. Thirteen festivals associated with rice cultivation are celebrated in Orissa in the span of a year (Ahuja & Ahuja, 2006, 2010; Ahuja, Thakrar, Ahuja, et al., 2000).

Rice and Religion

In India, rice is considered to have divine origin and is considered sacred. The religion is based on a feeling of fear of natural calamities, beyond the control of human beings. People worship nature gods such as Sun, Moon, and Mother Earth and their own ancestors to save themselves from their wrath and to get blessings by animal sacrifices. The ancient scripture forbade this act of cruelty toward animals and replaced it with an offering of rice.

Rice Goddesses

A panoply of rice deities and goddesses is found in Hindu India. *Annapurna* is pan-Indian deity for rice whose shrines are located in Varanasi in the north and Nellore in the south. Lakshmi, the goddess of all crops, is associated with rice, as in the preindustrial period, grain was the symbol of wealth and prosperity (Hamilton, 2003).

In India, even in areas where rice is not the mainstay of people, it is rice which is used in ritualistic observances (Hanchett, 1988). Rice is indispensable in many festivals for rituals both religious and otherwise. Farmers in Indonesia offer rice to the rain god to ensure favorable weather and a good crop, while the Chinese offer rice cakes to the monster god at the lunar New Year. Rice cakes are considered a symbol of prosperity. India is a country of traditions and an amalgamation of Vedic and tribal cultures and home to innumerable gods and goddesses. Worship and vrats are observed for family welfare and for fulfilling wishes or desires. Rice forms part of all these worships, vows, and festivals. Every religious ceremony in India starts with *tilak* (a mark made on forehead) with *akshat* (undamaged, washed rice). No religious ceremony is considered complete in the absence of *Akshat* or rice in some form.

Rice in Rites de Passages (Sanskara): In all traditional societies, the transition of life is observed and celebrated with ancient rites that predate written history. Rice is associated with the various rites of life in India, Indonesia, China, Malaysia, Thailand, Korea, and Japan. In Hindu ceremonies, rice is an emblem of purity, fertility, and prosperity and is thrown into the sacred fire during wedding ceremonies. Rice is an indispensable item and a figure in all rites of life, be it birth, marriage, death, or post death ceremonies.

Marriage is the most important event in anybody's life. In India, turmeric rice forms an integral part of the marriage invitation. The engagement ceremony is initiated with *tilak* of turmeric rice. The marriage ceremony starts with tying amulet-containing turmeric rice and ends

with a blessing of showering rice. The custom of welcoming a person by showering rice grains can be traced back to this ritual. It may be that the Western custom of showering rice during wedding ceremonies comes from the Hindu tradition. A *Kodava* marriage in Coorg offers a view of the extent of the use of rice in marriage rites. At least 13 times rice grains are used to complete the rites of various steps of a *Kodva* marriage (Ponnappa, 1986).

In most Asian countries, the concept of rebirth after death has evolved into elaborate ceremonies at death and after death to pay respect to the deceased person.

The deceased person is separated from the living, and the corpse must be separated from its spirit. Rites in death also involve much use of rice in different forms. Tribes in Assam, Orissa, Manipur, and Nagaland use rice beer and cooked rice in funeral rites. In South India, in the event of death of any person away from home, a mock cremation is conducted with bones and ashes. A replica of the figure is made with 360 *palas* leaves [*Butea monosperma* (Lamk.) Taubert, fire of jungle] over a black antelope skull, with 32 pomegranate seeds for teeth, and the people sprinkle rice grains over the figure. Then cremation is done (Crooke, 1896).

Forms of Rice Used

Ceremonial use of rice in various rituals in India is not of recent origin but dates back to the Vedic period (in ancient texts). Rice is offered as oblation to God, deities, village deity, and religious ceremonies; as alms to Brahmans and needy persons; and as part of festivals in different forms. An offering of unhusked rice (paddy); white unbroken grains, colored yellow (vermilion/turmeric), sun dried, cooked, fried, parched, and popped; rice flour; and rice beverages. Another form of rice used in religious ceremonies and tradition is rice flour and its paste. The paste forms part of the makeup of Kathakali performer in Kerala and also in making the ritual diagrams on the floor and walls.

Women create patterns using rice flour paste, wheat or barley flour, and rice powder mixed with turmeric, cow dung, and soil. Rice flour used in these designs becomes food for ants, insects, and birds. These are symbols that welcome the new bride and announce a marriage or a birth. These are also drawn on all ceremonies related to rites of passage from birth to death or after death *shraad* ceremony. Warlis of Bombay draw circular patterns with rice paste on the occasions of funerals and marriages. Likewise, *Sanja* wall motifs (drawn with rice paste and grain) of Madhya Pradesh, Rajasthan, Haryana, and Uttar Pradesh are drawn at the *Sharad* month to appease the ancestors. The tribal people offer rice beverages in order to propitiate the deities and use it in various ceremonial purposes, in rites of passage, and in rituals at various stages of the rice crop. Peasant Hindus do not employ rice beer (or fermented grain in general) in rituals.

Ceremonial rice use is not physical only but has symbolic values, too. Fried rice is a symbol of fertility. Hanchett (1988) identified the importance of rice in religious and social ceremonies in Karnataka and pointed out that other food items were used in rituals and rites and as offerings to God. Rice is a major symbolic element in ritual practices as food, as decorative item, or as object of play and medium of communication. Rice functions as a key symbol for Hindu culture. Its various cooked forms provide aesthetic guides and models for interpretations of life – birth, growth, maturation, and interrelationship – and even death and after death. Rice offering stands as a symbol for perceiving existence, consciousness, and experience in all things. Gupta (1991) explains, “Rice being one of the earliest cereals known to man, it started being associated with food and is often considered to be the creator. Rice being held sacred it is used in all religious ceremonies.”

Huggan (1995) says, “Rice is the mainstay of major population involved in its production. The loss of a rice crop can result in major human catastrophe.” In Asia, life starts with rice and ends with rice. Rice to an Iban farmer is life and

ancestor; to traditional Japanese, it means cool spirit; and to a Javanese, it is more than life and God (Ahuja & Ahuja, 2010).

The relation of rice, religion, and tradition is complementary; religion assures the conservation of rice varieties through its repetitive use in ceremonies, rites, and rituals.

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Rice in Korea

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Geography

Korea is a mountainous country, consisting of high mountains, hills, and valleys. Extended plains can be found on the western side of the Korean peninsula, where major rivers meet the West Sea. From the north to the south, Anju Bakcheon plains developed around the estuary of Cheongcheon river, Pyeongyang plains in the Daedong river, Jaeryeong plains in the Jaeryeong river, Yeonbaek plains between the Jaeryeong and Yeseong rivers, Gimpo plains in the Han river, Pyeongtaek plains in the Anseong river, Nonsan plains in the Geum river, Honam plains between Mangyeong and Dongjin rivers, Naju plains in Yeoungsan river, and Gimhae plains in the Nakdong river.

History

Rice planting in Korea can be traced back to 1000 or 2000 B.C. Archaeological evidence shows that people living on the Korean peninsula started to plant rice from the later period of the Neolithic Age or the early Bronze Age (National Museum of Korea [NMK], 2000, p. 11). In recent years, newly excavated archaeological evidence such as carbonized rice has reignited the discussions among archaeologists with respect to the origins of rice. Recent developments in scientific measurements have helped to determine the date of

plant opal, going back to even a. 3000 B.C. Carbonized rice and Neolithic tools such as stone hoes, plow shares, saddle quern, grinding stone, and pestles show that the ancient people lived in the areas where those archaeological items were found, cultivating grains such as rice, bean, millet, and other grains. The more precise date and place of the origin of rice is still debatable and open to more in-depth discussion. There are two different positions: one is the Chinese origin theory which has been widely accepted in the Korean archaeological scholarship, and the other is a new wild rice theory which is supported by the recently excavated plant opal showing the existence of wild rice that can be traced back to around 3000 B.C. (Ahn, Seung Mo, 1993, 1999; Lee, Ho Chol, 2004; NMK, 2000; Park, Tae Shik & Lee Yung Jo, 2004; Yim, Hyo Jae, 2001).

By the mid-Bronze age, rice cultivation was widespread on the Korean peninsula. Carbonized rice and pottery jars engraved by rice marks can be traced backed to the eighth to the seventh century B.C. The potter jars and the various farming tools which have been excavated evidence the cultivation of rice in the paddy. The carbonized rice has been found in many different locations in southern regions of the Korean peninsula, including Gangreung, Jinju, Sancheong, Yeosu, etc. (NMK, 2000).

Around this period, rice-farming communities began to form. Collective labor was crucial to rice farming. People came to live together and form social institutions in order to work together. After a while, such communities which were initially based on egalitarianism became stratified by power, leadership, and surplus production. In particular, since water control was significant for rice cultivation, those who could achieve efficient access to water were able to situate themselves as a ruling class. This eventually led to the establishment of a stratified political organization, chiefdom, or state (Kim, Bum Chul, 2005).

Farmers in Korea began to use iron tools for rice cultivation a. second to first century B.C. More importantly, historical records show that large-scale hydraulic facilities were constructed during this period. By the third

century A.D., people were able to control water by constructing dams and reservoirs. Sometimes, new paddies were created by building dikes along the river (NMK, 2000).

In around the fourth to fifth centuries A.D., rice production increased due to two different but closely related developments: the development and spread of iron farming tools such as rakes, shovels, axes, iron spades, and sickles on the one hand and the increase of farming populations who could use such iron tools on the other. For example, iron spades which were used for pulling and distributing water onto the paddies were found on the Korean peninsula around the fifth century A.D. but not in China or Japan during the same period. The use of these iron spades evidence the utilization of high technology in rice cultivation with irrigation systems (NMK, 2000).

There was a great increase in rice production as a result of the advancement of iron farming tools and the use of the cow to plow paddies. According to the old historical book called *Samguksagi* or the *History of the Three Kingdoms Period*, in the reign of King Jinjeung (502 AD) cow plowing was encouraged by the state (NMK, 2000, p. 84). In addition, many irrigation facilities were constructed around the sixth century. The detailed records about dam construction were found in several significant monuments erected around that period: Cheongje Monument in Yeongcheon and Musul Ojak Monument erected in 561. These records indicate that the irrigation facilities made it possible to enlarge paddy lands and increase rice production. Also as a result, farmers of that period were able to cultivate various grains both in paddies and dry fields (NMK, p. 85).

Irrigation systems were efficiently controlled by the state. The construction of many dams, dikes, and reservoirs were under the control of the central and local governments. Gradually, more and more local governments took over the establishment of irrigation systems such as constructing smaller-sized dikes and dams.

During the Choson Dynasty (1492–1910), advancements in rice farming consisted of the development of a systematic agricultural policy

and growing scientific research on rice. Many books related to agriculture written by renowned scholars were published. One of the noticeable developments in rice farming in the later Choson period was the introduction of transplanting and two-cropping. Farming tools were also developed in order to adapt to each region's soil and geographic features. Hundred and ninety-one different tools were recorded in the tool book written in the later Choson period. But records indicate that there were only about 40 different kinds of tools in the earlier Choson period (NMK, 2000).

During the Japanese colonial period (1919–1945), modern farming technology was implemented mostly by Japanese landlords and the colonial government. The main purpose of the implementation was to increase rice production. Many agricultural development policies were implemented including the introduction of new varieties of rice, utilization of fertilizers, construction of new dams and dikes, establishment of irrigation cooperatives, land reclamation in wasteland, seashore, estuaries, etc. Because of these developments, agricultural lands expanded from 1,320,000 *chongbo* (area unit used in Korea, 1 *chongbo* = 1 ha) in 1920, the very year of annexation, to 1,640,000 *chongbo* by 1941. Rice production had a corresponding increase from 12,400,000 *sok* (volume unit used in Korea, 1 *sok* = 180 l) in the 1910s to 25,000,000 *sok* in the 1940s. The production rate per are almost doubled from 0.77 *sok* per 10 are in the 1910s to 1.5 *sok* per are in the 1940s. However, the increase in rice production was outpaced by the increase in rice exports to Japan (NMK, 2000).

During the postliberation period (1945–1953), which was marked by chronic political instability, rice production in the Korean peninsula dropped to about 1.2 *sok* per are. The postcolonial government tried to rejuvenate rice production through various political means. One of the major problems faced by the government was a high tenancy rate which led to social and political clashes between wealthy landlords and poor tenants. The government forced land reform by implementing a return-land-to-cultivator policy in 1948. This reform contributed considerably to the establishment of a majority of petty

landowners who grew rice for themselves on their own land. Though much criticism has been levied toward the postcolonial land reform, evidence indicates that the reform turned out to be a successful farm policy overall.

Green Revolution in Korea

During President Park Cheong Hi's regime (1961–1979), a series of state-run economic development projects were implemented with vigorous enthusiasm. Because of chronic rice shortage faced by Koreans during the 1950s–1960s, there was an urgent emphasis by the state on increasing rice production. Dam constructions, repairs of old irrigation facilities, rearrangements of paddies, and expansions of arable land through reclamations were undertaken throughout the entirety of South Korea. New varieties of rice such as *jaegeon* (revival), *jinheung* (progress), *sinpung* (new wind), and *hogwang* (bright light) were bred. The yields associated with some of the new varieties, such as *tongil byeo* (reunification, IR667) among others, were successful in that the yield was double or triple of the yields associated with old varieties. Most farm households planted *tongil byeo* in the 1970s. It is interesting to note that the names of new varieties implied development, progress, and innovation. By building large-scale fertilizer plants, it was possible to increase production of chemical fertilizers in order to distribute widely to farm households. Government subsidies also provided financial support to cultivators for the purchase of weedkillers, pesticides, and insecticides. The state-driven rice production increase contributed greatly to the easing of food shortages and the stabilization of rice supply to consumers. The mechanization in agriculture also reinforced the increase in yield with a decrease in labor. In the past, rice cultivation was a very labor-intensive agricultural practice, but presently, the entire process, from transplanting to harvest, has been completely mechanized.

Total rice production in South Korea increased from 3,920,000 t in 1966 to

5,210,000 t in 1976. The production rate also greatly increased from 287 kg to 429/508 kg per 10 are (NMK, 2000, p. 196; Statistics Korea, www.index.go.kr). The green revolution that South Korea achieved in the 1960s–1970s is attributable to the strenuous efforts by all stakeholders, including policymakers, administrators, researchers, and cultivators.

Industrialization and Rice

Since the 1980s, the decreases in acreage of paddies and the farming population have been prominent (Figs. 1 and 2). Industrialization and urbanization have continuously shrunk the agricultural economy, which had always been the backbone of the nation. In addition, the eating habits of Koreans have gradually changed to result in a substantial reduction in rice consumption.

There is another factor threatening rice farming in Korea. Global market pressures have made their mark on South Korea's protectionist policy regarding rice farming. Korean farmers and their supporters insist that rice is important for Koreans not only as a staple grain but also because of an emotional attachment. Their position is that given the special status of rice within the Korean culture, Korean rice farming must be protected from global market competitions. Admitting the national sentiment or cultural nationalism, South Korean government has so far kept rice out of the Free Trade Agreement (FTA). However, such protectionist policies are due to run out. In 1994, the South Korean government made an agreement on rice import quotas with the World Trade Organization with a 20 year term. With the expiration of this agreement in 2015, South Korea will be opening its rice to the global market.

From the 1960s to 2005, the South Korean government purchased rice directly from producers after the harvest. The purchase price was negotiated between the government and farmers. As the government's protectionist policies come to an end due to the pressures of the global market, the government has set up an alternative

strategy in order to mitigate negative impact on South Korean farmers. The government is purchasing rice for storage in public granaries and thus protecting the rice farmers from the ups and downs of supply and demand in rice. It is an important and necessary measure, according to the government, to strengthen food safety.

At present, import of rice from China, USA, Thailand, and Australia is increasing. The imported rice makes up 8 % of total rice production. Most imported rice is sent out to North Korea and other developing countries but is also consumed domestically (Statistics Korea, www.index.go.kr) (Fig. 3).

How to Grow Rice in Korea?

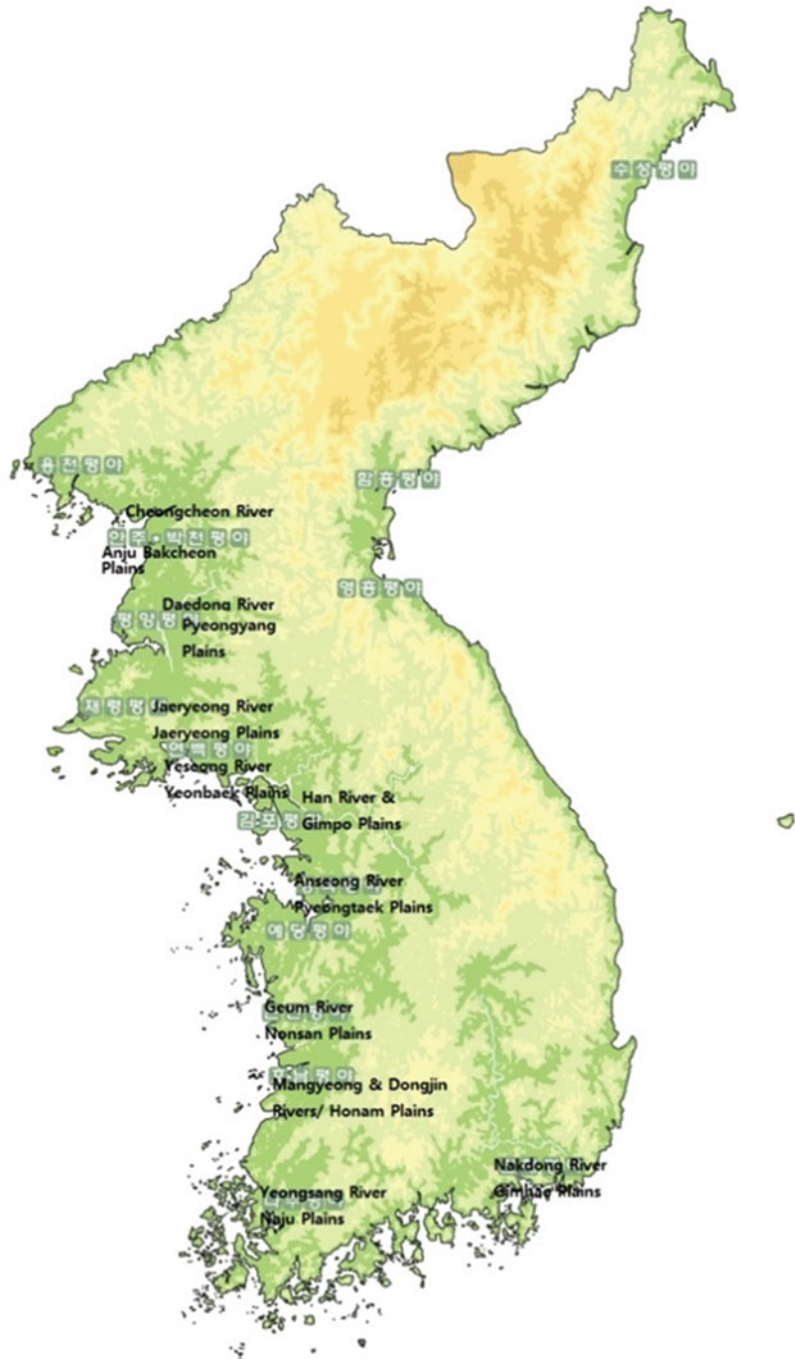
The preparation for rice cultivation starts in early spring, February or March. Farmers have always observed a farming schedule based on the 24 seasonal divisions, which originates from an old Chinese system. A year is divided into 24 seasons measured by the ecliptic longitude so that the 24 seasonal divisions for farming are congruent with the solar calendar. Given the fact that the lunar calendar was widely used in the past for everyday life, farming schedules were carefully set using celestial science (Table 1).

Culture of Rice: Different Entities and Meanings of Rice

In the minds of Koreans, rice does not exist as a single object. Rice is simplified in the Western way of classification. In comparison to the Western thought of rice as a single entity, in Korean thought, there are three to four different identities within the single physical concept of rice, and each identity delineates a different function and meaning for the general concept of rice. Koreans are confused by the Western way of classification of rice as a single object. Koreans have developed their own way of epistemology of rice based on its long history of agricultural livelihood (Hahm, Hanhee, 2005).

Rice in Korea,

Fig. 1 Plains and rivers in Korea (Source: Korea Digimap <http://koreadigimap.co.kr>)

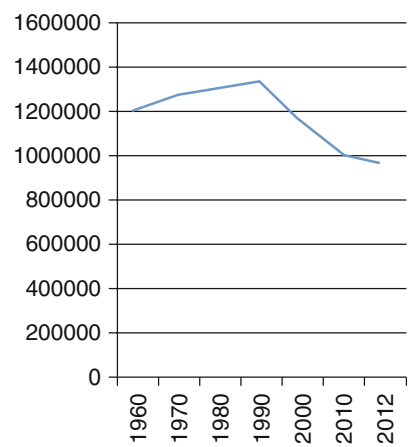


The English term, *rice*, has four different terms and meanings in Korean; *mo* is a very young stage of the rice plant; *byeo* means its later stage and is distinguished from *mo*; *ssal* means hulled grain; and *bap* means cooked rice.

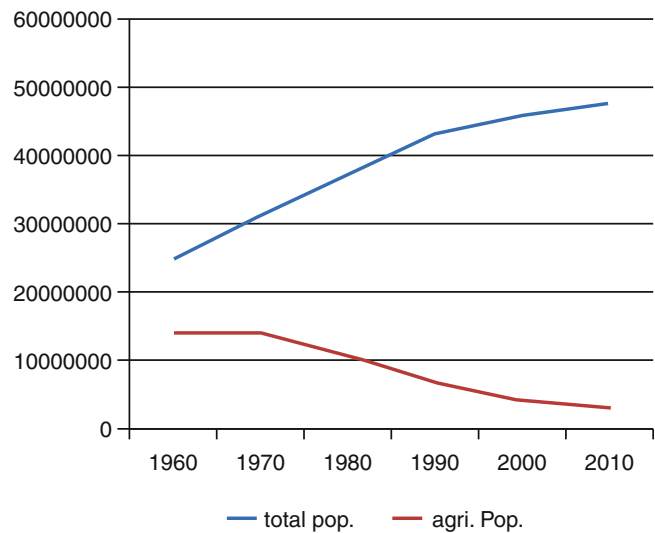
This linguistic difference between English and Korean is also directly related to the fact that speakers of each language understand the object (s) in a different way. Unlike in English, the articulations of rice in Korean have been

Rice in Korea, Fig. 2 Area of paddy, 1951–2012

year	Area of Paddy (unit: ha)
1951	1,149,650
1960	1,209,252
1970	1,272,954
1980	1,306,789
1990	1,345,280
2000	1,149,041
2010	1,010,287
2012	966,078
Source: Korean Statistical Information Service, 2012 Statistics of Agricultural Area	



Rice in Korea, Fig. 3 Total and agricultural population, 1960–2010 (Source: KOSIS, <http://kosis.go.kr>)



meticulously developed to describe rice in terms of growing, producing, and cooking.

The Stage of *Mo*

Farmers begin to prepare for rice farming in the early spring. They nurture seedlings from the seeds and plant them in the seedbed during April and early May. The seedlings are called *mo*, and the seedbed is *mop'an* (Picture 1). After waiting for about a month while *mo* grows in the seedbed, farmers transplant the baby *mo* to the rice fields in May and early June. Traditionally,

transplanting was the most difficult farm job. It required intensive labor in a short time period. Group work or cooperation among neighbors was indispensable to the completion of this task, and therefore, before the mechanization of the Korean agriculture industry, farmers established various forms of labor cooperatives such as communal work and labor exchange institutions in order to cope with the large amount of work necessary for transplanting (Pictures 2 and 3).

After transplanting, *mo* grows quickly in fields filled with water. *Mo* grows into *byeo* under the summer heat. Once the plant grows large enough to cover the field, farmers call it *byeo*. In the early

Rice in Korea, Table 1 The 24 seasonal division calendar and farming activities (sources: *sesi pungso*k published by Korean Cultural Heritage Foundation, and posted in the homepage of National Folk Museum, www.nfm.go.kr. '24 jeolgi' and 'sesi pungso'k'; Research Institute of Agricultural Cooperative Economy & Humanities Research Center in Kyeongbuk National University, 2007, *Farming Culture seen through Oral Data*. (in Korean))

Lunar cal.	24 seasonal divisions	Solar C. (approx.)	Farming activity (rituals)
1	<i>ipchun</i> [enter into spring]	Feb. 4	Slack season (New year day, full-moon day rituals, <i>ipchun</i> posting for good fortunes)
	<i>usu</i> [spring rains]	Feb. 19	
2	<i>gyeongchip</i> [frogs out of sleep]	Mar. 6	Start to plow paddies
	<i>chunbun</i> [the vernal equinox]	Mar. 21	
3	<i>cheongmyeong</i> [prepare to farm]	April 5	Prepare/purchase seeds and soak them in salt water
	<i>goku</i> [raining for crops]	April 20	Prepare a rice seed plot and sow rice seeds in seed-plot
4	<i>ipha</i> [enter into summer]	May 6	Plowing and harrowing a field.
	<i>soman</i> [start to farm]	May 21	Spreading fertilizers
5	<i>mangjong</i> [sowing seeds]	June 6	Transplanting
	<i>haji</i> [the summer solstice]	June 22	
6	<i>soseo</i> [summer hot days]	July 7	
	<i>daeseo</i> [very hot days]	July 23	
7	<i>ipchu</i> [enter into autumn]	Aug. 8	Watering
	<i>cheoseo</i> [summer heat dwindled]	Aug. 23	(Big festivals held for farm laborers)
8	<i>bakero</i> [clean dews drop]	Sept. 8	Preparation for harvest
	<i>chubun</i> [the autumnal equinox]	Sept. 23	Cutting & thrashing
9	<i>hanro</i> [cold dews drop]	Oct. 8	(Full-moon day ritual for thanksgiving)
	<i>sanggang</i> [frosts drop]	Oct. 24	
10	<i>ipdong</i> [enter into winter]	Nov. 8	
	<i>soseol</i> [snow falls]	Nov. 23	
11	<i>daeseol</i> [big snow falls]	Dec. 7	(Eat red bean porridge; expel rituals ghosts & evil spirit)
	<i>dongji</i> [the winter solstice]	Dec. 22	
12	<i>sohan</i> [cold days]	Jan. 6	Slack season
	<i>daehan</i> [very cold days]	Jan. 21	

fall, *byeo* starts to ripen. In July, *byeo* develops ears of rice. At the end of the summer, *byeo*'s head bows as the ears of rice get heavier. An ear of rice is called *isak*, and the plant whose ears get heavier is called *isak paenda*. The ripeness of ears of rice alerts the farmers to harvest time. Farmers are ready to harvest in the early fall (Pictures 4 and 5).

Byeo Seen as Heaven's Offering

It takes 6–7 months for the sprouting *mo* to transform into the harvest *byeo*, depending upon the natural environment. *Mo* and *byeo* are different stages of the rice plant. They are natural resources that the farmers believe belong to Nature,



Rice in Korea, Picture 1 *Mopan* around the end of May



Rice in Korea, Picture 2 Transplanting in June

Heaven, or an agricultural god regardless of who physically owns the plants. According to farmers' understanding of cosmology, the farmers are responsible for the rice plants and must take care of them, but the eventual success of a

farming season and a good harvest is always in the hands of supernatural forces. The farmers must ask help from these gods every step of the way. Every year, from the first day of New Year to the completion of the harvest, farmers dedicate

Rice in Korea, Picture 3

Mo is growing in paddy in July

**Rice in Korea, Picture 4** *Byeo* is ripening in September

various religious rituals to god(s) with sumptuous food sacrifices.

Because of the farmers' beliefs that *mo* and *byeon* are provided by the god(s), the farmers are open to collectively caring for *mo* and *byeon*. They share labor, tools, farming animals, and information. This system of cooperation for planting and growing *mo* and *byeon* is the traditional norm. The

farmers who grow *mo* and *byeon* consider themselves to be legitimate cultivators acknowledged by Heaven. There is a Korean classic expression, "Farmers are the foundation of the world (*nongja chonha ji daebon*)."

They are expected to cooperate with each other, be humble so as to hear the voice of Nature, follow the rules of the agricultural god, and wait until Heaven's orders. During



Rice in Korea, Picture 5 Harvesting season

the *mo* and *byeo* planting season, farming villages are filled with the spirit of cooperation, modest sense of living, and spirituality. In fact, at each stage of the rice season, farmers used to regularly practice worships for Heaven and gods who are in charge of rain, land, and agriculture and all other gods related to farming. These religious rituals are accompanied by village festivals.

In order to grow *mo* and *byeo*, farmers form various work units. The smallest work unit is a family, and a larger unit is made up of neighbors. The largest team is the village communal work team which comes together for the transplanting season regularly each year and also on special occasions for the construction or repairs of reservoirs and water routes. The village work team helps poor families that do not have enough labor resources to independently farm. The elderly, widows, and sick people benefit from the village cooperative work team.

***Ssal* as Commodity**

In the fall, farmers are busy harvesting the fully matured *byeo* with heavy ears. When a field

becomes covered by the fully grown golden *byeo*, Koreans call it the golden rice field. The term has double meaning. The golden color implies a good harvest and farmers' happiness as a result. Gold also implies money and wealth. In the agricultural economy, rice was used as a monetary exchange unit. Once *byeo* turns gold, its character changes as well as its color and shape. Unlike immature *byeo*, the golden *byeo* is ready to become a commodity. Matured *byeo* is thrashed and yields *ssal*, the husked rice. After *ssal* comes out of *byeo*, it no longer belongs to the realm of Nature and Heaven but belongs to the owners of the rice field. It means that *ssal* is a commodity and becomes enmeshed in the Korean political economy (Picture 6).

Summary

English speakers do not differentiate between *ssal*, *byeo*, and *mo*, which are three different objects for Koreans. Koreans have heightened awareness of the differences in the rice plant in each growing period. The rice plant has a different identity, as well as a different name, for each



Rice in Korea, Picture 6 *Ssal*

period of its development. I have analyzed the stages of *mo* and *byeo* together because the two stages have common cultural characteristics. However, *ssal*, unlike *byeo* and *mo*, raises issues of rent payment, tenancy contract, ownership of land, state taxes, market prices, etc. Landowners tried to get more *ssal* out of the land, and the government found ways to collect more taxes on the *ssal*. Historically, *ssal* was an object which was firmly controlled by the wealthy and the powerful in Korea.

As long as *ssal* remains a valuable economic resource, people compete with each other for limited ownership rights. The ruthless competition over a valuable resource creates conflict between the haves and the have-nots. During the Choson Dynasty, there were significant class conflicts between the *yangban* (noblemen) landlords and the peasant cultivators. The angry peasants who were often stripped of their legitimate share of yields by the *yangban* landlords fought against exploitation. Many of the poor peasants at the time did not possess enough land for subsistence so they were forced to rent agricultural land from rich landlords and paid annual rent to the landlords. From the Choson period to the colonial period, rent for agricultural land in Korea was 50–60 % of the total yield. The tenants paid rent with rice, usually in the husked form. Agents of the landlords collected rent on the spot at the harvest.

In the industrialized South Korea, farmers consist of less than 6 % of the South Korean population, and the agricultural economy constitutes 2.3 % of the nation's GDP as of 2011 (The Korea National Statistical Office, <http://kosis.nso.go.kr>; Han, Jang, Cho, & Park, 2011). Contrary to the numerical representation of agriculture in such economic indices, however, rice still retains an exceptional position in the mind and thought of Koreans. They have special cultural attitudes and historical memories of rice which have contributed to continued importance of rice in Korea despite evidence of decreased consumption.

First, Koreans are proud of the history of rice planting in their country. Evidence indicates that Korea was using advanced irrigation technology and facilities even in the early historical periods.

Second, the long history of rice cultivation has been embedded into the day-to-day culture of Koreans. From eating habits to religious beliefs, Korean culture cannot be understood without an understanding of the rice culture.

Third, the political economy of rice has been a scorching issue throughout Korean history. Mainly class conflict between wealthy landlords and poor tenants has been the focal point of social unrest. Antagonism between landlords and tenants often ended with tragic battles in village societies during the Korean War.

Rice has long been the major staple for Koreans. Koreans still prefer to eat rice at every meal. The ordinary Korean meal table, which is the same for breakfast, lunch, and dinner, consists of cooked rice, soup, kimchi, and various side dishes. The westernized lifestyle which has been adopted by many city dwellers allows them to have more options for meals such as bread for breakfast, noodle dishes for lunch, and pizza or meat for dinner. However, a recent survey indicates that 69.3 % of Koreans continue to eat rice for breakfast every day even though preparation for a meal consisting of rice and side dishes is far more inconvenient than preparing a western-style breakfast (Yeon-Seo Mun, Eun-Kyung Jung, Nami Joo, & Ji-Young Yoon, 2011). Another study shows that in contrast, the Japanese and Chinese have changed their eating habits in that



Rice in Korea, Picture 7 Korean table (*habsang*)

they prefer bread to rice at breakfast for the sake of convenience (Ahn, Myeong Su, 1992). Koreans tend to be more conservative in their eating habits than the inhabitants of the other two East Asian countries where rice has historically been the staple grain. Moreover, many South Koreans still believe that rice should be protected from free competition in the global market (Picture 7).

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Rice in Taiwan

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Taiwan is a small country located in Eastern Asia. It is about 161 km away from the southeast part of China and about 483 km north of the Philippines. The exact location is 120°E–122°E and

22°N–25°N. The Tropic of Cancer passes through the center of Taiwan. The south part of Taiwan is considered tropical and the north subtropical. The characters and habitat of the rice in Taiwan are quite unique because (1) there are many high mountains and rice has been grown from sea level to high altitude, (2) rice may be grown from February to November each year, and (3) both japonica and indica rice varieties are cultivated. For thousands of years, people in Taiwan selected several important traits such as insensitivity to photoperiod and semidwarfism that have affected modern rice cultivation in the world.

The arable land in Taiwan is about 803 kilohectares, and half of the land consists of paddy fields for rice production. Because the temperature from February to November is suitable for rice growth, rice is grown twice a year. The first cropping season is from February to June and the second from July to November. In the first cropping season, both temperature and day length increase from germination to harvesting and in the second, both decrease. Wild-type rice is a short-day plant in that it flowers when the day length is shorter than the critical day length (usually 14 h). If genes controlling day length sensitivity are not mutated, as in most modern varieties in Japan and Korea, rice could not be grown twice a year. Instead, they would flower and set seed very early, such as about 1 month after germination, or very late, such as more than half a year after germination. In previous times in Taiwan, people selected lines with insensitivity to day length. Thus, rice could be grown in different places at any time of the year as long as the temperature was suitable. Another trait selected in Taiwan that is important for world rice production is semidwarfism. Rice plants with this trait have a strong culm [stem] and are resistant to lodging and thus may improve yield production.

Rice in Taiwan in Ancient Times

Taiwanese aborigines were the original inhabitants of Taiwan. Their ancestors may have been

living on Taiwan and its surrounding islands for approximately 5,000 years before the major Han Chinese immigration began in the seventeenth century. Taiwanese aborigines are Austronesian peoples, with linguistic and genetic ties to other Austronesian ethnic groups such as people of the Philippines, Malaysia, Indonesia, Madagascar, Polynesia, and Oceania. Archeologists recently excavated the remains of several early cultures in Taiwan. The most plentiful plant remains were carbonated rice and foxtail millet grains. The earliest ^{14}C date of these excavation sites is ~5,000 BP. Sequence analysis of early aboriginal Taiwanese rice landraces suggested they were japonica rice. The aborigines first stayed in the plains area; some then moved to mountain areas. Both japonica and indica rice were cultivated in each village. The cultivated practice was basically upland or dry farmland. Several of the accessions consisted of important mutations in genes controlling insensitivity to day length.

Rice in Taiwan in Earlier Times

When Han Chinese moved to Taiwan in the late Ming and early Ching Dynasties, they brought paddy-field rice cultivation practice and tools as well as many indica rice landraces. Rice cultivation has been in paddy fields since then. More than 1,000 indica accessions were grown, all in paddy fields. During that period, many “early” and “semidwarf” lines were selected and fixed. Examples are *Ching-Yu-Tsau* from *Ching-Yu* and *Tsau-Chan* from *Chan* (*Tsau* means early). *Dee-Geo-Woo-Gen* (DGWG) was selected from *Woo-Gen* and *Dee-Geo-Hoe-Le* from *Hoe-Le* (*Dee-Geo* means semidwarf). About 100 years later, these important traits were used worldwide for modern varieties.

Rice in Taiwan During Japanese Colonization (1895 to 1945)

Japanese prefer the taste and texture of japonica rice to indica rice. Early during their colonization, the Japanese tried to improve the existing

indica rice accessions in Taiwan. They selected 175 landraces from the 1,197 accessions and promoted only these races. Later, they tried to grow japonica rice in Taiwan. They brought many Japanese accessions to Taiwan and tried to acclimatize them. The early attempt failed because of the slow growth and low yield. In 1924, two Japanese rice breeders used two Japanese landraces, Kameji and Shinriki, as parental lines for cross-breeding. Five years later, the new variety Taichung 65 was produced. After the first success, many more japonica varieties were bred and cultivated. The rice was more sticky and soft than the normal indica rice and people adapted to the varieties quickly. In 1935, the cultivated area was greater for japonica than indica, with continually increasing area. For 60 years, the major type of rice consumed in Taiwan changed from indica to japonica.

Rice in Taiwan After the WWII

Breeding programs for both japonica and indica rice were emphasized during the 1950–1970s in Taiwan. One well-known indica variety was Taichung Native 1 (TCN1), from the two parental lines DGWG and Tsai-Yuan-Chon. This was the first semidwarf rice variety in the world. The International Rice Research Institute (IRRI) was established near Manila in 1960, and Dr. T. T. Chang, a well-respected Taiwan rice breeder, was invited to move there. He brought several good germplasms, including TCN1 and DGWG, to IRRI. TCN1 was first cultivated in India, and its yield was much higher than the local varieties. Dr. Chang and another IRRI rice breeder, Peter Jennings, worked together and made several crosses. The combination of Peta (landrace from Indonesia) and DGWG had very good agronomic traits; the new variety was designated IR8. This was a semidwarf rice, about 120 cm tall, with a strong stem that held the plant upright even when heavily fertilized. In addition, it was insensitive to day length. IRRI scientists quickly demonstrated that IR8 rice yielded about 5 t/ha with no fertilizer and almost 10 t/ha under optimal conditions. This was

10 times the yield of traditional rice. With the insensitivity to day length, the rice could be grown in many latitudes and at any time of the year. This variety was successful throughout Asia and designated the “miracle rice” in the late 1960s. IR8 played an important role in world agriculture because it fed the fast-expanding world population and was known as the “green revolution” rice. Until current times, DGWG was used in the pedigree of about 90 % of the world’s indica rice breeding programs.

The breeding program for japonica rice during this period emphasized non-lodging, high yield, and resistance to pathogens and insects. Grain quality was not the major goal for breeding purposes. For instance, Tainung 67 was the leading variety, occupying at least 70 % of the cultivated area for 20 years. Although indica rice was still cultivated, most was used for food processing.

Rice Cultivation and Utilization in Current Times

After the economy improved in Taiwan, many changes occurred in rice breeding, cultivation, and utilization. For japonica rice, grain quality became an important factor: good taste, aroma, low chalkiness, and good texture. For indica rice, breeders crossed indica and japonica, and the new varieties had a similar texture to japonica rice, with less amylose content as compared with the indica varieties in Southeastern Asia. Cultivation moved to mechanical farming, so a strong culm was important. Currently, the cultivation area for japonica, indica, and glutinous rice in Taiwan is 87, 8, and 5 %, respectively. Rice is grown in both cropping seasons in about 81 % of the paddy field, about 4 % and 16 % of the field only for the first and second cropping season, respectively. The production is enough for self-consumption, with only a small amount for export.

Rice is also used for food processing. Mainly two types are used: the indica type with high amylose content and glutinous (sticky) rice. The processing involves whole grain, milk/paste, and fermentation. The products of whole-grain rice

include rice rolls, pearl pillion [a dessert], and fried rice. The products of milk/paste rice include rice noodles, rice pudding, rice tube pudding, rice cakes, and rice dumplings. The products of fermentation include rice wine, rice vinegar, and sweet fermented glutinous rice wine.

Rice and Life in Taiwan

Rice has been the major staple food in Taiwan for thousands of years and is very important in Taiwanese culture. For instance, “rice bowl” means job, and “eat soft rice” means jobless. Rice is also used in several village names, such as “Tien-Chun” (between rice field) and “Da-Dau-Chen” (big rice wall). Many bridges were constructed with bricks and rice paste, a mixture of glutinous rice and brown sugar. Rice is also important in religion and ideology. Rice puddings are always used for worship of ancestors or gods. Rice has been combined with the land deity temple in many villages.

Rice Paddy Storage in India

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Since ancient times, Indians have realized the importance and need of grain storage in the wake of their seasonal production (one harvest a year), proneness to weather vagaries, and importance as a major food. The Indians developed methods to store grains to ensure household food supplies. Storage of paddy grain, seed, and rice becomes of utmost importance, being the staple diet of two-thirds of the Indian population. Now storage is undertaken at the producer, consumer, trader, and government levels. The bulk of the rice crop is stored as paddy as the grain keeps far better and for a much longer period and it is husked when

required. The method and structure of storage may differ depending upon users' requirements, weather, climate, and level of storage.

Bulk Storage: Government Level

Various kings in India stored grains. Storage structures are mentioned in ancient scriptures such as *R̥gveda* (8000 BC), *Yajurveda* (3000 BC), *Sāmveda*, and *Samhitās* (7000 BC) (*Panini*, 600 BC; Varāhmihira, 505–587 AD) (*Misra*, 1982). These were referred to as *stivi* in *R̥gveda* (Pandey, Dubey, & Pandey, 2000). Grain storage in well-built granaries was described in Kautilya's *Arthaśāstra* (325–296 BC) and Vishwakarma's *Vastuśāstra* (Ahuja et al., 2010).

The remains of grain storage structures of different periods have been found in various sites in India. Granaries evolved from mud to brick platforms and to pit silos. The well-ventilated granaries in Harappa were on a mud platform with corridors between them. In Mohenjo-Daro (2500–1750BC), the granary was built of wood which disappeared and left a massive brick platform with steep sloping sides and blocks arranged crosswise to facilitate air circulation (Pandey et al., 2000). Storage in granaries built later in the Indus Valley (2500–1500 BC) was on a large scale and of a sophistication never matched later in India's history (Achaya, 1998). The granaries in compartments were well ventilated and well built with baked bricks (Wheeler, 1968). Later, granaries excavated at Inamgaon (Maharashtra) of Mid-Chalcolithic (1750–1000 BC) are characterized by pit silos with round mud platforms for keeping storage bins (Dhalvalikar, 1975–76).

During the Buddhist period (c. 500–100 BC), grains after cleaning and sealing in clay pots (*ghadā*) were stored in private- and state-owned stores called *kotār* or *kshtagar* (Jain, 1947). Storage of grains in well-built granaries provided with all necessary amenities for the protection of grains has been described in *Arthaśāstra* of Kautilya (325–296 BC) and *Vastuśāstra* of Vishwakarma (Pandey et al., 2000; Pranjape, 1993; Raychaudhuri & Roy, 1993; Sensarma, 1998).

Producer Level: Estimates reveal that 60–70 % of food grain produced in India is stored for seed as well as for consumption at home in indigenous storage structures. The storage techniques for both differ slightly as seed needs more careful handling. The seeds are stored in pots, boxes, baskets, or bags, while bulk grains are stored in storage structures. The seed is considered an important entity in agriculture since ancient times and references to its collection, preservation, and storage are found in ancient treatises. *Kashyapiyakrishisukti* refers to seed storage as the first duty of a farmer for the prosperity of his house and states that seed storage and its distribution in the proper season is the King's duty (Ahuja et al. 2010).

In the mid-historic period (beginning of Christian era to 1200 A.D.), seeds were stored in receptacles made of straw and leaves with the inside space coated with cow dung. Granaries made of earth, straw, or bamboo, standing on pillars, the upper storey of houses covered with lids coated with cow dung, and further coated with mud all over, closed and sealed with earthen rods, are all referred to in the ancient literature (Jain, 1947).

Various surveys came across different type of traditional storage containers and structures used since the mid-historic period. Indigenous storage practices were fulfilled by indigenous structures designed by farmers themselves with freely available materials at an affordable cost. The selection of a storage system by an ethnic group is related to climate, local natural resources, and customs. Clay provided an impervious coating which would not admit insect pests. Various plants and products used in the top cover and inside had insect deterrent action. Certain practices were unique to a given culture and vary between regions, villages, and even communities.

Storage structures could be indoor or outdoor, temporary or permanent, and underground or aboveground and could be individual or community based in the form of bins, mud houses, bamboo houses, brick houses, or some combination of these. The Rural and Agricultural Glossary of Crooke (1888) offers a number of terms associated with various types of house granaries such

asdhundki, bandā, dālā or korangā, bakhār, bakhārī, bukhārī, chauras, chahrasī, dehrī, kano, khātā, khātla, khāti, kothi, thekī, kuthlā, kotār, kothila, or kothī.

Storage Containers for Seeds

Earthen pots are made up of burnt clay with a capacity of about 5–10 lits and provide a storage time of about 2 years. The pot is topped up with dried leaves of *Pongamia pinnata* (L.) Pierre and *Azadirachta indica* A. Jussieu. These are called *matkā* (Haryana, Rajasthan, HP, Uttar Pradesh, Punjab, Bihar, M P, Jharkhand), *Kulukkai, sal* (Tamil Nadu), and *Utrani* (Dharwar). Sometimes the pots are arranged one above the other vertically in descending order based on their size from the bottom to reduce the space requirement and these are called *Paanai* or *Addukkupaanai* in Tamil Nadu (Kiruba, SamManohar Das, & Papadopolous, 2006).

Dry land farmers generally stored seed in jute bags. The advantage of using bags is that infested bags can be removed and treated easily and such storage also avoids the problem of the “sweating” of grains because the surface is exposed to the atmosphere (Kartikeyan, Veeraraghavantham, Karpagam, Firdouse et al., 2009).

In humid areas seeds are stored in tightly woven bamboo containers of different capacities 5–10 kg. These are plastered with mud and cow dung on the inner side and for sealing. Their shape may be conical, cylindrical, or spherical according to the dictates of custom and convenience. They are known by different names in different regions as *Khaniki* in Koraput Orissa, *Rigal, tukuri* in Assam, *Urai* in Tamil Nadu, and *Chabri* in Himachal Pradesh (Sarangi, Singh, Singh et al., 2009).

About 100–250 kg of produce is stored in replaceable bins constructed regularly with straw, mud, bamboo, wood, or some combination of these. In areas of heavy rainfall (in the North-east and Uttarakhand) where grain cannot be dried adequately prior to storage and needs to be kept well ventilated during the storage period,

traditional granaries are usually constructed with timber, reeds, midribs of toddy palm, or bamboo. Bamboo structures are made on a raised timber or stone platform to protect the grain from rat damage and prevent moisture absorption from the ground. They are called by different names such as *mar*, *dully* (Northeast) and *Urai* (Dharwar). A small pothole is left at the top which is closed by *Cymbopogon* sp. Hackel (ginger grass). In Karnataka (*Kanaja/Galagi*) and Himachal (*Peru*), bamboo structures are plastered with a mud and cow dung mixture to prevent spillage and pilferage. Seeds are often stored in *Peru* as the germination rate of stored seed is high. The *Worli* tribe of Maharashtra state store paddy inside a cylindrically folded bamboo mat coated with dry grass and mud.

Straw or rope bins are the most effective indoor storage structure in Bengal, Bihar, Tamil Nadu, Orissa, and Jharkhand. They are called *Mora* (Jharkhand), *Dhoosi* (Koraput Orissa), and *Thallpai* (Tamil Nadu) and have a capacity of about 100 kg. The paddy is enclosed in loose straw and bound together by means of straw ropes. This allows for the penetration of air and the seeds remain viable for about 2 years and free from any insect infestation for 4–5 years (Jha, 1991; Kiruba et al., 2006; Singh & Singh, 2007).

Wooden bins are used mostly in hilly and cold areas especially of Assam, Maharashtra, Karnataka, Himachal Pradesh, Uttaranchal, and Kerala with a capacity of 40–100 kg. The wooden structure provides strength and provision for locking. It is topped with leaves of locally available plants like *A. indica*, *P. pinnata*, *Annona squamosa* L., and *Eucalyptus globules* (L.) Pierre. The wooden bin made by the *Khasi* tribe is called *drli*, and a double-layered bamboo basket, plastered on both sides with cow dung and mud, is placed inside it.

Various types of mud bins are made by using clay, soil with plant fibers, or husks of cereal grains having a storage capacity of up to 40–80 kg. The height ranges from 1 to 3 m. with narrow mouths or openings at the top which is closed with a tightly fitted lid. A circular vat like a baked bin with tapering ends, made with rice

bran and paddy straw is called *Kulumaij* in Tamil Nadu. It is a common practice to top up the *Kulukakai* with dried leaves of *Pongamia pinnata* and *Azadirachta indica* A. Jussieu (Kartikeyan et al., 2009).

Permanent, storage structures, inside the house for bulk storage, are usually associated with dry climatic conditions, under which it is possible to reduce the moisture content of the harvested grain to a satisfactory level simply by sun drying it. These structures are named according to their shape and the raw materials used.

A proper room constructed with a large door for pouring grains with bricks or clay with wheat straw and cow dung is called *Kothi*. In south India if the platform of the granary room is made of wooden boards and sides and has brick and cement walls, it is called *Macchu*, and if a strong concrete base stone is used, it is called *Kalangiyan*. If bricks are pasted with a mixture of diluted lime and sand lime mortar and the inner walls are lined with Palmyra leaf mats, it is called *Kaambara* (Kartikeyan et al., 2009).

Wooden structures of various dimensions are used by cultivators for storing paddy in hilly and cold areas of Assam, Maharashtra, Karnataka, Himachal Pradesh, Uttaranchal, and Kerala. These are generally made by wood of *Acacia* sp. and rectangular in shape (Kartikeyan et al., 2009).

Various types of bamboo structures are used inside the house in hilly and humid zones with a storage capacity of 600–1,000 kg. In Cachar district of Assam, the Dimasa community constructs various types of bamboo structures called *Mico*. *Micos* are constructed using seasoned wooden poles, bamboo, cow dung (Muski), neem (*Azadirachta indica*) leaf extracts, and soils of paddy land (locally known as Haa) (Das & Ray, 2013). Verma, Roy, Mary Swarnalata et al. (2005) reported that bamboo structures, though light and cost-effective, are moisture proof but susceptible to attack by wood borers. Wooden boxes give protection from moisture, rodents, and insects but require carpentry skill.

Outdoor storage structures are generally used to store huge quantities of rice. Stores are raised

on stone platforms using clay, red soils, cement, and bricks with the top portion covered with a conical shaped roof using bamboo sticks and palm or coconut thatch; they are known as *Kodambae*. The biggest grain storage structure built in a circular fashion by using calcareous soil containing clay particles is known as *Kudhir*. These storage structures are durable even up to 100 years (Sundaramari et al., 2011).

Bamboo outdoor storage structures are generally used in Andhra Pradesh, Meghalaya, and Assam. The structure is suitable under highly humid conditions. These are generally erected on bamboo poles or wooden platforms. In Andhra such structures are made with paddy straw alone (*Pari*); in Karnataka they are made of straw mixed with mud (*kacheri*), and in Assam these are prepared by bamboo and mud which are plastered and painted with clay and cow dung (*Gummi*). Grain bags are placed inside *Gummi* (Jeeva et al., 2006).

Nahu, a traditional system of storing rice in Arunachal Pradesh, is an example of community storing. Clusters of *nahu* are constructed at one corner of the village, away from houses, to protect them from fire. The ground below is used to store fuel wood (Singh & Bag, 2002). *Nahu* is used for 20 years and Toko palm leaves for roofing are changed after 5 years (Sarangi et al., 2009).

Underground Storage Structures.

According to Jeyarajan (2000), the first known method practiced for grain storage in large quantities was underground pits in areas where the water level was low. These are known by different local names in various regions and can be both inside and outside the house to save space for storage. They may be circular or rectangular and may be lined with cow dung, stones, sand, or cement. A layer of straw is placed all round which absorbs moisture from entering the soil and creates an oxygen-free atmosphere. In Karnataka it is called *Hagevu* and the pit is lined with straw ropes. The outer opening is sealed off with chaff, clay, and cow dung plaster; it had to be maintained well as the monsoon downpour tended to wash it away. Grains are generally

free from the seasonal variations in temperature and humidity. In case of pitted grain, because of the heat developed, curing is hastened and a sample in the pit for a couple of months is equivalent to 1-year-old grain. Grains can be stored without damage from insects and moulds for a longer period. However, it becomes cumbersome to take out the grains from these structures. *Khātā* (underground) were in vogue during Sultanate period. Ibn Baṭṭūṭa (1,340) recorded preservation of rice for long spells, stretching from 20 to 100 years in *Khātā* which were lined with dried, bull grass (*Bromus erectus* var. *pannonicus*). Although grains turned black after such long storage, they tasted good (Naqvi, 1984).

Storing of rice was considered serious undertaking and special rites accompanied this process. In Mizoram, after storing rice in a granary (Jhumhouse), a rite called *Sikisa* would be performed in which a white fowl or a dog would be sacrificed and the family would come to the village to eat, and while returning to the village, a bamboo whistle would be blown to call back the spirits from the *Jhum* to the village (Ray, 1993). In Manipur, *Meiteis* worship the paddy room by adoration of the granary and a rite is performed in the month *Wakching* by offering materials and *pooja* called *Kotlai Khurumba*. In Mizoram, after the storage of grain in the granary, a pig or a red hen would be sacrificed in the granary invoking the paddy to increase and last from the present winter to the next so that the family would have sufficient rice (Ray, 1993).

With the passage of time, traditional storage structures are diminishing and being replaced by metal bins. Rural people feel that traditional storage structures require regular maintenance and need local skilled persons whose number is decreasing for their construction. These storage systems obviated the need for employing residual insecticides and fumigants with the accompanying hazards they posed to the users and the environment. Integrating these indigenous knowledge systems into current research could develop appropriate new modern techniques for storing the grains in dry tracts (Kartikeyan et al., 2009).

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Road Building in the Amazon

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The Amazon basin has long been seen by national governments in South America as a region of low population density but rich in natural resources and is in need of economic integration to support national development. This has influenced the geopolitics of the Amazon and prompted governments and other organizations to promote road building in the region. New or improved roads are key for providing access to natural resources, and

highway networks thus link sites of resource extraction to urban markets and ports.

There have been arguably two distinct waves of integration initiatives in the Amazon. The first transpired in the 1960s and 1970s and was driven primarily by geopolitical concerns of national governments to secure their borders in remote corners of the basin in order to support integration of the Amazon with other regions within their countries (Goodland & Irwin, 1975). The second wave, since the 1990s, has been impelled by governments and multilateral banks seeking to complement national road networks with cross-border infrastructure in order to facilitate trade among neighboring countries. The second wave is encapsulated under IIRSA, the Initiative for the Integration of Regional Infrastructure in South America (CEPEI, 2002; Dourojeanni, Barandiarán, & Dourojeanni, 2010; Killeen, 2007).

Government-led infrastructure projects have in turn stimulated other road building in the Amazon. It is useful to distinguish between “official” (or “primary”) roads built by governments and “unofficial” (or “secondary”) roads constructed by other interest groups (Perz, Overdevest, Arima, Caldas, & Walker, 2007; Perz et al. 2008). These two types of roads differ in various respects, including the geometric forms of their networks in landscapes, as well as their relationships with natural resource exploitation and thus economic outcomes such as local development as well as environmental outcomes such as deforestation. Regardless of the type of road in question, road building in the Amazon (and elsewhere) has been a cause for debate due to the mix of significant positive and negative impacts.

Economics literature on infrastructure was stimulated by studies that showed large impacts on economic growth (e.g., Aschauer, 1989). Public sector investments in infrastructure appeared to generate large increases in private investments that expanded employment and per capita GDP. A macroeconomic literature has consequently emerged on infrastructure and its implications for economic growth. The findings have generally been positive and significant,

especially in developing countries, including Latin America (Bourguignon & Pleskovic, 2008; Straub, 2008). Positive effects of infrastructure on growth also apply to the rural sector. The macroeconomic literature is complemented by a microeconomic literature on roads and poverty in developing countries. There the emphasis is on making road investments to maximize livelihood benefits and rural poverty reduction (Howe & Richards, 1984; van de Walle, 2002). Empirical studies show significant poverty reduction near roads, whether via analysis of subnational administrative units (e.g., Demurger, 2001; Fan, Hazell, & Haque, 2000), communities (e.g., Gunasekera, Anderson, & Lakshmanan, 2008; Pender, Jagger, Nkonya, & Sserunkuuma, 2004), or households (e.g., Gibson & Rozelle, 2003; Jacoby, 2000).

But if the economic literature has offered positive evaluations of infrastructure, ecological research on roads has compiled a long list of negative consequences. There are multiple reviews of the ecological impacts of roads (e.g., Forman & Alexander, 1998; Trombulak & Frissell, 2000). This has fostered the specialty of “road ecology” (Coffin, 2007; Forman et al. 2003). The road ecology literature pays particular attention to spatial aspects of road impacts on biophysical environments. Reviews often take as their point of departure the observation that roads fragment habitats and modify stream networks. From there, ecologists have catalogued a host of consequences ranging from habitat isolation and degradation, to road avoidance by wildlife, to contagion effects such as exotic species invasions, among others.

A parallel literature on tropical forest fragmentation, notably in the Amazon, has also emerged and has a similar list of fragment edge effects on a variety of ecological outcomes (e.g., Laurance & Bierregaard, 1997; Laurance et al. 2002). Both the road ecology and habitat fragmentation literatures focus on the spatial configurations of habitat mosaics and the distance up to which specific ecological effects are felt, whether from roads or habitat edges. One implication is that the extent of spatial effects of a road varies considerably depending on the type of

outcome under study; another is that areas closer to roads and habitat edges tend to be more heavily impacted.

A more scattered literature exists on the social impacts of roads. One concern has been the distribution of benefits among distinct social groups. Social research has problematized differential benefits to higher status groups (Mahapa & Mashiri, 2001; Shriar, 2009) and districts closer to new infrastructure (Rudel & Richards, 1990), often as the result of a lack of broad participation in infrastructure planning (Devres, 1981; Robinson, 2001). Lack of participation also raises issues of exclusion of indigenous and other minority groups, often where newcomers make legalistic claims to natural resources in order to discredit traditional claims. Such political pressure disrupts traditional livelihoods and indigenous cultures, something well known in frontier areas such as the Amazon (e.g., Davis, 1977; Leonel, 1992). In addition, roads in the Amazon are notorious for stimulating conflicts and violence over newly accessible natural resources (e.g., Schmink & Wood, 1992).

While different types of roads all have economic, ecological, and social impacts, the mix of these impacts is distinct among official and unofficial roads in the Amazon. Official roads are generally highways built by governments with the intent of integrating cities, regions, and even countries. Famous examples in the Amazon include the Transamazon Highway across the central Brazilian Amazon, opened in the 1970s (Walker, Perz, Arima, and Simmons (2011), and the Interoceanic Highway, paved in the southwestern Amazon across the Brazilian-Peruvian border under the first phase of IIRSA after 2005 (Perz et al., 2012). In these and other cases, governments and banks prioritized long-range linear corridors that linked strategic locations in different regions, permitting national or cross-border integration. While official roads have received considerable attention in debates over their environmental impacts in the Amazon, they form sparse networks in the basin, leaving large blocks of forest intact since parallel corridors are often hundreds of kilometers apart.

By contrast, unofficial roads are built by private interest groups. Whereas official roads are built for strategic purposes involving economic integration, which may indirectly lead to economic, environmental, and social change along highway corridors, unofficial roads are built specifically to gain access to local natural resources. Hence, unofficial roads play a much more direct and instrumental role in local economic activity and environmental change. Indeed, opening or paving of official roads can stimulate unofficial road construction. There is thus a certain synergy between official road building and unofficial road construction. Further, to the extent that they permit profitable economic activity, unofficial roads can become autocatalytic, leading to unofficial road extensions to reach more remote natural resources as those available along established road segments become exhausted. Unofficial roads also differ from official roads because unofficial roads form much denser networks in landscapes because they are often spaced only a few kilometers apart, frequently follow winding paths, and have many intersections. Consequently, unofficial road networks fragment forest cover into smaller, more irregularly shaped, and often more isolated patches that are more ecologically vulnerable.

Debate over the economic, ecological, and social impacts of road building in the Amazon has led to calls for governmental promulgation of policies and investments in the enforcement of rules governing the management of natural resources (Nepstad et al., 2002). This in turn has prompted efforts to broaden public participation in infrastructure planning that can permit more inclusive distribution of the benefits of new or improved roads while mitigating or avoiding their problems (Mendoza, Perz, Schmink, & Nepstad, 2007). Official road corridors in the Amazon are characterized by rapid economic change and large inequalities among social groups in terms of preparedness and thus pose large challenges as well as opportunities for improved environmental planning (Mendoza, Perz, Souza da Silva, Brown, & Pinheiro, 2014).

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Road Networks in Ancient Native America

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Pre-Columbian road networks in ancient America – specifically, the Southwestern United States, Mesoamerica, and Peru – provide a point of departure for exploring current issues in the study of non-Western technology. It should be noted that other major road networks have been documented for the Mississippian complex of eastern North America, Casas Grandes in Chihuahua, Mexico, and the Maya sacbe road networks of the Maya lowlands of Mesoamerica. These networks are currently the subject of ongoing investigations.

The three primary road networks of concern here are those of the North American Chaco Anasazi or Ancestral Pueblo of west-central New Mexico, Mesoamerican road networks centered on La Quemada and Xochicalco, Mexico, and the Inca system of Peruvian South America. These networks vary in scale, with the La Quemada complex representing a highly integrated, valley-wide network, dating to the period between AD 700 and 900. The Chaco network covers a circuit of over 300 linear miles of

ground-verified constructed road segments and features spanning the period from AD 920 to 1140. The Inca road network was expanded in a vigorous campaign to integrate all pre-existing road segments in the period between AD 1438 and 1532. This system incorporates over 2,000 linear miles of roads into the single most massive archaeological feature in the Americas (Hyslop, 1984).

The American Southwest

The formalized road network of Chaco Canyon, New Mexico, connects the canyon core with peripheral pueblo communities lying at relatively great distances from the core area. Over 500 miles of roads are indicated through the analysis of aerial photographs; however ground survey data are as yet incomplete, leaving unresolved the question of continuity in the network. The sociopolitical complexity of the Anasazi of the San Juan Basin is closely tied to the problem of road network continuity (Vivian, 1990). If the road network was contiguous throughout, this would support the contention that Chaco served an administrative function as the center of a regional system extending from Southwestern Colorado to South-eastern Utah, into Western Arizona and North-western New Mexico. Lack of continuity in the road network indicates a less integrated system, and a more autonomous character for the outlying communities.

Functional aspects of the Chaco road system are as yet unclear. Functional considerations center on the nature and control of goods transported as well as with the degree of interaction between core and peripheral communities. Proposed interpretations include (a) a defensive role for outlying pueblos, (b) protection of trade routes, (c) ceremonial functions, (d) political administration, and (e) the transport of subsistence-related goods. It has also been suggested that outlying pueblos served as rural sustaining communities directly affiliated with representative groups of the canyon core (Kincaid, 1983).

Chacoan road construction exhibits several characteristic features. Most notable is the

absolute linearity of the roads, despite potential topographic obstacles. The great North Road deviates $<1^\circ$ from its northerly course in over 46 km. Masonry road elements such as flanking walls, or curbs, ramps, and raised roadbeds also characterize the system. Several architectural features are associated with road segments. These range from simple cairns and shrines to residential room-blocks and Great House communities with Great Kiva ceremonial structures. Stylistically uniform, these features and structures employ Bonito-style construction of core-veneer masonry and massive walls.

There are no historical data available describing the Chacoan road system. To date, all interpretations have been based on archaeological research and remote sensing techniques. Gordon Vivian pioneered this research in 1948. From 1971 to 1977, the Remote Sensing Project of the Chaco Center – in conjunction with the National Park Service and the University of New Mexico – undertook investigations of the Chacoan road network. Their efforts focused on the use of ground verification studies for the extensive mapping of road alignments appearing in aerial photographs. From 1980 to 1983 the New Mexico Bureau of Land Management undertook a comprehensive effort to document the road network by means of ground verification (Kincaid, 1983).

Mesoamerica

Studies pertaining to Mesoamerican road networks are relatively recent, and most such studies have emphasized ground verification and mapping. The sites of Casas Grandes, La Quemada, Xochicalco, Teotihuacan, and the Maya lowlands have been the subject of most surveys to date, while the Tarascan and Sonoran regions have been the subject of the most recent surveys. The road networks of these regions provide a glimpse into both the Late Classic, and the Protohistoric developments of the fourteenth through sixteenth centuries AD (Mendoza, 2001).

The area of La Quemada, Zacatecas, lies within a semiarid region of Mesoamerica's Northern

Frontier. This area is dominated by a series of hill-fort centers, each of which is characterized by the presence of civic-ceremonial precincts, agricultural terraces, and secondary centers with related defensive features. An extensive intra-regional network of roads connected the primary centers of La Quemada and Los Pilarillos with secondary centers, and in turn, isolated mound groups, isolated platforms, defensive positions or fortifications, and agricultural terraces. This system, by contrast with that of Chaco Canyon, served to integrate communities within a tightly constricted area. Road segments linking the La Quemada road network with regions beyond the valley have yet to be fully mapped or verified.

The specific road-related features identified with La Quemada include (a) formal causeways or other elevated road segments; (b) road segments terminating at elevated platforms; (c) causeways of between 5 and 7 m to 12 and 14 m in width with road-bed elevations of between 30 and 40 cm; (d) causeways that extend to wide, low platforms and stairways with precipitous descents down steep escarpments; (e) parallel road and canal or other irrigation segments; and finally (f) where the larger causeways are concerned, such roads are identified with defensive positions. At La Quemada, the aforementioned features are taken to represent a sociopolitical pattern geared to militarism or related defense activity (Trombold, 1991b).

Where the road networks of the Mesoamerican Epiclassic era (ca. AD 650–900) are concerned, the central Mexican city-state of Xochicalco, Morelos, provides a salient example. The site of Xochicalco, like its La Quemada contemporary, is situated in a strategically located acropolis-centered hill-fort locality. Most of the road segments identified with Xochicalco emanate from the hill-fort to other centers within the valley below, and as such, Xochicalco provides a characteristic example of roads as symbols of power, prestige, and levels of regional integration. In other words, this position holds that Mesoamerican road networks function primarily as mechanisms for social integration or as symbols of the power and prestige of social or religious elites (Hirth, 1991). The scale and

magnitude of construction activity invested in the road systems of Mesoamerica have led some scholars to speculate that such roads were less functional and more ceremonial in character. Monumental construction and related public works are taken as indicators of political power, and thereby elite command of critical resources (such as slaves and construction personnel) in the valley during the pre-Columbian era (Trombold, 1991a).

Mesoamerican economic systems, by virtue of the nonexistence of draft animals, and thereby, wheeled vehicles, were limited to human burden bearers. Despite this limitation, such systems were every bit as formal as those of other Old and New World polities. Primitivist interpretations of New World economies have unnecessarily minimized the perceived scale of economic formations in Mesoamerica and the New World despite available ethnohistorical data. The extent and magnitude of investment in road construction, and scale of integration made evident by the contiguity in the system, is again a key indicator of the types of sociopolitical formations that once prevailed in Mesoamerica. The Aztec era provides only a hint at what prior civilizations engaged in the way of road network investment in construction and maintenance, and by any account, the investment was substantial and culturally significant. Robert Santley's recent projection of road networks for the Basin of Mexico presents us with a system that was highly integrated and equally complex (Santley, 1991).

The utility of a formalized – organized, linear, weatherproof – road network over which to maintain the movement of goods and services was critical to trade and exchange in Mesoamerica. Like the ancient informal paths that preceded them, formalized roads served to guide and expedite the movement of goods and services on both an intra- and inter-regional scale.

A typology of Aztec era roads was recorded by Fray Bernardino de Sahagun, the sixteenth century Franciscan cleric who documented such aspects of postconquest central Mexican culture (Sahagun, 1963). Of the seven types of roads identified by Bernardino de Sahagun the

ochpantli and oquetzalli road types have been isolated as representative of the Xochicalco road types. The first term pertains to the “main road” and the second to the “royal road” networks of the Aztec era. The well groomed roads of Xochicalco are interpreted as the royal road type. This interpretation is based on the monumental nature of the associated architecture (primarily defensive in character), the cut-stone pavements, and the relatively large width of the roadbed itself. In addition, archaeologist Kenneth Hirth distinguishes between “road” and “thoroughfare.” Roads are “transportation arteries at the regional level which connect two or more spatially separated sites”; thoroughfares are “streets and other communication corridors which organize space and/or direct traffic flow within the community” (Hirth, 1991). The fragmentary nature of the data precludes a region-wide economic and social interpretation of the Xochicalco network.

The Xochicalco road network exhibits a number of distinct architectural characteristics, including:

1. Stone-surfaced intra-site rough-cut mosaic pavements or roadbeds of 3–5 m widths
2. Intra-site masonry ramps
3. Parallel platforms flanking key road segments or thoroughfares leading into the site core area
4. Roads which bisect massive rampart walls with narrow gateways in order to access intra-site thoroughfares
5. Intra-site pavements or roadbeds edged with cut-stone masonry blocks
6. Stucco used along flanking masonry edging in the intra-site sectors
7. Intra-site pavements made flush with surfaces traversed and modified with ramps – both smooth and stepped
8. Lateral masonry walls flanking intra-site pavements
9. Access causeways along circuits of defensive ditches or moats
10. Evidence for the use of a probable wooden bridge spanning a defensive moat adjacent to Cerro de la Bodega

Transport architecture extending beyond the site perimeter consists of less formal construction techniques in addition to significantly less evidence of overall integration with the site core of Xochicalco.

Recent studies provide indications of a massive road network that connected the Classic period center of Teotihuacan with an ancient trade corridor linking that site with the Puebla Basin, and by extension, the Mexican Gulf lowlands. Unlike the more defensive character of the La Quemada and Xochicalco road networks, the Teotihuacan corridor linking Teotihuacan with a whole host of ancient mercantile centers in the Mesoamerican highlands and Gulf coastal plain served a key transport function for the movement of goods and services provisioned and sought by Teotihuacan.

The road-associated settlement hierarchy of the Teotihuacan Corridor, as well as the recent identification of specific features of transport network architecture along the Teotihuacan Corridor, is currently under study. Additional features of Mesoamerican transport network architecture include (a) causeways – such as the Street of the Dead – measuring some 40 m in width; (b) the presence of Momoztli structures, or elevated platforms or shrines (often laden with trade offerings) situated at the crux of important crossroads along the corridor; (c) an approximate inter-site road width of 24 m, and 60 cm depth, for sites located on the Teotihuacan Corridor; (d) spur roads that connect road-associated settlements with the principal arteries of the Teotihuacan Corridor and with other key nodal points or market centers; (e) related architectural styles and construction along the course of the transport network; (f) roughly equidistant spacing of road-associated settlements at 8–9 km intervals for specific Teotihuacan related centers; and (g) stepped ramps, road shrines, crossroads, and attendant roadbed linearity. The overall network is dendritic in structure, in that the main road connects with primary centers, which are in turn connected to a constellation of secondary centers sharing affinities with key terminals along the Teotihuacan Corridor.

Peru

The most intensively studied ancient road system of South America is that of the Inca Empire, extending over a vast area from Ecuador to Chile, from the coastal deserts to the Andean highlands, into the Bolivian forests. This network included some 20,000 miles of roadways and encompassed 40,000 miles at the point of European contact. This road system constitutes “South America’s largest contiguous archaeological remain,” and provides valuable insights into the organization and technology that are hallmarks of the Inca state (Hyslop, 1984).

In contemplating the vastness of this road network, one is struck by the enormity of the Inca achievement. First, there is the effectiveness of the political infrastructure that organized and mobilized a labor force specialized in the building and maintenance of roadways. Second, the Inca were exceptionally efficient in their use of resources, both natural and human. Pre-existing roadways were frequently incorporated into the Inca network. Inca engineers did not seek to modify natural topography to any great extent unless required to do so in order to achieve safe passage. Where road modifications were concerned, locally available materials were utilized and work was performed by locally organized labor pools under the supervision of a road administrator. Third, the Inca brought to bear a vast body of technical knowledge and expertise, accumulated over the course of centuries among the diverse ethnic groups of the empire. Finally, the efficiency of the road network insured that Inca rulers could maintain communication with – and thereby, the integration of – every corner of the empire.

Four primary state roads divided the empire into cosmologically defined quadrants (Urton, 1981). The sacred geography associated with road networks reflected the Inca preoccupation with cosmology defined *vis-à-vis* extant social divisions. Cuzco, the political and administrative center of the Inca state, was linked via these sacred paths to the most ancient shrines and temples. Roadways not only defined the

partitioning of sacred space, they also served as linkages in a massive transport and communication network.

Road characteristics varied considerably in terms of construction methods and the extent of labor investment. Construction methods varied with the highly fractured and variable topography of the region, and as such, a single road might include both road segments with very complex architectural features and evidence for intensive labor investment, and simple unpaved or earthen pathways. Ultimately, road construction varied with localized conditions, topographic obstacles, available materials and labor, and the importance of the specific road segment to ceremonial and ritual activities.

Coastal routes varied from simple “pole-roads” to broad thoroughfares with stone or adobe sidewalls. Pole-roads were paths marked by linear arrangements of wooden posts placed at intervals. High-altitude roads on nonagricultural lands were, by contrast, engineered for durability in order to withstand harsh climatic conditions. Such roads incorporated elaborate stone curbs, retaining walls, and paving. These later constructions are among the best-preserved roads in evidence for the Andes. Roads traversing agricultural fields are characterized by very high sidewalls – of 1 or 2 m in height – designed to protect crops from travelers or livestock such as llamas and alpacas. Such walls were likewise built of stone or adobe. Agricultural roads were relatively narrow so as to minimize their impact on the availability and productivity of arable lands.

Where roads crossed wet plains or slopes, stone paving was used to preserve the roadbed. If flooding was unavoidable, the road was constructed on an elevated surface or causeway. Inca causeways were of rubble-core construction, with or without stone retaining walls. In those instances where existing slopes were $<10^\circ$ off horizontal, the Inca used a combination of stone or rock-cut ramps, stairways, or switchbacks in order to buffer ascent and descent. Depending on the steepness of the existing slope, structures ranged from a single retaining wall to a series of walls and benches built on the downhill side of

the slope, and intended to serve as secondary retaining features.

Bridges are among the most spectacular structures engineered by the Inca. While sixteenth century European construction employed the principle of the arch in bridge construction, the Inca were able to span greater distances through a variety of engineering principles and techniques. Early Spanish explorers marveled at the sight of Inca suspension bridges which were unknown in Europe. Though made of woven and braided fiber coils, these suspended structures supported considerable pedestrian traffic, in addition to European horses and carts of the conquest period. Other types of spans built by the Inca included floating bridges supported by pontoons of reed bundles, wooden bridges manufactured from logs placed over stone abutments (with or without cantilevers), and a variety of stone bridges. Culverts were stone-lined troughs left open, or capped, if necessary for safe passage. Somewhat wider rivers were spanned by stone columns placed adjacent to one another, thereby forming “multicell” culverts which supported the overlying roadbed. Some stone bridges employed cantilevered abutments supporting very large stone pavers. Finally, natural rock formations were utilized as bridged areas where available.

An integral component of Inca era road networks was the *tambo* system. Tambos were multiuse structures or facilities maintained by the Inca state but administered locally. Hyslop estimates that between 1,000 and 2,000 of these facilities were in use throughout the Inca empire. Tambos exhibit considerable variation in size, ranging from sites with a few isolated structures to large administrative centers representing a multitude of activity areas. Storage and lodging constitute the primary uses for which tambos were employed. Storage structures included silos, corrals, and adjoining rooms. Lodging in tambo facilities was temporary, and intended either for travelers or as permanent residence for local administrators. Tambos were also employed in the processing of raw materials, military and ceremonial activities, local administration, and craft production. Tambos were equidistantly spaced on any given route at intervals

representing a day's travel time. According to recent Inca road surveys, *tambos* were spaced at intervals that average between 15 and 25 km. The combined *tambo* system and vast complex of roadways formed a critical component of the state's infrastructure. This highly efficient transport and communication network supported the state's practical needs for efficient military mobilization, colonization, economic maintenance, and administration. In addition, the complex network of roads supported the ideological needs of the Inca hierarchy, providing a highly visible set of linkages between the people and the state.

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Rock Art and Folk Islamic Practices in Central Asia

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Many of the Muslim peoples living within the Central Asian republics of Kazakhstan, Kyrgyzstan, and Turkmenistan carry out indigenous expressions of religion generally referred to as folk Islam. Some practices derive from pre-Islamic times, while others represent new forms of spirituality developed in response to their historical circumstances. Nevertheless, the most prominent feature of Central Asian folk Islam involves visiting a *mazar*, a holy place. Throughout the Muslim world, the common alternative to the *hajj*, the pilgrimage to Mecca, involves the practice of *ziyarat* (Arabic), continual visitations to the tombs of saints. Additionally, among the peoples of Central Asia, journeys to major holy shrines or mausolea located in or nearby urban areas can be an acceptable equivalent to the *hajj* as well as that of visiting special mazars in the countryside.

The Arabic word for saint is *wali*, god's representative, and it has been adapted into Kazakh as *auliye*, Kyrgyz *oliya*, and Turkmen *öwliýä*. Moreover, these latter words can also refer to the saint's burial place from which *baraka*, spiritual power, emanates from the tomb. Islamic saints are chosen by localized historical factors, and a Central Asian saint may have been once the heir of a Sufi master or an individual who had performed miracles during his or her lifetime.

Central Asian mazars are not only connected to saints but also have associations with prophets, heroes, ancestors, and spirit guardians. The mazar does not have to be a tomb and could be the cemetery where clan ancestors lie buried or sacred trees and springs, which are protected by spirit guardians. Most mazars possess healing powers and are sought by pilgrims in search of cures for physical or spiritual illnesses and also by women seeking to become pregnant. Moreover, these holy personages may reveal themselves to the pilgrim in

a dream at a mazar or appear in dreams instructing an individual to go on a shrine pilgrimage. This, in turn, reflects the medieval Sufi heritage of Central Asia as there is a cultural background of observing *ayan* (“personal revelation,” Arabic), the illuminationist dimension of Sufi spirituality, which manifests in dreams and impels religious activities.

Rock Art Mazars

Ethnographers and explorers since the nineteenth century have documented the various ways in which the peoples of Central Asia recognize special places in nature as sacred sites, such as trees, springs, stones, and caves, or secluded spots in valleys and mountains. Such places are usually identified by the accumulation of rags tied to the branches of local trees and shrubs or wrapped around poles and stones. Sometimes a formal structure may be constructed upon the site to enclose the natural feature.

Moreover, there are numerous rock art sites found in the rocky outcrops of Central Asia and their age can range from prehistoric to ethnohistoric times. Depictions feature a variety of human and animal figures as well as abstract and geometrical shapes, and many scenes were, arguably, created with religious or ritual intent. The majority of these panels are executed as petroglyphs, images carved or pecked into natural stone, while the occurrence of rock paintings is quite rare. Petroglyphs can be found within the vicinity of a shrine, and there are several cases of the rock art site itself being treated as a mazar by local peoples. Additionally, there are other markings in the natural rock found at shrines, which are not artificially made, that pilgrims believe to be the footprints or bodily impressions of saints or heroes.

Perhaps, the highest mazar in Central Asia is the major rock art complex of Saimaluu Tash (“decorated stones,” Kyrgyz) that spreads across two valleys high in the Fergana mountain range, western Kyrgyzstan, at about 3,200 m above sea level. The Kyrgyz locals believe the prehistoric carvings were not made by human hands and

consider the area to be *iyik zher* (“holy” Kyrgyz). It is a place of pilgrimage for groups who seek healing and women come here to cure infertility. Pilgrims bring livestock to be killed and eaten in a ritual meal accompanied by prayers and readings from the Qur’ān. During times of epizootic spreads of animal disease in the recent past, entire cattle herds have even been brought up to Saimaluu Tash to receive protection from harm.

Meanwhile, the shrine complex of Sulaiman-Too in the city of Osh, southern Kyrgyzstan, covers the entire mountain, which is named after the Muslim prophet Sulaiman (King Solomon). Sulaiman’s shrine is a small cave that is believed to be his grave and pilgrims pray here asking for reprieve from illnesses and other forms of help. Additionally, a mosque for the prophet was built on the eastern side of the mountain in the sixteenth century. According to legend, this is the place where Sulaiman admired the mountain and is affirmed by the presence of handprints which he is believed to have left in the rock.

The petroglyphs of Sulaiman-Too are situated in spots around the mountain on exposed surfaces and found inside caves and date from the Bronze Age to Medieval and later times. Kyrgyz pilgrims visit the rock art localities for blessings and healing from ailments, such as *Kol Tash*, “the hand stone” (Fig. 1). There is also a rock art panel that is believed to treat only headaches, while another bestows longevity upon children. Additionally, the Chiltan-Khana cave – named after chiltens, helpful spirits – located on the southwestern slope has many abstract images and local tradition considers the cave passage to be a pathway to Mecca.

Moving to southeastern Kazakhstan, there is the major rock art complex of Tamgaly valley, which is referred to by the local Kazakhs as *Tangbaly Aulie*, “sainted place of clan-markings.” The rock art is dated from the Bronze and Iron Ages to Medieval times. Large bushes growing near the river are covered with numerous rags tied by pilgrims seeking blessings, and visitors have even tied rags onto small jutting rocks near various petroglyph panels around the valley. Rags are also tied on the bushes growing beside the

famous scene of six Bronze Age “solar gods.” Locals believe the ground in front of this scene was once the grave of an unknown saint; however, archaeological excavations of the site did not find any evidence for such a burial.

Another sainted rock art site is Terekty-Aulie, an area of granite hills covered with Bronze Age petroglyphs that is situated north of the city of Jezqazghan in Central Kazakhstan. An important nineteenth-century cemetery was also founded at the base of the highest hill. Pilgrims had erected

a stone shrine (Fig. 2), which more recently has been replaced by wooden post, atop this hill in the natural crevice between two large petroglyph panels depicting numerous horses. Rags once covered the stone shrine and are now tied to the post as well as to any stray bush growing from the cracks in the hillside (Fig. 3). After visiting the shrine, Kazakh pilgrims return below to have a ritual meal involving the sacrifice of a live goat, which is accompanied with prayers and Qur’ān readings. They then visit the cemetery to commemorate the ancestors and tie rags to its fence.

Terekty-Aulie is a place of healing and its baraka derives from a visit by the prophet Khazrat Alī – ‘Alī, the son-in-law of Muhammad. There are also rock art images of his footprints as well as petroglyph hoofprints belonging to his faithful horse, Duldul. Furthermore, at Duldul-Ata in southern Kyrgyzstan, there is a small rock art site situated near a holy spring featuring the ancient petroglyphs of two horses. The name of this curative mazar derives from ‘Alī’s steed, and according to local legend, an invisible horse spirit once dwelled here that could only be heard by certain individuals. There is also a mysterious tomb of an unknown individual at this site, which is now enclosed by a mausoleum structure.

The important Hazret Ali shrine located southwest of Ashgabat, Turkmenistan, is another



Rock Art and Folk Islamic Practices in Central Asia, Fig. 1 A natural hole with small petroglyph images around its edges that is known in Kyrgyz as Kol Tash, “the hand stone” (Sulaiman-Too, Kyrgyzstan)

Rock Art and Folk Islamic Practices in Central Asia, Fig. 2 The shrine stone erected above petroglyphs at Terekty-Aulie, Kazakhstan, as seen in 2001 before its replacement by a rag post



Rock Art and Folk Islamic Practices in Central Asia,

Fig. 3 A prayer rag tied to a small bush found along a hillside at Terekty-Aulie, Kazakhstan



mazar with impressions in the rock that are believed by the Turkmens to be derived from ‘Alī’s hands and the hooves of Duldul. Moreover, there is an impression of a human body in a fetal-like position in a large boulder where pilgrims believe he lay down to rest.

Female saints can also leave markings for the faithful. At the shrine of Paraw Bibi in western Turkmenistan, there are impressions of knees and hands in the natural rock left by this holy Turkmen hero (*batır*). Pilgrims come from around western Turkmenistan to the shrine for healing, and there are also miracle-working stones that can be used to predict the future. Additionally, there is a small cave through which she is said to have entered into the mountain, and here young women come recite prayers for her blessings and to cure infertility.

In conclusion, it is important to consider that folk Islam is part and parcel of people’s engagements with the tangible and intangible aspects of the landscape. Concentrations of rock art images, like trees, stones, springs, and caves, can in effect become the medium through which people affect change in the world by seeking out their sacred properties. Furthermore, the rock art mazars are also situated at the crossroads of time where present-day practices acknowledge and

dynamically interact in exceptional ways with the artistic and religious endeavors of past societies.

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Rocket Machinery of the Mamluks

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Rockets for launching Greek fire by means of shooting flying fire arrows (*sihām khiṭā'i*) propelled by a primitive form of gunpowder appear in a number of Arabic military treatises, written mainly in the Mamluk period (1250–1517). The Mamluks paid special attention to the composition of military treatises known as *furūsīyah*, which were precious sources extensively describing horsemanship, military training, and weaponry (Al-Sarraf, 2000). S. al-Sarraf correctly remarks that a number of these treatises, mainly anonymous, had already been written before the Mamluk period and were reproduced with a few additions (Al-Sarraf, 2004, p. 143). The *furūsīyah* treatises are invaluable for the information they offer on pyrotechnic technology although they frequently recycle older material mixed with contemporaneous.

One of the most significant *furūsīyah* treatises by Najm al-Dīn Ḥasan al-Rammāh is called *Al-furūsīyah wa'l manāṣīb al-ḥarbīyah* (Horsemanship and ingenious war stratagems), written in the late thirteenth century (Al-Rammāh, 1998). It contains an admirable number of passages concerning weapons, mixing of various chemical materials, and war machines used not only on land but also in naval wars. He considers saltpeter the fundamental substance of pyrotechnics and, as Zaky points out, his description of the purification of saltpeter by crystallization preceded that of Roger Bacon (1214–1292) (Zaky, 1967, p. 49).

More important for the study of pyrotechnic technology are the *furūsīyah* treatises, *Kitāb al-makhzūn fī djāmī' al-funūn*, written by Ibn Akhī Hizām (dated to H875/1470, ms. C-686, Institute of Oriental Studies, St. Petersburg), and two by the fourteenth-century author Ibn al-Manqalī, i.e., *Al-adilla al-rasmīyah fī'l-ta'ābī' al-ḥarbīyah* (Ibn al-Manqalī, ed. Khaṭṭāb, 1988)

and *Al-aḥkam al-Mulūkīyah wa'l dawābiṭ al-nāmūsīyah*.

Ibn al-Manqalī provides us with unique information about the Greek (liquid) fire about which a great number of misconceptions have been created (Christides, 2013), although his remarks in the two abovementioned treatises are occasionally somewhat confusing because he was writing in the fourteenth century about Byzantine naval preparedness of the tenth century, based on the works of Leo VI's *Naumachica*. Thus, one of his significant remarks is his report that in every Arab warship, medical personnel was needed (Ibn al-Manqalī, 1988, p. 245). Obviously, such personnel must have also existed in every Byzantine warship, although it is not reported in any Byzantine naval treatise; it is only mentioned by the Byzantine author Constantine Porphyrogenitus (Karapli, 2013). More important is Ibn al-Manqalī's short reference to some Arab small-size warships especially equipped to launch fire arrows in order to burn enemy ships (Ibn al-Manqalī, 1974, p. 39). Ibn al-Manqalī reports that special personnel embarked on these ships under the guidance of the leader of the fire throwers (*muqaddam al-zarāqah*), well trained to operate the incendiary weapons. Unfortunately, few details are known about these operators of the incendiary weapons. They continued the function of the fire throwers, known as *naffātūn* or *zaraqūn*, who, as it has been shown by D. Ayalon, had been activated from early Islamic times and were used either in the sieges of towns or in the open battlefields (Ayalon, 1956, pp. 16, 36).

Ayalon's view that the units of the army trained for fighting in the open battlefields were abandoned sometime in the Abbasid period, due to the uncontrollable use of the produced fire, cannot be sustained. In contrast, at the time of Harūn al-Rashid (786–809), a whole regiment was composed of *naffātūn* who enjoyed great prestige thanks to their incendiary weapons (Zouache, 2008, p. 416; Elisséef, 1967, pp. 734–735).

Concerning the weaponry used by the *naffātūn*, it should be taken into consideration that it varied substantially through the long

period of their development from the early Islamic times to the end of the Mamluk era. In the early Islamic period, the *naḥḥāṭūn*'s task was to hurl fire bombs by hand or throw them by machines against the enemy's camp. The early fire bombs were stuffed with combustibles based mainly on a petroleum incendiary substance called *naḥḥ* (Christides, 2013, p. 147). Gradually, the incendiary mixture was replaced by crude gunpowder based on saltpeter, bearing the same name *naḥḥ*, and finally purified saltpeter, i.e., gunpowder called again *naḥḥ* and later *bārūd*, which was composed of saltpeter, sulfur, and charcoal (Christides, 1993, p. 886).

The chronological order of these transformations, discussed extensively by J. T. Reinaud and I. Favé (1845), D. Ayalon (1963), J. R. Partington (1999), S. G. Haw (2013a, b) and others, is beyond the aim of this article which is focused on the double development of the Arab naval weaponry of pyrotechnics under the Byzantine and Chinese influence culminating in the rocket machinery used by the Arabs for launching large fire arrows carrying cartridges of primitive gunpowder. Such machinery was used by the Arabs in both land and sea warfare and obviously can be identified with the weapon described briefly in the abovementioned passage of Ibn al-Manqalī, which, as it will be seen, was constructed by the Arabs under the influence of the Chinese naval technology, completing their knowledge based on the Byzantine naval technology. We can trace the incorporation of the Byzantine naval technology into the Arabic mainly after the eighth century following the second siege of Constantinople in ca. 717–718, during which the Byzantines made extensive use of the so-called secret weapon of the Greek fire (Strohmaier, 1989; Kollias, 1989, p. 31). The Arabs had also used a primitive form of Greek fire in this siege, as it is reported in the Arabic and Greek sources, but it is only sometime later that they became fully aware of the final form of the Greek fire during the Arab-Byzantine struggle at sea at the turn of the ninth century. At least in the year 825 AD, there is a concrete reference that whole Byzantine warships along with their crews were captured by the Arabs who, thus, acquired

complete knowledge of the so-called secret naval weapon of the Greek fire (Ibn al-Athīr, 1979, p. 339).

The acquaintance of the Arabs with the Byzantine naval technology enabled them by the tenth century to construct warships similar to the Byzantines with a main flame thrower mounted on the bow, stationed in a forecastle, and protected by a small guard of marines. Such large flame throwers could only be installed in a large average Byzantine and/or Arab warship whose length was approximately 30–40 m.

From the scanty information of the Arabic historical sources, it is evident that by the ninth century the small Arab warship, called *bārīj*, carried a crew of 39 including three naphtha throwers (Nakhili, 1979, pp. 10–11), who did not operate any machinery similar to that installed in the big warships, but instead they carried portable flame throwers, similar to those used by the *naḥḥāṭūn* of the land forces.

The construction of such portable fire throwers should be traced to the Chinese pyrotechnic technology. The Arabs had increased their trade relations with China in the Abbasid period and intensified them after the conquest of Egypt by the Fatimids in 969. Archaeological finds in Fustat (now a suburb of Cairo) of Chinese bowls and vases with fine incised designs reflect the strong trade relations between Fatimid Egypt and China (Gyllensvärd, 1975). Chinese influence on Arab naval technology and pyrotechnics continued especially during the time of the Mamluks. In a preliminary study, V. Christides (1992) expressed the view that the Arab rockets, composed of lances carrying Greek fire propelled by primitive gunpowder, as depicted in Arabic manuscripts, could have been constructed by the Arabs inspired by Chinese military technology.

Now a thorough study by Stephen G. Haw, a specialist in Chinese pyrotechnic technology, has enhanced this speculative theory. Based on literary and archaeological evidence, Haw has shown that fire arrows, from which rockets were developed, containing incendiary substances and/or gunpowder (or at least saltpeter, the vital ingredient of gunpowder), had existed in China since 1000 AD and explosive bombs as early as



Rocket Machinery of the Mamluks, Fig. 1 Chinese rocket arrow (Needham, 1964, Fig. 17, p. 248)

1150 AD, all widely used by the early thirteenth century (Haw, 2013a, pp. 442, 463; 2013b). Needham had already paved the way for Haw. He had reported that the Chinese literary sources describe fire lances (*huo ch'iang*), composed of a tube filled with rocket composition, held upon the end of a spear. He further added that such lances preceded the metal cannon which appeared in China ca. 1280–1320 and that the Chinese rocket arrows were originally made of bamboo tubes (Fig. 1) (Needham, 1964, p. 248). Needham's depiction of the Chinese rocket arrows strongly resembles the Arabic javelin rocket illustrated in an Arabic manuscript of the fourteenth century (Fig. 2) (Nicolle, 1999, Fig. 364a, p. 411).

It is undoubtedly that from this Chinese military technology, the Arabs drew their advanced pyrotechnic technology and their *naffāṭūn*, embarked on their small warships (*bārij*, pl. *bawārij*), mentioned above in Ibn al-Manqalī's passage, and carried portable flame throwers of irrelevant technology to those used in

Rocket Machinery of the Mamluks, Fig. 2 Javelin rocket carrying *naft*. Mamluk *furūsīyah* manuscript (fourteenth to fifteenth centuries) (Simplified sketch by D. Nicolle (1999), Fig. 364a, p. 411)



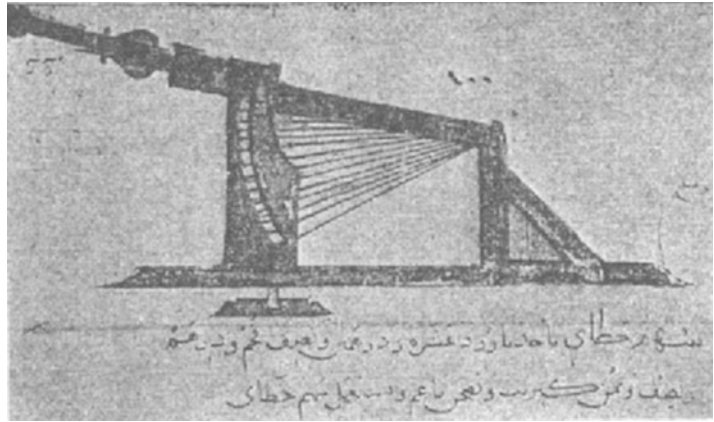
the big warships (*shīnī* corresponding to the Byzantine dromon), which were constructed according to Byzantine military technology.

Concerning the *naffāṭūn*'s naval weapons about which there is no particular information in the Arabic sources, we can assume that they were not different from a number of war machines described in the *furūsīyah* manuscripts. A. Y. Hassan describes several of them in a study (2006) with explanatory comments concerning their function and the composition of their ammunition. Unfortunately, they are dated after the twelfth century AD, and the transitional period, i.e., the end of the use of incendiaries followed by that of the explosives (ca. the eleventh to twelfth century), is sorely missing. The most interesting of them is the treatise *Al-anīq fī al-manājiq* written by Unbughā al-Zaradhash for the *atabāk* (chief commander of the Mamluk army) Manglī Bughā al-Shamsī, who was in office between 769/1367 and 774/1372 (Al-Sarraf, 2004, p. 184). An illustration in this treatise depicts a portable fire thrower which is a self-launching rocket, also reproduced in the anonymous treatise *Khizānah al-silāh* (Al-Sarraf, 2004, p. 180), published by Nabīl 'Abd al-'Azīz (1978, p. 70) (Fig. 3).

An Arabic inscription describes in detail the composition of the combustibles launched by the

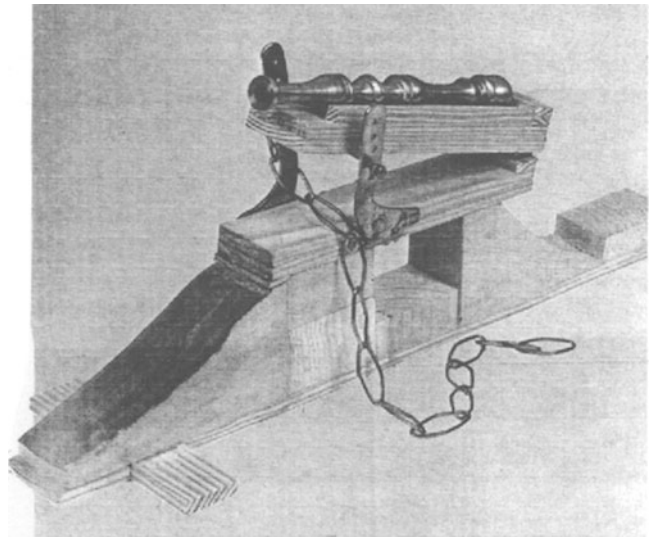
Rocket Machinery of the Mamluks, Fig. 3

Arab propel rocket. Arabic drawing in *Khizānah al-silāh*. Ed. N. ‘Abd al-‘Azīz (1978). Cairo, p. 70. Reproduction from *anīq fī al-manājiq* of Unbughā al-Zaradhash (Courtesy photo by IGOAS. V. Christides et al. (eds.) (2004). *Treasures of Arab-Byzantine navigation* (7th–13th c.). Athens: IGOAS, p. 44)



Rocket Machinery of the Mamluks, Fig. 4

Model of an Arab machine for launching fire arrows stuffed with gunpowder. Construction by N. Orphanoudakis and N. Hadjitheodorou (Courtesy photo by IGOAS. V. Christides et al. (eds.) (2004). *Treasures of Arab-Byzantine navigation* (7th–13th c.). Athens: IGOAS, p. 23)



fire throwers: “You take ten dirhams [one dirham = 3 g] of bārūd [=this word means both saltpeter and gunpowder] one and a half dirham of charcoal, one and a half and one eighth of a dirham of sulphur and you grind [the mixture] until it becomes thin, and you activate a propelling arrow.” Although this machinery is called “cannon” by some modern authors, it is actually a self-launching rocket (Christides et al., 2004; Christides, 2008). The explicit meaning of cannon is “a large gun fixed to the ground or to a gun carriage which fires a solid ball of metal” (Hornby, Cowie, & Gimson, 1974, p. 123; for a distinction between rockets and cannon firing [solid] projectiles, see Nicolle, 1999, p. 296).

No solid metals are fired in the abovementioned machinery in Unbughā al-Zaradhash’s manuscript. Instead a primitive rocket is depicted, which is self-ignited, shooting big firing arrows, propelled by a primitive form of incendiary gunpowder, the essential precursor of explosive gunpowder. As stated above, Christides’ theory of tracing the origin of those rockets to Chinese technology has been enhanced with the new studies by Stephen G. Haw (2013a, p. 442) who, based on Chinese literary sources, has shown that the Chinese had invented such rockets developed from fire arrows, called *huojian*, already in the eleventh century, which probably originally carried an incendiary substance, replaced later by incendiary gunpowder.

Based on the accumulated information above, the Institute of Graeco-Oriental and African Studies (IGOAS), under the guidance of V. Christides, has twice reconstructed a model of the Arab propel rocket, first by N. Orphanoudakis and N. Hadjitheodorou (Fig. 4) and second by I. Kakaras and G. Bothos (Fig. 5). From these reconstructed models by IGOAS, it is clear that the rocket included cartridges filled with incendiary propelling material. It is not known whether this material was a self-ignited substance for launching fire arrows (*sihām khitā'iyya*) or whether it was needed to ignite it. The black powder ignites when heated to



Rocket Machinery of the Mamluks, Fig. 5 Model of an Arab machine for launching fire arrows stuffed with gunpowder. Construction by I. Kakaras and G. Bothos (Dept. of Drawing and Technology of Wood and Furniture, TEI Larissa) (Courtesy photo by IGOAS)

Rocket Machinery of the Mamluks, Fig. 6

A Chinese soldier launches fire arrows stuffed with combustibles (From R. D. Franz, *History of Black Fire*. <http://footguards.tripod.com/06ARTICLES/ART28blackpowder.htm>. V. Christides et al. (eds.) (2004). *Treasures of Arab-Byzantine navigation (7th–13th c.)*. Athens: IGOAS, p. 45)

300 °C (572 °F) and it is easily lit by a flame. A Chinese illumination depicts a soldier ready to launch a fire arrow igniting a rocket (Fig. 6). According to Haw (2013), “each Chinese soldier [specialized in pyrotechnics] carried a small iron pot containing fire to light the lance.” Most probably the Arabic rocket was also similarly ignited.

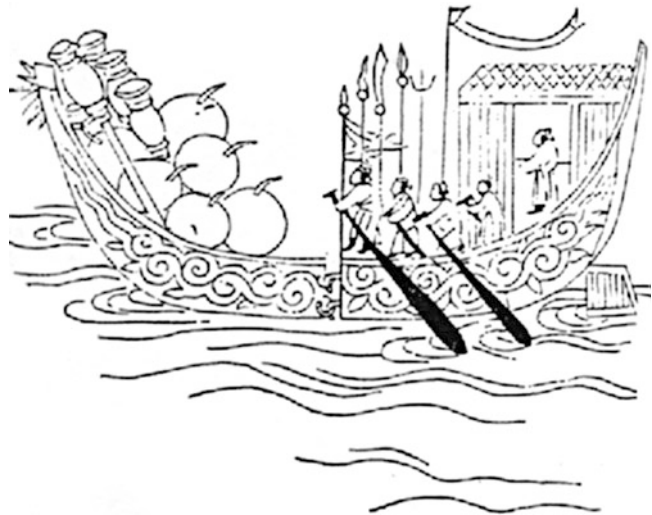
Such propel rockets could have been mounted on Arab warships following Chinese naval practices. The Chinese developed various types of explosive carrying warships after the tenth century. It is not, therefore, surprising that the Arabs acquired some important Chinese inventions concerning the construction of warships carrying Greek fire and other explosives, known as “burlot type.” There were various vessels of the burlot type in China after the tenth century. One of them (*lianhuanzhon*) was divided into two parts; the first loaded with firebombs was attached to the enemy while the second was detached and then withdrawn (Fig. 7). Another swift vessel (*chilonghuan*), full of explosives, was moved by four oarsmen who, after attaching it to the enemy ship, immediately abandoned it and retreated swimming. The existence of similar Arabic vessels is clearly manifested in a depiction of a -rocket-propelled torpedo in Ḥasan al-Rammāh’s abovementioned manuscript.

In conclusion, it should be noted that in spite of a number of Byzantinists who still hold the false impression that Greek fire was a secret Byzantine weapon, the primitive propel rocket



Rocket Machinery of the Mamluks, Fig. 7

A Chinese burlot is depicted loaded with firebombs carried on lances (Photo courtesy of Prof. Zhang Jun-Yan, Peking University)



described in the Arabic sources adds one more piece of evidence for the successful use of incendiary weapons by the Arabs, especially at the time of the Mamluks. Actually, the Mamluks who, in spite of their original indifference towards naval warfare, managed at the turn of the fifteenth century to develop an important navy although it was short lived (Christides, 2009) must have also used their newly discovered naval weapons.

Finally, it should be mentioned that the Byzantines also developed portable fire throwers which are laconically mentioned in Leo VI's *Naumachica* (Pryor & Jeffreys, 2006, p. 508), while there is also pictorial evidence of Byzantine movable hand siphons in land war (Zouache, 2008, p. 801). More research is needed to illuminate this neglected aspect of late Byzantine technology.

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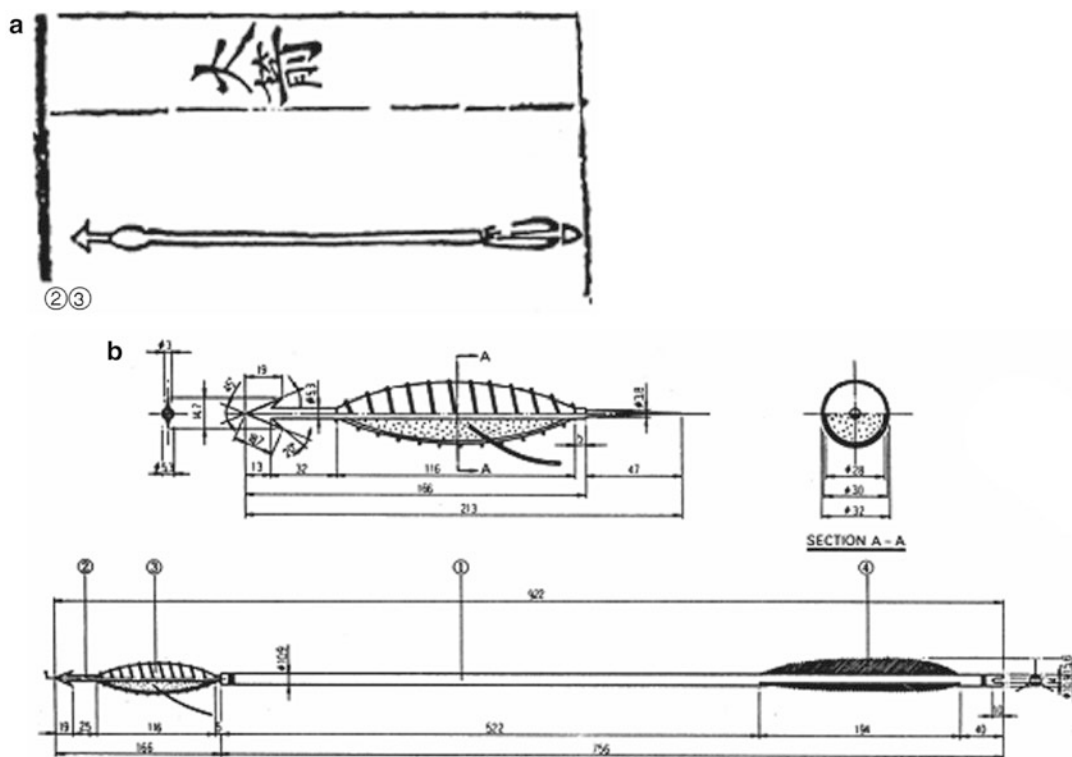
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Rockets in Ancient Korea

Chae Yeon-Seok

The development of Korean rockets as tactical weapons began in the late fourteenth century. According to *Koryo Sa* (The History of the Koryo Dynasty) and *Cho Son Wang Cho Silok* (The Historical Records of the Choson Dynasty),



Rockets in Ancient Korea, Fig. 1 Drawings of *Hwa-Jeon* (a) Fire arrow (*Ju-Hwa*) (Drawing from *Kuk Cho Ore Sorye* 1474). (b) Fire arrow (*Hwa-Jeon*)

(Drawing in metric units (from Chae 1981)). ①: arrow shaft, ②: arrowhead, ③: black powder, ④: fins

King Wu (1377–1389) of the Koryo dynasty (918–1392) ordered the establishment of the Hwa-tong-do-gam (General Bureau of Gunpowder Artillery) in 1377 on the recommendation of Choi, Mu-Son (1325–1395). Commissioned temporarily at the height of Japanese piracy, the Bureau was charged with administering the manufacture of gunpowder and firearms.

Choi, Mu-Son produced a variety of gunpowder and firearms in the newly commissioned Bureau. Fire arrows, called *Haw-Jon*, manufactured at Hwa-tong-do-gam between 1377 and 1391 near the end of Koryo Dynasty were not, unlike some Chinese counterparts, rocket-propelled arrows but exclusively incendiary arrows. They were shot with a bow. Figure 1a illustrates the fire arrow as described in *Kuk Cho Ore Sorye* (Introductory Remarks on National

Rituals/Formalities of National Functions) of the Chosun Dynasty (1392–1910) published in 1474. Figure 1b shows a drawing of fire arrows in metric units converted from the Korean measurement system in which one *chuck* corresponds to 312.4 mm, one *chun* to 31.2 mm, one *pun* to 3.1 mm and one *le* to 0.3 mm.

Unfortunately there is no direct documentary evidence attesting that firearms manufactured at Hwa-tong-do-gam involved rocket-propelled firearms. However, *Kuk Cho Ore Sorye* contains illustrations of rocket-propelled firearms called *Sin-Gi-Jeon*. Moreover, *Hwa Po Sik Un Hae* (Korean Annotation of Gunpowder and Firearms Method, 1635) makes reference to the identity of the propellant cases of *Sin-Gi-Jeon* and *Ju-Hwa* (running fire), a term used for rocket-propelled arrows of the Koryo Dynasty. It is inferred from these historical records

that the *Ju-Hwa* manufactured at Hwa-tong-dogam was the first Korean rocket.

According to *Kuk Cho Ore Sorye*, the arrow shaft of the *Ju-Hwa* is made of a ► **bamboo** stick, and the arrowhead is iron. The tail fins of the arrow are feathers. Although there is neither a direct nor detailed description attesting that *Ju-Hwa* was rocket-propelled, that may be inferred from other historical records. *Choson Wang Cho Silok* records King Sejong speaking to an official PyeongAn, in HamGil province:

Running-fire is very efficient and incomparable because it can be fired easily using a quiver by a mounted soldier. It is detrimental to the enemy; its loud noise and shape instill fear and incite surrender. Once used at night, its exhaust flame lightens the fields and shakes the enemy's spirits.

When used where the enemy is lying in ambush, its flame and smoke cause the enemy to disclose themselves for fear. Running-fire does not fly straight and it spends more powder and requires more precaution than cannon.

"Its loud noise and shape," implies a propulsive device which produces thrust by ejecting combustion gases and thus produces the loud noise. "Once used at night, its flame lightens the field," excludes the possibility that *Ju-Hwa* was a cannon or rifle as it produced "flame and smoke" during flight. In addition, the motion of ancient rockets does not generally follow a straight line because it depends on stabilizing sticks made of bamboo with an exhaust hole in the powder charge in the propellant case. Most of the weight of a solid-propellant rocket is due to the propellant. *Ju-Hwa* "spends more powder" than a gun or cannon as it continues to eject combustion gas in flight.

According to *Hwa Po Sick Eon Hae*, the medium running fire was charged with 41.4 g of black powder. Extrapolating the weights of small and large running fires from the weight of the medium-sized running fire and proscribed volumes of propellant cases of the small and large running fire, the weight of small and large running fire is given by 12 and 2,628 g, respectively. The weight of black powder for a large running fire is significantly larger than that of the

Rockets in Ancient Korea, Table 1 Powder charge of rockets and cannons in fifteenth century Korea

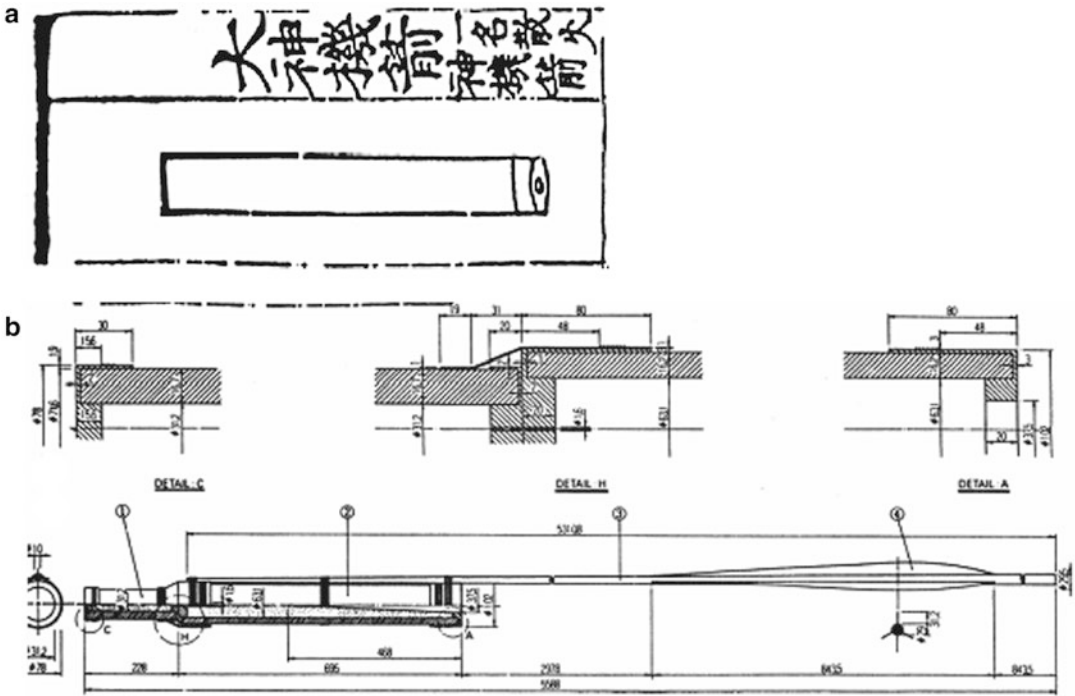
Rockets		Cannon and guns	
Name	Powder weight	Name	Powder weight
Large running fire	2,628 g	Chun Ja Chong Tong (General cannon)	870 g
Medium running fire	41.4 g	Dae Wan Gu (Large motor)	870 g
Small running fire	12 g	Sung Ja Chong Tong (Victory letter gun)	26.7 g

largest cannon used in fifteenth century Korea with the black powder weight of 870 g (Table 1).

Korean Rockets of the Fifteenth Century

The reign of King Se Jong (1418–1450) of the Choson dynasty marked a turning point in the development of firearms, moving beyond the imitation of Chinese models and creating a distinctive Korean model. In the 30th year (1448) of the reign of King Se Jong the details and manufacturing methods of firearms and ready-to-launch munitions were compiled, illustrated and published in the *Chong Tong Deong Rok* (Reproduced Records of Firearms and Gunpowder). No copy of *Chong Tong Deong Rok* had survived, but part of it is in *Kuk Cho Ore Sorye*.

According to *Hwa Po Sik Eon Hae*, three types of rocket-propelled arrows were in wide use in their mature form by the 29th year (1447) of King Se Jong's reign: large, medium, and small running fires. In *Choson Wang Cho Silok*, such firearms are no longer mentioned by those names after 1448 and onward, but instead a new set of names of firearms begins to appear, namely *Sin-Gi-Jeon*, literally meaning "magical machine arrow." However, the specifications and manufacturing methods of the medium-sized *Sin-Gi-Jeon* described in *Hwa Po Sik Eon Hae* are identical to those for the *Ju-Hwa*. Thus, it is inferred that the *Sin-Gi-Jeon* was based on the *Ju-Hwa* and developed further to include versions of various sizes: small (*So*), medium



Rockets in Ancient Korea, Fig. 2 Large magical machine arrow (a) Propellant case from *Kuk Cho Ore Sorye*, 1474. (b) (Drawing in metric units). ①: warhead, ②: propellant case, ③: bamboo, ④: fins

(*Chung*), large (*Dae*), and multiple bomblets magical machine arrows.

Dae-Sin-Gi-Jeon (Large Magical Machine Arrow)

Figure 2 shows a drawing of the *Dae-Sin-Gi-Jeon* (large magical machine arrow) in the *Kuk Cho Ore Sorye*, and a drawing reproduced in metric units. The propellant case filled with black powder is a cylindrical tube made of paper. It is 695 mm long, 17.8 mm thick, and the internal diameter is 63.1 mm. Both ends of the propellant case were sealed with paper several times and attached to the front end of the ► bamboo shaft by strings. At the bottom end of the propellant case, opposite the warhead, a hole was made to allow exhaust fumes to exit. The bamboo shaft is 5.3 m long with the cross-sectional diameter increasing from 10 mm at the front to 29.5 mm at the rear. At the rear of the bamboo shaft three feathers were evenly distributed in between. The “Firearms Illustration” in *Kuk Cho Ore Sorye* records that they are bird feathers. However,

there is no feather of size 30×840 mm, and it is reasonable to conjecture that they were made of leather, considering that arrows fired from a cannon at that time were equipped with feathers made of leather.

An explosive tube is mounted on the front end of the propellant case. A detonating fuse extends from the explosive tube through a hole made on the surfaces of the explosive tube and the propellant case into the propellant case. Such an arrangement enabled the explosives to detonate during or near the end of the flight to the target. The overall length of the *Dae-Sin-Gi-Jeon*, including the explosive tube, reached 5.6 m. *Dae-Sin-Gi-Jeon* was primarily used to launch an offensive on enemies across the Apruk river at its estuary from Eui-Ju City. Considering the width of the estuary, the *Dae-Sin-Gi-Jeon* is surmised to range from 1.5 to 2 km.

The *San-Hwa-Shin-Gi-Jeon* (Fire scattering magical machine arrow), an application of *Dae-Sin-Gi-Jeon*, was also used. Instead of employing the explosive tube of *Dae-Sin-Gi-Jeon*, the front



Rockets in Ancient Korea, Fig. 3 Image of large magical machine arrow

part of the propellant case was occupied by a bundle of paper explosives called *So-Bal-Hwa* (small fire burner) connected by a detonating fuse. *San-Hwa-Sin-Gi-Jeon* was designed to disperse paper explosives ignited when they were near the target.

Dae-Sin-Gi-Jeon is the largest rocket ever made employing explosive cases made of paper, and a reproduced version is shown in Fig. 3. It was 350 years later that rockets of comparable size were manufactured elsewhere; in 1805 William Congreve of England produced 6-pound rocket with a propellant case 550 mm long, a diameter of 110 mm and an overall length including stabilizing sticks of 4.3 m.

Medium and Small Magical Machine Arrow (*Chung- and So-Sin-Gi-Jeon*)

The *Chung-Sin-Gi-Jeon* (medium magical machine arrow) has a 1.4 m long bamboo shaft with a 200 mm long propellant case attached to

the front. An arrowhead weighing 5.5 g is fixed at the front end of the *Chung-Sin-Gi-Jeon*, and at the rear end are attached 17.8 cm long bird feathers. There is no mention on the range of *Chung-Sin-Gi-Jeon*, but it is estimated to range from 150 to 200 m.

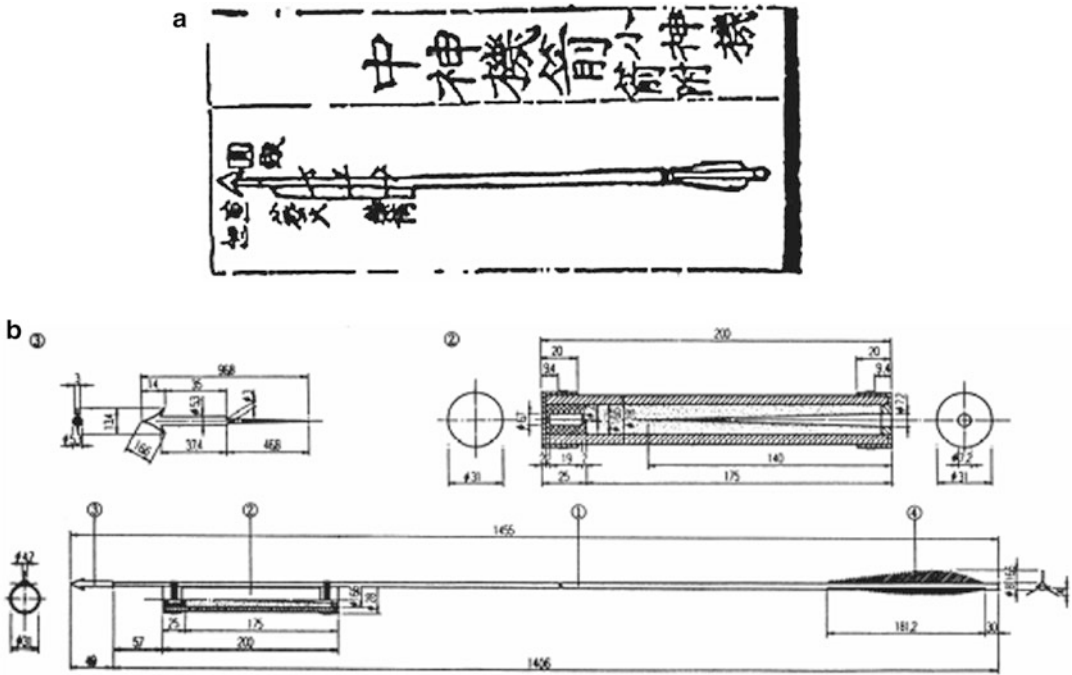
A detailed drawing showing the internal structure of the medium magical machine arrow is reproduced in Fig. 4. The lower part of the propellant case is bound with twine as in the large magical machine arrow. The propellant case is charged with powder up to the height of 175 mm leaving an empty space with a corresponding height of 25 mm. A small explosive tube (*so-bal-hwa-tong*) 56.2 mm long, 47.8 mm in circumference, 4.4 mm thick and 6.9 mm in internal diameter is inserted into the propellant case. The length from the end of the cylindrical case to the attachment twine is 6.3 mm, and the diameter of the nozzle is 2.2 mm. Finally, the powder in the propellant case of the medium magical machine arrow was connected with fuses.

The *So-Sin-Gi-Jeon* (small magical machine arrow) is the smallest version of the series as shown in Fig. 5. Its propellant case, 15 cm long with a cross-sectional diameter of 15 cm, is attached to the front of a 100 cm-long bamboo shaft. At the rear end bird feathers are attached. The diameter of the exhaust hole installed in the propellant case is 4 mm, and the range is estimated to be about 200 m. Figure 6 shows pairs of reproduced running fire, and small and medium magical machine arrows reproduced in 1979.

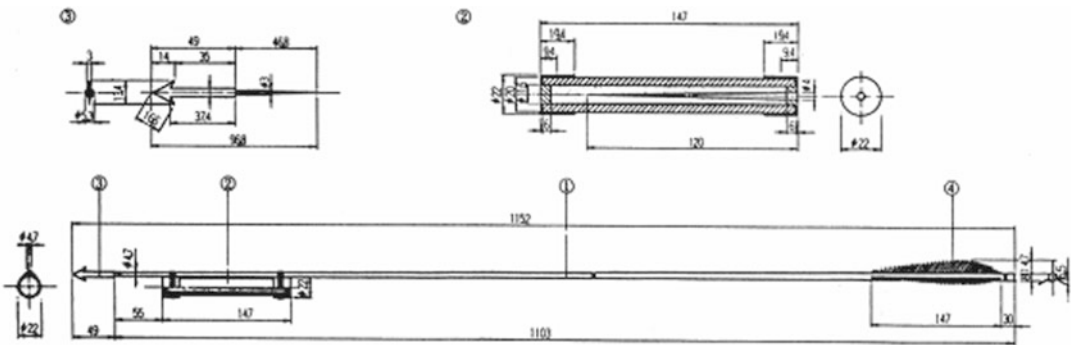
Multiple Bomblets Magical Machine Arrow (*San-Hwa-Sin-Gi-Jeon*)

The multiple bomblets magical arrow is similar to the large magical machine arrow in size, but it differs in the warhead system. A propellant case serves as a warhead instead of an explosive tube.

The detailed internal structure of the propellant case and explosive system of the multiple bomblets magical machine arrow is shown in Fig. 7. The lower part of the propellant case was bound with twine as in the large magical machine arrow. The propellant case was charged with powder up to the height of 579.5 mm, leaving an empty space corresponding to the height of



Rockets in Ancient Korea, Fig. 4 Medium magical machine arrow. (a) (Drawing from *Kuk Cho Ore Sorye*, 1474). (Drawing in metric units). ①: warhead, ②: propellant case, ③: bamboo, ④: fins



Rockets in Ancient Korea, Fig. 5 Drawing of small magical machine arrow in metric units

115.6 mm. Several layers of paper were attached to the top surface of the powder. Several land fire tubes (*Ji-Hwa-Tong*) attached to small explosive tubes (*So-Bal-Hwa-Tong*) were placed on the top of the propellant case with their fuses attached to the propellant charge.

The “Firearms illustration” section of the *Kuk Cho Ore Sorye* provides detailed explanations on manufacturing arrows, including charging propellant cases. A long, coned-shaped awl was

inserted through the hole in the bottom of the propellant case. Then a small quantity of powder was spread and hardened with an empty cylindrical iron stick with its external diameter equal to the internal diameter of the propellant case.

Rocket Launch Device: Hwa-Cha (Fire Cart) and Launch Pad

The structure of the launch pads for rockets is relatively simple, since it primarily serves the

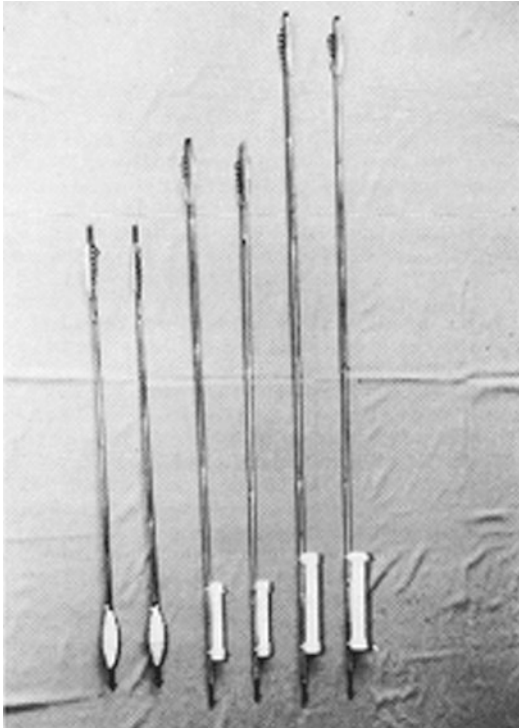
function of providing a direction to the target. Even now, launch pads of rocket cannons retain such simplicity, resembling a piece of a chimney.

During the reign of King Moon Jong (1450–1452), proper launch pads were developed for the *Sin-Gi-Jeon*. King Moon Jong himself was

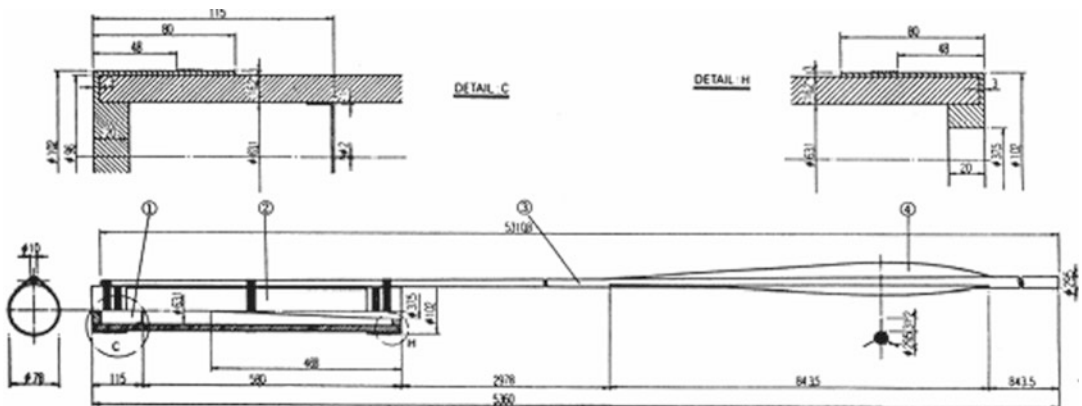
interested in the development of firearms. When he was a crown prince he assumed some responsibility at the Bureau of Weapons. He also played a pivotal role in developing a *Hwa-Cha* (fire cart). *Hwa-Cha* could be loaded either with a launch pad capable of launching 100 *Sin-Gi Jeon* in sequence or with a gun tube pad capable of launching 200 *Se-Jeon* (bullets). Figure 8 shows a drawing of the fire cart in *Kuk Cho Ore Sorye* and a drawing reproduced in metric units.

The most notable feature of the *Hwa-Cha* is that the inclination of the launch pad was variable. The general feature of carts up to the reign of King Se Jong was to load a launch pad on the axle of the wheel. However, the car invented during the reign of King Moon Jong employed a column on and in the middle of the axle of the wheel, which enabled the launch pad to be inclined up to 40°. The first *Hwa-Cha* was dispatched in 1,451, and in the same year 700 additional carts were soon dispatched to strategic coastal regions and fortresses. During peace time *Hwa-Cha* served as wagons.

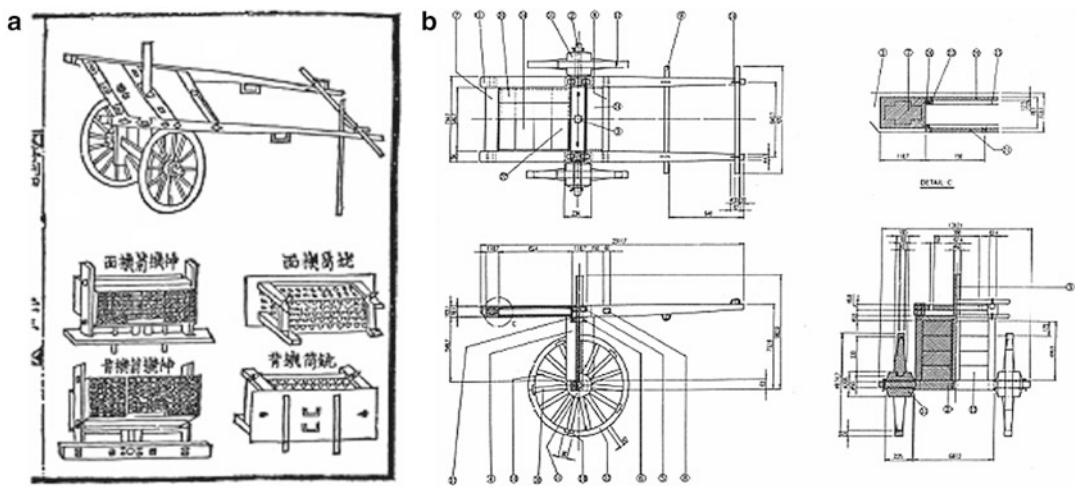
The diameter of the wheel is 874.7 mm. The hub is made of wood, 225 mm wide and 206.2 mm in diameter. Each wheel has 15 spokes. The spindle on which the wheels revolve is made of wood, 1,312.1 mm long, and consists of three parts: a middle square pillar and two end columns which are inserted into two wheels. Two wide posts are set up at both ends of the top side of the middle square pillar. A small post is set up at



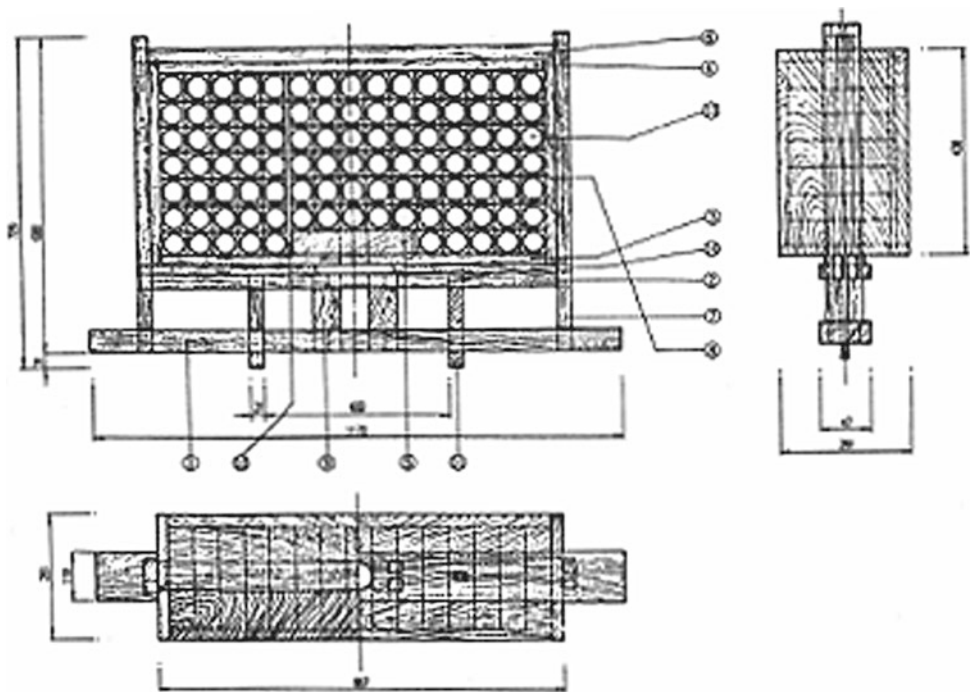
Rockets in Ancient Korea, Fig. 6 Pairs of running fire and small and medium magical machine arrows



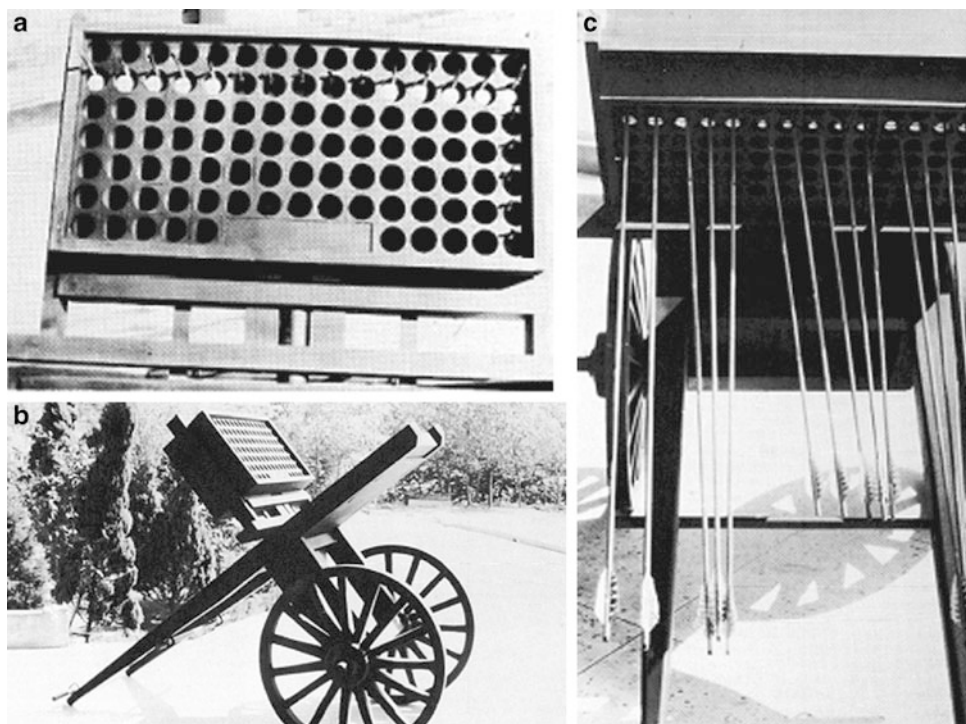
Rockets in Ancient Korea, Fig. 7 Drawing of multiple bomblet magical machine arrow in metric units. ①: warhead, ②: propellant case, ③: bamboo, ④: fins



Rockets in Ancient Korea, Fig. 8 Hwa-Cha (Fire cart) (a) (Drawing from *Kuk Cho Ore Sorye*, 1474). (b) Drawing in metric units. ①: yoke, ②: axletree, ③: small post, ④: wide post, ⑤: upper center crossbar, ⑥: lower center crossbar, ⑦: rear crossbar, ⑧: front crossbar, ⑨: rod, ⑩⑬⑰⑱⑳㉓㉔: thin wooden beam; ⑱: U-shaped nail



Rockets in Ancient Korea, Fig. 9 Drawing of magical machine arrow launcher in metric units. ①: first crossboard, ②: second crossboard, ③/④: top/bottom wide boards, ⑤: rectangular block of wood, ⑥: third crossboard, ⑦: column, ⑧: side wide board, ⑨: small square column, ⑩: detailed board, ⑪: assistant column; ⑫: thin column; ⑬: cylindrical-hole-wood-block



Rockets in Ancient Korea, Fig. 10 Fire cart and magical machine arrow launcher (Hangju Fortress Museum, Korea). (a) Magical-machine-arrow-launcher with medium and small magical machine arrows. (b) Fire cart

equipped with a launch pad. (c) Fire cart equipped with a launch pad loaded with small and medium magical-machine-arrows

the center of the square pillar. Thin wooden boards are attached between each wide post. Two yokes are set up at both ends of the wide posts. An upper center crossbar is placed between the ends of both wide posts. It has a hole in the center for the small post. A rear crossbar is attached at the rear of (four-cornered part) of both yokes. Several thin wooden crossbars are attached between the rear crossbar and the upper center crossbar. This forms a wooden box to hide some arms. Its length and width are 624.8 and 515.5 mm.

Four U-shaped nails are driven into the front and middle of the column part of the yokes to insert rods, which are used to pull the fire cart. Two men could draw the cart on level ground, but it would require another man pushing from behind going uphill, and two more men had to push the cart when it was going up a steep hill.

Figure 9 shows a drawing of the launch pad for magical machine arrows based on the

descriptions in *Kuk Cho Ore Sorye*. It consists of a rectangular box containing blocks with 100 cylindrical holes and a supporting mechanism. They are comprised of seven rows of blocks. The end of each block is pierced with a wire and both ends of the wire are attached to the external surfaces of the side boards of the rectangular box. The supporting mechanism houses the rectangular box and consists of a set of columns and crossboards. The first crossboard is 1,171.6 mm long, 109.3 mm wide, and 47 mm thick. It has a 62.4 mm diameter hole in the center into which the small post of the fire cart is inserted. The main body of the launcher is supported by two columns, small square columns, and assistance columns.

The design of the fire cart and the magical machine arrow launcher enabled the cart body to be raised above the axle by short pillars to regulate the angle from 0 to 43°. The magical machine arrow launcher when fully loaded could launch



Rockets in Ancient Korea, Fig. 11 Flight test of small and medium *Sin-Gi-Jeon* at Daejeon Expo 93

100 medium or small magical machine arrows in groups of 15 at a time. According to the *Moon-Jong-Silok*, 700 fire carts were built in Korea in 1451. Figure 10 shows a version of a fire cart and launch pad loaded with small and medium magical machine arrows reproduced in 1979.

The first Korean rocket manufactured in Hwa-tong-do-gam between 1377 and 1389 provided the technological heritage for forthcoming rockets called *Sin-Gi-Jeon*. *Kuk Cho Ore Sorye* served as a technical manual for manufacture and operation of the rockets. While the large *Sin-Gi-Jeon* is the largest rocket ever made amongst those employing a propellant case made of paper in the fifteenth century, the use of the unit of length “le” corresponding to 0.3 mm demonstrates that *Sin-Gi-Jeons* were manufactured with a considerable level of precision. Historical records attest that 33,000 or so running fires and magical machine arrows were maintained in Korea by 1447, and dispatched for action with the fire cart from 1451. These weapons are

believed to have served as powerful weapons for raiding Chinese and Japanese bandits.

Unfortunately, neither the *Sin-Gi-Jeon* nor the fire cart survives, primarily because they were made of wood and paper. In order to verify the technical feasibility of drawings and manufacturing methods in *Kuk Cho Ore Sorye*, small and medium *Sin-Gi-Jeons* were reconstructed together with their fire carts and launch pads for a flight test at the Daejeon Exposition in 1993. Figure 11 depicts the moment of the flight test of 100 small and medium *Sin-Gi-Jeons* in 1993. The *Sin-Gi-Jeons* traveled between 100 and 200 m in distance. The successful test cleared the obscurity surrounding the rockets which had arisen from the fact that there were no remaining models; it demonstrated that they were nearly flawless in terms of design and function.

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Rockets in China

Pan Jixing

Traditionally, a rocket is a flying device launched by direct-reaction using a solid black powder of high-nitrate composition. The appearance of rockets signified a revolution in the development of firearms. All modern rockets were gradually developed on the basis of traditional ones. In Ancient China the rocket was generally called *huojian* (fire-arrow) which sometimes meant incendiary arrow and sometimes rocket. Both of

them were invented in China. It is necessary to differentiate one from the other. From 968, the classical fire-arrow was sent by low-nitrate ► [gunpowder](#) in paste form from a bow or cross-bow. It was thus an incendiary arrow, although it was the earliest gunpowder weapon. Since the beginning of the twelfth century solid gunpowder of high-nitrate composition and fuses were made and used for making fireworks and firecrackers. Some of them were directional devices, such as the *di laoshu* (earth-rat), *qihuo* (flying fire), and others. This provided a necessary premise for making rockets. During 1127–1234 the invention and military use of rockets were perfected in China on the basis of fireworks technology. There were two types of early rockets having different names.

The so-called *pili pao* (thunder-bolt missile) used in the Battle of Caishi between the Song and Jin was actually the earliest rocket-propelled bomb in the world. It was an enlarged *ertijiao* (double-bang firecracker) and was made according to the principle of *qihuo* (flying fire) used by the Song people in an earlier time. The *fei huojian* (flying fire-lance) used in the Battle of Kaifeng between the Jin and Mongols in 1232 was an ordinary rocket for setting things on fire. Its rocket tube made of paper was fastened to the point of a lance or an arrow. During the thirteenth to fourteenth centuries the Song, Jin, and Mongol troops all used improved rockets to fight with each other. They even used the reaction weapon abroad. For instance, single rockets and multiple rocket-launchers with a common fuse were used by the Mongols in the Battle of Leignitz in Poland in 1241, known as the “Chinese dragon belching fire” in the West. Winged rockets must have been made in about 1300, since it was described in the *Huolong Jing* (Fire-Dragon Manual, ca. 1350).

In the Ming dynasty (1368–1644) rocketry entered a new epoch. Two-stage rockets were designed and made at the beginning of the fourteenth century. There were various kinds of different rockets from single ordinary ones to multiple rocket-launchers and wheelbarrows, as well as winged rockets and rocket-propelled bombs. Their range reached 200–500 paces (330–825 m). There was a special rocket troop

in the Ming army and rocket weapons were used as standing weapons by land and naval forces and cavalry troops. It is interesting that a Chinese military officer, Wan Hu (fl. 1440–1495), built a flight device made of 47 big rockets for a flight experiment. He was the first in history to try to use rockets for flight as a means of transportation. All of these ancient achievements in the field of rocket technology can be found in the military work entitled *Wubei Zhi* (Treatise on Armament Technology) written by Mao Yuanyi (ca. 1570–1637) in 1621. After rocket technology was perfected in China it was spread to other parts of the world. It went first to the Arab world in 1240–1260, then to Europe in 1260–1270. The term *rochetta* first appeared in Italian literature in 1330. In the eighteenth century rockets were popular in some major European countries. Rockets arrived in other Asian countries in the same time during the Mongol-Yuan period, first in Vietnam and Korea, then in India and Southeast Asia.

In 1805 the British military officer William Congreve (1772–1825) developed modern rockets made of iron tubes with black powder, which had a range of 2,300 m. But after the mid-nineteenth century rocketry ceased to develop, because modern cannons seemed to be more powerful and effective. Since the beginning of the twentieth century rockets have been given more attention and studied carefully. As a result, various new types of rockets have been developed and used, especially since World War II. Joseph Needham says:

In this day and age, when man and vehicles have landed on the moon and when the exploration of outer space by means of rocket-propelled craft is opening before mankind, it is hardly necessary to expatiate upon what the Chinese started when they first made rockets fly.

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Rockets in India

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Introduction

Fire arrows in some form have been known for thousands of years in several cultures (*agni-bāṇa* in Sanskrit). In contrast to arrows (even fire tipped) which are shot with the help of the stored elastic energy of a bowstring, rockets are entirely self-propelled, usually by conversion of the chemical energy stored in the propellant(s).

It is generally agreed that rockets were in use in China in the eleventh century CE, perhaps in the form of what we might now term a “rocket-assisted arrow”; over time the arrow came to be discarded as the rocket became sufficiently powerful to serve as a destructive warhead by itself. In 1232 CE, five years after Genghis Khan's death, Chinese rocket barrages repeatedly repulsed Mongolian cavalry led by his successors in attacks on the city of Kaifeng (which nevertheless fell in 1233; Grousset, 1965). The invention traveled rapidly (presumably through the Mongols) to Europe, where it was first mentioned in 1258 CE and was experimented with and used up to the fifteenth century: in England Roger Bacon (1214–1294) had worked on both advanced gunpowder and rockets. However, towards the beginning of the sixteenth century, the cannon (invented around 1300 CE) had improved so much that the military rocket fell into disuse, although it survived as a part of festive pyrotechnics.

In India rockets had been occasionally used by the Moghuls (Qaisar, 1982) and in a small way by the Nawab of Arcot in the south (Forrest, 1970) during the first half of the eighteenth century. The reemergence of the rocket as a significant military weapon occurred during the second half of the eighteenth century in the princely state of Mysore in south India. To understand the historical context in which this development took place, a brief appreciation of the political/military situation in eighteenth-century India is necessary (see map, Fig. 1). Following the collapse of the Moghul Empire early in the century, power began to shift to numerous regional rulers or adventurers, comprising (in the South) the Marathas, the Nizam of Hyderabad, the Rajas of Mysore and Travancore, and the Nawab of Arcot (Carnatic). Early in the century the Wadiyar dynasty in Mysore had become weak, and power was virtually handed over in 1760 to Hyder Ali (1720–1782), the illiterate but dynamic great grandson of a Sufi peer who had migrated southwards from Punjab in the North (Wilks, 1810). Hyder had entered service with the Commander of the Mysore Raja's forces in 1749 and, by sheer dint of his military and political ability, rose quickly to the position of Sarvadhikari (Supreme Officer, and for all practical purposes the Ruler) with the Wadiyars in 1760. (He must have been aided by a syncretic and tolerant Sufi philosophy that did not consider matter and spirit as distinct entities and was largely acceptable to both Hindus and Muslims.) Hyder was succeeded in 1782 by his son Tipu Sultan (1750–1799), who became the de facto ruler of Mysore. The Hyder-Tipu half-century coincided with the rise of British power in Bengal and the South, and the East India Company (EIC) became a new player on the South Indian chessboard. The nature of the company's power – military, political, administrative, technological, and intellectual – was correctly assessed by Tipu (Fig. 2) – and perhaps only by him among all the Indian rulers of the time.

The development of the rocket in Mysore, and its use in the conflict with EIC in the four Anglo-Mysore wars (respectively, in 1767–1769, 1780, 1792, and 1799), is a fascinating episode in the history of technology – not only in India but the

Rockets in India,

Fig. 1 Map of South India
(Joppen, 1920)



R

world. It is the purpose of this essay to narrate how this happened and the interesting sequel of its immediate development and industrialization in nineteenth-century Britain. We shall however touch only briefly on how the rocket spread to the rest of Europe including Russia, and to the USA and elsewhere in the world, during the twentieth century. The use of military rockets in the Anglo-Mysore wars thus provided the direct trigger for the spectacular developments that have taken place in the last two centuries and are continuing globally to do so even now.

Much of the material presented here is taken from Narasimha (2012); it is part review and part

update of the author's work on different aspects of the subject of the essay, as contained in the three references cited at the end. New material is introduced especially in sections "[Construction, performance, and use of the Mysore rockets](#)" and "[Tipu's character](#)."

Construction, Performance, and Use of the Mysore Rockets

The rockets used by the Mysoreans consisted of a metal cylinder (casing) containing the combustion powder (propellant), tied to a long



Rockets in India, Fig. 2 Tipu Sultan (Cover page, March of Karnataka 1999, Vol. 37, Government of Karnataka)

bamboo pole or sword which provided the required stability to the missile (Fig. 3). There is a recognizable resemblance to the familiar but much smaller pasteboard “rockets” one can see during fireworks in India and elsewhere to this day. Unfortunately there is little authentic technical documentation available in India about these rockets, as they were the work of artisanal communities that jealously guarded knowledge accumulated over generations (Narasimha, 2003) and kept it from becoming public in any way. The last of the three factories that had at one time made “real” war rockets at Tipu’s capital Srirangapatana (Seringapatam) was destroyed in an explosive fire in the early 1960s (according to Stripp, Bhogle 1991), making it too late now to construct even a reliable oral history. Much of our information about the rockets come therefore from early British accounts, dating back to the last decades of the eighteenth century. Useful summaries are available in Ley (1958), Von Braun and Ordway (1966) (referred to in the

sequel as L and vBO, respectively), and Baker (1978).

Two specimens, fortunately preserved in the Royal Artillery Museum, Woolwich Arsenal, have these dimensions (vBO, see Fig. 3):

- (i) Casing 2.3 in. O.D. $\times$ 10 in. long ($\sim$ 58 mm O.D. $\times$ 254 mm long), tied with strips of hide to a straight 3 ft. 4 in. ($\sim$ 1.02 m) long sword blade
- (ii) Casing 1.5 in. O.D. $\times$ 7.8 in. long ($\sim$ 37 mm O.D. $\times$ 198 mm long), tied with strips of hide to a bamboo pole 6 ft. 3 in. ($\sim$ 1.9 m) long

The propellant was gunpowder. The real advance in technology of these rockets over the state of the art in Europe was in the material of the casing, which was a metal cylinder made of hammered soft iron. European rockets of the time had combustion chambers made of some kind of pasteboard; e.g., Geissler in Germany used wood, covered with sailcloth soaked in hot glue (L). In the eighteenth century iron was still generally of much better quality in India than in Europe, as we shall discuss further below. The use of iron increased bursting pressures, permitting the propellant to be packed to greater densities. This gave the Mysore rockets a higher thrust, and hence also longer range, as later confirmed by tests in England as about 1,000 yards, approximately twice that of the most powerful European rockets of the time (see section [Tipu’s Character](#)). There are however other accounts (e.g., L) that speak of rockets generally weighing 3.5 kg, tied to 10 ft ($\sim$ 3 m) bamboo poles, and with a range of up to 1.5 miles (2.4 km): this was an “outstanding performance for the time” (Baker, 1978).

Incidentally, the superior characteristics of the iron used for the casing is not such a surprise, as ferrous metallurgy in India has a history that can be traced as far back as the middle of the second millennium BCE (Tripathi, 2008). In the Mysore area (Karnataka today) the earliest site has been dated to 1440 BCE. Premodern iron-smelting sites in South India occur in two clusters, of which the bigger runs north to south, from today’s south Andhra Pradesh (Telangana) through east Karnataka to northern Tamil Nadu.

Rockets in India,

Fig. 3 Replicas of the rockets used by Tipu's troops. *Top*: rocket with stabilizing blade; *bottom*: rocket chamber



A famous Mysore site in this “iron belt” was Chitradurga, which during Tipu’s times was one of the four specially selected industry centers called Taramandalpets (roughly translating to galaxy or star-cluster bazaars), which were Tipu’s “technology parks.” It is easy to imagine that the iron technology so easily available in Mysore was a major factor in the development of the casing of Tipu’s rockets. The steel from these and other Indian sites, especially the kind called wootz (derived from the Kannada word *ukku*, according to the Oxford English Dictionary), was used in the celebrated Damascus swords; it has been called “the first high-quality steel made anywhere in the world” (Verhoeven & Pendray, 1998, cited in Srinivasan & Ranganathan, 2004). Some Indian iron and steel was still being imported by Britain in the early nineteenth century (Tripathi, 2008).

The use of rockets by Hyder and Tipu is mentioned at various places in Wilks’s (1810) famous *History of Mysoor*. A recent, readable account of

the history of Tipu is Forrest (1970). There was a regular Rocket Corps in the Mysore Army (Fig. 4 shows a typical rocket-man), with about 1,200 men in Hyder’s times, growing to about 5,000 in Tipu’s army. In the Third Anglo-Mysore War of 1792, there is mention of two rocket units fielded by Tipu, commanded, respectively, by Qamar-ud-din Khan (120 men) and Purniah (131 men). Qamar-ud-din was a cousin and a favorite general of Tipu and Purniah the famous Hindu *dewan* (chief minister) who served the Maharajas of Mysore, Tipu, and the British through a time of rapidly fluctuating fortunes. Wilks mentions the skill of the rocketmen (see also Forrest, 1970) in selecting the elevation to suit the varying dimensions of the cylinder and the required range. Furthermore, the rockets could be launched rapidly using a wheeled cart with three or more rocket ramps. Other accounts speak of how Tipu’s rocketmen threw a “great number of rockets at the same instant” (vBO). Then there were the so-called ground rockets

Rockets in India,

Fig. 4 One of Tipu's soldiers, using as flagstaff the kind of rocket employed by the Mysoreans in 1792 (Source: Buddle, 1990)



which, “on striking ground, would rise again and bound along in a serpentine motion until their force was spent.”

British Reactions to Mysore Rockets

In most histories of the Anglo-Mysore wars, the use of rockets by the Mysore armies is frequently mentioned, often in association with muskets. Apart from Wilks and Forrest, we can cite Rao (1943), Kirmani and Mir Hussain Ali (1864), and Dirom (1793), among others. “Rockets and musket fire” appear almost casually in such accounts, indicating how widespread the use of rockets must have been. We shall briefly describe some specially striking military events involving Mysore rockets.

The Battle of Pollilur

This was fought on 10 September 1780 during the Second Anglo-Mysore War (Wilks, 1810): Pollilur is a small village between Kanchipuram and Arakkonam in today's Tamil Nadu. In July of

that year, Hyder, with 80,000 men and 100 guns, [had come] down upon the plains of the Carnatic (see map Fig. 1), “like an avalanche, carrying destruction with him” (Majumdar, Raychaudhuri, & Datta, 1958). Hyder and Tipu achieved a famous victory at Pollilur, and it is widely held (e.g., Forrest, 1970) that a strong contributory cause was that one of the British ammunition tumbrils was set on fire by Mysorean rockets; the scene is celebrated in a famous mural (Fig. 5) at Darya Daulat Bagh, Tipu's summer palace in his capital Srirangapatna. (An 1820 reproduction by an unknown Indian artist may be seen in the National Art Gallery at Edinburgh, Fig. 5.) Writing about this war, Sir Alfred Lyall remarked, in *Rise and Expansion of the British Dominion in India* (1914), “The fortunes of the English in India had fallen to their lowest watermark” (Majumdar et al., 1958).

Accounts of the use of rockets in the Second Anglo-Mysore War appeared in a book by Innes Munro titled *A narrative of the military operations on the Coromandel Coast* etc. etc., published in London in 1789. Munro had spent the period 1778–1782 as a correspondent of the *Times* accompanying British troops on their various campaigns in South India.

The Sultanpet Incident

During the Fourth (and final) War, rockets were again used on several occasions. One of these involved Col. Arthur Wellesley, to become famous later as the Duke of Wellington and hero of Waterloo. The incident is therefore of some special interest – not so much because of its impact on the war as of the light it throws on the psychological effects of a totally unforeseen encounter with the rocket in battle on British officers and men of the East India Company.

On the night of 5 April 1799, just before the impending siege of Srirangapattana, Wellesley was chosen as commander for an operation whose objective was to clear a *tope* (grove) which gave shelter to Tipu's rocketmen. The *tope* was near Sultanpet (or Sultanpettah), and what happened there is vividly described by Philip Guedalla in his biography of the Duke of Wellington (Guedalla, 1940). As Wellesley's

Rockets in India,

Fig. 5 Part of a mural celebrating the victory of Hyder and Tipu in 1780 over the British in Pollilur. Col. Baillie is seated in a palanquin in the middle of a square formed by British troops. An ammunition tumbril on the top left corner of the square is seen to have caught fire, by a rocket attack from Mysore rocketmen according to several reports. The mural decorates a wall at the Darya Daulat Bagh in Srirangapattana, but the image here is from a reproduction made by an unknown Indian artist in 1820, now in the possession of the National Gallery of Art at Edinburgh (Buddle, 1999)



column advanced from his camp towards the *tope* in pitch darkness, it was attacked all of a sudden by heavy musket fire and rockets. According to a report of Hook (1833) cited by Rao (1943), “the men gave way, were dispersed and retreated in disorder. Several were killed, and twelve grenadiers (these men were all murdered a day or two before the storm) were taken prisoners.”

A spent ball had struck Wellesley on the knee, and he left his men (in Guedalla’s words) to “report his failure... reeled back to camp ... and the exhausted man, his nerves all frayed, flung himself face down across the mess-table to sleep.” Wellesley’s behavior was sufficiently serious to give rise to talk of a possible court-martial. The “Sultanpet” incident clearly had a traumatic effect on Wellesley, for he used to come back to the incident even late in life, with his own explanations of what happened and why. At the same time, according to Guedalla, the incident was what converted Wellesley to transforming himself to a man with “nerves of steel,” the future “Iron Duke.”

Other British Responses

One account, from a young English officer named Bayly (cited by vBO) said: “The rockets and musketry from 20,000 of the enemy were incessant. No hail could be thicker. Every illumination of blue lights was accompanied by a shower of rockets, some of which entered the head of the column, passing through to the rear, causing death, wounds, and dreadful lacerations from the long bamboos of twenty or thirty feet, which are invariably attached to them.

To balance these was a report by a British “observer” (also cited by vBO), according to whom the rockets were very noisy and annoyed Indian cavalry (this observation seems doubtful as Tipu’s cavalry was used to rocket fire), but that they had less effect on British troops which were organized along the famous thin [“red”] lines (see Fig. 5), whose lack of depth saved them.”

[Incidentally the dates quoted in vBO for some events in the Anglo-Mysore wars are inconsistent with other reports and have therefore been corrected as proposed by Narasimha (2012).]

For the purposes of this essay, the main conclusion we draw is that these accounts leave no doubt that the rocket was a totally unfamiliar weapon to the Company's troops and its commanders, and whatever its military effectiveness might have been, its psychological impact was extraordinary even on seasoned European troops of the time.

Tipu's Character

The story of the Mysore rockets would not be complete without a few remarks on the character of the man who was chiefly responsible for the rocket program.

First of all Tipu (who was named after a Muslim saint) was a Sufi warrior. As a child he had two teachers, one Muslim and one Hindu. The syncretic religious environment that prevailed in South India was possible because of the close similarities in both Hindu and Sufi-Muslim views of sacred power, in particular of *śakti* and *barakat*, respectively, as analyzed by Brittlebank (1997). Tipu gave generous gifts to various Hindu temples and religious institutions and sought their prayers for his victory in battle. All this gave his rule a legitimacy and acceptability among most sections of the people of Mysore and a loyalty that went beyond the norms of the age in India. As Brittlebank (1997) argues, Tipu was gaining legitimacy in a largely Hindu state by following the popular Indic ideal of a universal king, without compromising his position as a devout Muslim. Tipu's treatment of his political opponents (of whatever religion) was however harsh, and this has led to several generally unjustified accusations of religious fanaticism, for he could also be surprisingly generous with people of other faiths under less threatening circumstances.

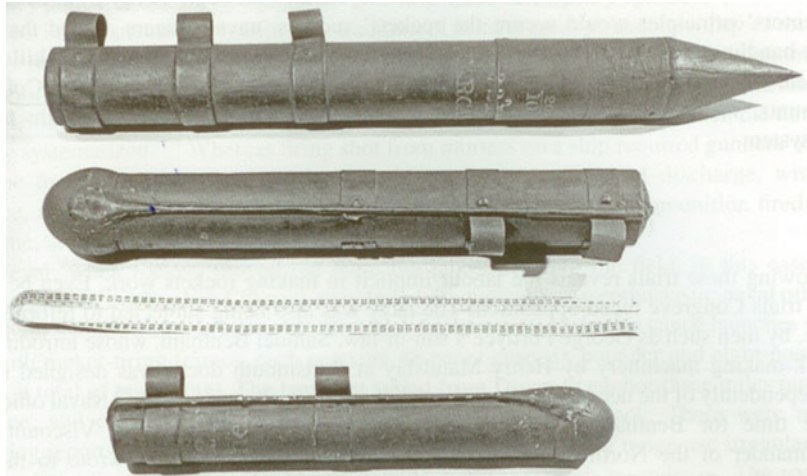
Secondly he was what today would be called a *technology buff*. According to a report cited by Wilks, Tipu's tent (in his besieged capital in 1799) housed "a very handsome case of instruments," and he possessed a library which contained "a translation of Euclid [into Farsi?],

several works of reputation on geometry, mathematics and astronomy." Even if (as the usually biased Wilks suggests) Tipu could not have practiced the mathematics, the very fact of Tipu's serious personal interest in such knowledge shows his keen appreciation of the importance of the contemporary science and technology of Europe. He may well have been the first Indian political/military leader whose response to the advent of the Europeans included a keen realization of the very significant advances that had been made by them in science, technology, administration, and discipline. Tipu was full of curiosity about European inventions such as barometers and thermometers and in turn gifted rockets to such notables as the Sultan of Constantinople (Rao, 1943). He was an enthusiastic patron of the technical arts and set up four special industrial zones called Tārāmaṇḍalpets, respectively at Srirangapattana, Bangalore, Bednur, and (as already mentioned) Chitradurga (Narasimha, 2003).

Finally he was a compulsive and indefatigable *innovator*. Wilks devotes a considerable part of one chapter of his book to discussing Tipu's "boasted improvements" and adopts an attitude of amused disparagement towards Tipu's numerous innovations, some of which were of course unsuccessful. But the range of Tipu's interests and his radical thinking were certainly singular for his time, look most impressive, and were often successful; apart from the rockets discussed here, we may cite the example of the introduction of sericulture: the "Mysore silk" that owes its origin to him is popular even today in India. Not only did his workshops make muskets, cannon, and other weapons but also glass, cutlery, paper, etc. His goal was what was called technological self-reliance or *swadeshi*, in the policy adopted by the new Indian government soon after the end of British rule in 1947; in this and other ways, he was ahead of his times. He was impatient and had a penchant for micromanagement. But his energy was extraordinary, and he did more for his state than any other prince did at the time for his own.

Rockets in India,

Fig. 6 Early rockets made by Congreve, beginning with copies of the Mysore rockets (with a typically blunt nose) and later with larger designs (with a typically sharp nose) (Congreve, 1827) (Source: Werrett, 2009)



Rocket Development in Britain

A vigorous program of what we would now call “research and development” on rockets took place in Britain beginning with the new century. There is no doubt that this interest in the rocket as a military weapon was inspired by the numerous reports from India, as well as the arrival of the Mysore rocket cases themselves in England (Baker, 1978). The ensuing development of rocket technology in Britain has been generally credited to Col. (later Sir) William Congreve, who was told (vBO) that “the British at Seringapatam had ‘suffered more from them [the rockets] than from the shells or any other weapon used by the enemy. . . . In at least one instance, an eye-witness told Congreve, a single rocket had killed three men and badly wounded others.’”

In 1801/02, Congreve bought (out of his own pocket) and tested the biggest skyrockets then available in London (L). Their range was found to be 500–600 yards, about half or less of that of the Mysore rockets. He then started developing his own, using the facilities of the Royal Laboratory at Woolwich Arsenal, with the support of such influential figures as his father who was Comptroller of the Laboratory and of Lord Chat-ham who was Prime Minister during 1783–1801.

Congreve first tested various combinations for propellant, made some rockets which were basically imitations of the Mysore rockets, and

eventually developed a rocket motor with a stout iron case 100 mm dia with a conical nose, weighing about 14.5 kg and attached to a 4.6 m long wooden stick 38 mm in diameter. Both of these early types are shown in Fig. 6.

In 1804 Congreve published a book titled *A concise account on the origin and progress of the rocket system* and claimed that his rocket’s “carcass is the largest of the kind that has hitherto been constructed for use,” obviously unaware of earlier European work, in particular the much larger rockets (with wooden casings, though) made by Geissler in Berlin in 1668 (L). Congreve’s rockets had iron hoops on one side, making it easier and quicker to fix the stabilizing stick, but later he also tried a configuration where the stick was fixed at the center of the casing with exhaust gases coming out of orifices around the circumference. By August 1906 he was reporting that 13,109 rockets had already been manufactured.

Although his program was directly inspired by the superior performance of the Mysore rockets, Congreve quickly thought of his program as one of developing “rational” rockets and a whole rocket *system*, implying that it was based on “philosophical” (i.e., scientific) principles (Werrett, 2009). Beginning with an application of Newton’s third law on action and reaction to understand rocket behavior, he recognized that one of the chief advantages of the rocket would

be the absence of the recoil force (“to ground,” so to speak) that made it so difficult to use cannon on ships. He therefore argued that rockets were particularly suited for seaborne assault, although he apparently came to feel later that this was not the best method of using them. He also experimented with a number of black powder formulas, set down specifications for their composition, standardized construction details, used improved production techniques (the stabilizing stick could be quickly inserted into hoops on the side of the casing and crimped), offered designs permitting either explosive (ball charge) or incendiary warheads (the former could be independently timed by trimming the fuse length before launching), studied the tactics of their use (recommending that they be fired in volleys of at least 20 and preferably 50 rockets once every 30 s, to compensate for their dispersion), and designed simple collapsible wooden frames to serve as launchers (dispensing with the heavy-wheeled carriages that were so necessary for transporting cannon and made them unusable in difficult terrain). Much of this work was clearly industrial in character.

A list of rocket types he developed, published by him in 1817, included seven rockets with carcasses varying from 12 to 42 lb and range varying from 2,000 to 3,000 yards. There were also flare rockets equipped with parachutes. And he also gave a detailed cost breakdown of the rockets, to contest the claim that they were too expensive. There can be no doubt that Congreve brought to rocketry ideas from the Newtonian science that had emerged a hundred years earlier, and the fruits of the industrial revolution sweeping Britain at the time.

However, as pointed out in Warrett’s interesting analysis, Congreve’s rational rockets “emerged at the same time as European attitudes to Eastern pyro-technics switched from reverence to disdain.” Congreve tried to introduce a “system” of his own whose objective was to make rocket manufacture and operation independent of the special skills and experience presumably possessed by the craftsmen who used to make them and reduced to a purely mechanical process. He quickly stopped giving credit not

only to the Indian roots of the rockets he was making but also to the contribution that the tacit knowledge of workers as well as operators in Britain (e.g., from the Navy), on the ground that he was making both fireworks and rockets more “philosophically.” He wrote extensively on the principles of both manufacture and operation and on tactics. As he was implicitly claiming to be the (sole) inventor of rockets and expected that as inventor he should control everything, his project became highly controversial in Britain. In one series of trials which he organized in 1805 as an attack on Boulogne, the test program was a dramatic failure. On the other hand a program organized differently by Capt. Owen of the British Navy in 1806, using the experience and tacit knowledge of Naval officers and men, turned out to be successful and was so acknowledged by Congreve himself. After a detailed account of these programs, Warrett concludes that Congreve “minimised the contribution of both Indian rocketeers and British Naval officers, in a process of orientalizing [in the sense of Said, 1979] and forcing discipline in action,” an attitude that was characteristic of an age when British power spread rapidly across India and elsewhere in the world.

The success in 1806 was followed in 1807 by a barrage of some 25,000 rockets on Copenhagen, which was also very effective. During the next decade the use of such rockets became routine in British naval operations, which included engagements at Aix, Callao (1809), Cadiz (1810), and Leipzig (1813). Congreve rockets were also used in several engagements during the Anglo-American “War of 1812” (see vBO), sometimes with little and on other occasions with great effect. The rockets were still rather unreliable and inaccurate, but had greater range than cannon and could be fired from rowboats. In the battle of Bladensburgh in 1814, rockets played a key role in a British victory, which was followed by a march into Washington and the burning of White House and the Capitol, among other public buildings. On the night of 13–14 September, Fort McHenry was bombarded from Baltimore harbor; the attack was spectacular and (although unsuccessful) inspired Francis Scott Key,

a young American lawyer who was watching it, to refer to “the rockets’ red glare” in a patriotic song he wrote – a song that later became the US national anthem.

The main advantage of these rockets was that their range exceeded that of the movable artillery of that time, and the absence of recoil eliminated the heavy “barrel” required to direct other projectiles. So a rocket barrage could be discharged rapidly from collapsible wooden frames (these would have been no surprise to Tipu’s rocketmen). Congreve thought, rather appropriately, that rockets were “the soul of artillery without the body” (L). But apart from the use of Newton’s laws and some good “systems” thinking, there were few striking conceptual advances; however, manufacture and operational procedures exploited advantages of scale and precision that the industrial revolution in Britain was making feasible. Here perhaps, and in his extensive publications, lay the major contributions of Congreve.

As the “Congreve” rocket virtually became a household word, he succeeded to his father’s position at Woolwich and the baronetcy and was elected to the Royal Society and Parliament. Not all of this was appreciated by his many detractors, who pointed out (correctly) that he never acknowledged how he started with imitations of Indian rockets nor how the tacit knowledge of his own countrymen had made a big difference to his success.

Other countries quickly followed the footsteps of Congreve and the British. Some, like Denmark, Egypt, France, Italy, the Netherlands, Poland, Prussia, Sardinia, Spain, and Sweden, attached rocket batteries to their artillery. Others, including Austria, England, Greece, and Russia, had rocket corps as independent units. The USA also formed rocket units (L).

Although they continued to be used for some more time, there was a considerable decline in the military use of rockets by midcentury, as artillery gained in range and accuracy and became more effective. However rockets found peace-time application in saving lives from shipwrecks. They began to be proposed seriously in 1898 by the Russian scientist Tsiolkovski for space

exploration, and by Goddard in the USA (beginning in 1915), for scientific investigations of the atmosphere. A few decades later they reappeared as military weapons in World War II when Germany attacked England with the V2. Rocket-powered missiles are now part of the military arsenals of many countries in the world.

Conclusion

I hope enough has been said in this essay to make two points. First, in the eighteenth century there were still certain products, of which the rocket was one, where Indian technology was superior to the British and was so recognized by them. Secondly, following this recognition, the British effort to understand and master the technology already had a sophistication that we have come to associate with research and development in this age: scientific principles were applied, appropriate designs were made, and suitable products were developed, tested, systematically evaluated, and produced on an industrial scale.

To understand how this came to happen, we must recall that this period saw what the historians agree was the first wave of the industrial revolution, which Derry and Williams (1960) date as lasting from 1750 to 1815. Simultaneously there was a marked decline in the technological capabilities of India. In the same period Indian exports declined because of stiff British duties, and imports of textiles from Manchester grew rapidly. Although India had for millennia produced iron of high quality and exported it to Britain as late as the early nineteenth century (Tripathi, 2008), the old Indian industry started to decline, and almost vanished by the 1850s, to pick up again only a few decades later but now with British technology (Pacey, 1983, Narasimha, 2012).

The period in question was one of extraordinary turmoil and ferment – political, social, cultural – and was a turning point in global history, especially in India, Europe, and North America. Britain was fighting military engagements at a variety of places around the globe as it laid the foundations for its empire. Europe saw

the French Revolution (1789) and the rise of Napoleon (1795) – and the American colonies of Britain successfully fought a war of independence (1776).

And the birth of modern rocketry that occurred in the same period of global transition can be traced directly to the 30 years of the Anglo-Mysore wars ending in 1799.

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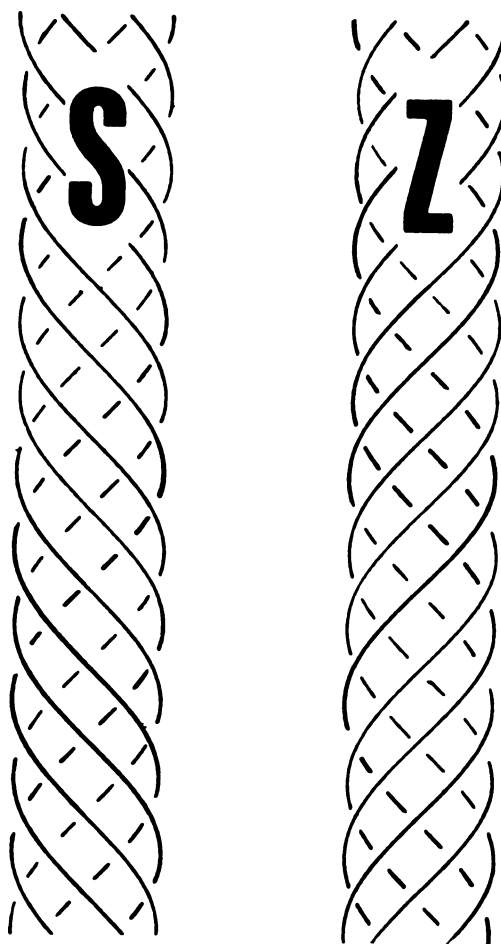
Rope and Knots in Ancient Egypt

Willeke Wendrich

From securing a ship, to tying cattle to a post, building shelters and curing headaches, rope and string were a multipurpose commodity in ancient Egypt. The technology to make rope and string is presumably one of the oldest, predating stone working. Due to the perishable materials used for rope, no extant examples have survived in Egypt until the predynastic period. The material used most widely for the production of rope was papyrus (*Cyperus papyrus*) and other sedges of the *Cyperus* family. For large ropes, the entire stem was used, while smaller string was made of the rind of papyrus stems. The production of papyrus sheets for writing required the thick triangular stems to be peeled and sliced. The peelings made a strong raw material from which extremely fine string could be made. Many examples of such string were found in archaeological contexts, for instance in cordage from the Giza Plateau, in the rubbish tips of the building phases of Khufu's pyramid (ca. 2600 B.C.E.). Its popularity continued into the New Kingdom. At the workmen's village of Amarna (ca. 1350 B.C.E.) remains of a papyrus amphora carrying net were excavated (Wendrich, 1989, pp. 182–185).

Cordage was made in a large variety of ways. The fibers were spun or twisted in either S or Z direction (see Fig. 1). Two or three strands were plied to form the string, usually twisted in the opposite direction of the orientation of the strands. Two or three strings might be twisted into a cable. Again the orientation was usually the opposite of the twist direction of the ply.

The production of yarn or fine string followed three steps: (1) spinning and splicing (adding short prespun lengths by twisting the fibers in the same direction as the spin) using a spindle whorl; (2) plying in the opposite direction, and (3) cabling in the same orientation as the spin. This type of string was usually made of flax and had a diameter of approximately 0.5–2 mm for



Rope and Knots in Ancient Egypt, Fig. 1 S and Z orientation of spinning, plying, or cabling

the spun and spliced yarn, 1–3 mm for the plied string, and 2–5 mm for a cable. Flax was typically spun and spliced in S direction, then Z-plied and S-cabled (Kemp & Vogelsang-Eastwood, 2002, pp. 75–76).

Producing string of other materials was often done in one phase. Grass string, for instance, was spun and plied in one movement of the hands, the opposite direction of spin (usually z) and ply (usually S) locking the string immediately and preventing it from unraveling (Wendrich, 1999, pp. 298–300). Materials for which this technique was used were tall hard grasses (*Desmostachya bipinnata* and *Imperata cylindrica*), leaf and leaf sheath fibre of the date palm (*Phoenix*



Rope and Knots in Ancient Egypt, Fig. 2 Representation of rope making, using weights in the tomb of Nefer, Saqqara. To the *right*: detail of the action of the man seated in the *middle*

dactylifera), leaf of the doam palm (*Hyphaene thebaica*) and probably also papyrus peel. The result of this hand-rolling technique was a string consisting of two yarns, usually ‘spun’ in Z-direction and plied in S-direction (sZ_2 string). A third plying strand (sZ_3 string) was added separately, by doubling the end of one of fiber bundles and working back along the string. For ropes, the entire length of string was folded double and twisted into a cable ($sZ_2[S]_2$ rope).

Papyrus rope, however, was usually not cabled. The enormous ropes used in shipping consisted of multiple strands of complete papyrus culms [stems] twisted together. Such giant plied ropes were built of up to 15 thick strands of papyrus culms, each with a diameter of approximately 30 mm, resulting in a thick rope of 160 mm in diameter. We have few depictions of rope making, for instance in the tomb of Nefer at Saqqara (Fig. 2), dating to the Fifth Kingdom, ca. 2465–2323 B.C.E.. This seems to be a more industrial approach than the hand-rolling method, which could typically be done by anybody at anytime, whenever a piece of string was needed. The use of swinging weights to make long lengths of rope was most probably needed to twist complete papyrus stems. Presumably the stems were first dried, then soaked (to render them pliable again), twisted into rope and left to dry, so that the twist would settle into a strong plied rope. Toward the Greco-Roman period, grass, papyrus, and doam palm leaf string became less ubiquitous and the material that was used most often was the leaf sheath fiber of the date palm. This hard

brown fiber did not need much preparation. Soaking in water for half a day would soften the fibrous sheets enough to enable them to be worked into small bundles or tufts, which were then used to make a very hard red-brown string or rope. This material was also worked in the hand-rolling method.

Knots and knotting are part of understanding the use of rope. In all periods of ancient Egyptian history, from at least the predynastic period onward, standard knots such as the overhand knot, the reef knot (also known as square knot), and the netting knot were known and widely used. Studying everyday objects from refuse dumps, clarifies that then, as now, certain people were better versed in the art of knotting than others. The occurrence of a considerable percentage of ‘granny knots,’ faulty reef knots, testifies to that effect (Wendrich, 1999).

Depictions of knots and knotting on Egyptian monuments had a very specific meaning. The hieroglyph for ‘protection’ (ancient Egyptian *shen*) represented a rope ring, which surrounded what needed to be protected. The *cartouche*, (French for ‘bullet’) was the protective oval inscribed around the name of the Pharaoh. It represented an elongated rope oval tied at the base.

Knotting had a particularly important protective function in Ancient Egypt. The *tit* amulet, also known as the “Isis knot” represented a looped knot with four ends hanging down. The *tit*, often made of the red semiprecious stone jasper, is thought to be either the girdle of the

goddess Isis, or a tampon, with the function of protecting pregnant women from a miscarriage (Wendrich, 2006). A more symbolic interpretation should be given to the quite common depiction of two nameless Nile gods, or the gods Horus and Seth, knotting the lotus and the papyrus (or the lily), symbols for Upper and Lower Egypt respectively, around a trachea with lungs. This was the hieroglyph for the verb *semaa* and the knotting of a reef knot around this hieroglyphic sign symbolizes the unification of the Nile Valley and the Delta, the two lands that together formed Egypt. In ancient religious texts, such as the Pyramid Texts, the Coffin Texts, and the Book of the Dead, several references were made to knotting. In all cases this seemed to be a protective action, in keeping with the important protective function of knots in medical and magical texts. This forms a stark contrast with terms used for ‘binding,’ or ‘fettering,’ which were used in funerary contexts to describe serious dangers to the deceased. The mummy wrappings were literally considered fetters that prevented the dead from functioning in the afterlife. The action of knotting, however, was related to encircling, the protective embrace, and the guarantee of the integrity of body and *ba*

(The *ba*, a concept often translated as ‘soul,’ is an integral part of a person. The *ba* is depicted as a bird with a human head and is the free-ranging part of a human being. When a person dies, the body is entombed, but the *ba* can exit the tomb, to return each night to the body).

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Şadr al-Sharīʿah

Ahmad Dallal

şadr al-Sharīʿah al-Thaṇī, ʿUbayd Allāh ibn Masʿūd (fl. Bukhārā, d. 747 AH/AD 1347), was a scholar and astronomer of the fourteenth century.

He belonged to a family of famous religious scholars; his great-great-grandfather, şadr al-Sharīʿah al-Awwal, was referred to as the second Abū ḥanīfa in recognition of his rank among the legal scholars of his time. şadr al-Sharīʿah, moreover, was himself a traditional religious scholar: he wrote on the subjects of *ḥanaḫī* positive law, principles of jurisprudence, Arabic grammar, rhetoric, theology, legal stipulations and contracts, and *ḥadīth* (the spoken Traditions attributed to the prophet Muḥammed). In addition, he wrote a three-volume encyclopedic treatise, *Taʿdīl al-ʿUlūm* (The Adjustment of Sciences). The first of the three books is on logic, and the second is on theology (*kalām*). The questions discussed in these two books were not unfamiliar to theologians of the time, and it seems quite probable that a jurist would be informed in such areas of research. What is uncommon, however, is şadr al-Sharīʿah's competence in astronomy, which he demonstrates in the third book of the above work.

This last section entitled *Kitāb Taʿdīl Hayʿat al-Aflāk* (The Adjustment of the Configuration of the Celestial Spheres) was finished in the year 747 AH (AD 1347) shortly before the death of its author. The motive for writing it, as expressed by the author in the beginning of the book, was to resolve the problems of the longitudinal motion of the moon and the other planets, as well as the latitude motion. The resulting work is indeed a revision of the astronomical tradition from within its own existing framework. In this şadr al-Sharīʿah was obviously driven by the momentum of the revisionist tradition of the thirteenth-century Maragha school, which aimed at reforming Ptolemaic astronomy.

şadr al-Sharīʿah was especially influenced by two sources: the *Tadhkira* of Naşīr al-Dīn al-ṭūsī (d. AD 1274) and the *Tuhfa* of Quṭb al-Dīn ► [al-Shīrāzī](#) (d. AD 1311). şadr al-Sharīʿah proposed to review critically the planetary models of his two predecessors, and in the course of this revision he proposed his own alternative configurations. The models which he purported to examine and replace were for (1) the longitudinal motion of the moon, (2) the longitudinal motion of the superior planets, (3) the longitudinal motion of Mercury, and (4) the motions in latitude. The mathematical mechanisms utilized by şadr al-Sharīʿah to solve the problems of these models were not new, but his ingenuity lay in bringing some of these different mechanisms together.

In three of the above cases he succeeded in producing new models, and in at least two of these the resulting configurations seemed to resolve the theoretical problems of earlier models, while predicting the planetary positions in accordance with the Ptolemaic observations.

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Salt

S. A. M. Adshead

Salt, its production, distribution and consumption, was an important element in the economies of all ancient societies and played a significant role in their societies, politics, and culture. This article falls into two parts. First, the principal methods of producing salt before 1800 will be analyzed. Second, the particular methods in use in the four primary civilizations of Western Eurasia (excluding Europe itself), East Asia, sub-Saharan Africa and pre-Columbian America will be outlined, together with their characteristic means of distribution and levels of consumption.

Salt exists in nature in two forms. First, there is actual salt. This takes the form of rock deposits from evaporated seas which can be quarried or mined, spontaneous evaporation at the edge of the sea or saline lakes, and incrustation on the surface of saline soil, both of which may be collected. Second, there is potential salt. This takes the form principally of brine from the sea, lakes, springs or wells, but also of saline earth and the plants growing in it. From potential salt, actual salt can be made by a variety of techniques. In most non-Western cultures these techniques were more important as a source of salt than quarries, mines or collection. Evaporation of brine, whether from the sea, lakes, springs or wells, or artificially prepared from saline rock, earth or plants, accounted for 90 % of all salt consumed before 1800. Brine could be made to yield salt in two ways. It could be boiled over an artificial fire and fueled in various ways: what the Chinese called *chien*. Or it could be evaporated naturally by the power of the sun and wind: what the Chinese called *shai*. Artificial boiling and natural evaporation produced different kinds of salt. Quicker, *chien* produced a small-crystal salt, or, if prolonged, cake salt. Slower, *shai* produced a large-crystal salt. Each method had subvarieties whose differences varied the cost, color,

consistency, purity, and cleanliness of the salt produced.

Subvarieties of artificial boiling may be classified according to the fuel used. Wood was commonest, but reeds, natural gas, coal, and oil shale were also used. Fuel was the chief item of cost and its availability the principal constraint. The amount required depended on the salinity of the brine. To reduce it, brine salinity was frequently intensified either by preliminary exposure to sun and wind or by filtration through saline sand, earth or ash. Since artificial boiling was everywhere an older method than natural evaporation, it may have been this preliminary exposure which provided the idea of using sun and wind to effect the whole process.

Subvarieties of natural evaporation may be classified according to the number and function of the basins used. First, there was single basin evaporation. Here, brine was run into a single basin, or battery of basins, and allowed to evaporate completely. Salt made in this way, however, was gritty, deliquescent, and possibly injurious to health, because the sodium chloride would be contaminated by the calcium and magnesium compounds contained in most brines and especially in sea water. Next, there was successive basin evaporation. Here, brine was run through a series of basins for catchment, condensation, and crystallization. In this way, sodium chloride could be separated from the calcium and magnesium compounds through the different sedimentation rates of these chemicals. Thus the calcium compounds settled in the condensers, while salt was removed from the crystallizers before it could be contaminated by the magnesium compounds in the mother liquor which was then drawn off. By this triple process, a much purer sodium chloride was obtained. The process could be tuned to give different degrees of cleanliness and size of crystal by varying the frequency of harvest and the ratio of condensers to crystallizers. The more frequent the harvest, the more likely the adherence of the floor of the crystallizer to the salt, so the dirtier the product. The higher the ratio of condensers to crystallizers, the longer the process, so the bigger the crystals. The choice of frequency and ratio depended on cost,

especially of land, convenience to the producer, climate, and consumer preference as to the kind of salt. Salt was a sophisticated industry.

Salt has been sought since the first agriculturalists found a vegetable diet bland and insipid compared to meat and fish. It was sought too for its supposed medicinal effects on the internal parasites with which early agriculturalists were endemically affected. Finally, as the "general of foods," it was sought to create flavor, cuisine, and social distance. Salt was an adjunct of civilization. Although the body does require a minimum intake, the quantity is small and satisfied by normal diet, so that salt deficiency is rare in humans.

Most human consumption is in excess of physiological need. Culture, not nature, called for salt. It traveled by whatever form of transport was cheapest for bulk goods, which in premodernity meant by water, where available, rather than by land.

In the Ancient Near East and in its successor the Central Islamic lands, natural salt in the form of rock, spontaneous evaporation and incrustation was widely distributed. Salt never became big business and consumption was high. When Muslims moved beyond their homeland, however, they experienced a shortage of salt. The expansion of Islam to the Mediterranean, North Africa, India, and Indonesia was therefore accompanied by the introduction of new techniques of salt production. In particular, Islam diffused the Chinese technique, invented around AD 500, of successive basin solar cum wind evaporation. That the technique was diffused rather than independently invented in a number of places is indicated by the presence everywhere initially of the original Chinese condensers to crystallizers ratio, itself functionally unnecessary and in some circumstances dysfunctional.

In China itself, before AD 500, salt had been acquired either, in the northwest, by the collection of natural deposit, or, in the southeast, by boiling of marine brine (*chien*). Initially *shai* was regarded as inferior to *chien*. Indeed, in the Mongol period it was temporarily abandoned in its original site. In the long run, however, its absence of fuel costs, plus a number of technical improvements, gave it complete victory over *chien*, save

in Szechwan which enjoyed the advantage of natural gas and more saline brine. In India too, though the mines of the Salt Range continued to operate, successive basin solar evaporation became the chief form of production: principally at the Sambhar Lake and on the west coast, but subsidiarily, with technical modifications, in Tamil Nadu. Bengal long remained a center of *chien*, till its industry was overwhelmed by imports from Britain and the Red Sea, the latter being a *shai* center.

In pre-Columbian America and in sub-Saharan Africa, production remained limited and consumption low until the coming of the Europeans to the first and of Islam to the second. Some Matto Grosso Indians neither produced nor consumed salt (the same is true of the Maori in New Zealand). Elsewhere in America, supply was by collection, boiling, or single basin evaporation, though one archaeological site has raised the possibility of an independent Maya invention of the successive basin technique. In Africa, supply was similar, though the Saharan quarries and mines may have been developed before the coming of Islam. The greatest consumers of salt were the Islamic world and China. Despite the development of marine based salines at its extremities, Islam supplied itself mainly by land, using camels for transportation. China supplied itself mainly by water, by junk. There, because sources of supply, chiefly on the coast, were relatively few, salt did become big business. Indeed, until it was supplanted in the eighteenth century by textiles, it was the chief component of the premodern Chinese economy.

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Salt in Bengal

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Long before the advent of British rule in Bengal, the salt industry was developed in its coastal belt stretching over about 700 mile. The prominent places of production were Tamlook and Hijli in the Midnapore district, the Sunderbans in the 24 Parganas, and Noakhali and Chittagong in the present-day Bangladesh. During the Mughal period, the salt merchants enjoyed the highest status in the trading society, and its highest bidder received the title of *fakir-ul-Tejar*. The technology of the industry was, however, based on traditional knowledge and practices, requiring locally manufactured implements. Since the caste-based division of work largely prevailed in the society, it percolated down the generations. Though, under the governance of the English East India Company, several reforms were tried on the industry's organizational aspects, its traditional technology was left unaltered. In 1836, the industry turned over around 246,000 t, giving employment to about 16,500 salt workers (*molunghees*) and 133,000 subordinate workers. The province was largely fed out of it and also its surrounding neighborhood.

The technology required saline water and saline earth as raw materials. They were mixed together and filtered suitably to obtain brine, which was afterward boiled and dried up to get the end product. Four technical processes were thus involved in this manufacturing: processing of raw materials, filtration, boiling, and drying. The salt manufacturing unit in Bengal was, however, called *khāllāri* (saltworks), which a *molunghee* operated with the help of his subordinate workers. It was set up on a salt bed (locally called *char*) over one-half to three bighas of land (1 bigha = 1,600 square yards), where he set up three salt fields (*chatturs*) for the collection of

saline earth, reservoirs (*joorees*) for holding saline water, a filter (*maidah*), a boiling house (*bhunri ghar*), and a drying house (*khuttee*). Locations of these centers were decided upon keeping in view the order of various technical processes in production.

Processing of Raw Materials

The initial task of a *molunghee* was to identify the land for saline earth and to divide it into three small rectangular fields (*chatturs*) of equal sizes. He then carefully uprooted all the weeds and shrubs from those fields and dug out their surface soil by about five inches, allowing the saline water to fill up the holes. The soil thus removed was used for the embankment of the *chatturs*. During the months of July and August, the fields were frequently plowed so that the saline component of water was impregnated in the soil. When the soils were thus sufficiently enriched with salinity, they were leveled by a lump crusher (*moi*) and left to the exposure of the sun for 5–6 days. It caused the saline component of the soils to come up in the surface in the form of small (as well as soft) blisters. When the *chatturs* were thus ripened, the process of *chāppākurna* began. It involved 7–8 persons standing side by side and moving their legs vertically and horizontally so that every saline blister in the fields was crushed. The fields were then again left to the sunrays for 7–8 days so that all the moisture of the ground was evaporated and the saline earth on the surface became dust. The dust saline earth was scraped by a *khoorpā* (made of one piece of iron and two handles) and collected in small heaps in the field. This was a crucial raw material for the industry.

For the other raw materials, viz., the saline water, a reservoir (*jooree*) was dug to a depth of 4–5 cubits on 2–4 *kathas* of land (1 *katha* = 80 square yards). It was connected through a small drain with a river or a canal so that it received the saltwater at high spring tides. Old *joorees* and drains were filled with rainwater during the rainy season. But *molunghees* cleared it by the end of September so that only the saline water was stored there from the first spring tide in

October or in early November. From each returning tide, however, saline water was stored for about 20 days of production.

Filtration Process

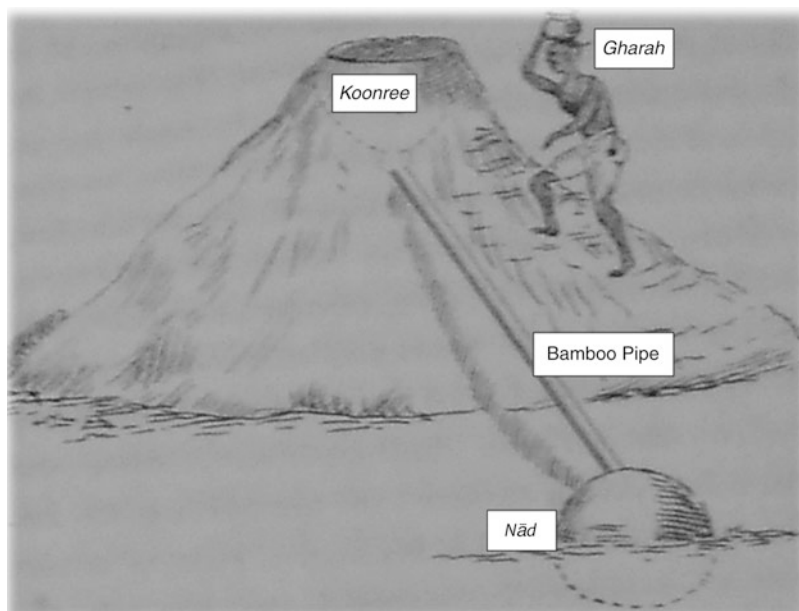
In Bengal's traditional technology, brine was prepared through the filtration process. The filter (*maidah*) was a pyramid-shaped, mud-built structure, $4\frac{1}{2}$ cubits in height and $12\frac{1}{2}$ cubits in breadth at base tapering to $7\frac{1}{2}$ cubits at the top (Fig. 1). A basin was fitted at its summit. It was roughly $1\frac{1}{2}$ cubit in depth and 5 cubits in diameter, and its bottom was made of clay, ashes, and sand with a hole at its center. An earthen pot (*koonree*), which was also centrally pierced at its bottom, was fitted there with their holes perfectly in alignment so that a hollow bamboo could be fitted through those holes at its one end and an earthen pot (*nād*) at the other. This hollow bamboo acted as a pipe for the movement of filtered saline water from the basin to the *nād*. A filter was, however, placed on the top of the *koonree*. It was made of a light bamboo frame containing a layer of straw and a layer of saline earth. The earth was repeatedly stamped with the feet to make it hard. The *nād* could, however, contain 30–32 *gharahs* (earthen vessels) of saltwater (each *gharah* contained about $3\frac{1}{2}$ gallons of water).

The process began with two *coolies* (porters) carrying salt earths from the *chattur* and throwing them into the basin. They used a carrier called *jhoolah* (a frame of two bamboos with a rope network), which could carry one-half to two maunds at a time (1 maund = 37 kg). When the basin was filled up to the brim, 3–4 persons began to knead the earth with their feet while the saline water was gently poured into it from the *jooree*. The process continued till about 80 *gharahs* of saline water were absorbed. The water was filtered down to the *nād* through the hollow bamboo pipe. By way of such a filtration process, 80 *gharahs* of saline water yielded 32 *gharahs* of strong brine.

Porters then carried the brine from the *maidah* to the *thannah nād* (a receiving pot) that could contain 30–40 *gharahs* of brine. It was kept

Salt in Bengal,

Fig. 1 Filter for salt manufacturing (maidah)
(Source: Hamilton, H.O. "Notes on the manufacture of salt in the Tamlook agency" p.15)



outside the boiling house. The brine was left to settle there for about 24 h so that impurities were precipitated out at the bottom.

Boiling Process

The boiling house (*bhunri ghar*) was built to the north and south near the *chattur* (Figs. 2 and 3). For an area of 25–26 cubits $\times$ 7–9 cubits, it took about 1–1½ *katha* of land, encompassing a store-house for fuel (*jullan thannah*) as well. Its northern wall was highly elongated – about 6 cubits in height as against 3–3½ cubits in height for the southern wall – for the accommodation of the furnace. The southern space was meant for the lodging of workers. An earthen furnace (*choolah*) was, however, built in its northern space, rising about 2½–3 cubits from the ground, with a boiler (*jhānt*) on its center. Since the boiler was semicircular, about 5 cubits in diameter, it was called *jhānt chakkra*. About 200–225 small earthen pots of conical shape (*koonrees*) were arranged on the *chakkra* in a pyramidal shape and cemented together with clay. Each pot could contain 1½ *ser* of brine (1 *ser* = 0.93310kg.).

Before boiling was started, the *molunghee* made every arrangement to ensure that there

was no interruption in the process. A cooly (porter) was posted on the southern side of the *choolah* with a bamboo-made, two-pronged fork (*jalthellee*) to continuously supply fuel. All the *koonrees* were filled with brine, and the *molunghee* stood near the *koonrees* with a ladle (made of a coconut fixed to a piece of bamboo) to pour brine into them whenever it was partly evaporated. Then the fire was lit, and the *pokhtan* (boiling) commenced. The *molunghee* went on pouring brine into the *koonrees* until a ratio of 3:1 was attained between salt and water. It, however, took 4–5 h for the formation of salt granules. Four to six maunds of salt were thus obtained at a time.

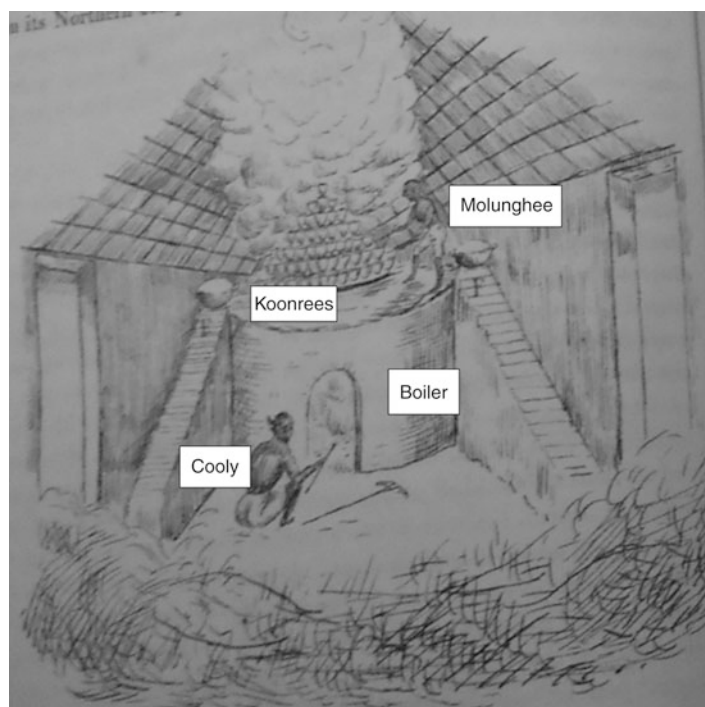
The salt granules were then collected in two baskets (*joorahs*) and kept by the side of the *choolah*. This was, indeed, the initial process of drying. Subsequently, however, those *joorahs* were dispatched to the drying house for further drying treatments.

Drying Process

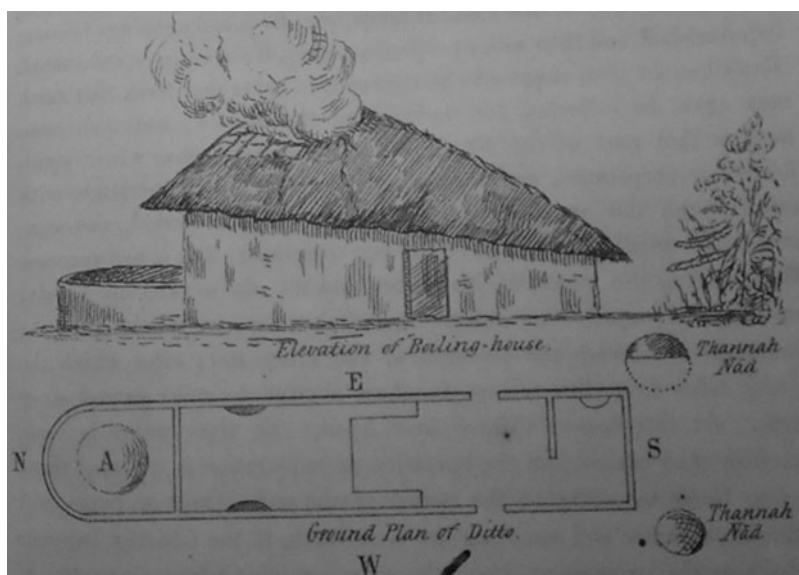
The drying house (*khuttee*) was a square enclosure with one storeroom (*golah*) at each side (Fig. 4). Its floor was specially built up by a

Salt in Bengal,**Fig. 2** Interior of a boiling house (*bhunri ghar*)

(Source: Hamilton, H.O. "Notes on the manufacture of salt in the Tamlook agency" p.18)

**Salt in Bengal,****Fig. 3** Exterior of a boiling house (*bhunri ghar*)

(Source: Hamilton, H.O. "Notes on the manufacture of salt in the Tamlook agency" p.17)



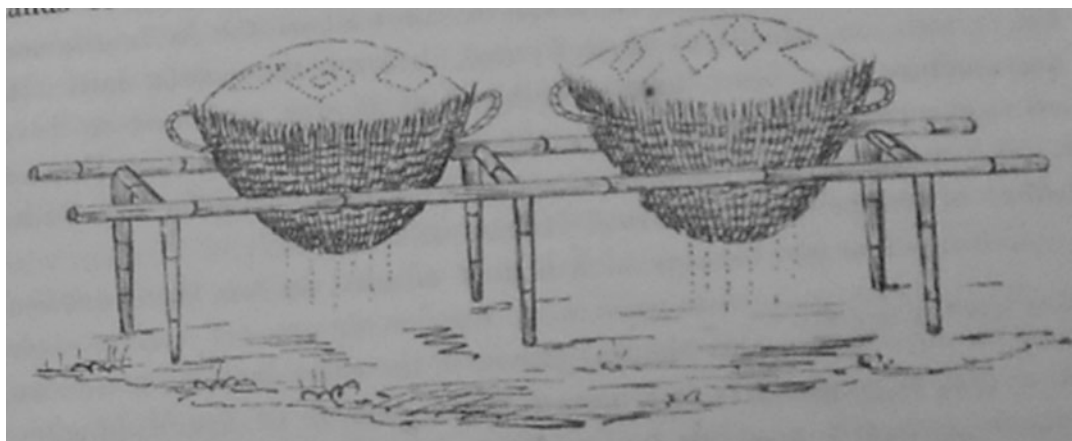
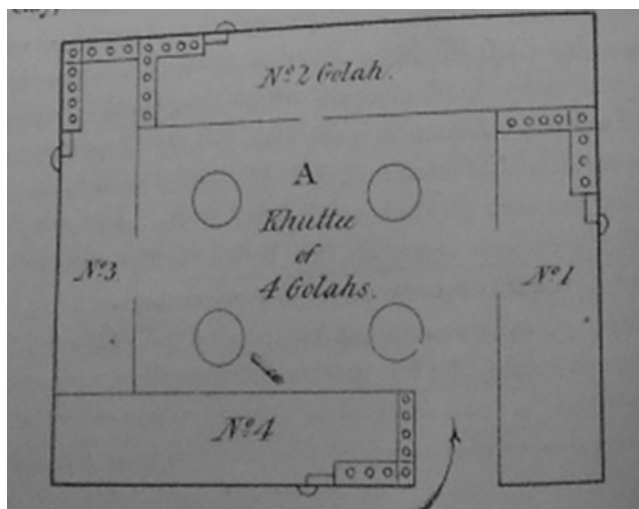
mixture of ashes and earth, making its surface very smooth and hard. Its center was slightly elevated with a slope toward an inside drain, which carried out bittern (*gewa-rus*), i.e., the moisture that exuded from the salt. The *golahs*

were usually 21 cubits in length, 7 cubits in breadth, and 4½ cubits in height.

In addition to the initial process of drying, four further treatments followed: (a) The *joorahs*, dispatched from the boiling house, were brought

Salt in Bengal,

Fig. 4 Drying house (*khuttee*) (Source: Hamilton, H.O. "Notes on the manufacture of salt in the Tamlook agency" p.20)



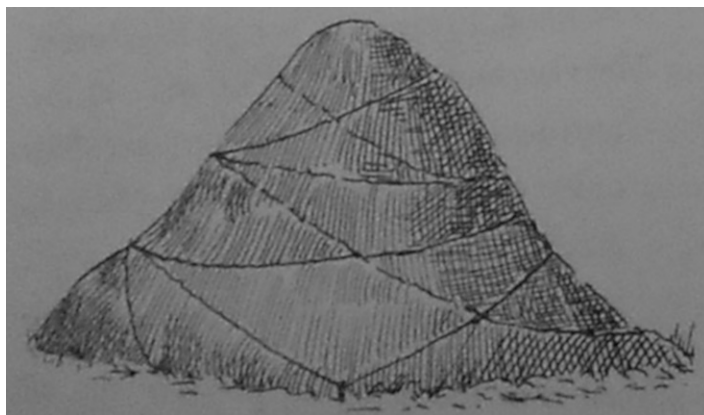
Salt in Bengal, Fig. 5 *Joorahs* on a bamboo frame (Source: Hamilton, H.O. "Notes on the manufacture of salt in the Tamlook agency" p.21)

inside the *khuttee* and kept on a bamboo-made frame, about one cubit in height, for 12–24 h (Fig. 5). Through this process, the aqueous contents of salts dropped down on the ground so that they were dried up to some extent. (b) After this stage, the salts were stamped (*adulled*) with wooden stamps to crush the lumps of salts into grains, and brought inside the *golah*; they were kept on its floor for 1–7 days so that the earth further absorbed their aqueous contents. Thereafter, they were collected in a heap, which was locally called *maharas kundy*. (c) The *maharas kundy* salts were then brought out of the *khuttee*

and kept on the elevated floor of the *golah* for some days. A few inches of its lower stratum got slightly discolored as the bittern oozed out, but the superincumbent mass of the heap became pure white, when all the moisture was tolerably drained off. And (d) in the final round of treatment, which local people called *baharkandy*, the salts were brought outside the *golah* and heaped in an open space opposite to it. They were then *adulled* all over and thatched with straws or grasses with a view to preventing the high winds from blowing them away (Fig. 6). A layer of clay or mud was placed at the base of the heap to absorb the

Salt in Bengal,

Fig. 6 The *baharkandy*
(Source: Hamilton, H.O.
'Notes on the manufacture
of salt in the Tamlook
agency', p.22)



moisture of the salts. They were left in that state for about a fortnight when the clay layer was replaced 3–4 times.

The salts thus manufactured were called *punga* salts in the contemporary market nomenclature. There was another variety of salt, called the *kurkutch* salt, which was manufactured by solar evaporation. But it was of very little significance in Bengal. In this process, the brine was obtained in the same way as followed for the *punga* salt. The difference lay in that the *kurkutch* brine was poured into salt pans by a depth of 1½–2 in. and was left to the exposure of the sun for 2–4 days. By way of evaporation, the *kurkutch* was granulated.

The manufacturing process for the *punga* salt, as described above, was typically followed in most places in Bengal. In Chittagong, however, slight deviations took place. The salt lands were selected there on the coast of the Bay of Bengal, or at its proximity. Salinity in the earth was so high in those lands that they did not need to be submerged for the impregnation of salinity. During the spring tides in October and November, highly saline earth could be obtained from the surface soil. The boiling process was also slightly different in those *khāllāries*. Two alternative methods of boiling were followed there, and they were called *jat* salt and *telinea* salt. In the former case, the boiling arrangement was similar to what we have described above, but the boiling house was fenced with bamboo and grass without any roof. In the case of *telinea* salt, however, the furnace was different. It was not raised above the

ground, but sunk in the earth. A cone (*kanda*) was constructed over it to contain about 180 pots (*telins*). There were also differences between Chittagong *khāllāries* and others in respect to the capacities of filters, reservoirs, and drying arrangements.

Contemporary market surveys reveal that people in Bengal preferred the *punga* salt over the *kurkutch* salt, or even the salt imported from Liverpool. But there was a great debate throughout the nineteenth century on the hygienic aspects of its production, and this culminated in statutory prohibitions on the technology in 1898. The allegation against the indigenous technology was that it used “the dirty and slimy brine of pestiferous marshes.” But a contemporary government official remarked “The boiling, indeed, being effected in small pots supplied with clear brine, and skimmed from time to time as impurities rise to the surface, struck me, when I saw the process, as peculiarly favourable to purity, though laborious, and expensive in the use of fuel, and I am not aware that the notion has been contradicted by an analysis.” (Ray, 2001 p. 190).

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Salt in China

Hans Ulrich Vogel

In premodern China, hundreds of terms for different kinds of salt existed which were distinguished according to place of origin, type of deposit, method of production, shape, physical appearance and properties, taste, color, translucence, use, and function within the salt monopoly system. An important and authoritative scientific explanation for the existence of various salt deposits was provided by the *Shujing*. There, in the chapter “Hong fan,” saltiness (*xian*) is related to the phase of Water, which by soaking and descending becomes salty. Another important explanation referred to cosmogonical thinking, stating that the clear and light (i.e., underground currents of sweet water and water of rivers and lakes) are to be found above, while the heavy and turbid (i.e., underground brine and sea water) below.

The economically and fiscally most important types of salt were, in descending order, sea salt (*haiyan*), lake salt (*chiyan*), well salt (*jingyan*), earth salt (*jianyan* or *tuyan*), and rock salt (*yayan*). In the late imperial period, sea salt accounted for more than 80 % of the empire-wide production. The percentages for lake salt and well salt were about 12 and 6 %, respectively. The shares of earth and rock salt are quantitatively negligible.

The Chinese salt production sector reflects typical features of the history of production techniques in China. The far greatest amounts of salt, that is sea, lake, earth, and rock salt, were produced with the help of rather simple and old-established production techniques, which in many cases required a high input of human labor. Manpower also played an important role in well salt production, but, because of the use of deep-drilling methods and exploitation of natural gas resources, this sector contained a revolutionary technological potential. Finally, we can observe that, sometimes, sophisticated production techniques were abandoned, like the method of basin solar evaporation at the salt lake of Xiezhou in Hedong (Shanxi) during the thirteenth to the sixteenth centuries.

Several partly overlapping stages of development may be observed in the production of sea salt. Early sources mention that salt was produced by boiling seawater. It is, however, far from clear whether this statement refers to the rather uneconomic process of boiling seawater directly down or whether prior to boiling a concentrated brine had been prepared. Probably both methods coexisted.

The first written account of the production of concentrated brine comes from the late ninth century. A hollow was dug, covered with wood and ► bamboo twigs. Sands enriched in salt were heaped up over the hollow and were then leached out by the invading flood. The concentrated brine dripped into the hollow and was tested with grains of cooked rice which floated or descended according to the degree of salinity. Finally, the brine was boiled to salt in iron pans, or pans made out of woven bamboo strips and coated with a layer of clamshell lime. This became the basic method of sea salt production in China. Improvements were added in later ages. For instance, besides sand, ashes were used which were spread out on specially prepared fields, artificially sprinkled from time to time, and exposed to the sun, thus raising their content of salt particles. In this way, the amount of brine and its salinity could be increased. The sophisticated and labor-intensive process of later ages is fully described and illustrated in the *Aobo tu* of 1334 (see Fig. 1).

Salt in China, Fig. 1 Sea salt production from the *Aobo tu* of 1334, with the title “Carrying the ashes and pouring them into the leaching basin”



The production of sea salt by solar evaporation (*shai yan*) began probably in the late Song period. The term *shai yan* is, however, ambiguous. It may either denote the production of salt in successive solar evaporation basins, making use of the fact that common salt would crystallize *after* the precipitation in the condensers of the calcium salts contained in the brine and *before* the precipitation of the magnesium compounds. Or it may be connected with the traditional leaching process, in which the last step in the production process, the boiling of enriched brine, was simply replaced by solar evaporation. The latter technique may be considered a transitional step in the slow shift from the original method of boiling brine to the production of salt in successive solar evaporation basins. This transitional method had probably already begun in the late Song period. A special form developed in parts of eastern Zhejiang where from the late eighteenth century onward the enriched brine was exposed to the sun in portable wooden trays.

While Adshead (1990, 1992) thinks that successive basin solar evaporation of sea salt first appeared in Changlu (Hebei) in 1522 at the latest, and then spread to Huaibei (1550), Shandong (1570), Fujian (1575) and other places, Liu (1988) is of the opinion that it was not adopted at the sea coast before the middle or late sixteenth century. Moreover, there is clear evidence that Fujian was prior to Changlu which took over the

method of successive basins from Fujian perhaps in the middle or late sixteenth century (Bai, 1988; Lin, 1992). From the seventeenth century onward the method of solar evaporation in successive basins gradually replaced the traditional methods of preparing enriched brine for the final crystallization either with the help of fire or solar heat. Generally speaking, either method of solar evaporation resulted in economies of fuel and manpower.

The use of solar evaporation basin methods, however, did not originate at the sea coast, but at the salt lake of Xiezhou in southern Shanxi. In the beginning of Chinese culture, this lake must have been an important and contested source of salt supply. First, salters extracted naturally and spontaneously produced salt, a process which had always been considered an auspicious and divine phenomenon. In the late fifth or early sixth century at the latest artificial solar evaporation basins emerged. For both methods of harvesting (see Fig. 2), the warm southern wind of the summer months was a decisive factor in bringing about crystallization. Salt production in basins was conceived basically as a kind of agricultural process which is suggested by the use of terms like “fields,” “parterres,” “ditches,” “raised paths,” and “sowing salt.” From the late thirteenth to the late sixteenth century, however, solar evaporation basins were given up, and probably only naturally and spontaneously produced salt was

Salt in China, Fig. 2 The two methods of harvesting salt at the salt lake of Xiezhou, as shown in the *Zhenghe* pharmacopoeia of 1249



extracted. Political reasons were partly responsible for this, because the method of solar evaporation basins was closely associated with the saline's corvée [a form of unpaid labor required by a lord] system. Solar evaporation basins were reintroduced in the late sixteenth century. A perennial problem was the protection of the salt lake's brine reservoir from intruding fresh water floods caused by inundating rivers. Dikes and spillover areas were constructed for this purpose. One of these inundations silted up the lake's brine reservoir in 1757, so that thereafter wells and pits were constructed for getting brine.

Whether single basin or successive basin solar evaporation was carried out at Xiezhou is debatable. Successive basin solar evaporation was

explicitly described for the first time in the early eighteenth century. Educated guesses about the actual date of invention or adoption of successive basin solar evaporation at Lake Xie, however, vary greatly. It is said to have been either the fifth or sixth century (Adshead, 1992), the eleventh century (Chai, 1993) or the late sixteenth century (Vogel, Needham et al., forthcoming).

The production of well salt in Sichuan province can be divided roughly into two periods. From the third century BCE to the eleventh century AD shaft wells were dug for exploiting the underground brine deposits. Recent research has shown that deep drilling was invented in the 1040s, thus inaugurating the era of deep drilled wells from the middle of the eleventh century up to the twentieth century. Salt produced by



Salt in China, Fig. 3 A Sichuan salt well, as depicted in the Sichuan salt gazetteer of 1882

privately run deep drilled wells was cheaper and of better quality than that offered by the state managed shaft wells. The new type of well was drilled with a heavy iron bit which was fastened to a cable made out of ► [bamboo](#) strips notched together. The cable was attached to the drilling frame's lever beam. By jumping up and down the lever beam the drill was lifted and dropped, thus crushing the rock down in the well and creating a hole with a diameter of only about 13 cm. The upper part of the finished well was tubed with large bamboo stalks. From the late sixteenth century onward it was also provided with a foundation of stone rings, and large tubes made out of wood were used. Slurry and brine were lifted with a bamboo tube which was equipped with a leather valve at its lower end. When entering the brine, the valve opened inward, and it closed under the pressure of the brine when the tube was lifted. A great number of utensils were invented to remove obstructions that occurred during the process of drilling and brine hoisting. Deep drilling,

hoisting, and repair operations developed in the course of time. This development was characterized by the use of heavier drill bits, more solid drilling frames, higher hoisting rigs, and larger hoisting tubes and hoisting drums, driven by up to four buffaloes. While in the mid-eleventh century a depth of about 200 m may have been sometimes reached, wells of the mid-eighteenth century may have been more than 500 m deep. And in 1835, the Xinghai well of Furong (*Ziliu jing*) measured more than 1,000 m. The nineteenth-century Furong wells (see Fig. 3) were much more successful than their predecessors in the tapping of subterranean brine and natural gas deposits.

Earth salt was produced in northern Shanxi and eastern Hebei in a way similar to producing sea salt, that is by leaching earth containing salt particles and by boiling down the resulting brine. The exploitation of rock salt was reported from Gansu and Shaanxi, where a kind of red-colored salt was collected in rocky caves.

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Salt in India

S. D. Gomkale

As India is one of the oldest civilizations, it is no wonder that salt was produced in ancient India and that one finds its mention in ancient scriptures. The salt industry flourished as a cottage industry for centuries. The word for salt is

Lāvaṇa in Sanskrit. A passage from *Arthaśāstra*, a book dealing with the history of the Mauryan period (300 B.C.E.), says that salt manufacture was even at that distant date supervised by a state official named Lavanadhyaksa and the business was carried out under a system of license granted on the payment of fixed fees or part of the output. This tradition, handed down from Hindu kings of old, is even now followed with variations by the Government of India through its Salt Department. The history of many countries shows connections with salt; in India salt was used by Mahatma Gandhi as a tool to win independence, when he completed his famous 400-km march to the sea at Dandi on 6 April 1930. The development of the Indian salt industry will now be briefly examined in two periods, pre- and post-independence.

Salt was prepared in ancient times and until British rule from sources like seawater, subsoil and lake saline water, rock salt deposits, and water extracts of saline soils (particularly in Uttar Pradesh) mainly by solar evaporation. If required, artificial evaporation was resorted to. The salt was produced in the coastal regions of Bengal, Bombay, Madras and the Rann of Kutch and in the inland regions of Rajasthan, Uttar Pradesh, and Central India from saline brines of lakes and as rock salt in Punjab. The salt industry provided a source of revenue to the rulers in the respective regions, and it received protection and encouragement from them. However, the industry faced a sort of setback and discouragement from the British rulers who not only raised the taxes and levies as early as 1768 but also later started importing salt around 1835–1836 from European countries, Aden, and other places. The salt industry in Bengal province first felt the impact of the British policy which then affected the salt industry not only in other parts of their empire but also in Goa, which was under Portuguese rule. The quantity of salt imported, mainly in Bengal, in the pre-independence period ranged between 0.4 and 0.6 million tons annually.

However, the British rulers reconsidered their drastic policies around 1930–1931, which helped to revive the Indian salt industry, and salt production picked up. Changes and improvements in salt

production methods, particularly from sea water, based on scientific principles were brought about by an Indian chemical engineer, Kapilram Vakil. Before establishing India's first large scale marine salt farm at Mithapur in 1927 with the support of the Maharaja of Baroda, he had earlier (1919–1920) studied in detail the status of the salt industry in the eastern states of Bengal and Orissa. Thus production of salt in large salt works established on the basis of scientific knowledge began in India before independence.

After Independence, the majority of rock salt producing areas went to Pakistan. Salt is now mainly produced from sea water, subsoil brines, and inland lake brines. India exports salt; the imports are around 8,000–15,000 tons per year in recent years and it is mostly as rock salt from Pakistan.

Efforts have to be made to improve the quality of salt produced from both sea water and subsoil brines in the field itself, and this is one of the challenges faced by the Indian salt industry. The industry is highly labor intensive and thus has a low output. It is necessary to upgrade the technologies, adopt mechanization, and improve transportation, loading, and port facilities. This is another challenge to be tackled by the Indian salt industry, an ancient industry that must adapt to changing times.

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Salt Production in Mesoamerica

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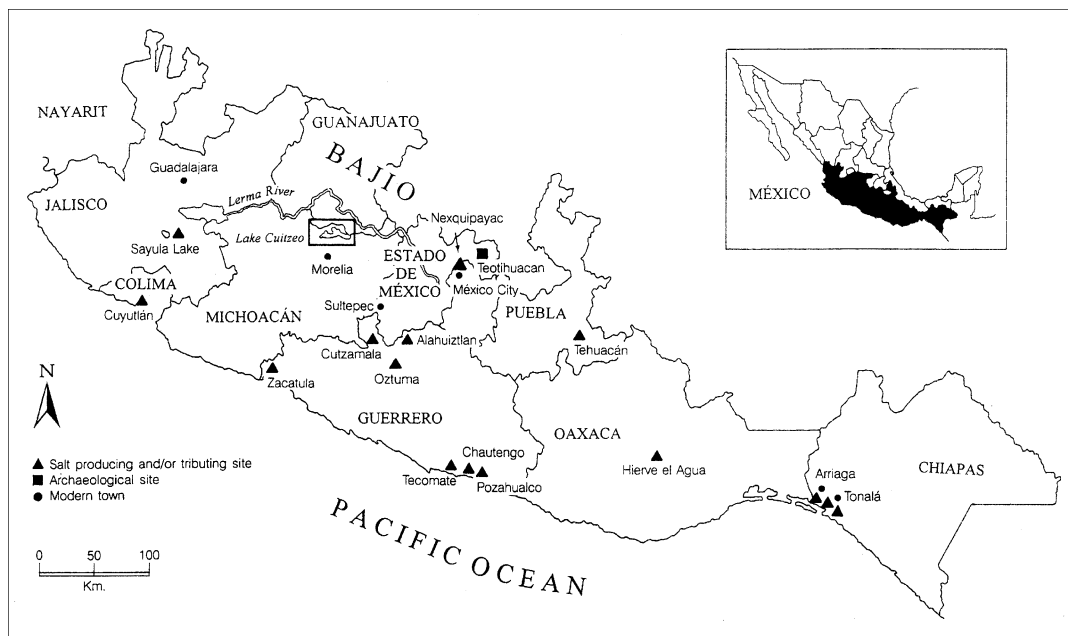
Common salt, or sodium chloride, has always been a strategic resource of primary importance.

In pre-Hispanic Mesoamerica salt was used mainly for human consumption, as the native diet (consisting mainly of plants such as maize, beans, chili peppers, and squash) had little chloride and sodium (Williams, 2003). Chloride is essential for digestion and respiration, and without sodium our organism would be unable to transport nutrients or oxygen or transmit nerve impulses. Throughout the world, once human beings began cultivating crops, they began looking for salt to add to their diet (Kurlansky, 2002, pp. 6–9).

In the preindustrial world, sodium chloride had several important uses apart from its role in the diet, particularly as preservative of animal flesh, as a mordant for fixing textile dyes, as a medium of exchange, and as a principal component in the preparation of soaps and cleansing agents (Parsons, 1994, p. 280).

An ancient technology where salt was very important was textile dyeing. There may have been a direct functional link between saltmakers and cloth dyers in Mesoamerica; saline solutions have been commonly used as mordants by traditional cloth dyers in several parts of the world to fix dyed colors in textiles (Parsons, 2001, p. 241). In fact, salt's important role in the Mesoamerican economy can be indirectly gauged by the huge number of dyed textiles that circulated through commerce and tribute. Among the Aztecs, for example, cotton cloth had many uses. Cloth was used for clothing, bedding, bags, awnings, decorative hangings, battle armor, adornment for statues of the gods, and shrouds for the dead (Smith, 1998, p. 91). Cotton textiles served as items of exchange, as well as currency in the markets; they were exchanged as gifts among the nobility, and formed the dominant item of tribute payment at all levels (Smith, p. 91).

Imperial tribute received by the Aztec state every year included 128,000 mantles or capes, 19,200 garments, and 665 warrior costumes. Most of these items were woven with dyed cotton thread, and the amount of salt used in the dyeing process must have been very high indeed. To this we should add the 4,000 “salt loaves” paid to the Aztecs by several tributary provinces every year (Smith, 1998: Table 7.2).



Salt Production in Mesoamerica, Fig. 1 Map showing salt-producing sites in central-western Mesoamerica (© Eduardo Williams)

Throughout Mesoamerica, salt was one of the most important items of trade and tribute. Access to major natural sources and control of long-distance salt trade was a fundamental factor in the formation of states. Among the Maya, for instance, many ancient trade routes had one or two key resources, whose exchange was the stimulus for the origin and growth of commerce. One of these resources was salt and to a lesser degree cotton, obsidian, and jade (Andrews, 1983, p. 134).

The Tarascans of west Mexico expanded their empire from their homeland in central Michoacán (Fig. 1) toward the Lake Cuitzeo basin in the east, the Sayula Lake in the west, and the Pacific coast of Michoacán and Colima to secure many strategic resources such as salt, obsidian, copper, gold, and silver, which were lacking in the empire's heartland (Pollard, 1993; Williams, 2003).

Mesoamerican salt sources can be broken down into three types: saline inland lakes, highland springs, and coastal estuaries (Kepecs, 2003, p. 126). The methods used to extract salt in pre-Hispanic times consisted of boiling brine,

leaching brine through salt-laden earths, and solar evaporation. These processes often were combined (Kepecs, p. 127). Salt itself is usually not preserved in the archaeological record. The archaeological markers or material remains linked to saltnaking with native techniques consist of (1) pottery vessels (which were used and discarded in great quantities at salt production sites); (2) shallow solar evaporation ponds made of sand and lime; (3) canals for taking the water from the springs to the production sites; and (4) mounds of leached, discarded earth (Williams, 2003).

Salt production and trade played a fundamental role in Mesoamerican culture from the earliest times. By 1200 BCE, Olmec merchants from the Gulf of Mexico penetrated highland and Pacific coastal Guatemala, Oaxaca, and central Mexico in their quest for salt and various other strategic resources such as obsidian, jade, serpentine, iron ores, basalt, cacao, marine shells, animal pelts, and exotic bird feathers. Olmec traders actively engaged in salt extraction and trade along the Gulf coast in the Formative (Diehl, 2004, p. 128). During this same period in Oaxaca

saltmaking was restricted to villages near saline springs. As early as 1300 BCE some salt-making areas were visited briefly, but no houses were built. During the Middle Formative (ca. 900–300 BCE), the production of salt by boiling brackish spring water in pottery jars was a common activity. Saltmaking was probably one of Formative Mesoamerica's most widespread regional specializations (Flannery & Winter, 1976, pp. 39–40).

What follows is a brief discussion of pre-Hispanic saltmaking in several areas of Mesoamerica. This discussion is based on archaeological, ethnohistorical, and ethnographic data (for a detailed discussion, see Williams, 2003).

The Basin of Mexico

Parsons (1994, 2001) studied saltmaking at San Cristóbal Nexquipayac, a small village on the northeastern shore of Lake Texcoco, central Mexico. According to Parsons, saltmaking at Nexquipayac involves six basic sequential steps:

1. Collecting the soils whose salts are to be leached
2. Mixing the soils in the correct manner
3. Filtering the water through the soil mixture in order to leach out the salts and concentrate them in a brine solution. A conical pit excavated in the workshop to a depth of 40–50 cm and 90–100 cm in diameter was used for this
4. Boiling the brine to obtain crystalline salt
5. Drying the crystalline salt and
6. Selling the dried salt (Parsons, 1994: 263, 269, 2001).

The Sayula Basin, Jalisco

The initial process used to extract salts in the Sayula basin must have been the leaching of saline sediments. The leaching process consisted of “washing” and filtering saline earth with fresh water; the result was a salt-laden liquid or brine. This stage of production required various types of installations. The producers built a filter

sustained by a wooden fork, composed of a rectangular base of sticks on which sedge, fodder, and sand were placed. The resulting brine was collected in a circular pan (Valdez, Liot, & Emphoux, 1996, p. 179).

Following the extraction process, it was necessary to reduce the collected brine through natural or induced evaporation to achieve the final product – salt. Although salt production carried out until recently in the Sayula basin relied on solar evaporation, the historical texts always refer to fire reduction in ceramic vessels (Liot, 2000; Valdez et al., 1996, p. 179).

Cuyutlán, Colima

In pre-Hispanic times, the most common salt-making technique in coastal Colima was by boiling the brine. When seawater or water from saline wells was not used, it was necessary first to obtain water with a high saline content, or brine, through several processes of leaching and washing of saline soils; later the resulting brine was boiled to evaporate the water. Both processes, filtering and evaporation, were carried out using clay pots. This method was effective, but not too practical when attempting to produce large volumes of salt. As demand increased, new technologies were developed. Toward the end of the sixteenth century filters were first introduced in Colima. These consisted of wooden platforms with woven branches or sticks supporting several layers of filtering substances. A similar device is still used in Cuyutlán, Colima (Reyes, 1995: 152, 154).

Lake Cuitzeo Basin, Michoacán

There are several thermal springs in the eastern end of Lake Cuitzeo, whose water, which has a high mineral content, is used for the production of salt. Each salt-producing unit (known as *finca*) consists of two or more *estiladeras* (Fig. 2), wooden structures that are used as filters to separate the salt from the earth by leaching. In every *finca* there are several *canoas* (wooden troughs,

Salt Production in Mesoamerica,

Fig. 2 This device, known as *estiladera*, is used for filtering the water from the springs through salty soil to obtain brine by leaching (© Eduardo Williams)



manufactured like dugout canoes; Fig. 3), where the brine that has been filtered in the *estiladera* is evaporated by the sun. Each *finca* has an area of some 50 m² where salt-bearing soils are extracted and mixed. There is also a network of canals that bring water from the springs to the *fincas*, with a depth of ca. 50–80 cm, and several meters in length (Williams, 1999).

The tools used by the saltmakers are quite simple: shovels, hoes, and picks to excavate the soil, wheelbarrows to take it to the *estiladera*, buckets to take the water to the *canoas*. The tools used in the past, however, were quite different: a type of sack made of jute fiber was used to carry the earth, and clay vessels were used to carry the water within the *finca*.

The salt-making process can be divided into four stages: (1) soils are extracted, mixed, and prepared; (2) brine is obtained by leaching the earth in the *estiladera*; (3) brine is evaporated by the sun in the *canoas* and salt is collected; (4) the finished product is packed and sold.

Although the tools and permanent fixtures used today for making salt in the study area are not the same that were employed during the early colonial era, much less in pre-Hispanic times, the basic process for saltmaking still used in this area is in many ways similar to the one described in the sixteenth century *Relaciones Geográficas*.



Salt Production in Mesoamerica, Fig. 3 The *canoas* are shallow troughs made with dugout pine trunks, used in the solar evaporation of brine. Note the crystallized salt on the right, the liquid brine on the left (© Eduardo Williams)

Salt Production in Mesoamerica,

Fig. 4 Filtering device known as *tapeixtle*, used on the coast of Michoacán for leaching estuary water to produce brine (© Eduardo Williams)



Salt Production in Mesoamerica,

Fig. 5 Shallow pools made of sand and lime, known as *eras*. They are used in the solar evaporation of the brine. The *tapeixtle* is in the background, covered by palm fronds (© Eduardo Williams)



Both ancient and modern saltmaking requires extracting the soil, mixing two or more types of earth, adding water, leaching and evaporation (Williams, 1999). Saltmaking in coastal Michoacán is similar to what has been described earlier (Williams, 2002; see Figs. 4, 5, and, 6).

Coastal Guerrero

The process known as *tapeite* in coastal Guerrero, still used in sites such as Tecomate, Chautengo,

and Pozahualco, consists of leaching salt from soils where saltwater marshes dry up during the dry season. The saltmakers carefully break up the thin upper crust of earth and carry it to their saltworks, where they deposit it in a large filter known as *tapeite*, which is constructed on a raised base of wooden or cane slats covered with palm or tough grass. Adobe sides create a rectangular basin lined with coarse sand and a second layer of fine, sifted sand. Brackish groundwater is drawn from a shallow well dug next to the *tapeite* and poured over the saline earth. After seeping

Salt Production in Mesoamerica,

Fig. 6 Harvesting the crystallized salt from the *era*, coastal Michoacan (© Eduardo Williams)



through the filter, the water is channeled into a plaster-lined holding tank. The concentrated brine is poured into the solar drying pans, where it evaporates to leave white granular salt crystals (Good, 1995, p. 2).

The Maya Area

Salt was a regional necessity everywhere in Mesoamerica, yet the white salt of Yucatán was also a bulk luxury, traded far beyond the regional level. Flowing from international trading centers to regional markets in foreign territories, it augmented regional supplies as a product of superior quality (Kepecs, 2003, p. 129). The pre-Hispanic Maya obtained salt from several sources, the most abundant ones being the coastal saltworks. The primary source of salt in pre-Hispanic Mesoamerica was coastal Yucatán, where salt was obtained through solar evaporation. Archaeological evidence shows that Yucatecan saltworks were active from the Late Formative (ca. 300 BCE–AD 300). In colonial times salt production in Yucatán was approximately 20,000 tons per year, enough to satiate the needs of several thousand people, or the whole of the Maya Lowlands through history (Andrews, 1997, p. 40). Salt was scarce in the southern Maya lowlands of Guatemala and Belize. It was

imported in bulk from the north coast of Yucatán, although recent fieldwork has documented closer sources of salt than those of the north coast (Mc Killop, 2002).

A method for making salt which is still found in a few sites near the Chiapas coast is the one known as *tapesco*. It involves leaching marsh soil with estuary water which is then evaporated in small solar pans. The *tapesco* salt-making operation takes place mainly during the dry season (from January to May or June). The soil to be leached is raked up and placed on raised wooden structures known as *tapescos*, the bottom part of which consists of a three-layered filter made of thin sticks covered with grass reeds, which in turn are covered by a thin layer of sand. Salt water is drawn from small shallow wells and poured over the soil in the *tapesco*, thus leaching the soil. After passing through the filter the water collects in a mud-lined pan beneath the *tapesco*. The brine is then placed in a series of small shallow solar evaporation pans, where evaporation takes place anywhere from 4 to 6 days, depending on available sunlight (Andrews, 1983, pp. 62–63).

Veracruz

During the Early Formative (ca. 1200–900 BCE) in El Salado, Veracruz, solar evaporation in

pottery trays was the primary method of salt production. This method was supplemented by some saltmaking involving boiling brine. During the late Classic (ca. AD 600–900) brine reduction involved a two-step process whereby salt content in the brine was first increased by boiling in pots; this brine was later reduced to loaves by boiling over fire in shallow ceramic basins (Santley, 2004).

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Sāmanta Candrasekhara

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Sāmanta Candrasekhara Siṃha (1835–1904) was a nineteenth-century astronomer from Eastern India. Popularly known as Paṭhāṇi Sāmanta, he was the last great exponent of traditional Indian astronomical knowledge and the author of *Siddhānta Darpaṇa*, the longest Indian text on astronomy.

Candrasekhara was born in 1835 at Khaṇḍapāḍā in the Nayagarh district of Odisha. He belonged to a princely family that had fallen on bad days and grew up in poverty with no exposure to formal education or modern science. Although he received his first tuitions in astronomy at the age of ten from an uncle, Candrasekhara was a self-taught astronomer who put his knowledge of Sanskrit to good use in studying the palm-leaf manuscripts on astronomy that he could access. How many works he could lay hands upon is not clear, but his proficiency in the *Sūryasiddhānta* and Bhāskara II's *Siddhānta Śiromaṇi* is well attested. By the age of 35, he had earned a reputation for himself among the intelligentsia of the region. The king of Puri conferred on him the title of Haricandana Mahāpātra in 1870. The British honored him with the title of Mahāmahopādhyāya in 1893. It is now customary, among enthusiasts and scholars alike, to refer to him as

Mahāmahopādhyāya Sāmantha Candraśekhara Siṃha Haricandana Mahāpātra.

Not much is known about Candraśekhara's life, which seems to have been mostly woeful. On the day of his wedding, the bride's parents called off the alliance, and although they were persuaded to change their decision, the marriage turned out to be unhappy. Five sons and six daughters were born of the marriage. The local ruler, a cousin of Candraśekhara, expelled him from Khaṇḍapāḍā over a personal dispute. Candraśekhara could return to Khaṇḍapāḍā only after the intervention of a senior British official, the Commissioner of Cuttack. He died in 1904 in Puri while on a pilgrimage.

Candraśekhara was convinced, even as a boy of 15, that many of the prevalent astronomical calculations in India needed serious revision. He discovered that texts like the *Sūryasiddhānta* from which he learnt the basics of astronomy were also not always reliable. He resolved to change this state of affairs and began observations, for which he built a number of instruments ingeniously, some of which are now preserved in the planetarium at Bhubaneswar in Odisha. The instruments included an armillary sphere, a gnomon, and a vertical wheel. The gnomon carried a mirror, which enabled measurement of time and angular distances even at night. Candraśekhara also used a water clock to measure sidereal time. An important instrument he devised on his own was a T-square (which he called the *mānayantra*), which had a 24-digit main limb and a crosspiece bearing notches with holes made at distances equal to the tangent of the

angles subtended at the free end of the main limb. He also made a wheel (which he called the *svayaṃ vāhaka*) that moved on its own with the help of spokes filled with mercury. After eight years of observation, he began to work on the *Siddhānta Darpaṇa*, which he completed in 1869. There are indications in this work that it was revised, perhaps at regular intervals. With 2,500 verses spread across five sections and 24 chapters, the *Siddhānta Darpaṇa* is among the greatest magna opera in Indian astronomy. The levels of perfection he achieved were not only due to his sophisticated use of instruments but also due to other factors like a better model of the planetary system and his ability to measure and correct all three errors in the lunar motion. One of Candraśekhara's major achievements, for which he is known among the orthodox literati of Odisha, is that he carried out major revisions to the *Jagannātha Pañji*, an influential traditional almanac of Odisha maintained by the Jagannātha temple of Puri. This almanac, which apparently owes its origin to Śātānanda's *Bhāsvatī*, circulated in an extremely corrupt form as no corrections had been carried out for a long time.

Candraśekhara followed a geocentric planetary model in which the planets Mercury, Venus, Mars, Jupiter, and Saturn moved around the sun and the sun, in turn, around a static earth. This was very similar to the model developed by Nīlakaṇṭha Somayāji in Kerala in the fifteenth century. Candraśekhara also adopted 3,927/1,250 or 600/191 as the value of π , instead of the popular 22/7. His observations and calculations yielded results that were often closer to their modern

Sāmantha Candraśekhara, Table 1 Inclinations of the orbits of planets to the ecliptic, based on Naik and Satpathy (1998)

Planet	According to Sūryasiddhānta	According to Siddhānta Śiromaṇi	According to Sāmantha Candraśekhara	European value in 1899	Modern value
Moon	4° 30'	4° 30'	5° 9'	5° 8' 48"	5° 8' 33"
Mars	1° 30'	1° 50'	1° 51'	1° 51' 2"	1° 50' 59"
Mercury	5° 55'	6° 55'	7° 2'	7° 0' 8"	7° 0' 18"
Jupiter	1° 0'	1° 16'	1° 18'	1° 18' 41"	1° 18' 18"
Venus	2° 46'	3° 6'	3° 23'	3° 53' 35"	3° 23' 41"
Saturn	2° 0'	2° 40'	2° 29'	2° 29' 40"	2° 29' 10"

value, as the following table on the inclinations of the orbits of planets to the ecliptic, based on Naik and Satpathy (1998), confirms (Table 1).

One of Candrasekhara's outstanding achievements was his observation with his naked eye of the 1874 transit of Venus. He found that during "the eclipse of the Sun by Venus," the shadow of Venus was 1/32 of the shadow of the Sun. The accuracy of this naked eye observation is simply astonishing. This was when the influential journal *Nature* was reporting the observations made by Norman Pogson from the Madras Observatory and by E.W. Pringle from Mananthavady in Kerala, the latter using a sophisticated Cooke refracting telescope. It is rather unfortunate that Candrasekhara does not tell us anything about the method he adopted to arrive at this finding. We also do not know if he was aware of the 1882 transit of Venus (which, however, was not visible in India).

See Also

- [Armillary Spheres in India](#)
- [Astronomy in Medieval India](#)

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Samarāṅganāsūtradhāra

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The *Samarāṅganāsūtradhāra* (SSD) is a complex and vast text that brings together a catalogue of heterogeneous topics, all directly or indirectly related to the thematic heading of Vāstu – a building site. The work is associated with the name of Bhoja, the Paramāra king, who is likely to have been its (partial) author and/or patron and inspirer. Considering the plausibly layered composition, the text's date may be best described by saying that some of its strata should have been coeval with Bhoja himself (eleventh century); also, the text seems to contain materials related to architectural practices that predate Bhoja.

The title of the work can be interpreted and translated in more than one way (multiple meanings being a virtue in the literary world of South Asia). "Stage Manager of Battlefields" and "Architect of Human Dwellings" are two plausible renderings for *Samarāṅganāsūtradhāra*, and thus, the title well captures the idea of a text on Vāstu authored and/or patronized by a powerful ruler.

The SSD offers an origin story that shows the close connection between the birth of the universe and the necessity of Vāstu as a branch of knowledge (*śāstra*). Since Vāstu is devoted to the sensible and beneficial organization of human dwellings, it becomes an indispensable tool for rulers to distribute human types and activities through their domains and palaces. In other words, the SSD presents Vāstu as the fundamental treatise on regulating human activities through the land. Vāstu is the technology through which

palace, and it is instructive to compare the available archaeological evidence with the SSD's sections on the king's palace and its layout. Similarly, Adam Hardy has offered a compelling visual translation of the SSD's instructions on temple architecture. What comes to light from these comparisons is that the SSD does work as a manual for actual building practices, and yet it leaves much unsaid. This too suggests that the text was employed within a broader context of training and oral instruction.

Linguistically, the SSD is in rather regular, well-written Sanskrit (except for a few, still easily comprehensible, features). One of the difficulties in understanding the treatise is the flexible use of terms and synonyms regarding measures, and some uncommon grammatical formations to express numbers and fractions. The editorial state of some sections makes it difficult to obtain a complete and reliable picture of what is being described; in some cases, though, the "architectural logic" of the passages is consistent enough that filling the blanks seems plausible.

The SSD presents itself as a vast and ambitious intellectual project. The world, including its origin and purpose for mankind, is retold and re-catalogued from the privileged perspective of Vāstu (the science of human and divine dwellings). To do so, this Vāstu treatise weaves in elements of Purāṇic and Sāṃkhya cosmology, cosmogony, and physical theories, and concludes (if indeed the text was ever closed) with the outer layers of the temple, where the depiction of dance and their suggested aesthetic flavors finds a place.

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Samū'īl ibn 'Abbās (Al-Maghribī)

E. Ruth Harvey

Samū'īl (or Samau'al) ibn 'Abbās, also called Abū Nasr Samū'īl ibn Yahyā ibn 'Abbās, was a Jew whose father's family origins were in Fez in Morocco. Samū'īl is often called al-Maghribī, "the westerner," but he spent his life in Iraq, Syria, Kurdistan, and Azerbaijan, and died in Maragha in about 1175 (570 AH). He was famous as a mathematician and physician, and left a number of works on both subjects. In 1163 he underwent a conversion to Islam and subsequently wrote a polemical treatise against the Jews; in an autobiographical appendage to this work he provided a very interesting account of his careful upbringing, extensive education, and the dreams which prompted his conversion. Samū'īl practiced medicine at Baghdad (where he wrote some of his works) and Maragha (where he served a number of local princes and important personages).

The early Arab biographers ascribe many works to Samū'īl, but not all of these are extant. Steinschneider and Brockelmann list 17 treatises, some of which are works not mentioned by the biographers but which are ascribed to Samū'īl in manuscript; some attributions are doubtful.

The only extant medical treatise attributed to Samū'īl is an elaborate work on sex and gynecology entitled *Nuzhat al ashāh fī mu'āsharat al-ahbāb* (The Entertainment of Friends and the Dealings of Lovers), often referred to in catalogs as *De Coitu*. Works of this kind are not infrequent

in the Arabian medical tradition; Samū'īl's treatise was written for the ruler of Hisn Kayfa, Muḥammad ibn Qara Arslan, and was famous enough to have survived in a number of widely scattered manuscripts; it has never been printed. An account of the work may be found in Leclerc. It contains two books. The first deals with sex, both homosexual and heterosexual, sexual desire, diet, and hygiene; it contains an account of the physical and moral characteristics of women from different countries. The second book deals with such topics as impotence, aphrodisiacs, conception, sterility, and female ailments. There are manuscripts in Paris, Berlin, the Escorial, I Leipzig, and Istanbul. The Berlin catalog lists (in Arabic) all the chapter headings of the *Nuzhat*.

Some of the treatises on mathematical subjects ascribed to Samū'īl by the early biographers are no longer extant, but copies of his *al-Tabsira fī 'ilm al-ḥisāb* (Introduction to Arithmetic) survive. Both Leiden and Oxford have manuscript copies of a work entitled *Fī ṭī kashf' awar al munajjimīn* (On the Errors of Astronomers), in which Samū'īl defends the idea of scientific progress, citing an arithmetical work of his own, *Al-bahir*, as an example of an advance on ancient mathematics. Brockelmann says that a manuscript of a work entitled *Al-bahir fī 'ilm al-ḥisāb* attributed to Samū'īl exists in Istanbul; perhaps this is the one referred to in *Errors of the Astronomers*. Another work on arithmetic, *Al-mujiz al-mardawi fī al-ḥisāb*, also exists in a single manuscript in Istanbul.

The Arabic text of Samū'īl's polemic against Judaism, *Ifhām al-Yahūd* (Silencing the Jews), together with his autobiographical addition, has been edited and translated into English by Perlmann, who provides in his introduction the best account of Samū'īl and his works. Perlmann points out that the work *Al-Ajwiba alfakhira raddan' an il-milla al-kafira* ascribed to Samū'īl by Brockelmann derives from Samū'īl's work but is not by him. Another polemical work against the Jews, the *Contra Judeos* of Samuel Marochitanus which was translated from Arabic into Latin in 1339, has often been ascribed to Samū'īl ibn Abbas; it contrasts Judaism unfavorably with

Christianity, not Islam, and is clearly the work of another author.

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Śaṅkara Vāriyar (ca. 1500–1560) was a brilliant expositor of astronomy and mathematics who hailed from Kerala in the south of India. He belonged to the *vāriyar* community, which was professionally assigned to certain peripheral duties in temples. Śaṅkara was a direct disciple of the well-known Kerala astronomer Nīlakaṇṭha Somyāji (b. 1444). Among other teachers whom he mentions in his works are Dāmodara (ca. 1450–1550), Jyeṣṭhadeva (ca. 1500–1610), and Citrabhānu (ca. 1475–1550). Śaṅkara

mentions that his commentary on the work *Pañcabodha* was completed on the day 1,692,972 of the Kali era, which occurs in AD 1534, from which his date is definitely ascertained.

Śaṅkara Vāriyar wrote an advanced astronomical manual entitled *Karaṇasāra*, to which he added a gloss of his own. But he is better known for his elaborate commentaries on such standard works as the *Līlāvātī* of Bhāskarācārya, the *Tantra-saṅgraha* of Nīlakaṇṭha Somayāji, and the anonymous *Pañcabodha*. The two commentaries, the one on the *Līlāvātī* called *Kriyākramakarī* (Sequential Evolution of Mathematical Procedures) and that on *Tantrasaṅgraha* called *Yuktidīpikā* (Light on Astronomical Rationale), are highly significant writings in Indian mathematical literature. After giving the meaning of each textual verse or group of verses from these two texts, Śaṅkara sets out the background and evolution of the enunciation commented on, the different aspects thereof, and the step-by-step derivation of the relevant formula or procedure. This exposition of rationale, couched in simple verses and often running to several pages, serves to give an exposure to Indian mathematical thinking and open up the normally unexpressed mental working of the Indian mathematician, which has led most modern historians of mathematics to presume that much of Indian mathematics and astronomy was borrowed and not original. The rationale elaborated here relates, among other things, to the summations of series; the circle and the irrationality of π and pulverization in the field of mathematics; and the theory of epicycles, ascensional differences, rising of the signs, and problems based on the gnomonic shadow in astronomy. These commentaries are valuable also for the information on earlier authors like Mādhava and Saṅgamaṅgrāma and their theories.

See Also

- [Nīlakaṇṭha Somayāji](#)
- [Rationale in Indian Mathematics](#)

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Santería

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Santería has its roots in the slave trade when a large number of slaves were taken from Africa to Cuba. Many were from the Yoruba people, who now live in southwestern Nigeria. The Yoruba, well known for their artistic traditions, urban lifestyle, and a well-developed division of labor, brought with them a belief in their divinities, *orishas*. In Cuba, the *orishas* merged with the saints of the Roman Catholic Church, which, in turn, led to the creation of santería, “the way of the saints” (Brandon, 1993; Cros Sandoval, 2006; Lawal, 1996; Matibag, 1996; Murrell, 2010; Thomas, 1997; Thompson, 1983; Wedel, 2004).

Only a handful of the more widely recognized *orishas* survived the Middle Passage. As the divinities acquired their Catholic equivalents, they became to be known as *santos* – saints. Oshún, for example, the *orisha* of fresh water, acquired a Catholic equivalent in the form of Virgen de la Caridad del Cobre. Shangó, the manly warrior who represents thunder, lightning, and fire, found a counterpart in the Catholic saint Santa Barbara. Apart from these two popular divinities, some of the most prominent

orishas/santos include: Eleggua, messenger and guardian of crossroads; Ogún, lord of war and iron; Obatalá, father and lord of peace and purity; Yemayá, mother and ruler of the seven seas; and Oyá, female warrior, guardian of the cemetery, who is associated with strong winds.

The actions and adventures of the divinities appear in the many santería myths (*patakies*), which, in turn, are related to various kinds of divination systems (Martínez Furé, 1979; Pérez Medina, 1998; Valdés Garriz, 1997). In one myth, the supreme god Olodumare-Olofi first created the universe and then distributed his *ashé*, life force, to the orishas/santos. As humans develop their relationship with the divinities through rituals and sacrifices, they benefit from the *ashé* that came from the high god Olodumare (Figs. 1 and 2).

In Cuba today, as well as in other Latin American countries and in the United States, people frequently turn to santería for all kinds of problems. Illness, however, is a particularly common reason for consulting a priest (see also Jones et al., 2001; Pasquali, 1994; Sandoval, 1979, 1995; Wedel, 2004). Using divination, the priest will relate the client's problems to the santería mythology and a number of proverbs. The priest (*santero* or *santera*) uses cowrie shells when divining with the dilogún divination system, while the high priest (*babalao*) uses a chain made of coconut shell or tortoise shell when divining with the Ifá system (Bascom, 1952, 1980; Mason, 1993; Matibag, 1997; Valdés Garriz, 1997; Wedel, 2004). It takes many years of training to become a skilled diviner. A *babalao* is considered "mature" after working and



Santería, Fig. 1 Eleggua, guardian of crossroads, is represented by a "head" of cement with eyes and mouth made of cowrie shells, while Ogún, lord of iron, is represented by a cauldron with iron tools (Photo by Johan Wedel)



Santería, Fig. 2 When sacrifice is performed, *ashé*, divine force, is released. The santería objects are then covered with feathers from sacrificed fowls in order to "cool" the "hot" blood (Photo by Johan Wedel)

divining for 16 years (Wedel, 2004, p. 92; Wirtz, 2007).

Once the priest has identified the client's condition through divination, spiritual cleansing, offerings, sacrifices, and minor rituals are commonly suggested. Santería priests usually have extensive knowledge of a multitude of herbs and plants, and some of these may also be recommended (Brandon, 1991; Cabrera, 1993; Marks, 1987; Wedel, 2004). In the case of an illness, clients are often told to pay a visit to a physician. From the perspective of santería, however, it is not sufficient to try just to cure the affliction; the underlying reasons for the problem must also be identified. The priest will also explain why a person has been struck by ill health and may attribute the problem to a lack of *ashé*, to afflicting spirits, to disturbed social relations and sorcery, or to the client's lifestyle (Wedel, 2004; Fig. 3).



Santería, Fig. 3 Sacrifice of a goat during an Afro-Cuban quasi-religious ceremony in the street Callejon de Hamell, Central Havana (Photo by Johan Wedel)

In santería, it is recognized that both physical and mental illnesses are frequently related to disturbed social relations, and these are expressed in terms of sorcery (cf. Stoller & Olkes, 1987; cf. Geschiere, 1997). An envious neighbor or family member, for example, might be said to have performed sorcery on the client (although the priest seldom reveals the name of the evil-doer). The client may then be advised to break up a relationship, move to another house, change jobs, or avoid certain persons in order to become well. An affliction may also be caused by a spirit or divinity who wants the person to change his way of life and become a practicing priest (Wedel, 2004).

When divination discloses a serious illness and it is established that medical treatment will not be adequate, initiation may be recommended. This was expressed by a Cuban *babalao* who also works as a physician, who said: "We do this when modern medicine can do no more, when you reach the limits of science" (Wedel, 2004, p. 121). A similar opinion was articulated by another *babalao*: "We religious people say that sometimes a person has to attend *el brujo blanco* [the 'white sorcerer'] who is the [biomedical] doctor. Sometimes he has to attend *el brujo Yoruba* [the 'Yoruba sorcerer'], who is the *santero* or *babalao*" (121) (Figs. 4 and 5).

Initiation into santería, which also may take place for reasons other than illness, is a "rebirth," a gradual process designed to change a person's experience and transform the whole lifeworld of the devotee (cf. Turner, 1969, 1986; cf. Clark, 2007; Wedel, 2004; cf. Willis, 1999). The "new-born" builds a beautiful altar for his/her personal divinities (Brown, 1996, 2003; Flores-Peña & Evanchuk, 1994) and is kept in isolation for seven days, while a godmother or godfather feeds and cares for them. The initiate is also given *omiero*, a mixture of secret herbs said to contain large quantities of *ashé* (Brandon, 1991).

During the initiation, which is largely secret and closed to the noninitiated, a divinity will be "placed in the head" of the initiate. This *orisha/santo*, who is said to be the "father" or "mother" of the initiate, will then offer its protection for the rest of the initiate's life. The initiation also

Santería, Fig. 4 Osain is the lord of herbs and plants. He is represented by a calabash with powerful, secret herbs, which is hung from the ceiling. If a menstruating woman comes into contact with the calabash, it will lose its power (Photo by Johan Wedel)



Santería, Fig. 5 Afro-Cuban objects arranged by the artist Salvador Gonzalez at Callejon de Hamell, Central Havana (Photo by Johan Wedel)

involves a complex divination session, including ritual cleansing, animal sacrifices, offerings to the dead ancestors, and dancing to the sacred santería drums. During the drum ceremony, the divinity may “descend” into the body of the novice, who

may experience possession trance (cf. Goodman, 1988, 1990; cf. Clark, 2007; Murphy, 1993, 1994; cf. Turner, 1992; Wedel, 2004; cf. Willis, 1999).

For one year after the initiation, everyone will address the initiate as *iyabó*. He/she is close to the divine world of the *santos/orishas* and must obey certain rules, such as wearing white clothes and not visiting cemeteries. The initiate will also acquire new social relations and become a “sister” or “brother” to others who have been initiated by the same godmother or godfather. Through initiation, an intimate relationship between humans and the world of the *orishas/santos* is created, and the initiate develops a new understanding of what has caused the affliction and how to avoid problems in the future.

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Śatānanda

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Śatānanda was a widely respected eleventh-century astronomer from the city of Purusottama

(now Puri) in Odisha. The son of a certain Śaṅkara, he was the author of the *Bhāsvatī*, an influential treatise on the making of almanacs. This work was completed in the year 1099–1100 CE (Śaka 1021).

By the year 1099–1100, Anantavarman Coḍagaṅga, the founder of the Western Gaṅga state, had established sway over large parts of coastal Odisha. He ruled for 70 long years from 1077 to 1147 CE. He was instrumental in redefining the political and religious life of the region in many ways. Today, his fame rests largely on the fact that he rebuilt the temple of Puruṣottama (Jagannātha, since the fourteenth century) in the town of Puri. We owe much of the political and religious legacy the region inherited in the coming centuries to this great pioneer. There are no historical documents to suggest that Śātānanda was Anantavarman's protégé. Nevertheless, this is not unlikely. The fact that his *Bhāsvatī* was regarded as the preeminent text on almanac making in eastern India and many parts of north India for several centuries seems to suggest that he was closely associated with the Jagannātha temple. A number of manuscripts of the *Bhāsvatī* have been retrieved from these regions. It is available today in many recensions, some of them carrying a follow-on called the *Uttara Bhāsvatī*. The *Bhāsvatī* was widely commented upon during the period between the fifteenth and the eighteenth centuries. Most of these commentaries have been obtained from eastern and parts of northern India. These include Aniruddha's *Śiṣubodhinī* (1495 CE), Mādhava's *Mādhavī* (1525 CE), Acyuta's *Ratnamālā* (ca. 1525 CE), Kubera Miśra's *Ṭika* (1685 CE), and Rāmakṛṣṇa's *Tattvaparakāśikā* (1739 CE).

Śātānanda expresses his debt to the *Sūryasiddhānta* and states that his work is based on its summary contained in Varāhamihira's *Pañcasiddhāntikā*. This, it is believed, is implicit in the name of his work, *bhāsvan* being a synonym for *sūrya* (the sun).

The *Bhāsvatī* is a short work of 82 verses, divided into eight chapters. It is different from other Indian texts on astronomy in many respects. First, works on astronomy generally give the epochal constants for the city of Ujjayini, but

the *Bhāsvatī* records it for the town of Puri. Second, its computation of Mean planets was based on the *varṣagaṇa* (number of years elapsed) and not the *ahargaṇa* (number of days elapsed). Third, the commencement of the year was recorded in terms of True *meṣādi* (Aries ingress) and not the Mean *meṣādi*. Fourth, Śātānanda's work adopted the centesimal system for the commencement of epochal positions and for specifying multipliers and divisors. Fifth, it stated the position of the sun and the moon in terms of *nakṣatras* (constellations) and not *rāśis*. Sixth, the *Bhāsvatī* identified 528 CE as the zero-precision year and determined the rate of precision as being 1 min per year. Śātānanda's methods became so powerful that the *Bhāsvatī* was widely used for centuries, especially due to the belief that eclipses calculated on its basis would always be marked by great precision.

Also see “► [Precession of the Equinoxes](#).”

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Science and Spirit

Nitin Trasi

The word “spirit” is derived from the Latin *spirare*, to breathe, or *spiritus*, breath. The term “spiritual” is sometimes taken to mean matters

concerning the supernatural or the occult. However, the true meaning of the word concerns matters pertaining to the spirit, the animating principle in man, as opposed to matters pertaining to the physical and material. Thus “spirituality” in Sanskrit is *adhyātma*; in Pali, it is *ajjhat*.

The true spiritual quest in the most rigorously scientific sense of the term would then mean research into consciousness itself. Although India has had its fair share of occultists and those interested in the paranormal, a significant contribution of India to the world, from ancient times down to the modern age, has been the remarkable research into the nature of consciousness. Right from the Vedic times, the seers of India have been interested in questions about life and its meaning and in consciousness itself. Who are we? Where do we come from? What is the nature of the consciousness that animates us? What is its source? Is there an unchangeable ultimate reality or first principle in life? What is the cause of human suffering, and what is its solution? These and other fundamental questions have engaged their attention. These men have conducted scientific research into consciousness, in which they have explored the mind and the inner world within man himself. They conducted thought experiments and delved deep into their own minds and thinking processes to seek out the basic truths about life, consciousness, and the universe.

Vedānta

The four *Vedas* are the most ancient sacred literature of India. They were probably composed over several centuries during the second millennium BCE. The early Vedic hymns contain extremely detailed poetical descriptions of nature, and speculations about the origin and nature of the universe. The *ṛg-Veda* declares, “Who verily knows and who can here declare it, whence it [the universe] was born and whence comes this creation?” (Nikhilananda, 1997). And before this creation? “There was neither existence nor nonexistence then, neither air nor the sky beyond...neither death nor immortality,

night nor day...darkness was concealed in darkness there!” (*ṛg Veda*, III.129.1–3).

Deities symbolized the different forces of nature, but even in these early hymns, there is an awareness of the unity of these deities. “They speak of Indra, Mitra, Varuṇa, Agni, [names of deities]...the One Reality the sages call by many names.” (*ṛg Veda*, I.164.46, *Atharva Veda*, IX.10.28). “In That all this unites, from That all this emerges. The all-pervading One is the warp and woof of all created things.” (*Yajur Veda*; *Vājasneya Saṁhitā*, 40.1).

Though the earlier parts of the *Vedas* (the *Karmakāṇḍa*, the ritualistic section) dealt more with means to derive health, wealth, and material prosperity, later on the approach changed, as it was realized that these benefits were all transitory and subject to corruption with time. It is in these latter parts (the *Jñānakāṇḍa*, the knowledge section) that the *Vedas* really begin to deal with the question of lasting peace and happiness and the nature of consciousness itself. The concluding portions of the *Vedas* are called the Vedānta (*anta*: end, essence) and include the treatises called the *Upaniṣads*, which date back to the last millennium BCE. There are 108 *Upaniṣads*, of which 11 are considered the most important.

The Knower

In the *Upaniṣads*, the approach is highly introspective, and a critically important distinction is made between the “seer” (*dṛk*) and the “seen” (*dṛṣya*). Through a lot of intricate discussion, it is shown that the seer is the unchangeable Consciousness or the knowing principle that cannot be recognized easily, because it is itself attempting to do the seeing or knowing. Just as the eye cannot see the eye, the seer cannot know itself as an object. “How can one know that by which all this is known?” (*Bṛhadāraṇyaka Upaniṣad*, IV.5.15). And yet, itself the knower, who else is there to know it? The seer or the knower is in reality the innermost consciousness within us, the *ātman*, “the light of lights which is my inner being” (*Yajur Veda*; *Vājasneya Saṁhitā*, 34.1–3). Since whatever it can perceive

(the seen or known) cannot be itself (the seer or knower), it therefore has to resort to elimination to recognize itself – a process symbolized by the famous words, *neti, neti* meaning, “It is not this, it is not this” (*Bṛhadāraṇyaka Upaniṣad* II.3.6). The ātman is finally said to be able to recognize itself only through intuitive knowledge and it is therefore said to be *svasākṣi* (self-cognized) (*Vivekacūḍāmaṇi*, 216). This knowing is not an objective but an intuitive knowing, “just as one knows of one’s own existence even without the aid of a mirror” (*Amṛtānubhava*, II.76).

The Ultimate Reality

The idea of a single ultimate reality (*Brahman*), the basis of the physical universe appears early in the *Vedas*: “I know the drawn out thread in which all these creatures are strung. I know the thread’s thread. I know the great *Brahman*” (*Atharva Veda*, X.8.38). But it is the *Upaniṣads* that elaborate on the details of this monistic idea of a single reality *Brahman* manifesting as the universe and its diverse objects, including human beings – the doctrine of *advaita*, monism. “Ever unborn, He is born in many forms. In Him alone reside all living things” (*Māhānārāyaṇa Upaniṣad*, 1.2). The relationship of the individual consciousness with this Reality is also stated. The ātman, the individual source of consciousness within a person, is not different from *Brahman*, the Universal Consciousness, but only appears to be separate because of the limiting adjuncts of the body and mind. The conclusion is finally reached that this (apparent) sundering from that reality is the true cause of insecurity and suffering in life, and reunion (or rather recognition of the essential oneness) with that reality is the only way to lasting, unqualified peace.

The Scientific Approach

Throughout the *Upaniṣads*, the approach is always investigative, and never dogmatic. The Truth is mentioned, but the pupil is expected and encouraged to question it and confirm it for himself, by his own efforts. The criteria of truth

are said to be not just *śruti* (scriptural authority), but its conjunction with *yukti* (reasoning) and *anubhava* (experience) (Nikhilananda, 1997, p. 17). “The true nature of things is to be known personally...and not through a sage. What the moon exactly is, is to be known with one’s own eyes; can others make him know it?” (*Vivekacūḍāmaṇi*, 54).

Monism was therefore not the only doctrine that was existent, though it was the dominant one. The spirit of enquiry dominated philosophical thought (*darśana*) both in ancient and medieval India, and a wide spectrum of philosophical ideas was explored. At one extreme of this diverse spectrum was the purely materialistic doctrine of the pre-Buddhist Cārvāka school, which approximated to pure hedonism. There were also the Pūrva Mīmāṃsa of Jaimini, the Uttara Mīmāṃsa ascribed to Vyāsa, the Sāṃkhya of Kapila, Patanjali’s Pātāñjala, Gautama’s Nyāya, and the Vaiśeṣika of Kānada. At the other extreme was the *bhakti* (devotional) tradition, with its total emphasis on love of God. But even within this devotional tradition, a variety of philosophical thought was expressed, and (apart from monism) there were several doctrines to explain the relationship of the human with the Divine. The *dvaita* (dualism) school taught that the soul (or self) and God are eternally separate. Its most important proponent was Mādhvācārya, a mediaeval philosopher and religious teacher of South India. The school of Viśiṣṭa Advaita (qualified monism) of Rāmānuja (eleventh century AD, South India), stated that the individual souls were very close to God and a part of him, but not one and the same (“like seeds in a pomegranate”); while the Śuddha Advaita doctrine (“pure” monism) of Vallabhācārya of mediaeval India made a fine distinction between the individual souls and God, saying that they are related “as sparks to a fire.”

Advaita and Science

Science and religion do not always agree with each other. Religion is generally a matter of faith, whereas science depends upon plausible theories and empirical confirmation.

Advaita seems to offer a model of spirituality which agrees with science on these points. In this philosophy, there is no separate individual soul (there is only an illusion or appearance of a separate self or soul). The reality of God according to this theory is that he is the Universal Consciousness, the Source or Ground of all being, and not a personal, anthropomorphic, all-powerful entity. And finally, these things are definitely not asked to be accepted on trust. The individual is encouraged to find out for himself and confirm and corroborate these findings on his own.

Thus advaita presents to the world perhaps the most elegant, the most feasible, and the most scientifically acceptable of all theories of ontology. Advaita has also been shown to be closest to the new physics and quantum mechanics (Capra, 1976; Goswami, 1993).

Bhagavad Gītā and Karma-Yoga

Probably originally composed in about 1500 BCE, the Bhagavad Gītā is considered to be as authoritative as the *Vedas*. The philosophy in the *Bhagavad Gītā* (BG) is generally consistent with the advaitic tradition, though like the *Upaniṣads*, the followers of the non-advaitic traditions interpret it differently. However, its most important scientific contribution to the world is the thoroughly practical philosophy of *karma-yoga* (lit. the art of action, BG: II-50). Consistent with modern management principles as well as modern psychology, karma-yoga teaches an attitude to be adopted toward everyday duties and actions. Excessive concern about results interferes with the efficiency of the activity. Specifically, karma-yoga suggests performing action without worrying unduly about the results – *karma-phala-tyāga* (lit. surrender of the fruits of action) (BG, II.47–48, XII.8–11).

Buddhism

The Buddha

Whereas a large part of Vedāntic philosophy involved intricate discussions on consciousness,

the Buddha (sixth century BCE) took a refreshingly different approach. At a young age, the Buddha, then Prince Siddhartha Goutama, was deeply disturbed by what he saw as the terrible inevitabilities of life: suffering, old age, and death. Desperately seeking a solution, and dissatisfied with the answers the scholars offered, he set out to discover the truth on his own. Rejecting all authority, discarding all theoretical speculation, he struggled for many years until 1 day, illumination dawned upon him. The Buddha spent the rest of his life spreading his message, until he died at the age of 80.

The Buddha proposed that ordinary human existence is an unsatisfactory state in which people make themselves miserable as a result of a basic misunderstanding of their own nature, and that there exists another way of being in this world, *nirvāṇa* (*nibbāna*), which is a release from this misery. Nirvāṇa is not some superhuman state, but rather a natural way of being, accessible to any human being. The way to nirvāṇa does not require acquisition of special powers, nor withdrawal from life or any other extremes. It is therefore called the “middle way.”

The Buddha decried appeals to authority or tradition. He proposed a highly scientific, completely empirical approach, without recourse to any pre-existing theoretical concepts. He offered no theory of God and discouraged all speculation on the subject, and restricted himself to purely practical teaching. Based upon a systematic rational analysis of the problems of life, his teachings offered a way to their solution. A psychologist and a philosopher, he formulated his own experiential techniques to study the mind.

The Buddha’s teachings include a set of concepts of how the mind works – the oldest psychology of which the world has any record (Anderson, 1979, p. 5). In the Buddhist view, the person is seen not as a solid reincarnating entity, but rather as a flow of mental processes. At any one time, a human being is an aggregation of events, and that aggregation is constantly changing. There is thus no identifying essence at the core of any human being – no eternal soul, no *jīvātman*. In other words, the “me” is

not a person, but a process, and that process is in a state of constant flux, like a flowing river. This is the principle of *anātman* (no-soul). However, this concept of no-self is most definitely not a dogma. The correct Buddhist position is not to hold any dogmatic views, but rather to see things objectively as they are without mental projections (Anderson, pp. 29–31).

The Buddha is also said to have formulated and taught a detailed step-by-step practical technique to approach the realization of the state of *nibbāna*. This technique is called *Vipaśśanā*.

The Technique

Vipaśśanā means knowledge by seeing, clear perception. It means to observe reality in the right way – as it is, and not as it appears to be, colored by belief and imagination (Goenka, 1994). The *Vipaśśanā* technique is a type of meditation – an observation-based, self-exploratory journey into one's own mind.

Vipaśśanā meditation trains the concentrated attention to follow the mechanics of mental processing with the base of concomitant physical sensations, in a detached fashion (Fleischman, 1986). As the sensations arise and pass away, the wisdom of impermanence arises in the mind (everything is impermanent – *anicca* – nothing is eternal) and one attains equanimity amidst life's vicissitudes. The mind is gradually deconditioned (Goleman, 1977), and life becomes characterized by increased awareness, reality-orientation and peace (Fleischman). Man is led away from narcissism to mature, social love, and this personal transformation becomes the catalyst for social change and development (Fleischman, 1991).

Mindfulness

Vipaśśanā consists ultimately in arriving at a state of mental alertness or attentiveness to the present, both with respect to the outer world, as well as to the inner – the workings of the mind. It is an ongoing process and results in enhanced insight and psychological maturity, as well as equanimity. The spontaneous (not enforced), easy state of mental alertness or awareness which results is known as *sati* (mindfulness), and could be

described as a prospective, ongoing awareness of thought and action (as opposed to analysis – which is retrospective deliberation).

Buddhist mindfulness practice has some strong similarities to Gestalt therapy of Western psychology. Both emphasize the *how* of life rather than the *why* (unlike Freudian psychoanalysis). Repression of feelings is not advised, nor is change through inner or outer coercion. Emphasis is on being attentive, perceiving the truth, and being free. As in Gestalt therapy, *Vipaśśanā* meditation involves focusing on the actual, reduction of conceptual activity, and noninterference in the flow of experience (Anderson, 2003, p. 85).

Vipaśśanā is considered a perfect antistress remedy, an effective cognitive technique for the development of self-awareness (Kutz, 1985), and an excellent human potential development method and tool for self-actualization (Chokhani, 1995). *Vipaśśanā* transforms one's approach to life and its vicissitudes including disease, and even death, which one now is able to face with serenity and fortitude. Though *Vipaśśanā* is not advocated for treatment purposes, it may have therapeutic value, and it has been suggested that combining and integrating it with psychotherapy may offer synergistic advantages (Kutz). Studies carried out on the impact of *Vipaśśanā* in jails in India have reported its efficacy as a reformatory measure.

Self-Reliance

The Buddha always stressed the importance of self-discovery, and nonreliance on external authority, even his own. Scientific to the end, his dying words were “Be ye lamps unto yourselves. Rely on yourselves, and do not rely on external help. Look not for assistance to anyone besides yourselves – either now or after I am dead” (Burt, 1955, pp. 49–50).

The Buddha's teachings have been kept alive in true Eastern tradition by several Buddhist Masters.

Jiddu Krishnamurti

Krishnamurti (1895–1986) was probably the most remarkable spiritual scientist in recent

Indian history. Fiercely independent, his approach was in many ways reminiscent of the Buddha's. He was dismissive of authority (including his own) and tradition, and had a completely empirical approach without recourse to theoretical speculation. His "choiceless awareness" sounds similar to Buddhist mindfulness. Like the Buddha, he encouraged people to be their own spiritual guides, and even insisted that he wanted no followers. "To follow another is evil," he said, "it does not matter who it is" (Krishnamurti Information Network).

But whereas the Buddha left a detailed step-by-step methodology, Krishnamurti decried all methods and techniques in the spiritual search. "Truth is a pathless land," he declared, "and you cannot approach it by any path whatsoever" (Krishnamurti Foundation Trust Ltd.). Again, whereas the Buddha created and left behind an organization, the sangha, to carry his message, Krishnamurti was against any organization in the spiritual field, and in his own case, allowed only the most perfunctory of organizations for the limited purpose of preserving an authentic record of his message.

"Discovered" as a young boy by members of the Theosophical Society who were convinced that they had found the modern messiah, Krishnamurti was declared the new World Leader and, by the 1920s, was attracting worldwide attention. Then in 1925 Krishnamurti experienced a mysterious spiritual awakening, and in 1929, in an act of renunciation, he abandoned the Theosophical Society, cut himself off from all organizations, and from that time until his death, traveled round the world speaking as a private person – a secular philosopher with no affiliation to any religion, sect or dogma.

The Core of the Teachings

Krishnamurti taught that man, out of his insecurity, has built within himself images as a fence of security – symbols, ideas, beliefs – religious, political, personal. Man's perception of life is shaped by these concepts established in his mind. His thinking, his relationships and his daily life are dominated by these images. They divide man from man, and are the cause of the

disorder that pervades the consciousness of mankind, and which prevents human beings from properly working together, ultimately resulting in widespread sorrow, conflict, and misery.

The root cause of this delusion is in the fact that we are ignorant of the general nature of our own processes of thought. To be free from this delusion, we must observe the workings of our own minds. Through observation – close attention to and observation of the activity of thought (Krishnamurti called this "meditation") – one discovers the lack of freedom. One does this observation without choice, without criticism, without acceptance or rejection. The very act of this meditation then, in itself, brings order to the activity of thought without the intervention of will, choice, decision, or any other action of the "thinker." The noise and chaos which are the usual background of our consciousness die out, and the mind becomes generally silent. Our day-to-day work is not affected adversely (to the contrary, it becomes more efficient), because thought arises whenever needed for some genuinely valid purpose, and then stops until needed again.

In this silence, said Krishnamurti, something new and creative happens that is of extraordinary significance for all of life. This something cannot be conveyed in words, so he did not attempt to do so. Rather, he asked those who were interested to explore for themselves, through actual attention to the nature of thought.

Man does not have to go to a hermitage or forest to be free. Freedom is found in the "choiceless awareness" of our daily existence and activity. When man becomes aware of the movement of his own thoughts he will see the division between the thinker and thought, the observer and the observed, the experience and the experiencer. He will discover that this division is an illusion. This will lead to pure observation which is insight without any shadow of the past or of time. This timeless insight brings about a deep radical mutation in the mind – and then there is love, compassion and intelligence.

Truth (spiritual truth) cannot be found through any organization, creed, dogma, priest, or ritual, nor through philosophic knowledge, psychological technique, or intellectual analysis. Man has to

find it through the understanding of the contents of his own mind, through observation.

Krishnamurti's teachings are of considerable relevance to mental health. It has been suggested that many of his ideas could be assimilated into modern psychiatric practice and aid toward promotion of mental health (Rao, 1995).

These scientists of the spirit from the land of the *Vedas* have much to offer to the world. Their discoveries may well complement modern scientific advances to make for a better future. While modern science has explored outer space, these are the scientists who have explored inner space. While modern science has perfected some kinds of technology, they have perfected the techniques of self-actualization. Whereas science and modern medicine have gone far ahead in studying and treating disorders of the mind, the spiritual psychology of the East has studied and perfected the further development and evolution of the human mind beyond the so-called normal (Wilber, 1977, 1989). Perhaps a meaningful synthesis of the wisdom of ► [East and West](#) can lead us to the next phase of human evolution, to a better and more loving human existence, what has been aptly termed the "Next Enlightenment" (Anderson, 2003).

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Science as a Western Phenomenon

Roshdi Rashed

Philosophers, historians, and sociologists of science all accept as a basic postulate that science is essentially Western. This postulate is still conditioning contemporary scientific ideologies. This article analyzes the characteristics, history, and validity of this doctrine by means of a confrontation with one of the non-Western scientific contributions: science written in Arabic.

Classical science is essentially European, and its origins are directly traceable to Greek philosophy and science; this tenet has survived intact

through numerous conflicts of interpretation over the last two centuries. Almost without exception, the philosophers accepted it. Kant, as well as Comte, the neo-Kantians as well as the neopositivists, Hegel as well as Husserl, the Hegelians and the phenomenologists as well as the Marxists, all acknowledge this postulate as the basis of their interpretations of Classical Modernity. Even until our time, the names of Bacon, Descartes, and Galileo (sometimes omitting the first, and sometimes adding a number of others) are cited as so many markers on the road to a revolutionary return to Greek science and philosophy. This return was understood by all to be both the search for a model and the rediscovery of an ideal. One might impute this unanimity to the philosophers' zeal to pass beyond the immediate data of history, to their wish for radical insight, or to their effort to seize what Husserl describes as "the original phenomenon (*Urphänomen*) which characterizes Europe from the spiritual point of view." One would expect that the position taken by those who have stuck more closely with the facts of the history of science would be quite different, but such is not the case. This same postulate is adopted by the historians of science as a point of departure for their work, and especially for their interpretations. Whether they interpret the advent of classical science as the product of a break with the Middle Ages, whether they defend the thesis of continuity without breaking or cutting, or whether they adopt an eclectic position, the majority of historians agree in accepting this postulate more or less implicitly.

Today, in spite of the works of many scholars on the history of Arabic and Chinese science, in spite of the wide representation of non-Western scientists in *Dictionary of Scientific Biography*, the works of the historians rest on an identical fundamental concept: in its modernity as well as in its historical context, classical science is a work of European man alone. Furthermore, it is essentially the means by which this branch of humanity is defined. Occasionally the existence of a certain practical science in other cultures might be acknowledged; nevertheless, it rests outside history, or is integrated into it only to

the extent of its contributions to the essentially European sciences. These are only technical supplements which do not modify the intellectual configuration or the spirit of the latter in any way. The image given of Arabic science constitutes an excellent illustration of this approach. Essentially it consists of a conservatory of the Greek patrimony, transmitted intact or enriched by technical innovation to the legitimate heirs of ancient science. In all cases, scientific activity outside Europe is badly integrated into the history of the sciences; rather, it is the object of an ethnography of science whose translation into university study is nothing more than Orientalism.

The effects of this doctrine are not limited to the domain of science, its history, and its philosophy. It is at the center of the debate between modernism and tradition. As was the case in eighteenth-century Europe, we find, in certain Mediterranean and Asian countries of today, that science (which is qualified as European) is identified with modernism. Our purpose here is not to redress wrongs, nor to oppose to that science qualified as European an alleged Eastern science. It is simply a matter of understanding the significance of the European determination of the concept of classical science, grasping the reasons for it and measuring its importance.

We shall begin by sketching the history of this view of European science and then estimate its effects. We shall limit ourselves to posing the problem and advancing several hypotheses, and we also add these two restrictions: the only non-European science considered is one which was produced by various cultures, by scholars of different beliefs and religions, all of whom wrote their science principally, if not exclusively, in Arabic. As for the tenets of the history of the sciences, we shall most often cite those of the French historians.

The concept of a European science is already present in the works of the historians and philosophers of the eighteenth century. In the debate of the Ancients and the Moderns, scholars and philosophers referred to science to define modernity where one combines reason and experience. Historical induction intended to give its concrete determinations to this dogmatic debate, so as to

render the superiority of the Moderns indisputable. But the West was already being identified as Europe, and "Oriental wisdom" was already counterpoised against the natural philosophy of the post-Newtonian West, such as we find in Montesquieu's *Persian Letters* (1721).

Classical science is European and Western only to the degree that it represents a stage in the continuous and regular development of humanity. The *Discours Préliminaire* of Abbé Bossut in Diderot's *Encyclopédie Méthodique* offers an illustration of this concept. Dividing the history of the progress of the exact sciences into three periods, this tableau allows conjecture, alleged facts, and facts to intermingle. Its initial postulate is that "...all of the eminent peoples of the ancient world liked and cultivated mathematics. The most distinguished among them are the Chaldeans, the Egyptians, the Chinese, the Indians, the Greeks, the Romans, the Arabs, etc.... in modern times, the western nations of Europe." Classical science is European and Western because, writes Abbé Bossut, "...the progress made by the western nations of Europe in the sciences from the sixteenth century to our times utterly effaces those of other peoples."

The concept of Western science changed in nature and extent at the turn of the nineteenth century. With what Edgar Quinet called the "Oriental Renaissance", the conceptualization was completed in its anthropological dimension in the last century. This Oriental Renaissance ended by discrediting science in the East.

If it is true that the eighteenth-century concept still survived here and there, from the first years of the nineteenth century the materials and ideas of Oriental studies contributed the most to the makeup of the historical themes of the different philosophies. In Germany as well as in France, the philosophers adopted Oriental studies for diverse reasons in accordance with an identical representation: the East and the West do not oppose each other as geographical, but as historical positivities; this opposition is not limited to a period of history, but goes back to the essence of each term. In this regard, *Lessons on the History of Philosophy* and other works of Hegel can be invoked. Also at this time, as is shown by the

French Restoration philosophers, the themes of the “call of the East” and the “return to the Orient” appear, which translate as a reaction against science, and more generally, against Rationalism. But it is with the advent and growth of the German philological school that the notion of science as a Western phenomenon was regarded as having been endowed with the scientific, and no longer purely philosophical, support which had been lacking until then.

This influence also extended into mythological and religious studies. For example, Friedrich von Schlegel distinguishes two classes of language: the flexional Indo-European languages, and others. The former are “noble,” the latter less perfect. Sanskrit, and consequently, German, considered the closest to it, is “...a systematic language and perfect from its conception”; it is “...the language of a people not composed of brutes, but of clear intelligence.” There is nothing surprising in this; with the advent of the German school we are already in the realm of classifying mentalities. From now on everything is in place for effecting the passage from the history of languages to history through languages.

The comparative study of religions and myths is developed around the middle of the century by A. Kuhn and Max Müller in particular. The classification of mentalities is perfected. It is from the basis of these tenets and dating from this period that one of the most important efforts to establish the notion of science as Western and European in an allegedly scientific manner is elaborated. This project achieves its full extent in France in the work of Ernest Renan.

For Renan, civilization is divided between Aryans and Semites; the historian only has to evaluate their contributions in a differential and comparative manner. The notion of race would constitute the foundation of historiography. By race, one meant the whole of the “... aptitudes and instincts which are recognizable solely through linguistics and the history of religions.” In the last analysis, it is for reasons attributable to the Semitic languages rather than the Semites themselves that they did not and could not have either philosophy or science. “The Semitic race,” writes Renan, “is distinguished almost

exclusively by its negative traits: it has neither mythology, epic poetry, science, philosophy, fiction, plastic arts nor civil life.” The Aryans, whatever their origin, define the West and Europe at one and the same time. Arabic science is, “...a reflection of Greece, combined with Persian and Indian influences.”

The historians of science borrowed not only their representation of the Western essence of science from this tradition, but also some of their methods for describing and commenting on the evolution of science. Thus, they applied themselves to discovering the concepts and methods of science and to following their genesis and propagation through philological analyses of the terms and on the basis of the texts at their disposal. Like the historian of myths or of religion, the historian of the sciences must be a philologist as well. In France, the situation is such that philosophers borrow Renan’s interpretation and, often, even his terminology. Even though this brand of anthropology has already been abandoned by historians, they nevertheless preserve and propagate a series of inferences engendered by it. These can be enumerated as follows:

1. Just as science in the East did not leave any consequential traces in Greek science, Arabic science has not left any traces of consequence in classical science. In both cases, the discontinuity was such that the present could no longer recognize itself in its abandoned past.
2. Science subsequent to that of the Greeks is strictly dependent upon it. According to Duhem, “...Arabic science only reproduced the teachings that it received from Greek science.” In a general fashion, Tannery reminds us that the more one examines the Hindu and Arabic scholars, “...the more they appear dependent upon the Greeks... (and)... quite inferior to their predecessors in all respects.”
3. Whereas Western science addresses itself to theoretical fundamentals, Oriental science, even in its Arabic period, is defined essentially by its practical aims.
4. The distinctive mark of Western science is its conformity to rigorous standards; in contrast,

Oriental science in general, and Arabic science in particular, lets itself be carried away by empirical rules and methods of calculation, neglecting to verify the soundness of each step on its path. The case of Diophantus illustrates this idea perfectly: as a mathematician, said Tannery, "...Diophantus is hardly Greek." But when he compares the *Arithmetics* of Diophantus to Arabic algebra, Tannery writes that the latter "...in no way rises above the level achieved by Diophantus."

5. The introduction of experimental norms which, according to historians, totally distinguishes Hellenistic science from classical science, is solely the achievement of Western science.

Thus it is to Western science alone that we owe both the concept and experimentation. We are not going to oppose this ideology to another. We propose simply to confront some of these elements with the facts of the history of science, beginning with algebra and concluding with the crucial problem of the relationships between mathematics and experimentation.

Algebra

As with the other Arabic sciences, algebra had practical aims, a flair for calculation, and an absence of rigorous standards. It is precisely this that allowed Tannery to make his statement. Bourbaki took this as his authorization to exclude the Arabic period when he retraced the evolution of algebra. The historical writings of the modern mathematician Dieudonné are significant; between the Greek prehistory of algebraic geometry and Descartes, he finds only a void, which, far from being frightening, is ideologically reassuring. Some historians cite ► [al-Khwārizmī](#), his definition of algebra and his solution of the quadratic equation, but it is generally to reduce Arabic algebra to its initiator. This restriction misconstrues the history of algebra, which in actuality does not show a simple extension of the work of al-Khwārizmī in the West, but an attempt at theoretical and technical overtaking

of his achievements. Moreover, this overtaking is not the result of a number of individual works, but the outcome of genuine traditions. The first of these traditions had conceived the particular project of arithmetizing the algebra inherited from al-Khwārizmī and his immediate successors. The second one, in order to surmount the obstacle of the solution by radicals of third and fourth degree equations, formulated in its initial stage a geometric theory of equations, subsequently to change viewpoint and study known curves by means of their equations. In other words, this tradition engaged itself explicitly in the first research in algebraic geometry.

As we have said, the first tradition had proposed arithmetizing the inherited algebra. This theoretical program was inaugurated at the end of the tenth century by ► [al-Karajī](#), and is thus summarized by one of his successors, al-Samaw'al (d. 1176): "to operate on unknowns as the arithmeticians work on known quantities."

The execution is organized into two complementary stages. The first is to apply the operations of elementary arithmetic to algebraic expressions systematically; the second is to consider algebraic expressions independently from that which they can represent so as to be able to apply them to operations which, up to that point, had been restricted to numbers. Nevertheless, a program is defined not only by its theoretical aims, but also by the technical difficulties which it must confront and resolve. One of the most important of these was the extension of abstract algebraic calculation. At this stage, the mathematicians of the eleventh and twelfth centuries obtained some results which unjustly are attributed to the mathematicians of the fifteenth and sixteenth centuries. Among these are the extension of the idea of an algebraic power to its inverse after defining the power of zero in a clear fashion, the rule of signs in all its general aspects, the formula of binomials and the tables of coefficients, the algebra of polynomials, and above all, the algorithm of division, and the approximation of whole fractions by elements of the algebra of polynomials.

In a second period, the algebraists intended to apply this same extension of algebraic

calculation to irrational algebraic expressions. Al-Karajī questioned how to operate by means of multiplication, division, addition, subtraction, and extraction of roots on irrational quantities. To answer this question the mathematicians gave, for the first time, an algebraic interpretation of the theory contained in Book X of the *Elements*. This book was regarded by Pappus, as well as by Ibn al-Haytham much later, as a geometry book, because of the traditional fundamental separation between continuous and discontinuous magnitudes. With the school of al-Karajī, a better understanding of the structure of real algebraic numbers is achieved.

In addition, the works of this algebraic tradition opened the route to new research on the theory of numbers and numerical analysis. An examination of numerical analysis, for example, reveals that after renewing algebra through arithmetic, the mathematicians of the eleventh and twelfth centuries also effected a return movement to arithmetic to search for an applied extension of the new algebra. It is true that the arithmeticians who preceded the algebraists of the eleventh and twelfth centuries extracted square and cube roots, and had formulas of approximation for the same powers. But, lacking an abstract algebraic calculation, they could generalize neither their results, their methods, nor their algorithms. With the new algebra, the generalization of algebraic calculation became a constituent of numerical analysis which, until then, had only been a sum of procedures, if not prescriptions. It is in the course of this double movement which is established between algebra and arithmetic that the mathematicians of the eleventh and twelfth centuries achieved results which are still wrongly attributed to the mathematicians of the fifteenth and sixteenth centuries. This is the case with the method attributed to Viète for the resolution of numerical equations, the method ascribed to Ruffini-Horner, the general methods of approximation, in particular that which D. T. Whiteside designates by the name of al-Kāshī-Newton, and finally, the theory of decimal fractions. In addition to methods, which were to be reiterative and capable of leading in a recursive manner to approximations, the mathematicians of the

eleventh and twelfth centuries also formulated new procedures of demonstration such as complete induction.

We have just seen that the concept of polynomials is among those elaborated by the algebraist arithmeticians from the end of the tenth century. This tradition of algebra as the “arithmetic of unknowns”, to use the expression of the time, opened the road toward another algebraic tradition which was initiated by ‘Umar al-Khayyām (eleventh century), and renewed at the end of the twelfth century by ► [Sharaf al-Dīn al-ṭūsī](#). While the former formulated a geometric theory of equations for the first time, the latter left his mark on the beginnings of algebraic geometry.

The immediate predecessors to al-Khayyām, such as ► [al-Bīrūnī](#), ► [al-Māhānī](#), and Abū al-Jūd, had already been able, in contrast to the Alexandrian mathematicians and precisely because of the concept of the polynomial, to treat the problems of solids in terms of third degree equations. But al-Khayyām was the first to address these unpondered questions: can one reduce the problems of straight lines, planes, and solids to equations of a corresponding degree, on the one hand, and on the other, reorder the group of third degree equations to seek, in the absence of a solution by factoring, solutions which can be reached through means of the intersection of auxiliary curves? To answer these questions, al-Khayyām is led to formulate the geometric theory of equations of a third or lesser degree. His successor, al-ṭūsī, did not delay in changing perspective; far from adhering to geometric figures, he thought in terms of functional relations and studied curves by means of equations. Even if al-ṭūsī still solved equations by means of auxiliary curves, in each case the intersection of the curves is demonstrated algebraically by means of their equations. This is important, since the systematic use of these proofs introduces into the practice instruments which were already available to the mathematical analysts of the tenth century: affine transformations, the study of the maxima of algebraic expressions, and with the aid of what will later be regarded as derivatives, the study of the upper bounds and lower bounds

of roots. It is in the course of these studies and in applying these methods that al-ṭūsī grasps the importance of the discriminant of the cubic equation and gives the so-called Cardan formula just as it is found in the *Ars Magna*. Finally, without enlarging any further on the results which were obtained, we can say that both on the level of results as well as that of style, we find al-Khayyām and al-ṭūsī fully in the field allegedly pioneered by Descartes.

If we exclude these traditions and justify this exclusion by invoking the practical and computational aims of the Arab mathematicians and an absence of rigorous standards of proof in their work, we can say that the history of classical algebra is the work of the Renaissance.

Among the mathematical disciplines, algebra is not a unique case. To varying degrees, trigonometry, geometry, and infinitesimal determinations are likewise illustrative of the preceding analysis. In a more general sense, optics, statistics, mathematical geography, and astronomy are also no exception. Recent works in the history of astronomy render Tannery's understanding of the Arab astronomers and the interpretations which he gives of them manifestly outmoded, if not erroneous. But since we assigned ourselves the task of examining the doctrine of the Western nature of classical science, we shall restrict our discussion to an essential component of this doctrine, experimentation.

Experimentation

In fact, is not the cleavage between the two periods of Western science, the Greek period and the Renaissance, often marked by the introduction of experimental norms? Undoubtedly the general agreement of the philosophers, historians, and sociologists of science stops here; the divergences become apparent as soon as they attempt to define the meaning, the implications, and the origins of these experimental norms. The origins are linked in one case to the current of Augustinian-Platonism, in another to the Christian tradition, and particularly to the dogma of

Incarnation, in a third case to the engineers of the Renaissance, in a fourth to the *Novum Organum* of Francis Bacon, and finally, in a fifth, to Gilbert, Harvey, Kepler, and Galileo. Some of these attitudes superimpose upon one another, become entangled or contradictory, but they all converge on one point: the occidental nature of the new norms.

Nevertheless, as early as the nineteenth century, historians and philosophers such as Alexander von Humboldt in Germany and Cournot in France diverge from this predominating position to attribute to the Arab period the origins of experimentation. It is difficult to analyze the origins or the beginnings of experimentation correctly, since no study has been made of the interrelations of the different traditions and the different themes to which the concept of experimentation has been applied. Perhaps it would be in writing such a history, especially a history of the term itself, that one could give an accounting of the multiplicity of uses and ambiguities of the concept. For this analysis two histories are needed: the history of the relationship between art and science and that of the links between mathematics and physics.

With the history of the relationship between science and art, we are in a position to understand when, why, and how it became accepted that knowledge can emanate from demonstrations and from the rules of practice at the same time, and that a body of knowledge possesses the stature of a science while, at the same time, it is conceived in its possibilities of practical realization with an external purpose. The traditional opposition between science and art seems likely to be the work of the intellectual currents of the Arabic period. Certainly one fact is striking: whether we are dealing with Muslim traditionalists, rationalist theologians, scholars of different fields, or even philosophers of the Hellenistic tradition such as ► [al-Kindī](#) or al-Fārābī, all contribute to the weakening of the traditional differentiation between science and art. In other respects, this general trait is at the origin of the opinion of some historians regarding the practical spirit and realistic imagination of the Arab scholars. Knowledge is accepted as scientific

without its conforming either to the Aristotelian or to the Euclidean scheme. This new concept of the stature of science promoted the dignity of scientific understanding of disciplines which traditionally were confined to the domain of art, such as alchemy, medicine, pharmacology, music, or lexicography. Whatever might be the importance of this concept, it could only lead to an extension of empirical research and to a diffuse notion of experimentation. One does witness the multiplication and systematic use of empirical procedures: the classifications of the botanists and the linguists, the control experiments of the doctors and alchemists, and the clinical observations and comparative diagnostics of the physicians. But it was not until new links were established between mathematics and physics that such a diffuse notion of experimentation acquired the dimension that determines it, a regular and systematic component of the proof. Primarily it is in Ibn al-Haytham's work in the field of optics where the emergence of this new dimension can be perceived.

With Ibn al-Haytham the break is established with optics as the geometry of vision or light. Experimentation had indeed become a category of the proof. The successors of Ibn al-Haytham, such as al-Fārisī, adopted experimental norms in their optical research, such as that performed on the rainbow. What did Ibn al-Haytham understand by experimentation? We will find in his work as many meanings of this word and as many functions served by experimentation as there are links between mathematics and physics. A thorough look at his texts indicates that the term and its derivatives belong to several superimposed systems, and are not likely to be discerned through simple philological analysis. But if attention is fixed on the content rather than the lexical form, one can distinguish several types of relationships between mathematics and physics which allow one to spot the corresponding functions of the idea of experimentation. In fact, the links between mathematics and physics are established in several ways; even if they are not specifically treated by Ibn al-Haytham, they underlie his work and are amenable to analysis.

As for the field of geometric optics, which was reformed by Ibn al-Haytham himself, the only link between mathematics and physics is a similarity of structures. Owing to his definition of a light ray, Ibn al-Haytham was able to formulate his theory on the phenomena of propagation, including the important phenomenon of diffusion, so that they relate perfectly to geometry. Then several experiments were devised to assure technical verification of the propositions. Experiments were designed to prove the laws and rules of geometrical optics. The work of Ibn al-Haytham attests to two important facts which are often insufficiently stressed: first of all, some of his experiments were not simply designed to verify qualitative assertions, but also to obtain quantitative results; in the second place, the apparatus devised by Ibn al-Haytham, which was quite varied and complex, is not limited to that of the astronomers.

In physical optics one encounters another type of relationship between mathematics and physics and therefore a second meaning of experimentation. Without opting for an atomistic theory, Ibn al-Haytham states that light, or as he writes, "the smallest of the lights", is a material thing, external to vision, which moves in time, changes its velocity according to its medium, follows the easiest path, and diminishes in its intensity depending on its distance from its source. Mathematics is introduced into physical optics at this stage by means of analogies established between the systems of movement of a heavy body and those of the reflection and refraction of light. This previous mathematical treatment of the concepts of physics permitted them to be transferred to an experimental plane. Although this situation on the experimental level might be somewhat approximate in nature, it nevertheless furnishes a level of existence to ideas which are syntactically structured, but semantically indeterminate, such as Ibn al-Haytham's scheme of the movements of a projectile.

A third type of experimentation, which was not practiced by Ibn al-Haytham himself but was made possible by his own reform and his discoveries in optics, appears at the beginning of the fourteenth century in the work of his successor

al-Fārisī. The links established between mathematics and physics aim to construct a model and to reduce by geometric means the propagation of light in a natural object to its propagation in an artificial object. The problem is to define for propagation, between the natural and the artificial object, some analogical correspondences which were genuinely certain of mathematical status. For example, they built a model of a massive glass sphere filled with water to explain the rainbow. In this case, experimentation serves the function of simulating the physical conditions of a phenomenon that can be studied neither directly nor completely. The three types of experimentation studied all reveal themselves both as a means of verification and as furnishing a plane of material existence to ideas which are syntactically structured. In the three cases, the scientist must realize an object physically in order to handle it conceptually. Thus, in the most elementary example of rectilinear propagation, Ibn al-Haytham does not consider any arbitrarily chosen opening of a black box, but rather specific ones, in accordance with specific geometric relationships, in order to realize as precisely as possible his concept of a ray.

To recapitulate several points:

1. The tenet of the Western nature of classical science which was launched in the eighteenth-century owes to the Orientalism of the nineteenth century the image that we now recognize.
2. On the one hand, the opposition between East and the West underlies the critique of science and rationalism in general; on the other, it excludes the scientific production of the East from the history of science both *de facto* and *de jure*. An absence of rigor is invoked, as well as the computational attributes and the practical aims of science written in Arabic, to justify this effective debarment from the history of science.
3. This tenet reveals a disdain for the data of history as well as a creative capacity for ideological interpretation, which are admitted as

evidence for ideas that raise many more problems than they solve. Thus we have the notion of a Scientific Renaissance, when in several disciplines everything indicates that there was merely a reactivation. These pieces of pseudoevidence quickly become conceptual bases for a philosophy or sociology of science, as well as the departure point for theoretical elaborations in the history of science.

We must ask ourselves if the moment has not arrived to abandon this characterization of classical science and its still lively traces in the writing of history, to restore to the profession of the historian of science the objectivity required of it, to ban the clandestine importation and diffusion of uncontrolled ideologies, to refrain from all reductionist tendencies which favor similarities at the expense of differences, and to be wary of miraculous events in history. The neutrality of the historian is not an *a priori* ethical value; it can only be the product of patient work which will not be duped by the myths which the ► [East and West](#) have engendered. Above all, it is necessary to cast out the periodization everywhere admitted in the history of science. The term used for classical algebra or classical optics, for example, will integrate the works which extended from the tenth to the seventeenth centuries. Consequently, it will realign not only the idea of the classical sciences, but also that of medieval science. The classical sciences will then reveal themselves as the product of the Mediterranean which was the hub of exchanges among all civilizations of the ancient world. Only then will the historian of science be able to enlighten the debate over modernism and tradition.

Science as a Western Phenomenon: Postscript

The 26 years since the publication of the original French edition of the text above has been a very fertile period for the study of the history of Islamic science. Indeed, we have witnessed an

unprecedented rebirth of this discipline. Texts have been written and translated, new collections have appeared, and specialized reviews and journals have been published. These have offered historians the possibility of developing and comparing their research findings with facts. The task remains huge, and we are only at the beginning, but at least this new growth of information puts to rest the argument of ignorance.

With all this new information, one would have expected historians and philosophers to rectify the impressions and ideas they had inherited from the nineteenth century. One would have thought that the doctrine of Western science which we have described and analyzed here would have disappeared along with the props on which that doctrine was based. Indeed we were beginning to see a growing tendency to break with this doctrine and its implications. Then, for reasons which are extraneous to science and its history, images of Islamic society – if not of Islam itself – arose, according to which it was seen as irrational and intolerant and thus a society foreign to science. The aging doctrine was naturally given new life because of these images. How is it possible, under these conditions, to reconcile such an image of Islamic society with scientific results obtained from the heart of that same society? It was enough to back up the preceding doctrine with another, the doctrine of double marginality: with regard to the society which saw the development of science, and with regard to the history of the sciences. Thus, one could still write in 1992, “We must remember that at an advanced level the foreign sciences had never found a stable institutional home in Islam,” or “Greek learning never found a secure institutional home in Islam, as it was eventually to do in the universities of medieval Christendom” (Lindberg, 1992). As for the second marginality, we have already described how it works. Thus, we are back where we started and the doctrine of the Westernness of science is saved. Undoubtedly, these ideological views are beginning to give way, weakened by new research findings. And even if they are still capable of

slowing down the acceptance of facts, it is not widespread, and it certainly will not last much longer.

See Also

- [Ibn al-Haytham \(Alhazen\)](#)
- [Umar al-Khayyām](#)
- [Western Dominance](#)

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Science East and West

Dhruv Raina

The social shaping of representations of nonwestern astronomy and mathematics in eighteenth- and nineteenth-century European scholarship has been of recent scholarly interest from the perspective of the politics of knowledge (Charette, 1995; Raina, 1999). My own concern has been to focus upon Indian astronomy and mathematics in the French Enlightenment and post-Enlightenment historiography. In dialogue with Said's *Orientalism*, this exploration has sought to examine whether the history of mathematics (the least likely case) is also inscribed within the frame of European colonial adventure and enterprise, as happened in the arts, literature, and social sciences (Assayag, Lardinois, & Vidal, 1997). In the study of the French Enlightenment I had qualified the Saidian thesis by suggesting that the so-called "European tradition" was fractured along national lines (Raina, 1999). The present project is to focus upon British Indology (Indology refers to the study of India. It is the study of cultural aspects such as religions, philosophies, art, and architecture, as well as spiritual and social aspects.) and its relationship with the corpus of French scholarship that preceded it. More specifically, the article attempts to ascertain when the first texts of Indian astronomy were translated into a European language, and by whom, and it elaborates upon how the Indian tradition of mathematics came to be constructed as one that was devoid of the idea of proof. While this characterization acquired stability in the nineteenth century, the construction itself was prefigured in the eighteenth century. In other words, it is suggested that historians of science mobilized the ideas of proofs or demonstrations as a criterion for demarcating different mathematical traditions.

Edward Said's thesis links the production of knowledge about the Orient with the exercise of colonial power (Said, 1978). Does this thesis

envelope the landscape of European writing on India? The thesis needs qualification from a number of points of view, for the landscape in Said's view is envisioned as monolithic and homogeneous. The eighteenth century has been considered the formative period for the emergence of the discourse on colonialism, but this discourse was not yet "monolithic or univocal." European writing on India comprised a network of "intersecting and contending discourses," and was preoccupied with a wide range of questions on authority (Teltscher, 1995, p. 2). The representations of India in this writing are naturally very "diverse, shifting, historically contingent, complex, and competitive." The texts themselves are shaped often by "national and religious rivalries, domestic concerns," and the cognitive or intellectual cultures of the respective interlocutors (Jami, 1995; Raina, 1999; Teltscher, 1995, p. 2). Critical studies on oriental scholarship have sought to situate these texts in national and religious contexts and to identify the elements they share (Inden, 1990; Županov, 1993). It has been argued that until the eighteenth century it was possible to speak of a European tradition of writing about India that differentiated into several national traditions by the middle of the eighteenth century. The birth of a specifically British tradition is put around 1765 when the East India Company was granted rights to collect land revenues and administer civil justice in Bengal (Teltscher, 1995, p. 3). With the founding of the Asiatic Society British writing on India especially from the 1780s onward was marked by the impulse of British writers to "foreground the textual nature of their activity" (Teltscher, p. 6).

European writing on India following the discovery of the sea route has been categorized into three distinct genres. The first comprises writing relating to travel, trade and the exploits of European powers on Indian soil. This writing was limited to the activities of Europeans in India; wherein an exotic India was presented to the West, and which either projected European superiority or criticized European institutions. But there was little elaboration of the philosophical or religious literature of India or its history (Kejariwal, 1988, p. 14). The missionaries in

India in the seventeenth and eighteenth century provided a second set of accounts. This writing itself is internally differentiated. On the one hand, we have letters recording the progress of missionary activity in India. On the other, Jesuit missionaries resident in India were studying Indian philosophy, religion, and culture. It may even be suggested that they were the first Europeans to be acquainted with Indian languages (Kejariwal, p. 15). And finally, there is the scholarly writing on India. The French missionaries who came to India in the late seventeenth century were the first to have spoken of India's scientific past. French Indology, according to Filliozat, emerged in the early decades of the eighteenth century, when the King's librarian requested Étienne Fourmont, of the Collège Royale, to draw up a list of works of note from India and Indo-China, to be purchased for the King's library. By 1739, a catalogue of Sanskrit works had been prepared, and copies of Vedas, epics, philosophical and linguistic texts, and dictionaries had been procured (Filliozat, 1955, pp. 1–3). Curiously enough there were very few, if any, scientific texts that were included in the cargo to the King's library (Raina, 1999). The first generation of Indianistes was possibly preoccupied with studying the speculations of the Indians, their philosophy, and the “niveau de connaissances scientifiques” (Filliozat, 1954). The Jesuit astronomers were the first to study the Indian astronomical systems that Filliozat considers “the first scientific or even cultural achievements of India studied by Europeans” (Filliozat, 1957). Kejariwal goes so far to suggest that the “history of French Orientalism is also the history of the rediscovery of ancient Indian astronomy in the modern period” (Kejariwal, 1988, p. 17). The latter point needs some nuancing.

In any case, these accounts were constantly contrasting India with Europe, “through explicit analogy or through implied difference.” A fruitful approach into this archive of scientific texts and not just literary or religious texts is to pay attention to moments “which unsettle the confident moments of cultural description,” to trace those “competing and fluctuating logics of similarity and difference,” that characterize the

early discourse of India (Teltscher, 1995, p. 14). In examining these mathematical texts, it is essential to be alert to those moments and descriptions of mathematical results and procedures encountered within Sanskrit texts that were not accompanied by demonstrations or proof or exegesis. Thus the British mathematician and geologist John Playfair in introducing Indian astronomy to an English-speaking audience wrote:

The astronomy of India is confined to one branch of the science. It gives no theory, nor even any description of the celestial phenomena, but satisfies itself with the calculation of certain changes in the heavens... The Brahmin... obtains his result with wonderful certainty and expedition; but having little knowledge of the principles on which his rules are founded, and no anxiety to be better informed, he is perfectly satisfied, if, as it usually happens, the commencement and duration of the eclipse answer, within a few minutes, to his prediction. (Playfair, 1790)

There are three core ideas that are evident in this passage, and that run constantly throughout the construction of Indian astronomy and mathematics. Inasmuch as Indian astronomy is a science it differs from modern astronomy in that it (a) lacks a theoretical basis, (b) does not provide a description of celestial phenomena, and (c) is not methodologically reflective (“little knowledge of the principles on which his rules are founded”). On account of the predictive accuracy of the astronomy it merits being a science, and the Indian astronomers are concerned no more with it than in this instrumental context.

The Origins of British Indology and the History of Indian Mathematics

British studies on Indian astronomy and mathematics may be said to lie at the juncture of two different historiographies: the French historiography of Indian astronomy and British studies on Indian society and culture. Consequently, British historiography of the sciences of India draws upon these sources and develops not unexpectedly in different directions. Without stretching a point too far it could be added that British

Indology on the sciences of India commences with the pioneering work of John Zephaniah Holwell (1711–1798). Holwell came to India as a surgeon's mate in 1732 and was Governor of Bengal for a couple of months in 1760. To historians of science he is best known for his *An Account of the Manner of Inoculating for the Smallpox in the East Indies* (1767). The relevant issue here is not Holwell's article, but the different point of view he adopted for studying the traditions, cultures, and sciences of India. This strayed from the central precepts of Jesuit historiography (Murr, 1986). While insisting as the Jesuits did on the antiquity of the Indian people and their literature, he proposed that this antiquity was not reconcilable with the "Christian view of History" (Holwell, quoted in Kejariwal, 1988, p. 19). Misidentifying his account from earlier European scholarship that he considered "defective, fallacious, and unsatisfactory," Holwell proposed instead a philological approach to the "sublime rational source and foundation" of what to the Western eye appeared preposterous superstition founded on irrationality (Kejariwal, p. 19). It is not germane here to establish whether Holwell could be considered the inaugurator of this approach; but this view was shared by a number of British scholars who founded the Asiatic Society.

One of the earliest British Indologists to speak of the distinctive tradition of Indian algebra was Rueben Burrow. The prior French tradition of the history of science had been preoccupied with the origins of Indian astronomy. Burrow centered the question about the origins of Indian algebra and arithmetic. This will become evident further ahead. That Burrow shared the same viewpoint as Holwell is evident in his "Hints concerning the Observatory at Benaras" (1783):

Notwithstanding the prejudices of the Europeans of the last century in favour of their own abilities, some of the first members of the royal society were sufficiently enlightened to consider the East Indies and China & c, as new worlds of science that remained undiscovered. . . had they not too hastily concluded that to be lost, which nothing but the prejudice of ignorance and obstinacy, had prevented being found, we might at this time (be) in possession of the most finished productions

of Asia as well as Europe; the sciences might, in consequence, have been carried to a much higher degree of perfection with us than they are at present; and the elegance and superiority of the Asiatic models might have prevented the neglect and depravity of geometry, and that inundation of Algebraic barbarism which has ever since the time of Descartes, both vitiated taste, and overrun the publications, of most of the philosophical societies in Europe. (Burrow, 1783, pp. 94–95)

It is evident from the above that beyond the aesthetic of the search for the marvelous, the encounter with other non-European scientific traditions was encouraged by the ideological impulse to advance the frontiers of knowledge. In that sense Burrow's philosophy of science resonated with that of the Enlightenment thinkers. As far as the history of astronomy is concerned, this project was quite consistent with historical astronomy being pursued in China and India since the late seventeenth century (Han, 1995; Raina, 1999). The most striking feature of the above passage is that the Indian tradition for Burrow is not characterized as algebraic or geometric. In fact, at this point the characterization is the very reverse of the late nineteenth-century one. Modern European mathematics since Descartes had been overwhelmed by "algebraic barbarism." An exposure to Asiatic models would then have prevented the neglect of geometry that marked contemporary sciences. The relevant concern here is that "until the end of the eighteenth century the British Indologists still entertained the hope that they would discover Indian geometrical texts that would unveil to them the foundations of an Indian geometrical tradition." Thus Playfair would in 1792 pose six questions to the researchers of the Asiatic Society, the first of which was: "Are any books to be found among the Hindus, which treat professedly of Geometry?" (Playfair, 1792, p. 151). For one it could be said that the question that the geometry of the Hindus could have a different basis from the Greek ones is implied by the "professedly" in the question. That this is what Playfair meant might be inferred from his elaboration upon the question he posed:

I am led to propose this question, by having observed, not only that the whole of the Indian

Astronomy is a system constructed with great geometrical skill, but that the trigonometrical rules given in the translation from the *Surya Siddhānta*, with which Mr. Davis has obliged the world, point out some very curious theorems, which must have been known to the author of that ancient book. (Playfair, 1792, p. 151)

The rule according to which the “trigonometrical canon” of Indian astronomy is constructed according to Playfair, is based on a theorem:

If there be three arches of a circle in arithmetical progression, the sum of the sines of the two extreme arches is to twice the sine of the middle arch as the cosine of common difference of the arches to the radius of the circle. (Playfair, 1799, p. 152)

Although the theorem was not known to Europe before Viète, the method was employed by the Indian astronomers for constructing trigonometrical tables, and was based on a simpler procedure of calculating sines and arches than through the use of methods that were based on extracting square roots (Playfair, 1798, p. 152). The immediate task for Playfair appears to have been to identify those mathematical works where the theorem on which the trigonometrical rule employed in astronomy is first laid out. This brings us back to Burrow’s concern with the origins of Indian mathematics.

Where Are the Geometrical Texts, or Is the Tradition Algebraic?

In the eighteenth century it would be possible to differentiate between the efforts of the British Indologists and that of their French counterparts studying Indian astronomy and mathematics on two counts. Methodologically speaking, while the British Indologists were busy underlining the textual nature of their enterprise, the French astronomers-savants relied a great deal on protoethnographic descriptions of the mathematical and astronomical practices of India. Second, the histories of Indian astronomy of Bailly (1787) and Le Gentil (1781) are preoccupied with astronomical literature and the origins of Indian astronomy.

Even Montucla (1799) relies extensively upon the sources employed by Le Gentil and Bailly and draws inferences concerning Indian mathematics from them. The British Indological tradition on the other hand, engages with specific texts and from the astronomical rules presented there makes a claim that these rules must be based on a mathematical system. They subsequently proceeded to discover mathematical texts. Their focus thus shifts from the origins of astronomy to the origins of Indian mathematics, in particular Indian algebra and arithmetic.

What were the rules encountered and what were the claims made?

Rueben Burrow, a British official in Bengal, was probably amongst the earliest of the British Indologists to engage with the textual tradition of Indian mathematics, although this search was prompted through his exposure to and study of astronomy, including Indian astronomy. This does not mean that these texts did not relate in any way to the histories of Le Gentil and Bailly. Actually, the texts of the former provided an initial viewpoint to interpret the differences between the two traditions. Burrow, like Bailly, entertained a wild hypothesis concerning the origins of the sciences, but this never seemed to have been noticed as much as Bailly’s antediluvian hypothesis. Consequently, for Burrow the study of the procedures employed by Indian astronomers in calculating eclipses would advance the progress of modern astronomy as well: “...and the more so as our methods of calculation are excessively tedious and intricate” (Burrow, 1783, p. 101). The sentiment echoes that of Le Gentil and Bailly, and it is certain that he was acquainted with the work of Le Gentil (Burrow, p. 116), although it is not possible to say the same of Bailly’s *Traité*. This fascination with the computational procedures employed in astronomy led Burrow to infer in 1783 the existence of an advanced algebraic tradition:

It is also generally reported that the Brahmins calculate their eclipses, not by astronomical tables as we do, but by rules. . . If they (the rules) be as exact as ours, . . . it is a proof that they must have carried algebraic computation to a very extraordinary pitch, and have well understood the doctrine of

“continued fractions”, in order to have found those periodical approximations.... (Burrow, 1783, p. 101)

The rules for computing eclipses employed by the Brahmins were not only different, but their complexity varied with the requisite degree of exactness:

...which entirely agrees with the approximation deduced from algebraic formulae and implies an intimate acquaintance with the Newtonian doctrine of series... and therefore it is not impossible for the Brahmins to have understood Algebra better than we do. (Burrow, 1783, p. 101)

This was to become the central point from which in subsequent papers Burrow would build his argument for the existence of an advanced algebra among the Indians. One of the first histories of Indian algebra was authored by Burrow and was entitled “On Early History of Algebra” (Burrow, 1810), and was possibly published posthumously. The paper emphasized the originality and importance of algebra among the Hindus and contained extracts that were translated from the *Bījagaṇita* and ► *Līlāvati*. These extracts were translations into English from Persian translations of the original Sanskrit texts. If we were to go by his own admission in an earlier paper (Burrow, 1790), these extracts were translated in 1784, but he deferred publishing them until a full text was obtained. But he prizes the moment “when no European but myself... even suspected that the Hindoos had any algebra” (Burrow, p. 115). The rationale provided for the existence of treatises on algebra in India in this paper is based on the knowledge of the binomial theorem among the Indians and is the same as that suggested in the earlier paper. Many of the approximations used in astronomy were “deduced from infinite series; or at least have the appearance of it” (Burrow, p. 115). These included finding the sine from the arc and determining the angles of a right-angled triangle given the hypotenuse and sides without recourse to a table of sines, etc.

The urgency of the moment was then to discover those texts before they perished. Burrow

thus emphasized the need for the collection of available astronomical and mathematical texts that until then had not been the focus of attention of the French Académiciens. The idea that the existing tradition was probably algebraic was being insinuated:

That many of their books are depraved and lost is evident, because there is now not a single book of geometrical elements to be met with; and yet that they had elements not long ago, and apparently more extensive than those of Euclid is obvious from some of their works of no great antiquity. (Burrow, 1790, p. 115)

And while Burrow promised to publish translations of *Līlāvati* and the *Bījagaṇita*, the promise was not fulfilled possibly during his life. Inspired by Burrow’s research, Colebrooke embarked on a study of Sanskrit in order to probe some of the issues raised more deeply.

But the just-mentioned paper by Burrow contains a very brief demonstration of the knowledge of the binomial theorem in the Indian tradition, which unlike Newton’s understanding was limited to whole numbers alone. Burrow first offers a translation from Persian of the problem:

A Raja’s palace had eight doors, now these doors may either be opened by one at a time, or by two at a time, and by three at a time; and so on through the whole, until at last all are opened together: it is required to tell the number of times that this can be done. (Burrow, 1790, p. 118)

Setting out the procedure for resolving it follows the statement of the problem. Write down the number of doors by decreasing from eight to unity. Just under these numbers write down the numbers in the reverse order.

- *Step 1.* The number of times the door can be opened one at a time is obtained by dividing the first number 8, by the number under it, the quotient being 8.
- *Step 2.* To obtain the number of times that two different doors may be opened, multiply the quotient 8 by the next number 7, and divide the product by 2 beneath it, the result being 28.

- *Step 3.* To obtain the number of times three different doors may be opened, multiply 28 by the next number 6, and divide the product by 3, and the quotient is 56.

8	7	6	5	4	3	2	1
1	2	3	4	5	6	7	8

And so on.

“The sum of all the different times is 255” (Burrow, 1790, p. 119). This setting out of the procedure, Burrow calls a “demonstration” and insists that it should be “evident” to mathematicians when inspecting the coefficients of a general equation. So to Burrow goes the credit for providing the first glimpses into the Indian algebraic tradition.

It was left to Samuel Davis to publish the first full-fledged translation and analysis of an Indian scientific work from the Sanskrit into a European language. This was a translation of the *Sūryasiddhānta* (Davis, 1789). This translation was based on the reading of an original version of the text procured by Sir Robert Chambers in 1788. Davis encountered a number of obscure technical terms and had to rely upon a *teeka* or commentary procured by Jonathan Duncan (Davis). In fact, if you examine the structure of Davis’ paper, it appears as a *teeka* on the *Sūryasiddhānta*, with passages translated from the text and Davis’ explanation intercalated between the translated passages. Most British Indologists who worked on Indian astronomy toward the last decades of the eighteenth century were familiar with two canonical European accounts, that of Bailly and Le Gentil.

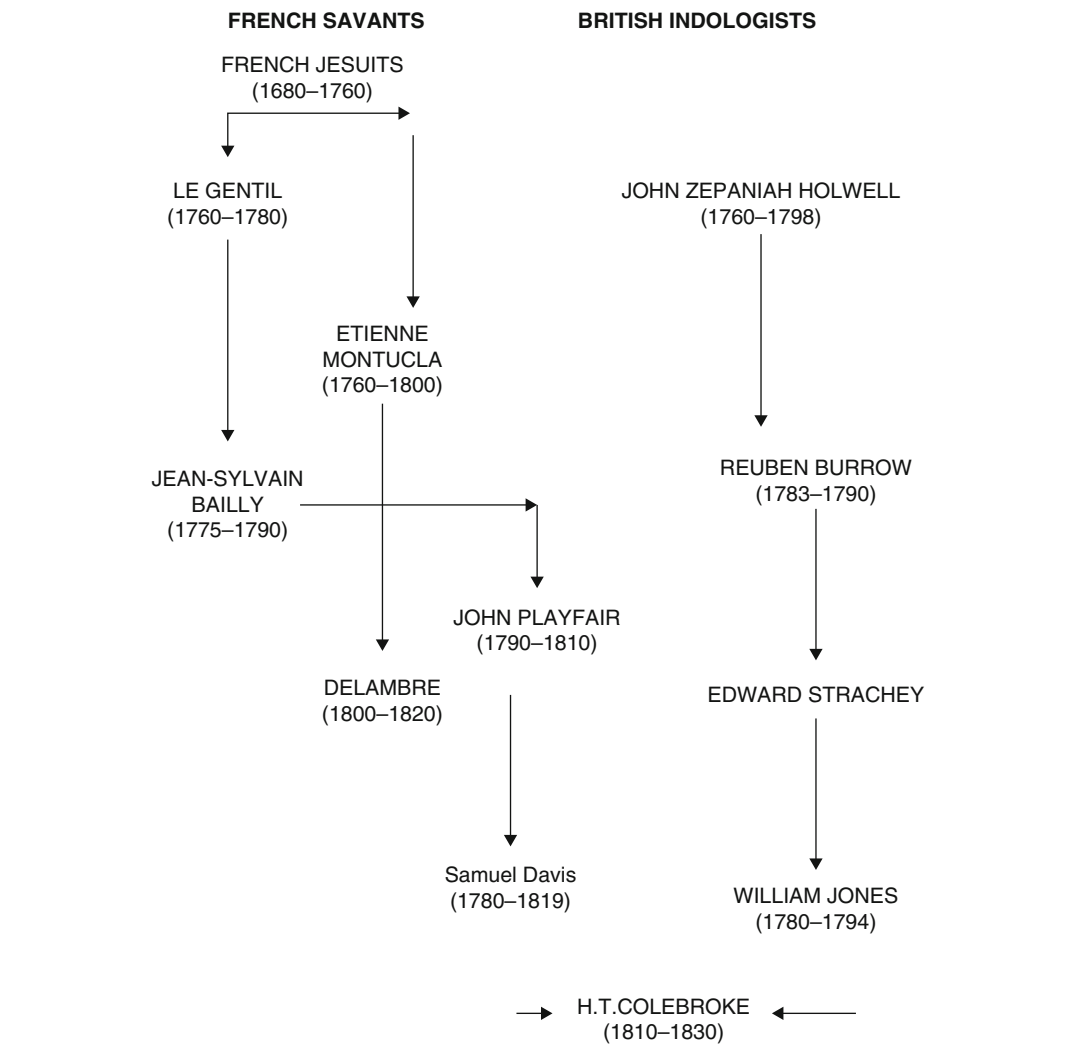
Without referring to either, Davis begins by contesting the portrait of Indian astronomy and astronomers projected by Le Gentil and Bailly. (More than Bailly and Le Gentil, Davis was refuting Sonnerat’s constructions of Indian astronomy: “my present intention, which is to give a general account only of the method by which the Hindus compute eclipses, and thereby to show, that a late French author was too hasty in asserting generally that they determine by set

forms, couched in enigmatical verses & C.’ So far are they from deserving the reproach of ignorance, which Mons. Sonnerat has implied, that on inquiry, I believe the Hindu science of astronomy will be found as well known now as it ever was among them, although perhaps, not so generally, by reason of the little encouragement men of science at present meet with. . .” (Davis, 1789, p. 177). Evidently, Sonnerat, unlike Davis, could not enter the world of the Hindu astronomers on account of his inability to abandon a hermeneutic of suspicion.) without naming either of them. The first idea that he rejected was that this astronomical tradition was disfigured over the years by idolatry and that the gems of Indian astronomy had been irretrievably lost over the centuries, in the absence of a textual tradition. The second idea was that the Brahmins had shrouded their astronomy in mystery such that it was impossible to arrive at a cogent account of it. Further, they loathed sharing their ideas with others. Davis set out to show that:

... numerous treatises in Sanskrit on astronomy are procurable, and that the Brahmins are willing to explain them. . . I can further venture to declare that, from the experience I have had, that Sanskrit books in the science are more easily translated than almost any others, when once the technical terms are understood: the subject of them *admitting neither of metaphysical reasoning nor of metaphor*, but being delivered in plain terms *and generally illustrated with examples in practice*. (Davis, 1790, p. 175) (emphasis added)

The British Indologists were departing from the reading of Académiciens grounded in Jesuit protoethnography, by textually locating their work. This textual grounding would revise the portrait of the French savants (Table 1). A hundred years later in a review of the history of the history of Indian astronomy Burgess was to write: “Mr. Davis’ paper, however, was the first analysis of an original Hindu astronomical treatise, and was a model of what such an essay ought to be” (Burgess, 1893, pp. 730–731). It appears then, as has been argued elsewhere, that the French savants in India were unable to establish trust

Science East and West, Table 1 French savants and British Indologists



with their Indian interlocutors, in total contrast to the first generation of British Indologists such as William Jones (Raj, 2001). Two papers of William Jones followed closely on the heels of Davis' papers and a cursory glance at them reveals that they mutually respected and supported each other's enterprise. And yet they both were in agreement with Bailly's thesis of the

independent origins of the Indian zodiac, differing very strongly with Montucla on this count:

I engage to support an opinion (which the learned and industrious M. Montucla seems to treat with extreme contempt) that the Indian division of the zodiac was not borrowed from the Greeks or Arabs, but having been known in this country from time immemorial and being the same in part with other nations of the old Hindu race. . . . (Jones, 1790)

But then they were also gradually transforming and refining the portrait Bailly had left behind. Thus Jones recognized that in Davis' translation resided the hope that it would "convince M. Bailly that it is very possible for an European to translate and explain the Surya Siddhānta" (Jones, 1790a).

John Playfair's Program and Colebrooke's Recovery of Indian Algebraic Texts

As far as the history of Indian astronomy and mathematics is concerned I have tried to argue that the French Jesuits of the seventeenth and eighteenth century are the inaugurators of a tradition, which was to inspire the histories of Le Gentil and Jean-Sylvain Bailly (Raina, 1999). As has been argued elsewhere, it was Bailly's history that inspired the work of the British mathematician John Playfair and provided a stimulus to subsequent generations of British Indologists writing on Indian mathematics; although they were to disagree with the details of Bailly's *Histoire*, adding some nuance here and digressing from it in another context (Raina, 2001). The antediluvian hypothesis proposed by Bailly was the source of both fascination and controversy, and was the outcome of his attempt to juxtapose observations of ancient Indian astronomy with astronomical theory of his day; from which he went on to draw the inference that ancient Indian astronomy was the source of Greek astronomy (Bailly, 1775). However, this reading was located within Jesuit historiography that sought to accommodate Indian history within the Christian conception of history (Raina, 2003).

Bailly's work was introduced to English-speaking readers through an article authored by the mathematician and geologist John Playfair (1748–1819), entitled "Remarks on the Astronomy of the Brahmins" published in the *Transactions of the Royal Society of Edinburgh* in 1789 (Playfair, 1790). The article draws extensively upon the *Mémoires* of Le Gentil (1785)

published by the Académie des Sciences, Paris and Bailly's *Astronomie Indienne* (Bailly, 1785). This article of Playfair's was of prime importance for Indologists working on the history of Indian astronomy for the next four decades, despite the fact that it was inspired by the work of such "unvulgariser."

Just in and around the time Bailly's *Traité* appeared, the important tradition of British Indology was beginning to crystallize. Marsden and Bentley were the first to contest Bailly's assumptions and calculations. This opened the floodgates of criticism in France. Playfair jumped into the controversy attacking Bailly's critics for their amateurism and for daring to question Bailly's superior abilities. One of the early papers of the legendary William Jones was dedicated to defending Bailly's thesis concerning the origins of the Hindu zodiac. Playfair's central contribution resided in reappropriating Bailly's *Traité* in the light of the contributions of Davis and Burrow and proposing a set of tasks that could well be considered a research program for the Asiatic Society. These included (a) to search for and publish works on Hindu geometry; (b) to procure any books on arithmetic and going by Burrow's article on the binomial theorem amongst the Indians to ascertain those arithmetical concerns whose trace is not to be found among the Greeks; (c) to complete the translation of the *Sūryasiddhānta* as initiated by Samuel Davis; (d) to compile a catalogue raisonné, with a scholarly account of books on Indian astronomy; (e) to examine the heavens with a Hindu astronomer in order to determine their stars and constellations; and (f) to obtain descriptions and drawings of astronomical buildings and instruments found in India (Playfair, 1792, pp. 152–155).

Bailly had stirred a hornet's nest in his time by suggesting that the origins of astronomy were in India, albeit this astronomy was inherited by the Indians from an even more ancient people. Burrow's paper did the same with the origins of algebra. It is at this time difficult to separate the discussion on the history of astronomy from the history of algebra; for both the Académiciens and

the Indologists often turn to the history of astronomy to evoke computational procedures that were analyzed mathematically. This program of the recovery of the mathematical literature from the astronomical literature was taken up by Colebrooke, who may be seen as providing translations from the Sanskrit into English of the first texts supposedly dedicated solely to algebra and arithmetic. I say supposedly because portions of some of the texts that Colebrooke's discovers for the English-speaking world were essentially the mathematical sections of larger astronomical canons of the Indian tradition.

A brief recapitulation is required before we proceed to the translations of Colebrooke, for his work certainly marks a departure in the study of the history of Indian mathematics. The objective of this study thus far has been to examine the textual legacy that leads up to the translations of Colebrooke. Stated briefly, two main historiographic currents in the eighteenth century oriented the study of the history of the mathematics and astronomy of India. The first approach was that pursued by the Jesuit savants in India, who were observing the astronomical and computational procedures circulating among Indian astronomers. Their audience did not merely comprise the devout back in France, but the Académiciens and astronomers, two of whom transcribed these protoethnographic accounts into a history of Indian astronomy. Administrator-scholars, who studied texts, collated fragments of texts, and published translations with critical editions and commentaries, while indebted to the first, pursued another approach. In the late eighteenth century, Sanskrit commentaries and canonized astronomical or mathematical works were considered the key to obscure technical terms and texts. What needs to be examined is whether by the late nineteenth century, commentaries shared the same destiny as some of the Vedic texts. For it has been pointed out that by the second half of the nineteenth century some Sanskritists belittled, marginalized, and removed "explicit references to the intermediary process of transmission and exegesis of texts without which they would not have had access to them" (Vidal, 1997, p. 25). The status of proofs in the

Indian tradition is related to how these commentaries on mathematical texts were read.

	Trope of forgetting	Trope of disfigurement	Historiography
Jesuit savants	The Brahmins had forgotten the original true Noahic religion from which they had descended and fallen into idolatry	The religion of the Brahmins had been disfigured over the centuries as they had tumbled into idolatry and superstition	Jesuit historiography of India
Astronomer savants of the French enlightenment	The Brahmins had forgotten the intelligence of the astronomical methods that had been their legacy from an ancient people	The Brahmins had disfigured the core of an ancient science that they had inherited from an ancient people	Enlightenment historiography of astronomy

Taken from Raina (2003)

The point needs some reaffirmation, since both Colebrooke and Davis who worked with commentaries of canonized astronomical and mathematical texts, respectively, do mention the existence of demonstrations and rules in the texts they discuss. In Colebrooke's introduction to his *Algebra with Arithmetic and Mensuration, from the Sanscrit of Brahme Gupta and Bhascara*, there are four terms of concern to us here, namely, demonstration, rule, proof, and analysis that come up often, but it is only the last of these that Colebrooke clarifies. Noted by its absence in the title is the term "geometry," as a systematized science; on the contrary, the translation does allude to mensuration as discussed in the books he translates. The crucial problematic for Colebrooke was, as with Burrow before him, to determine the origins of Indian algebra. Inspired, as it were, by the textual exemplars of Davis and Burrow, and guided by the research program John Playfair had drawn up for the researchers of the Asiatic Society, Colebrooke highlighted the pathway to his own work:

In the history of mathematical science, it has long been a question to whom the invention of algebraic analysis is due, among what people, in what region

was it devised, by whom was it cultivated and promoted, or by whose labours was it reduced *to form and system*. (Colebrooke, 1817, p. 121) (emphasis added)

The subsequent narrative focuses upon establishing that “the imperfect algebra of the Greeks,” that had through the efforts of Diophantus advanced no further than solving equations with one unknown, was transmitted to India. The Indian algebraists, through their ingenuity, advanced this “slender idea” to the state of a “well-arranged science” (Colebrooke, 1817, pp. 145–146). In his reading, Colebrooke shares a fundamental historiographic principle, disputed by current scholarship, with Burrow, one that enjoyed currency among historians of mathematics into the twentieth century. In this historiographic frame,

...the Arabs themselves scarcely pretend to the discovery of Algebra. *They were not in general inventors but scholars*, during the short period of their successful culture of the sciences. (Colebrooke, 1817, p. 121) (emphasis added)

The science of “algebraic analysis,” a term Colebrooke would later expand upon, existed in India before the Arabs transmitted it to modern Europe (Colebrooke, 1817, p. 121). The evidence for these claims resided in the translations of the *Bījagaṇita* and ► *Līlāvati* of Bhāskarācārya, (I have given here the contemporary English spellings of the names of Sanskrit books and scholars. Colebrooke himself spelled the *Bījagaṇita* as *Vija-Gaṇita* and Bhāskarācārya as Bhascara Acharya.) as well as Brahmagupta’s (Colebrooke: “Brahmegupta”) *Gaṇitadhyāya* and *Kuṭṭakadhyāya* (Colebrooke: “Cuttacadyaya”), the last two as their name suggests were the mathematical sections of Brahmagupta’s *Brāhmasphuṭasiddhānta*. Without focusing too much on the antiquity of these texts, Colebrooke saw his oeuvre as disclosing that the

...*modes of analysis*, and in particular, *general methods for the solution of indeterminate problems* both of the first and second degrees, are taught in the *Vija-Gaṇita*, and those for the first degree repeated in the *Līlāvati*, which were unknown to the mathematicians of the west until invented anew

in the last two centuries by algebraists of France and England. (Colebrooke, 1817, p. 124) (emphasis added)

The terrain of historical studies on Indian mathematics was being transformed into a polemical one, with Colebrooke surreptitiously introducing categories that the French Indologists had denied the Indian tradition: typically for the first time he speaks of “modes of analysis,” or the “general methods for the solution of indeterminate problems.” The historians of astronomy had previously advanced the idea that the Indians had no idea of the generalizability of the methods they employed. In the absence of such generalizability, how could it have been possible to extend the idea of generalized methods dedicated to solving classes of problems in order to extract the different “modes of analysis”? The intention here is not to paint Colebrooke’s construction as the diametrical opposite of that of the French historians of science that provided a context to his effort. On the contrary, Colebrooke’s project is naturally marked by a deep ambivalence. The ambivalence arises from the fact that he attempted to draw the characterization of Indian mathematics away from the binary typologies of the history of science that were already set in place. The lack of mathematical authority amongst the network of the British Indologists served as major handicap and deterred his ability to create a new vocabulary. This also explains why John Playfair was so important to the Indological enterprise. He was a mathematician of repute who conferred the Indological accounts with authority.

However, Colebrooke begins by pointing out that ► *Āryabhaṭa* was the first of the Indian authors known to have treated of algebra. Possibly a contemporary of Diophantus, the issue was important for drawing an arrow of transmission from Alexandria to India or vice versa. Colebrooke leaves the issue of the invention of algebra open by suggesting that it was Āryabhaṭa who developed it to the high level (The high level of attainment was ascribed to the ability of the Indian algebraists to solve equations involving several unknowns and of possessing a general

method of solving indeterminate equations of the first degree (Colebrooke, 1817, p. 130).) that it attained in India; this science he called an “analysis” (Colebrooke, p. 130). It is here for the first time that a portion of the Indian mathematical tradition is referred to as analysis, and it is important to get to the sense in which he employs the term. Thus it is noticed that the use of a notation and algorithms is crucial to this algebraic practice. Colebrooke then proceeds to elaborate upon the idea and takes note of the procedures not merely for denoting positive or negative quantities or the unknowns but of manipulating the symbols employed (Colebrooke, pp. 131–132). An important feature of this algebra is that all the terms of an equation do not have to be set up as positive quantities; there is no rule requiring that all the negative quantities be restored to the positive state. The procedure is to operate an equal subtraction “. . . (*samasodhana*) for the difference of like terms.” This operation is compared with the *muqabalah* employed by the Arab algebraists (Colebrooke, p. 135). The presence of this “analytic art” among the Indians was apparent from the canvas of their mathematics.

This included the arithmetic of surd roots, the cognizance that when a finite quantity was divided by zero the quotient was infinite, an acquaintance with the procedure for solving second-degree equations and “touching upon” higher orders, solving some of these equations by reducing them to the quadratic form, of possessing a general solution of indeterminate equations in the first degree. And finally, Colebrooke finds in the *Brāhmasphuṭasiddhānta* §18:29–49; and *Bījagaṇita*: §75–99; a method for obtaining a “multitude” of solutions to second-degree equations starting from a single solution that is plugged in. It was left to Lagrange to show that problems of this class would have solutions that are whole numbers (Colebrooke, 1817, pp. 135–136). The analytic art of the Indians or algebraic analysis is then for Colebrooke: “. . . calculation attended with the manifestation of its principles.” This is manifest in the Indian mathematical texts being discussed since they intimate to the reader a “method aided

by devices, among which symbols and literal signs are conspicuous” (Colebrooke, p. 141). In this sense Indian algebra bears an affinity with D’Alembert’s conception of analysis as the “method of resolving mathematical problems by reducing them to equations” (Colebrooke, p. 141). Delambre and Biot would subject these views of Colebrooke to trenchant criticism, but that is another subject (Raina, 1999). The issue at stake here is that Colebrooke had insinuated the idea that Indian mathematics was not lacking in methodological reflection or generality, a feature that had hitherto been denied.

Did this algebraic analysis provide for demonstrations or proofs of its rules or procedures? Citing specific sutras from the *Brāhmasphuṭasiddhānta*, the *Bījagaṇita* and the ► *Līlāvātī*, Colebrooke moves to a characterization of Indian algebra, just as Diophantus is evoked to characterize early Greek algebra. Thus, we are informed that these Indian algebraists applied algebraic methods both in astronomy and geometry, and in turn, geometric methods were applied to “the demonstration of algebraic rules.” Obviously, Colebrooke was construing the visual demonstrative procedures employed by Bhāskara as exemplifying geometrical demonstration. Further, he goes on to state that:

In short, they cultivated Algebra much more, and with greater success than geometry; as is evident in the comparatively low state of their knowledge in the one, and the high pitch of their attainments in the other. (Colebrooke, 1817, p. 136)

This passage came to be quoted so often in subsequent histories of science, and in the writings of mathematicians (The nineteenth-century British mathematician Augustus De Morgan, a self-proclaimed aficionado of Indian mathematics, wrote a preface to the book of an Indian mathematician punctuated with aperçus from Colebrooke’s introduction. The introduction in fact provides him the ground to legitimate the work of the Indian mathematician for a British readership (Raina & Habib, 1992).) as evidence of the algebraic nature of Indian mathematics. The power of its imagery resides in its ability to draw the boundary between different civilizational styles of mathematics. In this contrast

between Western and Indian mathematics it could be suggested that Colebrooke's qualification concerning the "comparatively low" state of one and "high pitch" of the other was lost sight of, and the contrast between the two traditions came to be subsequently accentuated.

This leads me to conjecture that Colebrooke's translation is a watershed in the occidental understanding of the history of Indian mathematics on a second count as well; this is that it inadvertently certified the boundary line drawn between Indian algebra and Greek geometry. This was not Colebrooke's intention at all, but a consequence of the comparative method he had adopted. Colebrooke's particular comparative method consisted in displaying where India's specific contributions to mathematics resided, and he always contrasted these contributions with the Greek and Arab traditions of mathematics (Going by his text alone, he appears to have been totally oblivious of Chinese mathematics.). This attempt to accentuate the contrast certainly revealed the differences, but with the loss of the context of the contrast, it was first transformed into a caricature and then stabilized as a characterization. The boundary lines had however been marked out before Colebrooke's time (This passage reminds me of the simplistic manner in which Marx's "religion is the opium of the masses" is read out of context.).

Thus there are four specific areas in which "Hindu Algebra appears particularly distinguished from the Greek" (Colebrooke, 1817, p. 137). Some of these have been mentioned above. The additional one that has not been mentioned concerns the application of algebra to "astronomical investigation and geometrical demonstration." In the process the Indian algebraists, Colebrooke suggests developed portions of mathematics that were reinvented recently. This last statement of his prompted a very severe reaction. He then takes up three instances, which he considers "anticipations of modern discoveries" from the texts he discusses and lays out their procedures of demonstration. There is nothing in the subsequent portion of the introduction to

suggest that he did not consider these as demonstrations.

On reading of the early responses from a French savant to the work of Colebrooke, it is possible to discern that Delambre for one uses a very fine comb in rebutting several of the points taken up by Colebrooke. While Colebrooke himself does not draw a very fine distinction between the use of the term "proof" and "demonstration" in his reading, he does distinguish between algebra and analysis, and as mentioned earlier, he specifies wherein the Indian tradition could be characterized as an algebraic analysis. A study of the reception of Colebrooke's translations of the works on Indian arithmetic and algebra is a matter for a separate study. The curious question to be examined by such a study is that despite its canonical status in Western scholarship on the history of Indian mathematics and algebra, neither Colebrooke nor Davis ever insinuated that it was a tradition devoid of proof or demonstration. And yet, as the historiography of nineteenth-century Oriental mathematics evolved, a theory of the absence of proof would become one of its salient elements. One of the factors responsible for the strong criticism of Colebrooke's work at the time was that it might have been provoked by Colebrooke's method of taking up those demonstrations from Indian mathematics for which equivalents existed in eighteenth-century European mathematics. This would have vitiated both the claims of novelty and originality, both very important features of the new sciences. Second, until the end of the eighteenth century these Indologists still believed that they could discover the origins of an Indian geometry, and the later work of the French Indologist G. Thibaut may be seen to be in continuity with this tradition. But by the end of the nineteenth century the binary typologies of the history of mathematics, that portrayed the West as geometric and the East as algebraic, were well in place in the standard picture.

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Science in China

Ho Peng Yoke

Scholars in the past found it difficult to focus their attention on Chinese science because in traditional China knowledge did not come under the same groupings as in the West. For example the Chinese pharmacopoeias included knowledge on natural history; the official dynastic histories, some Daoist writings, and the works of some great poets contain information on astronomy and alchemy, and compendia on military science mention meteorology and firearms together with magic and divination. It is true that there are some Chinese monographs on science and technology, such as the *Tiangong kaiwu* (Exploitations of the Work of Nature) and the *Jiuzhang suanshu* (Mathematical Manual of the Nine Sections). Nevertheless knowledge of traditional Chinese science exists mainly in the official dynastic histories, the compendia (*leishu*), the gazetteers, religious works like the *Daozang* (Daoist Tripitaka), the numerous book collections (*congshu*), and the general literature.

In sixteenth-century Europe, Francis Bacon (1561–1626), Jean Fernal (1497–1558), and Jerome Cardano (1501–1576) all made reference to three great inventions, namely the compass, the art of printing, and ► [gunpowder](#). In the minds of many there was only some vague connection between China and these three inventions. Indeed, prior to the middle of the twentieth century the history of Chinese science received little attention both from inside and

outside China. It gained recognition in the middle of the twentieth century when Joseph Needham launched his monumental work, *Science and Civilisation in China*. Needham did not pioneer the study of the history of Chinese science. Sinologists and scientists before him had written on acoustics, alchemy, architecture, astronomy, gunpowder, hydraulics, mathematics, and medicine in traditional China. However, Needham demonstrated the originality of many Chinese discoveries and inventions, including the “three great inventions” of Renaissance Europe, and made Chinese science a new discipline of study. Modern scholarship and recent archaeological discoveries have increased our understanding of Chinese science and helped in the reappraisal of some old interpretations.

Excavations carried out first at Anyang between 1928 and 1937 and again after 1950, followed by those done at Zhengzhou in Henan province, substantiated the existence of the Shang dynasty (sixteenth–eleventh centuries BCE) and brought to light many bronze artifacts, foundry sites, and proto-porcelain wares. At the ruins in Anyang the remains of the capital of the last Shang kings were found. This later period of the Shang dynasty is known as Yin (fourteenth–eleventh centuries BCE). Besides bronze artifacts, archaeologists uncovered gold, jade, pottery, and shell objects, wooden artifacts with traces of lacquer, traces of silk fabric, and even a chariot. The most important find, however, was the oracle bones, which were carapaces of a species of tortoise or shoulder blades of buffaloes that bear inscriptions written by the people of Yin for divination purposes. They contain records of eclipses and novae, as well as names of stars and asterisms. They also show that the Yin people were already using a lunisolar calendar with 12 moons or lunar months in 1 year. Each month consisted of either 29 or 30 days each, and every 2 or 3 years there was one extra month, known as the intercalary month, added to the year. The numerals in the oracle bones were the earliest known Chinese numerals until the discovery of the inscriptions on the pottery at the ruins of Banpo, which dated back to about the year 3000 BCE. From the oracle bone numerals

we know that the Yin people were already using a decimal system. We also find that the Yin people already had some knowledge of irrigation, agriculture, sericulture, and wine-making. For example, for tooth decay they used a character that included the character for “worms,” suggesting that they had made an effort to attribute the problem to a cause. Chinese archaeologists have been quite active in recent years trying to re-establish the Xia dynasty. According to their tradition this dynasty existed for four centuries immediately before Shang, which itself lasted six centuries. Erlitou in Henan province, where bronze vessels dating back to the year 1700 BCE were recovered in 1971, is one of the more promising sites where they hope to discover epigraphical evidence to confirm the existence of that ancient dynasty.

Bronze vessels and pottery are some of the works of art characteristic of the Chinese. Shang bronzes show that the technique of bronze casting had already reached an advanced level. It was also in Shang China that the earliest proto-porcelain ware was discovered. It took the form of a wine container (*cun*), made of kaolin clay, with a yellowish green glaze on the surface about the mouth and a translucent deep green glaze on the inner and outer surfaces. The Western Zhou period (eleventh century – 771 BCE) produced beautiful bronze vessels with inscriptions and proto-porcelain wares, some of which can be seen in many museums today.

In the Spring-and-Autumn period (722–481 BCE) two early texts, which Confucius (551–479 BCE) himself referred to, namely the *Shujing* (Book of Documents) and the *Shijing* (Book of Odes), were written. Both contain astronomical material from about the tenth to the fifth century BCE. The earliest sighting of Halley’s comet in the year 613 BCE is recorded in the *Chunqiu* (Spring-and-Autumn Annals), which also contains references to solar and lunar eclipses, meteor streams, and other comets. The *Zhouli* (Records on the Rites of Zhou) informs us that the Zhou kings employed star clerks to observe astronomical and meteorological phenomena and to make astrological prognostications therefrom. The earliest star catalog is said to have been made by a court astronomer

Wu Xian, of whom little is known. Two other catalogs were produced by ► [Gan De](#) and Shi Shen between 370 BCE and 270 BCE. The three original catalogs have long been lost. Some fragments claimed to be from the originals are quoted in many old astronomical writings. In the early fourth century Chen Zhuo (fl. ca. 310) constructed a star map supposedly based on such information.

Two weapons with iron plates taken from meteorite sources and dating back to the Western Zhou period were discovered in 1949. In 1976 a steel weapon of the sixth century BCE was excavated in Changsha, Hunan province, showing that by then China had already entered the Iron Age. Subsequently more iron artifacts of the fifth century BCE were found in Jiangsu and Henan provinces. It is interesting that although Europe knew about iron earlier, the Chinese came to know about the making of cast iron not later than the fifth century BCE, soon after iron was known to them. Another interesting technology developed by the Chinese of about that period is the breast-strap harness seen on the horses among the terra cotta warriors guarding the tomb of Qin Shihuangdi in Xian. Showing good understanding of the horse, this method was far superior to the throat-and-girth harness of the Roman chariot adopted in Europe in the early days. Some time between the years 600 and 1,000 the breast-strap technique went to Europe and evolved into the modern harness.

Between the sixth and the fourth centuries BCE the “Hundred Schools of Philosophical Teachings” flourished in China. Some of these schools played an important role in the development of science and technology in China. The philosopher Mozi (b. ca. 479 BCE) is remembered for his techniques of defense and for his knowledge of mechanics and optics embodied in his *Mojing* (The Canon of Mozi). Confucius is said to have edited the *Yijing* (Book of Changes), which contains one of the most subtle and influential methods of Chinese divination. In the past, especially in China, it was difficult to draw a sharp line of demarcation between science and divination. These two subjects were included within the term *shuxue* (mathematics).

The writings of the Daoist philosophers and the Naturalists exerted a great influence on early Chinese science, and indeed they provided a set of natural laws that was supposed to be “universal”, even more so than what modern scientists believe. Indeed the attempt to be too universal made it difficult for science in traditional China to separate itself from philosophy and to develop into modern science. The greatest name among the Naturalists was ► [Zou Yan](#) (fl. ca. 300 BCE) who lived in the eastern seaboard state of Qi (in modern Hebei province). He was the greatest exponent of the yin and yang theory and that of the *wuxing* in ancient China.

Traditional Chinese science was based on the philosophy of Harmony of Nature, in which heaven (*tian*), earth (*di*), and human beings (*ren*) were all mutually related. Attempts were made to develop a philosophy to explain everything – from astronomy to astrology, from mathematics to fortune-telling, from alchemy to magic, from philosophy to ethics, from politics to fine arts, and from medicine to music – in a common concept based on *qi*. The word *qi* has a wide range of meanings, which cannot be adequately covered by a single term in translation. Its modern meaning includes “air”, “gas”, “vapor”, “steam”, “weather”, “trend”, “demeanor”, “manner”, “temper”, and a sort of life-giving force, reminding us of the Greek concepts of *pneuma* and *psyche*, the Hindu idea of *prāṇa*, and what modern scientists call “matter-energy”.

From *qi* the two opposite and yet complementary cosmological forces yin and yang and the five *xings* were derived. Yin conveys the idea of darkness, the shady part of a mountain, coldness, cloudiness, rain, anything that is feminine, and so on. Yang, on the other hand, refers to brightness, the sunny side of a mountain, warmth, clear sky, sunshine, anything that is masculine, etc. The term *wuxing* was generally translated as “Five Elements”. This gave rise to some confusion. When the Jesuits rendered the Four Elements of the ancient Greeks into Chinese they used the term *siyuan*, (four *yuan*s), but when they translated the Chinese term *wuxing* they called it Five Elements. Unlike the Greek Elements (earth, air, fire, and water), the Chinese *xing*’s were not

stationary but were in a state of constant motion rather than rest. They are Fire, Water, Wood, Metal, and Earth. There is an order of production or generation in which Fire produces Earth, Earth produces Metal, Metal produces Water, Water produces Wood, and Wood produces Fire. Then there is an order of conquest or destruction in which Fire conquers Metal, Metal conquers Wood, Wood conquers Earth, Earth conquers Water, and Water conquers Fire. In Chinese medicine for example, the ► [Huangdi neijing](#) divides different parts of the body into yin and yang and associates them with the five *xings*. For example, the heart, the small intestines and the tongue are associated with Fire, the kidneys and the ears with Water, the gall-bladder and the eyes with Wood, the lungs, the large intestines and the nose with Metal, and the stomach, the spleen and the mouth with Earth. The foundation of health, tranquility, and well-being rests on the perfect equilibrium and harmony of the two cosmological forces yin and yang, which continually ebb and flow. Everything is produced by union and perishes by decomposition. From the two orders of mutual production and mutual conquest the Chinese derived two principles, namely the “principle of control” and the “principle of masking”. Any of the five *xings* that conquers another *xing* is controlled by the *xing* that conquers it. For example, Fire conquers Metal, but the process is controlled by Water. Any *xing* that conquers another *xing* is masked by a *xing* that produces the conquered *xing*, i.e., Fire conquers Metal, but Earth masks the effect.

Then comes the system of the Yijing (Book of Changes) with its 64 hexagrams said to be derived from the theory of yin and yang and that of the *wuxing*, although the system was sometimes used to support those two theories instead. Traditionally the origin of the system traced back to the eleventh century BCE when the sage father of the founder of the Zhou dynasty got inspiration from two mystical diagrams, the *Hetu* (River Diagram) and the *Luoshu* (Luo Chart). These two diagrams supposedly held the secrets of yin and yang as well as the *wuxing*. In the Yijing heaven and earth, thus yang and yin, originated from *Dao*. This term probably refers to natural

order in this context but is opened to a broad range of diverse interpretations. The system of the *Yijing* was mainly employed for the purpose of divination. Besides divination it also found its use in the “explanation” of scientific phenomena, such as in astronomy and alchemy.

In traditional Chinese thought, divination and mathematics were inseparable. The word *shuxue*, the modern term for mathematics, was only first used in the modern sense in the last century when ► [Li Shanlan](#) (1811–1882) translated Western mathematical works into Chinese. Before then the same term in traditional China referred not only to divination and mathematics but also to astronomy and music. One is reminded of the word mathematics as defined by Boethius (480–524) to include arithmetic, geometry, astronomy, and music, which became the *quadrivium* in medieval Europe. In the eyes of traditional Chinese mathematicians, such as Liu Hui (fl. 263) and ► [Qin Jiushao](#) (1202–1262), divination was the loftiest form of *shuxue* while mathematics (in its modern sense) was only its common form. *Shu* was something that could be predicted by calculations, whether by means recognized by modern scholars as mathematics, such as finding the unknown number in a mathematical equation, or predicting rain in weather forecasts and telling the future using the system of the *Yijing*.

Buddhism and Daoism gradually gained ground over the Confucianists after Han China in the third century. A revival of learning during the time of Song China (960–1279) saw the neo-Confucianists attempting to cover science, particularly cosmology, within their schools of philosophy. The most celebrated among them was Zhu Xi (1130–1200), who sought to explain everything, both natural and human, with *li* (Nature’s pattern), *qi*, and *shu*, while Zhang Zai (1020–1077) applied the concept of *qi* to explain natural phenomena and moral issues. Then there was the *xiangshu* (numbers of the symbols of the *Yijing*) school that focused its attention on the elucidation, verification, and application of the system of the *Yijing*. The most famous member of the school was Shao Yong (1011–1077), who used the system to explain natural phenomena

and human affairs and to work out past and future events. His new order of the 64 hexagrams was shown by Leibniz (1646–1716) to be similar to the arrangements using the binary notation. Although Zhu Xi’s philosophy was adopted as state orthodoxy, it does not imply that it met no opposition. For example, a contemporary, Lu Xiangshan (1139–1192) developed the neo-Confucian school of Idealism or of the Mind, which was later further developed by the Ming philosopher Wang Shouren (1472–1529), who had a large following.

The earliest text on Chinese astronomy and mathematics is the ► [Zhoubi suanjing](#) (Mathematical Manual of Zhoubi), which Christopher Cullen showed recently to be a compilation of the first century. In 1973 many important discoveries were made in the excavation of a Western Han (206 BCE–AD 9) tomb in Mawangdui, Hunan province. They included a manuscript recording the ephemerides of Jupiter, Saturn, and Venus between the years 246 BCE and 177 BCE and a silk manuscript illustrating comets in various shapes. Astronomical instruments such as bronze clepsydrae and bronze sundials have also been discovered in other excavations.

The Commentary to the *Jiuzhang suanshu* (Nine Chapters on Mathematical Arts) by Liu Hui (fl. 263) was the most influential text in the history of Chinese mathematics. In 1983 the *Suanshushu* manuscript (Mathematics Book), written on ► [bamboo](#) strips, was discovered in an ancient tomb dating back to the second century BCE at an excavation carried out in Hubei province. A preliminary study shows some similarities between this manuscript and the *Jiuzhang suanshu*. Liu Hui also wrote another, but much shorter text, the *Haidao suanjing* (Sea Island Mathematical Manual), using the right-angled triangle to measure distance and height. Before the time of Liu Hui, around the year AD 190, ► [Xu Yue](#) wrote his *Shushu jiyi* (Recording Omitted Items in Mathematics). Between AD 280 and 473 the *Sunzi suanjing* (Mathematical Manual of Sunzi) appeared. Of all the problems it contains, the one that has aroused most attention among modern scholars is that of the Remainder

Theorem. The problem is to find a number, which when divided by three leaves a remainder two, when divided by five leaves a remainder three, and when divided by seven leaves a remainder two. The required answer is 23. Actually this problem involves three indefinite simultaneous linear equations of one unknown, and there is an infinite number of answers of which the required answer is the smallest. Historians of mathematics study this purely as a case of the Remainder Theorem. However, a more important application of this problem was recently revealed. It was found to be the method adopted by Chinese astronomers up to the eighth century to calculate and construct new calendars.

Several other mathematical texts were written in the following three centuries. One must note the evaluation of the ratio of the circumference to the diameter of a circle made by Zu Congzhi (429–500) and his son Zu Keng. They gave three different values, of which the most accurate was $3.1415925 < \pi < 3.1415926$. The method used by Zu Congzhi was described in his book, the *Zuishu*, which unfortunately is already lost. Chinese mathematics reached its golden age of development in the twelfth and the thirteenth centuries. During the twelfth century, mathematicians like Liu Yi and others could solve cubic equations numerically. Their writings are no longer extant, but fortunately we have the works of four great thirteenth-century mathematicians, namely ► [Qin Jiushao](#), Li Zhi (1192–1279), ► [Yang Hui](#) (fl. 1261–1275), and Zhu Shijie (fl. ca. 1280–1303). The study of numerical solutions of equations of higher degrees is yet another of the characteristics of Chinese mathematics. Li Zhi also had a great influence in the development of ► [mathematics in Japan](#).

The Chinese emperor regarded calendar-making as one of his duties that came with the mandate bestowed upon him from Heaven. The Chinese calendar took into account the apparent cycle of the sun and the cycle of the moon, both of which cannot be expressed in an exact number of days. The astronomer responsible for constructing a lunisolar calendar had to make accurate observations of the sun, the moon, and the planets, but however accurate his

observations, his calendar would eventually, in just a matter of decades, go out of step with observations. In 1972 archeologists working at the site of a Han tomb at Linyi in modern Shandong province, discovered a calendar for the year 134 BCE. Throughout the history of China no less than 100 calendars had been constructed, not to mention other unofficial calendars sometimes used in certain regions. The most renowned among the Chinese calendars were the *Dayanli* calendar completed by the Tang Tantric monk Yixing (683–727) in 727 and the *Shoushili* calendar prepared under the Mongols by Guo Shoujing (1231–1316) in 1280. They used the method of differences in mathematics to make their calculations. Accurate and new astronomical observations had to be made for the purpose of calendar making. New astronomical instruments were constructed for this purpose. Yixing, for example had to construct his own armillary sphere. The Song dynasty (960–1279) is remembered for the several large armillary spheres made for this purpose. The most famous was that made by Su Song (1020–1101). It was an armillary sphere driven by a water wheel using the principle of escapement.

In the early stages medicine and magic were indistinguishable from each other, as both were practiced by the shamans (*wu*). Shamans and doctors were together referred to as *wuyi* (shamans and doctors). During the Spring-and-Autumn Period (722–480 BCE) there were signs that physicians and shamans had already parted company. There was the celebrated physician Qin Yueren, better known as ► [Bian Que](#) (fl. 501 BCE), who was the counterpart of Hippocrates (465–370 BCE) in China. He was already acquainted with the four important diagnostic procedures used in Chinese medicine: observing external signs (*wang*), listening to sounds (*wen*), asking the patient's history (*wen*), and feeling the pulse (*qie*). These are sometimes referred to as looking, listening, asking, and touching. The earliest Chinese medical writing known to us until recently is the ► [Huangdi neiijing](#) (The Yellow Emperor's Manual of Cor-poreal Medicine). Consisting of two parts, the book appears to have been written by several

earlier unknown authors but took its final form during the second century BCE. Between the winter of 1973 and the spring of 1974 some valuable medical writings were discovered during the excavations at Mawangdui near the city of Changsha in modern Hunan province. The tomb where these writings were found dated back to the year 168 BCE and hence the medical writings concerned must have belonged to an earlier date. These are the two most ancient Chinese medical writings extant.

The earliest Chinese pharmacopoeia that we have is the *Shennong bencaojing* (Pharmacopoeia of the Heavenly Husbandman). We do not know its exact authorship and neither are we certain about when it was written, although the date could not be later than the second century. It sets a tradition followed by a long series of succeeding pharmacopoeias over a period of more than a thousand years. It mentions the *yin* or *yang* property and the indications of each medicinal substance, noting that some combinations of two or more of them are either beneficial or counter-indicative. It divides all the 365 items of medicine that it contains into three categories. Those in the first category have the efficacy of nourishing or prolonging life; those in the second are, as a rule, nontoxic and can be used to restore the constitution of the patient; and those in the third are usually toxic or have side effects. The last category is used for combating diseases. Thus the *Shennong bencaojing* catered to the needs of both the physicians and the aspirants of longevity.

While the physicians had parted company with the shamans, some of the latter devoted their attention to prolonging the human life span. Some of the substances they ingested, such as mercuric sulfide, mica, licorice, and asparagus, are listed in the *Shennong bencaojing* pharmacopoeia. The search for the way to physical immortality probably began in China at least 2,500 years before our time. It is recorded that in the Warring States Period (480–221 BCE) someone presented an elixir to the prince Jingxiang wang in the State of Qu. Some modern writers attribute the first practice of ► [alchemy in China](#) to ► [Zou Yan](#). Later on the story of the elixir told

by the shamans got the fancy of the emperor Qin Shihuangdi, who made several attempts to procure an elixir for himself so that he could live and rule his empire to eternity. Another patron of the shamans was the emperor Han Wudi, who reigned about 133 BCE. It was then that the shamans talked about making gold as the first step toward the elixir. At about the same time, Liu An, the Prince of Huainan, compiled, with the help of a group of shamans and alchemists retained by him, the *Huainan wanbishu* (The 10,000 Infallible Arts of the Prince of Huainan). Tradition says that this book dealt mainly with alchemy, especially the making of gold, but unfortunately we no longer have the complete text, and the fragments of the book now left are only concerned with magic. In the following century Liu Xiang, who was said to have inherited this book, was commissioned by the emperor to make gold for the Treasury. His failure landed him in prison.

The earliest Daoist alchemical treatise that is still extant today was written by the alchemist ► [Wei Boyang](#) in the second century AD. Entitled *Cantongqi* (The Kinship of the Three), the text is very obscure, containing a number of alchemical terms with “hidden” meanings. The use of the system of the Yijing (Book of Changes) has contributed directly to the obscurity of the text of the *Cantongqi*. Alchemy gained popularity following the work of Wei Boyang. During the fourth century ► [Ge Hong](#) wrote his *Baopuzi neipian* (The Esoteric Chapters of the Solidarity Master), showing the great advancement made in alchemy since the time of Wei Boyang. Ge Hong was at the same time an accomplished physician. Other famous physicians who were also great alchemists after Ge Hong were ► [Tao Hongjing](#) (456–536), ► [Sun Simo](#) (?581–?682), and his disciple Meng Shen (621–718). For the next 800 years or so after Ge Hong, alchemy continued to flourish and many alchemical works were written. Most of these works are lost; those that survived are included in the present version of the *Daozang* (Daoist Tripitaka), a collection of 1464 Daoist works, only a small fraction of which deal with the subject of alchemy.

In many of their experiments the Chinese alchemists used the process of sublimation and of distillation. They often made use of the reaction-vessel, called *yaofu*. Many of the elixir recipes contained toxic ingredients such as mercury, arsenic, and lead. Hence such elixirs would be quite poisonous. Quite a number of Chinese emperors showed great interest in the elixir and some of them unwittingly perished. For example, the Jin emperor Aidi died in his very prime, aged only 25, as a result of his attempt to avoid growing old. The emperor Wenxuandi of Northern Qi, on the other hand, exercised more caution. When presented with the elixir he decided that the most opportune moment to test it would be on his death bed. At least three Tang emperors died as a result of taking the elixir. Political motives might be behind the early demise of some Chinese emperors, but the alchemists responsible were quickly punished for their failure. With the evidence so efficiently destroyed the full case is difficult to investigate.

There were probably many charlatans among the alchemists, who, when their elixirs brought about the early demise of unfortunate emperors, managed to escape before it became too late. However, there were also alchemists sincerely interested in their work who believed in the elixirs they made. So strong was their faith that many alchemists must themselves have fallen martyr to their own beliefs, or become victims to mistakes in following the obscure and contorted instructions of their predecessors. The most experienced or industrious experimenters were often the most enthusiastic believers, and in the end the surest victims. In this respect the elixir mania must have acted as an inhibiting factor to the progress of chemical knowledge in China.

Many Chinese alchemists were aware of the toxicity of their products. Some tried to neutralize the poison; some recommended only symptomatic treatment; some believed that the ill effects were only side effects associated with the elixir and as such should be completely ignored; some turned to the vegetable kingdom to look for suitable ingredients; and some turned away from the material elixir and practiced “physiological alchemy” (*neidan*) following a regime of

meditation and breathing exercise. By the ninth century ► [alchemy in China](#) had already seen its best days. The alchemists gradually relied more and more on the vegetable kingdom for their raw material. Hence there was an alchemical work that included the term *bencao* (pharmacopoeia) in its title, namely the *Waidan bencao* (Pharmacopoeia of Operative Alchemy) by Cui Fang (fl. eleventh century). After the turn of the fourteenth century several books on elixir plants made their appearance. The Chinese alchemists seemed to have gone round one full circle back to the days of the ancient shamans. Alchemy merged again with the tradition of Chinese medicine set by the *Shennong bencaojing* pharmacopoeia.

Hence traditional Chinese medicine and alchemy arose from the same source. At first the shamans practiced both magic and medicine. About the sixth century BCE medicine and magic took different courses. Some shamans developed the art of prolonging human life and reached the conclusion that one had to make gold by artificial means as a first step to physical immortality. That was the beginning of alchemy. Alchemy maintained a close link with medicine, dealing only with different aspects of human life. Quite a number of alchemists were at the same time famous physicians, as in the case of ► [Ge Hong](#), ► [Tao Hongjing](#) and ► [Sun Simo](#). A preliminary study shows a close connection between alchemy and Chinese medicine in the similarities between the basic principles used in medical and elixir prescriptions. Medicine and alchemy borrowed from each other. For example, alchemical works are liberally quoted in the more important pharmacopoeias of later time such as in the *Bencao gangmu* (the Great Pharmacopoeia) written in 1596. Although the Chinese alchemists did not succeed in their quest for the elixir of immortality, they played a part as the iatrochemist in Chinese medicine. Another by-product of their experiments was that they stumbled upon ► [gunpowder](#) when some of them caused an accident when they did not exercise sufficient caution in using saltpeter and sulfur, allowing some carbon impurities to get in from the charcoal or wood that they used as fuel.

There was early intercultural transmission of scientific and technological knowledge between China and her neighbors, especially west Asia, before the Christian era. Buddhism first came to China in the second century. Scientific knowledge followed the wakes of missionary and pilgrimage activities. During the eighth century Indian monks and calendar experts, Nestorians, Arab merchants, Korean and Japanese students, and others lived together in the Tang capital Changan (modern Xian) which had a population estimated to be over one million. Mutual exchange of knowledge was inevitable. Muslim astronomers found employment in the astronomical bureau in thirteenth-century China and some Chinese astronomers could have been sent by Hulagu Khan to work in the observatory in Maragha under its director Naṣir al-Dīn al-tūsī (1201–1273). The Renaissance in Europe was influenced in no small measure by Arabic and Indian learning, but Europe also acquired knowledge of Chinese science and technology through the Arabs and the invasion of the Mongols during the thirteenth century. Since the seventeenth century science in Europe has advanced by leaps and bounds while Chinese traditional science remained in a state of stagnation. Toward the end of the sixteenth century the Jesuits arrived in China, using science as a tool to promote their mission. Science from Europe, particularly mathematics and astronomy, demonstrated its superiority to traditional science. In the latter half of the nineteenth century modern science came to China from Europe and North America, and by the twentieth century China had joined the world in the common enterprise of modern science.

See Also

- [Alchemy in China](#)
- [Armillary Spheres in India](#)
- [Astronomy](#)
- [Calendars in East Asia](#)
- [East and West](#)
- [Ethnobotany](#)
- [Magic and Science](#)

- [Medicine in China](#)
- [Metallurgy in China](#)
- [Yinyang](#)

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Science in Japan

Nakayama Shigeru

The history of Japanese science, technology, and medicine is divided into two distinctly different periods, traditional and modern, the dividing line being the late nineteenth century when Japan started wholesale Westernization. Since the subject matter of modern Japanese development is not much different from Western development, this article deals only with the traditional and transitional periods.

The Traditional Period

The written history of Japan started approximately in the sixth century when Chinese writing, culture, and institutions were brought in by Korean immigrants. Technical professions began in Japan with the immigration of Korean experts in the sixth to eighth centuries.

The immigrants slowly settled into Japanese society, and the Chinese view of nature gradually began to take root in Japan. Thus, traditional Japanese science, technology, and medicine are basically a ramification of Chinese paradigms. In the following, we shall elucidate the points of Japanese deviation from the Chinese prototype.

Whereas the Western world of learning had an integral structure of trivium, quadrivium, scientia, or Wissenschaft, the corresponding Chinese world of learning was thoroughly structured with Confucian classics at the center of a structured bureaucracy. Scientific subjects were of peripheral importance, with mathematics and calligraphy being necessary for the civil service examination system, and astronomy, medicine, and architecture being fields with their own branch offices in the bureaucracy. The small replica of the Chinese world of learning and bureaucracy was created during the eighth century in Japan.

In principle, the Japanese Astronomical Bureau was a miniature reproduction of the Chinese bureaucracy, but a closer look reveals significant remodeling to meet local requirements. While in China the astronomical organizations that computed the ephemerides and observed celestial phenomena had important astronomical bureaux, in Japan all of these activities were subsumed under the single ► [Yinyang](#) Board, the name of which indicates a clear priority for divination. After that time, the Japanese *Yinyang* art developed into a complex of divination techniques.

Given a Chinese manual of calendrical science from which to determine basic parameters and computational procedures, there was little that local talent or preference could add. On the other hand, when unforeseen and ominous celestial phenomena were observed they had to be interpreted without delay. Thus in astrology the Japanese were thrown upon their own resources, and the practical application of imported knowledge was valued over basic theory.

It was not the regularities of the eternal truths of mathematical astronomy but the unforeseeable omens of the astrologers that attracted attention

in Japan. Whereas abstraction and involved theoretical argument were by no means rare in Chinese science, they were vastly less important in Japan.

As the Chinese influence became less noticeable from the tenth century on, the bureaucracy also diminished in strength. Throughout the medieval period, it was in family businesses rather than the government bureaucracy where those with talent enough to pass civil service examinations were employed. Kinship ties returned to their former importance.

Because they were separated from the Asian continent, the Japanese were not totally overwhelmed by Chinese influence. Japanese society was much less bureaucratic than that of China or Korea, and as a result was more able to respond to the incoming intellectual flux. The Japanese received Chinese influence selectively to meet local needs.

Meanwhile, Buddhism reached Japan from India by way of China and Korea. Although enthusiasm for Buddhism waned somewhat in China and Korea, the Japanese have retained it throughout history. In medieval times, Buddhist monks competed with official astronomers in predicting eclipses by use of their *Fu-tian* calendar. In the paradigmatic treatise of Japanese divination art, *Sukuyōkyō*, excerpts from classics of Tantric Buddhism were mixed side by side with Chinese Daoist texts. In Japanese medical classics, certain Buddhist recipes were mixed and preserved. This reflects Japanese intellectual pluralism.

The Platonic conviction that eternal patterns underlie the flux of nature is so central to the Western tradition that it might seem that no science is possible without it. Nevertheless, although Chinese science assumed that regularities were there for the finding they believed that the ultimate texture of reality was too subtle to be fully measured or comprehended by empirical investigation. The Japanese paid even less attention to the general while showing an even keener curiosity about the particular and the evanescent.

This attitude may be seen in the career of ► [Shibukawa Harumi](#) (1639–1715), the first official astronomer to the Japanese Shogun. In the

preface to his early treatise *Shunju jutsureki* (Discussions on the Calendar Reflected in the Spring and Autumn Annals, the oldest Chinese chronicle), he stated that astronomers had rigidly maintained that when Confucius dated the events in his *Annals of the Spring and Autumn Era* he made conventional use of the current calendar with little care for its astronomical meaning, so that the dates were not very reliable. "This error is due to the Chinese commitment to mathematical astronomy, so that they do not admit that extraordinary events happened in the heavens. Extraordinary phenomena do in fact take place in the heavens. We should therefore not doubt the authenticity of [Confucius'] sacred writing brush."

Once admitting, as Shibukawa did, that regular motion was too limited an assumption, one could easily conceive such notions as that astronomical parameters could vary from century to century. In the official Chinese calendar in the thirteenth century and earlier, the discrepancy between ancient records and recent observations was explained by a secular variation in tropical year length. Shibukawa revived this variation in the Japanese calendar, and ► [Asada Goryu](#) (1734–1799) extended it to other basic parameters to account for Western as well as Eastern observations then available to him.

The variation terms used in Japanese astronomy were too large to survive empirical testing, and were eventually discarded. It is, however, noteworthy that their cosmological outlook was so flexible that they accepted the notion that all astronomical parameters were subject to change and the whole universe was changeable, while in the West the Aristotelian notion of an unalterable universe was followed rigorously, and irregular motions in the sky were inconceivable.

In early Chinese history, higher mathematics was always associated with calendrical science, in terms of solving indeterminate equations for ascertaining the time of grand conjunction. In Japan, interest in mathematics was also raised in connection with calendrical science in the seventeenth century, and was soon developed as mathematical puzzles to be enjoyed by hobbyists, in the same way as there were enthusiasts of flower

arrangement and the tea ceremony. This form of Japanese mathematics called *wasan* was mostly viewed as a popular art. It was not considered a scholarly activity.

I shall not attempt a conceptually rigorous definition of scholarship and hobby here, but merely note that scholarship is usually thought to have some public function while hobbies are regarded as private indulgences which may or may not have significant social value. While art does not require legitimation, scholarship does, and there has to be some basis on which to differentiate one from the other. Some kind of legitimation was found to be necessary for mathematicians and one way of doing so was to invite Confucian scholars to write prefaces to their books, in effect borrowing Confucianism's prestige.

The Japanese mathematicians were generally socially marginal curiosity seekers. During the Tokugawa period, mathematics was not formally recognized by the government. The Tokugawa mathematical tradition existed entirely in the private sector and had no official support. Whenever scholars demand legitimacy from society, they display a sense of mission which reinforces their commitment. This sense of mission is associated with the rise of professions, but the Japanese mathematicians cannot be called professionals.

With the use of mathematical rods, Chinese mathematics developed quite sophisticated algebraic formulae. Building on the Chinese tradition, a significant development was made by Japanese mathematicians to develop numerical algebra into symbolic algebra by writing on paper and making it possible to obtain a more general treatment. Curiously enough, the formulae of *wasan* resemble modern algebraic formulae but they are written vertically. However, due to stylistic differences, there was no intercourse between Japanese and Western developments in mathematics.

Wasan mathematics developed a unique custom in the formative period consisting of the posting of mathematical problems called *idai* (bequeathed questions). A mathematician would post scores of problems of several kinds at the end of a book and then publish it. Another

mathematician would post answers to these problems and present his own in the same manner. According to convention, yet a third mathematician would post answers to these problems and issue his own in relay fashion. This mechanism of *idai* caused a chain reaction and greatly stimulated the formation of *wasan* groups. The tradition began with 12 problems from the *Shinpen Jinkoki* published in 1641. A succession of mathematical lineages soon developed and reached their peak during the life of ► [Seki Kowa](#) (Takakazu). Practically all of the important problems in the history of *wasan* date from the period above.

Another feature of *wasan* development was the *sangaku* (mathematical tablet) form that came in the later phase. These tablets included both problems and answers and were dedicated at shrines. The best mathematicians made their accomplishments known through books, but it was largely the custom of *sangaku* which supported the activities of the *wasan* enthusiasts. That *wasan* was a hobby which cost money to pursue is best shown by the elegant diagrams which embellished such work. In fact, the offering of *sangaku* had a strong attraction as it showed a desire to keep their work on more or less permanent view.

Chinese natural philosophy developed certain abstract concepts in ancient times. The *qi* concept, one of the basic ideas which appeared in the *Huangdii Neijing* (The Yellow Emperor's Internal Classic), the earliest Chinese medical compilation, is today interpreted as something akin to energy which is imponderable but permeates and circulates in the macro- as well as the microcosmos. When the *qi* concept was introduced into Japan, medical doctors tended to interpret it as materialistic, unable to comprehend such a highly abstract concept of imponderable energy. Given the difficulty of understanding the subtleties of Chinese philosophical speculation, the Japanese physicians adopted a more simplistic, pragmatic, and empirical approach.

For instance, certain tumors and internal swellings were thought to be stagnated or congealed *qi*. Indeed, the seventeenth-century Japanese physician, Goto Gonzan, attempted to

explain the cause of all medical disorders by stagnation of this kind.

Traditional Chinese medicine was concerned primarily with function and only secondarily with tissues and organs. Internal disorders were never local in Chinese medicine. The major physiological and pathological theory was to regulate energy flow internally and externally between the micro- and macrocosmos, so that holistic diagnoses could be applied. They depended heavily on pulse diagnosis as the indication of energy flow. More materialistic Japanese physicians such as Yoshimasu Todo (1701–1773), however, developed stomach and abdomen diagnosis by touching the location of disease, rejecting the traditional pulse diagnosis. Yoshimasu, the foremost figure of the radically critical school, declared that the *qi* of the universe had nothing to do with medicine. This group was prepared to take a position much closer to that of the solidists in the West than had been possible in Japan at an earlier time. Functional analysis lost its importance, and the physical organs could be studied for their own sake. This was nothing less than a gestalt change.

In accordance with the extension of the materialistic inclination of Japanese physicians, they were interested in anatomy and found that Western schema were a great deal more accurate than the Chinese anatomical charts. In mathematical astronomy and calendrical science, Western superiority in accuracy was quickly recognized. In medicine, there is good reason to doubt that there was any difference in therapeutic efficacy before the late nineteenth century. It is above all in the comparison of anatomical charts that the strength of Western medicine would be apparent.

In the second half of the eighteenth century, Sugita Genpaku took up the study of anatomy because it seemed the most tangible, and therefore the most comprehensible, part of Dutch medicine. Following the solidist breakthrough, Sugita's successors in medicine studied physics and chemistry and opened up the world of modern science. The Copernican influence was minor by comparison, because the Japanese cosmos had not been defined by religious authority. The impact of anatomy challenged the energetic and functional commitments not only of

medicine but also of natural philosophy. Its effect was bound to be revolutionary.

The learned treatises of the Chinese and Japanese medical traditions lacked terminology not only for brain function but also for mental processes. It was only later scholars with considerable knowledge of Western anatomy, such as Sugita Genpaku, who could abandon the Chinese tradition entirely and display as much anatomical interest in the brain as in the viscera.

Materia medica and natural history books were brought first from China and later from Holland. The first thing for a Japanese natural historian to do was to identify local species with imported Chinese books. This identification work endowed Japanese scholars with new insights into comparative study. While the original Chinese texts were intended for the collection of medicinal herbs for pharmaceutical purposes, the Japanese developed this study into a natural history of visual observations for identification.

In feudal Japan, all occupations were hereditary. The post of official astronomer to the Shogun was created to recognize the personal achievement of ► [Shibukawa Harumi](#), and was passed down to his descendants. It had no significance beyond the technical, and thus was of no interest to the generalists. Those who held technical posts of this kind, such as medical doctors and Confucian scholars, were from the beginning separate from the general samurai bureaucracy.

When the official astronomer and his subordinates were compiling the ephemerides, Confucian scholars were not consulted. The astronomers had inherited the tradition through their family line since medieval times. At the time of a calendar reform, once every hundred years for a Chinese-type lunisolar calendar, the descendants were usually incapable of innovative work, but able to perform the routine calculations necessary for the distribution of the yearly calendar according to a given formula. In most such cases, talented astronomers in the private sector were appointed to the post of official astronomer. Beginning with Shibukawa Harumi, the number of such hereditary official astronomers amounted to seven families toward the end of Shogunate rule.

Often professionals were encouraged to adopt talented young boys rather than their own sons. Under the rules of samurai society in the Tokugawa period, only the first son was entitled to inherit the family stipend. Later born sons were adopted by other sonless samurai families or left to find ways of obtaining their livelihood themselves. For either, they had to show their ability by studying hard. These younger sons would provide Japan with a pool of talented professionals.

In Japan, there was no social or political reason for a single philosophical orthodoxy. Although nominally based on the centralized Chinese model, Japanese feudal society remained multifocal, consisting of the Shogunate and a hundred fiefs. Thus freedom to choose between several paradigms seems to have been as desirable as the search for a unitary principle was in China.

In China and Korea, the official character of science and learning was rigidly maintained by adherence to the civil service examination system. The Japanese imitated the Chinese bureaucracy for only a short time in the seventh and eighth centuries, and subsequently this failed to take root in Japanese society. It was only in the last quarter of the nineteenth century with the establishment of a modern government system that a centralized bureaucracy complete with civil service examinations emerged. During the Tokugawa period, it was centralized feudalism, in which the Tokugawa government had overwhelming power but in which each fief government was able to maintain a degree of autonomy by having their own independent schools, bureaucracy, and policies, in competition with other fiefs.

The Tokugawa Shogunate wanted to instigate centralized civil and medical service examinations but was unable to impose such a system on the fief governments. As a result, there was no rigidly maintained state orthodoxy of science and learning, although the exclusion of Christian tenets was executed with considerable harshness. In short, the Japanese have enjoyed the merits of multiculturalism. It is not the kind of multiculturalism which involves the peaceful coexistence of different races in one society but rather signifies the acceptance of different cultures by largely one single group.

Science and learning had been substantially privatized and able to respond to imported foreign ideas by the late eighteenth and early nineteenth centuries. Even during the semiseclusion period under the Tokugawa Shogunate, the activity of Dutch learning was practiced by city intellectuals, medical doctors, and merchants in the private sector. Only after the Western threat of invasion became substantially felt in the nineteenth century, particularly after the news of the Opium War and the arrival of Commodore Perry's gunboats in 1853, did the knowledge of Western learning become the business of the public sector. Samurai became interested in Western [military technology](#), finally overthrowing the feudal government and replacing it with a centralized state.

From the seventeenth century onward, when Western knowledge began to exert claims of its own against the backdrop of Chinese learning, Japanese thinkers were critically attentive. As soon as they were convinced that European technical knowledge was superior, the Japanese switched to the new paradigm with remarkable speed. They quickly modified their attitudes and oriented themselves toward achieving certain desirable goals that had been reached in the West. For the Chinese, the encounter with European ideas was traumatic; to accept them was to reject traditional values, and to reject them would leave them with no defense against dismemberment by Western powers. For the Japanese it was merely the appearance of another paradigm to be accepted in their eclectic manner. The Japanese were flexible enough to accept the Western paradigm without strong resistance.

The Transitional Period

Let us now turn to the occupational support groups who successively played a leading role in the introduction of Western science to Japan.

Astronomers and Interpreters

The adoption of Western "barbarian" astronomy in the seventeenth century by the Chinese dismayed conservative elements in Japan. However, it did not promote the desire in others for a similar

change in the Japanese calendar, which was modeled on that of the ancient Chinese. As has been mentioned, the eighth Shogun Yoshimune and his court astronomers recognized the superiority of Western over Chinese astronomy, but astronomers were primarily government bureaucrats or technicians whose scope remained limited to their assigned duties of drawing up the official calendar. Their interest in Western science was limited to the precision of astronomical data and methods of calculation, and they made no attempt to jeopardize their hereditary posts by entertaining revolutionary paradigms such as were developing in Europe at that time.

Professional interpreters at Nagasaki were the most well versed in the Dutch language, through which they must have become acquainted with the concepts of Western science. But again, they were also hereditary government officials who remained within the boundaries of their duty of faithful translation and nothing more. Neither official astronomers nor interpreters published their work for general audiences.

Independent Scholars and Physicians

From the late eighteenth century on, a sizeable number of Dutch books containing the term *Natuurkunde* (study of nature) found their way into the country and aroused the interest of various independent scholars in the private sector who set about translating them, although their foreign language skills were much inferior to those of the Nagasaki interpreters. The majority of these "Dutch scholars", as they came to be called, were avant-garde physicians who were primarily freelancers, with no strict subordinative links to the governing elite or subsequent interest in maintaining an existing *status quo*. Thus they were not inhibited in stepping out of their line of work and were free to extend their interests to anything Western except perhaps the Christian doctrine. Astronomy was the first area in which people sensed that the West was superior, but the notion that the West was superior in other fields of scientific endeavor first spread among these independent physicians.

As they inched their way through Dutch texts, they realized that Western science was more than

a variant of the natural history line of their own tradition. As they saw it, its essence could be translated as *kyuri* (literally, investigating the principles of things, a new Confucian term, or “natural philosophy”, being a systematic and fundamental investigation and consideration of the nature of things). Thus, although at first there was no clearly established tradition for the term, *kyuri* was later to become the most common, and given the vocabulary of the period, it was an informative translation. In recognizing an enquiry into principles at the bottom of such traditional practical studies as medicine and calendar-making, in becoming aware, i.e., of natural philosophy or physics, they also grasped the hierarchical structure of modern science, from basic to applied. Above and beyond the culturally bound achievements of Western science, they seemed to have sensed that it contained a revolutionary paradigm, since the belief in underlying laws in Nature which could be formulated was weak in Japanese traditional thought. This was in marked contrast to the official astronomers who looked upon science as something that could be handled at the technical level and assigned it only a supplementary role.

The physicians recognized the importance of physics and chemistry as the basis of medical work, and several founded schools for the teaching of Western medicine. Their students, during their apprenticeship and internship days, moved from one school to another in major medical centers like Nagasaki, Osaka, Kyoto, and Edo (Tokyo), and played a role of diffusing knowledge of Western culture as well as medicine. While some physicians remained in the practice of medicine, others turned to the teaching of the Dutch language and even the discussion of international knowledge and politics and also founded schools for such. Thus, the cultural influence of the physicians was more considerable than that of the astronomers who limited their activities to the translation of technical works.

But these support groups were by no means adequate preparation for the reception of contemporary science. The Dutch scholars were still only amateur supporters of uninstitutionalized

paradigms, comparable in this respect to gentleman members of the Royal Society. Their schools were few and regarded on the whole as avant-garde. Had they flourished in the seventeenth and eighteenth centuries their work might have had greater consequences. By the mid-nineteenth century, however, modern science in the West had entered the systematically structured world of the university and reached new advanced levels. Reception of learning that was now systematically pursued in Europe within the structures of the university required the creation of an institutional system. It had to be met not by self-taught amateurs but with professional scientists who had received a modern systematic education. These early scholars were not aware of the institutionalized aspect of Western science up until the mid-nineteenth century, remaining bookish translators of the *kyuri*, paradigmatic aspect of Western science.

Samurai

The Opium War between the Chinese and Western colonialists created concern among the samurai cognoscenti, but Commodore Perry's visit to Japan in 1853 and the subsequent threat of war caused all samurai to realize that the Westerners' science was needed for national defense. As a result, young samurai flocked to the schools of Western learning established by physicians. As they were traditionally the ruling class, and in time of war the warriors, it was natural that samurai interest in Western science and technology training was based on more real and pressing needs than reception of and support for particular scholarly paradigms.

First, they tried to learn the Western art of manufacturing firearms, but soon realized that it was impossible to catch up and compete with Western forces by a crash project of manufacturing cannons. They could purchase hardware, but what was really needed was the software of Western military training and tactics. Moreover, the acquisition of Western military discipline was one of the contributing factors in the overthrow of the ruling Tokugawa family by anti-Tokugawa samurai and the subsequent establishment of the Meiji government in 1868. The samurai

recognition of Western science was therefore political rather than cultural.

After the revolution, convinced that Western scientific learning was essential, the ruling class set out to disseminate their conviction through the establishment of an educational infrastructure. With Meiji effort and initiative, modern science was fully assimilated in a wholesale introduction through governmental institutions rather than a piecemeal cultural infiltration, as in the previous era, and modern scientific and technological professions became the artificial creation of the new Western-oriented government.

The main practitioners of these new professions were former samurai. In the past they had received hereditary family stipends in exchange for their loyalty to the feudal powers, the Shogunate or local feudatories. But in the 1870s, efforts were made by the Meiji government to curtail the inherited family stipends of the samurai class as a step toward social modernization. While other classes, farmers, artisans, and merchants, could continue to be engaged in their inherited vocations, samurai completely lost their guaranteed source of income. Consequently, they had to find new ways of living independently. Since the samurai could not compete with other classes in the fields of traditional occupations like agriculture and medicine, science and technology was one of these new fields into which jobless samurai were attracted and invited. Almost all of the early graduates of the engineering colleges were samurai. Even as late as 1890, the percentages of Imperial University samurai graduates in engineering and science were 86 and 80, respectively.

Thus, Japanese modern science and technology professions were, in the beginning of their formation, very much “samurai-spirited.” The samurai were the class long accustomed by mental habit to think in terms of public affairs and by behavior patterns to play the game of public office. Unlike the European pattern in which science and technology training was one experience of the rising bourgeoisie, the new Japanese scientific and technological professions in the last quarter of the nineteenth century were dominated by the proud old samurai class, comprising the top 5 % of the total population.

Table 1 summarizes the sequence of support groups’ thrust toward Westernization in Japan.

In the first stage, Western science was confined merely to technical knowledge by technicians in the government sector. In the second, Western knowledge in the form of its revolutionary paradigms was garnered by vanguard physicians but they were alienated from the central power structure. Only in the third stage was Western science fully admitted into the power structure, and after the Meiji Restoration, through institutionalization, it was recognized as a most legitimate study for the youth of the samurai class.

The modernist samurai leadership soon established a policy of Westernization in which the establishment of Western-style educational institutions occupied a central position. During the 1870s and 1880s greater emphasis was placed on science and technology in the Japanese educational curriculum, from elementary school to university level, than in any other nation. For instance, mathematics and science occupied about one-third of the school curriculum at the lower grades (first 4 years) and two-thirds at the

Science in Japan, Table 1 The sequence of support groups’ thrust toward Westernization in Japan

Occupation	Astronomers and interpreters	Physicians	Samurai
Leading century period	Eighteenth century	Late eighteenth to early nineteenth century	Mid-nineteenth century
Interest	Technical	Cultural	Political
Status	Technicians	Freelancers	Planners and administrators
Role	Referees of superiority	Diffusion and popularization	Institutionalization

upper grades of the 8-year elementary education, though due to the shortage of qualified teachers available, it is somewhat questionable to what extent these ideal plans were put into practice. At the tertiary level too, the emphasis on science and technology was evident in the high percentages of graduates in scientific disciplines of Tokyo University (85 % in the 1880s). In Europe in the nineteenth century, the voluntary activities of scientific or professional societies usually preceded their inclusion into the university curriculum. In the case of Meiji Japan, however, and as is generally the case when a foreign discipline is artificially transplanted under state sponsorship, this process was reversed. Tokyo University was established as an indispensable part of the modern technocratic bureaucracy. Graduates in science and technology were mostly samurai descendants who were accustomed to working in the public sector and inspired in technocratic policy-making, rather than by engineering apprenticeship of the traditional artisan class. They were adaptable in “public science” initiated by the government, which was indispensable for the operation of a modern state, in areas such as geographical and geological surveys, weights and measures, meteorological observations, sanitation, printing, telegraph and telephone system, military works, railways, and surveys of national resources.

In addition, the government participated in private entrepreneurial activities, constructed and managed pilot plants, and guided and subsidized new kinds of industries. Their enterprises were, however, from the beginning exposed to financial risk. Many of the projects of the Ministry of Technology eventually proved to be too far ahead of their times, as they intended to introduce the technology of an industrialized society into a preindustrial environment. For instance, their railway construction and textile mill enterprises were economically unsuccessful at the time.

Some of the samurai experiments in the public sector were successfully transferred into the private sector, where they were transformed to the market-oriented “private science” of the traditional artisan, such as Toyota Sakichi, the founder of Toyota Motors. The privatization of science phase was finally completed after World War II.

See Also

- ▶ [Asada Goryu](#)
- ▶ [Astronomy](#)
- ▶ [Computation: Chinese Counting Rods](#)
- ▶ [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- ▶ [Environment and Nature: Japan](#)
- ▶ [Mathematics in Japan](#)
- ▶ [Seki Kowa](#)
- ▶ [Shibukawa Harumi](#)
- ▶ [Yinyang](#)

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Science in Korea

Jeon Sang-Woon

Korea is a nation with 5,000 years of history. Located on the periphery of East Asian civilization, it was greatly influenced by China. However, Koreans have developed a culture and tradition independent from that of the Chinese. At the same time, the history of Korean science can be regarded as a branch or an adaptation of Chinese traditional sciences, although, in most cases, Chinese sciences and technology were not adopted in their original form.

Korea had its own unique Paleolithic Age some 500,000 years ago. Some of the tools of the Paleolithic Age found in Korea are not found in any other parts of East Asia. The Korean people of the Neolithic Age differed from the Chinese people in that they belonged to what is often called the northern race. Unlike the lineage from the Paleolithic Age, the lineage from the Neolithic Age has continued to survive down to the formation of the Korean people. Elements of

the Neolithic Age combined with each other and then with elements of the Bronze Age in the formation of the Korean people.

The highly developed Bronze Age culture in Korea around the year 1000 BCE was influenced by a northern culture that was different from the Chinese scientific one. Chinese science and technology were adopted on the basis of an indigenous technological tradition. Koreans have always attempted to reshape Chinese technology whenever it was introduced into Korea to make it uniquely Korean and to develop new technology.

Typical examples of this kind of endeavor are found in the bronze sword and mirror. The lute-shaped bronze sword and Korean-style sword and the bronze mirror which has a thick lined design with two knobs, and the thin lined mirror, are uniquely Korean bronze instruments. These instruments reveal unique design and casting skills indicating the highly developed state of bronze-making technology. This technology in Korea has a different lineage from that of the Chinese. This is found in the chemical make-up of the bronze instruments themselves. Even the earliest bronzes found in Korea there are alloys of zinc and bronze.

Koreans demonstrated a special creativity by developing an advanced skill in bronze production and alloy making. Bronze makers in Korea used both mud molds and stone molds to produce bronze items. Stone molds, which are frequently found in Korea, are very seldom discovered in China.

Casting technology utilizing stone molds led to the development of a unique iron ax casting system that developed from the third century BCE in Korea. In this period iron axes were produced in massive quantities by using stone molds. It is a commonly held belief that the Iron Age in Korea started in the fifth to fourth centuries BCE with the introduction of Chinese iron culture. The mass production of iron axes can be explained as the creation of a new technology, which would not have been possible if there had not been an autonomous tradition of iron technology in Korea.

The development in iron-casting technology brought about a dramatic increase in agricultural

production on the basis of the mass production of farm instruments. Iron ingots of the late Iron Age found in the southern regions of the Korean peninsula are unique symbols of power and wealth. Iron ingots developed by Koreans spread to Japan, setting in motion the development of an iron culture there.

The widespread use of iron brought about new kinds of earthenware. Kaya culture (or Kimhae culture) of the region produced hardened quality earthenware produced through the combination of the technology of the indigenous people of the area (who were known for their designs which lacked ideogrammatic characters) and Chinese ashen-earthenware skills.

Other regions on the Korean peninsula, such as Koguryo, Paekche, and Silla, were also developing a technological culture. The people of Koguryo, Silla, and Paekche each constructed their tombs in unique ways. The painters of the Koguryo tombs painted their walls with individual and powerful lines and colors. The many kinds of pure gold objects discovered in kings' tombs, with their distinctive designs and refined inscriptions, testify to what seems to have been a highly refined manufacturing technology.

Besides those kinds of technical cultural traditions, several examples of scientific inquiry are known to have been written in the Three Kingdoms period (first century BCE-seventh century AD). Among the most outstanding are the developments in astronomy and medicine. Records indicate that Koguryo had maps of stars in the sky inscribed on stones, and a special astronomic observatory. The paintings of the stars found in a mural of Koguryo support this likelihood. Paekche also had astronomical observatories, and special calendrical specialists were appointed in the sixth century.

The Ch'omsongdae observatory in Kyongju is symbolic of the astronomical enterprise of the Three Kingdom period of Korea. Ch'omsongdae, a stone brick edifice, built in AD 647, is the oldest surviving astronomical observatory. The delicate aesthetic lines that characterize Ch'omsongdae are a symbol of the Korean sense of beauty. Records of astronomic observations dating from the Silla period are indications of very active

institutionalized astronomical observation in that period. Astronomers in Silla learned calendrical studies from the Chinese, but were not content with just learning or copying from them. They endeavored to develop their own kind of astronomy. Ch'omsongdae is a valuable part of the heritage of their efforts.

Although actual records of medical prescriptions for long life and for the curing of diseases are scanty, they enable us to picture the systematic herbal medicine practiced in the period.

The period of Unified Silla is best represented by the great quantity of surviving remnants and records. Korea achieved a high level of creative development in science and technology in this period.

The Sokkuram grotto and the Darani scripture, among others, are representative of the achievements of Silla science and technology. The grotto, the most highly regarded edifice left by the craftsmen of Silla in the eighth century, is seen as the highest point in traditional architecture because of its geometric design and daring construction skills. There is no doubt that the Sokkuram grotto was a copy of a rock cave temple in China. However, while the Chinese edifice was built into a natural rock cave, the Sokkuram grotto is an artificial stone cave created on the basis of a harmony of various compositions including circles, spheres, triangles, hexagons, and octagons.

Silla master craftsmen also produced a number of beautiful bells. They successfully combined ancient Chinese bells and tinkle-bells in creating a unique Silla style. A special feature of the Silla bells is found in the dragon shaped hooks for hanging them. Historical records assert that Silla's craftsmen produced an alloy of bronze combined with copper, tin, and lead for a better sound. This was found to be true in a chemical analysis. The Chinese naturalist, ► [Li Shizhen](#), wrote in his *Bencao Gangmu* that "Persian bronze is good for making mirrors and Silla bronze for making bells." The bell preserved in the Kyongju National Museum was made in 771. It has a height of 3.3 m. Its solemnity and the arrangement of its design patterns are typical of Silla bells.

Master craftsmen of Silla began developing wood print type in the early part of the eighth century. The scroll of Darani scripture found in 1966 was assessed to be a wood type print on white hammered paper produced between 705 and 751. This makes it the oldest surviving printed material in the world. On the basis of surviving evidence, this would prove that printing technology was invented in Korea prior to its development in China. Whatever the merits of this claim are, the fact that Silla technology had developed, in the eighth century, to the level of producing wood type print, is a significant demonstration of its technology. It indicates that the gap between the level of technology in China and Silla was not very wide.

The science and technology of Koryo developed on the basis of the achievements of the sciences and technology in Silla. They were also greatly influenced by the Sung and Yuan dynasties in China, and there are signs of the indirect influence of Islamic scientific and technological culture. The representative achievements of science and technology in Koryo are the development of wood block printing, the invention of bronze type printing technology, and the development of Koryo celadon.

Wood block printing in Koryo developed as a result of the aristocratic interest in print copies of calligraphy in pine wood blocks. It was also stimulated by a religious motivation. Buddhist scripts were made into wood type in order to draw on the power of Buddha in the struggle against the Mongol invasion. Eighty Thousand Scriptures, the world's largest and oldest surviving wood block printing set known, was also produced out of this motivation. The printing of the Eighty Thousand Scriptures is regarded as the highest level of technology in wood block printing.

The invention of a bronze type printing system was created from a totally different motivation. Koryo, having less demand for books than China, could not maintain the enormous amount of wood blocks, time, and labor to produce a variety of kinds of books. Bronze type was invented as a solution to this problem.

Ceramic type printing was invented by Bi Sheng in the China of the eleventh century.

However, a metal type printing system was not established even by the fourteenth-century because of the difficulties in casting and the ink and paper needed for metal type printing. However, all these were possible with the science and technology available in Koryo. There, craftsmen knew of the technique of producing sand molds to make bronze print type, and were already producing oil ink suitable for printing with metal type and good quality paper. Because of this, the master craftsmen of Koryo were able to invent bronze type from wood type.

The central element in making bronze type was making sand molds. This was one of the greatest contributions in the development of printing technology. It may have been developed from the accumulated knowledge from production of various bronze vessels and casting of the grand bells.

The craftsmen of Koryo were successful in developing their skills for making celadon. They also adopted the inlaying method, which until that time had only been used in metal ornament making, for celadon making. This illustrates that, while Koryo celadon skills were adopted from Sung China they were never a simple copying of the Sung products.

Astronomy and herbal medicine were also two of the central pillars of science in Koryo as in the previous dynasties. Koryo scientists also developed geography. Major efforts in astronomy in the Koryo period were in observational astronomy and in calendar making. Official records of astronomical observations contain records of observation over 475 years. Among the records, there is a record of 132 occasions of an eclipse of the sun. This is on a par with the astronomic records of Islamic astronomers. There are also notable observations of sunspots.

A systematic foundation of herbal [▶ medicine in Korea](#) was established from the sixth to the seventh centuries at the height of the Three Kingdom period. It came as a combination of traditional medicinal prescriptions and the influence of medical theories from China. A system was developed for utilizing herbs found in Korea. *Bencao jingjizhu* (The Shennong Pharmacopoeia with Collected Annotations) written by Dao

Hungzhang contains 11 medicinal herbs that originate from Korea. And *Ishimpō* (Tamba no Yasayori's Collected Prescriptions), a famous medicinal book in tenth century Japan, contains various quotations of prescriptions from medical texts from Paekche and Silla. By the ninth century, 22 kinds of medicinal herbs originating in Korea were recorded in the medicinal texts used in China and Japan. A national medical school was established in the tenth century, and national examinations for medical practitioners were introduced. In the twelfth and thirteenth centuries, Sung medical science was introduced into Korea, while native prescriptions of local medicines emerged in Koryo in the form of three volumes entitled *Hyangyak kuguppang* (First-aid Measures with Local Medicines). This represented the first medical text describing herbal medicinal practice in the Koryo period.

In the early period of the Choson dynasty, efforts to create an independent culture brought about a forceful development of science and technology. In 1402, King Taejong proceeded with the development of bronze type print despite strong opposition from high ranking government officials. However, the books printed with the newly developed type (*kemi*) were not of better quality than the books printed with wood type. Furthermore, it resulted in lower efficiency in printing one kind of book, and it did not bring about any improvements in cost and labor productivity. It was a low efficiency technology. However, this project provided the basis for greater improvements when the succeeding king adopted it as a state-funded program. As a result Choson type printing developed to a state of perfection.

Achievements in science and technology reached their highest point during the King Sejong period, which is regarded as the golden age of Korean traditional science. The invention of the rain gauge is one of its achievements. Rain measuring instruments and watermarks were developed between 1441 and 1442, enabling the scientific measurement of rainfall. The invention of a cylindrical rain gauge resulted from efforts to obtain a precise measure. As a result the scientists in the court of King Sejong were able to develop a

scientific method for the quantitative measurement of natural phenomena. Government officials maintained the measurement and recording of rainfall throughout the country, utilizing a highly systematic method, for over 400 years.

New astronomical observatories were built during the reign of King Sejong. The great equatorial torquetrum observation platform built in Kyongbok Palace contains a torquetrum, armillary clock, armillary sphere, gnomon, direction markers, an automatic striking clepsydra, a jade clepsydra, and various other kinds of sundials. In order to construct these astronomical observatories, which took 7 years to complete, King Sejong sent mathematicians, astronomers, and technicians to China to study astronomical observational instruments. Scientists designed an astronomical instrument that was modeled on the Guo Shoujing system of the Yuan dynasty in China. However, major aspects of the instrument were modified to reflect Korean characteristics. The astronomical observatory built through such a process was the largest of its kind and among the best equipped in the fifteenth century.

Astronomers of the King Sejong period developed an independent calendar on the basis of their observations and calculations. The publication of the calculation of the motions of the seven governors, the inner and outer parts (*Ch 'ilchongsan Naep 'yon* and *Ch 'ilchongsan Oep 'yon*), is the product of such efforts. The outer part is regarded as one of the most authoritative texts written in Chinese characters on Islamic astronomy and calendar science.

The scientific achievements of the King Sejong period were found in all fields of endeavor. Koryo celadon was developed into Punch'ong ware by early Choson craftsmen to produce unique Choson celadons that differed in style and quality from Koryo celadons. A blue and white porcelain was first imported from China during the King Sejong period and began to be produced in Korea from the middle of the fifteenth century. However the geometric shape and design of the porcelain were entirely different from the Chinese originals.

► **Military technology** also developed unique characteristics in the early period of Choson. The

development of Choson style firearms and turtle ships are representative examples. Firearms began to be used widely from the late Koryo period after introduction of the skill from China. However, by the King Sejong period, firearms production in Choson had abandoned a great many of the Chinese features leading to the development of unique firearms. By totally recasting the firearms, which were improved to strengthen the national system, the Choson court, they were modified and standardized until they had their own style.

There were also notable achievements in geography. The map of the world drawn by Choson geographers in 1402, while based on some of the central maps in China, was a more complete one. Although it did not overcome the Chinese world view, it contained a depiction of Europe and Africa and the Far East which can be said to make a true world map with the most up-to-date geographical knowledge.

In the King Sejong period, actual national measurements were undertaken to produce a complete map of the country.

The map of Choson produced in the fifteenth century, currently preserved in Japan, is a map of the highest quality in comparison with others produced in the same period. Geographical scientists in the King Sejong period endeavored, in addition to making maps from thorough field surveys and study of literature, to do proper geographic work that included national and provincial maps.

The field of medicine experienced a total systematization and concentration of Korean herbal medicine and Oriental medicine. Study of local medicinal herbs was collated into a basic foundation for herbal ► [medicine in Korea](#). It was developed into a comprehensive system for prescription. The *Hyangyak chipsongbang* (Great Collection of Native Korean Prescriptions), in which a total of 703 Korean native medicines were included, was completed in 1433. Concurrent with these efforts was the editing and publishing of *Uibang yuch 'ui* (Classified Collection of Medicinal Prescriptions). This was a medical encyclopedia, completed in 1445, which incorporated 153 different

Korean and Chinese texts, and was regarded as one of the greatest medical texts of the fifteenth century. Also, the *Tongui pogam* (Precious Mirror of Eastern Medicine) was completed from 1556 to 1610 by Hochun.

Agricultural technology also experienced great development in the King Sejong period. Much of the agricultural technology in Korea until this period was based on Chinese agricultural texts. However, they could not provide appropriate guidelines for farming in Korea. To provide these, an agricultural technology text, *Nongsa chiksol* (Theories and Practice of Farming), was edited and published in 1429. This book surveyed the various farming methods in different fields and summarized the most developed and practical methods. This book contributed greatly to the improvement in agriculture in Choson and became the basic farming textbook.

However, Korean traditional sciences suffered a series of ruptures along with their creative development. A number of foreign invasions which decimated the entire territory disrupted the creative tradition in Korean scientific endeavors. The history of Korean sciences and technology is at the same time a history of these efforts. The introduction of Western science and the efforts to systematize the traditional sciences and technologies by “Sirhak” scholars from the seventeenth to the eighteenth centuries is just one example. These scholars advocated practical learning (*sirhak*) under the slogan *silsa kusi* (verification of truth on the basis of factual studies), and accepted some of the little European science that came their way. They thus began what might have become a scientific reformation because they were influenced by modern science and technology in Europe through Qing China, where the same kind of movement had been going on for some time, partly as a reaction to mystical tendencies in late Confucian philosophy. Sirhak scholars pioneered new frontiers in scientific and technological theory and scientific philosophy. However, their efforts were frustrated because of the onset of another round of invasions.

See Also

- [Ceramics: Mimbres Pottery](#)
- [Eclipse Observations](#)
- [Maps and Mapmaking in Korea](#)
- [Mathematics in Korea](#)

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Science in Ottoman Turkish

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Until the eighteenth century, Turkish was the language used in administration, not the language of learning. Just as the primary language of early modern European science was Latin, the language of early modern Ottoman science was Arabic. Prior to the nineteenth century, writing in Turkish meant writing for the lay elite. Until the eighteenth century, the *medrese* (Islamic college) and the *tekke* (Sufi lodge) were the main sites of learning. Mehmed II's fifteenth century *medrese* reform firmly placed the exact sciences within the orbit of higher learning, while Süleyman I's sixteenth century medical *medrese* helped create the Ottoman “learned doctor.” *Tekkes*, on the other hand, were home to the occult sciences, especially alchemy.

Over the seventeenth century, the lay elite developed a stronger relationship with learning. This was evident in Mehmed IV's and Ahmed III's large-scale translation and compilation projects in the naturalistic and the humanistic disciplines. Unlike Arabic-language books, most books in Turkish were written for a patron – the

Sultan himself or an administrator of high rank. As such, the Turkish language books help us monitor the intellectual trends within the Ottoman administration. The extant evidence suggests that from the seventeenth century onward, the patronage of vernacular authors working on naturalistic subjects was prevalent. Some of these authors also leveraged the position of their powerful patrons to advocate new ideas or to affect a break with the Islamic tradition. However, the fields that broadly fell under the Aristotelian notion of theoretical philosophy (physics, metaphysics and pure mathematics) remained the domain of *medrese* until the establishment of modern, state-run, institutions of higher learning. Consequently, philosophical literature of this type is exceedingly rare in the Turkish language. By contrast, we find a large number of Turkish manuscripts on scientific practice, such as clinical observations, drug recipes, instrument manuals, and portolans [sailing directions].

By the nineteenth century, the Empire's medical and military elite were firmly under French and German influence. As the Ottoman government forged critical alliances with European powers, it also began to use a greater number of European experts and to send students to Europe. While our knowledge of scientific practices in the nineteenth century is still lacking, European science increasingly became the standard idiom of naturalism as the century progressed.

Astronomy and Astrology

The vast majority of astronomical literature in the Ottoman Empire was in Arabic, intended as it was for *medrese* students and *medrese*-trained timekeepers (*muvaqqit*). From the seventeenth century onward, one finds an increasing number of Turkish works dealing with both mathematical astronomy (*ilm-i hey'et*, *ilm-i ziccat*) and with judicial astrology (*ahkam-ı nücum*). In astrology, *Ahkam-ı Mehmed Çelebi* (Judgments of Mehmed Çelebi), an early seventeenth century work composed by the Münecimbaşı Mehmed b. Ali

al-Rumi (d.1630), seems to have enjoyed long-term popularity. Another important astrological work was composed by Mustafa Zeki al-Istanbuli, who was patronized by Şehid Ali Paşa in the early eighteenth century. Among Ali Paşa's clients was also the future Ottoman ambassador to the Versailles Yirmisekiz Mehmed Çelebi, who was a practicing chymist and ran the Imperial Foundry and the Imperial Mint. There was a vernacular revival of Islamic astronomy in the eighteenth century, where we find a Turkish rendition, with commentary, of *Zicc-i Uluğ Bey*. The aim of this work *Netayicü'l-Buluğ fî Şerh-i Zicc-i Uluğ* was to encourage the practice of astronomy, which, its author Abbas Vesim surmised, had been confined to theoretical training. A second important translation was Jamshid al-Kashi's *Süllemü's-Sema*, which dealt with reckoning the sizes and the distances of heavenly bodies. From the late seventeenth century onwards, we also find a number of Turkish ephemerides that were translated from Latin and French. Since ephemerides always placed planetary positions from the perspective of a terrestrial observer, they were readily put to use within the geocentric framework of Islamic *hey'et*. Although İbrahim Müteferrika, printer to Sultans Ahmed III and Mahmud I, presented a Cartesian defense of the "new astronomy" of Copernicus, the geocentric *hey'et* tradition seems to have continued throughout the eighteenth century, where the introduction of Copernicus to *medrese* manuals happened no earlier than the nineteenth century.

Geography and Cartography

Since geography and cartography were useful to sailors, administrators and military officers, most of the Ottoman geographical and cartographical literature was in Turkish. One of the most celebrated works was Piri Reis's *Kitab-ı Bahriye* (The Maritime Book), which included a number of important portolans. One of the most curious artifacts that Piri Reis left behind was his early sixteenth century map of the Americas.

The Turkish cartographic tradition merged Islamic-Ptolemaic cartography with the practice of portolan making. With Katip Çelebi, the famous polymath and translator of *Atlas Minor*, the cartographic projection methods of Gerhard Mercator also took a foothold among Ottoman geographers. The late seventeenth century was a turning point in the history of Ottoman geography and cartography, where three important books, Katip Çelebi's *Cihannüma*, Evliya Çelebi's *Seyahatname*, and Ebubekir Behram el-Dimaşki's *Terceme-i Atlas Maior* cultivated new approaches to both mathematical cartography and human geography with an unprecedented level of depth and breadth. Cartography was also one of the central concerns of the imperial printing press established in 1729, where the very first work to appear was a map of Iran – territories that the Ottoman Sultan claimed to have conquered. Over the eighteenth century, with the switch from a fortress-based understanding of territory to a border-based understanding of the land, geodesy became a permanent concern of the administrative elite.

Medicine and Natural History

Medicine always had a double career in Islam. As part science (*ilm*) and part art (*fenn*), the Ottoman medical marketplace was composed, much like Germany or Spain, of state-employed learned doctors and fee-collecting medical artisans. Formal medical training in Arabic was offered to doctors at the various hospitals and at the medical *medrese* of Süleyman I, where Ibn Sīnā's *Canon of Medicine* served as the backbone of medical training. However, from the fifteenth century onward, there was also a steady stream of Turkish language medical books that addressed the lay physician. One of the most important developments in seventeenth century Ottoman medicine was the emergence of the vernacular *tıbb-ı cedid* (new medicine), a movement that tried to merge the exact sciences, alchemy, and medicine under the same rubric inspired by Paracelsus and European authors who worked within a broadly

Paracelsian framework. Natural history, particularly accounts of the wondrous and the curious also attracted tremendous attention among Turkish readers. This is evident in the three independent translations of Qazwini's *Ajaib al-Makhlūqat wa Gharaib al-Mawjudat*. Natural history took on a more practical and borderline commercial tone after important drugs and herbs from the Americas became a fixture in the Ottoman markets. An Ottoman Grand Vizier, Mehmed Said Pasha, even wrote a polyglot lexicon of herbs and minerals in the eighteenth century.

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Science of the Native Americans

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It is commonly accepted practice to refer to the peoples and cultures established in the territory now called the Americas as Native Americans. When the expedition of Christopher Columbus reached the Caribbean Islands in 1492, they called the inhabitants "Indians." This is because of the Spaniards' mistaken view that they had arrived in Asia. Although Columbus himself never realized that he had reached another continent and kept referring to the lands as "Cipango," soon the conquerors realized that they were indeed in a continent as far from Asia as from Europe and dealing with a completely different culture. However, the early chroniclers used the denomination "West Indies," and up to now all the peoples and the cultures native to these newly encountered lands are called Indians.

The denomination "America" also came as the consequence of a fortuitous event. The navigator Amerigo Vespucci, who had visited and described practically the entire coast of the newly found lands, was consulted by German Cartographer Martin Waldseemüller, when he was writing the treatise *Cosmographiae Introductio*, a sort of revised version of Ptolemy's *Geography*. The cartographer, without a name for the new territories added to the original maps, coined the name "Americas" to honor the man who helped them to place these additions to the old maps. This vast amount of land stretched from about the North Pole to the South Pole, between Europe and Asia, roughly in the middle of the waters surrounding the known world. The peoples and cultures of this territory reached by Columbus, strangers to the conception of the world prevailing in the fifteenth century, are mostly referred to as "American Indians." The name Native Americans is not widely used.

The original occupation of the Americas (North, Central, and South) is uncertain.

The colonizers have claimed, an obvious political assertion, that the peoples in the Americas were immigrants who arrived from Asia through a glaciation of the Bering Strait no more than 20,000 years ago. Some theories claiming that these peoples are autochthonous were advanced in the early twentieth century, but they were disclaimed on the basis of a lack of scientific support. The best known of these theories is from the Argentinean anthropologist Florentino Ameghino (1854–1911). These claims recur frequently. The theory of a common origin for all of mankind, coming from the heights of Eastern Africa, is the most accepted version for the origin of humans in the Americas. They arrived in migratory fluxes through the Bering Strait, which does not exclude the possibility of ocean access, both through the Atlantic and the Pacific. There is mounting evidence of the presence of humans in these lands since 70000 BCE, but this evidence is very controversial. The most accepted versions place early findings of *Homo sapiens* at about 40000 BCE, without the presence of early hominids.

There is a considerable amount of material relating the impressions of the first Europeans who arrived in the Americas. The first one, the journal of Columbus, is the most important one, but others have also told of the enormous impression made by these peoples and lands on the Europeans. The chroniclers of the conquest reveal their surprise and failure in understanding such different cultures.

Most of the attempts to interpret scientific knowledge in the Americas prior to the arrival of Europeans are limited to a description of what was seen. Buildings, roads, agricultural fields, and artifacts are always listed as evidence of knowledge. Their meaning and cultural context are problematic. An example is the *quipu*, a collection of colored strings with knots, taken as a form of abacus. We now understand these are a very elaborate form of register, both qualitative and quantitative. Also, the wheel appears frequently in pre-Columbian cultures but without the uses so well known in the history of Europe and Asia.

There is a reasonable amount of literature on science and technology in the Americas in the pre-Columbian era written by anthropologists and psychologists. To relate this to the work of historians and philosophers of science and technology is an important step toward a broader understanding of the nature of science and technology and their places in societies. This asks for a clear recognition of the dynamic character of knowledge, from its generation through its organization, both intellectual and social, and through its diffusion. Although these aspects are studied in disciplines such as cognition, epistemology, history, politics, and education, it is practically impossible to understand and explain knowledge in such a fragmented way. This is an important step toward recognizing different modes of thought which lead to different forms of science, which we may call *ethnosciences*.

Research on the status of knowledge in the Americas in the pre-Columbian period uses methodological instruments and an intellectual posture of classifying it according to accepted, European, views of science. The underlying epistemology is dictated by current scholarship. Thus, research focuses on ethnoastronomy, ethnobotany, ethnochemistry, and so on. The “ethno” prefix stands for “the astronomy of the Aztecs,” for example. This reductionist approach does not take into account the meaning of “astronomy” for the Aztecs. This is true for every science. A special situation occurs in the recognition of an ethnomethodology in different cultures. Researchers in this field rely on ethnography, the use of direct observation, and extended field research. This produces a naturalistic description of peoples and their culture, uncovering codes, symbols, and categories of analysis which these peoples use to conceptualize, explain, understand, and interpret reality. The generation of these instruments is the essence of studies in cognition and culture. We are thus led to look into the history of science in a broader context, so as to incorporate other possible forms of knowledge, interpretation, and explanation, to deal with nature and natural phenomena.

Generation of knowledge goes on in different environmental settings, according to a

multiplicity of stimuli. Practices are created by individuals in response to their immediate needs, motivation, and curiosity, and thus generated, they are intellectually organized as knowledge. A communication system of codes and symbols allows this knowledge to be transmitted informally throughout society and socially organized before it is diffused through education. Its growth into more and deeper knowledge is now a response to further needs and curiosity. These new responses (the *hows* and the *whys*) are incorporated in the pool of common knowledge which keeps a group of individuals together and operational. This is usually called *culture*.

Cultural forms, such as language, eating and drinking preferences, musical and bodily expression, mathematical practices, religious feelings, familial hierarchy and structure, dressing, and behavior patterns, are thus diversified. A larger community is partitioned into several smaller ones, from individuals and their immediate kin to communities and societies, each with distinct cultural variants. The multiplicity of cultural factors is essentially responsible for the dynamic process of the production of new forms of thought and of more sophisticated expressions of the ingenuity of individuals and societies in satisfying their needs of survival and of transcendence. This is the process we call *cultural dynamics*.

A theory of culture is thus the result of analyzing the intellectual evolution of humankind, focusing on the search for different practices and intellectual tools for explaining, understanding, learning about, and managing their natural and sociocultural environment. In “explaining, understanding, learning about, and managing,” we recognize the Greek root *mathema*. And a natural and sociocultural environment is well expressed by the prefix *ethno*. Thus we have coined the word *ethnomathematics* to describe the mathematical practices of the day-to-day lives of preliterate cultures. In a broader sense, *ethnomathematics* is a research program in the history and philosophy of mathematics, with pedagogical implications.

Much has been said about the universality of knowledge, in particular of scientific knowledge. This concept of universality becomes harder to

sustain as recent research shows evidence of practices, such as health care and tool use, which are typically scientific, and methodological practices, such as observing, counting, ordering, sorting, measuring, and weighing, all performed in distinctive ways in different cultural environments. This has encouraged further studies on the evolution of scientific concepts and practices within a cultural and anthropological framework. We feel this has been done only to a very limited, and we might say very timid, extent. Indeed, universality of knowledge, more specifically of scientific knowledge, is a fabrication of the colonial ideology.

A new historiography reestablishing authentic universality is needed. There is some agreement about this in several areas of knowledge, but the history of science seems to be immune to this movement. Indeed, the tone of some reviews of recent books and papers in the history of science, in particular mathematics, focusing on this form of redeeming cultural history or proposing a non-Eurocentric view, is discouraging and, sometimes, contemptuous. It is well recognized that the best strategy for hegemony is the suppression of historicity of the subordinates. Here is an example from the history of science: the first nonreligious book published in the New World was Juan Diez Freyle's *Treatise Dealing with the Arithmetic of the Aztecs* in 1557. Less than a century later, this book had lost its appeal and became completely lost, along with pre-Columbian arithmetic. Freyle's book was ignored and replaced by the arithmetic of the Spaniards.

The suppression of the history of a people involves the removal of all traces of structured knowledge, labeling all forms of knowledge as "popular wisdom," superstition, and folklore.

Early Cultures in the Americas

The early cultures in the Americas are distinct, according to broad ranges of latitude. The peoples in the icy northern regions developed into a culture generally known as Inuit, or Eskimos. Those in the fertile northern prairies and woods

of what is now the United States and Canada, ranging from the Pacific to the Atlantic, were identified under the generic name of "Indians," organized into several distinct nations. Those in the more desert regions neighboring the Rio Grande were distinct nations with a distinguishable urban organization and rather unique architectural forms. South of the Rio Grande, in the highlands of Mexico and Central and South America, there are peoples with cultural styles of a rather different nature. These peoples are now called Aztecs in the region around what is now called the Ciudad de Mexico, Mayas in the Central American jungles, mainly southern Mexico and Guatemala, and Incas, spread throughout the mountainous region called the Andes, from the northern part of South America to the northern part of Chile. Aztecs, Mayas, and Incas are called the "high civilizations" of the Americas. In the "lower lands" – coastal areas, the Amazon Basin and subsidiary basins to the South, and much of the territory east of the Andes – other cultures flourished in a very different style. Apart from the high civilizations, and not mentioning those cultures north of the Rio Grande, we have to mention as best organized those located in the Island of Marajo (in the mouth of the Amazon River), with a considerably developed pottery; the agriculturalist Araucanians in the Southern part of South America; and the Guaranis, the latest major group to organize themselves in an agricultural economy, in central South America.

The Aztecs are distinguished by a monumental religious architecture, with abundant pyramids with precise designs to accommodate astronomical data. The Aztec calendar reveals these achievements. Sculpture was at a level of sophistication comparable to civilizations in the Old World. Commerce was developed and practiced in large fairs. They used numbers and measures but had no commerce by weight. The Aztecs were skilled workers in ceramics and in metals (gold, silver, copper, tin, and bronze). They had hieroglyphic writing, using colors which endure to the present day, literature, and a school system.

The Mayas had distinctive urbanization styles. Stone pyramids, temples, and palaces, decorated

with very elaborate sculptures, were religious centers, and the population was spread in the surrounding jungles. These centers appear to have been temporary. One hypothesis is that they were abandoned as new ones became ready – another possibility is that the mobility was the result of destruction by wars. These peoples had a very advanced astronomy, with data comparable to those available to the Europeans. From the sixth century, they had developed the zero and positional number system, thus producing an advanced arithmetic. They also had a pictorial writing system which was not recognized as such by Europeans. Some early translators relied on reports of books and documents without recognizing this as reading.

Among the classics of their literature, we have the elaborated description of the origins of the world and men, the *Popol Vuh*, a book written in the mid-sixteenth century, in Central America. The book describes, simultaneously, the myths of origin, the history of kings, and the peoples of the region, as well as the catastrophe of the Spanish conquest.

Also very important is the book of natural phenomena, the *Chilam Balam*. It describes a myth of origins, similar to the *Popol Vuh*, when gods of the underworld kept the universe captive. Also of great importance is the war drama *Rabinal Achi*, a piece showing the existence of a form of ritual theater. It is typical of the post-Classical period of the Maya civilization, from the tenth to the fifteenth centuries. Maya cultures developed a series of artistic expressions which included dancing, theater, music, and literature.

The third high civilization, known as the Incas, took the name after their monarch. The Inca was the highest religious, civilian, and military authority. Although succession was by blood, the successor was not necessarily the eldest son. Like the Aztecs, the religion of the Incas was focused on the divinity of the sun, and human sacrifices were common. The architecture of the Incas was of a varied nature. Visitors still marvel at what is called cyclopic architecture, buildings and palaces constructed using enormous stones, as in Machu Picchu, Peru.

The early history of these cultures reveals a great dispersion of nomadic groups, with an economy of hunters and collectors. In general, in all of the Americas, animal domestication was modest. In Mexico, turkeys were domesticated; in Peru, the llama and the alpaca, as pack animals and for textiles, were also domesticated, as were dogs and some rodents. Some tribes farmed turtles, some bees and birds, mainly parakeets and parrots. Fish from the coasts of Peru were consumed in the high altitudes, transported and preserved through a sophisticated system of utilization of natural ice.

Agriculture was much more developed. About 6000 BCE, we see evidence of the domestication of plants, mainly in the northern region (north of Mexico and southeast United States), among them squash, cotton, and several species of beans. The important development of maize (*Zea mays*) opens up a new era in the development of agriculture and the settlement of people in larger regions, which characterizes the urbanization period. There is much controversy about when this occurred. A recent academic argument about the occurrence of maize in Panama, 5000 versus 3000 BCE, is more important for revealing the search for a new historiography for science and technology in pre-Columbian Americas than for the dating question itself.

Intensive Agriculture and Urbanization

Up to the beginning of the Christian era, we see the formation of agricultural cultures. They developed different techniques, using fire, intensive irrigation, fertilization, and terrace agriculture. Agriculture was the main subsistence form and the determinant of the political struggles and the development of economy.

A special and unique type of building, characterized by yards built with stone walls, was recently located in the center of a village in La Puntilla, Peru. There are indications that these buildings, dating about 2,000 years ago, were for centralized work and not for ceremonies. Other findings, such as finding manufactured products in domestic units, reveal an organized

structure for distribution of the production, suggesting the existence of a dominant class controlling production. An intense craftsmanship, which included making andesite and obsidian tools, manufacturing ornaments of marine shells, weaving, and spinning, and agricultural processing tasks are present. It is also notable that some of the raw material used in the crafts, as, for example, spondylus shells, are not local but brought from distant lands, probably the coastline of Ecuador.

As we advance in time, around the second millennium AD, we see the development of a variety of urban styles: the weaving of cotton and wool; pottery and ceramics; statuary; metallurgy, especially work in gold; ritual decoration; and architecture. We notice the development of several forms of pyramids, possibly evolving from the common funerary mounds, and other forms of religious architecture. Ceremonial dressing is varied, with feathers, plants, animals, painting, and bright colors. The period also reveals, probably as a consequence of the permanent struggle for land, the development of a variety of languages, with more than 2,000 distinct languages or dialects. In the lower lands, there is considerable development of agriculture, mainly manioc or cassava (*Manihot utilissima*) and sweet potatoes (*Ipomoea batatas*).

There is also evidence of an intense coastal commerce. Indeed, navigation in the Pacific seems to be highly developed among the Andean cultures. There is recent evidence of Japanese arrivals in what is now Ecuador about 3000 BCE. Also, there is a possibility of commercial exchanges between China and South America in the first century AD, and contacts between Mexico and Africa in the first millennium are most probable. There are no doubts about the practice of considerably advanced navigation among the high civilizations.

There is much controversy about the development of a written/pictorial form of language. As mentioned above, recent findings reveal a written language among the Mayas. They also developed calculations, especially for astronomical and commercial purposes, with a sophisticated

vigesimal (base 60) system. The register of historical and statistical data was rather sophisticated, as with the surprisingly powerful *quipus* among the Incas. Calculating devices, such as the *yupana* (see <http://www.quipus.it/english/Andean%20Calculators.pdf> for a detailed discussion of Andean calculators), reveal theoretical approaches as yet not sufficiently studied. We are just beginning to recognize the formal knowledge – logic, mathematics, philosophy – possessed by these cultures.

Colonial discourse was absolutely biased in saying that the American peoples were not highly developed. Agriculture was developed in Asia in the eighth millennium BCE, while there is evidence that it was developed in Mexico only in the fifth millennium BCE. Ceramics and pottery are seen in Asia about 6000 BCE, while they appear in 3000 BCE in the northeast of South America. Proto-literacy is recognized in Mesopotamia about 3300 BCE but in Mesoamerica only about 800 BCE. Urban cultures are seen in Egypt and Mesopotamia using writing and bronze about 2800 BCE, while limited writing and metallurgy are identified in urban complexes of Mexico and Peru only in the beginning of the Christian era.

What was going on in the centuries preceding the arrival of Columbus was a political process very similar to that which took place in Europe during the Middle Ages, when principalities and other smaller domains were uniting into larger organizations such as kingdoms and nations. The Spanish conquerors were able to take advantage of the local conflicts in destroying the emergent power elites and replacing them with the power of the conqueror, based on a well-balanced state/church structure controlling the means of production. Although effective production was in the hands of natives, the conqueror assumed the role of the native monarchy in controlling the centralized system. Even now, production is, to a great extent, done by impoverished natives. A 1950 study showed that in Bolivia, about 4,000 native communities were responsible for about 25 % of the agricultural production. The conqueror succeeded in deepening these conflicts. As a result, today different cultures, even

different tribes, do not recognize their common history. In the lower lands, east of the Andes and the Amazon Basin and subsidiary basins in the south, and mainly in the Atlantic coast, the strategy was no different.

As we have said before, knowledge is generated as a permanent activity of human beings. It is carried out by individuals and groups of individuals in different environmental settings, according to a multiplicity of stimuli. Among the several stimuli, we have to consider cultural encounters and mutual exposition of different modes of thought. In the evolution of cultural forms subjected to mutual exposition, the possibilities are, first, an absolute domination of one form, either leaving the others in the state of latency or leading them to an eventual total elimination and, second, allowing coevolution, which eventually leads to new cultural forms. This second possibility occurs in systems which are tolerant of the different, of the stranger. Thus, our analysis of the formation of scientific knowledge and the development of technology among the civilizations of Latin America necessarily goes through an analysis of the occupation of territory and the development of means of production.

To conceptualize modes or styles of development is crucial for better understanding of the evolution of native knowledge systems, in particular science, in the Americas. The Latin America Economic Commission of the United Nations proposed, in the 1960s, the conceptual basis for development. Development is understood as a strategy resulting from political agreement or group alliances, with the objective of reaching a common goal. Thus a model of development is the result of the power structure and of the social conflicts resulting of the prevalent forms of capital accumulation and distribution of richness. These are based on a complex of historical circumstances that go back to the conquest, colonial period, and the early decades of independence. These internal and external conjunctures are in conflict with the values intrinsic to the cultures. To understand the native knowledge systems, a new historiography is needed, anchored in the concept of models of development.

See Also

- [Animal Domestication](#)
- [Astronomy](#)
- [Aztec Science](#)
- [Ethnomathematics](#)
- [Knowledge Systems of the Incas](#)
- [Mathematics](#)
- [Quipu](#)

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Sde Srid Sangs Rgyas Rgya Mtsho

Zhen Yan

Sde srid sangs rgyas rgya mtsho is a famous Tibetan politician and naturalist. Nicknamed Sde pa, he was born in the water snake year of the 11th Rab-byung (Tibetan calendar, 1653) in the Northern suburb of Lhasa, Tibet. His father's name was A sug, and his mother, Bu khrid rgyal mo.

Politically, he was a person who inspired controversy, either commendatory or derogatory. But he was a great naturalist. His contributions

in Tibetan medicine greatly promoted the development of this branch of science during his time.

Since he was a very talented child, he came to the attention of the fifth Dalai Lama Ngag dbang blo bzang rgya mtsho, who paid special attention to his education. He was summoned to the Dalai Lama's Potala palace to learn the classics of the Buddhism, apparent and esoteric sects. He had many tutors. 'Dar pa was the tutor for languages, Sanskrit and calendar-mathematics; Rong ge ngag dbang for astrology; Lhun sdings rnam rgyal rdo rje for allegorical trees, body measurement, and esoteric recipes. Thus, he became a versatile scholar with a high reputation.

The fifth Dalai Lama assigned him to the post of Sde srid (the Regent or Prime Minister), which was like giving wings to a tiger. During his tenure as Sde srid, he used any leisure time to take advantage of having access to many rare documents and materials available in the palace. He was very erudite in natural sciences, including medical science. His works, for instance *Baidurya dkar po* (White Lapislazuli), and *Baidurya ser po* (Yellow Lapislazuli), deal with the calendar, mathematical sciences, and religion. However, his achievements in medical science will be emphasized here.

First, he studied *Rgyud bzhi*, the most important ancient Tibetan medical canon. Due to his political position, he had contact with many famous physicians. He admired Dar mo sman rams pa blo bzang chos grags very much, claiming that he was very erudite and had many esoteric effective recipes. He learnt from the different revised and annotated editions produced by the new Gyu thog yon tan mgon po, the greatest ancient Tibetan medical figure. He also made his own annotations and revisions on *Rgyud bzhi*.

Rgyud bzhi, authored by Gyu thog rnying ma yon tan mgon po, or the old Gyu thog, is written in archaic Tibetan language, which is hard to read; moreover, it is written in the form of an ancient Sloka-poet form, which is difficult to comprehend. Based on his experiences and practice, he adopted all the merits from different schools and physicians, discarded the erroneous and extracted the essence. With all these elements as a basis, he wrote a new detailed commentary

on *Rgyud bzhi* with the title *Gso ba rig pa'i bstan bcos sman bla'i dgongs rgyan rgyud bzhi'i gsal byed baidurya sngon po'i malli ka zhes bya ba bzhugs so* (The Medicine Buddha's Decorated Four Tantras Annotation, The Blue Lapis Lazuli), or *Baidurya sngon po* for short. The book, twice as long as the original *Rgyud bzhi*, was finished in 1687. Since this is a comprehensive text embodying the merits of all scholars with refined contents, easy to read and understand, many scholars appreciate it. It has become the standard commentary on *Rgyud bzhi* and is treated as a compulsory text for learning it.

Sangs rgyas rgya mtsho also wrote many other medical books. Among them, *Gso rig sman gyi khog 'bugs* (History of Tibetan Medicine) is the most famous and important. Its full title is *Dpal ldan gso ba rig pa'i khog 'bugs legs bshad baidurya'i me long drang srong dgyes pa'i dga' ston bzhugs so* (General Introduction to Medicine, The Happy Feast of Immortals). This is by far the most authoritative text in Tibetan medical history. Furthermore, he was not satisfied with *Baidurya sngon po* only, so he wrote another book, *Man ngag rgyud lhan thabs* (Supplement to Secret Tantra) to make up for the deficiencies of the original classic. His medical works number over 20.

Sangs rgyas rgya mtsho was very enthusiastic about education in Tibetan medicine, paying attention to the training of successors. Right after the enthronement of the fifth Dalai Lama, the spiritual leader ordered that a medical school be established at 'Bras spungs Monastery in the Western suburbs of Lhasa, enrolling young people from the region with *Rgyud bzhi* as its main curriculum. Moreover, the Dalai Lama also instructed the restoration of the class in Xigatze to continue its training of Tibetan medical workers. The title of the class was changed to *Shen xian yun ji si* or *Drang srong 'dus pa'i gling* (Monastery for Aggregation of Immortals). Again, *Rgyud bzhi* was its main curriculum. Unfortunately, the latter was suspended upon the death of the Dalai Lama.

Several years later, Sangs rgyas rgya mtsho selected the site of Lcag po ri (Iron Hill) just opposite the Potala Palace to set up another

medical school in line with the will of the late Dalai Lama. The curriculum included, in addition to *Rgyud bzhi*, other books such as *Zeng bu si bu yi dian mi jue ben ji* (Supplements to Collection of Man ngag rgyud) and *Cao yao mi fang* (Secret Herbal Formulary). Practice was also summarized. For instance, herbs were collected each year in the mountains, and students were encouraged to recognize various medicinal herbs and gain a better understanding of nature.

Sangs rgyas rgya mtsho set up an advanced medical class within the Potala Palace, and famous physicians were invited to teach. To improve teaching efficiency, Sangs rgyas rgya mtsho designed and produced a set of intuitive teaching tools, hanging painting scrolls, called *Sman thang* in the Tibetan language.

Under the auspices of Sangs rgyas rgya mtsho, the drawing of a series of *Sman thangs* was initiated. Sangs rgyas rgya mtsho used his *Baidurya sngon po* as a basis for the paintings and, by 1688, a series of 60 paintings had been completed. But, Sangs rgyas rgya mtsho was not satisfied, and he added more detail of pulse feeling, urine analysis and ► [moxibustion](#), and sketching the actual samples of herbs collected from places throughout the region. Thus, a complete set of 79 paintings was finally produced in 1704.

As an epochal event in the history of Tibetan medicine, Tibetan medical paintings include all aspects of the medical field, such as the origin of medicine, fundamental theory, physiology, anatomy, etiology, pathology, therapeutic methods, surgical instruments, symptoms of all clinical aspects, diagnostics, materia medica and prognosis, and medical ethics as well which is not only the first of its kind but also the only example in the history of world medicine. This popularized medical knowledge with intuitive education, playing a very active role in the spreading and popularization of Tibetan medicine. It is a rare valuable historical relic with very high value that has attracted much attention around the world.

Sangs rgyas rgya mtsho was a great medical man. He made substantial and distinguished contributions to the development of Tibetan medicine. Unfortunately, his political notions clashed with other politicians, and the relationship among

them deteriorated after the death of the fifth Dalai Lama. He was assassinated by his enemy and died a premature death at the age of 53.

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Seafaring

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When humans began to cross sea barriers, they demonstrated what they were capable of by harnessing nature. This may have been the most consequential single achievement in human history, because it marked the advent of the domestication of natural systems – the evolution of technologies that harness such energies as wind, wave action, current and buoyancy. The importance of this is not so much in the expanded ability of colonization or the introduction of “assisted locomotion,” but in the cybernetic feedback derived from the conscious manipulation of natural systems and its impact on the cognitive and intellectual development of hominins. From an archaeo-technological perspective, early maritime navigational ability provides a more accurate determination of maximal technological capability than any other available evidence – rather in the same way as space travel does today. Hence there are several good reasons

to take a special interest in how, when, and where seafaring began.

No physical evidence of Pleistocene seafaring has ever been reported, nor have we any credible depictions of watercraft in the rock art or portable art of the Ice Age. Direct archaeological evidence of navigation peters out between 8,000 and possibly 10,500 years ago (Bednarik, 1997), consisting of Mesolithic paddles from Holmgaard (Denmark) and Star Carr (England); a worked reindeer antler that may have been a rib of a skin boat in the Ahrensburgian of Husum (Germany); and the somewhat younger canoes and dugouts from Pesse (Holland, $8,265 \pm 275$ carbon years), Noyen-sur-Seine (France, $7,960 \pm 100$ carbon years), and Lystrup 1 (Denmark, $6,110 \pm 100$ carbon years) (Arnold, 1966; Bednarik & Kuckenburger, 1999; Clark, 1971; Ellmers, 1980; McGrail, 1987, 1991; Zeist, 1957). Watercraft and paddles of the late first half of the Holocene are also known from two Japanese sites (Aikens & Higuchi, 1982, p. 124; Ikawa-Smith, 1986). Bitumen-covered wooden slabs thought to have been part of boats, about 7,000 years old, were found in the Kuwaiti desert, in a stone building at the site As-Subiyah. The subsequent development of watercraft in the Middle East and later elsewhere is not considered here; it does not refer to the beginnings of seafaring.

Indirect evidence of maritime travel occurs in a variety of forms: as human occupation evidence, human remains, rock art, or exotic materials found in the archaeology of islands or continents that were never connected to another landmass since humans first appeared. For instance, such evidence can be in the form of insular obsidian on the mainland, as that from Frachthi Cave in Greece, 11,000 years old (Perlès, 1979; Renfrew & Aspinall, 1990). Much earlier sea crossing and island colonization is indicated by Mousterian tools on Kefallinía, west of Greece (Kavvadias, 1984; Warner & Bednarik, 1996), and by the presence of Clactonian-like stone tools and human remains in Middle Pleistocene sediments on Sardinia (Bini et al., 1993; Ginesu et al., 2003; Martini, 1992). Crete was also occupied during Paleolithic

times, as indicated by human remains of a modern specimen with preserved archaic features (Facchini & Giusberti, 1992, p. 200) and extensive deposits of Lower and Middle Paleolithic stone tools (Mortensen, 2008; Strasser et al., 2010, 2011). In Japan, Paleolithic seafaring is demonstrated by the remains of four humans at Okinawa (Baba, 1998) and by transported obsidian at Kozushima (Anderson, 1987), and in North America by the two femora fragments and one humerus from Arlington Springs on Santa Rosa Island (reportedly 13,000 years old). However, in comparison to the seafaring evidence in the region of Indonesia and Australia, most such finds from Europe and elsewhere are comparatively recent. The only evidence of a Lower Paleolithic island occupation outside that region is that from Sardinia, on the order of 300,000 years old. It seems also probable that the first colonizers of Europe crossed the Strait of Gibraltar, even though secure evidence for this is lacking (Bednarik, 1999a).

In March 1957, Dutch researcher Theodor Verhoeven found stone implements eroding from a fossiliferous deposit at the site Ola Bula in Flores, a geologically recent island of Indonesia (Verhoeven, 1968, p. 400). A leading archaeologist, Henri Breuil, recognized among these finds a number of typical Lower Paleolithic stone implements (Verhoeven, 1958, p. 265). In mid-1963, Verhoeven succeeded in demonstrating by excavation the contemporaneity of Flores artifacts with fossil remains of *Stegodonts* (extinct elephants) at a second, nearby site, Boa Leza. Johannes Maringer, an archaeologist of the Anthropos Institute, Germany, joined him in 1968, and the two excavated together at Boa Leza, Mata Menge, and Lembah Menge. The three sites occur within easy walking distance and are all exposures of a geological stratum rich in fossil remains and stone tools (Maringer, 1978; Maringer & Verhoeven, 1970a, b, c, 1972, 1975, 1977). This deposit is overlain by a series of rock facies up to 120-m thick, so there can be no question about the great antiquity of this presence of humans on an island that has never been connected to any other landmass. Initially this evidence was estimated to be up to

Seafaring,

Fig. 1 Stegodont remains and stone tools in solid siltstone deposit, ca. 840,000 years old, Boa Leza, Flores (Photo by author)

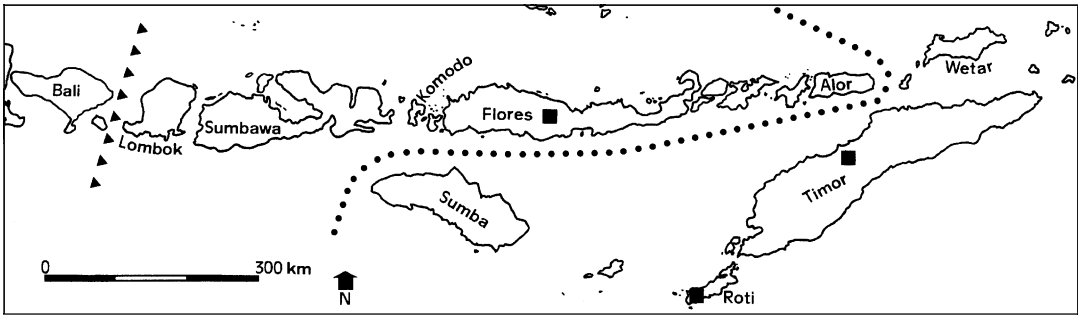


830,000 years old, based on the geology, paleontology, and the presence of tektites. (Tektites are glassy objects that are thought by most scientists today to be melt products of terrestrial rocks formed by hypervelocity impacts of large, extra-terrestrial objects.) (Koenigswald & Ghosh, 1973) Subsequent paleomagnetic analyses at Mata Menge (Bednarik, 1995; Sondaar et al., 1994) suggested that the Matuyama-Brunhes reversal to normal polarity (780,000 BP) occurs just below the fossiliferous stratum. Later applications of fission-track analysis of zircons yielded datings of stone tool-bearing sediments from Boa Leza, Mata Menge, Koba Tuwa, and Ngamapa, and all fell between 750,000 and 850,000 years BP (Morwood et al., 1999) (Fig. 1).

It thus seems soundly demonstrated that *Homo erectus*, currently the only available hominin candidate, was sufficiently well established on the island of Flores towards the end of the Early Pleistocene to leave behind numerous major deposits of stone tools. Flores is separated from Bali, the furthest extension of the Asian mainland during the Pleistocene (at times of low sea level), by two other islands, Lombok and Sumbawa (as well as several smaller islands which may have been connected to the larger ones at times of lower sea level), and the lack of any former land bridge between Bali and Lombok was initially recognized by Wallace (1890). While this is based primarily on biogeographical observations, it is supported by the continuing uplift in the “inner arc” of the Indonesian archipelago, which

amounts to at least several 100 m over the past million years in this tectonically active subduction zone. Despite the rich mainland fauna of both extant and fossil terrestrial eutherians (placental mammals) that can be found as far east as Bali, few of them ever reached the islands of Nusa Tenggara, or southern Wallacea (Bednarik & Kuckenburg, 1999, pp. 108–109). Some, such as the dog, pig, and macaque, were probably carried by humans, while small mammals, mostly Muridae (mice, rats, voles, and relatives), probably crossed on floating vegetation (Diamond, 1977). Elephants, however, swam to many of the islands of Wallacea (Bednarik, 1999b; Glover, 1969; Hooijer, 1957; Verhoeven, 1958, 1964) and the Philippines (Koenigswald, 1949), where they underwent speciation and dwarfism. Elephants are superb long-distance swimmers, able to swim 48 km at sea and at a speed of 2.7 km/h (Johnson, 1980). Hominins, however, lacked the trunks and swimming ability of elephants. Even deer, hippos, tapirs, and pigs, four of the most capable terrestrial long-distance swimmers, never colonized Wallacea unaided (Fig. 2).

In 1998, Australian Bednarik demonstrated the contemporaneity of human occupation with a Stegodont-dominated Middle Pleistocene fauna in West Timor (Bednarik, 1999b). His fieldwork in Timor and Roti has involved several Pleistocene sites in the island’s western half (East Timor having become politically stable only recently), focusing on the Weaiwe valley near Atambua.



Seafaring, Fig. 2 Map of southern Wallacea (Nusa Tenggara), Indonesia. The presumed dividing line between the Eurasian and Australian continental plates is shown *dotted*, and Wallace's biogeographical line is

between Bali and Lombok. The *squares* indicate known hominin occupation sites of the Early and Middle Pleistocene

There, a sequence of Pleistocene sediments occurs above estuarine clay deposits containing an abundance of marine shells and snails. This demonstrates an uplift of well over 300 m since they were formed. The Weaiwe Formation, a Pleistocene conglomerate, has yielded remains of *Stegodontidae* from six sites now (Bednarik & Kuckenbug, 1999), and evidence of human presence in the fossiliferous stratum occurs at two, Motaan and To'os (Bednarik, 1999b). At the time of its formation, the Pleistocene occupation layer was located close to sea level, which could itself have been much lower at the time.

All of the islands from Bali to Timor and Roti are well visible from the shores of departure, but once the Middle Pleistocene mariners had settled Timor, they could travel no further. The shores of Australia have never been visible from Timor, at any sea level, and it appears that the lack of visual contact prevented the human colonization of Australia for many hundreds of millennia. The initial landfall in Australia is presently thought to have occurred about 40,000–60,000 years ago. By that time, it appears, the Ice Age seafarers had acquired sufficient experience to venture into the unknown, to depart without the certainty of seeing their destination. It would have been known to them since time immemorial that there was a large landmass to the south. They could have predicted this from plumes of smoke occasionally rising from grassfires in Australia, from cumulus clouds regularly forming over the land, and from the movements of waves, currents,

migratory birds, and turtles. But there is a great leap from merely predicting the existence of land to having the courage of embarking on a journey of no return to an unseen shore.

A good deal of evidence from about 33,000 to 27,000 years ago indicates that many islands near northern Australia had been settled by that time. These amazing seafarers, with their still essentially Middle Paleolithic technology, undertook lengthy journeys to in some cases very small target landmasses (Bednarik, 1997). Most of these islands could not have been sighted until a raft reached their proximity; this is the case with the Monte Bello Islands (100 km from Australia), Gebe Island (west of New Guinea), New Ireland (east of New Guinea), and Buka Island (180 km from New Ireland). It thus seems very probable that the maritime competence of the much later Polynesians was the ultimate outcome of a process that began almost a million years ago.

The complete lack of any direct physical evidence of maritime technology from the entire Pleistocene renders it pointless to speculate about the circumstances of these endeavors without additional information. No sustained replicating experimentation of archaeology had been conducted in relation to this subject before 1996. Since then, the First Mariners Project (<http://mc2.vicnet.net.au/home/mariners/web/mariners.html>) led by Bednarik has set out to determine the most likely means employed by *Homo erectus* in crossing Lombok Strait >840,000 years ago and the most likely

Seafaring,

Fig. 3 Paleolithic bamboo raft in heavy seas on Timor Sea, its bow rising several meters above the water (Photo by author)



circumstances of first landfall by *Homo sapiens* in Australia and elsewhere. The project investigates all demonstrated human sea crossings of the Pleistocene and plans to replicate many of them. Archaeologically derived knowledge about the technology of the periods in question, particularly in stone tool knapping and wood and bone working, serves as a reference source for these projects (Bednarik, 1997, 1999b, 2001a). Some aspects of relevant material use can be replicated precisely on the basis of form of, and work markings on, archaeological finds, as, for instance, Middle Paleolithic bone harpoons or Lower Paleolithic wooden artifacts. Others must be determined according to systematically derived probability estimates based on experimentation. Expeditions endeavor to create authentic conditions for the construction of a series of primitive vessels and their sailing across the sea barriers in question. This involves, for instance, the use of appropriate stone tool replicas in felling and working bamboo and in constructing and sailing the rafts. Hundreds of issues of technology need to be addressed, including the means of carrying freshwater, of fishing at sea, of locating sources of stone tool materials for raft construction, issues of maritime design, and the procuring, selection, treatment, and utilization of materials for the construction of vessels and equipment (Fig. 3).

The first full-size experimental vessel was launched at Oeseli in southern Roti in early

1998 and sailed for sea trials with a crew of 11 (Bednarik & Kuckenburger, 1999). Some aspects of this 23-m-long, ocean-going bamboo raft of about 15 t plus cargo were judged to be unsuitable and the vessel was beached for destructive sampling and material testing. A radically different, simpler design led to an 18-m bamboo raft of only 2.8 t. It travelled with a crew of five men from Kupang to Darwin in December 1998, sailing part of the 1,000-km journey under extreme conditions (Bednarik, 1999b; Bednarik et al., 1999). In March 1999, a simple 11-m bamboo platform set out from the easternmost point of Bali to attempt a crossing of Lombok Strait. It was forced north by strong seas and the attempt was abandoned. But by the end of that year, a similar, 12-m-long simple platform of bamboo, lacking any sail or means of steering, was being built for a second attempt. This vessel was as rudimentary as a raft can possibly be, weighing only 1,080 kg. It crossed Lombok Strait successfully with a crew of 12 men in January 2000. The experiment showed how even a treacherous stretch of sea such as Lombok Strait could be crossed with purely Lower Paleolithic means (Bednarik, 2001b). Similarly, the 12-m *Rangki Papa* ("Father of all Rafts," in the local dialect) succeeded with a crew of 12 in October 2004 in crossing Sape Strait, which separates Sumbawa from Komodo and Flores. In that experiment, filmed by *National Geographic*, the assembly of the 970-kg bamboo vessel took only 4 days. Four years later, a similarly sized raft, this time constructed from green bamboo but



Seafaring, Fig. 4 Use of a firebox on a Paleolithic vessel, the fire having been lit by traditional method (Photo by author)



Seafaring, Fig. 5 A dorado fish just harpooned with a Middle Paleolithic weapon is about to be gutted with a stone flake (Photo by author)

performing outstandingly well, succeeded in crossing the treacherous currents between Lombok and Sumbawa with ten men, as filmed by *BBC*. The experiments in the Mediterranean had commenced earlier, in September 1999, on the coast of Morocco, where two prototype rafts were constructed entirely with Lower Paleolithic stone implement replicas and then taken for sea trials. One of these vessels, a pontoon-type raft, was made of cane, the other of inflated animal skins (Bednarik, 2001a) (Figs. 4 and 5).

The primary purpose of these experiments is to examine each of the many variables involved in Pleistocene seafaring quantitatively, to create the conditions for constructing multiple scenarios within a realistic framework of probability. In this procedure, the confidence that the most probable scenario can convincingly be identified is a function of the variables or determinants accounted for satisfactorily. Therefore, numerous experiments are essential, and all need to be conducted under controlled conditions. While the most sensible, economic, or logical course of action is not necessarily the one always taken by hominin mariners, there are several arbitrary limiting factors. For instance, these journeys had

much to do with survival, and we can reasonably assume that they were on the very limits of the technologically possible at the times in question (Bednarik, 1999c). The most probable scenarios can then be tested by reference to known parameters of technological competence at the time in question. These are derived from the archaeological research forming part of the overall project. This would seem to be the only scientific method available to us to generate informed and plausible explanations for the very early maritime feats of hominins.

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Seafaring in the Polynesian Outliers

Richard Feinberg and Marianne George

Observers, for many years, viewed indigenous Pacific Islands seafaring as a vanishing art, largely confined to the Central Carolinian atolls of Micronesia. Yet, in a number of small, remote Polynesian communities, traditional vessels and knowledge of how to use them are an active, ongoing concern. Our awareness of these systems of knowledge and practice is preserved in works on Ontong Java and Nukumanu (Feinberg, 1995; Haddon & Hornell, 1975 [1936–1938]; Sarfert & Damm, 1929), Taumako (Davenport, 1962, 1964, 1968; George, 1998, 1999, n.d.; Lewis, 1972; Vaka Taumako Project, 1997, 1999), and Anuta (Feinberg, 1988, 1991). Important information also is presented on Kapingamarangi by Lieber (1994) and on Tikopia in Firth's voluminous writings.

Generalizations about these “Polynesian outliers” are difficult. They range from communities like Sikaiana (Donner, 1995), where sailing canoes have been entirely abandoned, to such isolated specks of land as Taumako and Anuta, where traditional equipment and techniques remain in use or are remembered to a remarkable degree. Even in precontact days, the Polynesian outliers incorporated a good deal of diversity.

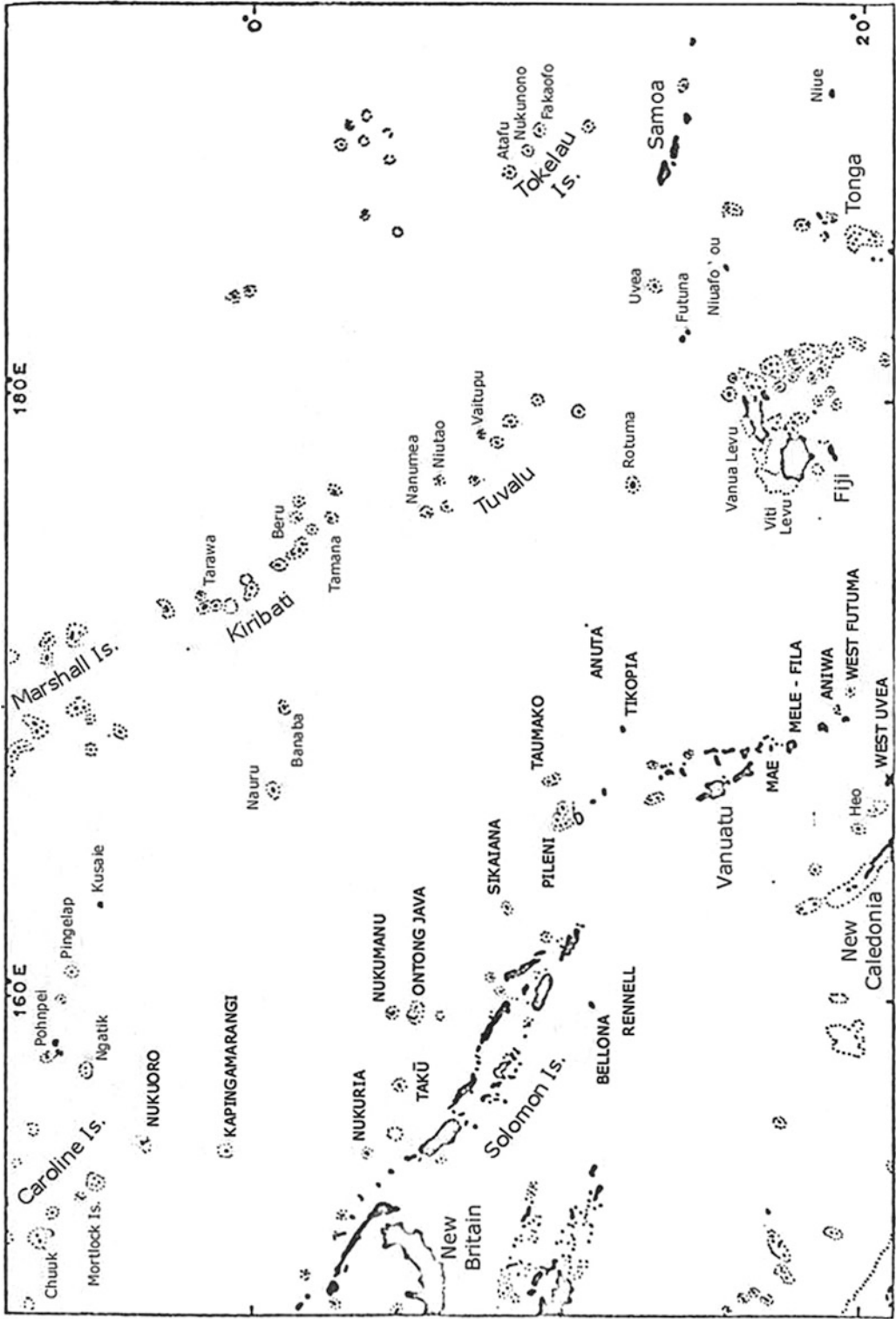
On Ontong Java, Nukumanu, Takuu, and Nukuria, vessels as well as sailing and wayfinding techniques closely resembled those of Micronesia; on Tikopia and Anuta, maritime technology and practice have been closer to the standards typical of Polynesia. Meanwhile, the impressive seafaring technology of Taumako (Duff Islands) and the Polynesian Reef Islands of the eastern Solomons combines elements known from Eastern Polynesia, the central outlier atolls, and Micronesia (Fig. 1).

Canoe Construction and Design

Hull design in the central and northern Polynesian outlier atolls resembles that reported for the Micronesian Caroline and Marshall Islands. This is particularly evident in the voyaging canoes that have been described for Takuu (Haddon & Hornell, 1975) and Nukumanu (Feinberg, 1995; Haddon & Hornell, 1975; Neyret, 1977; Sarfert & Damm, 1929), and in the model voyaging canoes that Takuu craftsmen still produce for sale to art collectors and tourists. These vessels were 40–50 ft long, constructed with deep-V hulls, rigged with triangular pandanus-leaf sails, and were symmetrical from end to end, making bow and stern identical. The outrigger float was significantly shorter than the hull, and small shelters might be built on the outrigger platform, which was always kept to windward when the vessel was underway. These atolls also produced smaller canoes, most of which were round-bottom dugouts, that might be sailed, poled, or paddled. Since the late nineteenth century, large voyaging canoes have no longer been built. On some atolls like Sikaiana (Donner, 1995), canoes have been almost totally abandoned except for very small vessels that are intended for fishing on the lagoon, although there is evidence of significant canoe voyaging in times past. (According to elderly Duff Islanders, the Sikaiana were in regular communication with Taumako prior to the 1917 influenza pandemic, and they ordered and used large voyaging canoes from Taumako.) Small fishing canoes intended for calm water are also used on Ontong Java, Nukumanu, and

Takuu. Somewhat larger canoes may be used to transport cargo to and from visiting ships or for hauling copra and taro from the outer islets. Nukumanu still construct and use large canoes for voyaging to Ontong Java, across 30 miles of open ocean. Contemporary Nukumanu voyaging canoes may be as long as their predecessors, but they are less carefully constructed and resemble the smaller ones in design. They may be rigged for sail, but Nukumanu prefer outboard motors for propulsion, especially on longer journeys. In 2000, Nukumanu islanders told Feinberg that fiberglass motor-driven boats on all of these atolls are gradually replacing canoes (Figs. 2 and 3).

On Taumako (Duff Islands) and the Polynesian Outer Reef Islands of Nifiloli and Pileni, voyaging canoes are called “canoes of Lata.” Lata, a widely recognized Polynesian culture hero, is said to be the first person to build and sail a voyaging canoe of the type known as *te puke*. These are built with a roundish hull that is hollowed out from a single log. The top is boarded over and made watertight, except for the area enclosed by a riser box, which provides access for bailing and stowage of nonwater-sensitive cargo and ballast. When under sail the hulls are almost entirely submerged. The crew stays on one of two platforms that straddle the riser box and outrigger beams. Although there is one outrigger float (*ama*) per canoe, it may be fashioned from as many as four float timbers lashed together, depending on how much flotation is needed. The crew situates itself on whichever platform is most appropriate for sea conditions and the trim of the cargo. The predominantly submarine hull is subject to less surface tension and wave action than more conventional hulls, making them considerably faster. To the best of our knowledge, this hull design is unique to Taumako vessels. (We must note, however, that few ancient hulls have been recovered from Pacific waters. Perhaps, with further research, we will find evidence of submarine hull shapes from other parts of Polynesia.) Like the vessels of the central outlier atolls, as well as some from the Polynesian heartland (e.g., the Tongan *kalia*), *te puke* are equipped with shelters on the outrigger platform.



Seafaring in the Polynesian Outliers, Fig. 1 Map of Polynesian outliers and surrounding islands

**Seafaring in the
Polynesian Outliers,**
Fig. 2 Nukumanu
outrigger sailing canoe
under sail on lagoon



**Seafaring in the
Polynesian Outliers,**
Fig. 3 Small Nukumanu
outrigger sailing canoe
immediately after
launching from beach on
lagoon side of the village
islet



Taumako sails are made from panels of plaited pandanus mats, sewn together vertically to form a graceful, slender foil, or delta wing shape. Unlike many Pacific Islanders who have abandoned pandanus sails in favor of cloth, Taumako sailors prefer pandanus, which they say lasts longer and is easy to maintain and repair. The design resembles “crab-claw” sails of Tahiti and Hawai’i as depicted by artists on early European voyages of exploration, but its symmetrical shape, with long, slender, arcing wingtips, has few parallels in Oceania (Fig. 4).

Most canoes of this description have been constructed on Taumako on order from other

communities in the Santa Cruz Islands and elsewhere in the Solomons. In the 1920s, over 200 *te puke* were observed to be sailing in what is now Temotu Province (Davenport, 1968). Generally, the Outer Reef Islanders specialized in navigation while the Taumako specialized in canoe building.

For a period of a few decades in the middle to late twentieth century, construction of *te puke* was almost abandoned because of depopulation and suppression of voyaging by colonial authorities. The last working *te puke* broke up off Nifiloli in 1963, although a few local vessels of other designs kept sailing between Santa Cruz (Ndeni) and the Reef Islands until the early

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Fig. 4 *Te puke* type voyaging canoe from Taumako island under sail on open sea



1970s. However, since around 1980 – and particularly since the mid 1990s – interest in actively making and using traditional voyaging canoes has revived, in large part thanks to the activities of the Vaka Taumako Project (see below).

Te puke canoes (*nga puke*, pl.) are distinguished from other Taumako vessels by their very large cargo carrying capacity. They are made of heavier and harder woods than other canoe types, have a riser box that lifts the outrigger beams some 3 ft or so above the top of the hull, have a shelter on the windward platform, and are at least 36 ft in length. Older Taumako state that until Lata made the first *te puke*, they depended on double-hulled *vakalua* for interisland travel. *Nga puke*, being lighter and faster, offered superior performance. One that a group of Duff Islanders sailed from Taumako to Vella Lavella in 1980 was observed by a Solomon Islands government ship to be cruising at a speed of ten knots. (In 1979 people of Taumako built a *te puke* to represent the Solomon Islands at the 1980 Pacific Arts Festival in Port Moresby. The voyage from Taumako to New Guinea had to be cut short for political reasons. Local officials required them to travel via Honiara, the national capital, which meant taking a risky and nontraditional route. Those officials then held the canoe so long that the seasonal winds ceased before the crew could navigate the vessel from Vella Lavella in the Western Solomons to Papua

New Guinea.) With their massive outrig and ingenious lashings, *te puke* are also very strong and seaworthy (Fig. 5).

Te alolili canoes are lighter and faster, designed to carry people and light cargo. They range in length from 18 to 33 ft. The Taumako also make smaller, less elaborate outrigger canoes called *te alotovi*, which may or may not be rigged for sail. And they construct monohulled, nonoutrigger paddling canoes, on which they may either rig lateen sails made of rice bags or add a wooden plank to serve as a motor mount. They use these primarily to transport cargo within the Duff Islands and to visiting government ships. For some purposes they, like other islanders, would like to have fiberglass canoes propelled by outboard motors, and in 2001 there were at least two working outboard engines on Taumako. Scarcity of fuel, however, normally precludes their use. As of January 2002, Taumako still had no fiberglass vessels. However, such canoes from Lata, the Temotu provincial capital, occasionally go to the Duffs on emergency missions.

Canoes on Tikopia and Anuta more closely resemble those documented in the so-called Polynesian Triangle. Anuta is a tiny volcanic island with a small reef flat and no protected water. As a result, Anutan canoes tend to be larger than their Tikopian counterparts. Otherwise, they are similar in design. Hulls are of deep-V construction. They are hewn from a single tree and generally

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Fig. 5 “Earth oven” and “fish eye” lashings on cross beams and outrigger struts of *te puke* canoe



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Fig. 6 Outrigger canoe of *vaka pai manu* type, rigged with rectangular sail, on beach at Anuta island



built up with one plank to increase freeboard. Unlike canoes of the Santa Cruz Islands and the Polynesian atolls to the north and west, Anutan craft have a distinct bow and stern, and the outrigger is always kept to port regardless of one's heading in relation to the wind. They range up to about 35 ft in length and average 20–25 ft, with a few that are much smaller. Virtually all Anutan canoes have the same design, with high gunwales and carefully carved bow and stern covers to minimize shipping of water as one passes through the surf and sails on choppy seas. Anutans and Tikopians who live in the central Solomons, either in Honiara or the Russell Islands, have more sheltered water and less time for fishing than their compatriots at home. Their canoes, therefore, are smaller, are usually designed to be

paddled rather than sailed, are not augmented by gunwale planks, and typically lack bow and stern covers. Canoes of this type are known as *tovi*; the larger, more elaborate canoes with ornately carved bow and stern pieces are termed *vaka pai manu* “birdlike canoes.” The bow and stern pieces (*puke*) are intended to resemble birds (Figs. 6 and 7).

Like the Taumako, Anutans still make their canoe hulls exclusively from local materials – primarily wood and sennit cord. They do not use nails, screws, or other commercial fasteners. They occasionally employ a piece of Styrofoam for caulking, and commercial glue sometimes replaces breadfruit sap to help caulk the joint between the plank and the main hull. However, the only commercial product that they use with

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Fig. 7 Anutan outrigger canoe of *tovi* type, on beach in Russell Islands. The canoe is rigged with a lantern holder for catching flying fish at night



Seafaring in the Polynesian Outliers,

Fig. 8 Anutan child paddling a large bowl (*kumete*) through the surf on the reef flat at high tide



any regularity is water-resistant paint, which they apply in an effort to protect the hulls of their larger vessels.

The sail and rigging show more Western influence than the hull. Stays may be commercial rope, and rectangular sails usually fashioned from cotton cloth have replaced the old triangular pandanus-leaf sails. Like many other Pacific Islanders, Anutans were happy to abandon pandanus sails, which become heavy and difficult to handle when they get wet. The rectangular sails were introduced in order to provide more surface area in proportion to the

mast height. This increases the canoe's speed without decreasing stability; the tradeoff is that rectangular sails do poorly beating against a headwind.

In addition to *vaka pai manu* and *tovi*, Anutans recognize outriggerless canoes, which they call *puai vaka* "egg canoes." However, they do not make such vessels. Their closest analogues are large wooden bowls (*kumete*) of the type that might be used for preparing puddings or making turmeric dye. These bowls are vaguely canoe-shaped and can be paddled if the sea is not too rough (Fig. 8).

Sailing Techniques

As Lewis (1972) noted, most of the Polynesian outliers use the Micronesian strategy of sailing with the outrigger to windward. In order to accomplish that, they tack by moving the mast, sail, and rigging to the opposite end of the canoe, converting the old bow into the new stern and vice versa. Tikopians and Anutans have adopted the more common Polynesian strategy of having a distinct bow and stern with the outrigger fixed to the port side of the hull. As a consequence, the outrigger is sometimes in the canoe's lee, and many hulls are constructed with a slight bulge on the port side to help keep the outrigger float from being submerged when the wind blows hard from starboard.

Among outrigger canoes, those of Nukumanu and Ontong Java, with their triangular sails, do a relatively good job of beating into a headwind, and Taumako's *te puke* may do better still. George found that one such vessel, *Vaka Taumako*, could point higher and go faster than her 32.5 ft-long gaff cutter rig. It made better than 5 knots at 75° off the wind in a steep, choppy sea and a 20-knots breeze. In addition to being extraordinarily efficient, the Taumako sail and rigging may be trimmed to suit a wide variety of conditions.

Anutan vessels, with their rectangular sails, do not sail well unless the wind is either astern or abeam. Therefore, Anutans try to arrange their trips in such a way as to avoid having to beat against the wind. For example, their voyages to Patutaka, 30 miles to the southeast, are usually made during the trade-wind season but at a time when the wind shifts temporarily to the north or west. They assume that it will shift back to the southeast within a few days, and they will be able to journey in both directions with a favorable wind. Should they need to travel at much less than a 90° angle to the wind, they either wait for a change in weather, return to their point of embarkation, or stow their sails and paddle into the wind.

Navigation

Those communities that continue moderate- to long distance voyaging have retained much of

their ancestors' knowledge of constellations, movement of astronomical bodies, and star paths. Feinberg (1988, 1995), for example, has documented the continuing astronomical knowledge of Anutan and Nukumanu wayfinders. Conversations with islanders from both communities over a period of several months in 2000 made clear to him that young people have perpetuated this knowledge. At the same time, however, astronomical knowledge in the late twentieth and early twenty-first centuries has apparently declined from what it was a century earlier. Present-day Anutans insist that members of previous generations knew more than they know, and similar views among Nukumanu appear to be confirmed by the reports of Sarfert and Damm, which list many more constellations than islanders recognized in the 1980s.

Both Nukumanu and Anutan navigators maintain their course by swells as much as by the stars, which cease to be helpful during the day or any time the sky is overcast. In this respect, they resemble most other Pacific Island voyagers, many of whom depend on swell patterns even when piloting large ships. Both Nukumanu and Anutans also distinguish between swells and reflected waves, which may be felt at distances of up to 20 miles from land and are useful for making landfall. These are more difficult to discern than ocean swells, and only a few of the most proficient navigators are able to use them effectively. Islanders insist that skill at detecting "land waves" was more widely distributed in their communities in earlier generations. Along with swells, islanders pay attention to wind patterns, which tend to be relatively stable even when stars and the sun cannot be seen.

Like Nukumanu and Anutans, Taumako and Outer Reef Islanders agree that much knowledge of celestial navigation has been lost over the past century. The most authoritative commentator on this point is Taumako Paramount Chief Koloso Kaveia. Kaveia began his voyaging career as a small boy sailing on canoes based at Pileni in the Outer Reefs prior to 1920. Fellow islanders consider him to be the most experienced and distinguished living navigator and voyager. While Kaveia and other Duff Island navigators are

familiar with star paths, however, they consider celestial movements and swell patterns to be secondary to knowledge of the “wind compass” (*nohoanga te matangi*).

Nohoanga te matangi is a comprehensive system that correlates information about wind directions, calendric seasons, and movements of celestial bodies with sea routes. It is not just a wind compass in the unexplained and often partial forms that have been previously reported (e.g., Lewis, 1972). It is a tool, rather like a clearing house or slide rule, for bringing into relationship the various fields of information relevant to planning a particular voyage. Its use also presumes facility with weather magic to control wind and sea states, and this requires good command of the protocols for dealing with one’s ancestral spirits. *Nohoanga te matangi*’s major elements include ten main celestial bodies that are used in navigation plus the two “wing stars” located to either side of each primary star. The “wing stars” are used in cases when the current, sea state, or wind conditions preclude reliance on the central star paths. Navigation also presupposes a working knowledge of *te lapa* – the luminous lightning-like appearances that signal the direction and distance of land (see below).

In addition to wind, waves, and stars, islanders rely on a variety of subsidiary techniques to hold a steady course or to home in on a target island. In recent generations, some of these techniques have been abandoned and receded into legend. For example, Anutans say that dolphins, to which they refer as *nga ariki o te moana* (kings of the ocean) might lead a lost voyager to land. Nukumanu speak in similar terms of meteors, which they term *tanaloa* – the name for one of the great pre-Christian gods in much of Polynesia. Other subsidiary techniques are still relied upon and are apparently effective. Most islanders continue to observe the flight patterns of birds as a technique for land finding. Lewis (1972) has reported patterns of phosphorescence (*te lapa*) which Reef and Duff Islanders continue to employ for the same purpose. George has learned that Taumako navigators can make effective use of this phenomenon at impressive distances. In 1980, Kaveia used *te lapa* to find his way between

the large islands of the Solomons chain, sometimes at a distance of over 110 nautical miles. It also appears that the appearance of *te lapa* from each island or reef has a distinctive character. The phosphorescent flashes shoot across the ocean surface and are easiest to see in the interstices of intersecting waves.

Social Relations

On Nukumanu and Anuta, navigators are admired and respected for their skill, but they do not hold a formal position. An Anutan navigator is known as *tau tai mau kaavenga* (expert at finding star paths), which is more a description the navigator’s skill than a title. In neither community are there rites of passage that mark one’s transition to navigator status; most men have some knowledge in this area, but some have considerably more than others. An expert navigator may come from any descent group and any social stratum, from chiefs to commoners. On both Nukumanu and Anuta, education in the skills of boat building, sailing, and navigation also is informal. There are no navigational schools, nor is there any formal apprenticeship. A novice watches the experts and learns primarily through emulation.

On Taumako, the navigator is a highly trained specialist. Kaveia apprenticed for many years with Pileni relatives, then married and returned to Taumako where he studied navigation with his father. In addition, a Taumako navigator must have a canoe and, in earlier times, contacts or partners on distant islands as well as access to red feather money and other valuables. An enterprising person of low rank can acquire the necessary assets, but high-status males have a clear advantage. Today, education in canoe building and navigation has been incorporated into the Vaka Taumako Project in an attempt to ensure the maintenance of older knowledge and practices.

Change

Seafaring practices have changed in all the Polynesian outliers over the past two centuries, but to

different degrees and in different ways on different islands. The great voyaging canoes (*vaka hai laa* or *vaka fai laa*) of the central outlier atolls have not been produced since the late nineteenth century, but sailors from Nukumanu and Ontong Java continue to make the 30-mile voyage between the two atolls, and they sometimes still use wooden outrigger canoes powered by sail. Sikaiana, at the opposite extreme, has entirely given up production of ocean-going canoes. Even Anutans, whose seafaring activities depend entirely on outrigger canoes of traditional design, who regularly voyage 60 miles to Patutaka and back, and occasionally still sail to Tikopia, a 150-mile round trip, have replaced pandanus sails with cotton cloth or (occasionally) plastic sheets.

While much has been lost, some of the outliers have nonetheless maintained a good deal of their seafaring knowledge and continue to put it to good use. Anutan reliance on wooden *vaka pai manu*, held together with sennit cord, has continued uninterrupted to the present day. Equally impressive is Taumako's self-conscious effort to reverse a decline in seafaring knowledge through the Vaka Taumako Project – an educational enterprise intended to promote mastery of traditional canoe-building and voyaging skills among younger community members by constructing several *te puke* and *te alo* voyaging canoes and sailing them to remote destinations under the direction of skilled navigators. In 2001 the Vaka Taumako Project launched the first class of over 50 students. The students aim to learn eight necessary skills for building and navigating voyaging canoes using only traditional Polynesian methods. A 65-foot by 40-foot canoe house was erected to shelter and maintain three vessels that have been produced by the project. It is hoped that this canoe house will also serve as a classroom and archive for Taumako voyaging knowledge, and to accommodate visiting students and voyagers.

See Also

- [Maps and Mapmaking: Marshall Island Stick Charts](#)

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Seaports of the Maya

Rafael Cobos

The marine seacoast of the Maya area extends for more than 1,000 miles and is composed of different environments, which include sandy and rocky beaches, mangrove swamps, and riverine deltas (Fig. 1). These environments were occupied during pre-Hispanic times by individuals who founded numerous communities and built an elaborate infrastructure that caused the rise of seaports during the Preclassic (1200 BCE–AD 200), Classic (AD 200–1050/1100), and Postclassic (AD 1050/1000–1550) periods (Andrews, 1990; Nondédéo, 1998; Vail, 1988).

Ancient Maya seaports are found either directly on the coast or less than 2–3 miles inland. As with other seaports in the world, ancient Maya seaports were permanently settled by individuals engaged in different duties that included the maintenance of their community by political, economic, social, and ideological activities. Ancient Maya seaports also provided shelter to sailors, traders, and the merchandise they transported. They facilitated the transportation of goods and gifts that were moved between close and distant regions; they were also used to satisfy basic as well as secondary needs of communities located a few miles inland or hundreds of miles away.

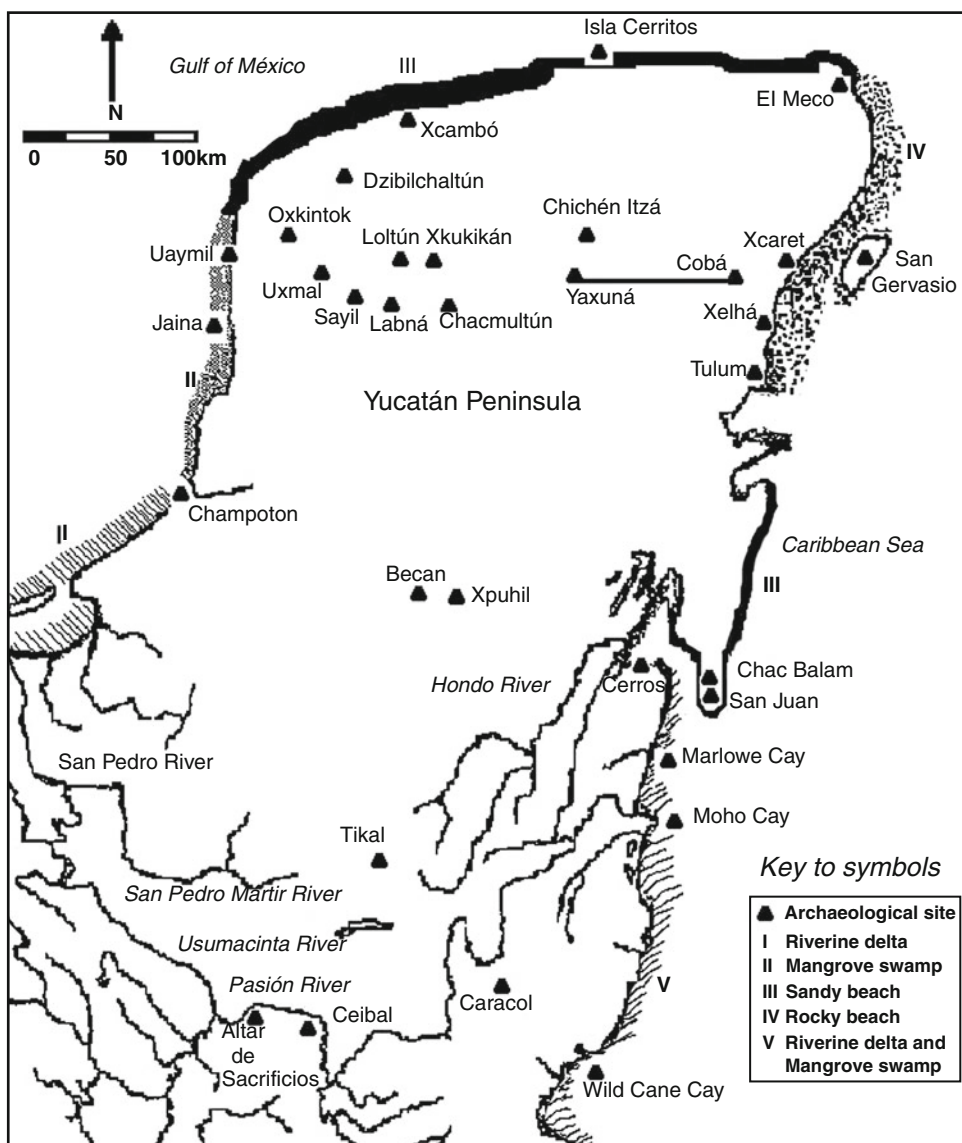
Early explanations about the function of ancient Maya seaports were put forward during the first half of the twentieth century. For instance, it has been suggested that settlements such as Jaina, located in western Yucatán, and Xcaret, located in front of Cozumel Island, functioned as an island necropolis and a port of embarkation to an offshore island respectively. Over the past 50 years, however, the Maya marine seacoast has been the focus of several systematic archaeological investigations, and previously assigned functions of pre-Hispanic coastal communities such as Jaina have been rejected. Regarding Xcaret, archaeological

investigations have corroborated its role as a port of embarkation to Cozumel Island as well as a complex seaport that functioned during the Classic and Postclassic periods (Andrews, 1990).

Systematic research conducted on several pre-Hispanic Maya coastal communities that functioned as seaports indicates that these ancient settlements were arranged in distinctive ways and date to different periods. The unique characteristics of ancient Maya seaports were the result of social, economic, political, and ideological processes that each of them experienced throughout time. For instance, archaeological investigations have revealed three different forms through which these marine seacoast settlements interacted with other marine coastal sites as well as with inland settlements. These three forms of interaction include the coastal port associated with a regional capital, trans-shipment seaports, and the seaport as a social, political, and economically independent unit. A description of each one of these follows.

The Coastal Port Associated with a Regional Capital

Isla Cerritos and Chichén Itzá exemplify the interaction and dependency generated between a top-ranking political unit and a lesser-ranking site. Isla Cerritos is an island off the northern coast of Yucatán whereas Chichén Itzá is located 55 miles directly south and inland (Andrews, Gallareta, Robles, Cobos, & Cervera, 1988; see also <http://www.ncf.edu/andrews/Index.html>). The material expression of that dependency suggests that the coastal community of Isla Cerritos was subordinate to the political and economic control of Chichén Itzá to the extent that the main architectural group of the island reproduces on a lesser scale a group of buildings that characterize the regional capital, which include a temple, altar, and colonnaded hall. The contemporaneous nature of the coastal port and the regional capital is demonstrated by the presence of the same types of commercial and utilitarian ceramics. Obsidian found in the coastal port as



Seaports of the Maya, Fig. 1 Maya seaports located in México and Belize

well as in the regional capital reflects the same supply sources. The remains of shells discovered both in Isla Cerritos and in Chichén Itzá are integrated into the body of archaeological evidence, which demonstrates the interest that the regional capital had in making its presence felt in a very specific sector of the northern Yucatán coast between AD 900 and 1050/1100.

It has been proposed that other settlements located on the seacoast of Belize functioned as ancient Maya seaports of major inland capitals. The examples include Marlowe Cay associated with Altun Ha, Ramonal-Condemed Point linked to Shipstern, and the Northern River Lagoon associated with Colhá. However, the relationship between Marlowe Cay, Ramonal-Condemed

Point, Northern River Lagoon and major inland capitals continues to be speculative, because none of these Maya seaports has been investigated in detail.

Trans-shipment Seaports

This type of seaport, which served a specialized function, is recognizable by the following characteristics: they are small settlements in comparison to other inland communities, they exhibit a minimum of formal architecture, they are strategic points in the movement of commodities and/or merchandise among regions, and they contain a wide variety of exotic goods by having been part of a complex system of trade or exchange (Inurreta, 2004). To date, the best examples of trans-shipment ports analyzed in the Maya area are San Juan, Chac Balam, Moho Cay, Wilde Cane Cay on the coast of Belize, and Uaymil on the northern coast of Campeche (Guderjan & Garber, 1995; Inurreta, 2004; McKillop, 1996, 2005).

For instance, Uaymil emerged as an important coastal port on the northern Campeche coast after AD 800. Uaymil maintained a close relationship with Uxmal and Chichén Itzá, and the archaeological evidence uncovered at Uaymil confirms that this port was founded during the apogee of those two major political units. Uaymil functioned as another link in the chain of coastal sites that facilitated the transport of commodities between Chichén Itzá, located in central Yucatán, and the regions of the western Guatemala highlands, central Veracruz, central México highlands, and western México. When we consider the very strategic location of Uaymil on the northern Campeche coast, along with its internal characteristics and the archaeological materials found at the site, we can interpret that Uaymil functioned as a trans-shipment station. Uaymil's role was to facilitate the movement of merchandise and goods that eventually arrived at Chichén Itzá via Isla Cerritos. Evidently, Uxmal - the great capital of the western portion of the northern

Maya lowlands located 55 miles inland – also benefited from the specific role that Uaymil played during the tenth and eleventh centuries (Inurreta, 2004; <http://www.famsi.org/researchreports/bysite/uaymil>).

The Independent or Autonomous Seaport

The third type of seaport documented in the Maya area is characterized by its autonomous role. In other words, this type of port was a social, political, and economically independent entity. The autonomous seaport was never under the jurisdiction or hegemony of larger and powerful political units, and this condition allowed such a port to rise and flourish in several environments and during different periods in the Maya area. For instance, Cerros in Belize was an independent seaport located in a region where the riverine delta meets the open sea. By the Late Preclassic period, Cerros functioned as a complex seaport with a site center housing monumental buildings with elaborate architecture and a large residential zone surrounding the site center. The strategic position of Cerros on the coast of northern Belize allowed this site to have access to commodities and merchandise that were transported from inland to the Caribbean Sea or vice versa (Robertson & Freidel, 1986).

Xelhá was another autonomous seaport located on the east coast of the Yucatán Peninsula. Xelhá was first settled during the Late Preclassic period or around 100 BC, and was continuously occupied until the sixteenth century (Andrews, 1990). The archaeological evidence suggests that Xelhá functioned as an independent seaport during the Early and Late Classic periods and seems to have played a key role in the exchange system of obsidian, jade, and other goods that circulated along the Caribbean Sea and between Central America, Belize, and northern Yucatán (Guderjan & Garber, 1995; McKillop, 1996; McKillop & Healy, 1989). The role played by Xelhá as an important seaport

might be attributable to its geographic position along an important marine route that was established by the fifth century.

At Cozumel Island the site of San Gervasio became a seaport by the ninth century. San Gervasio is located in the northern sector of Cozumel and the archaeological evidence suggests two important moments of occupation at the site. The first of these moments dates between the eighth and tenth centuries and corresponds to the Classic period. The second moment of occupation dates from the eleventh to the sixteenth centuries and this period ends around 1518 when the first European conquerors arrived at Cozumel. The role played by San Gervasio as an autonomous seaport during the pre-Hispanic era is attributed to two precious goods produced at the island – cotton for textiles and honey (Sabloff & Rathje, 1975). Sixteenth-century historical documents confirm the production of cotton and honey at Cozumel whereas the archaeological data corroborate the important role that these precious goods must have had on the economy of San Gervasio (Roys, 1957).

Other Maya seaports that rose as independent political entities include Jaina, Xcambó, and Tulum. The first two seaports flourished during the Classic period whereas Tulum's apogee dates to the Postclassic period (Andrews, 1990). The importance of Xcambó as a seaport is attributable to its control of the large salt beds located on the central coast of Yucatán. It seems Xcambó controlled the production of salt and exported this mineral to other communities located in the Maya area and beyond. The function of Jaina and Tulum as seaports might be explained by their strategic midpoint position along the commercial sea routes that dominated the Gulf of México (Jaina) and the Caribbean Sea (Tulum). In fact, Tulum was spotted by Spanish conquerors early in the sixteenth century and they described it as a town larger than Seville.

This information represents a small part of the tremendous potential that awaits discovery

regarding the function of ancient Maya seaports. Future archaeological investigations will continue to contribute to the increase in our knowledge of the features that characterize such complex coastal communities.

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Seki Kowa

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SEKI Kowa, also called Takakazu, was born about 1642, probably in Fujioka, Gumma, Japan. Seki is his surname, and Kowa is the Chinese reading of characters, so the Japanese reading is Takakazu. His middle name is Shinsuke and pen name is Jiyutei. He was born into a samurai warrior family, the second son of UCHIYAMA Shichibei Nagaakira (unknown–1662) (In official documents, Uchiyama Nagaakira died in 1646, but Seki Kowa's youngest brother, Uchiyama Nagaaki (1661–1725) was born in 1661. So Uchiyama Nagaakira was alive in 1661 at least. More, Uchiyama Nagaakira's father was died in 1662 in these documents, thus we conclude that Uchiyama Nagaakira was died in 1662 (Jochi 2005, p. 19).), and he became a son-in-law of SEKI Gorozaemon (Gorozaemon is a middle name, and the first name is unknown. Perhaps he is Seki Yoshinao (1591–1673) or part of another Seki family, Seki Toyofusa (about 1632)) and succeeded to the SEKI family. First he became an auditor of TOKUGAWA Tsunashige (1644–1678) at Kofu (now Kofu, Yamanashi) about 1661, then a chief of the meal service section (His annual salary was 200 *pyo* (150 kg of rice)). He lived at Yamabushi-cho (now Minami Yambushi-cho, Shinjuku, Tokyo) about 1695. In 1704, he became a chief of the Store Room of the Shogun's family, and finally became a landlord of a 300-person village. (His annual salary was 300 *pyo*, which is the same as being a landlord of a 300-person village. The samurai warrior who earned over 200 *pyo* could be received in an audience by the Shogun) The Shogun's government normally kept the family records of landlords. But since Seki Kowa's son-in-law,

Shinshichiro (1690–unknown) lost his position, owing to his gambling activities, we cannot fix even Seki Kowa's birth year exactly.

Seki studied mathematics under TAKAHARA Yoshitane. Takahara Yoshitane was a disciple of MORI Shigeyoshi, who wrote the *Warizansho* (Books of Division 1622), the second mathematical book in Japanese. But Takahara Yoshitane was little known for his mathematical works. Basically Seki taught himself mathematics, using famous texts of Chinese and Japanese mathematicians, such as the ► *Yang Hui Suan Fa* (Yang Hui's Method of Computation 1275), which he copied in 1661, and SAWAGUCHI Kazuyuki's *Sampo Ketsugi Sho* (Solving Mathematical Questions 1659). He amended works of other mathematicians, and founded the Seki-ryu school. He is generally considered the founder of Japanese mathematics (Figs. 1, 2, and 3).

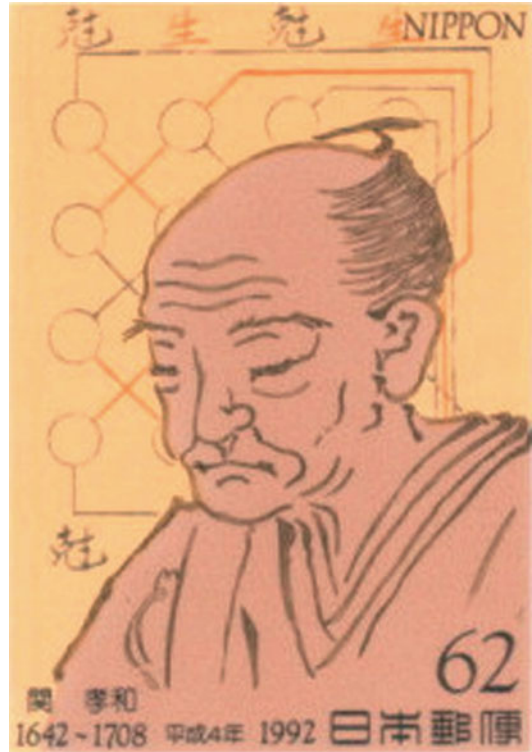
The *Tianyuanshu* (lit. Celestial Element Method, Chinese Algebra System) had already been introduced from China by Zhu Shijie's *Suan Xue Qi Meng* (Introduction to Mathematics Studies 1299). This system was for the *Suan Chou* (*Sangi* in Japanese) – counting rods, in the Song and Yuan dynasties in China. In the Ming dynasty, however, new counting tools, *Suanpan* (*Soroban* in Japanese) – abacus – became popular, since no mathematicians understood the *Tianyuanshu* even in China. Japanese mathematicians taught the *Tianyuanshu* by themselves using a Korean edition of the *Suan Xue Qi Meng*. Sawaguchi Kazuyuki was the first Japanese mathematician who mastered it.

Traditional Chinese mathematics used counting tools, *Suan Chou* or *Suanpan*; they had no algebraic symbols. The position of rods (or beads of *Suanpan*) indicates numbers and the power of unknown numbers. This system could only operate with unknown numbers. Seki Kowa created *Tenzan-jutsu* (Japanese algebra system), which could operate with unknown formulae, making it possible to solve complicated problems.

Seki called his method *Endan-jutsu* or *Bosho-ho* (Methods of writing by the side).



Seki Kowa, Fig. 1 Picture from the Kojukai, Shimminato, Toyama



Seki Kowa, Fig. 2 Stamp issued in 1992

MATSUNAGA Yoshisuke (1693–1744), a mathematician of the Seki-ryu school, renamed it *Tenzan-jutsu*. Seki indicated one unknown number using one Chinese character and created the symbols of calculations and powers. And he solved the $1,458^\circ$ equation in the *Hatsubi Sampo* in 1674.

His works cover the following categories:

1. Japanese algebra system
2. Solution of higher degree equations
3. Properties (e.g., number of solutions) of higher degree equations
4. Infinite series
5. Approximate values of fractions
6. Indeterminate equations
7. The method of interpolation
8. Obtaining Bernoulli numbers using *Ruisai Shosa-ho*
9. Computing the area of polygons
10. Principle of the circle
11. Newton's formula using the *Kyusho* method
12. Computing the area of rings
13. Conic curve lines
14. Magic squares and magic circles
15. Mamakodate (Josephus question) and Metsuke-ji (the game of finding a Chinese character)

These categories had been very problematic before him, and he offered excellent solutions.

In 1712, TAKEBE Katahiro (1664–1739), Seki's student, edited Seki's works and published the *Katsuyo Sampo* 1 year before Bernoulli's *Ars Conjectandi* (1713). Seki obtained Bernoulli numbers using the *Ruisai Shosa-ho* system. It is a typical example of his mathematics. He also worked with what we call Pascal's triangle.

Seki computed to higher powers and obtained the fraction numbers of the last line of Table 1;

$$\begin{aligned} \lambda_0 &= 1, \lambda_2 = 1/2, \lambda_3 = 1/6, \lambda_4 = 0, \lambda_5 = -1/30, \\ \lambda_5 &= 0, \lambda_6 = 1/42, \lambda_7 = 0, \lambda_8 = -1/30, \lambda_9 = 0, \\ \lambda_{10} &= 5/66, \lambda_{11} = 0 \end{aligned}$$

Seki Kowa, Fig. 3 Seki's tomb at Jorin-ji temple, Ushigome, Edo (now Benteen-cho, Shinjuku, Tokyo)



Seki Kowa, Table 1 Shosa-ho's table, Chap. 1 of the Katsuyo Sampo (1712)

	1	1											
x^2	1	2	(1)										
x^3	1	3	3	(1)									
x^4	1	4	6	4	(1)								
x^5	1	5	10	10	5	(1)							
x^6	1	6	15	20	15	6	(1)						
x^7	1	7	21	35	35	21	7	(1)					
x^8	1	8	28	56	70	56	28	8	(1)				
x^9	1	9	36	84	126	126	84	36	9	(1)			
x^{10}	1	10	45	120	210	252	210	120	45	10	(1)		
x^{11}	1	11	55	165	330	462	462	330	165	55	11	(1)	
x^{12}	1	12	66	220	495	792	924	792	495	220	66	12	(1)
Power	1	2	3	4	5	6	7	8	9	10	11	12	13
	1	$\frac{1}{2}$	$\frac{1}{6}$	0	$-\frac{1}{30}$	0	$-\frac{1}{42}$	0	$-\frac{1}{30}$	0	$\frac{5}{66}$	0	

These are just the same as Bernoulli's numbers. He was able to compute too much higher numbers than other mathematicians before him, and he obtained the general rule by the inductive method. He, and mathematicians of his school, used this system habitually.

Seki died in Edo (now Tokyo), on December 5, 1708 (October 24, 1708, in the Japanese calendar).

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Seki Kowa's published writings are *Hatsubi Sampo* (Edo 1674) and *Katsuyo Sampo* (Edo 1712). Other MS papers are collected in the Library of the Japan

Academy (Nihon Gakushuin), Tokyo and Tohoku University Library, Sendai and others. Many important works were discussed in Vol. 2 of Fujiwara, 1954. Shimodaira, 1965 (Vol. 1) devoted many pages to Seki Kowa. All the works of Seki Kowa have been collected by Hirayama et al. (Eds.), 1974. One of the best English discussions is Mikami, 1912.

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Settlements in Egypt: Alluvial Settlements in the Nile Valley (and Delta)

David Jeffreys

The River Nile forms a long thin strip of alluvial valley floor, rarely more than 15 km wide, through the hyper-arid desert of north-eastern

Africa before fanning out into the Nile Delta north of Cairo. The Nile is fed by two main tributaries, the Blue and White Niles, which merge near Khartum in Sudan, and a minor tributary, the Atbara. The Nile Delta is now reduced to two main distributary channels, the Rosetta (Rashid) and Damietta (Dumyat) branches, with outlying residual canals serving Alexandria in the west and Pelusium in the east; in antiquity up to seven channels are recorded.

Before the construction of the first Aswan Dam in the late nineteenth century, the Egyptian Nile valley and the delta were subject to annual flooding due to monsoonal rains over the Ethiopian plateau which boosted the volume of the Blue Nile. The flood lasted several months, rising in late spring and receding in early autumn, and brought a new deposit of high-nutrient alluvium which provided the basis for Egypt's successful agricultural economy. Despite the popular picture of an idyllic, non-labour-intensive labour cycle, this flood-recession economy was vulnerable, being almost entirely dependent on a successful or "perfect" flood (i.e. neither too high nor too low), and left little resilience to fluctuation (Hassan, 1993, 1997): there is for example hardly any evidence for man-made water storage facilities or canals serving marginal or extended catchment areas.

During the Epipalaeolithic period the Nile was building in response to changes in sea level; subsequently there was a down-cutting phase, with the result that the only surviving Palaeolithic sites are now preserved in the high terraces flanking the existing river valley. During the Neolithic (from 10,000 BCE) the valley had again been building with alluvial sands and silts accumulating at the rate of about 10 cm per century. The valley floor today presents as a virtually dead flat plain dropping slightly to the eastern and western edges, and forming a slightly convex appearance with the highest, heaviest and newest sediments closest to the river. Throughout Egypt and Sudan the course of the Nile and its subsidiaries is of relatively low sinuosity, although this changes across the delta flood plain.

Upstream of Aswan and the first cataract lies that section of the valley known as Nubia (also

Kush, Wawat or Napata); during the 3,000 years of pharaonic culture in Egypt there was a long and complex history of exchange and interaction between the two polities. Culturally Egypt and Nubia seem to follow a similar trajectory up to the foundation of a unified cultural and political Egyptian state in about 3,000 BCE, with similar traditions in their lithic and ceramic industries. Thereafter Egyptian material culture develops differently into the highly distinctive pharaonic style in dress and body decoration, pottery production and metalworking, visual representation, and architecture. In Egypt both valley and delta were divided administratively into large land parcels or provinces called *nomes*, each with a local capital. In the Valley these nomes generally straddled the river; in the Delta they were determined by the changes in the distributary system and usually lay between the main channels. In Egyptian texts Nubia is recorded in less detail, and seems to be divided into ethnic/geographical zones: the part north of the second cataract, closest to Egypt's southern frontier at the first cataract, was under Egyptian control through most of the second and first millennia BCE. The desert regions outside the alluvial corridor were only lightly inhabited, except for the Saharan oases, but were exploited for their mineral contents, especially gold, high-grade building and sculptural stones, and pigments, and as an access to the trading routes of the Mediterranean and Red Seas and the African interior.

Settlement archaeology in Egypt is, astonishingly, still in its infancy (O'Connor, 1993), and may never achieve its full potential with the onset of modern threats including industrial and residential development, climate change and the rise in the groundwater table brought about by the construction of the Aswan high dam in the 1960s. Traditionally the emphasis in exploratory fieldwork has been on the burial grounds of the valley edges and visible monumental architecture within established archaeological sites such as Thebes (Luxor). A critical factor in the recognition and recovery of information from Nile valley settlements is the mean rise of the valley floor over the past 5,000 years, which has had the effect of obscuring even quite well established

settlements or those which have been abandoned by the river as it has shifted course. Stratigraphically shallower and more deeply buried sites, such as the older, shorter-lived towns, and ephemeral rural habitations of all periods, tend therefore not to survive unless they are on the higher ground at the valley edges. We are just beginning to understand just how much settlement archaeology has yet to be recorded from the examples of sites such as Avaris-Piramesse, the sixteenth- to twelfth-century royal capital in the northeastern delta also known by the modern names of Tell el-Daba/Qantir (Bietak, 1996), where magnetometer survey has recently revealed huge areas of built environment lying beneath what is now agricultural land which is in private or municipal ownership. In Memphis, a far more extensive settlement area was visible in the eighteenth and nineteenth centuries than can be seen today. How zones such as these are to be treated in the future is yet to be resolved: no effective strategy has yet been proposed for their management, and archaeologists currently proceed largely through private negotiation, returning the land for agricultural or other destructive use after survey and/or excavation.

In Egypt, discussion of settlements has therefore focussed until recently on an impossibly small sample of sites which are almost all atypical of conditions in the Nile valley, leading one leading Egyptologist in the past to suspect that pharaonic Egypt was a "civilization without cities" (Wilson, 1960). The handful of sites most often referred to are:

- The Middle-Kingdom (Twelfth Dynasty, eighteenth century BCE) site of Illahun (also known as Lahun or Kahun);
- The New Kingdom (fifteenth-fourteenth centuries) artisan village of Deir el-Medina on the Theban west bank;
- The newly discovered workers' quarters to the southeast of the Giza pyramids; and
- Particularly the large royal Eighteenth Dynasty (fourteenth century) town of Amarna, including its outlying suburbs, flanking necropolis, and another artisans' compound somewhat similar to Deir el-Medina.

None of these towns are strictly speaking “alluvial”, however: they are all establishments built (probably deliberately) on the desert edge, whose layout was almost certainly unaffected by the river, and apart from Amarna they are attached to specific monumental building projects, all funerary. Paradoxically there is better data for Nubia, largely due to the intensive series of archaeological surveys in that region, especially the international UNESCO project in the 1960s in advance of the construction of the Aswan High Dam (Säve-Söderbergh, 1987). Some of the best-known settlements of all periods are now those in Nubia, as for example the large town and cemetery at the local capital of Kerma, lying in the Nubian heartland above the second cataract (Bonnet, 1995, 2000).

In both Egypt and Nubia the tendency was to construct the main settlements in the two main areas not constricted by the floodwaters, that is on the desert margins and the riverside levees (Butzer, 1976). It is no accident that many of the earliest known settlements are on the lower desert regions to the ► east and west of the main alluvial zone, although this itself raises the question whether traces of settlement in other parts of the valley might have been removed by movements in the main and subsidiary channels. In the Delta settlement was more or less confined to natural marine and riverine sand banks (often called “turtlebacks”) projecting above the general level of the flood plain. Largely due to the lack of any effective national survey strategy over the years, the impression is given of a gradual migration of settlement from the desert to the flood plain, as seen in the case history of the important pre- and proto-dynastic site of Hierakonpolis (Hoffman, Hamroutsh, & Allen, 1986). Regional studies at this site and elsewhere (e.g. Memphis) have shown that river movement in both directions was a determining factor in the success and survival of flood plain communities, and the study of post-pharaonic settlements has shown that viability was dependent on the means to provide high ground beyond the reach of the floodwaters. This might be through lateral migration following the levees, or the rapid vertical development of residential building to maintain

high, dry living conditions. Over time continued occupation must have been impossible to sustain in certain areas: there are some graphic accounts in more recent times of urban blight due to the rising water level, and examples of structures dating from the Late Antique (Byzantine) period having to be abandoned during the seventeenth to nineteenth centuries as the mean level of the inundation gradually rose. Many towns co-operated in the maintenance of river defences on an annual basis, and the fear of their failure is occasionally alluded to in the pharaonic literature. Paradoxically, religious sites in valley regions were especially vulnerable, because they tended to remain low-lying: they were sacrosanct and did not attract vertical accretion through new construction over the decay of earlier building fabric. There is even some evidence that temples were in fact occasionally flooded: such events were regarded as catastrophic, despite the symbolic inundation-based character of religious architectural ideology. It is worth remembering that while this was an ever-present danger in antiquity and into medieval times, conditions have been quite different for the past century, with perennial irrigation, and increasing urban and suburban sprawl, now possible through the construction of the successive Aswan dams. An appreciation of former living conditions is therefore possible today only through pre-twentieth century documents, notably the excellent series of early landscape photographs dating from the mid-1800s to the early 1900s.

Other considerations aside, it is clear that a seasonal pattern in behaviour and mobility must have applied to the annual rhythm of urban living: during the sowing and harvesting seasons, farmers may well have spent most of their time in temporary accommodation in the countryside, migrating to the desert edges and the main urban areas during the flood. In view of the impermanence of many kinds of rural and at least some kinds of urban habitation, it is perhaps interesting that there should be evidence of a considerable attachment to place. Eulogies of cities survive in the written record, probably the best known being a “hymn” to the city of Memphis (Camino, 1954).

The more typical types of flood plain town share several defining characteristics. Some, but by no means all (and perhaps even a minority) had defensive walls, although the river and municipal earthworks seem to have doubled as military defences; all known large conurbations contain at least one religious centre, with the identity of the cult varying with location; these temples and shrines often had enclosure walls of their own, which have a defensive appearance but are not necessarily built primarily for that purpose (Smith, 1998). Future work may confirm the suspicion that some major cities, such as Memphis and Thebes, which are often described as capitals, may at times have been long ribbon developments built along the river banks rather than the more familiar model of a highly nucleated, densely occupied urban core (Jeffreys & Tavares, 1994).

The only complete town site that survives today in any detail above ground is Amarna, built by the pharaoh Amenophis III and his son Akhenaten (Amenophis IV) in the fourteenth century BCE as a breakaway royal city for the celebration of a new solar cult (Kemp & Garfi, 1993). Significantly this is one of only a very few urban regions to be surrounded by boundary markers in the form of rock-cut inscriptions declaring the intention of the ruler, ranged along both sides of the valley but in sight of the town centre. This was probably because the territory for the new foundation was appropriated from the existing nearby provincial capital of Khmunu (Classical Hermopolis Magna, modern Ashmunein), although the major part of the town is on the low desert, not the alluvial plain, probably to maximise the agricultural yield of the requisitioned section of valley floor. Amarna consists of distinct zones representing various discrete functions:

- Residential zones of all social ranks (royal palaces, elite villas interspersed with dependents' quarters, and purpose-built artisanal compounds);
- Religious (temples and solar shrines), economic (food storage and food preparation areas);

- Administrative (police barracks, libraries or storage for diplomatic correspondence) and
- The outlying mortuary districts, including the royal tombs, segregated from the private tombs in a valley due east of the town centre.

Amarna illustrates an interesting tendency in settlement selection, which highlights the importance of landscape symbolism: the "royal valley" is thought to focus sight lines on the central feature of the rising sun, and is embodied in the Egyptian name of the town, Akhetaten ("horizon of the Aten" or sun-disk). In the same way prominent landscape features at other sites acquired symbolic importance, notably at Thebes with its pyramid-shaped mountain on the west bank, and Memphis, at the southern apex of the Delta, with its high-profile layered cliffs to either side (possibly the origin of its earliest name "White Walls").

Even within communities some common features can be identified. Temples conform to a highly distinctive and recognisable pattern, with almost universal features such as the twin-towered pylon featuring flagpoles and monumental statuary, colonnaded courtyards and hypostyle halls with clerestory windows and embrasures; dark and restricted inner sanctuaries; artificially created sacred lakes, and not infrequently causeways, often flanked by ritual statuary such as sphinxes, which linked separate enclosures. There even seems to be a standard plan for houses, the quadripartite ground floor layout incorporating an entrance chamber, communal room and split back section used for different purposes and sometimes featuring a stair to an upper storey or roof terrace (there is evidence for multi-storey structures from both archaeological and representational evidence). Living units of this kind usually occur in terraces along axial or subsidiary streets and alleys, as at Amarna, Deir el-Medina, Karnak and Memphis. Other evidence comes from funerary architecture: it is very likely that tomb plans at different times reflect the general layout of town houses as also illustrated in tomb scenes, with (for example in the New Kingdom) entrance halls, atria that might contain pools or gardens, and back rooms which become

sanctuaries and statue rooms in the funerary context. Some tombs at this time have miniature pyramids over or behind the sanctuary, which are certainly an exclusively funerary feature.

For elite residential structures we are more or less dependent on Amarna, where they take the form of villas or compounds freely dispersed through the northern part of the city, and Illahun, where they form a suite of terraces either side of the main street. Relatively few royal palace structures are recorded in any detail (Malqata at Thebes; Piramesse/Qantir in the delta; three separate palace compounds at Amarna; Balat (Ayn Asil) in the Dakhla Oasis (Soukiassian, Wuttman, & Schaad, 1990); the short-lived early New Kingdom site of Deir el Ballas just north of Thebes; and a supposedly “ritual” palace at Memphis). There are in addition small “palace” structures incorporated in the large mortuary temples of the Theban west bank, especially those of Ramesses II (the Ramesseum) and Ramesses III (Medinet Habu) (O’Connor, 1989).

See Also

- ▶ [Hairstyling Technology and Techniques Used in Ancient Egypt](#)
- ▶ [Metallurgy in Egypt](#)
- ▶ [Stone in Ancient Egypt](#)
- ▶ [Tombs in Ancient Egypt](#)

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Sexagesimal System

Marvin A. Powell

The sexagesimal system was an ancient system of counting, calculation, and numerical notation that used powers of 60 much as the decimal system uses powers of 10. Rudiments of the ancient system survive in vestigial form in our division of the hour into 60 min and the minute

into 60 s. Origins of the system of counting are essentially irretrievable because they lie in the period before the invention of writing. They are associated with the ancient Sumerians, whose language incorporated the only known system of sexagesimal counting. The Sumerians were probably also the inventors of the system of calculation, which seems to have its origin in a system of counters (small clay objects also referred to as tokens or calculi) representing the units 1, 10, 60, 60×10 , 60^2 , $60^2 \times 10$, and 60^3 . This counter-calculation system may go back as far as ca. 3500 BCE. The method of numerical notation apparently originated from the system of counters by adapting it to a form that could be represented in writing when the first writing system was invented ca. 3000 BCE.

By 2000 BCE this had developed into a system of sexagesimal place notation that functioned like our decimal system but with several important distinctions. Whereas the decimal system uses ten unique symbols, plus a period or comma to separate fractions from integers, the fully developed sexagesimal system of notation used only two unique symbols (those for one and ten) and essentially ignored our distinction between fractions and integers. These features, as well as lack of a symbol for zero, reflect its origins in the system of calculating with counters: zero would not have been represented in a system of counters (obviously, one does not count something that does not exist), and unique symbols for the integers 1–60 would have been excluded for practical reasons. Lack of a distinction between fractions and integers goes back to the fact that fractions are essentially alien to prehistoric systems of counting. Names for small quantities that we would call fractions are based on subdivisions of the weight system (*mina* and *shekel*) and were clearly not thought of as fractions in our sense of the word. In keeping with this picture is the symbol for medial zero that appears in Babylonian mathematical texts of the late first millennium BCE. This so-called *zero* is really nothing but a “spacer” symbol and reflects the practice (occasionally observable in surviving texts) of leaving a blank space where we would place a zero.

During the third millennium BCE, this Sumerian sexagesimal system was adopted, along with

other features of Sumerian culture, by Semitic-speaking Akkadians, and the Akkadian language, which – like Sumerian – was written in cuneiform script on clay tablets, served as the vehicle for its diffusion and preservation. As an essential part of the education of scribes, it was still very much alive when Greeks conquered the Near East in the time of Alexander the Great. The two centuries of Greek presence in Mesopotamia (330–129 BCE) facilitated the incorporation of Babylonian mathematical astronomy into the Western tradition, and with it also came knowledge of the Babylonian sexagesimal system. This, however, seems never to have been used systematically by Greeks outside of Babylonia. Division of the circle into 360° is a vestige of the Babylonian system that has been transmitted to us by the Greeks.

Modern knowledge of the existence of an ancient sexagesimal system goes back as far as the recovery of Greek mathematics, beginning in the Renaissance. Little, however, was known about its true character until the middle of the nineteenth century when decipherment of cuneiform writing revealed the system in its developed form of the first millennium BCE. Speculations about its origins have tended to postulate conscious creation, as opposed to gradual evolution. The 360-day year and choice of 60 as base (because 1, 2, 3, and 5 are all prime factors) are among these theories, all equally without evidence. Only in the twentieth century has the Sumerian system of counting become relatively well understood, and the role of clay counters as prototypes of number symbols has only become clear in the last decade.

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Shamanism in Pre-Columbian Mesoamerica

Keith Jordan

Shamanism is a term used by anthropologists and historians of religion to describe similar systems of religious thought and practice centered on the role of ritual specialists who enter trance states in order to communicate with the supernatural world for the benefit of their communities. Derived from an indigenous Siberian term for such a practitioner, shamanism is distributed through Asia from Siberia south to Korea and Vietnam. Across the Pacific, it is characteristic of Inuit culture and of many Native American groups throughout North, Central, and South America. It has been used as a model for understanding religious experience and ritual process in New Guinea and other regions of Oceania and to classify the belief systems of peoples from the San Bushmen of southern Africa to the pre-Christian Lapps. It has been posited as the first human religion, the inspiration behind the cave art of Ice Age Europe, and even suggested as prevalent in Bronze and Iron Age Europe.

The shaman is a specialized ritual practitioner who is adept at entering altered states of consciousness understood as journeys to the spirit world. Ritual, asceticism, music, and hallucinogenic plants may be employed to facilitate entry into visionary experiences. The other world entered by the shaman may be conceptualized as the land of the dead, the realm of animal or nature spirits, or the domains of various deities. At least in Asian and American shamanism, the universe is pictured as divided into upper, middle and lower worlds, connected by a central vertical axis, often a World Tree spanning the cosmos from the bottom of the underworld to the farthest regions of the sky. The shaman is able to visit these other worlds by traversing the central axis or similar portals, often via a state experienced as flight, in order to interact with supernatural beings for the good of the community. The

purpose of the voyage may be to obtain cures and defeat witches on behalf of an individual client, as is frequent in small hunter-gatherer societies, or to control weather, promote the fertility of game and agriculture, and predict the future. Generally, shamans are “called” to their vocation by unusual hallucinatory experiences, personality traits, dreams, or by a prolonged or severe illness. They train by serving as apprentices to older shamans, and frequently attain full status by initiation rites and/or visionary experiences in which they are symbolically killed and reborn to their new identities. In many varieties of shamanism, the specialist cultivates a relationship with an animal spirit as a familiar and/or alter ego, and is believed to take the form of this animal when traveling the spirit world.

Shamanic practices are still prevalent among some contemporary Native Mesoamerican groups, notably many Maya communities in Chiapas, Yucatan and Guatemala, where shamanism mingles with Christian beliefs, and the Huichol of northern Mexico. Because of these ethnographic observations and because of the shamanic features of pre-Columbian cosmologies, anthropologists and art historians have employed shamanism extensively over the past several decades as a heuristic device for understanding ancient Mesoamerican beliefs. However, some of these interpretations seem to be better founded than others.

The so-called Olmec culture of the Early to Middle Formative Periods (ca. 1500–400 B.C.E.), centered on the Mexican Gulf Coast states of Veracruz and Tabasco, has been conceptualized by many scholars as the “mother culture” of Mesoamerica, the origin of the basic traits shared by all later Middle American civilizations and of an art style diffused from central Mexico to El Salvador and Honduras. More recently, other archaeologists argued that the Olmec were a “sister” culture to their contemporaries and successors. Rather than originating the art style associated with them by champions of the “*cultura madre*” view, they may have produced the finest and most monumental expressions of a pan-Mesoamerican art style which did not originate on the Gulf Coast. Olmec portable stone

carvings frequently depict men who appear to be transforming physically into jaguars, the most common animal ally or alter ego for modern Central and South American shamans. In some of these images, human features predominate, while in others varying mixtures of human and feline traits seem to represent shape shifting in varying degrees of progress. One of these figures, now in the Princeton Art Museum, bears an engraving of a toad on its head, and toad bones occur in refuse at the Olmec site of San Lorenzo. This is further evidence for shamanic practice: *Bufo marinus* and other toad species are a source of potent hallucinogens. The shamanic model, as proposed by Peter Furst, F. Kent Reilly and others, fits the evidence well in this instance, though caution is always required in comparing the visual culture of a Mesoamerican group which has left us no written records with ethnographic data collected thousands of years later and from across wide expanses of North, Central, and South America. Equally intriguing but uncertain are interpretations of the body postures of Olmec portable figures as positions facilitating meditative states and the cultivation of trance.

Olmec monumental reliefs at the sites of La Venta and Chalcatzingo, and paintings at Oxtotitlan, showing elaborately costumed figures emerging from the mouths of monsters, have also been given a shamanic interpretation. Reading backwards, from the beliefs of contemporary Maya shamans and the inferred practices of their Classic Maya predecessors, these saurian, ophidian and/or feline mouths represent symbolic portals into the earth and underworld, or perhaps to the celestial realms. The richly garbed figures are Olmec kings performing the functions of the shaman, in these instances journeying to the spirit world to obtain adequate rainfall and agricultural bounty for their polities. They may be the earliest instances of a conception of otherworldly portals in zoomorphic form that has survived to the present Mesoamerica. The difficulty, however, with readings of this sort is that they are inferences based on chains of extrapolations from the historic to the pre-Hispanic Maya and then back to the Olmec. Even assuming the continuity of use of such motifs, disjunctions in their meaning

might be expected over time and across geographic and linguistic boundaries.

The late Linda Schele used the shamanic beliefs and practices of contemporary Maya as a fruitful analog for comprehending Classic Maya ritual and iconography, like the images of ancestors conjured through "Vision Serpents" by the bloodletting rites of Classic Maya kings. These represent supernatural portals to the realm of the ancestors and are analogous to the supernatural serpents that swallow and excrete contemporary Maya shamans in their initiatory experiences. Similarly, her work led to the identification of a class of supernatural beings represented in Classic Maya art as the spirit alter-egos of Maya rulers, called *wayob* in the accompanying texts. Her work has received considerable support from the ongoing decipherment of Maya glyphs but is not without its critics. These point out, among other things, that the autosacrifice of blood from their tongues and genitals by Maya rulers may not be physiologically conducive to trance states as claimed in Schele's original formulation.

The iconography of ceramic sculpture accompanying burials in the Late Formative to Classic shaft tombs of West Mexico has been interpreted by analogy to the shamanism of the Huichol and other contemporary indigenous groups. The most prominent proponent of this approach, anthropologist Peter Furst, identifies horn-like protrusions on the heads of some anthropomorphic figures as a mark of shamanic status akin to the coiffures of historic Sioux medicine men and the horns of shamanic figures in Asian myths. First interprets the emaciated or skeletal state of some of the humans in West Mexican ceramic effigies as representing forces of renewal rather than death, by analogy to the initiation experiences of contemporary shamans who are stripped of their flesh in visions and reconstructed by the spirits in their new identity as ritual practitioners. (Jill Leslie Furst has used the same complex of imagery as a fruitful heuristic device for interpreting the meaning of skeletal deities in Mixtec manuscripts as gods of fertility and rebirth.) The geographic proximity of these West Mexican sites to the

current territory of the Huichol and other tribes with strong shamanic traditions supports Furst's readings, but again caution is required in generalizing meanings across great expanses of time. Contra Furst, Mark Miller Graham interprets the "horns" of West Mexican tomb figures as conch shells symbolic of rulership. While not dismissing the presence of shamanic themes and imagery in this art tradition, he emphasizes the manipulation of such ideas by pre-Hispanic political elites to maintain their status, over what he criticizes as the ahistorical generalizations about visionary experiences in Furst's writings.

In other instances, the attempt to read ancient Mesoamerican images through a shamanic lens seems strained and stretched. Some scholars seem to interpret every form, material, and function of any given pre-Columbian art object as related to shamanism, as though the culture consisted of little other but such religious practices. A recent catalog of pre-Columbian art from Mesoamerica, lower Central America, and the Andes in the Michael Carlos Museum at Emory University seeks to interpret almost every formal and iconographic feature of portable objects like ceramic vessels in terms of ethnographic observations of shamanism often removed in time by centuries and often by geographical distances of hundreds of miles. Designs on Central American ceramics, for instance, related to the altered perceptions of the shamanic trance; the rattles attached to effigy vessels attempt to evoke the sound of animal allies. All of these interpretations are brilliant and creative. Some may be quite accurate, while others may be stretching the concept of shamanism as a hermeneutic tool for interpreting pre-Columbian art to its limits and beyond. In the present state of knowledge and absence of written records for most of this material, these interpretations are largely unverifiable. There is always the risk of projecting the ethnographic present onto the archaeological past, when, because of the lapse of intervening centuries and the major cultural changes wrought by Christianity and European conquest, ancient beliefs may have been quite distinct from their latter-day descendants in the same region. When

analogies to pre-Columbian material are sought in modern shamanistic complexes as far away from Mesoamerica as the North American Plains and the Amazon, their explanatory value becomes more questionable.

Recently, some Mesoamerican scholars, notably the American art historians Cecelia Klein and Esther Pasztory, have sharply criticized the characterization of pre-Columbian art and religion as shamanic. They point out that most societies described as having shamanistic religions in the ethnographic literature operate on a far less complex level of social organization than the civilizations of Mesoamerica. They question the validity of using a construct developed to explain religious behavior among hunter-gatherers or small villages for understanding Mesoamerican state-level societies, like the Aztec and Maya. In the case of the Aztec at least, it is clear that religious life was dominated not by shamans but by a vast bureaucratic hierarchy of priests, most of who were probably not natural born visionaries. Although the mercurial Aztec deity Tezcatlipoca may have had shamanic origins, he was the patron deity of the Aztec monarchy. For the Classic Maya, hereditary sacred monarchs performed the rites characterized as shamanic—clearly a different social context than most of the behaviors classified as shamanism in other parts of the world. On the other hand, Furst contests these critics' categorization of shamanism as limited to relatively egalitarian hunter-gatherer groups, pointing out the dominance of shamanism in several northern South American agricultural town societies.

Some critics equate the use of shamanism to explain pre-Columbian cosmology and symbolism with the romantic primitivism of the New Age movement and its fetishization of Native American religions. Yet, much of Schele's and others' work on Classic Maya shamanism has been confirmed by—and has stimulated—recent epigraphic work. It appears that the beliefs of modern Native Mesoamericans can serve as springboards for framing hypotheses about the ways of their ancestors, but caution is needed to avoid overspeculation and casting the past in the mold of the present.

See Also

► Cosmology in Mesoamerica

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Shanghan Lun

Richard Bertschinger

The *Shanghan Lun* (Treatise on Cold-Induced Fevers) by Zhang Zhongjing was written about AD 210. It is the first important practical work in Chinese medicine that has come down to us. The legend is that within a period of 10 years nearly two-thirds of Zhang's village died of illness, mostly from infectious diseases. Zhang, seeing so much suffering, forced himself to find a way to save them, and looked up the ancient prescriptions and read the ancient books. At the end of the third century, after the political turmoil accompanying the breakup of the Han dynasty, the book was reorganized and edited. In the eleventh century, the Song scholar Lin Yi further recompiled and divided it into two sections: the *Shanghan Lun* as we know it today and the *Jingui Yaolue*

Fang Lun (Treatise on the Golden Casket Collection of Prescriptions).

Most admirable in Zhang was his scientific approach to medicine. He berated doctors who used secret remedies to dupe people, saying “what looks magnificent on the surface may be rotten underneath.” He attached great importance to close observation and early treatment of conditions, adjusting the remedies to suit the disease and changing the medicine as the cure progressed. He deplored the frequent use of purgatives. As a mild laxative he prescribed pig’s bile mixed with vinegar poured into the rectum through a ► [bamboo](#) tube. He observed the fluctuation in temperature during fevers, and devised a model for the progression of disease based upon the separation of Yin and Yang into *Shaoyang*, *Taiyang*, *Yangming*, *Shaoyin*, *Taiyin*, and *Jueyin*. This has been a most influential categorization in Chinese medical literature.

Earlier works had recorded the reaction of the pulse to pathological conditions, but Zhang extended his theory to include the pulse’s reaction to the effects of drugs.

About 200 simple herbal medicines were then known, of which the most common were emetics, purgatives, and antipyretics. For instance rhubarb, sodium sulfate, and croton plant were used as purgatives. For reducing fever there was scutellaria, cinnamon bark, ephedra, and bupleurum. As emetics the stalks of various gourds or melons, and parts of the gardenia were recommended. Such remedies are now in use throughout the world. Rhubarb, for instance, was introduced into Europe in the fifteenth century, and imported up to the nineteenth century. The action of ephedra has been mimicked by modern drugs and is invaluable in asthma.

As analgesics and sedatives, various parts of the aconite plant and almond were used. Almond extracts are still used to relieve coughing. Aconite was toxic, but with extreme care it could be useful as a cardiac tonic and nervine. Ginger, licorice, dates, onion roots, and orange peel were used as digestives.

Artificial respiration is mentioned and the use of it in suicides by hanging. In cases of poisoning, water was forced down the victim’s throat to

wash out the stomach – much as in modern hospitals. In diet, Zhang also forbade the use of food derived from animals which had died from disease, and stressed the importance of proper storage and hygiene.

His whole work is a clear example of early scientific method. His manner, most obviously suited to herbal medicine, has been largely adopted by the modern Chinese in their presentation of Chinese traditional medicine. With its differentiation of disease by signs and symptoms, it guides the student into a clear etiology, differentiation of condition, treatment plan, and prescription – whether treatment by acupuncture, herbal medicine, massage, diet, or therapeutic exercise is intended.

See Also

► [Zhang Ji \(Zhang Zhongjing\)](#)

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Sharaf al-Dīn al-ṭūsī

Jan P. Hogendijk

Little is known about the life of Sharaf al-Dīn al-Muẓaffar ibn Muḥammad ibn al-Muẓaffar al-ṭūsī. He was born in ṭūs (Iran), probably around 1135. He spent part of his life in Syria and Iraq, and died in Iran around 1213. He had a number of pupils, including the famous polymath Kamāl al-Dīn ibn Yūnus.

Sharaf al-Dīn al-ṭūsī was one of the best mathematicians of the Arabic tradition. His most important work is a treatise on cubic equations, in which he develops the theory quite beyond the limits reached by al-Khayyām. The Arabic mathematicians only considered positive coefficients, and they therefore distinguished various types of cubic equations, such as $x^3 + bx = c$, $x^3 + c = bx$, $x^3 = bx + c$, $x^3 + ax^2 = bx + c$, $x^3 + bx = ax^2 + c$, and so on. For all these types, ‘Umar al-Khayyām indicated a geometrical solution of a positive root x (negative and zero roots were not taken into account). For al-Khayyām, the coefficients a , b , c were not in the first place numbers: a was a line segment, b was a rectangle, and c was a parallelepiped. Using these data, al-Khayyām constructed two conic sections, and he supposed that these ► [conics](#) intersected in a point P . He then constructed x by means of P . It is obvious that this procedure only works if point P exists. For some types of cubic equations (for example $x^3 + bx = c$ and $x^3 + bx = c$) it is easily proven that a point P always exists, so the equation always has a root x . For other types of cubic equations (such as $x^3 + c = bx$) P may or may not exist, depending on the coefficients of the equation. The only way in which al-Khayyām could find out whether point P existed was by actually drawing the conic sections, which could be done with limited accuracy (it is unclear whether al-Khayyām ever constructed a root x this way, because the subject seems to have been of theoretical interest only). Thus it was not precisely clear when a cubic equation like $x^3 + c = bx$ had a root.

For the particular case of $x^3 + c = ax^2$, some predecessors of al-Khayyām had shown that a root x exists if and only if $c \leq (4/27)a^3$. Thus these mathematicians knew in advance whether a root existed, and they only needed the conic sections to construct x . Sharaf al-Dīn showed that similar (but much more complicated) conditions exist for all types of cubic equations which do not always have positive roots. He meticulously proved the correctness of these conditions by means of the methods of “geometrical algebra” used by Euclid in Book II of the *Elements*.

He then gave a geometrical construction of the roots x , and (unlike al-Khayyām) a numerical procedure, which could be used to approximate the roots with any desired accuracy. In the theory of cubic equations, no further progress was made until the discovery of the algebraical solution in Italy after 1500.

In addition to his treatise on equations, Sharaf al-Dīn wrote two short works on elementary geometry. He also invented the “linear astrolabe,” consisting of a staff with a plumb line and two cords. The staff contained the markings of the North-South line of an ordinary astrolabe. Although this instrument is easier to construct than an ordinary astrolabe, it does not look nice and it is not user-friendly. Thus it is not surprising that no examples have survived.

See Also

- [Ibn Yūnus](#)
- [Umar al-Khayyām](#)

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Shell Middens of the Coast of Balochistan

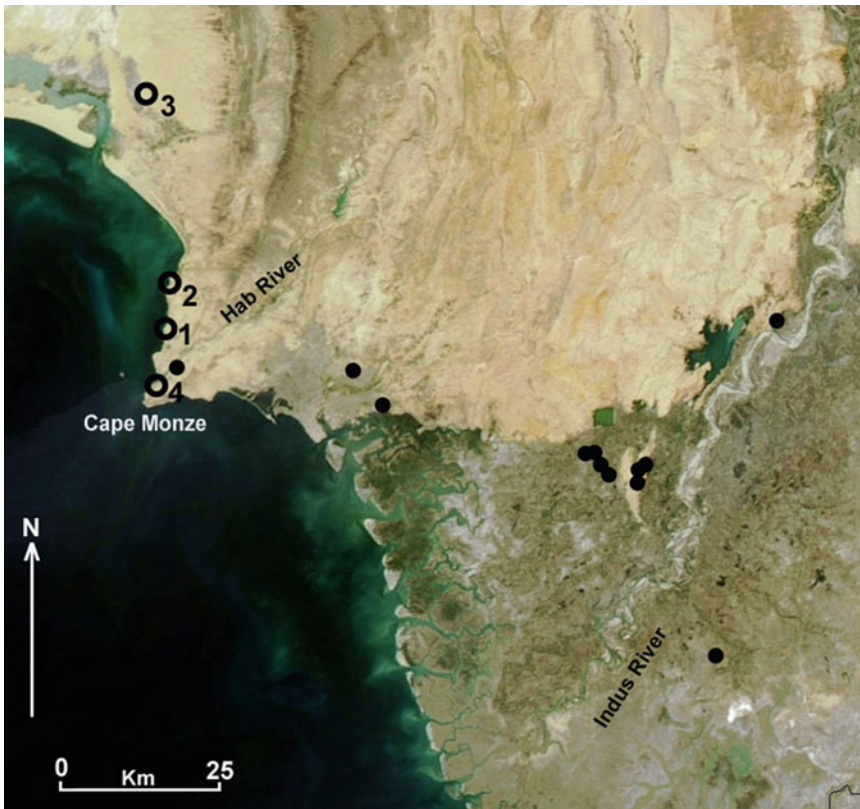
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According to Arrian, the Greek historian, the region that extends west of the Hab River,

which divides Sindh in the east from Las Bela in Balochistan in the west, has been known since the Hellenistic times to have been settled by the Oreitai, an ethnic group similar to the Ichthyophagi (McCrindle, 1973), although no archaeological trace of their presence has ever been recorded during the surveys made in the area (De Cardi, 1983; Khan, 1964, 1979; Raikes, 1967–1968; Stein, 1943). In effect the first traces of prehistoric shellfish eaters were discovered by chance, when Professor A. R. Khan of Karachi University showed me, in his museum, a few decolored specimens of *Terebralia palustris* mangrove shells he had collected a few years before along the shores of a small bay called Daun, some 15 km south of Cape Gadani, in Las Bela province. A brief visit paid to Daun in January 2000 led to the discovery of a few shell middens (Biagi, 2003–2004, 2004, 2013), while

many others were recovered between 2004 and 2008, south of the same bay and on the Pleistocene marine terrace that raises from the beach just to the southeast (Biagi, Fantuzzi, & Franco, 2012). Further surveys conducted along the southeastern coast of Las Bela in the following years have shown that shell middens with different characteristics and variable chronology exist in many places (Fig. 1) among which are Gadani and Phuari Headlands (Biagi, Nisbet, & Girod, 2012–2013) and the shores of Lake Siranda (Biagi, 2011; Biagi, Girod, Nisbet, & Fantuzzi, 2013a; Biagi, Girod, & Nisbet, 2013b). Shell middens are places where the debris from eating shellfish and other food has accumulated over time. They can contain shellfish remains; bones of fish, birds, and land and sea mammals used for food; charcoal from campfires; and tools made from stone, shell, and bone. Shell middens tell us



Shell Middens of the Coast of Balochistan, Fig. 1 Location of the sites mentioned in the text: 1 Daun, 2 Capes Gadani and Phuari, 3 Lake Siranda,

4 Sonari. The smaller black dots show the location of other radiocarbon dated mangrove and marine shell sites in the Indus Delta (Sindh)



Shell Middens of the Coast of Balochistan, Fig. 2 Daun: distribution map of the shell middens with their respective numbers

a lot about Aboriginal activities in the past. The types of shells in a midden can show the type of marine environment that was used and the time of year when Aboriginal people used it (Kristiansen, 2002).

The Balochistan Sites

Daun

As mentioned above, prehistoric shell middens were discovered in three distinct spots around the Bay of Daun and its surroundings, where they cover a roughly rectangular area between $24^{\circ}59'18.08''$ – $25^{\circ}00'27.29''$ N and $66^{\circ}42'19.35''$ – $66^{\circ}43'07.22''$ E (Fig. 2). They are

represented by heaps or scatters of fragmented mangrove shells, mainly *Terebralia palustris*, although specimens of *Telescopium telescopium* and *Anadara uropigmelana* also occur. Among the sites, a special role was undoubtedly paid by shell midden 1 (Fig. 3), on the surface of which 50 pitted crushing stones with pecked round or oval grooves were recorded, most probably anvils used for opening shellfish (Figs. 4, 5, and 6). The site also yielded a few chipped stone artifacts made from both Gadani dark red flint and other varieties of chert most probably derived from a source located in the interior Las Bela. In addition to site 1, site 10 is also unique. Located somewhat far from the others, well sheltered between volcanic rocks, its surface is



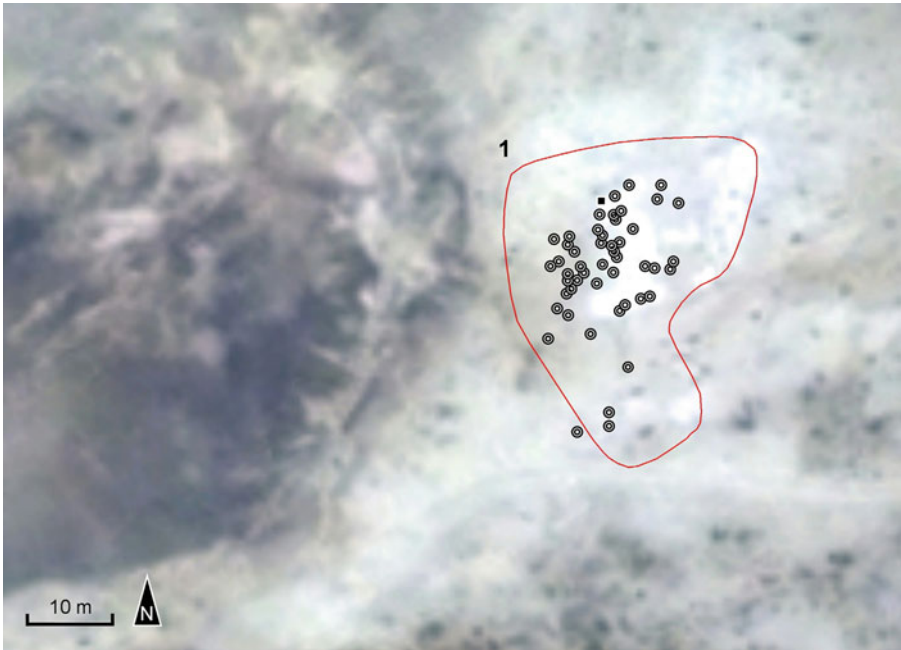
Shell Middens of the Coast of Balochistan, Fig. 3 Daun: shell midden Daun 1, in the center of the picture taken from Daun 10



Shell Middens of the Coast of Balochistan, Fig. 4 Daun: shell midden Daun 1, with a concentration of ground stone anvils in its center



Shell Middens of the Coast of Balochistan, Fig. 5 Daun: characteristic ground stone anvils, in the center of Daun 1



Shell Middens of the Coast of Balochistan, Fig. 6 Daun: distribution map of 50 ground stone tool anvils recorded from Daun 1



Shell Middens of the Coast of Balochistan, Fig. 7 Daun: shell midden Daun 10 photographed from the south

characterized by mangrove gastropods in a very high state of fragmentation (Fig. 7). Narrow bladelet small cores (Fig. 8) and geometric, microlithic chipped stone tools, among which are one lunate and one trapeze, were collected from its surface (Biagi, Fantuzzi, & Franco, 2012, Fig. 12). Other shell middens located further south are sometimes grouped together. Their distance from the present Arabian Sea coast varies from 60 to 700 m (Fig. 9). Seventeen out of 29 sites have been radiocarbon dated mainly from samples of *Terebralia palustris* shells. The analyses yielded very interesting results, which help us follow the environmental changes that took place in the surroundings of the bay between the first half of the seventh and the end of the fifth millennium BP (Fig. 10). They show that Neolithic shellfish gatherers first visited the bay when favorable conditions led to the establishment of mangrove environments. The area was almost uninhabited during the Copper Age and visited again during the Mature Indus Civilization, to be finally abandoned around the end of the Bronze Age (Fig. 11).

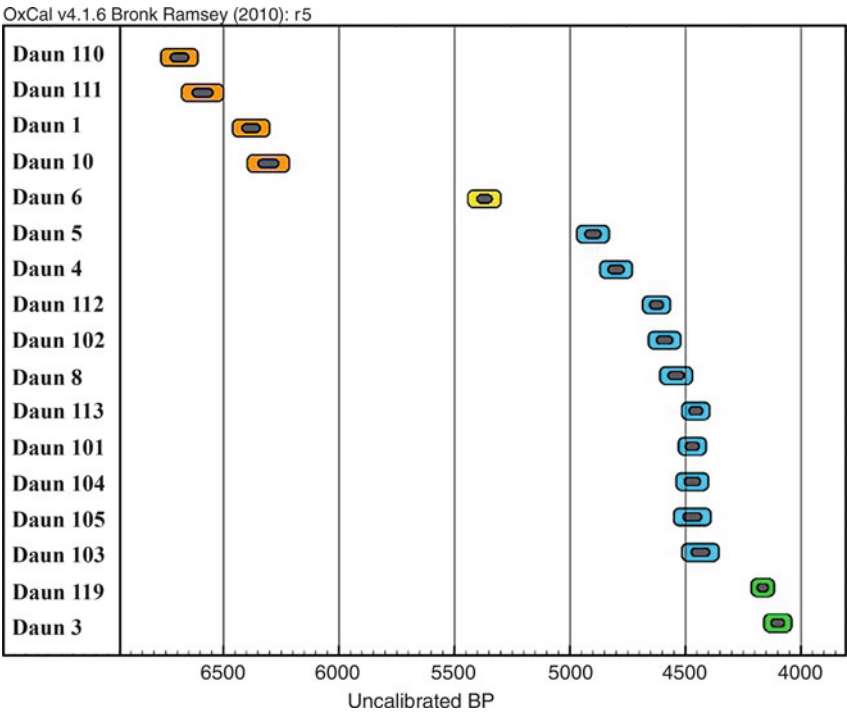
Gadani and Phuari Headlands

Gadani is a small promontory, 87 m high, easy to recognize because of the pinkish color of the Parh limestone formations that characterize it (Khan, 1973). The cape is separated from Ras Phuari, some 3.5 km to the south, by a strip that runs in NNE–SSW direction, in the center of which flows a small, seasonal stream called Kunari Dora (Fig. 12). The territory has a complex sedimentary sequence, characterized by Bela Ophiolites (Sarwar, 1992) and Parh limestones (Naseem, Sheikh, & Qadeeruddin, 1996–1997), the latter containing good quality, dark red flint nodules that were exploited in prehistory since the Mesolithic for making tools (Figs. 13, 14, and 15). Prehistoric sites, mainly shell scatters containing a few chipped stone artifacts and potsherds, were discovered on both capes during three brief surveys conducted in 2002, 2011, and 2012 (Biagi, Nisbet, & Girod, 2012–2013). The AMS results obtained from four mangrove (*Terebralia palustris*) and marine (*Purpura panama*) shell samples have shown that both capes were

Shell Middens of the Coast of Balochistan, Fig. 8 Daun: flint microlithic prismatic core with microbladelet detachments on the surface of Daun 10



Shell Middens of the Coast of Balochistan, Fig. 9 Daun: distribution map of the shell middens Daun 110 to Daun 117 with the location of one net sinker (*star*), one anvil (*circle*), and one flint core (*square*)

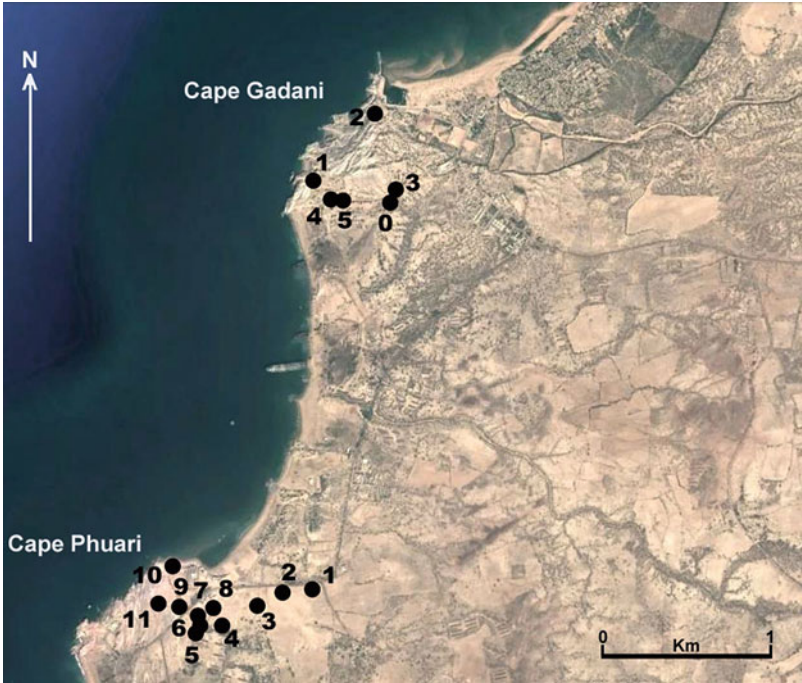


Shell Middens of the Coast of Balochistan, Fig. 10 Daun: scatterplot of the uncalibrated BP radiocarbon dates obtained from mangrove and marine samples from the shell middens

Shell Middens of the Coast of Balochistan, Fig. 11 Map of Balochistan



Shell Middens of the Coast of Balochistan, Fig. 12 Distribution map of the sites discovered at Capes Gadani, in the north, and Phuari, in the south



Shell Middens of the Coast of Balochistan, Fig. 13 Cape Gadani, in the background, photographed from Cape Phuari



Shell Middens of the Coast of Balochistan, Fig. 14 Cape Gadani: area in which the prehistoric sites 4 and 5 were discovered in the center of the photograph. The cape is in the background

sporadically settled during the middle of the fifth millennium BP, when mangrove swamps flourished in the area, and the end of the second millennium BP, when the seasonal gathering of marine shellfish had taken place (Fig. 16).

Lake Siranda

Intensive surveys carried out between 2011 and 2013 by the Italian Archaeological Mission have shown the importance of the archaeological region surrounding Lake Siranda, a shallow basin some nine miles long and two miles wide that receives seasonal water from the Watto River and is sometimes filled with summer monsoon rains. Siranda depression, which is considered by some authors a playa remnant of the Sonmiani Lagoon (Snead, 1966, 1969), formed by a gradual recession of the sea (Minchin, 1907), is delimited by sand dunes that elongate in north–south direction along its western side (Snead & Frishman, 1968). Its shores are dotted with prehistoric shell middens that are easy to recognize because of the

presence of mangrove shell fragments, mainly *Telescopium telescopium* and *Terebralia palustris* gastropods. Many sites have been discovered along the southeastern low terrace of the lake. Given that more than 70 shell middens of different shape, size, and age have been so far discovered, we can assume that Siranda was repeatedly visited or temporarily settled for the gathering of shellfish mainly during the Neolithic (Fig. 17). Copper and Bronze Age sites have also been recovered as shown by the results from the AMS dates obtained from 27 middens, which attribute them to a period comprised between the second half of the eighth and the second half of the fifth millennium BP (Fig. 18). Along the lake perimeter, which shows different morphologic characteristics region by region (Fig. 19), shell middens occur as real mounds up to 3 m thick (Fig. 20), small mangrove shell scatters (Figs. 21 and 22), and thin, almost circular sites, up to some 75 m in diameter (Fig. 23). The material culture remains from the Neolithic shell middens consist of chipped stone tools often obtained from Gadani dark red flint,



Shell Middens of the Coast of Balochistan,
Fig. 15 Cape Gadani: dark red Gadani flint natural block and tools on the surface of one of the prehistoric sites

among which are geometric microlithic inserts. They are represented by lunates and isosceles trapezes obtained from microbladelet blanks (Fig. 24). Coarse stone tools were also recovered, among which are lower querns and anvils (Fig. 25), as well as a few net weights. The results of the surveys carried out around the lake show that the depression was a shallow tidal lagoon surrounded by mangroves at least during the Neolithic and Chalcolithic periods. The basin emptied most probably around the end of the Bronze Age when the sea definitively reached the present-day level. At present some of the lake's surfaces are covered with millions of *Melanoides tuberculata* freshwater gastropods (Fig. 26) that might contribute to the interpretation of the events that took place after the retreat of the sea. The AMS dating of a *Melanoides* sample retrieved in situ from a profile close to site

2 (Figs. 16, 27, and 28) yielded the result of 830 ± 30 uncal BP (GrA-57527), a date that marks some important event connected with the freshwater filling of the lake.

Sonari

Sonari is a very important Bronze Age village built on a terrace located at some 25–30 m of altitude west of the Hab River mouth (Fig. 29). The site was discovered by Professor A. R. Khan in the 1970s and never reported in any of his papers. The terrace was revisited in January 2001 (Biagi, 2004) and systematically surveyed in August 2013. Apart from the above Bronze Age fishermen village that consists of rectangular stone structures, a few of which are covered with *Meretrix* marine bivalves (Fig. 30), traces of older shell middens have been recorded on the same terrace, at least one of which is to be attributed to the Neolithic because of the presence of characteristic lunate microliths. The Bronze Age village has been radiocarbon dated to dated to 4780 ± 60 uncal BP (GrA-59839) and 4850 ± 60 uncal BP (GrA-59837) from two specimens of *Meretrix* marine bivalves (Biagi & Nisbet, 2014). From its surface come many net sinker (Fig. 31) ground stone tools, among which is a saddled lower quern, and a few potsherds.

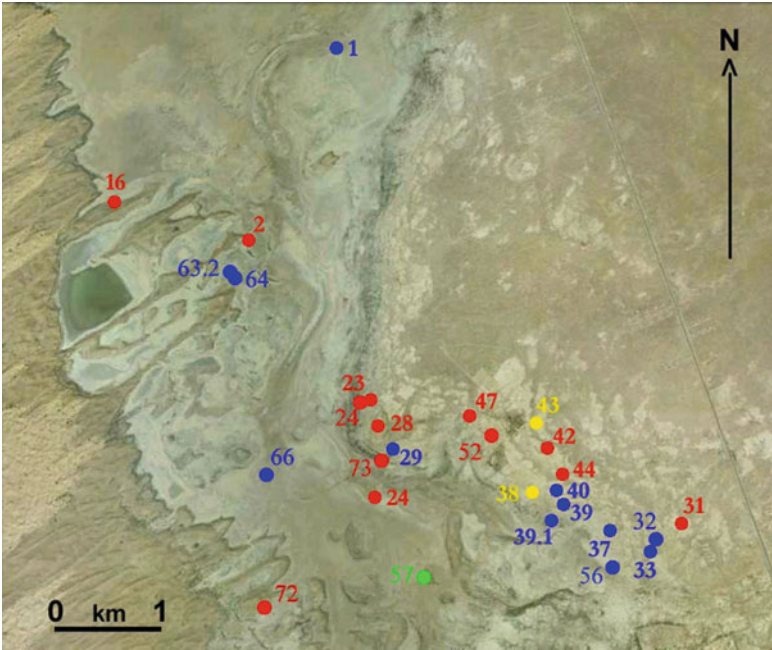
Considerations

The data presented above show that the first Holocene peopling of Las Bela coast took place during the last centuries of the eighth millennium BP, when most of the shores of the Arabian Sea and the Persian/Arabian Gulf started to be settled at least temporarily by fishers and shellfish gatherers who exploited the resources available from specialized mangrove environments (Biagi, 2008; Boivin & Fuller, 2009). The discovery of shell middens around the shores of Lake Siranda is of major importance because it helps us define the geographic and environmental characteristics of some traits of the coastal landscape settled by the earliest Neolithic inhabitants of the

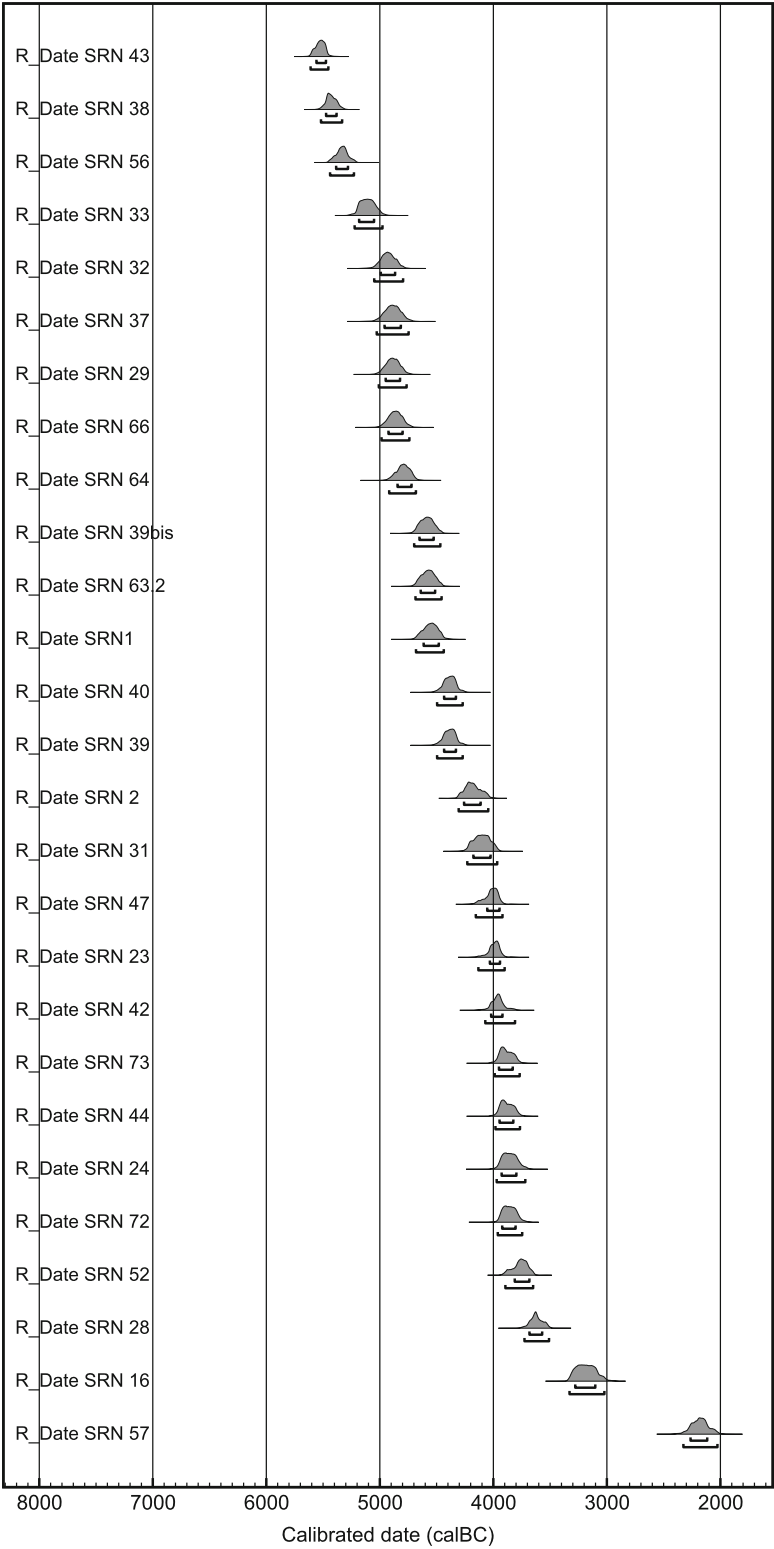


Shell Middens of the Coast of Balochistan, Fig. 16 Cape Gadani: site 1 that consists of a scatter of *Purpura panama* marine shells

Shell Middens of the Coast of Balochistan, Fig. 17 Lake Siranda: distribution map of the AMS-dated shell middens. Eighth millennium BP (yellow), seventh millennium BP (blue), sixth millennium BP (red), and fifth millennium BP sites (green)



Shell Middens of the Coast of Balochistan,
Fig. 18 Lake Siranda:
scatterplot of the AMS
calibrated dates obtained
from the shell middens





Shell Middens of the Coast of Balochistan, Fig. 19 Lake Siranda: part of the southeastern shore photographed in January 2013



Shell Middens of the Coast of Balochistan, Fig. 20 Lake Siranda: the impressive shell mound 29



Shell Middens of the Coast of Balochistan, Fig. 21 Lake Siranda: shell scatter of site 30

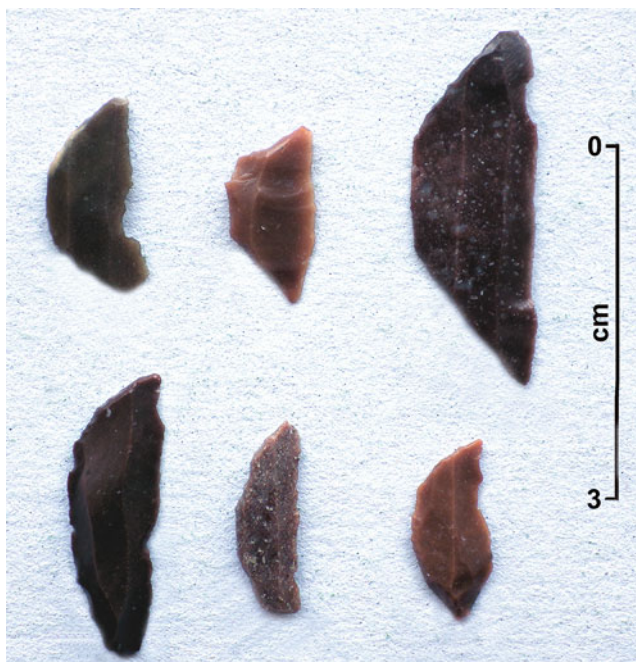


Shell Middens of the Coast of Balochistan, Fig. 22 Lake Siranda: shell midden 21 with *Telescopium telescopium* mangrove gastropods on its surface



Shell Middens of the Coast of Balochistan, Fig. 23 Lake Siranda: surface of large shell midden 73

Shell Middens of the Coast of Balochistan, Fig. 24 Lake Siranda: geometric microlithic tools obtained from Gadani flint collected from the surface of shell midden 29. *Top line*, isosceles trapezes; *bottom line*, lunates





Shell Middens of the Coast of Balochistan, Fig. 25 Lake Siranda: coarse stone tools from the surface of shell midden 64



Shell Middens of the Coast of Balochistan, Fig. 26 Lake Siranda: surface of the basins rich in *Melanoides tuberculata* freshwater shells



Shell Middens of the Coast of Balochistan, Fig. 27 Lake Siranda: the area of shell midden 2, where a profile containing *Melanoides tuberculata* freshwater shells was found in situ



Shell Middens of the Coast of Balochistan, Fig. 28 Lake Siranda: profile close to shell midden 2, with location of the point from which a *Melanoides tuberculata* sample was taken for AMS dating



Shell Middens of the Coast of Balochistan, Fig. 29 Sonari: the terrace at the mouth of the Hab River where the Bronze Age site is located, in the center of the photograph



Shell Middens of the Coast of Balochistan, Fig. 30 Sonari: Bronze Age rectangular stone structure covered with *Meretrix* marine bivalves



Shell Middens of the Coast of Balochistan, Fig. 31 Sonari: net sinker in situ on the surface of the Bronze Age village

northwestern corner of the Indian Ocean and compare it with the information available from other regions of the Arabian Sea, Oman, for example (Berger et al., 2013). In both countries the Neolithic coastal peopling seems to have followed the same trend, with fisher–gatherers exploiting well-developed mangrove environments along the shores of lagoons that started to dissect just after the retreat of the ocean waters that took place in the Bronze Age.

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Shen Guo

Fabrizio Pregadio

The Chinese scholar, statesman, and scientist Shen Guo was born in 1031 in present-day Hangzhou (Zhejiang). Born into a family of gentry, he entered civil service in 1054, holding minor posts in different provinces where he distinguished himself in a series of projects involving water control. After passing the national doctoral examinations in 1063 he moved to the capital, Kaifeng, and in 1072 was named Director of the Astronomy Bureau. In that position he reorganised the Bureau, planned a program of astronomical observations, and devised a calendar that was effective from 1075 to 1092. His work as astronomer alternated with missions to the provinces, where he was again able to display his skills in hydraulic engineering. The relief maps he made in 1074 (using wooden plates, sawdust impregnated with glue, and melted wax) are among the most celebrated specimens of Chinese cartography.

The whole of Shen's career was influenced by his partnership with Wang Anshi (1021–1086), the leader of the “New Policies” (*xinfu*) group which advocated a reform program aimed at strengthening the central government, regulating finances by law, and exploiting nature for the state's benefit. Shen's memorials to Emperor Shenzong (r. 1067–1084) on a variety of subjects – including military strategy and tax levies – won approbation in a dozen instances.

In a related development, Shen was sent as an envoy to the Khitan court in 1075, and, in a feat of diplomacy, was able to put at least a temporary end to the borderland skirmishes and the repeated Khitan claims of Chinese land.

Following his diplomatic victory, Shen Guo was appointed Finance Commissioner in 1077, but that very year also marked the turning point of his political fortune. The opponents of the “New Policies” had succeeded in pressing Wang Anshi into retirement. Shen was in turn charged with duplicity in his fiscal policies, and demoted. Three years later, partially rehabilitated, he was sent to the Shenxi province as Commissioner for Prefectural and Military Affairs. In 1081 he obtained an important military victory against the Tanguts. One year later, however, he was held responsible for the disastrous defeat that the Chinese troops suffered in the same area, and put on probation.

Shen spent the following years completing a map of the territories under Chinese control, for which he was commissioned by the Emperor in 1076. When he submitted it to the throne in 1088, his rewards included the right of choosing his residence. He thus moved to the “Dream Brook,” a garden estate that he had bought some years earlier near present-day Zhenjiang (Jiangsu), and devoted most of his time to writing, until his death in 1095.

Shen Guo’s writings include treatises on administration, military strategy, astronomy, medicine, poetry, ritual, and several other subjects. His best known work, entitled after the name of his retreat, is the *Mengqi bitan* (Brush Talks from Dream Brook). Written in the final years of his life, and supplemented by two shorter works probably published posthumously, it consists of about 500 jottings on disparate matters, usually short and organized into topics. The original edition was in 30 chapters, of which 26 are extant. Of special importance from the point of view of the history of science are the sections pertaining to mathematics, astronomy, meteorology, optics, physics, geology, and medicine.

To give only a few examples, chosen among the more important parts of his work but clearly inadequate to reflect the richness of its contents,

in the field of astronomy Shen Guo described solar and lunar eclipses, studied the moon phases, and provided reasons for the apparent planetary motions. During his appointment as Director of the Astronomy Bureau, moreover, he modified the design of the sighting tube pointing to the Pole Star in the armillary sphere. In the field of geology he recognized the origin of fossils, and gave an account of the role of erosion. Other jottings are concerned with magnetism, the production of inverted images on concave mirrors, the formation of rainbows, the fall of a meteorite, and the process of printing. All this adds to his skills in cartography and hydraulic engineering.

As several scholars have remarked, Shen Guo never attempted to organize his observations into a general theory. His work is, in many ways, the product of an exceptionally bright mind, motivated by a sharp curiosity in observing, understanding, and describing whatever phenomenon aroused his interest. This was by no means limited to natural processes or to man-made techniques. One chapter of the *Mengqi bitan* deals with supernatural matters, which the author treats with the same sympathy he accords to the other fields that attracted his attention. For a proper assessment of Shen Guo’s personality and production, the “scientific” features of his works should be evaluated without neglecting their own context or disregarding other features which we might label as “unscientific.”

From another point of view, Shen Guo reveals the short-comings inherent in the equation between Daoism and scientific progress on one hand, and Confucianism and scientific conservatism on the other, which has influenced some recent work in the history of Chinese science. While Daoists were not interested in nature per se (nature was before all an “image,” *xiang*, of the absolute principle, the *Dao*), Shen Guo shows that interest in natural facts could be, and indeed was, actively pursued by a “Confucian” scholar and state administrator.

See Also

- [Armillary Spheres in China](#)
- [Astronomy in China](#)

- [Calendars in East Asia](#)
- [Maps and Mapmaking in China](#)

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Shibukawa Harumi

Nakayama Shigeru

Shibukawa Harumi (1639–1715) was a Japanese astronomer and calendar reformer whose distinguished service in calendar reform led to his appointment in 1685 as official astronomer.

The Chinese lunisolar Xuan-ming calendar, adopted in Japan in 862, had not been reformed for more than 800 years. Over the centuries the discrepancy in the length of a solar year had increased so that by Harumi's time there was a 2-day delay in the winter solstice.

With able diplomatic skill, Harumi urged that the Shogunate government undertake calendar reform. In 1669 he began conducting astronomical observations, probably the first systematic observations made in Japan. Following the procedures of traditional Chinese astronomy, he set up a gnomon and measured the lengths of shadows at various points before and after the

winter solstice, in order to calculate the time of occurrence. He was especially interested in the Shoushi calendar of the Yuan dynasty (1279–1368), a crowning achievement of calendrical astronomy adopted in China in 1282, and his observations were based upon its methods.

In his reference to Western theories, Harumi based his information on scanty sources and came to regard Western astronomers as “barbarians who may have theories but cannot prove methods.” It is regrettable that sufficient material for evaluating Western theories was not available to him.

During the eighteenth century Japanese astronomy altered its orientation from China to the West. Harumi belonged to the first generation of astronomers who, with only limited knowledge of Western astronomy, began evaluating the merits of both systems.

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Ship- and Boatbuilding in Ancient Egypt

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We lack evidence of construction techniques for the earliest Egyptian vessels, but in the Naqada II period (c.3500–3200 BC), there is a change in iconography from boats with a flat profile interpreted as papyrus rafts to “sickle-shaped” boats (Fig. 1). These boats must have been built from wood as most of the hull is out of the water, and it coincides with the earliest evidence of

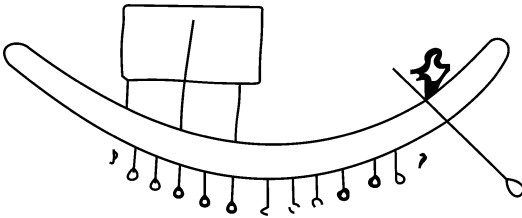
wooden planks in graves and copper woodworking tools (Mark, 2013a).

In the second half of this period appear depictions of the earliest known sailboats, an especially important invention because consistent north winds allowed boats to sail upstream for c.1,200 km, and its appearance coincides with the earliest evidence of bulk cargoes transported in pottery containers over long distances. Sailboats may also have influenced the development of the Egyptian state. During the Naqada III period (c.3200–3000 BC), Upper Egyptian sites appear in Lower Egypt probably to control trade. An

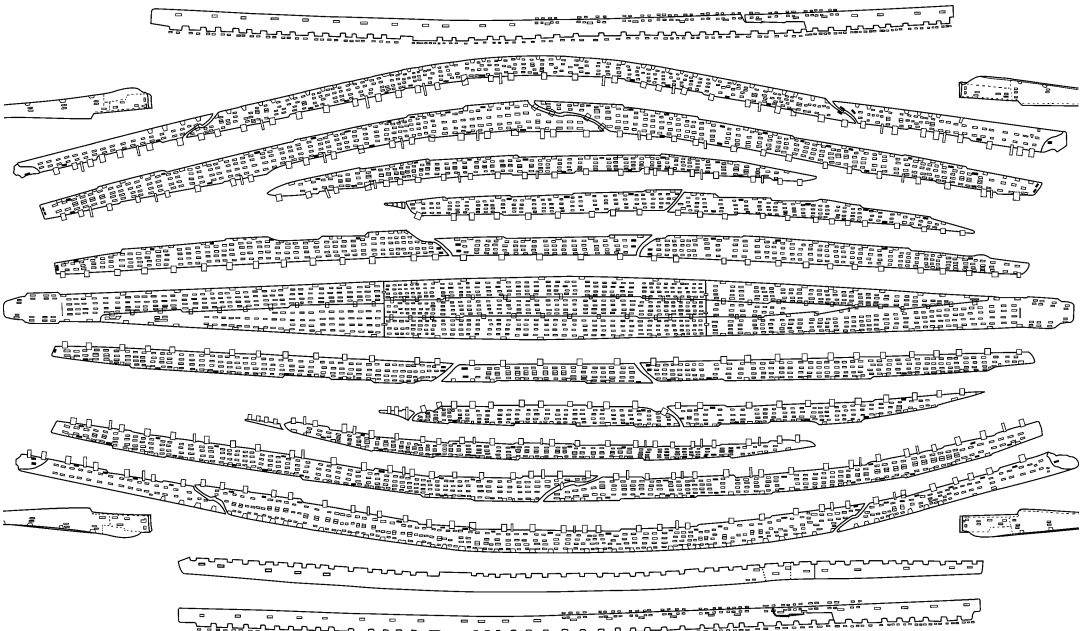
uninhabited region of c.250 km separated the two regions, but sailboats allowed for the establishment, resupply, and support of colonies or armies, leading to the eventual unification of Egypt. The importance and effectiveness of the Nile as a highway is emphasized by the lack of a well-developed system of roads before the Roman period (Mark, 2013a).

Early Dynastic and Old Kingdom Vessels

A few fragmentary boats have been studied from the First Dynasty, but an excellent example survives from the reign of Khufu (c.2566 BC) in the Fourth Dynasty. It is $c.43.63 \times 5.66 \times 1.8$ m and built primarily of c.38 t of Lebanese cedar (*Cedrus libani*) (henceforth cedar). The planking is very thick (12–15 cm), long (7–23 m), and wide (widest c.70 cm) with joggled edges to help lock them together (Fig. 2) (for this vessel, see Lipke (1984), Ward (2000), and Mark (2009, 2011)). The technique of overlapping planking is seen as early as the First Dynasty in the Abu



Ship- and Boatbuilding in Ancient Egypt, Fig. 1 Graffito of a sickle-shaped sailboat (After Červíček (1974), Fig. 156)



Ship- and Boatbuilding in Ancient Egypt, Fig. 2 Planking plan (After a photograph from the Paul Lipke Collection http://inadiscover.com/projects/all/africa/cheops-khufu_i_boat_documentation/photo_gallery-1/)

Rawash boat (c.2970 BC), but planking is irregularly shaped and lacks the numerous joggles seen in the Khufu I planking probably because it was smaller and was built with shorter, local woods with more flaws.

Hull planks in the Khufu I vessel are edge-joined with mortise-and-tenon joints (Figs. 2 and 3A). Tenons are sidder (*Ziziphus spina-christi*), a deciduous wood, while planking is typically a coniferous wood because when wet, coniferous planking swells around tenons for a tighter fit but deciduous tenons swell less, keeping planking from splitting. Egyptian boatwrights probably adapted this joint to boatbuilding so vessels could be broken down and rebuilt.

Once fitted together hull planks were lashed in place by 105 transverse plaited straps that ran through rows of V-shaped lashing holes from port to starboard sides where they were probably tied off to crossbeams. Their size (c.7 × 2 cm) and placement (spaced c.25 cm longitudinally and c.10 cm transversely) appear to be standardized (Figs. 2 and 3B). Transverse lashing holes are on the Abu Rawash boat and on the First Dynasty Abydos BG 10 boat.

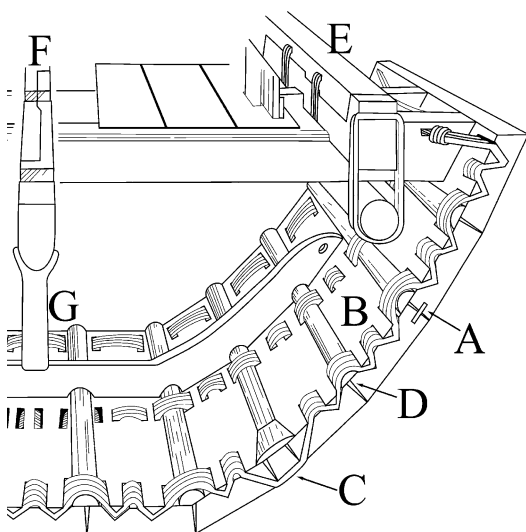
Most transverse lashings run over seam battens, but an unknown number passed under

battens and either through plank edges or pierced exterior surfaces to reinforce planking under considerable stress (Fig. 3C). Battens had four functions: tightening lashings, maintaining watertightness by pressing down on seams, distributing pressure on seams uniformly between widely spaced transverse lashings, and large battens completely covered scarfs, adding structural reinforcement. Before battens were fitted, an organic material called wadding may have been laid on interior seams that were slightly open (Fig. 3D). If so, when lashings were tightened, battens would force wadding into seams increasing watertightness.

Hull planks were lashed to 66 crossbeams. Only the lengths were measured as crossbeam sizes and shapes were standardized. The widest is 30 × 10 cm, those forward of it are 10 × 10 cm, those directly aft are 12 × 12 cm, and those aft of the deckhouse are 11 × 11 cm. The widest crossbeam either supported a mast or reinforced the main hatch or both.

These features indicate this hull was designed to be broken down and rebuilt, but they produced a weaker hull. Longitudinal girders were therefore needed at deck level. Side girders (11 cm × 26 cm × c.26 m) were notched and fitted on top of the middle 48 crossbeams and then lashed to poles (c.10 cm in diameter, c.7 m long) below crossbeams (Fig. 3E) to allow further tightening. Side girders were designed to resist longitudinal forces and were also reported on the First Dynasty 3506 boat at Saqqara.

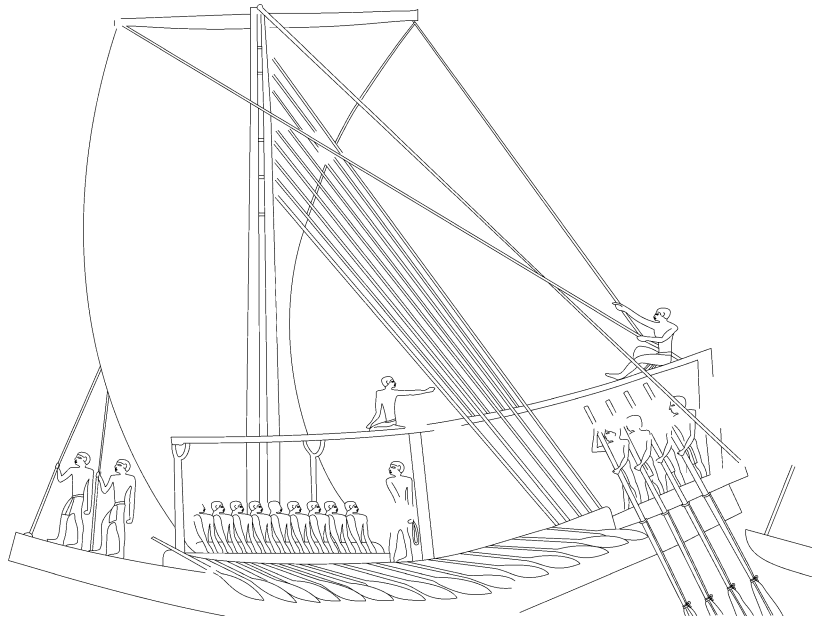
A central girder of the same dimensions was notched and fitted to the underside of the same 48 crossbeams (Fig. 3F) and primarily resisted lateral forces from flexing crossbeams. It also absorbed longitudinal stress and therefore was supported by 16 stanchions fitted on top of 16 frames, 8 full length and 8 three quarters, each carved from a naturally curving timber (Fig. 3G) and notched to fit over battens and then lashed in place. Frames were too widely spaced (c.170 cm) and too small (c.7 cm sided (wide), c.12–20 cm molded (high)) in relation to the hull planks (c.12–15 cm thick) to support planking. Instead, they uniformly spread downward forces from the central girder across a hull.



Ship- and Boatbuilding in Ancient Egypt, Fig. 3 Half-breadth of the Khufu I vessel (After Lipke (1984), Fig. 48 and photographs from the Paul Lipke Collection)

Ship- and Boatbuilding in Ancient Egypt,

Fig. 4 Sailboat from the Tomb of Ti (After Steindorff (1913), pl. 78)



The ends of this hull were tied together by a complex combination of overlapping planking with beveled edges and scarfs designed to support papyrus decorations. In contrast, most Nile boats before the Sixth Dynasty were built with flat transoms (Fig. 4).

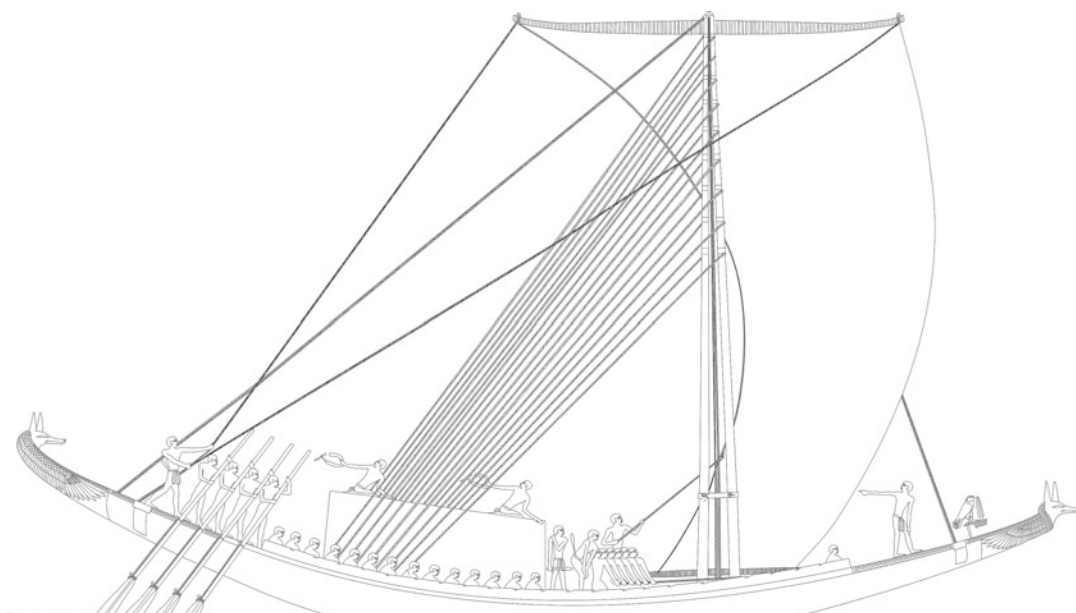
Cedar deck panels were prefabricated, ranging in size from .32 to 9.19 m². The smallest panels directly forward of the deckhouse were easily removable, and the one aft of the widest cross-beam was large enough to take a mast. Reliefs from the reign of Sahure depict the same type of craft under sail, and the location of the mast is close to the location of the wide crossbeam on the Khufu I vessel (Fig. 5). Masts are bipod with tall, tapering sails. The lower spar sits on the hull to reduce weight. Single pole masts are only on the smallest vessels, but the lower spar still rests on deck (Fig. 6), suggesting structural limitations in hulls. Changes in mast and sail from predynastic times suggest sails became too large and heavy for hulls to support them with only pole masts (Figs. 1, 4, 5, and 6).

The cedar deckhouse (c.9 m long) was also prefabricated and probably standardized (Fig. 7), allowing it to be constructed at another location, like the deck panels. A prefabricated deckhouse

may have been on the First Dynasty Saqqara 3506 boat.

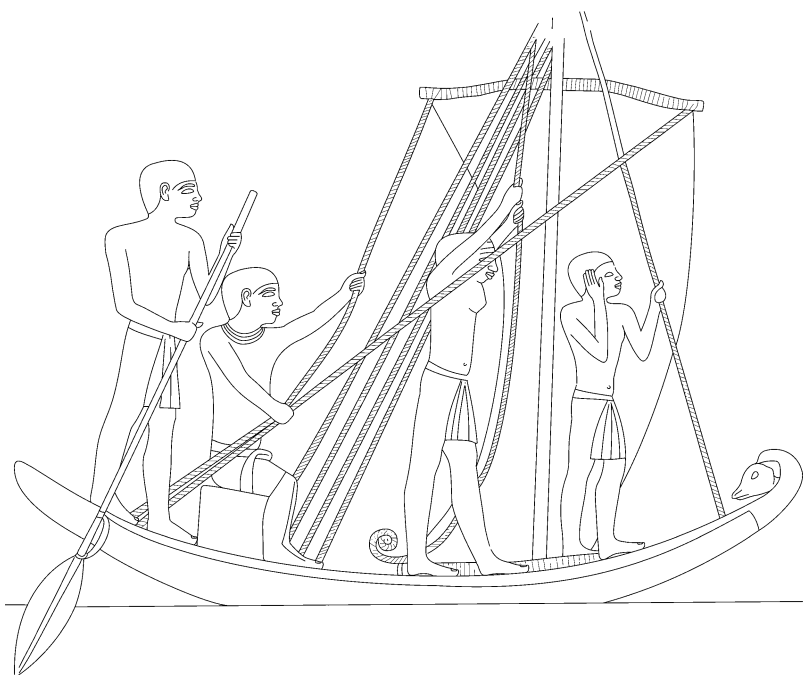
Finally, this vessel was steered with multiple pairs of quarter rudders. At present only one pair of quarter rudders is outfitted on this vessel and the other five pairs are mounted as oars (Fig. 7), but they are too long (c.6.5–8.5 m long) and too heavy (smallest 57.15 kg) for oars. Furthermore, contemporaneous vessels portrayed on reliefs have multiple sets of quarter rudders (Figs. 4 and 5), except the smallest boats (Fig. 6). Only one line secured each rudder with the lower end attached above the blades and the upper end wrapped around the loom near deck level and then secured to a grommet (Figs. 4, 5, and 6). It supported a rudder's weight and acted as a fulcrum around which a rudder was rotated. Oars were mounted in a similar fashion and sat in notches cut into side girders.

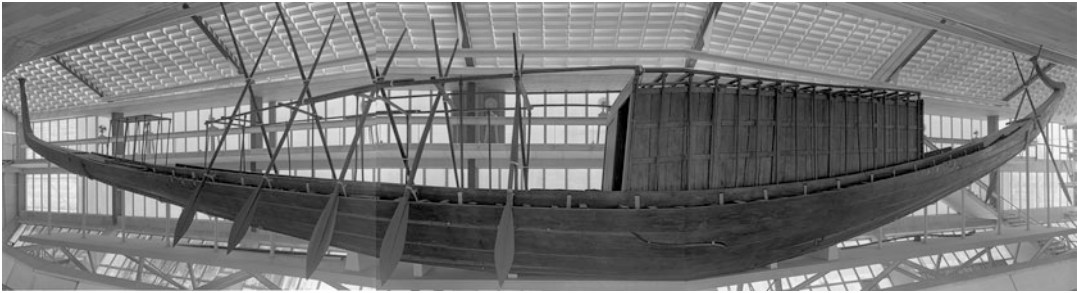
The number of quarter rudders outfitted on a vessel was dictated by its size and speed. Reliefs from the Fifth Dynasty Tomb of Ti portray sailboats rowed, paddled, and at rest with two or three pairs of rudders while the same vessels under sail typically have four or five pairs. Sahure's royal sailboat is the largest with 13 pairs while smaller escort sailboats have four



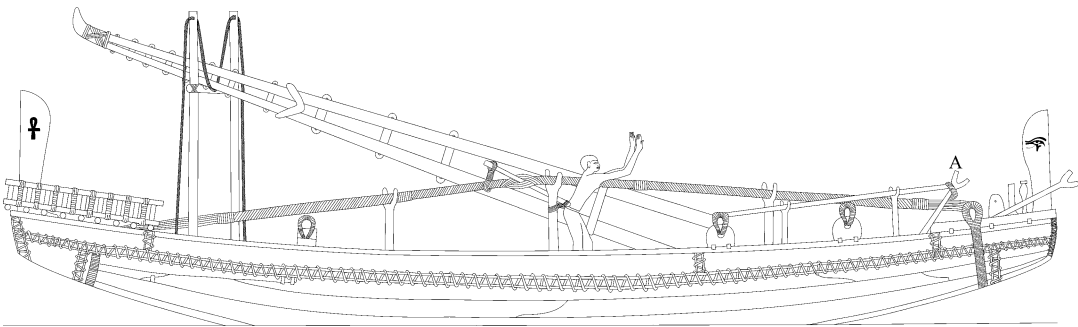
Ship- and Boatbuilding in Ancient Egypt, Fig. 5 Reconstruction of a royal escort sailboat (After El Awady (2009), pls 2–4)

**Ship- and Boatbuilding
in Ancient Egypt,
Fig. 6** Small sailboat
(After Junker (1941),
Fig. 14b)





Ship- and Boatbuilding in Ancient Egypt, Fig. 7 Composite photograph of the Khufu I vessel by John Ross (Reproduced with kind permission of the Griffith Institute, © Griffith Institute, University of Oxford)

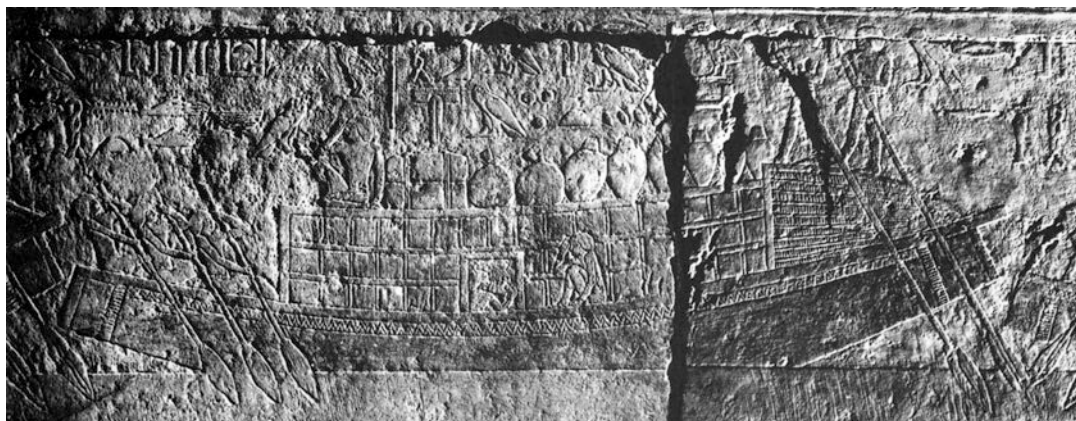


Ship- and Boatbuilding in Ancient Egypt, Fig. 8 Reconstruction of Sahure's Mediterranean ship (After Borchardt (1913), pls 11–12, and photographs from the University of Chicago, Oriental Institute, B 567–571)

or five pairs (Fig. 5). As the Khufu I vessel has six pairs, it was the same size as Sahure's escort sailboats or slightly larger. The Palermo Stone states that Sneferu (c.2613–2589 BC) had a vessel 100 cubits (c.52 m) long, which is a reasonable length for Sahure's royal sailboat. Sahure's sailboats are so large that men on deck-houses used U-shaped devices to transmit orders from lookout to helmsman (Fig. 5) while none were needed on smaller sailboats (Fig. 4) (See Mark, 2012b, 2013b).

This is a sophisticated method of construction that appears to have been perfected no later than the First Dynasty, and it “must have been standard maritime technology in ancient Egypt” (Steffy, 1994, p. 28). The only substantial ship timber from the Old Kingdom is a single naturally curving frame notched to fit over battens from the Red Sea port of Wadi al-Jarf, dating to Khufu's reign (Tallet, 2012, Fig. 20).

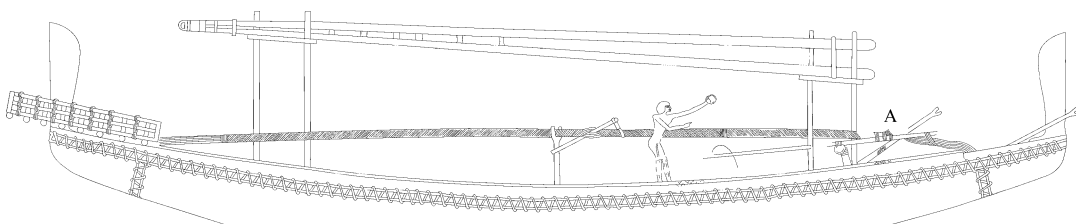
Ship reliefs from Sahure's reign portray Mediterranean ships, and features on them are consistent with structural elements on the Khufu I vessel, including very long hull planks with long, rolling scarfs. At the ends of some scarfs are small rectangles consistent with the external lashings on the Khufu I hull, suggesting transverse lashings (Fig. 8). Other exterior hull lashings suggest a reliance on lashings over timbers. Longitudinal lashing reinforced crossbeams while vertical lashings at bow and stern suggest a complex system of lashings and joinery to tie the ends together as on the Khufu I vessel. Since similar lashings were used on Nile workboats (Fig. 9), shipbuilding techniques were probably adapted from them, and Mediterranean ships were prefabricated and designed to be broken down and rebuilt rather easily (for this discussion, see Mark, 2014).



Ship- and Boatbuilding in Ancient Egypt, Fig. 9 Nile cargo boat (From Verner (1977), pl. 10, pg. 187 With kind permission of the Czech Institute of Egyptology)



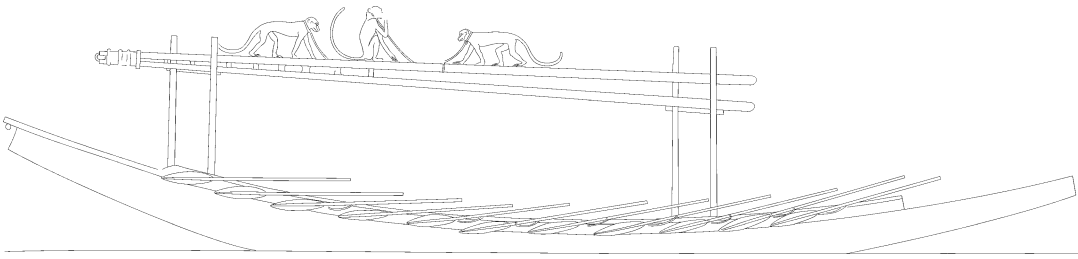
Ship- and Boatbuilding in Ancient Egypt, Fig. 10 Unas' stone carriers (After Selim Hassan (1954), Fig. 1)



Ship- and Boatbuilding in Ancient Egypt, Fig. 11 Reconstruction of a Punt ship (After El Awady (2009), pl. 5)

Blade-shaped objects (henceforth “blades”) depicted at the ends of ships and Nile stone carriers, which carried the greatest weights, were structural timbers because as weights increased, blades were added. A stone carrier carrying one sarcophagus, as well as all ships, was outfitted with one blade, while stone carriers carrying two larger stone columns were outfitted with eight blades (Fig. 10). Before the reign of Unas (c.2375–2345 BC), all blades sat inboard of hull planking; thus it was during his reign that a stem and a stern post were first developed.

Sahure's Punt ships are smaller adaptations because they had to be broken down and carried to the Red Sea. When both ships are scaled to the same length, the Punt ship is shallower by two plank widths amidships (Figs. 8 and 11). Although both have bipod masts, the mast on the Mediterranean ship is heavier as it has more and larger pieces with more fasteners, and it rests in one gallows, while the Punt ship's mast is so light both ends were stowed on gallows and was similar to masts on boats (Fig. 12) which were designed for the relatively gentle north winds on



Ship- and Boatbuilding in Ancient Egypt, Fig. 12 Riverboat (After El Awady (2009), pl. 5)

the Nile instead of the “notorious” winds and gales on the Red Sea.

Moreover, each ship has a hogging truss, a heavy cable running from bow to stern (Figs. 8 and 11). It is a primary structural element to what is typically described as a weakly constructed hull, compensating for a flat bottom, no keel, and a lack of internal timbers. This is an oversimplification because a Chinese Kiangsu trader had these features but no hogging truss. Instead, trusses were probably required because Egyptian ships were designed to be broken down and rebuilt, resulting in an inherently weak hull unable to take additional stresses while at sea.

A truss also indicates a ship’s size. It is waist high on Punt ships and is supported by only one stanchion, while on Mediterranean ships, it is shoulder high and supported by three stanchions. If it parted, structural failure of a hull would follow. A forked stanchion located at the bow of each ship was probably used to raise the mast. On the Punt ship, it was lashed to the truss but not on the Mediterranean ship (Figs. 8A and 11A). Every use of it on the Punt ship would pull against and chafe a truss, fraying and weakening it over time. Securing it in this manner was a calculated risk taken by shipwrights to keeping weight to a minimum.

Punt is believed to have been located between present-day northern Eritrea to southern Somalia for one-way voyages from 1,300 to 2,200 km. Even for Mediterranean ships, this would be a long voyage in notorious waters, lacking harbors for major repairs, but shipwrights could not use large planks and frames as on the Khufu I vessel or Mediterranean ships because they could not be transported to the Red Sea. Thus,

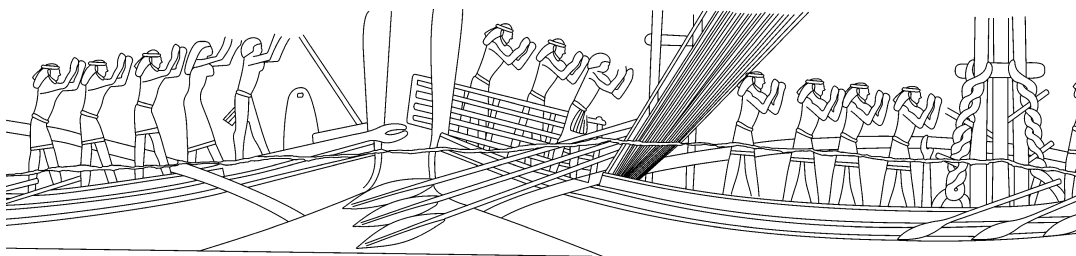
shipwrights were forced to design small and light ships while taking a number of calculated structural risks.

While prefabrication was required for Punt ships, it was not for Nile or Mediterranean vessels. Prefabricated vessels, regardless of size or function, allowed for an unprecedented maintenance of hulls, extending their working life, and provided the most efficient method of recycling wood. Also, standardization was as important because it reduced waste (See Mark, 2012a, 2014).

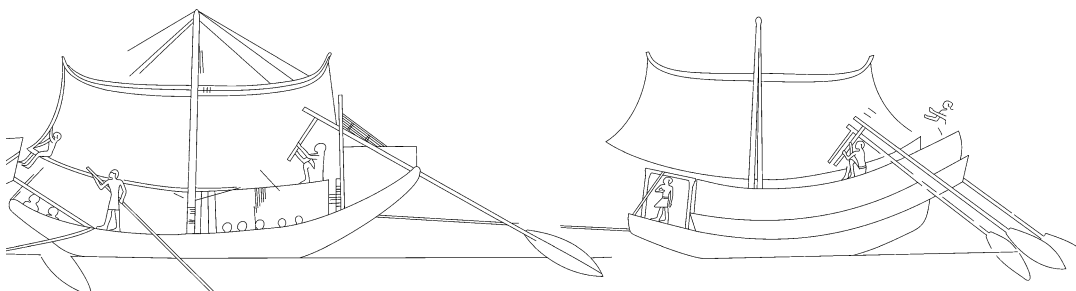
Changes in Technology

At the beginning of the reign of Unas and through the end of the Old Kingdom, a number of changes were made to vessels. A ship depicted on Unas’ causeway lacks most external lashings while blades are now a stem and stern post (Fig. 13), producing a stronger hull. A stem is also depicted at the bow of his stone carrier (Fig. 10). The height of hogging trusses with only one stanchion suggests Unas’ ship is similar in size to Sahure’s Punt ship (Figs. 11 and 13), but previously cited features along with a larger, heavier tripod mast with only one gallows indicate a heavier, stronger hull. Moreover, the earliest known tillers are outfitted on rudders of workboats, making them more efficient and reducing their number.

By the end of the reign of Pepi II (c.2278–2184 BC), older boat types with bipod masts and a pair of quarter rudders are seen for the last time, but even these appear larger and heavier. They are replaced with a vessel common in the Middle Kingdom with only a pole mast and



Ship- and Boatbuilding in Ancient Egypt, Fig. 13 Unas' ships (After Hassan (1954), Fig. 2)



Ship- and Boatbuilding in Ancient Egypt, Fig. 14 Sailboats from the reign of Pepi II (After Blackman (1953), pl. 22)

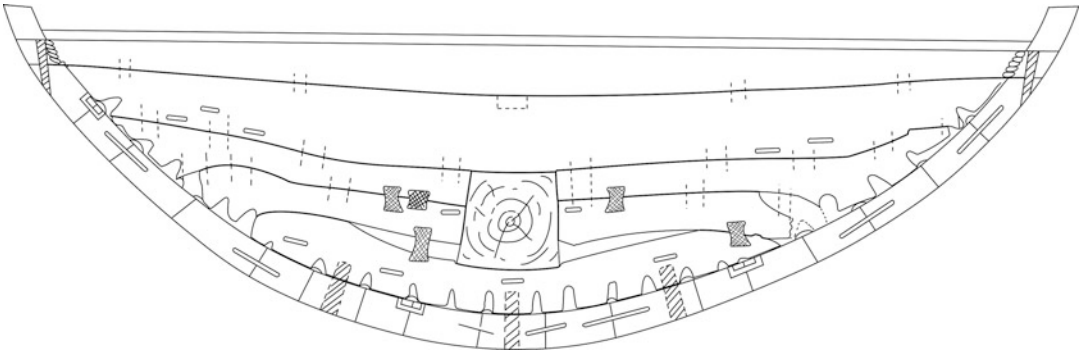
a single stern rudder fitted on a stanchion (Fig. 14).

Middle Kingdom

On boat models of this new hull, bulwarks replaced side girders, while a central girder was still used on larger vessels or vessels outfitted with masts. Stern rudders were now standard except on ceremonial boats or boats with stern decorations while ships always carried a pair of quarter rudders in case one broke.

The same philosophy of construction continued. Hull planks from a workboat from Lisht (c.1950 BC) were thick, short, and irregularly shaped and were overlapped. They were edge-joined with a combination of single and parallel mortise-and-tenon joints secured with woven straps in L-shaped holes (c.6.5 cm W; 5 cm D; 1 cm T) but have single instead of transverse lashings. Parallel joints are an indication of the heavier loads these boats carried (see Ward, 2000).

At the port of Ayn Soukhna (Sukhna) on the Gulf of Suez, hull plankings of two ships interpreted as c.13.5–15 m long were found in two caverns (G2 and G9). Plank lengths for both ranged from 2.35 to 6.4 m long. In cavern G2 planks are 28–44 cm wide and 9.5–13 cm thick, while in cavern G9 they are wider 30–40 cm with some 50 cm and one 70 cm and were thicker (11–13 cm). They also appear to have been sawn into flat planks (Pomey, 2012). If so they must have been bent to shape, as on the Khufu I vessel, instead of the prevailing belief they were carved to shape, which would have been very wasteful of timber. For each ship only one hull extremity survived, while the opposite end and all crossbeams, decking, and deck cabin were completely destroyed in the fire that carbonized these planks (Pomey, 2012). Egyptian ships, however, lacked cabins, and instead of two separate ships, there may have been only one ship c.27–30 m long with the narrower forward end in cavern G2 and the wider aft end in cavern G9. If so, the missing timbers may have been stowed in different caverns.



Ship- and Boatbuilding in Ancient Egypt, Fig. 15 Lisht bulkhead (After Ward (2000), Fig. 70)

Planking shapes are similar to those seen on the four Dahshur boats described below. This does not mean these ships were modified Nile boats. Instead, Egyptian craftsmen probably had similar planking plans for cedar and different ones for local woods to efficiently use each type of timber, reducing waste. Like the Lisht timbers, hull planks were edge-joined with mortise-and-tenon joints, but larger planks had a parallel row and smaller planks a single row of them. Planks were secured with straps laced through the same L-shaped holes. Pegs appear to be secondary fastenings but their function and frequency are not clear (Pomey, 2012).

Fragmentary remains of Punt ships were found at the harbor site of Mersa/Wadi Gawasis. Planks are thicker (6.5–22.5 cm) with only parallel rows of mortise-and-tenon joints, suggesting larger ships, some 30 m long (Ward & Zazzaro, 2010a, 2010b), but this estimate is based on two Ayn Soukhna ships, each being 13.5–15 m long. If there is only one ship, Punt ships may have been considerably larger.

According to the *Tale of the Shipwrecked Sailor* (henceforth the *Tale*, a Middle Kingdom story of an Ancient Egyptian voyage to the King's mines), a Red Sea ship was 120 cubits (c.62 m) long and 40 cubits (c.21 m) at the beam for a 3:1 length-to-breadth ratio, indicating a beamy ship that would be expected for a cargo ship only able to make one voyage per year. Since craftsmen could build vessels c.52 m long as early as the reign of Sneferu, a ship 62 m long would not be difficult; the difficulty would be

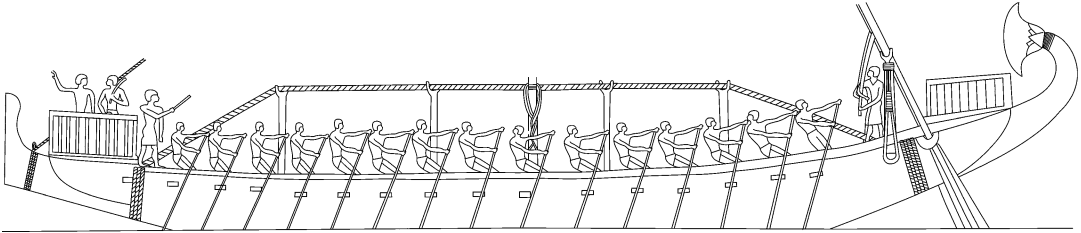
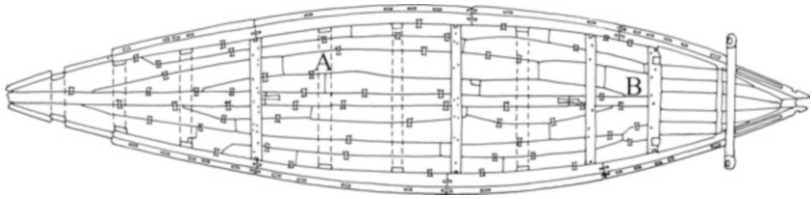
moving it to the Red Sea. Bulkheads may have allowed this feat. Timbers found at Lisht (c. 1950 BC) appear to have been part of a bulkhead, consisting of short, thick overlapping timbers joined with mortise-and-tenon joints and lashings in L-shaped holes. It was also designed to secure a large longitudinal timber (Fig. 15) (Ward, 2000). An advantage to using bulkheads to replace naturally curving frames would be ease of transport since bulkheads could be disassembled, and they would produce considerably stronger hulls. The longest hull plank at Ayn Soukhna was 6.4 m long while the shortest plank on the Khufu I vessel was c.7 m long. Thus, Egyptians must have developed a technique to build large ships from smaller pieces of wood.

According to an inscription from Mersa/Wadi Gawasis, one expedition required 3,765 men, which included 3,200 soldiers and 500 sailors (Fattovich & Bard, 2012). In the *Tale* above the ship had 120 sailors. Thus, four ships with a crew of 125 are consistent with the ship in the *Tale*.

Four nearly complete cedar boats (9.25–9.92 m long) were recovered near the pyramid of Senusret III (c.1978–1941 BC) at Dahshur. They have heavy, thick planking edges joined with mortise-and-tenon joints and overlapping planking (Fig. 16). Through-beams, like those found at Mersa/Wadi Gawasis, are another structural improvement, but instead of closely spaced L-shaped lashings, boatwrights used widely spaced dovetail joints, which some believe were the original type of joint while another interpretation is that the original lashing

Ship- and Boatbuilding in Ancient Egypt,

Fig. 16 Dahshur boat 4925 (After Landström (1970), Fig. 275)



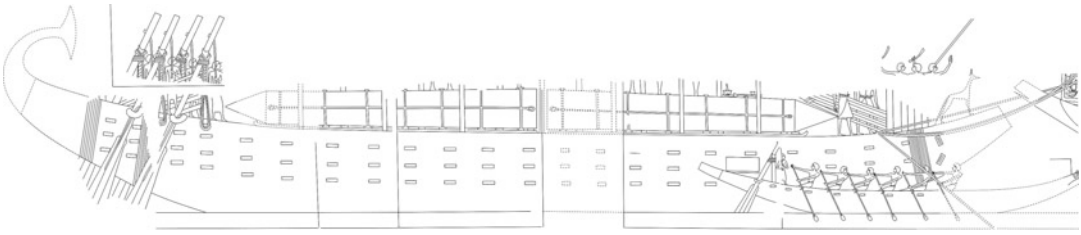
Ship- and Boatbuilding in Ancient Egypt, Fig. 17 Hatshepsut's Punt ship (After Naville (1898a), pl. 73)

holes were recut as dovetail joints by the discoverers (see respectively Creasman (2010) and Ward, (2000)). Regardless of type, they appear to be too shallow and narrow, especially across the seam (c.15 cm L, c.3 cm W at seam, 2 cm D), and too widely spaced (c.80–100 cm, Khufu I vessel c.25 cm) to have been a standard fastening system on working Nile boats. Moreover, the consistent standardization in Egyptian boat- and shipbuilding to efficiently use, maintain, and recycle timbers suggests it was unlikely a unique fastening system was used only on these boats, especially since deeper L-shaped lashing holes (c.5 cm D) with wide woven straps (c.6.5 cm W) used on the Lisht and Ayn Soukhna timbers would produce very sturdy vessels. The only advantage to these dovetail joints or original small lashings is both could be fashioned faster, especially if a king suddenly died. If built for burial, these boats would only need to be structurally sound enough for transportation to the burial site. There are parallels. The BG 10 boat at Abydos was a symbolic boat held together by lashings, plaster, and the brick tomb, while a number of structural features on the Khufu I vessel also suggest it was rushed to completion, such as recycled framing. Evidence of a rush to completion is seen in drawings of Cairo boat 4925 by Reisner (1913, Fig. 313) and later by Landström (1970, Fig. 275). Dovetail joints are

missing along one seam for a length of c.3.5 m (Fig. 16A, B). The other three Dahshur boats have two or three joints along this same seam, indicating it is structurally unsound for continuous use.

New Kingdom

Hatshepsut's (c.1473–1458) temple at Deir el-Bahri has reliefs depicting five Punt ships that appear larger than Sahure's Mediterranean ships. The hogging truss is above the heads of rowers (cf. Figs. 8, 11, and 17) and supported by four stanchions of equal height to maintaining a maximum height over a greater percentage of the hull, suggesting a considerably larger ship. The number of stanchions is important because when a truss was tightened and the ends of a ship were pulled up, forces increased on each stanchion. As ships became larger and heavier, more stanchions were required to distribute this increasing force more evenly throughout a hull. If these ships, as well as Middle Kingdom Punt ships, were the size of the ship in the *Tale*, there probably was no difference between Mediterranean and Punt ships, allowing for a greater degree of standardization and no more calculated risks to reduce weight (Mark, 2014).



Ship- and Boatbuilding in Ancient Egypt, Fig. 18 Hatshepsut's obelisk carrier (After Naville (1898b), pl. 154)

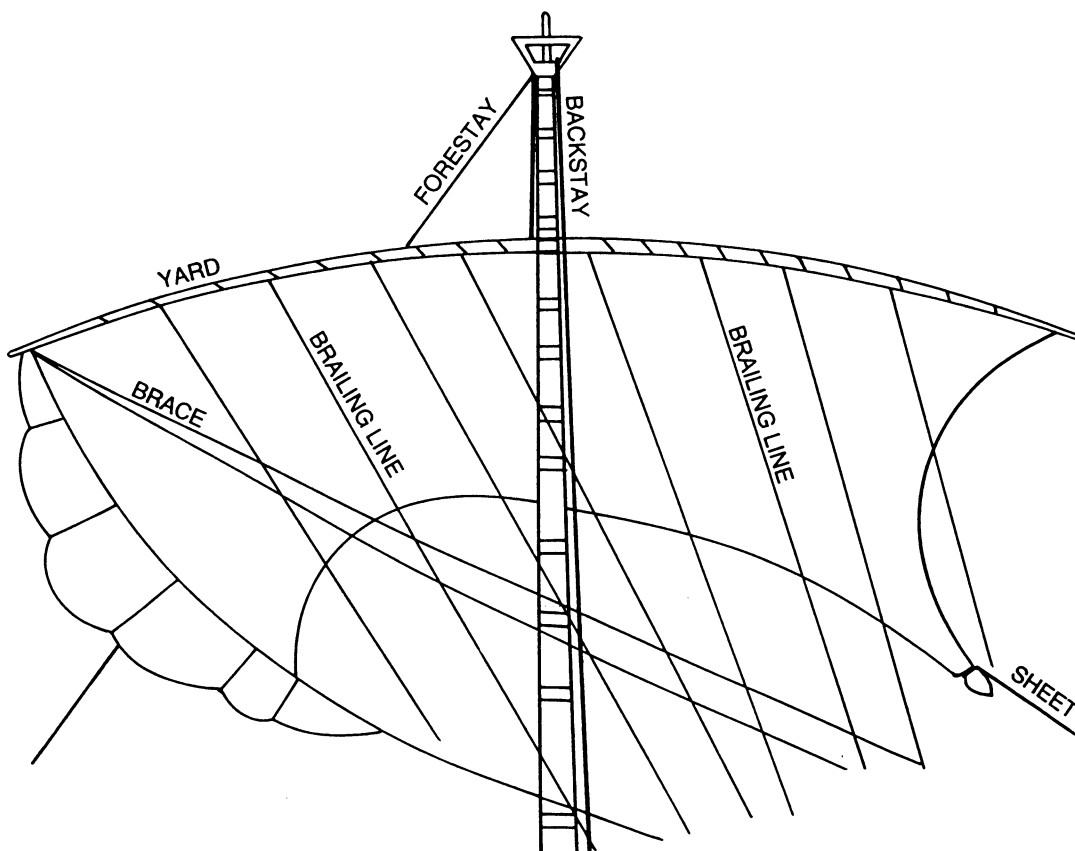
The largest known Nile barge is also depicted at Deir el-Bahri, and it carries two obelisks end to end (Fig. 18). Hatshepsut's two shortest obelisks, c.30 m each, would require a barge c.84 m long, but her two highest obelisks, c.57 m high, would require one c.140 m long. Some believe it was simply impossible to build such a large barge and obelisks were side by side. They were depicted end to end to show both obelisks. So far no substantive structural arguments have been made to support this belief. Moreover, Ineni describes how he oversaw the construction of a barge built with local sycamore 120 cubits (c.62 m) long to carry two obelisks for Thutmose I, Hatshepsut's father (see Landström 1970). His only surviving obelisk is 20 m high, and based on the above proportions, a barge 55 m long would be required to carry both end to end, which is consistent with Ineni's boast. Thus very large barges were being built especially when compared to Unas' barges (cf. Figs. 10 and 18).

Although the Egyptians based their construction techniques on standardization to efficiently use timber resources (see Ward, 2000), which promotes conservatism, they were also employed as problem solvers. Egypt was a wealthy and centralized state, which could more easily absorb losses in time and resources than could other ancient societies. Also, Egyptian craftsmen built a wider range of vessels, and if the king demanded a specific vessel from a barge to a ship, they would have both the time, resources, and experience to do so. Regardless, Hatshepsut's reliefs suggest a continuation of a trend that may have begun as early as the

reign of Unas, building larger, stronger vessels with smaller pieces of timber (See Mark, 2012a).

Based on iconography, two technical innovations appeared in the New Kingdom. One was the brailed sail (see Wachsmann, 1998), which lacked a lower spar. Instead, parallel lines were sewn along the lower edge of a sail then threaded through lead rings sewn on the face of it. They then passed over the upper spar and back to the helmsman (Fig. 19). A helmsman could manipulate the shape and area of a sail by pulling on different brails to take advantage of different types of wind. It was so efficient it was the standard sail configuration for the Greeks and Romans.

A second innovation was the construction of vessels with pegged mortise-and-tenon joinery as a primary fastening system for hull planking (Wachsmann, 1998). It was the standard technique used to build vessels by the Canaanites, Greeks, and Romans. Yet, to adopt this new system required a change in the basic philosophy of Egyptian vessel construction. At least as early as the First Dynasty, all vessels were designed to be broken down and rebuilt, but this is impossible when planking is built with pegged mortise-and-tenon joinery. The degree of preventative maintenance was greatly reduced, shortening a vessel's life, and even recycling becomes far less efficient. Why and when they made this change and how widely it was used to build different types of vessels is unknown. Their earliest known ships built with them as primary hull fasteners were found at the Egyptian port of Thonis-Heracleion, dating to the sixth century BC (Fabre & Goddio, 2013), but even later



Ship- and Boatbuilding in Ancient Egypt, Fig. 19 Brailed sail

Herodotus (2.96) (c.484–425 BC) describes a boat built using the older method. If pegged mortise-and-tenon joinery was used to build vessels during the New Kingdom as iconography suggests, it was probably limited to specific projects or types of vessels needing extra hull rigidity.

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Shipbuilding in Bengal

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Shipbuilding is an ancient art in Bengal. Ancient temple sculptures in Java testify about various kinds of ships “the people of Lower Bengal built and used in sailing to Ceylon, Java, Sumatra and Japan in pursuits of their colonizing ambition, commercial interests, and artistic and religious missions” (Mookerji, 1912, p. 156). The developed state of this art enabled its products to get access to distant markets. It caused, as Adam Smith believes, a division of labor in the society and thus ushered in its ancient economic prosperity. The art survived through the Middle Ages so that the Emperor Akbar (1556–1605) could have maintained a flotilla of 3,000 vessels with headquarters at Dacca (now in Bangladesh). In the early seventeenth century, the Bengal flotilla consisted of 4,000–5,000 ships, similar to the Chinese or Arabian *junks*, at 400–600 t each. The mercantile tonnage was also substantial, roughly about 207,500 t in the sixteenth–seventeenth centuries, as against the Dutch mercantile tonnage of 450,000–550,000 in 1630. The industry, however, eclipsed with the Europeans’ monopolization in the Indian Ocean trade but was revived again under the British entrepreneurship in the last quarter of the eighteenth century. Since the wooden ships still prevailed, Bengal’s traditional knowledge and expertise could be explored to give the industry a very competitive edge in international outlets.

Types of Ancient Ships

A ship is a large vessel that can navigate in deep seas. Technically, it was first defined as a vehicle

that carried at least three masts with a square sail. In ancient India, many such ships were constructed to meet the needs of defense as well as a means of commerce. From the standpoint of their physical properties, they were categorized as *Dīrghā* (longer ones) and *Unnatā* (taller ones). As many as ten types of ship belonged to the former category and five to the latter. In cubits, the length, breadth, and height were, for the former, (i) *Dīrghikā* ($32 \times 4 \times 3\frac{1}{5}$), (ii) *Taranī* ($48 \times 6 \times 4\frac{4}{5}$), (iii) *Lolā* ($64 \times 8 \times 6\frac{2}{5}$), (iv) *Gatvarā* ($80 \times 10 \times 8$), (v) *Gāminī* ($96 \times 12 \times 9\frac{2}{5}$), (vi) *Tarī* ($112 \times 14 \times 11\frac{1}{5}$), (vii) *Jangātā* ($128 \times 16 \times 12\frac{4}{5}$), (viii) *Plābīnī* ($144 \times 18 \times 14\frac{2}{5}$), (ix) *Dhārīnī* ($160 \times 20 \times 16$), and (x) *Begīnī* ($176 \times 22 \times 17\frac{3}{5}$), and, for the latter, (a) *Ūrddhvā* ($32 \times 16 \times 16$), (b) *Anūrddhavā* ($48 \times 24 \times 24$), (c) *Svarnamukhī* ($64 \times 32 \times 32$), (d) *Garbīnī* ($80 \times 40 \times 40$), and (e) *Mantharā* ($96 \times 48 \times 48$). As seafaring vessels, contemporary sources underscore the efficiency of (i), (ii), (ix), and (x) in the former category and (a) and (c) in the latter.

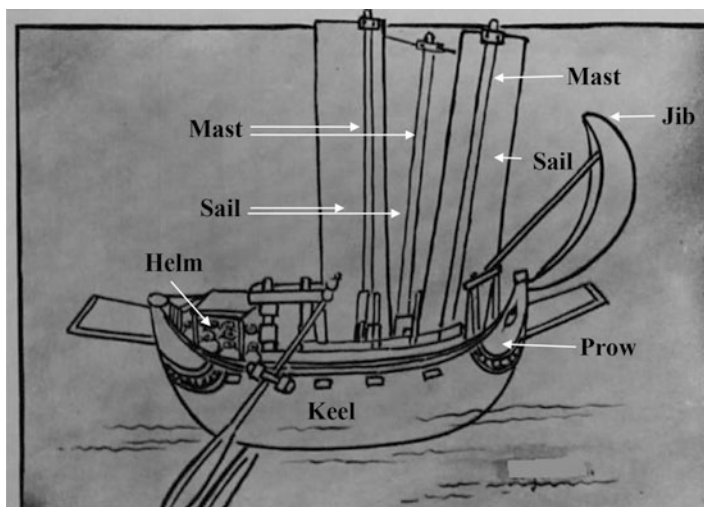
Two things should be noted in this context. Firstly, the concept of boat gave rise to the art of shipbuilding that extended it in every dimension – length, breadth, and height – by way of suitable planking in different directions, as well as through the innovation of riggings. Though its length could be greatly enlarged in different civilizations, the extension of width and height posed a serious challenge elsewhere in the contemporary world. The Roman galley, for example, which was driven by 2–3 banks of rowers on each side, ran 100–150 ft in length but only 10–15 ft in width. Even in the mid-nineteenth century when the wooden ship attained the peak of its prosperity, the width could not be significantly augmented. Thus, for example, the clippers like *Ariel* (UK built, 1865), *Donald McKay* (US built, 1855), and *Dreadnought* (US built, 1853) had respective dimensions of $197\frac{1}{2} \times 33\frac{9}{10} \times 21$, $266 \times 46\frac{1}{4} \times 29\frac{5}{12}$, and $212 \times 41\frac{1}{2} \times 26\frac{1}{2}$, all in feet. In contrast, ancient shipbuilders in India constructed vessels by 60–72 ft in width (taking 1 cubit = $1\frac{1}{2}$ feet). Both length and height wise

also, Indian ships were substantial, running up to 364 and 72 ft, respectively. Secondly, for the taller ships (*Unnatā*), a given proportion was always maintained among different sides for the sake of stability in deep seas. For such ships, the width always equaled the height, at a half of the length. Such a proportion was never maintained when the ships were not very tall but prominent in length.

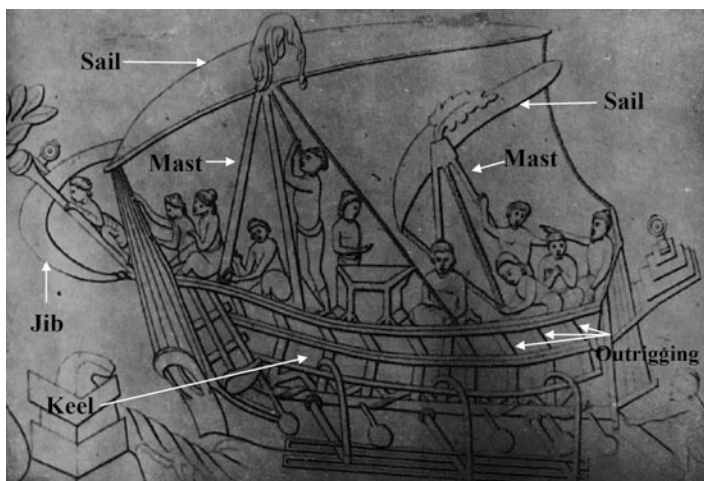
From the viewpoint of cabins, ancient ships in India were categorized as *Sarbamandirā*, *Madhyamandirā*, and *Agramandirā*. For the *Sarbamandirā*, the cabin was extended from one end of the vessel to the other, and it was used for the transportation of royal treasure, horses, and women. The cabin was located at the middle for the *Madhyamandirā*, which plied mainly during the rainy season, and the *Agramandirā*, which had the cabin at the prow, was used in naval warfare.

One of the major innovations in nautical technology was harnessing wind power by using masts and sails, where ancient shipbuilders in India also excelled. An early fifteenth-century European travelogue thus narrates that the natives of India “build some ships larger than ours, capable of containing 2,000 butts, and with five sails and as many masts” (Conti, p. 27). India’s ancient knowledge on masts and sails is preserved in cave paintings (Fig. 1) and temple sculptures (Figs. 2 and 3). Figure 1, a painting at the Ajanta Caves (525–650 CE), shows that there are three upright masts, each surmounted by a truck, carrying a lugsail (a square sail bent upon a yard that hangs obliquely to the mast). There is also an out-flying jib (a sail borne in front of the foremast) in the ship, which is also square in form. These lugsails and jibs resemble those in the nineteenth-century wooden ships of Europe. Figure 2 (a temple sculpture in Java in the early Christian era) shows a ship with two masts, one long sail, one short sail, and a jib, while in Fig. 3 (a similar sculpture), there are two masts with two individual square sails and also one staysail (jib). Bengal shipbuilders presumably constructed these types of ships since the culture of Bengal was reflected in Java’s contemporary temples.

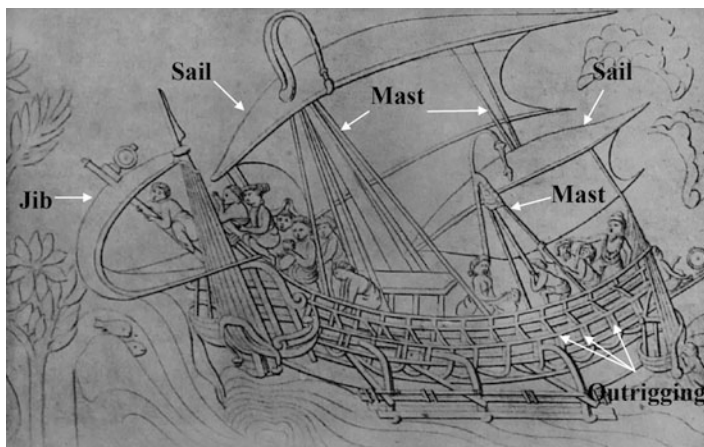
Shipbuilding in Bengal,
Fig. 1 A seagoing vessel
 (Source: Mookerji, History
 of Indian maritime and
 shipping activity)



Shipbuilding in Bengal,
Fig. 2 A Bengal-built ship
 with two masts and one
 long sail (Source:
 Mookerji, History of Indian
 maritime and shipping
 activity)



Shipbuilding in Bengal,
Fig. 3 A Bengal-built ship
 with two masts and two
 square sails (Source:
 Mookerji, History of Indian
 maritime and shipping
 activity)



Raw Materials of the Industry

The quality of a ship is reckoned by its stability, capacity, strength, and speed, which, in the age of wooden ships, were determined by the dexterity of workmanship, as well as the quality of woods that the shipwrights employed. Ancient shipbuilders in India acquired immense knowledge and expertise in this field. Similar to the caste division in the Indian society, they divided woods into four categories: *Brahmana* (light and soft), *Kshatriya* (light and hard), *Vaisya* (soft and heavy), and *Sudra* (hard and heavy). Where woods contained properties of two separate classes, they were categorized as *Dvijati* (mixed). For shipbuilding, however, the *Kshatriya* category of woods was considered most suitable since such ships could withstand any hazards of a turbulent sea for its hardness and also could ply fast for its lightness. For sundry purposes, the *Brahmana* was used as it could be easily joined to any other wood.

To the *Kshatriya* category belonged teak, *gāmbhāri*, *tamāl*, *peal*, and *jackwood*, which were extensively used in Bengal's ancient shipbuilding. There were several references of another kind of wood in the medieval literature, called *manapaban*, which ensured utmost speed to a ship. The use of teak, however, survived down to the early modern age when shipbuilding was resurrected under British entrepreneurship. Owing to its centuries' long use, the teak forest in and around this region was possibly exhausted by the early nineteenth century, necessitating that teak be imported from the neighboring country, Rangoon. Along with teak, however, Bengal shipbuilders employed *sal* and *sisoo* in the early modern age. The former resembled oak in quality but was much heavier and stronger. It grew about 90 ft to the branches and is proportionately thick. The latter grew in various shapes, enabling a builder to make use of it for many purposes. These two species of trees, however, grew abundantly in the northern fringe of the province stretching over the Himalayan foothills and also along its border with Bihar. The later shipbuilders generally used the *sisoo* timber for ribs, knees, and breast hooks (i.e., for the frame of a ship), the

sal for beams and inside planks, and the teak for bottoms, sides, decks, masts, keels, and sternposts.

Cordages that were extensively used in shipbuilding were made of coir (the husk of coconut), ejoo (a fiber obtained from the leaves of sago palm tree), plantain, and sunn. The coir was famous for its elasticity and lightness, the ejoo for its durability, and the plantain for its strength. The Bengal sunn, similar to the quality of Russian hemp, was also used extensively for rope making. The province abounded with all these raw materials. Pine tar (for use in ropes), as well as *dammer* (which was an Indian substitute for pitch), was also locally available in plenty. For sails, local shipbuilders preferred jute cloths (*gun*) from the ancient ages, which artisans spun and wove at their cottages.

Insofar as the need for joining was concerned, the ancient shipbuilders avoided the use of iron nails since the ship might be caught into the influence of the magnetic effect in a deep sea and thus suffer wreckage. They fitted the bottom planks together or mortised them with other materials. Metals, such as gold, silver, copper, and any compound of these, were used only for decoration. However, when the industry was revived in the late eighteenth century, the British entrepreneurs extensively used various metals, including iron, and for these purposes, they imported bar iron, sheet copper, copper bolts, and lead from Great Britain. Locally available iron, brought from nearby districts like Balasore, Midnapore, and Burdwan, was also used to an extent.

Lastly, paints and paint oil were also locally available. The painters mainly used *hurtal* (yellow arsenic), which abounded in Bengal, to get the yellow color. They obtained the blues from indigo and the blacks from rattan charcoal. Hurtal and indigo were mixed together to obtain the greens and the red earth and the ochers for the reds. Ancient shipbuilders generally used white for four-mast ships and red for three-mast ones, while yellow and blue were reserved for two- and one-mast vessels, respectively. Other colors were meant for painting fanciful shapes or forms on the prows. For use in these paints, however, the oil

was obtained from wood oil trees that grew abundantly in the district of Chittagong. In colonial days, this oil was used for coarse works and the European linseed oil was preferred for finer paints.

Method of Construction

Modern shipbuilding is contingent on naval architecture, where every part of a ship is detailed out. Workmen were concerned only with construction based on those designs. That was not, however, the Indian tradition. Without any such blueprints, Bengal shipwrights built vessels relying only on the dexterity and skill of the workers. According to the medieval Bengali literature, there were 12 principal components of a ship: (i) keel (*dārā*), (ii) bottom (*tālā*), (iii) prow (*māthākāsthā*), (iv) deck (*pātātan*), (v) shed (*chhaighar*), (vi) mast (*mālumkāsthā*), (vii) sail (*pal*), (viii) helm (*patwāl*), (ix) chord (*fāns*), (x) oar (*dandakerwāl*), (xi) bamboo pole (*bangsakerwāl*), and (xii) anchor (*nangar*). At the beginning, the keel, bottom, and prow were constructed, keeping in view the dimension of the ship to be built.

Shipbuilding started with a ritual, called *dārābindhā*, where the owner of the ship thrusts a gold nail (*sonārjal*) to the keel with a silver hammer (*hātur*). A similar practice was also performed in Bombay (even in the late 1830s), where a silver nail was thrust. After the ceremony, the keel was placed carefully on the construction site, and the bottom planks were joined to it with nails. The planks forming the bottom of the ship were fayed (or joined) together in a way where caulking was minimum. Indian shipwrights usually rabbeted the planks into each other, filled cottons in the interstices, and applied *dammer* on its entire exterior. When the planks were so joined, “the bottom presents, as it were, one impenetrable surface” (Charnock, v. 3, p. 303). Also, the lower part of the ship was constructed with double or triple planks (with the lighter ones at upper layers) so that they could withstand the force of the tempests to

which they were exposed. It also augmented their natural durability. In fact, the use of an additional plank over a decaying one (i.e., the sheathing) was a traditional practice in India. An eighteenth-century British naval architect observes that these Indian practices of faying and sheathing predate the corresponding knowledge of nautical technology in Europe (Charnock, v. 3, p. 303). Two more facets of Bengal technology should be noted. Firstly, Bengal artisans often built ships in compartments so that a ship could accomplish the voyage even if one of its several parts was wrecked. This is corroborated in a fifteenth-century European travelogue (Conti, p. 27). Secondly, Figs. 2 and 3 suggest that Bengal shipbuilders fitted many curved ribs on the hold. Since those ships were top heavy, outriggers were meant for safety. Once, however, these were accomplished, the prow (*galui*) was fixed, and the hold of the ship was complete.

Then, the deck (*pātātan*) was constructed by joining the planks to the keel. These joinings also obeyed the aforesaid principles. On the deck were fitted the masts (*mālumkāsthā*), yards (*jokābāri*), and helm (*patwāl*) and also the shed (*chhaighar*) and cabin (*raighar*). Finally, it was painted and decorated. Special attention was paid for decorating the prow. Often was it given the shape of a bird like a peacock, a lion, a tiger, an elephant, a buffalo, or a serpent, with their eyes bedecked with jewels.

The quality of raw materials and workmanship in Bengal gave its shipbuilding industry a sharp competitive edge in the international market. A shipping register for 1781–1839 suggests that the average expected life of a Bengal ship was more than 20 years, as against only 11 years for Bristol- or Liverpool-built ships, and 12 years for vessels built on the Thames. After comparing a London-built ship, the *Enterprise*, and a Bengal-built one, the *Forbes*, a contemporary document notes, “Surely this speaks something for the superiority of substantial teak-built vessels, over the oak and fir ships of colder climates” (quoted in Ray, 2011, p.188).

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Shipbuilding in India: Wadia Shipbuilders

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The British created a vast overseas empire through their supremacy over the high seas. In their colonial enterprise, they were ably assisted by the Wadia shipbuilders of Bombay (old spellings are advisedly used) who, drawing on their own skills, local tradition, and the raw material available, provided the British navy and merchants with excellent ships.

In the year 1498, Portuguese arrival in India by an all-sea route introduced the navy as a factor in the geopolitics of India, placing the landed rulers

at a disadvantage for all times to come. The Portuguese and the Dutch success brought the British to the Indian west coast in 1608; after 4 years, they inflicted a crushing defeat to the Portuguese at sea. The Portuguese were fanatically anti-Muslim and particularly severe on the Haj pilgrims. The victory of the religiously neutral British was viewed with relief by the Mughal emperors who in turn granted them attractive trade concessions. It was the desire to get such concessions enforced at lower levels that fuelled the (British) East India Company's territorial ambitions. Ironically, the British task was made easier by the Portuguese themselves.

The island of Bombay, which the Portuguese had taken over in 1534, was ceded and granted to the crown of England in full sovereignty under a marriage treaty signed in 1662. Never before had the dowry of a princess been so detrimental to the interests of a kingdom. Bombay was an excellent natural harbor. More importantly, unlike Surat where the British had been permitted to set up their headquarters, it laid outside the territorial reach of the Mughals. The Portuguese viceroy of Goa, Antonio de Mello e Castro, had boldly declared: "I foresee that India will be lost the same day on which the English Nation is settled in Bombay" (Da Cunha, 1900; cited in Wadia, 1957, p. 9). These words turned out to be prophetic indeed.

The instructions from London were "to keep Bombay always the seat of our power and the centre of our trade in India." It gradually became an attractive destination for the native settlers especially the Indian Zoroastrians, the Parsis, who particularly valued the religious freedom and the business opportunities the new city offered.

Until this time, the British had been getting their ships repaired and built mostly in Surat. Like many coastal places, Bombay already had facilities for building small vessels, "but no proper establishment with a dockyard, attendant builder and ancillary factories for rope-making, coopering, etc., existed" (Wadia, 1957, p. 119). What lent urgency to the establishment of a proper shipbuilding facility at Bombay was

the harassment from 1707 of foreign ships by a fleet led by Kanhoji Angre (anglicized to Connajee Angria and variously spelled) and his successors till their defeat by the British in 1751.

The first priority for Bombay was to build coastal boats. The man of the hour was Lowjee Nusserwanjee (ca. 1700–1774) who had been working for a Parsi shipbuilder in Surat since his boyhood and was known to the Bombay officials as the foreman responsible for actually building the ship “Queen.” In March 1736, he, along with ten other carpenters, came to Bombay expressly to build a grab [a usually two-masted, square-rigged coastal vessel]. When the Master Builder, Mr. Robert Baldry, died in 1740, no replacement was sought from Britain. Instead Lowjee was given the charge. From 1740 till 1764, he was generally designated Master Carpenter and subsequently Master Builder.

It was under his guidance that the first dry dock was built in 1750, and others were added later. A subsidiary dock, the Mazagon, was built in 1774. There was also a small private dock, Old Mughal dock, built around 1835, which was rented out to the Peninsular and Oriental Company in 1854 for their new mail service between Bombay and Suez. Remarkably the government post of Master Builder remained in the family for six generations till 1884, when the dockyard was transferred from the Bombay government to the Indian. There were other Wadias working in junior dockyard positions where they continued until 1913. The Wadia skills were made use of by foreign governments, companies, and merchants. The family name Wadia, meaning boatbuilder in Gujarati, was not used in official records, even though later Master Builders sometimes signed their names as Lowjee. All official correspondence was however addressed to the formal name consisting of the given name followed by the father’s.

In the first phase of shipbuilding in Bombay, the emphasis had been on repairs and construction of coastal boats for protection. Things soon changed. Increased merchant activity and marine rivalry in Europe resulted in large-scale felling of oak trees in Britain. In 1772 the Company was prohibited from building any large ships. It

therefore shifted the shipbuilding activity to India. In any case, teak was a better material than oak.

The dockyard was at its zenith during Jamsetjee’s tenure (1792–1821), while his son and successor Nowrojee (1821–1844) “was the last person to enjoy all the rights and privileges attached to the office. After his retirement there was an all round decline in ship building in Bombay” (Wadia, 1957, p. 296). The golden age of shipbuilding in Bombay however spelled disaster for the teak forests in India. The forests in Gujarat and Konkan were soon exhausted and the Malabar forests severely depleted. It is only when iron and steel ships came into increased use that in 1847 a conservator of forests, Dr. Alexander Gibson, was appointed in Bombay.

Racism

Although the Wadias were well regarded in official circles, they did come across racism. In a particularly unsavory incident, in 1781, a dockyard carpenter was flogged in a visiting British navy ship on suspicion of petty theft. When the Master Builder Bomanjee Lowjee himself went to the ship to remonstrate, he was also struck. He immediately wrote to the government stating, “unless they could be supported in their station with reputation they must with reluctance request permission to quit the place and the employment they held under the Company.” When the ship commander stood his ground, it was left to the admiral to write “a healing letter” (Wadia, 1957, p. 164).

The next Master Builder’s revenge against racism was subtler. The frigate *Marquis Cornwallis* built by him in 1800 for the Company was found to be so beautifully constructed and of such great strength that the Admiralty purchased it 4 years later. On the keelson [the timber immediately above the keel], he secretly carved the words: “this ship was built by a d...d Black Fellow AD 1800.” Jamsetjee himself drew attention to this when the ship, since renamed *Ackbar*, returned to the Bombay docks many years later (Wadia, 1957, p. 191).

In 1810, the Wadias built a 74-gun vessel “Minden” for the British navy, their first ship of the line built outside the UK. At the same time in competition to Bombay, a similar vessel was built at Kidderpore on subscription by Calcutta inhabitants and presented to the British navy, which however was not impressed. The Minden saw service during the British-American War of 1812. Francis Scott Key wrote the lyrics of the US national anthem in 1814 aboard the “Minden” where he was detained.

Steam Navigation

Once James Watt’s steam engine became available, it was used for propelling ships. The lead came from the USA, which had no roads or canals, but had large tree-lined rivers that would not mind inefficient engines. The first practically successful steam vessel on a river was launched in 1807 and on the sea the next year. Britain soon caught up, with the British navy acquiring its first steamer in 1819. Incidentally, the first steam-propelled vessel in India was fitted with an engine and built to the plan brought from England in 1819. It was built for Nawab Ghazi-ud-din of Oudh at Lucknow for use as a toy.

The Calcutta merchants were keen to introduce steam navigation on three routes: on the placid north Indian rivers, in the opium and tea trade with China, and between Calcutta and England via the old Cape of Good Hope route. Early steam machinery was rather daunting. It used coal voraciously and was extremely complex for easy maintenance. The merchants neither had the capital nor the patience to experiment. The Company, divested of its trade monopoly in 1813, had no intention of sinking its money into steam for trade, but it had wars to win. The initiative by private individuals looks significant in retrospect but was economically unviable in its time. What gave steam navigation the initial boost was the amphibian Burmese war of 1824–1826. An 8 HP engine privately brought to Calcutta in 1817 or 1818 was used to power a paddleboat that carried troops over creeks and estuaries of the Arakan coast. Similarly, in 1825, the Company bought a private river steamer “Diana” built 2 years

previously to operate against the monsoon winds. It was dubbed “fire devil” by the hapless Burmese (Bernstein, 1960, p. 30).

Bombay’s interest in steam was even more pronounced than that of Calcutta and Madras. Monsoon winds made it easier for a sailing ship to reach Calcutta than Bombay. Steam would give Bombay the benefit of its shorter distance to Europe. After waiting for 6 years for the court of directors to respond to “a distinct official proposition” first made in 1823, the Bombay government decided to go ahead on its own and got the Wadias to build a steamer, cleverly named “Hugh Lindsay” after the skeptical Company chairman. It was a small ship of 411 t with two 80 HP engines, launched in 1829. In the next 4 years, it made a total of five voyages to Suez, all heavily subsidized. Average receipts from passengers and letters stood at Rs.14,225 as against the expenditure of Rs.46,250. The acclaimed success of “Hugh Lindsay” in contrast to the declared failure of “Enterprise” in its voyage to Calcutta via the Cape established the viability of the overland route (Khan, 1971). This had far-reaching and widespread consequences. Bombay became a gateway to India. The Red Sea and the Persian Gulf were scientifically surveyed and the Suez Canal was dug. More importantly all the countries en route lost their independence.

Introduction of steam navigation did not mean the immediate end of sailing ships. The commercial viability of steam came only when engines were greatly improved and ships were made of iron and then of steel. This effectively brought teak ship building at Bombay to a close, bringing to an end a fascinating chapter in colonial history.

From 1736 to 1884, the Wadias built a total of 334 vessels for a wide variety of owners: the East India Company, private merchants, the Nizam of Hyderabad, the Imam of Muscat, and the British navy. Out of these 334, thirty-nine were either specifically built for or subsequently acquired by the British navy during 1777–1849. (For completeness, it may be added that from 1885 to 1936, another 46 vessels were built at the Bombay dockyards.) If we were looking for a single ship to sum up the career of the Wadia shipbuilders, it would have to be the frigate “Trincomalee” built in 1817

and probably the oldest ship still afloat. It served the British Navy for 76 years and was then sold off. It was renamed “Foudroyant” about 1902 and used for the training of boys in seamanship. The original name was restored in 1993 and after that the ship itself. It is now open to visitors at the Hartlepool Historic Quay.

The Wadias received three land grants in Bombay, in 1783, 1821, and 1849 (in two installments) and in 1884 on the retirement of the last Master Builder. In addition, there were a number of presents of medals, rulers, and shawls. The prestige carried by the shipbuilding Wadias helped other members of the clan in establishing themselves in various lines of business.

From Ships to Industry

The introduction of steam necessitated the upgrade of Wadia skills. Master Builder Nowrojee Jamsetjee (1774–1860) sent his son Jehangeer Nowrojee and nephew, Hirjibhoy Merwanjee, for an extended stay during 1838–1841 in England, where they studied naval architecture at the Royal Dockyard at Chatham under the Master Shipwright. Jehangeer rose to become the Master Builder himself.

Historically, far more significant was the 15-month England sojourn during 1839–1841 of Ardaseer Cursetjee (1808–1877) then an Assistant Builder at the dockyard and son of Cursetjee Rustomjee who later (1844–1857) became the Master Builder. “The prompt repair of the engines of the numerous steamers” arriving in Bombay posed a problem. “Few of the European engineers and drivers could withstand the climate, and those who were enabled to do so proved so troublesome that a remedy for the inconvenience appeared of paramount importance” Cursetjee, 1840, v). The remedy was Ardaseer’s officially sanctioned and partly financed visit. While in England, he spent his time getting practical experience in construction and maintenance of steam engines and moving in influential circles. He successfully applied for the post of Chief Engineer and Inspector of Machinery at the Company’s factory and foundry in

Bombay. The Bombay newspapers variously commented that there would be a “body of English workmen” under his charge.

This appointment in turn helped him to become the first Indian to be elected as a Fellow of the Royal Society of London in 1841. The distinction seems to have had no impact whatsoever in India. Bombay was perhaps too practical to make sense of an honor bestowed in London, while it was too early for Calcutta to be interested. In any case the Royal Society then was more of a gentleman’s club than the learned body it became later. Ardaseer was in effect introduced to India 100 years later, in 1944, by the visiting Secretary of the Royal Society. Belatedly, in 1969, an Indian stamp was issued commemorating Ardaseer Cursetjee (Kochhar, 1993).

The Wadia’s familiarity with the steam engine had far-reaching consequences. It led to the mechanization of the textile industry. Ardaseer Cursetjee’s son Nusserwanjee, who had joined the dockyard in 1844 at the age of 12, quit his job 6 years later as he was directed to Manchester by the well-known Parsi textile magnate and philanthropist Sir Dinshaw Petit to select machinery and engines for Petit’s textile mill. Nusserwanjee in turn sent his son Nowrosjee “to school in Liverpool and for factory training.” In 1879 Nowrosjee Wadia set up the Bombay Dyeing and Manufacturing Company, which has maintained an uninterrupted record of dividend payment since 1885. Nowrosjee established another successful mill, the “Century Mills,” which however was sold by his other heir (Koffend, 1979, pp. 37–41). The Bombay Dyeing’s former Chairman Mr. Neville Ness Wadia, in 1994, did not seem to know much about his FRS ancestor, certainly not that he had published a diary from England. He was greatly helpful in providing source material on the Wadias to this writer.

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Shizuki Tadao

Nakayama Shigeru

Shizuki Tadao was a Japanese natural philosopher, born in 1760. He was adopted by the Shizuki family, whose head was a government interpreter from the Dutch. In 1776 he became an assistant interpreter, succeeding his adoptive father, but he retired from that post the following year because of ill health. After leaving public service, he spent the rest of his life in the private study of Dutch books and in contemplation. He died in 1806.

He wrote books about the Dutch language and partially translated the Dutch translation of Engelbert Kaempher's *Geschichte und Beschreibung von Japan* (History and Description of Japan). But Tadao's major work was *Rekisho shinsho* (Introduction to True Physics), a compilation of his own theories on natural

philosophy, inspired by his translation of the Dutch version of John Keill's *Introductio ad veram physicam* and the *Introductio ad veram astronomiam*.

In advocating Newtonianism, Keill's work had a polemical tone, and more importantly and quite unlike the readjusted interpretations of later authors, it dealt in abstractions and included a great many elements of natural philosophy. The book especially suited Tadao's inclination toward natural philosophy and Tadao thus became the first Newtonian in the East. He established unitary *qi* (energy) and its dual function (rarefaction and condensation) as the basis for his natural philosophy. He was not successful, however, in relating the natural philosophy that he derived from the theory of monistic *qi* to Newtonian dynamics.

Tadao also raised the question of why the planets rotate and revolve in the same direction in planes not greatly inclined to the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). He proposed a hypothesis concerning the formation of the planetary system, which resembles the celebrated hypothesis of Kant and Laplace.

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Shushu Jiuzhang

Ulrich Libbrecht

The *Shushu Jiuzhang* (A Mathematical Book in Nine Chapters) is a Chinese mathematical work, written by ► [Qin Jiushao](#) and published in 1247. This book is one of the highlights of Chinese mathematics of the Song-Yuan period, 960–1368.

The work is not organized according to mathematical methods, but topically arranged according to domains of administrative practice, with the exception of Chap. 1. The nine chapters are as follows:

1. Indeterminate analysis (*Dayan*);
2. Heavenly phenomena, which dealt with chronological and meteorological questions;
3. “Boundaries of fields,” which covered surveying;
4. “Telemetry” or measuring at a distance, a kind of prototrigonometry;
5. Taxes and levies of service;
6. “Money and grain,” i.e., taxes;
7. Fortifications and buildings;
8. Military affairs; and
9. Commercial affairs.

An investigation of the socioeconomic information contained in the work proved that all the information was indeed related to the Southern Sung society, especially regarding money and currency (including paper money), credit systems, commercial life, harmonious purchase (*heti*), transportation problems, construction of dikes, taxes and levies of service (*fuyi*), architecture, military affairs, and astronomy. This could mean that the work was written for practical purposes, although it was, partly because of the Mongol invasion of China, never used as a handbook for practical training.

The basis for the common arithmetical procedures was the ancient mathematical classic, the *Jiuzhang Suanshu*. There was one method, the *dayan* rule, which Qin Jiushao learned when he worked in the Board of Astronomy. This method is preserved only in Qin’s work.

As for notation and terminology, it is important to note that the zero was printed for the first time in this book, so that we have a complete decimal place-value system. The arithmetical algorithms are the traditional ones, as are the geometrical methods and trigonometrical procedures. The most important part of the work is the “algebra.” This dealt with simultaneous linear equations, determinants, and series and progressions. Also covered were numerical equations of

higher degree, an extension of the method for square and cube root extraction used in the *Jiuzhang Suanshu* and the *Ten Books of Mathematical Classics*. This method is the same as the Horner-Ruffini procedure. The most important part is undoubtedly the Chinese Remainder Theorem, solved by means of the *dayan* rule. It is the solution of the problem:

$$N = r_1(\text{mod}_1) = r_2(\text{mod}_2) = \cdots = r_n(\text{mod } m_n)$$

It is remarkable that Qin Jiushao was able to solve problems where the moduli are not relatively prime – a method not known to Euler and Gauss, and only solved definitively by Stieltjes in 1890.

See Also

- [Jiuzhang Suanshu](#)
- [Qin Jiushao](#)

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Silk and the Loom

Dieter Kuhn

In China the raw material silk dominated textile technology as a whole, and dictated the development of looms and their technology in particular. Thus the weaving methods and the patterns depended to some extent on the loom technology available.

The biological prerequisites for silk production on a commercially significant scale are domesticated silkworms *Bombyx mori* L. (sericaria) [*jiacan*] which belong to the family Bombycidae in the order of the Lepidoptera

nocturno and various mulberry trees of the family of the Moraceae, such as the *Morus alba* Linn. (*baisang*), *Morus bombycis* Koidz. (*jingsang*), and *Morus alba* var. *multicaulis* (*lusang*), commonly called the domestic mulberry (*jiasang*). Silkworms are generally fed with the fresh leaves of the mulberry tree.

Not only were these two prerequisites present from an early stage in China, as can be seen from pictographs on bone inscriptions of the Shang era, but their biological connection was also recognized. Various archeological discoveries, fragments of textile, and imprints show that in many areas of Neolithic China a form of silk technology already existed which clearly belonged to a long and practically, perhaps even experimentally, oriented agricultural tradition. The production and treatment of silk had begun many years before and by then had already reached a high technical level. So far the earliest find of silk in China is dated between 2850 and 2650 BCE. The earliest cocoons of the domesticated spinner are from the Tang dynasty (618–907).

To understand the importance of silk as far as weaving and the development of weaving patterns are concerned, it is essential to look at the genuine properties of a single silk thread. Unlike other textile fibers silk is not spun but reeled. Silk-reeling (*sao si*) involves taking up the ends of fibers from several cocoons and combining them into a thread. It takes place just before the moth tries to break through the cocoon. This timing is crucial if endless silk threads are required. The length of the cocoon-filaments which can be obtained varies between 700 and 900 m, but without a silk-winding instrument, a reel, and a water basin in which to float the cocoons, silk-reeling cannot be performed. Through the centuries hand-driven silk-reeling was practiced as a seasonal business in small-scale family production. From the terminology used it is certain that prototypes of silk reels and silk-reeling frames (*saochechuang*) were known in the Zhou period. The earliest detailed description of the treadle-operated, highly mechanized silk-reeling frame is from ca. 1090.

Loom weaving, the production of even-textured fabric, requires that the warp threads be kept at a consistently high level of tension. The warp threads (*jing*) are those which, in parallel, run lengthwise across the loom; the weft threads (*wei*) are introduced laterally at right angles to them. A high weaving tension necessitates the use of comparatively elastic warp threads of a kind not naturally found in raw silk. This elasticity is obtained through winding or throwing or else doubling and twisting the thread. Various spinning techniques could spin the thread in the requisite manner. In China the spindle wheel (*fangche*) had been in use since the middle of the first millennium BCE. The spindle wheel was not only very efficient in the spooling of threads, which means transferring a thread from a reel to a spindle, but also most useful in the processes of doubling and quilling, when an empty spindle is filled with a twisted thread which now combines two or three threads in one. Much has been published about the origin of the spindle wheel in the East and in India, but all the pictorial and textual evidence available points to China as the geographical area where the spindle wheel originated in the context of silk technology, especially the spooling and doubling process, as pictured on some Han stone reliefs. It took a long time before the spindle wheel made its appearance in Europe in the thirteenth century. All these inventions and innovations in the processing of silk threads have to be seen in the context of the treadle-operated loom (*jiaotaji*) which was equipped with two treadles in order to mechanize the opening (*kaikou*) of the shed. Thus a clear shed for the shuttle (*suokou*) was formed through which the weft thread could be passed. Such a loom was employed to weave simple tabby fabrics to standards on a large scale. From its structure it may be described as a combined horizontal-vertical or oblique warp sheet loom (*xiezhiji*). Depictions of the loom on stone reliefs from Han times which were found in Shandong, Jiangsu, and Sichuan provide ample evidence of this type of loom. A more complicated loom with a treadle mechanism for the forming of the shed and a system of draw cords (*tihuaxian*) or pattern rods (*wen 'gan*) which

looped the warp threads required for the pattern already existed in Zhou times.

If maximum benefit was to be got from the exceptional length of the silk threads, then it was only logical to dress the loom with a silk warp. For this one needed a warp beam (*jingzhou*). The width of the fabric was determined by the length of the warp beam, and by the ideal working width for the weaver, who not only inserted the shuttle containing the weft, but also operated the treadles with her feet so as to form the sheds. In addition, she would have to perform other operations in order to create the particular pattern. On account of these factors, most fabrics of the Han era as well as later generally had a width of about 50 cm (two *chi* and two *cun*). The length varied between 9 and 12 m. The qualities of silk as an ideal warp thread and hence too the dominance of the warp in the weave resulted in the weave pattern being created by accentuating the warp threads. From the Zhou era (1045–221 BCE) until the early Tang era (618–907), therefore, Chinese silk possesses a warp pattern unlike that of other cultures, which, due to differences in the raw material, was produced on wholly different looms and which is weft patterned. Only in Tang times did the patterning technique change to the weft, which resulted in more colorful fabrics. Although it is known from a few silk fragments that the weft pattern was practiced in early China, the change in weaving technique in Tang times was certainly due to influence from the region of Samarkand or Persia.

Several types of looms were already in use and operated as early as Han times (206 BCE–AD 220). They are documented in historical works from Han and Jin times, and especially in the agricultural and encyclopedic works from the Song, Yuan, Ming, and Qing dynasties (960–1911).

The loom which combined 70 or even more movable shafts (healds) with the function of many treadles (*duozong duonie*) was widespread. Although this type of loom was difficult to set up, it was operated until recently in Sichuan province. The big advantage of this type of loom was that one weaver could operate it easily and quickly. Furthermore its advanced and highly

efficient patterning equipment qualified it for the production of so-called brocades and other complicated weaves.

Another type of loom which is not clearly distinguished in the Chinese publications from the above-mentioned loom made use of figuring healds or pattern rods (*tihuazong*, *wen 'gan*), which were manually lifted. Textual sources mention up to 120 patterning devices. This ingenious hand-operated patterning device was already used on the backstrap loom (*yaoji*) in very early times. The simple backstrap loom originally had no wooden frame but consisted exclusively of functional parts. The weaver sat on the ground. In many old publications it is depicted with a wooden framework. It was used until recently. The earliest weaving implements which may be ascribed to such a loom were excavated from the site of Hemudu, datable to ca. 4300 BCE. It may be justified to assume that the patterning technique with pattern rods which can be created in a sitting position on the ground is older than the use of looms with shafts and treadles which require a wooden frame. Although the simple type of backstrap loom was an excellent device for weaving on a comparatively small scale, it had its obvious limitations which were set by the length and width of the circular warp. In the view of Chinese textile historians this loom with pattern rods belongs to a loom category either of an early primitive type or of ethnic minorities. Only after the horizontal backstrap loom had been equipped with a real warp beam, supported by a wooden framework, which helped to facilitate its operation, can it be regarded as a loom which worked economically and which was suitable for silk weaving with patterning on a large scale. In all probability and in the opinion of a few eminent Western weaving specialists, such a loom with two shafts producing a tabby ground and a system of pattern rods of the heddle rod type that were lifted by the weaver as required by the pattern was the type of loom used and preferred to all others for the production of complex-patterned weaves before Tang times in China.

The third type of loom before Han times was a forerunner of the Chinese drawloom. It employed

a string heddle patterning device (*shuzong tihua zhuangzhi*) and a simple treadle-operated shedding device. During Eastern Han times its equipment was improved in such a way that the whole “machine” (*ji*) gained the structural and functional features of a real drawloom (*hualou tihuai*). This drawloom was equipped with a figure or harness tower and all the lifting devices for the warp threads required. Furthermore there were lifting and depressing shafts. It was operated by a weaver and a drawgirl. This type of loom, which was fashioned in a large variety, dominated the production of high-quality polychrome-patterned silk fabrics until the late nineteenth century when Western looms were introduced into China. Some Western historians of weaving technology have ruled out the use of a drawloom in Han times in China and suggested that it was invented somewhere in the region of Samarkand, Persia, or even the Near East. To support their notion they practically demonstrated that even difficult polychrome weaves could have been produced on pattern rod looms. However the “Rhapsody on Women Weavers” bears witness to the fact that the drawloom with all its characteristic features was already in use in the big workshops of China as early as the first half of the second century AD. The earliest technical description and illustrations on the subject were published in the *Ziren yizhi* (Traditions of the Joiners’ Craft) of 1264.

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Silk in Bengal

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Silk manufacturing is an important facet of industrial heritage in Bengal. The high profile of this industry is confirmed in many European travelogues during the late medieval and the early modern periods. They narrated how the province fed different markets in the Indian continent – and even beyond – with decorative pieces of silk cloth. Village establishments, such as Cassembazar, might have turned out more than two million bales of silk a year. Working on low technology and capital, village artisans in Bengal designed their own implements and organized production at their huts. They left the distant sales of their fancy outputs to the trading communities like the Marwaris and the Parsis, who created their markets at Surat, Delhi, Lahore, and Agra. Later on, they were sold to the Portuguese, the Dutch, and the English, who sold them at European outlets. In 1703–1708, the English East India Company annually exported about 162,000 lbs of raw silk and 28,000 pieces of silk fabrics from Bengal. To these we add the export of the Dutch East India Company as also

enormous intakes in India's domestic markets to get an idea about silk-related economic activities in Bengal.

There are three distinct branches in silk manufacturing: (a) sericulture (cocoon rearing), (b) raw silk (cocoon spinning), and (c) weaving. Actually, the Italian (Novi) technology put a dent in indigenous practices during the British Raj. But that was confined to raw silk alone, leaving cocoon rearing and weaving to the fiefdom of native artisans. Also, as a courtesy to domestic weavers, indigenous technology continued predominantly in raw silk manufacturing.

Cocoon Rearing

Traditionally, Bengal artisans reared four species of cocoon: *bara-palu* (*Bombyx textor*), *chhotapalu* (*Bombyx fortunatus*), *nistari* (*Bombyx craesi*), and *cheena-palu* (*Bombyx sinensis*). The *bara-palu*, yielding by far the best quality of silk, breeds once a year as against as many as eight times by others. They are accordingly called univoltine and multivoltine. Though less productive, the *nistari* was most popular among rearers because of the softness and fineness of the silk they produce. Silkworms were, however, prone to fly attacks, especially when all the possible eight crops were tried for. Artisans, therefore, generally reared cocoons in one *bund* (i.e., one season) and nourished the mulberry trees in the next, yielding only four crops in a year. Generally, they opted for three with the *nistari* and one with the *chhotapalu* or the *bara-palu*.

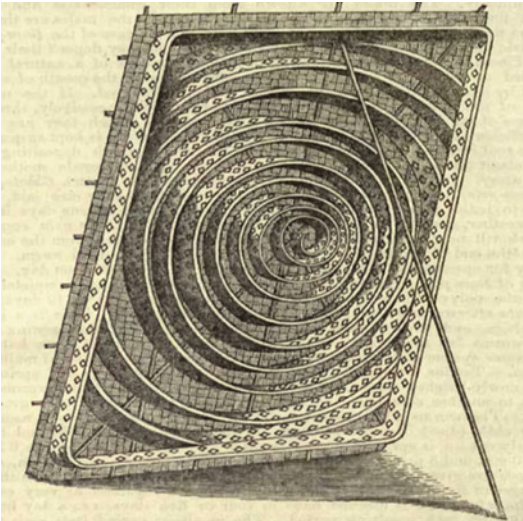
The art of cocoon rearing revolved around the selection of seed cocoons and their feeding. In search for good seeds, rearers often walked for several miles – sometimes 50–60 miles at a stretch – and stayed at *joars* (silk-rearing centers) for days to judge the quality of seeds that depended on their ripening process. This was, indeed, an expert job. Expertise was also involved in feeding, especially in respect to quantity and quality of food, as well as time scheduling. Their singular diet, the mulberry leaf, contained water, fiber, color, saccharine, and resin. Of these, saccharine accelerated their

physical growth, and resin ensured the secretion of silk in proportion to their sizes. Rearers, therefore, avoided fermented or worn-out leaves that were deficient in these substances.

More frequently, rearing took place in mud-built houses of roughly 24 × 15 f. in area and 9 ft in height, where about 256,000 worms could be stored at a time. Such a hut accommodated five big bamboo mats (*ghurrahs*), each having a capacity to contain 15 *dalis* (trays), made of bamboo. Rearers thinly spread seed cocoons over those *dalis*, and, in 8–16 days, moths came out. Immediately, they paired together and remained so for several hours. When they were separated, the males were thrown out so that the females could lay eggs uninterruptedly. The multivoltine moths, however, laid eggs on the same *dalis*, which hatched in 8–16 days. For the univoltine moths, a piece of rag was spread on each *dali*. When eggs were laid, those were preserved in an earthen vessel. It took about 11 months for them to hatch.

Tender mulberry leaves, finely chopped, were the appropriate diet for newborn worms. For the initial 3–4 h, they ate vigorously but spoiled the *dalis* with excrement. For the sake of cleanliness – which was imperative for their survival – rearers put them on separate *dalis* and sprinkled fresh leaves on them. Food was, however, served four times a day regularly, save the day of molting. There were four molts for silk worms when they refused food. After awakening, they shed their skeins and began to eat again. Since their sizes were enhanced about three times after each molt, a proportionately larger amount of food was required, and that with more mature leaves. After the fourth molt, however, they refused to eat and swung their heads restlessly, spitting out silk fibers. At this stage, rearers placed them on the spinning mat (variously called *chandrakies*, *tâlis*, *chânces*, and *fingás*) (see Fig. 1).

On this mat, cocoons were spun in 2 days during the summer and four in the winter. If any delay was noticed, rearers put the mat in the morning sun and also near a fireplace in the winter night.



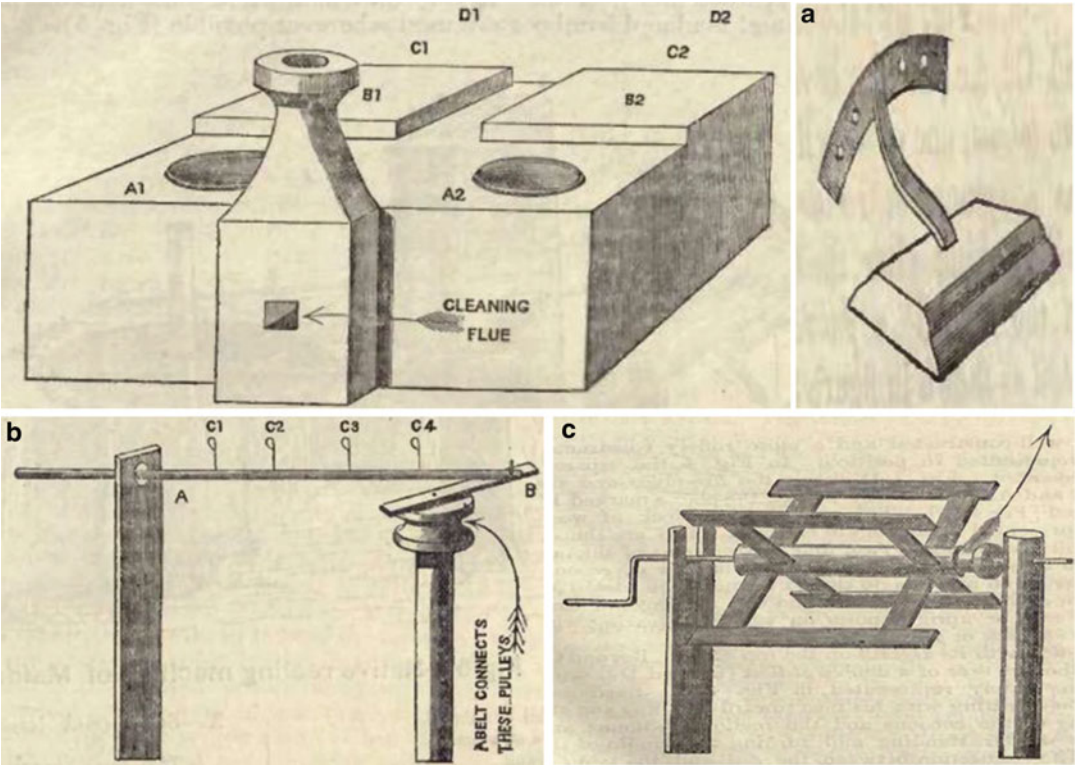
Silk in Bengal, Fig. 1 *Chandraki* (spinning mat) (Source: N. G. Mukerji, A Monograph on the Silk Fabrics of Bengal, p. 12)

Cocoon Spinning

Two types of spinning were followed in the indigenous sector: the *khamru* spinning for “healthy” cocoons and the *matka* spinning for “pierced” cocoons, i.e., the cocoons where moths came out.

Khamru Spinning: This was the widely held technology in Bengal, which processed more than half of its cocoon outcrops even in the hey-days of the *Novi* culture. The technology was embedded in an apparatus called *ghai*, which might be operated by one set of artisans or double the set. They were called the single *ghai* and the double *ghai*. A model of the latter, as used in the Rajshahi district of Bengal, is shown in Fig. 2.

The apparatus consisted of four components: (a) two fireplaces at A_1 and A_2 , as in Fig. 2, with basins (called *ghai* or *karai*) on their top; (b) two *banti-kals* at B_1 and B_2 (Fig. 2), each made up of



Silk in Bengal, Fig. 2 The double *ghai*. (a) The *banti-kal*; (b) the *khelná* on *ará*; (c) the *tahabil* (Source: N. G. Mukerji, A Monograph on the Silk Fabrics of Bengal, p. 25)

a block of wood and an arc-shaped iron with a few holes on it (see **a** in Fig. 2); (c) two *khelnás* (or *ghargharis*), each on an *árá* at C_1 and C_2 , as in Fig. 2 (the *árá* was a structure of two wooden posts where the *khelená*, a wooden rod with elongated holes, were attached to a pulley (see **b** in Fig. 2)); and (d) two *tahabils* at D_1 and D_2 . The *tahabil* – a wooden structure as seen in **c** in Fig. 2 – had one iron handle on the left and a wheel on the right. The wheel was connected by a belt with the pulley of the *árá*. Threads were collected at the central part of the *tahabil*. However, if there were two holes in the *banti-kal*, two skeins could be reeled simultaneously from the basin. Through those holes of the *banti-kal*, the skeins were passed on to (c1) and (c2) of the *khelná*. When the iron rod of the *tahabil* was manually rotated, the pulley of the *árá* was also rotated so that skeins were spun into a single thread on the *khelná*. Finally, the threads were collected on the *tahabil*.

Proper processing of cocoons was sine qua non for good spinning. It started with exposing them to the sun, followed by steaming, so that pupas were killed, and the cocoons became soft. Artisans thereafter put them in boiling water and sought their ends with the help of a brush or a bundle of sticks. With those ends in the left hand, they shook cocoons in the water in such a way that a greater length of those cocoons was worked off. For spinning, however, 10–20 ends were taken together to divide them in two lots if

there were two holes on the *banti-kal*. Each of those lots was then pushed manually through the holes of the *banti-kal* and the *khelná*. For the double *ghai* apparatus, there were two winders (*pákdárs*) at *tahabils* and two spinners or reelers (*kátánis*) at basins. As the winders revolved the handle at *tahabil*, cocoons were worked off at basins, where the spinners sat and managed the cocoons to unfold properly. When adequately twisted, those threads were collected at *tahabils*.

Matka Spinning: This was an alternative technology which could spin pierced cocoons where there were several ends. A large quantity of such cocoons usually piled up at the rearers' huts every season. Destitute persons, especially widows in the artisan's family, took up this profession as it involved a very low amount of capital.

This technology required three rudimentary implements: a spindle (variously called *teko*, *tékia*, *tākur*, *jūta*, and *jāmtākur*), a bobbin (*latai*), and an earthen vessel. The spindle was made up of thin bamboo, about 10 in. long, with its upper end acting as a hook to hold fibers. An earthen disc was attached to its lower end and acted as a fly shuttle. The *latai* was a conical bobbin, about 6 in. in length, with a long handle. It was also made of bamboo. The earthen vessel was, however, required to keep up pierced cocoons. These implements are seen in Fig. 3 on *matka* spinning.

The process started with kneading pierced cocoons with mud so that the strands of those

Silk in Bengal,

Fig. 3 *Matka* spinning
(Source: N. G. Mukerji,
A Monograph on the Silk
Fabrics of Bengal, p. 23)



cocoons could be drawn out one by one. The spinner then took out a few strands together and attached them to the spindle. When she revolved the shuttle, those strands were twisted into a single thread. She then collected the thread at the base of the spindle and repeated the process. Generally, 400 cocoons were thus spun in a day. At the end of the day, those threads were taken out of the spindle and reeled on the *latai*.

Silk Weaving

The *khamru* silk was generally used in indigenous weaving. Weavers always preferred to unwind the skeins – for the sake of the uniformity of thickness as also the continuity of thread in each *latai* – and, in some cases, to the twisted (*pakwan*) threads. As a rule, they used *pakwan* threads as warps in superior fabrics and the *kham* (untwisted) threads in inferior fabrics. For wefts, the latter was universally used.

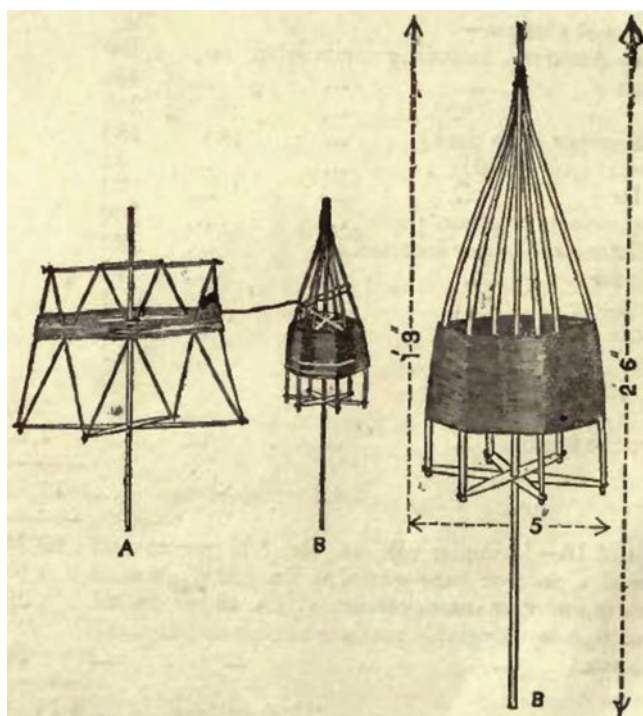
Unwinding (Phiran): Threads were unwound using a bamboo-made wheel (*polti* or *chorki*) and

a *latai* (see Fig. 4). The former had a long stick, which was planted loosely on the ground so that it could revolve. The *phiran* artisan put the skein of silk around it and knotted it with the *latai*. While revolving the *latai* with the left hand, the thread passed through the thumb and the index finger of the right hand so that its thickness could be judged. Since the threads of equal thickness were wound on one *latai*, 3–4 *latais* were sometimes required to unwind one skein.

Throwsting or Twisting: Five appliances were used in traditional throwsting (Fig. 5): (i) a *latai* (see A in Fig. 5), where filaments had been collected after unwinding; (ii) an iron guide (called *loibangri khunti*) (see L in Fig. 5); (iii) a cane-made structure (called *dôl*) with holes on it, as seen in Fig. 5b, fitted on bamboo posts; (iv) a number of *takurs* (see C in Fig. 5), i.e., long pins with mud weights at the bottom; and (v) a number of *thhaks*, i.e., holes in a structure of bamboo that was fitted on two posts (see Fig. 5a). The *thhaks* were placed parallel to the *dôl* at a distance of about 27 yards, and the *latai* and the iron guide were planted nearby the *dôl*. From the *latai*

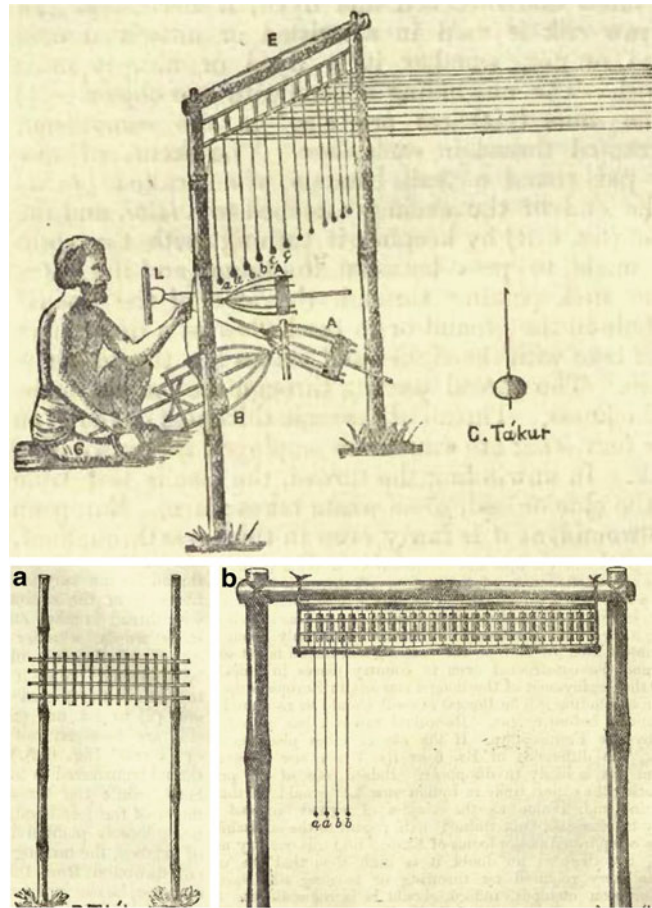
Silk in Bengal,

Fig. 4 Unwinding of skeins (Source: N. G. Mukerji, A Monograph on the Silk Fabrics of Bengal, p. 36)



Silk in Bengal,

Fig. 5 Twisting of raw silk. (a) The *thhák*; (b) the *dól* (Source: N. G. Mukerji, A Monograph on the Silk Fabrics of Bengal, p. 38)

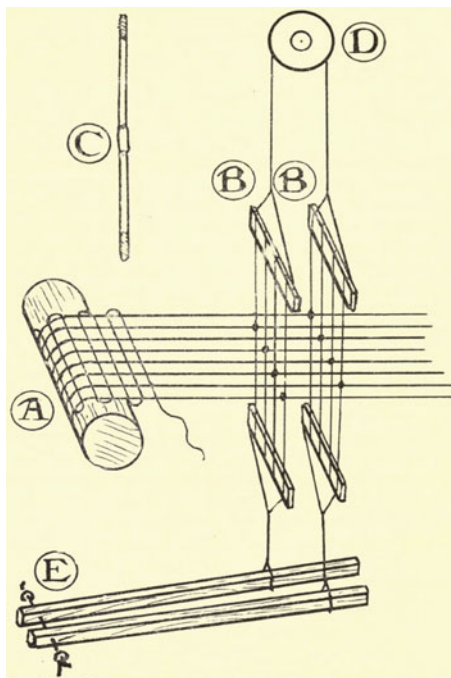


a number of silk filaments were passed successively through the iron guide, the first space of the *dól*, and the uppermost space of the *thhák*. They were brought back through the second uppermost space of the *thhák*, and the second space of the *dól*, to be finally knotted with a *takur*. The other ends of those filaments were then snapped at the iron guide and knotted with another *takur*. There were thus two *takurs* hanging at two ends of those filaments. Usually, seven sets of filaments were thus arranged with 14 *takurs* in such a way that their ends hung at a same distance from the ground.

The throwster (*pakwan*) successively rubbed the pins of those *takurs* between the palms of his hands so that they simultaneously revolved fast without any interruption. When the *takurs* initially hung 9 in. from the *dól*, the thread was

considered well twisted when it was shortened by 9 in. On this apparatus, a throwster could twist 14×27 or 378 yards at a time.

Weaving: Silk was woven in a traditional loom that was also used in cotton weaving. Fig. 6 displays its basic mechanical principle. A weaver first arranged the warp horizontally on the loom, such as the figure displays with a warp of eight threads. His or her next task was to intersect the weft threads through the warp, which the mechanism of the loom helped him to perform. At A of Fig. 6 there was a roller where woven materials were collected. There were two pairs of laths, each called a *headle*. One of each *headle* was above the warp and the other below it, and they were joined together by four strong threads. There were three loops in each thread, the thin central one being meant for the warp thread to



Silk in Bengal, Fig. 6 Mechanical devices of a loom (Source: L. Hopper, *Silk: its production and manufacture*, p. 68)

pass through (see C in the figure). Through the front *headle* loops, the first, third, fifth, and seventh warp threads passed, and through the back *headle* loops, the second, fourth, sixth, and eighth warp threads passed. The figure, however, shows that upper laths of the *headles* were joined together through a pulley, and their lower laths were attached with treadles.

If one treadle was pressed down, four warp threads were sunk so that the weft thread could be passed through them. When this was followed by pressing the other treadle, the second opening got ready for the return of the weft. This was how the weft was woven through the warp.

Various types of weaving were done using this principle. For satin weaving, for example, eight weft threads were taken together, and one after another, they passed over one warp thread and under seven of its consecutive threads. They were so arranged that there were equal spaces between satin ties, both vertically and laterally.

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Sinān ibn Thābit

Yvonne Dold-Samplonius

Abū Saʿīd Sinān ibn Thābit ibn Qurra was born in Baghdad ca. 880. He was the son of the translator and scientist Thābit ibn Qurra (ca. 830–901), who dedicated his *al-Dhakhīra fī ilm al-tibb* (Treasury of Medicine) to him, and the father of the mathematician and astronomer ► [Ibrāhīm ibn Sinān](#) ibn Thābit (908–946). His family came from ḥarrān, crossroads of caravan routes and cultures on the Upper Euphrates, and the religious center of the Sabian sect. One of the most famous physicians of his time, he directed the hospitals and medical administration of Baghdad under the reign of the Abbassid Caliph al-Muqtadir (908–932). He also served as physician to him and to his successors al-Qāhir (932–934) and al-Rāḍī (934–940). Under the former’s persecution of the Sabians Sinān had to convert to Islam. He later fled to Khurāsān, and returned when al-Rāḍī came into power.

Sinān’s work, as catalogued by Ibn al-Qifṭī, can be divided into three categories: historical-political, mathematical, and astronomical; no medical texts are mentioned. None of it is extant. In the first category he wrote a description of the

life at the court of Caliph al-Muʿtaḍid (892–902), his father’s protector, and a sketch for a government along the lines of Plato’s *Republic*. Both treatises are mentioned by al-Maʿsūdī, who criticizes the latter, adding that Sinān should rather have occupied himself with topics within his competence.

Four mathematical treatises are listed, of which two cannot be by Sinān, since the dates given were in the second half of the tenth century. Of the remaining two, one is connected with Archimedes’ *On Triangles*, whereas the other consists of an improvement, with additions, of the book by Aqāṭun (Yāqūt = Euclid), *On Elements of Geometry*.

As to the third category, only the content of the *Kitāb al-Anwāʾ*, dedicated to al-Muʿtaḍid, is somewhat known through excerpts given by ► [al-Bīrūnī](#) in the *al-Āthār al-bāqīya min al-Qurūn al khāliya* (Chronology of Ancient Nations). A *Kitāb al-Anwāʾ* is a kind of almanac describing the astrometeorological properties (*anwāʾ*) of the individual days. Sinān’s almanac is fundamentally based on an anonymous Arabic translation of Ptolemy’s *Phaseis*, in which he provides the times of the rising and setting of prominent fixed stars. Other sources are ► [Ibn Māsawayh](#) (d. 857) and Hippocrates, as well as personal contributions by Sinān. According to al-Bīrūnī, Sinān also relates an Egyptian theory and one by Hipparchus, on where to fix the beginnings of the seasons. Another treatise, seemingly also of astrometeorological content, is on the assignment of the planets to the days of the week, composed for the Sabian Abū Ishāq Ibrāhīm ibn Hilāl (ca. 924–994). The seven planets were important in Sabian religion; each one had its own temple. Ibn al-Qifṭī lists several works on Sabian rites and religion. Sinān died, probably in Baghdad, in 943.

See Also

- [al-Bīrūnī](#)
- [Astronomy in the Islamic World](#)
- [Thābit ibn Qurra](#)

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Siyuan Yujian 四元玉鑒

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France

This book (*The Jade Mirror of the Four Unknowns*, also translated as *Precious Mirror of the Four Elements*) by Zhu Shijie 朱世傑, dating from 1303, appears to represent the most advanced achievement of the mathematical tradition of polynomial algebra or the “procedure of the celestial unknown (lit.: origin) 天元術” which developed in North China in the second half of the thirteenth century. Jock Hoe (1977) describes the history of its reception among mathematicians and historians in both ► [East](#) and ► [West](#). The *Siyuan yujian* shares the same basic features with the first book that has come down to us on this topic, Li Ye 李冶’s (or Li Zhi 李治’s, according to the name chosen for this scholar) *Ceyuan haijing* 測軍海鏡 (Sea Mirror of the

Circle Measurements, 1248). The mathematical knowledge it contains is presented in the form of problems, the first four of which lay the foundations for the whole book by gradually presenting, though extremely concisely, how to use polynomials with up to four indeterminates to solve given problems. Mirroring the intimate relationship that the right-angled triangle had with the topic of algebraic equations, and later of polynomials, from the very first appearance of these matters in China, these problems all concern the right-angled triangle, as do 101 of the 284 problems that follow in the *Siyuan yujian*. Once a problem is set, Zhu suggests the choice of one or several unknowns to form polynomials on the basis of the conditions given in the terms of the problem. In the case when one unknown suffices, like Li Ye, Zhu forms two *polynomial expressions*, representing the same quantity, and thus by elimination between them establishes an algebraic equation, a root of which is the unknown sought. Since Zhu does not explain the algorithms, similar to the so-called Ruffini-Horner ones, that can be used to determine this root, he seems to have assumed the reader's knowledge of this procedure. They are found in ► [Qin Jiushao](#) 秦九韶's ► [Shushu jiuzhang](#) 數書九章 (Writings on Mathematics in Nine Chapters, 1247) and seem to be common knowledge in the milieu developing the "procedure of the celestial unknown." Yet Zhu elaborates them further, especially in cases where the result is a rational number; he then systematically introduces techniques to expand the root sought.

These polynomials he uses are written in the form of an array of numbers, as in Fig. 1, where the indeterminate and its successive positive or negative powers receive a positional expression. Note that the writing of a polynomial differs from the writing of an equation, as in Fig. 2, in that the constant term of the polynomial is indicated, being accompanied by a character, thus allowing the polynomial to contain any power of the indeterminate.

When more than one unknown is needed, Zhu designs several equations involving them, which he represents by tables of numbers, where again position is used to express the various powers of

太
0
729
-81
-9
1

Siyuan Yujian 四元玉鑒, **Fig. 1** $729x^2 - 81x^3 - 9x^4 + x^5$

-3888
0
729
-81
-9
1

Siyuan Yujian 四元玉鑒, **Fig. 2** $x^5 - 9x^4 - 81x^3 + 729x^2 - 3888 = 0$

2	0	太
-1	2	0
		1

Siyuan Yujian 四元玉鑒, **Fig. 3** $x^2 + 2xy + 2y^2 - y^2x = 0$

-1	太	-1
		1
-1	0	-1

Siyuan Yujian 四元玉鑒, **Fig. 4** $xyz - xy^2 - x - y - z = 0$

the unknowns. For two unknowns, the vertical direction refers to one unknown whereas the horizontal one refers to the other; the surface of the plane suffices for any monom to be represented by its coefficient written in an appropriate place on the counting board, as in Fig. 3. Yet for three or four unknowns, limitations occur in the representation of all possible monoms and new positions on the counting board are brought into play, but in a less systematic way, as in Fig. 4.

In contrast to equations with one unknown, such equations need the constant term to be indicated by a character. Once these equations are determined, elimination is performed between them until an equation with only one unknown

is obtained, which is then solved. Several techniques are used for this purpose, the most basic one resembling the elimination between linear equations put into play by the algorithm to solve systems of simultaneous linear equations presented in the Han book ► [Jiuzhang suanshu](#) 九章算術 (The Nine Chapters on Mathematical Procedures). The difference lies in the fact that now the terms involved in the procedure of elimination are polynomials, and no longer numbers. Stress must be placed on a conceptual gap. In contrast to the case for one unknown, the only one Li Ye dealt with, the elimination no longer bears on polynomials representing a given *quantity*, but rather on equations with several unknowns representing a *relationship* between the unknowns.

In the rest of the book, this apparatus is applied to all kinds of mathematical situations, such as geometry and summation of series, involving various applications to economic or social life.

See Also

- [Li Zhi \(Li Ye\)](#)
- [Jiuzhang suanshu](#)
- [Mathematics in China](#)
- [Qin Jiushao](#)
- [Zhu Shijie](#) 朱世傑

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Song Ci

Hong Wuli

Song Ci was born in Jianyang in 1186 of the Southern Song Dynasty and died in 1249 in Guangzhou. He was a forensic scientist, an expert in legal medicine.

A native of Jianyang (now Jianyang County, Fujian Province), Song Ci was born to a family of middle-class bureaucrats. His father was Song Huifu. He was well educated and passed the feudal examination at the highest (imperial) level. He held several posts, including the confidential secretary of the local government, county magistrate, and provincial officials until he was promoted to the provincial official responsible for law suits and jail affairs. At that time, most feudal officials did not take their responsibilities seriously, especially those involving the law, resulting in the pile up of unsolved law suits. Many were legal offenders themselves. Song ordered deadlines to sort out all these cases. Eventually, he cleared a backlog of over 200 cases (Gao, 1978).

During his tenure, he set up a whole series of rules for examiners of the wounded or the dead. He stressed that legal medical experts or officials must, under the accompaniment of an examiner, arrive at the spot as soon as possible, and that no fumigation or incense was to be used. The officer or expert should examine the case in person, instead of hearing the examiner's report. He also claimed that "the most important issue in criminality is the death sentence, which should

be carefully understood at the very beginning of the case by serious investigation”. He also pointed out that the malfeasance of prison officials always begins with a tiny error during the investigation. Lack of experience and cursory investigation are the direct causes of wrong cases and unjust verdicts. He criticized or even punished those fraudulent examiners whenever cases were in question, and he pondered carefully and conscientiously so that few wrong conclusions were drawn (Song, 1981). Based on his long-term practical experience, he compiled, in 1247, the famous *Xi yuan ji lu* (*Collected Records of Washing Away the Wrong Cases*, also translated as *The Washing Away of Wrongs*) which is the earliest work in medico-jurisprudence both in China and abroad. This book has been translated into several Western languages (Jia, 1984).

See Also

► [Medicine in China: Forensic Medicine](#)

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Song Yingxing and *Tiangong Kaiwu*

Pan Jixing

Son Yingxing (alias Changgeng, 1587-ca. 1666) was a great scientist and thinker of the seventeenth century. He was born in Fengxin county

in Jiangxi province in 1587. After graduating from the county school he became *jüren* or a successful candidate in the imperial examination at the provincial level in 1615. He took part in the highest imperial examinations in Beijing six times, but failed to become a *jinshi*. After that he decided to give up Confucianism and turned to the practical knowledge of natural science. From 1635 to 1638 he taught at Fenyi county school; then he was appointed the prison officer of Tingzhou prefecture in Fujian province from 1638 to 1640. In 1643 he worked as the magistrate of Bozhou prefecture in Anhui province. After the Ming dynasty (1368–1644) was overthrown by Manchu-Qing rulers, Song lived at home as a hermit until his death in about 1666. He had extensive knowledge in both humanistic and natural sciences. He traveled from the south to the north to obtain practical knowledge of agricultural and industrial techniques as well as political and economical information on Chinese society. This made it possible for him to write more than ten books, most of which were completed at Fenyi from 1636 to 1637.

The *Tiangong Kaiwu* (Exploitation of Products from Nature by Means of a Combination of Artificial Skills and Natural Power, also translated as *The Creations of Nature and Man*, 1637) is his most important work. It consists of 18 chapters on 33 departments of agricultural and industrial production including grain planting, sericulture, spinning and weaving, dyeing, salt and sugar making, vegetable oils, distiller’s yeasts, ceramics and porcelain, metallurgy and casting, paper and ink making, coal, alum and copper producing, carriages and shipbuilding, cold weapons and firearms, and pearl and jade exploiting. Apart from detailed descriptions of the above-mentioned techniques, there are 123 useful illustrations in this book. It recorded many advanced technical achievements from the distant past until the Ming dynasty and made a comprehensive generalization them. Some had been rarely talked about in previous works, such as improving paddy and silkworm varieties through artificial hybridization, smelting zinc from calamine, smelting wrought iron from pig iron, producing alloys of copper and zinc, etc.

This work also developed many advanced technical ideas, especially the *Tiangong Kaiwu* thought which emphasized the coordination between mankind and nature as well as artificial skills and natural power in order to exploit various products from nature for people's use.

Not only was the *Tiangong Kaiwu* welcomed in China, but it also spread to Japan and Korea from the seventeenth to the eighteenth centuries and became a popular reference work for Japanese and Korean scholars during the Edo period (1608–1868) and the Yi dynasty (1392–1910). It was reprinted in Osaka in 1771. During 1830–1840 five chapters of it were translated into French, then into English and German. The part on sericulture was cited by Charles Darwin and highly valued. In 1869 many chapters on industrial techniques were collected in the *Industries anciennes et modernes de l'Empire Chinois* published in Paris. The first four chapters on agriculture were translated into German in 1964; 2 years later the whole book was published in English in the United States. It was regarded as an “encyclopédie technique” by French sinologist Stanislas Julien of the nineteenth century, and Joseph Needham, the British scholar, called Song a “Chinese Agricola” or “Chinese Diderot.” It has now become a world-famous classical scientific work.

Among Song's existing works there are also the *Ye Yi* (Proposals to the Court from Common People, 1636), *Si Lian Shi* (Poems on Praising the Good and Pitying the Foolish, 1637), *Lun Qi* (On the *Qi*, 1637), and *Tan Tian* (On Celestial Bodies, 1637). The *Ye Yi* reflected the author's political and economic thought. He put forward a plan of political reform for the Ming court for averting the political and economical crisis in society. He considered that social wealth was created by labor and that currency should not be the definition of wealth. He believed that increasing social wealth meant producing more consumable goods. Therefore, his ideas are similar to those of Adam Smith.

The *Lun Qi* is a work on natural philosophy. It explains the formation and composition of all things by means of a combination of the theory on the *qi* and the new theory of ► [yinyang](#) and

five elements. He introduced a new conception of *xing* (form or shape) between the *qi* and five elements, and he explained the material unity in the composition between organic and inorganic substances. He also discussed the idea of conservation of matter in this work. It also dealt with acoustical problems, and pointed out that the formation of sound is the result of the vibration of substances, and the medium of the spread of sound is the air. Song considered that the spread of sound in the air should be in the form of a water wave; he thus put forward a preliminary conception of a sound wave.

In his astronomical work, the *Tan Tian*, he criticized a traditional theory that the solar eclipse was connected with human affairs. He thought that all things including the sun are always changing. He said: “Therefore, the sun today is no longer the same one as yesterday.” Most of Song's advanced philosophical thought was further developed by another great philosopher, Wang Fuzhi (alias Chuanshan, 1619–1692). Those in academic circles are familiar with his scientific achievements, but much less familiar with his political, economic, and philosophical thoughts, because those works were only found in the mid-twentieth century and have not been carefully studied yet.

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Soy Sauce

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Introduction

The term soy sauce commonly refers to a light- to dark-colored liquid made from soybeans. Soy sauce is a condiment and seasoning which has a savory taste and specific aroma, and it contributes to palatable cuisines in many Asian countries. There are three different categories of soy sauce on the market, according to the production process, i.e., fermented soy sauce, chemical soy sauce, and a combination of fermented and chemical soy sauce (Fukushima, 1981; Hesseltine & Wang, 1980). However, the original soy sauces are usually the fermented ones (Fukushima, 1981).

They started to use chemical soy sauce decades ago; it was made by a rapid acid hydrolysis of soybean proteins. Fermented soy sauce has been produced since ancient times by using microbes to ferment soybeans for months. Traditionally, the fermentation process involves molds at the first stage and then bacteria and yeasts at the next stage under high salt condition.

History

Soy sauce has been traditionally produced since 2,000 years ago in China, where it was formerly called *chiang* and *shih* and then *chiang-yu* in the sixteenth century. This tamari-type soy sauce was introduced into Japan before 700 AD, and in the sixteenth century, the name of *shoyu* was recognized. Chiang-yu in China and shoyu in Japan have the same Chinese characters (Yokotsuka, 1986).

The tamari-type soy sauce was also widely produced in Southeast Asian countries, including

Indonesia, Singapore, Malaysia, Thailand, and the Philippines, previously following the Chinese or Cantonese traditional techniques spread from generation to generation, but since several decades ago applying Japanese modern production techniques. In Indonesia, soy sauce is called *kecap*. But, this term is also familiar to people in some Southeast Asian countries such as Malaysia and Singapore.

Types of Soy Sauce

Soy sauce can be grouped into two types: Japanese and Chinese. Japanese soy sauce uses soybeans and wheat in equal amounts; this type is differentiated further into *koikuchi*, *usukuchi*, and *saishikomi shoyu* in Japan regarding their different production process and product characteristics in color, aroma, and viscosity. Another type of shoyu, *shiro shoyu* (*shiro* means white in Japanese), actually has a very light and transparent yellow color because of the large amount of wheat with very few soybeans. Chinese soy sauce uses no or a small amount of wheat as an addition to the soybeans; this type is called *tamari shoyu* in Japan and has a very dark color.

The type of soybeans used for Japanese soy sauce production is commonly yellow soybeans, while the Chinese type found in Indonesia uses black soybeans. Yellow and black soybeans are of the same species *Glycine max*, but they are different in their outer color.

Traditional Production

In general, there are two steps to the fermentation process in soy sauce production either in traditional or modern industrial production. The first step is solid-state fermentation (typically called *koji* in Japan or *bungkil* in Indonesia) which involves some molds. The second step is brine fermentation (called *moromi* in Japan or *baceman* in Indonesia) at high sodium salt concentrations, ranged 17.5–20 %w/v, by involving some halophilic bacteria and osmophilic yeasts. Molds in the first step are mainly *Aspergillus oryzae*,

Aspergillus sojae, and *Aspergillus tamarii* as found in soy sauce production in Japan, China, and Southeast Asia. Bacteria and yeasts in the second step of fermentation are salt-tolerant lactobacilli, *Saccharomyces rouxii* and *Candida versatilis* found in Japanese soy sauce (Yokotsuka, 1986) and *Pediococcus halophilus*, coryneform bacteria, *Zygosaccharomyces rouxii*, and *Candida parapsilosis* found in traditional Indonesian soy sauce production (Röling, Apriyantono, & van Verseveld, 1996; Röling, Schuurmans, Timotius, Stouthamer, & van Verseveld, 1994; Röling, Timotius, Prasetyo, Stouthamer, & van Verseveld, 1994). In Indonesia, traditional production applied the spontaneous solid-state and brine fermentation.

A study on traditional soy sauce production in Southeast Asia was conducted with Indonesian soy sauce, kecap. The boiled whole soybeans are subjected to spontaneous solid-state fermentation for 1–2 days, and then the resulted bungkil is sun dried and mixed with brine solution (three to four times of volume); afterwards the baceman fermentation stage started for 4 months or less spontaneously. Since ancient times, people used sun drying for the bungkil and the baceman. The sun-dried bungkil gave a faster growth of lactobacilli in the next step of fermentation. The baceman process under the sun could avoid the growth of spoilage microbes at the surface. Otherwise, the salt hygroscopic property might lower the salt concentration at the surface, and therefore lesser salt-tolerant microbes such as film/pellicle-forming yeasts could grow and spoil the baceman (Röling, Timotius, Stouthamer, & van Verseveld, 1994). The salt concentration range could be maintained if the baceman was simply left to be opened under the sun with a periodic mixing.

At the final process of traditional production, the moromi or baceman yielded is then filtered manually or mechanically to obtain a raw liquor. This liquor is then pasteurized and bottled for shoyu before being marketed, or else it is boiled, and then a high amount of brown sugar is added during boiling to produce a thick and sweet soy sauce, called *kecap manis*. Or a very small amount of brown sugar is added to produce a thin and salty soy sauce, called *kecap asin*.

Modern Industrial Production

Modern industrial production has been widely applied for Japanese-type soy sauce production, either in Japan or in Indonesia, which applied the modern soy sauce process technology and used defatted yellow soybean flakes and wheat for raw materials. The modern technology allows a more controlled koji and brine fermentation with the use of pure microbial cultures, temperature controls, and mechanical mixing. The full equipment process for automatic koji preparation replaced the traditional process. The equipment consists of a continuous soybean cooker as well as continuous wheat roaster, automatic inoculators with an automatic mixer, large perforated shallow vats equipped with forced air devices, temperature control device, and mechanical turning device during incubation (Fukushima, 1985). The length of koji preparation, nevertheless, is almost the same as in the traditional process, 48 h.

By the use of modern technology, the length of brine fermentation could be reduced from 1 to 3 years in the traditional shoyu production to less than 1 year (4–8 months) in modern industrial production in Japan (Yokotsuka, 1986). The length and condition of brine fermentation either in traditional or modern production in Indonesia are the same, 4 months and at the same spontaneous condition subject to tropical weather. This is because the soy sauce aroma found in shoyu is less important for Indonesian soy sauce (Röling et al., 1996).

In the final process, moromi filtration using modern equipment with high pressures is applied. Currently, the membrane technology using nanofiltration has been developed to provide the standard color for soy sauce products in modern industries (Miyagi, Suzuki, Nabetani, & Nakajima, 2013).

Chemistry and Biochemistry

Yong and Wood (1977) studied the release of extracellular protease and carbohydrase complex enzymes during koji fermentation. Protease

complexes in koji hydrolyze soy proteins into peptides and amino acids, while carbohydrase complexes hydrolyze wheat carbohydrates into sugars. The ratio of peptides to amino acids in koji is nearly 1:1. The main free amino acids found in koji are glutamine and glutamic acid (Flegel, 1988). Glutamic acid is related to an umami taste (Lioe, Apriyantono, Takara, Wada, & Yasuda, 2005).

In the brine fermentation, lactic acid is produced at the earlier stage by the action of lactobacilli; therefore, the pH of moromi decreases rapidly, and then some phenolic and aroma compounds are formed due to the alcoholic fermentation by osmophilic yeasts at the next stage of moromi production. However, the alcoholic fermentation was not found in Chinese- or tamari-type soy sauce because of the lack of carbohydrate during the fermentation process as a result of the use of different composition of raw materials (Apriyantono, Husain, Lie, Jodoamidjojo, & Puspitasari-Nienaber, 1999). The presence of lactic acid as a dominant organic acid in soy sauce could be used to identify the fermented soy sauce from chemical soy sauce which is dominated by formic acid.

Glutamic acid is the main amino acid in soy sauces and contributes to their intense umami taste. In fact, the use of black soybeans could lower the glutamic acid present in soy sauce, compared to the use of yellow soybeans (Apriyantono, Setyaningsih, Hariyadi, & Nuraida, 2004).

Nitrogenous compounds such as small peptides and free amino acids, as well as sugars, are still present in the final product and contribute to the quality and taste of soy sauce. However, the peptides make a relatively low contribution to the intense umami taste of soy sauce (Lioe, Takara, & Yasuda, 2006). Some dipeptides – Ile–Gln, Pro–Lys, Ile–Glu, Thr–Phe, and Leu–Gln – are clearly found to correlate to soy sauce sweetness (Yamamoto et al., 2014). Japanese-type soy sauce has more esters and phenols as aroma compounds. Volatile organic acids are dominant in Chinese- or tamari-type soy sauce.

Potential Benefits and Risks

The use of soy sauce as an antioxidant in a food system such as raw beef patties has been investigated (Kim et al., 2013). A *kokumi* peptide is also found in soy sauce, i.e., γ -Glu-Val-Gly (Kuroda et al., 2013) at concentrations 1.5–6.1 ppm. The *kokumi* characteristic could contribute to the savory taste of the food.

The use of molds during koji fermentation has become a concern about the mycotoxin in soy sauce. As much as 97.5 % of soy sauces marketed in China were contaminated with deoxynivalenol or DON at concentrations of 4.5–1,245.6 ppb (Zhao, Wang, Zou, & Zhao, 2013). Kojic acid, another mycotoxin, is also produced by *Aspergillus oryzae*, *Aspergillus sojae*, and *Aspergillus tamarii* (Flegel, 1988). Therefore, harmless strains of the molds should be used for soy sauce production.

A high-temperature-derived contaminant, 3-monochloropropane-1,2-diol (3-MCPD), could be found in the half-fermented soy sauce and chemical soy sauce products. This contaminant is formed during the acid hydrolysis of soy proteins by hydrochloric acid (HCl) under a certain condition due to the reaction between HCl and the soybean fat under heat (Nagodawithana, 1995; Nyman, Diachenko, & Perfetti, 2003). 3-MCPD is carcinogenic in human with a tolerable daily intake (TDI) of 7 μ g/kg body weight/day (Rietjens, Scholz, Berg, Schilter, & Slob, 2012). However, 3-MCPD is found even though at a relatively low level in some traditional fermented soy sauces.

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Sphujidhvaja

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Sphujidhvaja was apparently of Greek descent and flourished in Western India under the patronage of the Kṣatrapa ruler Rudradāman II. He wrote the extensive genethliological manual entitled *Yavanajātaka* (Horoscopy of the Greeks) in AD 270, which shows the position and influence

of the stars at one's birth. Toward the close of his work, Sphujidhvaja says that before him, in AD 150, the great Greek genethliologist Yavaneśvara redacted into Sanskrit prose a Greek astrological work, so that it could be studied by those who did not know Greek, and that he, Sphujidhvaja, is composing a versified redaction of the work of Yavaneśvara. The work reveals Sphujidhvaja as a competent scholar, a master of Sanskrit versification, and an expert genethliologist.

Sphujidhvaja states that he composed the work in 4,000 verses. But the only manuscript of the work available today contains only 2,300 verses. In this imperfect manuscript, the first few sections are numbered but not so the subsequent ones, which number, in all, 79. Possibly, several sections are lost. In these 79 sections, the work covers a large number of aspects of horoscopy and natural astrology, including

- Zodiacal signs and planets, their icons, nature, and relationships
- Iconography of *horās* and decons
- Astrology of conception, birth, and nature
- Horoscopes
- Planetary placements and combinations affecting human beings
- Prediction on the basis of questions
- Reconstruction of lost horoscopes
- Omens and dreams
- Military astrology

The several aspects of each of these topics are looked at from different points of view, and intimations, indications, and predictions based thereon are stated categorically.

It is interesting that although based ultimately on a Greek text, there was substantial Indianization effected in the *Yavanajātaka*. This was accomplished by using Indian equivalents to Greek terms, adopting Hindu deities in place of Greek ones, incorporating the names of Hindu castes and professional orders, mentioning local manners and customs, and the like. *Yavanajātaka* was looked upon as authority by all later Indian genethliologists and used as such even in the foremost of Indian texts like *Bṛhajjātaka* and *Bṛhatsaṃhitā* of Varāhamihira,

Sārāvalī of Kalyāṇavarman, *Praśnavidyā* of Bādarāyaṇa, and many others.

The significance of *Yavanajātaka* stems from another point as well. The work refers to contemporary social orders, professions, religious classes and groups, items of ordinary use, manners and customs, dress, and a host of other things related to the life and society of the times. The information provided by the work on these subjects makes it a good source for the study of the culture and civilization of India during the early centuries of the Christian era.

See Also

- [Astrology in India](#)
- [Varāhamihira](#)
- [Yavaneśvara](#)

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Śrīdhara

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The mathematical works of Śrīdhara were very popular and made him quite famous. In spite of his great popularity, some controversies have been raised about his life, work, and time, such

as whether he was a Hindu or a Jain, and whether he wrote before or after ► [Mahāvīra](#) (ninth century AD). Some uncertainties exist because Śrīdhara's works are not fully extant. Often he is confused with other authors of the same name. Here we shall give views which are now generally accepted.

Like so many ancient Indian authors, Śrīdhara did not provide any information about himself in his works. Other sources have not been helpful in finding any glimpse of his personal life. So we do not know his parents or teachers, or even where he was born, educated, or worked. But some evidence shows that he was a Saivite Hindu. An example in his *Pāṭīgaṇita* is about the payment for the worship of the five-faced Hindu god Śiva. He starts his *Triśatikā* with a homage to the same god. However, in a manuscript which has a possible commentary and additional examples written by an apparently Jain writer, the word “Jinam” is found in place of “Śivam”. This led to the claim that Śrīdhara was a Jain, but other evidence does not support this view.

More serious is the controversy about Śrīdhara's time. That he lived after ► [Brahmagupta](#) is evident from the fact that he literally quoted (and criticized) a rule from Brahmagupta's *Brāhmasphuṭa-siddhānta* (AD 628). The most significant question in this connection is whether Śrīdhara wrote before or after Mahāvīra, whose date of ca. AD 850 is certain. There are similarities in the works of these two mathematicians. Most scholars believe that indications generally place Śrīdhara before Mahāvīra. A new fact has come to light recently; David Pingree found that a rule of Śrīdhara's had been quoted by Govindasvāmin (about AD 800–850) in his commentary on the *Horāśāstra* of Parāśara (under 14.97). This latest and direct evidence once again supports the generally accepted view of placing Śrīdhara in the eighth century or ca. AD 750.

Śrīdhara is known to be the author of the following three works on mathematics:

1. *Pāṭīgaṇita* (on arithmetic and mensuration)
2. *Pāṭīgaṇita-sāra* (an epitome of the above)
3. *Bījagaṇita* (on algebra)

The *Pāṭīgaṇita* is a standard Indian treatise on practical mathematics meant “for the use of the people”. It is also called *Br̥hat-Pāṭī* (Bigger Pāṭī) and *Navaśatī* (Having Nine Hundred) because it is believed to have 900 stanzas. Unfortunately, it is not extant in full; the available text contains only 251 stanzas. In terms of topics, treatment of definitions, logistics, mixtures of things, and series are available in full, but that of the plane figures is incomplete. Many other treated topics are mentioned in the list of contents, but they are totally missing from the manuscript. These were excavations, piles of bricks, sawn pieces of timber, heaps of grain, shadows, and the mathematics of zero (whose loss is quite sad).

The *Pāṭīgaṇita-sāra* is also called *Triśatī* or *Triśatikā* because it was a “Collection of 300 verses”. It was the author’s own summary of the larger work on the subject.

Śrīdhara’s *Bījagaṇita* (Algebra) seems to be lost completely. We know about it from a statement of ► *Bhāskara II* (AD 1150) who also quoted a rule from it. The rule gives a method for solving any quadratic equation and has also been quoted by others. Many other rules from different works of Śrīdhara have also been quoted by various writers. This shows the popularity of his works.

A recently discovered work called *Gaṇita-Pañcaviṃśī* is also stated to be from the pen of Śrīdhara, but it may not be his genuine work. Similarly, a number of astronomical, astrological, and other works authored by different persons of the same name have been ascribed wrongly. Confusions were created both by the similarity of names and also by the proximity of their dates.

In India, ten has been the base of counting since very early times. But the number and names of decuple terms used in the decimal numeration were at variation throughout the ancient period. Later on, the decuple terms were used to denote the notational places when the positional system was developed, and their number was standardized to 18 (which was a traditionally sacred number). Śrīdhara gave a definite list of 18 terms which became standard in Indian mathematics. It runs thus: *eka*, *daśa*, *śata*, *saharsa*, *ayuta*, *lakṣa*, *prayuta*, *koṭī* ($=10^7$), *arbuda*, *abja* (or *abda*), *kharva*, *nikharva*,

mahāsaroja, *śaṅku* (or *śankha*), *saritāmpati*, *antya*, *madhya*, and *parārdha* ($=10^{17}$).

Among the arithmetical rules discussed in the *Pāṭīgaṇita*, *Sūtra* 49–50 gives a formula for finding the time in which a sum lent out at simple interest will be paid back by equal monthly installments. Under the *Sūtra* 63–64 he presents the famous problem of a Hundred Fowls, in which we have to solve the indeterminate equations in integers. [The hundred fowls problem goes like this: Roosters cost three coins each chicks are three for one coin. If 100 fowls are purchased for exactly 100 coins. Then how many of each are bought?]

For mensurations related to a circle, Śrīdhara used the approximation $\pi = \sqrt{10}$, a very ancient Indian value. But there is some evidence to show that he used $\pi = 22/7$ in the lost part of *Pāṭīgaṇita*.

Another of Śrīdhara’s great achievements was his mensuration of the volume of a sphere.

See Also

- [Algebra in India: Bījagaṇita](#)
- [Bhāskara II](#)
- [Mahāvīra](#)
- [Mathematics in India](#)

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Śrīpati

Kripanath Sinha

Śrīpati was the most prominent Indian mathematician of the eleventh century. He was the son of Nāgadeva and lived in Mahārāṣṭra. He flourished during the period from AD 1039 to 1056.

General appreciation for Śrīpati's fame as a mathematician is based on his arithmetic, *Gaṇitatilaka*, and the two mathematical chapters of his astronomical work entitled *Siddhāntaśekhara*. The 13th chapter, the *Vyktagaṇitādhyāya*, contains arithmetical rules, series, mensuration, and shadow reckoning. The 14th chapter, the *Avyktagaṇitādhyāya*, is one of the few extant Hindu works on algebra. The only edition (by Kapadia) of the *Gaṇitatilaka* contains a valuable commentary by Sihatilaka (ca. AD 1275).

Besides including in his works selected rules of his predecessors, Śrīpati enriched Indian mathematics by giving some improved and some original rules. The *Gaṇitatilaka* contains the earliest known treatment of simple addition and subtraction in any Indian work. Also included is the earliest version of our angular method of addition used to check the accuracy of a sum and simplify addition. The *Vyktagaṇitādhyāya* gives an improved rule for the volume of an excavation.

The *Avyktagaṇitādhyāya* contains most of Śrīpati's original ideas and rules. In it, he presents the idea of an extensive system of symbolism in algebra, the only Hindu treatment of the cubing of signed numbers, and explicit recognition of the nature of imaginary quantities that is second only to Mahāvīra's. He also provides the earliest versions of our ordinary method of solving simple linear equations by using inverse operations and an early formal treatment of factorization. The rules not only give the ordinary method of factoring based on successive division, but also provide an additional method for factoring a nonsquare number by expressing it as the difference of two squares.

Śrīpati also displayed his mastery of indeterminate equations by giving an improved rule for solving the factum and original rules for solving the pulverizer. He also described an original method to obtain rational solutions of the square-nature.

All Śrīpati's works are in verses. The *Siddhāntaśekhara* contains only rules, but the *Gaṇitatilaka* is written in an autocratic style of teaching strategy, in which a rule is followed by plentiful exercises. The book is quite secular in nature. According to the author's testimony, it was written for public use. It contains arithmetical and commercial rules, and some problems solvable by simple linear, quadratic, and radical equations. A garland problem and numerous other fanciful problems included in the book make it pleasurable and interesting. The practical and aesthetic values of the *Gaṇitatilaka* cannot be underestimated.

Śrīpati, however, also had some weaknesses. His mathematics of division by zero is all wrong. In the *Vyktagaṇitādhyāya*, he uses the term *caturbhujā* to mean a square, a quadrilateral in general, a cyclic quadrilateral, a quadrilateral with equal altitudes, and an isosceles trapezoid. Because of this inconsistency, his rules on mensuration of quadrilaterals are hard to interpret.

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Šā'id al-Andalusī

Sema'am I. Salem

Abū al-Qāsim šā'id ibn Abū al-Walīd ibn 'Abd al-Raḥmān ibn 'Uthmān al-Taghlibi, better known as šā'id al-Andalusī or Qāḍi šā'id, was

born in Almeria in southern Spain in AD 1029. He was a philologist, natural philosopher, and historian as well as judge. As his name indicates, he was a member of the tribe of Taghlib, one of the largest tribes of Arabia. When the Arabs invaded Spain in AD 711, members of this tribe entered the country and prospered there.

ṣāʿid was born into a well-to-do family, whose members spent much of their time and wealth in the quest of knowledge and education. His father occupied a highly respected position in the city of Cordoba, and his grandfather, ʿAbd al-Raḥmān, was a judge in Sidonia, Spain. After receiving his early education in Cordoba, ṣāʿid toured Muslim Spain to further his education. For the same reason, at the age of 17, he moved to the city of Toledo.

Like most young Arab students, ṣāʿid studied law, Islamic religion, Arabic language, and Arabic literature. Later in life, he specialized in the study of mathematics and observational astronomy. Among his most famous teachers were al-Fātiḥ Muḥammad ibn Yūsuf (d. AD 1059), Abū Walīd al-Waqshī (d. AD 1059), and Ibn Idris al-Tajībī, who taught him mathematics and astronomy.

Early in the eleventh century, Cordoba ceased to be the principal intellectual center of Spain, and the capital cities of the *Mulūk al-Ṭawāʾif* (party-kings) tried to capture its former glory. One such city was Toledo, the capital of the principedom of Banū al-Nūn. When ṣāʿid entered Toledo, it was governed by Yaḥyā ibn Dhi al-Nūn (r. AD 1037–1074) and extended his kingdom to include Valencia and most of the eastern parts of Andalusia. During his reign, Toledo became an important literary and intellectual center. In addition to several authorities in Islamic sciences, Yaḥyā's court had several good mathematicians, well-known astronomers and astrologers, several men of medicine, poets, and geometers.

The number of eminent scholars, poets, and philosophers in a ruler's court was one of the status symbols of the time. Probably for that reason, Yaḥyā invited ṣāʿid into his court and appointed him a judge (*qāḍī*).

Several of ṣāʿid's students later became accomplished scholars. Among them was ʿAbd

al-Bāqī ibn Baryal, who was in part responsible for the style and language of some of ṣāʿid's writing. There was also the outstanding astronomer and mathematician Abū Ishāq al-Zarqālī (Arzaquiel) who, with the assistance and the guidance of his mentor, constructed the famed Toledan Tables. These astronomical tables, which were accurate calendars, were translated into Latin by Gerard of Cremona, and became the basis for the Marseilles Tables.

ṣāʿid wrote several manuscripts on a variety of subjects. All of his works except for *Ṭabaqāt al-ʿUmam* (Book of the Categories of Nations) are lost. He mentioned in *Ṭabaqāt al-ʿUmam* that he wrote a document on observational astronomy, one on the history of nations, and another on their religions. He may have written a manuscript on the history of Andalusia and one on the history of Islam. *Ṭabaqāt al-ʿUmam* is an authoritative source and a precise reference that identifies the natural philosophers of Muslim Spain.

ṣāʿid died in July, AD 1070. Ibn Yaḥyā al-ḥadīdī, the most illustrious dignitary in the court of Ibn Dhi al-Nūn, read his official obituary.

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Stars in Arabic-Islamic Science

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The Arabs in pre-Islamic times – mostly Bedouins in the Arabian Peninsula – already had a good knowledge of the stars. They used certain stars or asterisms for orientation in their desert

travels, to fix seasons, and to predict weather, especially rain. For the last two purposes, they developed a system of so-called *anwāʾ* (sing. *nawʾ*), in which a star or asterism was observed setting shortly before sunrise and another simultaneously rising, just opposite (the latter one was called *raqīb*, with respect to the first one). At an unknown time and through unknown channels they received – most probably from India – the system of the 28 lunar mansions (*manāzil al-qamar*), stars, or asterisms along the path of the moon, near the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The indigenous *anwāʾ* were then merged with the lunar mansions, and the 28 mansions were given names from among the former *anwāʾ*. All the five planets visible to the naked eye seem to have been known, since the Arabic language has old indigenous names for them: Mercury, *ʿuṭārid*; Venus, *al-zuhara*; Mars, *al-mirrīkh*; Jupiter, *al-mushtarī*; and Saturn, *zuḥal*. Also, fragments of the Babylonian zodiac seem to have reached the Arabs in pre-Islamic times, though their location in the sky was different from that in Babylonian and Greek (and modern) astronomy; the figure corresponding to Gemini (*al-jawzāʾ*), for example, was located in the stars of Orion, or the figure corresponding to Aquarius (*al-dalw*) in the Pegasus square. Such star lore was also much used in classical Arabic poetry, in pre-Islamic times, and afterward. From the ninth century on, Arabic lexicographers and philologists collected the dispersed elements of old Arabic folk astronomy and put them together in special monographs (called *Kutub al-anwāʾ*, Books of the *anwāʾ*). From these, more than 300 old Arabic names for stars and asterisms could be recovered.

A new development began after the Muslim conquest of the lands of the Middle East. Now the Arabs came into contact with Greek science as transmitted and practiced in learned circles, mostly by Christian monks and scholars, in the area. After a period of undocumented first contacts, from the eighth century on, Greek scientific texts were translated into Arabic in great numbers. Scientific astronomy in the Islamic world therefore was largely built on Greek knowledge,

with additional elements received from India and Persia. Greek cosmology and Greek theories of the planets, the fixed stars, and other celestial phenomena formed the basis of Arabic-Islamic astronomy. Later Muslim astronomers continued to work with this material, developed it, and introduced many corrections and improvements. But the “Copernican Revolution” did not reach the Islamic world; Arabic-Islamic astronomy continued to be Ptolemaic into the nineteenth century.

On the (fixed) stars, the main source for the Arabs was Ptolemy’s *Almagest*, which contains in Books VII and VIII a catalog of 1,025 stars arranged in 48 constellations and listed with their ecliptical coordinates, longitude and latitude, and magnitude. These 48 constellations (which also live on, in modified form, in modern astronomy) and the derived nomenclature of the 1,025 known stars were used by Muslim astronomers through all times, in books as well as on instruments (astrolabes, celestial globes, quadrants). To make the catalog valid for all times, Ptolemy proposed to add to the longitudes of the stars a constant of 1° in 100 years, to correct for precession. The Muslim astronomers very soon (in the ninth century) found a better value, 1° in 66 years, later also 1° in 70 years, and other values were used. The pictorial figures of the constellations were also basically taken from Greek models; only details of the physiognomy of human figures and clothing were more or less adapted to contemporary local styles.

The main Arabic work on the fixed stars and the constellations was the *Book on the Constellations* by the Persian astronomer Abu’l-ḥusayn al-Šūfī (903–986); al-Šūfī anxiously followed the Arabic versions of the *Almagest*, added criticisms based on his own observations, but established his star catalog exactly according to the data given in the *Almagest* (adding a constant of $12^\circ 42'$ to the longitudes, for precession, for his epoch AD 964). For each constellation, al-Šūfī added two drawings, one showing the figure as seen in the sky and the other showing it as seen on the celestial globe (in reality, however, the figures simply appear as seen in a mirror, with the right and left sides reversed). Most Islamic globe

makers, through all centuries, followed al-Šūfī's models in depicting the constellation figures.

Several Islamic astronomers established star catalogs in the manner of the *Almagest*: al-Battānī (epoch 880, precession constant added $11^{\circ}10'$), al-Šūfī, al-Bīrūnī (epoch 1031, precession constant $13^{\circ}0'$), and Ulugh Beg (epoch 1437, own observations but some stars taken over from al-Šūfī). Besides these big catalogs, smaller star lists were drawn up by very many astronomers, for use on astrolabes or other instruments. Most of the catalogs and star lists, however, were not obtained through observation; they were adapted from the *Almagest* or derived catalogs by adding the precession constant to the longitudes. A small list of 24 stars obtained through independent observation was established by the astronomers of the caliph al-Ma'mūn for the epoch 214 Hijra = AD 829–830; also other star tables were afterward derived from it by adding the precession constant.

Other celestial phenomena, such as comets or meteor showers, were not considered by the Arabic-Islamic astronomers. Following Greek cosmological theory, they supposed these to belong to the sublunar sphere, i.e., the space between the Earth's surface and the moon, and not to the sphere of the stars. The fixed stars in their opinion were all situated on the farthest, eighth sphere, beyond the seven spheres of the planets and the sun and moon. It was mostly in chronicles and in astrological works that such phenomena were registered, and they were usually regarded as bad omens indicating evil events.

Through Latin translations in late tenth and mainly in the twelfth century in Spain, many star names of Arabic origin entered the West and continue to be used in Western astronomy, mostly in heavily distorted spellings, today.

See Also

- [al-Battānī](#)
- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [al-Šūfī](#)

- [Celestial Vault and Sphere](#)
- [Lunar Mansions in Islam](#)
- [Maps and Mapmaking: Celestial Islamic Maps](#)
- [Precession of the Equinoxes](#)
- [Ulugh Bēg](#)

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Stars in Chinese Astronomy

Sun Xiaochun

In Chinese astronomy, stars were called *Hengxing* (fixed stars) or *Jingxing* (warp stars), while planets were called *Xingxing* (movable stars) or *Weixing* (web stars). The traditional Chinese sky was composed of 283 constellations which included 1,464 individual stars. This unique system was first established by Chen Zhuo, an astronomer of the Three Kingdom period (AD 220–280), who collected knowledge about stars from the Han time and summarized it in a new catalog of stars. According to Chen Zhuo, these constellations belonged to three separate astronomical schools: 93 constellations belonged to Shi Shi (Master Shi), 118 to Gan Shi (Master Gan), and 44 to Wuxian Shi (Master of Wuxian). There were also 28 lunar mansions (*Xiu*), which were very important in the Chinese sky. Stars of the three astronomical schools were preserved in the *Kaiyuan Zhanjing* (Treatise on Astrology) of the Kaiyuan period (AD 729) from the Tang Dynasty (AD 618–907). After Chen Zhuo little was changed of the Chinese system of constellations.

The observation of stars started as early as civilization began. Among the oracle bone inscriptions from the Shang Dynasty (ca. sixteenth–eleventh centuries BCE) some stars were mentioned. In the *Shangshu* (Historical Classic), the paragraph concerning four cardinal asterisms has generally been agreed to be the record of the observation of stars from before the twenty-first century BCE. But before the Han Dynasties (106 BCE–AD 220), no description of the total sky existed; only 38 star names were mentioned in pre-Han literature. These stars were either of the 28 *Xiu* or were very popular stars such as *Beidou* (Ursa Major), *Niulang* (α Aql), and *Zhinü* (Vega, α Lyr). They appeared in folklore and poems. During the Warring States period (480–222 BCE) there lived two famous astronomers, Shi Shen and ► [Gan De](#),

who were founders of two of the abovementioned astronomical schools. But what were called Shi Shi's and Gan Shi's constellations did not seem to exist in their own time; they were later developments of the nomenclature of stars during the Han. The earliest descriptions of the total sky was in the *Tianguan Shu* (Monograph on Heavenly Officers) by Sima Qian (145–86 BCE) in which 91 constellations including about 500 stars were mentioned. The earliest star catalog, giving coordinates of 92 leading stars of Shi Shi's constellations and of 28 determinative stars of the 28 *Xiu*, were observed a few decades after Sima Qian. That is, the evidence shows that Shi Shi's constellations were scientifically established during the Former Han (206 BCE–AD 25). Shi Shi's constellations consisted of the brightest stars in the sky. They served as the referential system to constellations of other schools. Most constellations of Gan Shi and Wuxian Shi were just fill-ins among Shi Shi's constellations. It is quite certain that the constellations of the three schools obtained their complete forms during the Han times. Chen Zhuo's work was to summarize them.

Constellations in the Chinese sky are much smaller than the Greek ones. A constellation usually includes several stars linked together with imaginary lines. Some constellations are even composed of single stars. Constellations were called inner ones or outer ones according to their location to the North or South of the equator.

The 28 *Xiu* were the basis of the Chinese sky. They spread near the equator and served as one of the dimensions of the Chinese polar-equatorial coordinate system. One coordinate corresponding to the Right Ascension was given as the hour distance to the determinative star of a certain *Xiu*, which was almost always the most western star in the *Xiu*. With great circles linking the determinative stars and the North Pole, the celestial sphere was divided as segments of an orange. Constellations were described in the sequence of the *Xiu* as they were located.

Historical research shows that the 28 *Xiu* are much earlier than the whole constellations of the three astronomical schools. Some star names seemed to be direct derivations from the

mythological, legendary, or astrological meaning of the *Xiu*. A complete set of the names of the 28 *Xiu* was discovered on a lacquered box cover excavated from a tomb dated from 433 BCE. The *Xiu* were formed into four groups of seven which were called Four Images. The Four Images corresponded to the four cardinal points in the sky and the four seasons of the year.

Ancient India and the Islamic world also had similar lunar lodge systems. It is certain that these three systems were originally related. But when and where they were first constructed and how they diffused is still an unsolved problem.

Another feature of the Chinese sky is the existence of the three-wall system. There were three enclosed areas in the sky: *Ziwei Yuan*, *Taiwei Yuan*, and *Tianshi Yuan*. The meaning of *Yuan* is a wall, which was formed by stars surrounding the enclosed area. *Ziwei Yuan* indicated that polar area which included 15 constellations, and the wall was formed with 15 stars. *Tianshi Yuan* and *Taiwei Yuan* indicated two other groups of constellations between *Ziwei Yuan* and the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The former had 13 constellations, and the wall was formed with 22 stars; the latter also had 13 constellations, but the wall was formed with 10 stars. The names of the three-wall system might have existed early, but their use to indicate groups of constellations was rather late, probably after Chen Zhuo.

Since the Tang Dynasty, the three *Yuan* and the 28 *Xiu* became the main structure by which the stars were organized. The famous astronomer ► [Li Chunfeng](#) (AD 602–670) used this system to describe the sky in *Jinshu Tianwenzhi* (The Astronomical Chapter of the History of the Jin Dynasty, AD 265–420).

The names of the Chinese constellations provide a unique document to be studied. The way stars were named was completely different from the Greek. Stars were organized into a heavenly human society. In the sky you can see:

- Emperor, queen, and princes
- Royal court and clan
- Imperial bureaucracy and administration

- All kinds of buildings and facilities, even a toilet in the sky
- Military installation, armies, and weapons
- Traffic and transportation
- Rituals, ceremonies, and pictures of social life
- Philosophical and religious concepts
- Mythological and legendary figures
- Local states and geographical features

It is a total cultural complexity projected in the sky. In the polar area, for example, the *Ziwei Yuan* was furnished with an emperor, queen, princes, royal high-ranking officials, and facilities in a court. There was one constellation called the North Pole, *Beiji*, the brightest star of which was called *Di* the Emperor. The *Ziwei Yuan* was just like a royal palace; it took the polar area and all the stars turned round it. It reflected the social order of the imperial society of ancient China, as Confucius analogized: “He who is a governor because of his Virtue may be compared to the North Pole Star, sticking to its place and all stars turning about it.” In other parts of the sky, social life pictures were reflected. The *Tianshi Yuan* was a heavenly market, in which all kinds of shops were marked. The Autumn harvest of peasants, the imperial hunt ceremony, and cavalry troops could also be found in the Chinese sky.

Because the appearance of a certain part of the sky is related to seasons, and because it also changes with the precession of the sky, seasonal considerations may help to estimate the time when these earthly happenings were projected in the sky. By and large this practice happened during the Han and was carried on with the impetus given by the philosophy of *Tian Ren Gan Ying* (The Interaction between Heaven and Human Beings) which came to a climax during the Han and which urged a new type of astrology by means of division of the sky. The sky was constructed as a heavenly imperial society so that astrologers could interpret imperial society straightforwardly in correlation with the terrestrial society. Stars in the Chinese sky provided a basis for ancient Chinese astrology.

Throughout the history of China, there has been continuous observation of stars. Although the constellations have been kept basically

unchanged, new measurements of the position of the stars were made in almost every dynasty. Star maps were made to study the sky. The earliest existent star map is from the *Dunhuang* collection of manuscripts of the Tang Dynasty. More accurate and scientific star maps are from the Song Dynasty (AD 960–1279). The Suzhou Astronomical Chart on a stone plate made in AD 1274 is well known. Almost all stars in the Chinese sky were carved quite precisely on the planisphere. The star map was based on the observations made during the Song. Even the supernova of the year of 1054 in Taurus was marked on the star map.

Since the late Ming Dynasty (AD 1368–1644), European astronomy began to influence China. Star catalogs and star maps were made in the way Westerners did. Traditional stars were identified with the sky and more stars were observed. But the framework of the traditional constellations was not abandoned. Newly measured stars were counted as supplementary stars in old constellations. New constellations were added only in the southern sky, where stars had not been registered by ancient Chinese astronomers. The pioneer work of this kind was done by Xu Guangqi (AD 1562–1633) and the German Jesuit Adam Schall von Bell (AD 1592–1666) in *Chongzhen Lishu* (Calendrical Treatise of Chongzhen Period, AD 1628) at the end of the Ming Dynasty. In this book, 23 new constellations including 126 stars were constructed in the southern hemisphere of the sky. Their work paved the way for the Chinese sky to be absorbed into world astronomy.

See Also

- [Astrology in China](#)
- [Astronomy in China](#)
- [Gan De](#)
- [Lunar Lodges in Chinese Astronomy](#)

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Steam Power in China

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The power that drove the machines of the Industrial Revolution was produced by the steam engine's valved piston-cylinder mechanism, which turned the pressure differential within and without the cylinder into a motive force. Its success relied on machine tools that produced metal parts with precision and thermodynamics that facilitated the accurate calculation of heat and motive force. Although premodern Chinese blacksmiths' wooden double-acting piston bellows shared a similar mechanism, human arms were the source of their power (Needham, 1962, pp. 136–137). Previously, China had not had a strong tradition in using metal cutting machine tools. Nor was the Chinese understanding of the atmosphere and heat expressed in mathematical formulae. Therefore, the transfer of steam engine technology faced great technical and scientific challenges. The process of adaptation began with Chinese encountering paddlewheel steamships.

From the late 1820s to the mid-1830s, several foreign steamships visited the port of Guangzhou, south China. The sight of smoke puffing out of the novel vessels' funnels and their rotating paddlewheels attracted attention. In 1828, an anonymous Chinese observer described that a flame fed by burning coal in a copper cylinder drove the paddlewheels. During the Opium War (1839–1842), in which British firearms and steam gunboats defeated Qing troops and war junks, the government officials who witnessed the British steamers gave similar accounts. Their misunderstandings led to a few failed attempts to build paddlewheel boats to fight against the British fleet. Having discovered that smoke had no effect, the Chinese inventors adopted a traditional technology, the treadmill mechanism, to build water wheel boats (*shuilunchuan* 水輪船), a type of treadmill paddlewheel boat that could be traced to the twelfth century. Probably for that reason, the Chinese named the steamer as “fire wheel boat” (*huolunchuan* 火輪船). As late as 1842, a Qing senior official who boarded a British steam warship reported to the emperor that the paddlewheels were driven by fire according to the principle of the clock (Wang, 2010).

Unable to understand the steam mechanism, Qing government officials sought foreign expertise. In early 1842, a Guangdong merchant commissioned foreign technicians in Macau, a Portuguese colony, to build a steamer and donated it to the government. Although the emperor forbade the pursuit of the technology because of its high cost and dubious effectiveness, in 1845, a senior official in Guangdong recruited an American shipwright to build a steamer. Unfortunately, the building work halted after the shipwright died. Qing government officials did not experiment further with steamship technology until the early 1860s.

However, not all Chinese people misunderstood the steam mechanism. Ding Gongcheng, a merchant interested in gunnery, figured out the steam mechanism when he was living in Guangzhou. His book, *Yanpaotushuo* (Illustrative Treatise on Gunnery), printed in 1841, contained an essay describing his experiments with the steam

engine. According to the essay, Ding hired an artisan to build a model locomotive, which was nearly 1.9 ft long and 7.6 in. wide. He used the same engine to build a model steamboat, which was 4.4 ft long and 1.6 ft wide. Both models ran well. Ding admitted that a full-scale steamer could not be built due to the lack of proper tools. His friend Zheng Fuguang tried to figure out the steam mechanism by studying diagrams and a model steamer but did not conduct any experiments. In his essay on the paddlewheel steamer, which was included in his 1846 book on optics, he correctly described the mechanism. Although Ding and Zheng's writings circulated among the Chinese literati, there is no evidence that anyone else learned about the steam mechanism from those essays.

After the war, the Chinese people had more opportunities to observe the steam engine, because, with the opening of five ports to foreign trade, more foreign steamers were visiting China. Additionally, foreign-owned machine shops and dockyards were set up in the treaty ports to service those vessels. In Shanghai, the number of dockyards rose from one in the late 1840s to nine in the 1860s. By 1860, three docks were operating in Hong Kong and four near Guangzhou. Those dockyards hired foreign technicians and Chinese workmen (Xin, 1999, pp. 34–36, 40–42).

Furthermore, because of the Protestant missionary publications in the treaty ports, which aimed at converting Chinese people to Christianity by introducing general knowledge of Western science and technology, Chinese literati had greater opportunity to learn about the steam engine. For example, *Xia'erguanzhen* (Chinese Serial), which began publication in Hong Kong in 1853, and *Bowuxinbian* (Natural Philosophy), which was first published in Guangzhou but after 1855 in Shanghai, contained short essays about the steam engine. Some of the dockyards became leading private shipbuilding enterprises of the Far East in the late nineteenth century. Those changes were the background of the first Chinese-built steamer in the early 1860s.

Two more wars aggravated Qing China's need for steam technology. In the Taiping Rebellion (1851–1865), which was one of the most

devastating civil wars in Chinese history, Western firearms and steam gunboats proved the key factor that decided the results of battles. In the Second Opium War (1856–1860), the Anglo-French allied forces overwhelmed Chinese defenses and seized the capital Beijing, forcing the Qing court to flee. Only in such a critical situation did senior officials call for self-strengthening with foreign firearms and steamships (Kuo & Liu, 1978). In 1861, Zeng Guofan, a leading anti-Taiping commander, recruited Hua Hengfang and Xu Shou, two literati interested in mathematics and chemistry, into his staff and instructed them to experiment on building steamships. They learned the basics of the steam mechanism from the sketchy description published in the *Bowuxinbian* and observed the steam engines on board foreign steamers. After building a model steam engine and a test steamboat, they completed in 1863 the *Huanghu*, which was fitted with a high-pressure engine and a tubular boiler, without foreign assistance (Wang, 2010).

After the Taiping rebels were defeated, the Qing government established modern arsenals that employed steam-driven machine tools. Among these arsenals, the Jiangnan Arsenal (*Jiangnanzhizaoju*, 江南製造局) was one of the foremost firearm manufacturers and shipyards in nineteenth-century China. The arsenal was established in 1865 by Li Hongzhang, Zeng Guofan's lieutenant in the anti-Taiping campaign, on the basis of a foreign-owned machine shop. Zeng, who took over the Arsenal from Li, added the metalworking factory, the boiler shop, the foundry, the dock, as well as the fitting and setting-up shop to its facilities in order to build steamers. The Arsenal recruited foreign technicians to direct Chinese workmen, who, in 1869, numbered 1,000. In 1868, it built its first paddlewheel steamboat, which was fitted with a refurbished 150-hp steam engine. The Arsenal also built five screw-propelled steam gunboats and their engines by 1876. After that, it focused on firearm manufacture but also completed one steel-hull gunboat in 1885 before it suspended its shipbuilding program (Xin, 1999, pp. 107–118).

Although the Jiangnan Arsenal had made some technical progress, a more complete

program for the wholesale transfer of steamship-building technology from its theoretical foundation to its application was established in the Fuzhou Navy Yard (*Fuzhou chuanzheng*, 福州船政局). The Navy Yard was established in 1866 by Zuo Zongtang, another senior official who rose to prominence in the Taiping Rebellion. It had four major workshops: the metalworking shop, the boiler shop, the fitting shop, and the foundry. These shops could produce every part of a steamer, from the engine to the barometer, from raw materials. It recruited a team of 75 French managers and technicians, including the French naval officer Prosper Giquel, to direct Chinese workers in the ship and engine building works. By 1868, the Navy Yard employed as many as 3,000 Chinese workers who were given on-the-job training in drafting, carpentry, machine tool operating, and metalworking. It completed its first screw-propelled steamboat (223 × 29.5 × 13.2 ft dimension, 1,450 t displacement, 150 hp single-cylinder engine) in 1869 and, by the end of 1870, built four more similar vessels. It completed its first domestically built engine in 1871 (Pong, 1994, pp. 203–244).

In order to train naval officers and marine engineers, the Navy Yard established the Fuzhou Naval School (*Chuanzhengxuetang* 船政學堂), which had two divisions: the school of navigation and the school of naval construction. The latter recruited French teachers to teach French, arithmetic, and geometry to students as a prerequisite for physics, descriptive geometry, trigonometry, analytical geometry, calculus, and mechanics. The students were also required to gain practical experience by participating in the shipbuilding works. The number of the students was not large. By 1874, 39 students attended the school. Although the students managed to design and direct the building of a small steamboat without the French technicians' assistance in 1876, the naval yard considered the technological environment of China could not make them competent engineers. Hence, in 1877, it sent some of the students to Europe for further training.

After the expiry of the contract with the French technicians in 1874, the Navy Yard continued to upgrade its technology. Between 1877

and 1880, it completed five ships fitted with the 750 hp compound engine, which was much more sophisticated than the single-cylinder reciprocating engine it had built before. Then, it further introduced the triple expansion engine and, between 1883 and 1886, completed three cruisers that were fitted with purchased 2,400 hp engines of such a kind. It also introduced steel-hull construction and, between 1888 and 1907, built 13 steel-hulled warships. Then, it ceased to build any ships because government funding stopped. In total, the Navy Yard completed 40 steam warships and merchant ships (Wang Zhiyi 1986, p. 99, 110).

The demise of the Fuzhou Navy Yard did not mark the end of China's steamship-building ambitions. The Jiangnan Arsenal's shipbuilding arm became the independent Jiangnan Dockyard in 1905, which recruited a team of foreign technicians to take over the managerial and technical works. It became a successful government-owned enterprise through competing in the shipbuilding business by accepting orders from the Chinese or foreign governments as well as shipping companies. It built sea-going cargo ships and also small displacement gunboats and cargo barges.

Beyond arsenals and shipyards, steam power was mainly used in the shipping business, which was booming after the 1860s, when the conflicts with Britain and France were resolved and the civil war ended. In 1872, when the first Chinese steam navigation company was formed, there had been as many as 13 foreign shipping companies, mostly American and British, operating in Chinese waters (Zhu, 2008, p.4). The number of companies and mercantile steamers fluctuated, but in 1893, the three largest operators, the China Merchants' Steam Navigation Company, the China Steam Navigation Company, and the Indo-China Steam Navigation, had 26, 29, and 22 steamships respectively (Liu Kwang-ching, 1959, p.448).

In comparison, however, the railway industry grew slowly. From the 1860s, the Qing government had rejected foreign diplomats' lobbying for allowing foreigners to build railways (Kent, 1907, pp. 1–8). In 1876, a group of foreign

merchants built a 9½ mile long light railway in Shanghai without obtaining official permission. After negotiation, the Qing government purchased the line and moved the equipment to Taiwan. Unfortunately the line was never rebuilt due to lack of funds (Pong, 1973). In the 1880s, railway building was still a controversial issue in politics. Yet, after the Sino-French War (1884–1885), the Qing government acknowledged the strategic importance of the technology and hence gave the power of managing railway building to the newly established Admiralty (*Haijunyamen* 海軍衙門). However, due to financial difficulties, the speed of construction remained slow. By 1895, only 650 miles of railway lines were completed, but the speed of development increased thanks to foreign loans. By the time the dynasty collapsed in 1910, 5,606 miles more lines had been constructed (Chen, 1981, pp. 6–9).

Because of the need for fuel and raw materials, the Qing government sponsored the opening of coalmines and iron mines with steam power. The Kaiping Coalmine in Zhili province and the Han-yang Iron Works in Hubei province were established in 1871 and 1890, respectively (Carlson, 1971; Quan, 1972). Those enterprises were profitable and survived well into the first half of the twentieth century. The Qing government officials were also willing to sponsor steam power in textile manufacturing. It established two cotton weaving and spinning mills, Shanghai Cotton Cloth Mill (1876) and Hubei Cotton Cloth Mill (1889), and one mechanized woolen mill in Lanzhou, Gansu province (1880). In total, by 1910, the Qing government set up 69 arsenals and factories that employed steam power.

In the private sector, before 1895, Chinese or foreign entrepreneurs were slow to exploit steam power for legal reasons. The Treaty of Tientsin [Tianjin] between China and foreign powers only stipulated that foreigners were allowed to build residential houses, churches, hospitals, and graveyards. Accordingly, the Qing government forbade foreigners from establishing factories in China. Yet, it only prosecuted the key industries mentioned above but ignored those small factories such as a mechanized soybean oil mill in

Niuzhuang (1868–1970) or flourmills in the treaty ports (Wang, 2013). The best available data suggest that by 1895, 88 mechanized factories had been established in the treaty ports (Feuerwerker, 1980, p. 29). The legal constraint was lifted by the Treaty of Shimonoseki (1895), which concluded the Sino-Japanese War (1894–1895), and allowed foreigners to establish factories. Thereafter, 136 more steam-powered factories were founded between 1895 and 1913 (Feuerwerker, 1980, p. 29).

The introduction of the theoretical knowledge of the steam engine to the wider Chinese public was achieved in a limited scope and depth by translation. In 1860, the Qing government established the School of Combined Learning (*Tongwen guan* 同文館) in Beijing for training translators. Apart from teaching foreign languages, it offered courses in Western science and technology. The textbook, *Natural Philosophy* (*Gewu rumen* 格物入門), gave an introduction to the atmosphere and its pressure. It also explained how steam pressure might be turned into motive force by the cylinder-piston mechanism. Furthermore, more books about the steam engine were translated by the Translation Bureau (*Fanyi guan* 翻譯館), which was established in 1868 within the Jiangnan Arsenal for translating books about Western science and technology (Reardon-Anderso, 1991, pp. 29–52; Wright, 2000, pp. 24–127). By the end of the nineteenth century, five translations of marine engineers' manuals or textbooks had been produced. All of these publications were reprinted and circulated among Chinese literati, but none of the publications were included in any coherent technical course that educated engineers. Moreover, readers who did not have basic schooling in modern science and mathematics would find it difficult to gain the competence in the calculation of heat, pressure, and mechanical force, even if formulae were printed in the books. Isolated translations could not produce competent engineers any more than the school of naval construction at the Fuzhou Navy Yard.

A radical educational reform took place in 1904. The Qing government abolished the imperial examinations and started to formulate

a modern system of education after the Western model. Public and private technical schools were established to provide technicians and engineers for the growing industries. Universities were also formed to house engineering departments and foreign professors were recruited. Private publishers which saw the commercial prospects of the reform started to produce translations of textbooks in the fields of modern science and technology at a much larger scale. These educational institutions would provide a greater number of engineers and technicians to China's industrialization.

To conclude, the introduction of steam power between 1838 and 1911 effected a great transformation of technology in China. Although the Chinese people initially misunderstood the steam mechanism, they experimented on it and successfully built a full-scale steamer. After trial and error, the Qing government realized that the existing technical expertise and tools were not enough to build more than one steamer and one engine. Hence, it established modern arsenals and navy yards that employed foreign technicians and imported machine tools. They made good technical progress by the end of the dynasty. They also trained Chinese workmen and a small number of engineers. However, financial difficulties hampered development until they were allowed to enter the market for profits. Although the Qing government intended to introduce the theoretical knowledge about the steam engine to the Chinese literati, that impact was limited.

From the early twentieth century, China underwent an industrialization in which the steam engine was the dominant source of motive power, although different types of motive force, such as the internal combustion engine and the electrical motor, were simultaneously introduced. According to an industrial survey conducted in 1937, 86 % of motive force in terms of horsepower in China's factories was steam powered (Liu Dajun, 1994, p. 96, 128, 160). More than 50 % of electricity was generated by coal-fired steam turbines (Tao Liumen, 1930, p. 490); locomotives were all steam driven (Yang Yi, 1948, pp. 1–4); and the vast majority of domestically built inner-river or

ocean-going ships were still steam propelled (Wang Shiquan, 1948 pp. 2–3).

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Stone Beads

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Beads are small artifacts, usually perforated, that are used for adornment on the human body, clothes, artifacts, or animals. They are used to express social status, wealth, gender, and other symbolic attributes. The earliest known prehistoric beads were made of seashells (from about 100,000 years ago). From about 50,000 years ago, ostrich eggshell, animal bone and teeth, ivory, and antler were also used (Taborin 2004; Álvarez Fernández and Jöris 2008; Miller and Willoughby 2014). The earliest stone beads found in Upper Paleolithic sites in Western Europe from ca. 32 ka were made of mostly clay and soft stones (chlorite, talc, calcite, hematite, and lignite; Taborin 2004; White 2007). The earliest known wooden beads are Neolithic (Nahal Hemar Cave, Israel; Werker 1988). Metal beads were first made of copper (in ninth millennium BCE Anatolia) and are later made of gold and silver. The crushing, shaping, and heating of soapstone into a paste which became glazed enstatite in the fifth millennium BC in Pakistan form another leap forward, which lead to the production of faience, then glass

beads in the third millennium BCE in Egypt and the Near East (Lankton 2003; Bar-Yosef Mayer et al. 2004; Dubin 2009). Additionally seeds and other organic materials served as beads.

Stone beads become widespread around 12,000 years ago, for example, when amber beads appear in Starr Carr, England, jade beads appear in Japan in Early Jomon sites, and apatite and other green mineral beads and pendants appear in the Levant in the Late Natufian culture. Besides their role of adornment and symbolism, they become a trade and exchange item in a society that changed its economic basis from hunting and gathering to farming and herding (Bar-Yosef Mayer 2013; Wright and Garrard 2003).

Hundreds of rocks and minerals exist in nature, but only a selection, which are relatively easy to find and durable enough, were chosen for bead production. Stone beads are made of either minerals, composed of a specific combination of elements (e.g., quartz, a combination of silica and oxygen, SiO₂), or rocks made of a combination of minerals, but are sometimes monomineralic (Table 1). Their proper identification may indicate the origins of the raw material, vital to archaeological research (Rapp 2002; Aston et al. 2000). Lab tests used for materials identification include hardness (Mohs scale); the presence of carbonates using hydrochloric acid; structure as seen under a stereoscopic microscope; mineralogical composition using one of more of the following methods, Scanning Electron Microscope equipped with Energy Dispersive Spectroscopy (SEM-EDS), X-ray fluorescence (XRF), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FTIR); and isotopic composition. For example, limestone and calcite beads can be divided using XRF, but to differentiate them from shell disk beads, one should use a microscope that will reveal their structure, and in order to differentiate them from marble, ratios of oxygen isotope should be tested for.

Stone beads research is based mostly on typology and technology that indicate the period and culture that beads were made in. Typology was first developed by Horace Beck but each region

Stone Beads, Table 1 Common stone types used to produce beads

Category	Group/class/family	Name	Other names or minerals
Rock	Igneous	Basalt	
		Obsidian	
	Sedimentary	Limestone	Calcareneite
		Sandstone	
	Metamorphic	Marble	
		Quartzite	
		Steatite	Soapstone, talc
		Jade	Nephrite, jadeite
		Serpentine	Serpentine
Mineral	Carbonates	Calcite	
		Malachite	
	Phosphates	Apatite	
		Fluorapatite	
		Turquoise	
	Silica (SiO ₂)	Quartz	Rock crystal
		Amethyst	
		Agate	
		Cornelian	
		Onyx	
		Jasper	
	Aluminum silicates	Garnet	Lapis lazuli
		Amazonite	
		Lazurite	
		Chlorite	
	Sulfate	Gypsum	
	Iron oxides	Ochre	
		Hematite	
Fossilized tree resin		Amber	

and period require specific definitions (Beck 1928; Bar-Yosef Mayer 2013). Technological traditions are continuous in some regions for many millennia (e.g., the Indus Valley), and recent ethnographic observations shed light on past activities (Kenoyer 1991; Kenoyer et al. 1991; Roux 2000; Caubet 1999). The indistinct shapes of rocks and minerals require planning ahead for the artifact produced. It involves the collection of raw materials, hammering and sawing into a rough shape, fine chipping and grinding into a bead blank, drilling, filing, or polishing sometimes complemented by etching. Heating (especially cornelian) enhances the color and if practiced it is a first step before shaping.

In the case of thin disk beads, the perforation precedes filing, and then a group of beads strung together is filed to produce beads of equal diameter. Perforation methods include the use of a hand, bow, or pump drill, with drill bits made of flint or harder materials. In later periods metal drills were used, and abrasive materials added (Kenoyer et al. 1991; Gwinnett and Gorelick 1999; Roux 2000; Lankton 2003).

Beads have universal symbolic meanings based on their colors or shapes. Red universally connotes the color of blood, which life depends on and in ancient Egypt it symbolized energy, dynamism, and power. It also embodies blood of sacrifice or resulting from violence. Red or reddish beads were made in the old world first from ochre and clay, then from carnelian. In South America red shells and corals were used for the same purpose. Cornelian was common in the civilizations of Egypt, Mesopotamia, and Indus valley but is also known from East Africa. In the nineteenth century, cornelian from Brazil was imported to Germany where it was made into beads that were traded to Africa. Red, white, and black beads are among the oldest. White is often associated with purity and perhaps innocence as it relates to human milk and semen, and as an example, among Bedouin women, white beads serve to enhance the milk of a mother. Black is associated with excreta and earth and denotes decay, but in ancient Egypt, it is considered to represent depth and profundity (Andrews 1994; Sciamia and Eicher 1998; Morris and Preston-Whyte 1994; Mershen 1989; Kay and McDaniel 1978).

Ethnographically green and blue indicate ripeness, fertility, and strength. In ancient Egypt, it is the color of new vegetation and symbolic of new life. It has been suggested that the appearance of green beads during the agricultural revolution was as fertility charms and as amulets to ward off the evil eye (Bar-Yosef Mayer and Porat 2008). Green and blue beads, made of copper bearing minerals (malachite, chrysocolla) but also turquoise and lapis lazuli, are associated with growth, productivity, and good health. They can be found in Mesopotamia and ancient Egypt, as well as Mesoamerica and South America and the American Southwest. Jade beads and

pendants are known from East Asia, mostly China, as well as ancient Mesoamerica but also from Maori New Zealand. Turquoise was mined in Southwest USA (Chaco Canyon in New Mexico being the most famous) and traded into Mexico. Turquoise was also mined in the past in Persia and Sinai, from where it was transported to ancient Egypt (Andrews 1994; Hull et al. 2014; Tait 1986).

Neither rock nor mineral, amber is known mostly from the Baltic region from where it was traded to western Asia in the third millennium BC and in historic period to East Africa and Arabia. In some Bedouin societies, yellow beads often made of amber are apotropaic against jaundice. Brown and purple are less fundamental colors and are more rare in the ethnographic and archaeological record of beads and ornaments (Mershen 1989; Dubin 2009).

Gemstones, not perforated but cut and inlaid in metal, are broadly associated with nobility, examples being the Turkish sultans and their contemporaneous Mughal dynasty of India. The precious stones ruby and sapphire (two forms of corundum), emerald, and diamond are extremely hard and usually not exposed on the surface of the earth; therefore they were rare in antiquity. Rubies are known from China from about 200 BC and in the past were used as drills for making beads of softer stones, as were diamonds in India (Tait 1986).

Beadwork, the union of a group of beads with or without thread into one artifact such as an apron or necklace, is first found with stone beads from Egypt in the late third millennium BCE. In beadwork, stone beads are sometimes combined with beads of other raw materials (Hector 2005). One type of beadwork is prayer beads used to count prayers that originated in India in the second century BCE and which are common in Hindu, Buddhist, Islamic, and Catholic rosaries (Tait 1986; Dubin 2009). Based on observations of hundreds of photos and items in museums, it appears that most non-western cultures today use mostly colored glass seed beads, shell, and metal with relatively small numbers of stone beads (Allen and Hector 2007).

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Stone in Ancient Egypt

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Rock Varieties and Sources

Much of what remains of ancient Egypt consists of stone (Aston, Harrell, & Shaw, 2000; Baines, 2000; De Putter & Karlshausen, 1992; Klemm & Klemm, 2001, 2008). There are building stones for temples, pyramids, and tombs; ornamental stones for vessels, sarcophagi, shrines, stelae, statues, and other sculptures; gemstones for jewelry; and utilitarian stones for tools, weapons, pigments, and other applications. Still other stones were processed to extract their precious metals. This record of stone use ranges from the

Stone in Ancient Egypt, Table 1 Ancient Egyptian chronology

Predynastic or Neolithic period (5500–3100 BCE)
Dynastic or Pharaonic period (3100–332 BCE): dynasties 1–30
Early dynastic period (3100–2686 BCE): dynasties 1 and 2
Old kingdom (2686–2160 BCE): dynasties 3–8
First intermediate period (2160–2055 BCE): dynasties 9 to early 11
Middle kingdom (2055–1650 BCE): dynasties late 11–14
Second intermediate period (1650–1550 BCE): dynasties 15–17
New kingdom (1550–1069 BCE): dynasties 18–20
Third intermediate period (1069–664 BCE): dynasties 21–25
Late period (664–332 BCE): dynasties 26–30
Greco-Roman period (332 BCE–395 CE)
Ptolemaic period (332–30 BCE)
Roman period (30 BCE–395 CE)

Predynastic period (beginning about 5500 BCE) to the Roman period (ending about 400 CE; Table 1). In common parlance, the term “stone” includes “rocks” as well as the “minerals” they contain. There are three general categories of rocks – sedimentary, igneous, and metamorphic – and these are further subdivided according to their textures and constituent minerals.

Sediments (mud, sand, and gravel) deposited on ocean floors and land surfaces are hardened into sedimentary rocks through a variety of lithification processes, including compaction, cementation, and recrystallization. Continental sediments are derived from weathered and eroded preexisting rocks and are deposited mainly by rivers but also occasionally by wind, glaciers, and other processes. Marine sediments, in contrast, are composed mainly of biogenic material (hard skeletal parts of algae, protozoa, and especially invertebrate animals) or inorganic precipitates produced by evaporation of seawater, but also sometimes include continental sediments carried by rivers to the seas. Other sedimentary rocks are the result of secondary mineralization of preexisting sedimentary rocks.

Sedimentary rocks used by the ancient Egyptians include limestone (from biogenic marine sediments); rock gypsum and rock anhydrite (both from evaporative marine sediments); sandstone, including the harder silicified (quartz-cemented) sandstone or quartzite (from continental sediments and, in part, shallow nearshore marine sediments); and travertine and chert (both from secondary mineralization of limestone). Nearly all the ancient quarries for limestone, travertine, and chert were located in the hills and cliffs bordering the Nile River valley between Cairo in the north and Isna in the south. Some limestone was also quarried along the Nile Delta’s Mediterranean coast near Alexandria. Quarries in the Nile valley from Isna southward into northern Sudan supplied the sandstone. Silicified sandstone came only from the Aswan area and Gebel Ahmar near Cairo. Rock gypsum and rock anhydrite were obtained from Egypt’s Red Sea coast, and rock gypsum also came from the Faiyum in the Western Desert. A beautiful blue rock anhydrite has no known Egyptian source and so may have been imported.

Igneous rocks form through the crystallization of magma (molten rock). They are referred to as “plutonic intrusives” when they form deep below the Earth’s surface, “volcanic intrusives” when emplaced in the shallow subsurface (dikes and related rock bodies), and “volcanic extrusives” when coming from a volcano and deposited on the surface (lava flows, and airborne pyroclastic falls and flows).

Igneous rocks used by the ancient Egyptians include granite, granodiorite, pegmatitic diorite, peridotite, and quartz diorite (plutonic intrusives); andesite, dacite, dolerite, rhyolite, and trachyandesite porphyries (volcanic dikes and lava flows); basalt and obsidian (volcanic lava flows); and tuff (volcanic pyroclastics). Apart from the famous granite and granodiorite quarried at Aswan on the Nile River and another variety of granite further up the Nile at northern Sudan’s Third Cataract, the igneous rocks came from the Faiyum in the Western Desert (basalt) and especially the mountains of the Eastern Desert (all other rocks, excluding obsidian). Obsidian (volcanic glass) does not occur in

Egypt and was imported either from the eastern Mediterranean or southern Red Sea regions.

Metamorphic rocks are derived from preexisting sedimentary, igneous, or other metamorphic rocks through the application of high pressures, high temperatures, or chemically active hydrothermal fluids deep below the Earth's surface. The metamorphosis occurs in the solid state (without melting) through secondary mineralization and recrystallization. The resulting rocks are either foliated, with a parallel alignment or planar segregation of their constituent minerals, or non-foliated.

Metamorphic rocks used by the ancient Egyptians include anorthosite, gabbro, granite, granodiorite, and tonalite gneisses (foliated) and marble, metaconglomerate, metagabbro, metagraywacke, serpentinite, and steatite (non-foliated). The anorthosite and gabbro gneisses come from the Nubian Desert west of Lake Nasser, the granite and granodiorite gneisses were taken from the Third and Fourth Nile Cataracts in northern Sudan, and all the other rocks were quarried in the mountains of the Eastern Desert.

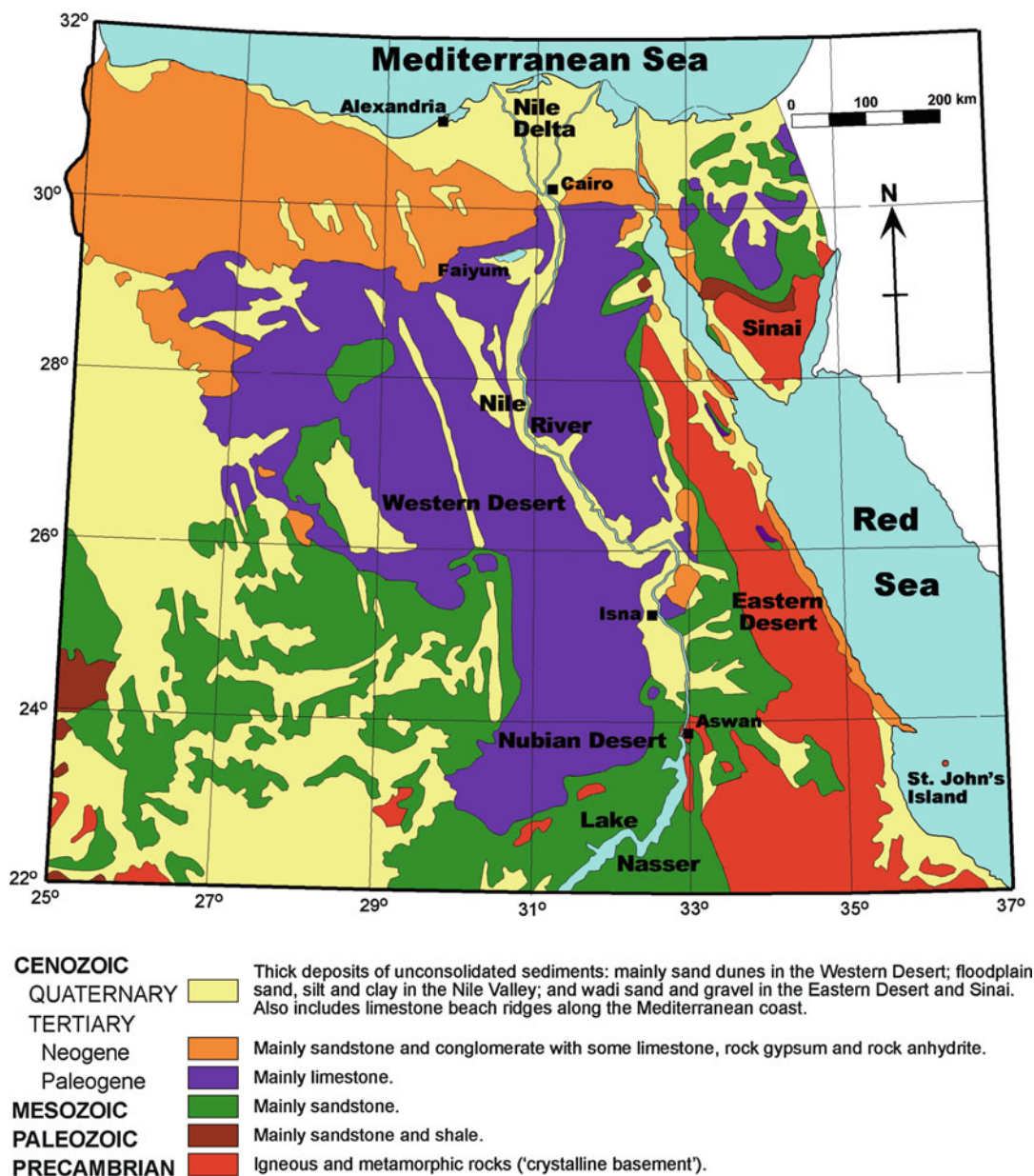
The other stones employed by the ancient Egyptians are minerals found mostly within the plutonic and metamorphic rocks. These are the gemstones used for jewelry and include amazonite, a variety of microcline feldspar; emerald, a variety of beryl; fluorite; garnet; hematite; jade (or nephrite); Libyan desert glass; malachite; macrocrystalline quartz (amethyst, milky quartz, and rock crystal), microcrystalline quartz (banded agate, bluish-white chalcedony, carnelian, jasper, onyx, petrified wood, sard and sardonyx); peridot, a variety of olivine; turquoise; and occasionally other stones. These minerals were mined in the Sinai (turquoise), St John's (or Zabargad) Island in the Red Sea (peridot), the Nubian Desert west of Lake Nasser (agate, carnelian, and other chalcedonies), the sand sea in the Western Desert (Libyan desert glass), and the mountains of the Eastern Desert (all the rest). Lapis lazuli, a gemstone rock rather than a mineral, was also widely used in Egypt but was apparently imported from Afghanistan. During the Ptolemaic and Roman periods, other

gemstones were imported from India, including aquamarine (a variety of beryl), garnet, onyx, sapphire (a variety of corundum), and sardonyx. The plutonic igneous and metamorphic rocks are also the source of much of ancient Egypt's gold, copper, silver, tin, and some iron and lead, with sedimentary rocks supplying additional copper, iron, and lead. All of these were obtained from the Eastern Desert with much of the copper (derived mainly from malachite and chrysocolla) also coming from the Sinai.

Plate tectonics and other earth movements in combination with erosion processes have brought the originally deeply buried sedimentary, igneous, and metamorphic rocks to the surface in Egypt. The geologic map in Fig. 1 shows the generalized distribution of these rocks. The exposed plutonic igneous and metamorphic rocks, which form mountains in the Eastern Desert, are commonly referred to as the Precambrian "crystalline basement" and in Egypt are over 550 Ma old, whereas the sedimentary and volcanic igneous rocks are mostly less than 100 Ma in age. For images of many of the stones used by the Egyptians as well as information on the ancient mines and quarries, see Harrell (2012a, 2012b, 2012c, 2012d) and Harrell and Storemyr (2009).

Building Stones

Limestone and sandstone were the main building stones of ancient Egypt. From Early Dynastic times onward, limestone was the material of choice for pyramids, mastaba tombs, and temples within the limestone region. From the late Middle Kingdom onward, sandstone was used for temples within the sandstone region as well as many of those in the southern part of the limestone region. Both limestone and sandstone were also employed for statuary and other non-architectural applications, when harder and more attractive ornamental stones were not available. Along the Red Sea coast, the temples and other important buildings of the Ptolemaic and Roman periods were built with the locally available rock gypsum and rock anhydrite.



Stone in Ancient Egypt, Fig. 1 Generalized geologic map of Egypt (Adapted from an unpublished geologic map by the Egyptian Geological Survey and Mining Authority)

Ornamental Stones

In contrast to the drab, unpolished building stones, those employed for ornamental applications have attractive colors and patterns and also take a good polish due to their greater hardness. The principal applications of the various stones and their periods of use are as follows:

1. Exterior veneer on pyramids: Old Kingdom – granite and granodiorite.
2. Pyramid capstones: Old and Middle Kingdoms – granodiorite and possibly basalt.
3. Linings of burial chambers and passages in pyramids and mastaba tombs: Early Dynastic period through Middle Kingdom – granite, granodiorite, and silicified sandstone.

4. Door lintels, jambs, and thresholds of temples: Early Dynastic through Roman periods – granite, granodiorite, and silicified sandstone.
5. Temple pavements: Old Kingdom – basalt, bituminous limestone, and travertine.
6. Temple columns: Old and Middle Kingdoms – granite.
7. Temple walls: Old Kingdom – basalt, bituminous limestone, granite, and granodiorite.
8. Interior wall veneer, pavement, columns, and other architectural elements for temples and other buildings: Ptolemaic period – granodiorite; Roman period – andesite-dacite porphyry, granite, granodiorite, metaconglomerate, metagabbro, metagraywacke, pegmatitic diorite, quartz diorite, rhyolite porphyry, tonalite gneiss, and trachyandesite porphyry.
9. Basins: Roman period – andesite-dacite porphyry, granite, and tonalite gneiss.
10. Barque shrines: Middle and New Kingdoms – granite, silicified sandstone, and travertine.
11. Small statue shrines (naoi): Old Kingdom through Roman period – granite, granodiorite, metagraywacke, and silicified sandstone; Middle Kingdom – travertine; Late Period – dolerite porphyry; Roman period – metagraywacke.
12. Obelisks: New Kingdom – granite, metagraywacke, and silicified sandstone; Roman period – granite.
13. Offering tables: Old Kingdom through Roman period – granite, granodiorite, metagraywacke, silicified sandstone, and travertine.
14. Small vessels and figurines: Predynastic period through Old Kingdom – andesite porphyry, anorthosite gneiss, basalt, bituminous and buff limestones, dolostone, gabbro gneiss, granite, metaconglomerate, metagraywacke, obsidian, pegmatitic diorite, quartz rock crystal, red-and-white limestone breccia, rock gypsum, serpentinite, silicified (petrified) wood, travertine (the most commonly used stone), tuff, and tuffaceous limestone; Early Dynastic period and Old Kingdom – recrystallized limestone; Middle Kingdom and Second Intermediate period, blue rock anhydrite.
15. Canopic jars (placed in tombs for storage of the decedent's viscera): Old Kingdom through Roman period – travertine.
16. Sarcophagi: Old through New Kingdoms – travertine – Old Kingdom and Late to Ptolemaic periods – basalt; Old Kingdom through Roman period – granite, granodiorite, metagraywacke, and silicified sandstone; New Kingdom through Late Period – metaconglomerate.
17. Sarcophagus plinths: New Kingdom – travertine.
18. Embalming tables: Late Period – travertine.
19. Small to colossal statues and other sculptures: Early Dynastic through Roman periods – granite, granodiorite, metagraywacke, red-and-white limestone breccia, silicified sandstone, and travertine; Old and Middle Kingdoms – anorthosite gneiss and gabbro gneiss; Old through New Kingdoms – buff limestone; New Kingdom – marble and peridotite; New Kingdom through Roman period – granite gneiss and granodiorite gneiss; Late Period – dolerite porphyry; Late through Roman periods – basalt and metaconglomerate; Roman period – andesite-dacite porphyry.
20. Scarab and shabti (a model servant figure placed in tombs to assist the decedents) figures: New Kingdom through Roman period – metagraywacke, serpentinite, steatite (usually glazed), and travertine.
21. Stelae: Old Kingdom through Roman period – granite – granodiorite, metagraywacke, and silicified sandstone; Late Period – granite gneiss, granodiorite gneiss, and metaconglomerate.
22. Cosmetic and ceremonial palettes: Predynastic and Early Dynastic periods – metagraywacke.
23. Headrests: Old through New Kingdoms – travertine.
24. Ceremonial mace heads: Predynastic and Early Dynastic periods – andesite porphyry, granite, granodiorite, red-and-white limestone breccia, metagraywacke, pegmatitic

diorite, recrystallized limestone, travertine, and occasionally other stones.

Note that many of the above objects were also carved from non-ornamental limestone and sandstone.

Gemstones

The many precious and semiprecious gemstones available to the ancient Egyptians were employed primarily for beads, pendants, amulets, inlays, and seals. The periods of use for the many gemstone varieties are as follows: Predynastic period – fluorite; Predynastic period through Middle Kingdom – milky quartz; Predynastic period through New Kingdom – malachite; Predynastic through Roman periods – amazonite, banded agate, bluish-white chalcedony, carnelian (and sard), garnet, hematite, jasper, lapis lazuli, onyx, sardonyx, steatite (usually glazed), and turquoise; Middle Kingdom and Ptolemaic and Roman periods (and very rarely at other times) – amethyst; New Kingdom – jade, Libyan desert glass, and petrified wood; Ptolemaic and Roman periods – peridot; and Roman period – aquamarine, emerald, and sapphire.

Utilitarian Stones

Perhaps, the heaviest used and least glamorous stone employed by the ancient Egyptians is chert, which is also commonly referred to as flint. From Predynastic times onward, it was used for tools (adzes, knives, and sickle blades; ax and pick heads; choppers; drill bits; and scrapers) and weapons (dagger blades and spear and arrow points). Even when metals (copper, bronze, and later iron) became commonplace for these applications, chert was still a popular low-cost alternative. For tools and weapons requiring the sharpest edges, imported obsidian was employed. A wide variety of stones, especially hard ornamental ones, were used for the heads of maces, a club-like weapon.

From Predynastic times into the Late Period, the quarrying and much of the carving of ornamental stones was done with hard, fracture-resistant stone tools known as pounders and mauls. These were primarily of dolerite, but silicified sandstone, anorthosite gneiss, and fine-grained granite were also occasionally used. These same rocks, especially silicified sandstone, were additionally employed as rubbing stones for smoothing rough stone surfaces. The actual polishing of these surfaces was probably done with ordinary, quartz-rich sand of which Egypt abounds. For quarrying the softer sandstone and limestone, metal chisels struck by wood mallets were employed. The metal was originally copper and this was gradually replaced by the harder bronze during the Middle Kingdom, and by the Late Period, tools of the still harder iron came into use.

Eye shadow made from finely ground galena (dark gray) and malachite (green) was used by both Egyptian men and women. The grinding was done on cosmetic palettes carved mainly from metagraywacke. Egyptian temples and tombs were richly painted with bright primary colors made largely from ground stones: azurite (blue), gypsum and limestone (white), hematite ochre (red and orange), limonite ochre (yellow and brown), and malachite (green).

Grinding stones for grain have been used throughout Egyptian history, and generally were carved from the harder and less valuable ornamental stones, such as granite, granodiorite, and silicified sandstone. During the Ptolemaic and Roman periods, large numbers of grinding stones made from vesicular basalt were imported.

Extra 1: What Is in a Name?

A persistent problem in Egyptian archaeology is the misidentification of ornamental stones. The primary sources of these errors are archaeologists, museum curators, and art historians who are unfamiliar with correct petrological nomenclature as applied by geologists. Geologists themselves have also contributed to the problem by applying different, competing rock classifications

to the stones. It is not uncommon to see objects carved from the same stone referred to by multiple, contradictory rock names in museum exhibits and catalogs as well as in reference works. This is not only a great source of confusion to the general public, but it has also misled some scholars into thinking the different rock names refer to different materials. A classic example of this problem is the stone known by the technically correct name “metagraywacke” (a slightly metamorphosed graywacke sandstone to siltstone), which is commonly referred to incorrectly as schist, slate, basalt, and siltstone. Travertine is another notorious example. This stone, which consists of the mineral calcite, is frequently called alabaster, which in geological nomenclature is a rock consisting of the mineral gypsum. In an effort to avoid this misidentification, travertine is increasingly being referred to as “calcite-alabaster” or simply “calcite.”

Another commonly misidentified stone is the granodiorite from Aswan, which is often referred to as black granite, diorite, or basalt. For example, the famous Rosetta Stone, which provided the key to translating Egyptian hieroglyphic writing, is widely described as basalt when it is actually Aswan granodiorite. A final example is the anorthosite gneiss from the Nubian Desert, which is frequently misidentified as diorite.

Extra 2: Bekhen-Stone to Basalt

Basalt is the fine-grained, black volcanic rock seen in lava flows all over the world. What few realize is that the word *basalt* is of ancient Egyptian origin. It began in the third millennium BCE as *bekhen*, which was the ancient name for a dark grayish green metagraywacke, a slightly metamorphosed graywacke sandstone to siltstone, quarried in Egypt’s Wadi Hammamat. During the Greco-Roman period, *bekhen* was transliterated into *basanites*, and during the Middle Ages, a transcription error in a copy of Pliny the Elder’s *Natural History* changed *basanites* to *basaltes*. This error went undetected in subsequent centuries when Pliny’s description of the misnamed

basaltes as having a “dark color and hardness of iron” was mistakenly thought to refer to the volcanic rock that today we call *basalt*.

Extra 3: Limestone or Concrete Pyramids?

The Old Kingdom pyramids at Giza, Saqqara, and other nearby necropoli on the Nile River’s west bank have long been recognized by Egyptologists and geologists as having been constructed with blocks of limestone. The limestone for the bulk of the pyramids, the core blocks, came from quarries excavated in the limestone bedrock surrounding the pyramids. A better-quality limestone, with a uniform light gray color and finer texture, was applied over the core blocks to form the pyramids’ exterior surfaces. These casing blocks came from the Tura-Masara quarries across the Nile River, on its east bank.

In the early 1990s, these long-held beliefs about the building materials for the pyramids were challenged by David Davidovits, a French materials scientist, who claimed the pyramids were made from poured concrete rather than quarried limestone. Although the concrete pyramids hypothesis has received a lot of attention in the international media, Davidovits has so far failed to convince any Egyptologists or geologists of his views. The reasons for this are two-fold. First, Davidovits’ arguments ignore and run counter to nearly all archaeological and geological evidence bearing on the pyramids. And second, Davidovits has been unable to experimentally produce a concrete resembling the pyramid stones using the techniques he thinks the ancient Egyptians employed.

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Stone Technology in Arabia

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The Importance of Arabia in Prehistory

Prehistoric research in the Arabian Peninsula is in its infancy, and it has long been treated as an

empty spot on the archaeological world map. While information about Arabian prehistory is still relatively scarce, archaeological sites are, in fact, abundant. Archaeological sites are found in many places across Arabia, usually represented by stone tool industries. Arabia is a key geographic zone of the Old World, as it lies at the crossroads of three continents: Africa, Europe, and Asia. The Peninsula therefore plays a leading role for studying the worldwide expansion of early humans.

Archaeological surveys have been carried out in Arabia for more than half a century, revealing the existence of prehistoric sites spanning over a long time period, some perhaps extending back to more than one million years ago. Stone tools (also called lithics) represent the main kind of material objects found in archaeological sites. Based on the typology of stone tools, archaeologists working in Arabia have constructed a chronological and cultural framework that was modeled after the technological stages known elsewhere, such as the Lower Paleolithic (Oldowan, Acheulean) and the Middle Paleolithic (sometimes labeled as Mousterian or Middle Stone Age). All archaeological site discoveries made in Arabia were adapted to this broad typological and chronological framework. Prehistoric research in Arabia is currently progressing, as Paleolithic sites have now been radiometrically dated and systematic site excavations have been conducted.

Having today a somewhat better picture of the chronological framework of prehistoric Arabia, lithic industries are currently being compared with better-established neighboring stone tool assemblages, such as those of northeast Africa and the Levant. Comparisons are important in this case, as there is a desire to determine the regional source of Arabian populations. Stone tool industries in Arabia can therefore provide an opportunity to examine cultural influences and interconnections and human migrations and dispersals.

Paleoenvironmental research has been growing in Arabia over the past few years, situating prehistoric activities in ecological context. Studies include study of satellite images to identify

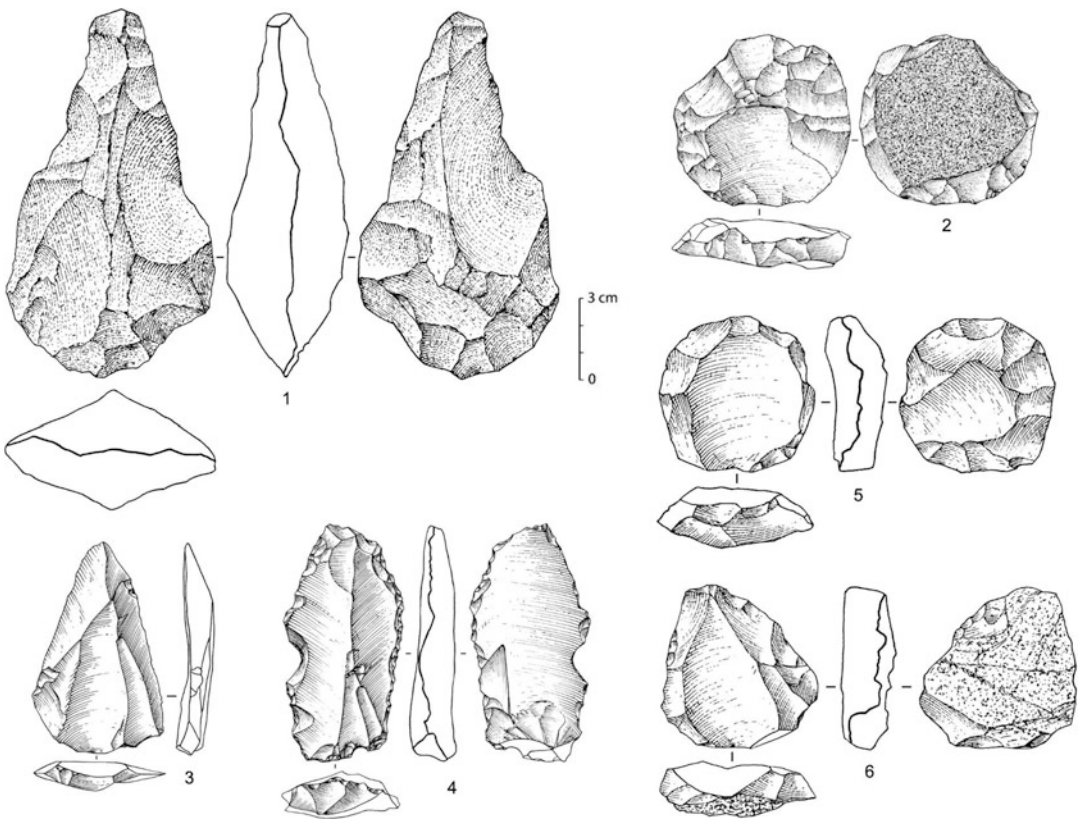
paleohydrological features (lakes, rivers), analysis of riverine and lacustrine (lake) deposits themselves, and study of cave speleothems which provide an accurate picture of climate change history. All of these studies contribute to the reconstruction of past environmental conditions, providing a framework to understand prehistoric occupations and activity.

The Peopling of Arabia

The oldest archaeological sites identified in Arabia are not well dated, but based on interregional analysis and stone tool typology, they comfortably belong to a Lower Paleolithic tradition known as the Acheulean, dated between 1.7

million years ago and 200,000 years ago. Lithic industries typed as Acheulean typically contain large bifacially made artifacts, called handaxes and cleavers, as well as simpler tools, called choppers. These large bifacial tool forms are hand-held implements, probably used in a variety of tasks, such as butchering animal carcasses.

Middle Paleolithic stone tool industries are better known in Arabia in comparison to Lower Paleolithic industries (Fig. 1). In Europe, the Levant and Africa, the Middle Paleolithic is generally characterized by Levallois flaking methods, which begins in the late phases of the Acheulean. Levallois technology is characterized by a hierarchical system of flaking, including predetermined forms of flaking products. Middle



Stone Technology in Arabia, Fig. 1 Arabian Paleolithic stone technology: (1) Lower Paleolithic Acheulean handaxe (From Jubbah, JKF-8 site, northern Saudi Arabia); (2) Middle Paleolithic (MP) Levallois preferential core (From Jubbah, JSM-1 site); (3) MP Levallois

preferential flake (From Jubbah, JKF-1 site); (4) MP retouched tool (From Mundafan, MDF-1 site, southern Saudi Arabia); (5) MP Levallois preferential core (From Al-Kharj, AK-22 site, central Saudi Arabia); (6) MP Nubian core (From Al-Kharj, AK-22 site)

Paleolithic industries in Arabia are also characterized by Levallois tool methods. The key innovation is the use of flakes for tipping spears, thus providing advantages to prehistoric hunters who were able to kill prey from a distance more efficiently.

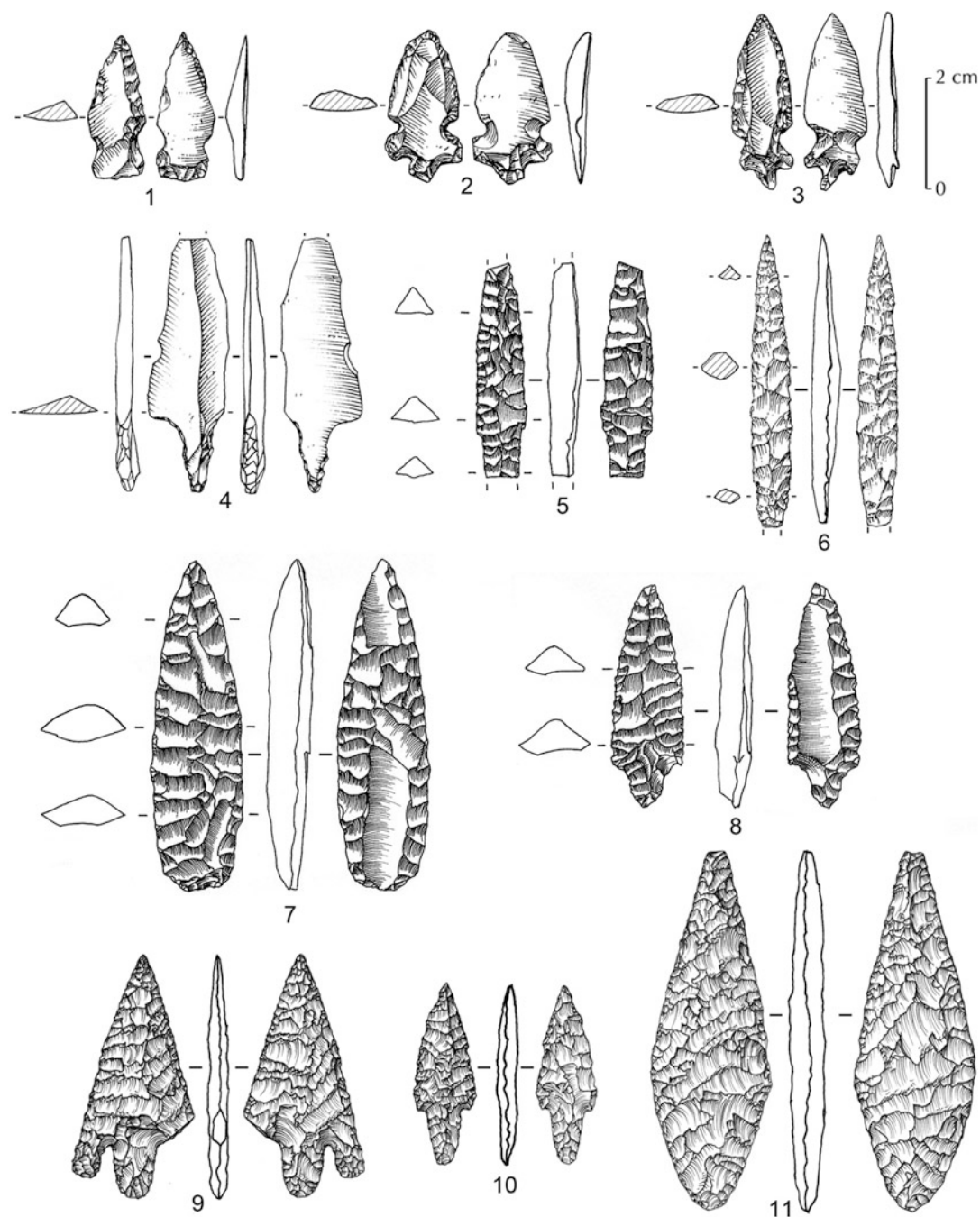
Middle Paleolithic sites are found all across the Arabian Peninsula, thanks to numerous surveys by archaeologists. In recent years, archaeologists have identified sites with stone tools in stratigraphic context and in association with absolute dates ranging between 125,000 and 55,000 years ago. The main sites are Jebel Faya (Marine Isotopic Stage (MIS) 5e, United Arab Emirates; Armitage et al., 2011), the Nubian Complex of Arabia (MIS 5c, South and Central Arabia; Crassard & Hilbert, 2013; Rose et al., 2011), the Jubbah paleolake localities (MIS 7 to MIS 5c, northern Saudi Arabia; Petraglia et al., 2012), the Mundafan paleolake localities (MIS 5, southern Saudi Arabia; Crassard et al., 2013), and Wadi Surdud (MIS 3, southwestern Yemen; Delagnes et al., 2012). The episodic peopling of Arabia during the Middle Paleolithic is associated with well-established humid phases in which increased rainfall facilitated the expansion of both freshwater systems and mammal populations (Groucutt & Petraglia, 2012). Conversely, during arid or hyper-arid periods, the Arabian environment may have presented a substantial obstacle to human survival, at times resulting in population contraction into refugium zones [areas of relatively unaltered climate that are inhabited by plants and animals during a period of continental climatic change]. The Nubian sites in south and central Arabia were only formerly known in southern Egypt and northern Sudan; hence recovery of them raises questions as to whether these tool industries represent an early expansion out of Africa by our species *Homo sapiens*).

The Late Prehistory of Arabia

Stone tool industries dating to 50,000 years ago and later are characterized by the use of blade technology. Blade tool industries, called Upper

Paleolithic in the Levant and Europe and Late Stone Age in Africa, are still extremely rare in the Arabian Peninsula. The absence of these blade industries in Arabia raises the question as why the Peninsula was uninhabited during this period. Alternatively, the absence of these industries in Arabia may, in part, be due to preservation conditions, or perhaps a product of the lack of research. Though rare, recent discoveries in southern Oman could help to fill the gap in our knowledge about such sites, as blade tool assemblages have been found that may date back to 20,000 years ago (Hilbert, 2014). From the information available today, it is also possible to suggest that some regions of Arabia were sparsely inhabited, explaining the paucity of Upper Paleolithic sites, whereas in other more favorable ecological settings, foraging populations may have been continually present.

During the Early Holocene, after 10,000 years ago, stone tool assemblages begin to include projectile weaponry (Fig. 2). Stone tools include small tanged arrowheads made on a thin flake or blade-like blanks. Certain forms of arrowheads, named Fasad points, appear to be geographically restricted to the southern part of the Peninsula, especially in Oman and the Emirates (Charpentier & Crassard, 2013). Later on, and in correspondence with the rise of the Neolithic (mainly characterized by pastoralism) from the mid-seventh millennium BC, a typical facies of trihedral arrowheads appears in Yemen and spreads across southern Arabia, from the Red Sea coast to the Gulf. These finely made trihedral arrowheads are bifacially, and sometimes trifacially, shaped, showing a triangular cross section. Some of these stone tool forms are fluted, the fluting method consisting of the extraction of a flake along the longitudinal axis of the point, on its ventral face. This highly characteristic fluting method of stone tool manufacture is so far only found in south Arabia. Neolithic developments include the production of sophisticated bifacial foliate industries and other types of bifacial and unifacial arrowheads, as well as small finely shaped semicircular end scrapers (Crassard & Drechsler 2013),



Stone Technology in Arabia, Fig. 2 Arabian Late Prehistory stone technology: (1–3) El-Khiam and Helwan points (From Jubba, JQ-101 site, northern Saudi Arabia); (4) Fasad point (from Qi Haid site, Oman); (5) Trihedral point (From Manayzah site, Yemen); (6) Trihedral point

(From HDOR-419 site, Yemen); (7–8). Fluted points (From Manayzah site, Yemen); (9–11). Bifacial arrowheads and tool (From Mundafan, MDF-16 and MDF-20 sites, southern Saudi Arabia)

quite clearly present in the whole of south Arabia. For the rest of the Peninsula, stratified and dated Early and Mid-Holocene sites are still infrequent. Surface finds (sometimes broadly attributed to a vague “Arabian Bifacial Tradition”) indicate a probable difference with the traditions observed in Yemen, Oman, and the Gulf.

Stone technology does not entirely disappear in the Bronze Age which begins at about the fourth millennium BC. Yet, there is a clear tendency for expediency: retouched tools are made on flakes, with no particular method to produce specific forms of particular sizes and shapes. The blade and bladelet component, sometimes abundant in Neolithic assemblages, begins to disappear in favor of metal products. During the Bronze Age and Iron Age in Yemen, geometric microlith traditions are reinvented. These tool forms are typically made of a distinctive volcanic material called obsidian, found locally and imported from Africa. These microlithic tool forms represent the final phase of stone tool industries used in Arabia, coming to an end by the beginning of the Common Era (Crassard, 2008).

Conclusions

Arabia is central in debates concerning human origins and the colonization of the Old World. Stone technology helps archaeologists to examine cultural traditions, human activities, and population relationships and movements. Today’s explorations and excavations are helping to improve our understanding of Arabia’s role in past history, and studies of stone technology are fundamental in tracing interactions, influences, and dispersals of early human groups out of, and into, Africa. Analysis of stone tool variations and patterns also help in evaluating the more recent peopling and re-peopling of the Arabian Peninsula, up to the rise of urbanized and complex civilizations.

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Stone Tools in Mesoamerica: Flaked Stone Tools

Bradford W. Andrews

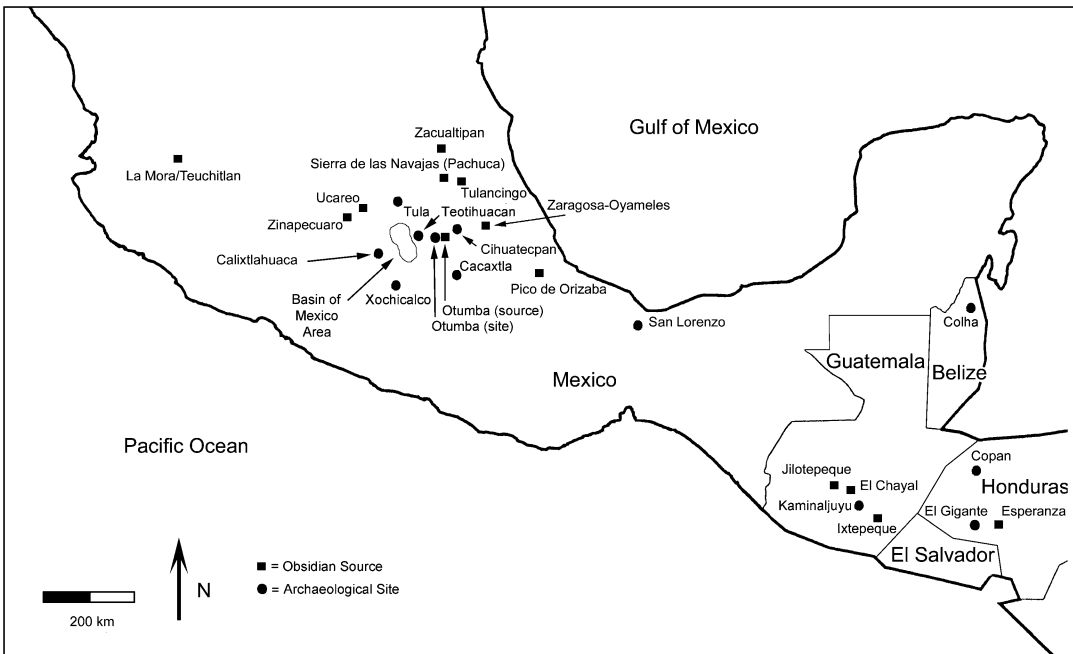
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Flaked stone tools in pre-Hispanic Mesoamerica were used for a wide range of domestic, militaristic, and ritualistic activities. Geographically, Mesoamerica refers to present-day Mexico, Guatemala, Belize, and parts of Honduras and El Salvador. The prismatic blade was the most common tool, usually made of obsidian, which was the most important tool stone in the region (see “[Extra: Obsidian in Mesoamerica](#)”). Flake tools and biface implements, like projectile points and knives, were also used throughout Mesoamerica. These implements, however, were not as prevalent as blade tools except during early Mesoamerican prehistory or at sites like Colha in the chert-bearing zone of Belize where obsidian was scarce (Fig. 1) (Hester & Shafer, 1994; Shafer & Hester,

1983). This discussion focuses on the Mesoamerican blade technology, but flake and biface technologies are also reviewed. Reference is made to chronological trends and how blades and other items were produced and used. Although the topic here is technological, obsidian production and use also had considerable symbolic and ritual significance (see “[Extra: The Ideological Significance of Obsidian](#)”).

Early Prehistory

Research indicates that as early as 15000 BCE, small foraging groups who made impressive projectile points inhabited much of Mesoamerica (MacNeish, 1976; Weaver, 1981). These groups are referred to as Paleo-Indian (prior to 7200 BCE) “big-game” hunters. They practiced a biface technology requiring the use of percussion and pressure techniques to shape biface (e.g., projectile points) and uniface (scrapers) tools. The manufacture of biface tools like projectile points requires the removal of flakes from both sides or “faces” of a relatively flat piece of stone.



Stone Tools in Mesoamerica: Flaked Stone Tools, Fig. 1 Map of Greater Mesoamerica (Illustration by the author)

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 2 The direct freehand percussion technique (Illustration by Karen Andrews. Used with her permission)



Uniface tools like many scrapers, in contrast, are made by removing flakes from only one side of a piece of stone. The flaking techniques used to make both types of implements are similar, so they are referred to here as products of biface technology.

Paleo-Indian bifaces were initially made from large flakes using direct percussion, which were then “thinned” with pressure. Direct percussion involved directly striking a piece of raw material (i.e., nodule, flake, or blade) with a stone, bone, antler, or wood hammer (Fig. 2) (Hester, 1972, p. 99). In contrast, the pressure technique involves placing a tool of bone, antler, or wood against the edge of a piece of raw material and pushing on it to “press” off flakes.

Many Paleo-Indian points in Mesoamerica were the fluted varieties associated with the Clovis and Folsom Traditions (Weaver, 1981). Clovis points have been found in Northern and Western Mexico and as far south as El Salvador (Weaver, 1981). In Central Mexico, a similar development referred to as the Cordilleran Tradition emerged around 13000 BCE; it was associated with the appearance of pressure flaked, willow-shaped projectile points, crude blades, and scrapers (MacNeish, 1976, p. 322, Fig. 2). Early Paleo-Indian points were hafted on spears and used as thrusting weapons. By about 9000 BCE, however, the *atlatl* or spear thrower appeared, providing hunters with greater thrusting force and accuracy. In the Aztec language of Nahuatl, the word *atlatl* refers to what is known in English as the spear thrower. This device consists

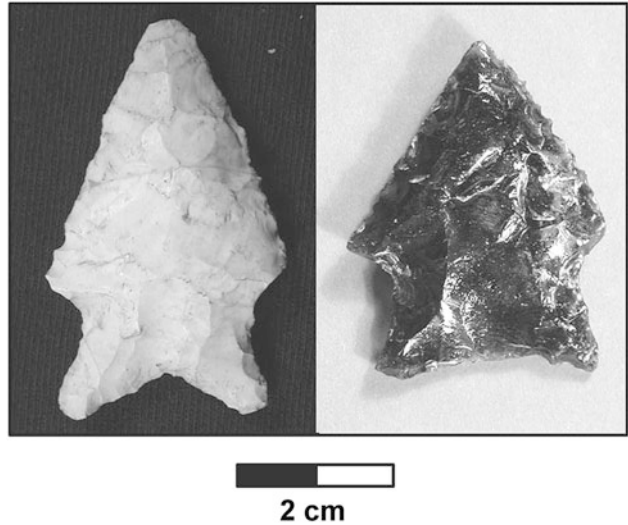
of a stick that supports a dart-tipped shaft. During the throwing action, the stick acts as an extension of the arm and a lever that propels the “butt” end of the dart shaft generating greater thrusting power and accuracy than a shaft thrown by hand (Adams, 1977, p. 339). Point size is usually used to differentiate larger spear points from smaller *atlatl* points, with *atlatl* points measuring generally less than 6 or 7 cm in length. This criteria is subjective, however, and many finely flaked points dating to this period could have been either spear or *atlatl* points (Fig. 3).

The appearance of the spear thrower occurred in tandem with the gradual replacement of big-game hunters by groups who foraged for a wider range of plant and animal resources. This shift is associated with the Mesoamerican Archaic period (7200–2500 BCE). Generally, Archaic flaked stone tools are characterized as expedient, consisting of flakes made with direct percussion or bipolar percussion. Bipolar percussion involved striking the top of a cobble resting on an anvil stone, enabling the transmission of force from both “poles” of the cobble (Fig. 4). Unmodified bipolar flake tools, or those flaked into slightly refined forms, were “amorphous” in form, and their production resulted in a miscellany of chunks and shards. Some argue that this technology was nonspecialized (Clark & Lee, 1984) and required limited skill (Clark, 1981). It allowed the knapper an easy means to maximize the amount of available cutting edge in areas where obsidian was a scarce and distant resource. More recently, however, evidence

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 3 Paleo-Indian projectile points from El Gigante cave, Honduras (Photos by Tim Scheffler. Used with his permission)



Stone Tools in Mesoamerica: Flaked Stone Tools,
Fig. 4 The bipolar percussion technique (Illustration by Karen Andrews. Used with her permission)

from the Olmec site of San Lorenzo supports the notion that rather than scarcity, it was used primarily for reducing relatively small pieces of obsidian that are otherwise difficult to flake

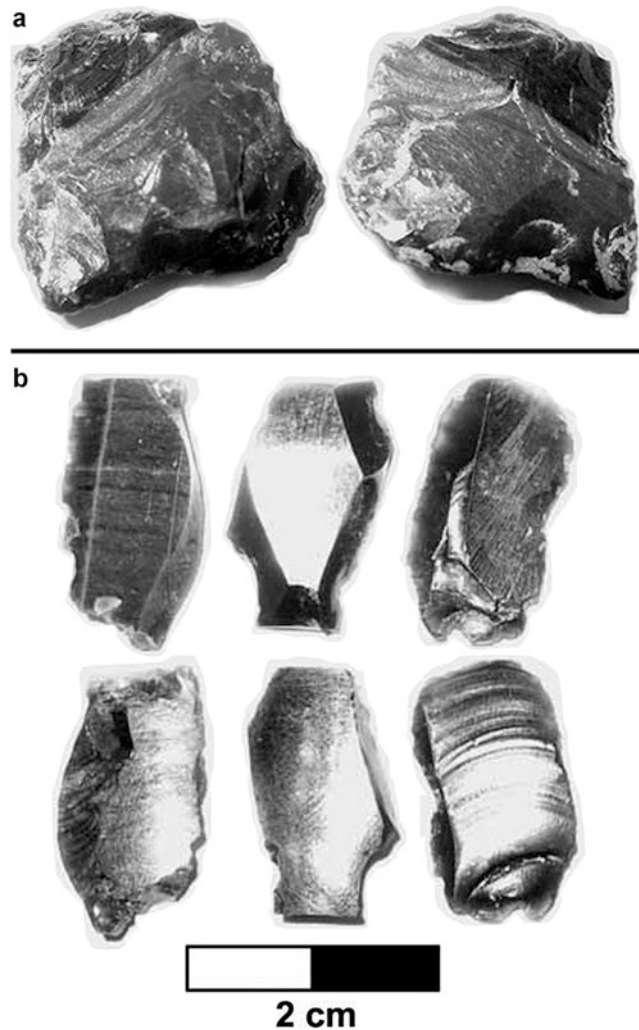
(De León, 2008). Moreover, it did require much more skill than has been previously appreciated. This expedient technology is found in Mesoamerica from the Basin of Mexico (Boksenbaum, 1980; Tolstoy, Fish, Boksenbaum, Blair Vauhn, & Smith, 1977) to the Pacific coast of Guatemala (Fig. 1) (Coe, 1961).

Although expedient techniques were prevalent well into the Preclassic (2500 BCE–AD 300) period (Aoyama, 1994, p. 136; Clark, 1987), some Postclassic sites (AD 900–1521) also have bipolar artifacts (Andrews, 2013). Recent research at the Aztec site Calixtlahuaca indicates that bipolar reduction was a limited but significant component of the city's flaked stone economy (about 10 %). It was used to reduce small nodules of obsidian and to further process “used up” bifaces and prismatic blades and cores (Fig. 5). Scalar cores might have provided flakes for various uses, but their relatively thin, V-shaped longitudinal profiles suggest that they may have functioned as wedge-type tools. The identification of bipolar prismatic blade segments was most surprising. The technique created new sharp cutting edges and “burinated” fracture surfaces good for scraping. Evidence of a similar use of bipolar percussion was also identified at the Aztec site of Xico in the Basin of Mexico (Brumfiel, 1986, p. 258). Its great time depth is consistent with the additive nature of

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 5 Bipolar artifacts from Calixtlahuaca: (a) “scalar” bipolar core; (b) bipolar blade sections, dorsal surfaces *top* row, ventral surfaces *bottom* row (Photos by author)



culture – early technologies are often never completely replaced; they just become supplementary to their newer counterparts. Bipolar reduction was probably used elsewhere but has gone under reported because few researchers have looked for it in Post-Formative archaeological collections.

Mesoamerican Blade Technology

Even though a few pressure blades may have been made in Central Mexico after 3400 BCE, blade production did not become prominent until the Middle Preclassic (900–300 BCE) period

(Hirth & Flenniken, 2002, p. 123). The factors responsible for the emergence of the Mesoamerican blade technology remain a topic of debate (see “[Extra: Origins of the Mesoamerican Blade Technology](#)”). By the time socially complex societies like Teotihuacan (AD 100–650) and Xochicalco (AD 650–900) (see Fig. 1 for site locations) had emerged, blade production had become a specialized occupation carried out by skilled craftsmen. Teotihuacan, located near the Basin of Mexico (Fig. 1), had an impressive population of 125,000 people by AD 500, most of whom performed their domestic cutting and piercing activities with blade tools. As such, evidence for specialized blade production has been

used to study the complexity of this society's economy (Andrews, 2002, 2012; Hirth & Andrews, 2006; Millon, 1973; Spence, 1981, 1987). Recent research has examined the skill of blade makers to determine how often they worked (see “[Extra: Measuring the Skill of Ancient Blade-Making Craftsmen](#)”).

The Mesoamerican blade technology resulted in the production of similar types of tools, although production techniques definitely varied. This variation can be attributed to numerous factors including distance to obsidian sources, the quality of different types of obsidian, how it was acquired (e.g., directly from the source, in the marketplace, etc.), different production techniques, and localized demand for specific types of products (Hirth & Andrews, 2002). Hence, readers must keep in mind that the following sequence is a generalized ideal; all local reduction sequences were to varying degrees unique.

In general, blades were detached from cylindrical cores using percussion and pressure techniques. Obsidian was acquired from quarries in the form of blocks and nodules and as cobbles in stream deposits (Spence, 1981). The initial step involved making a core platform. A platform is the surface where force was applied to remove blades. Large platform preparation flakes were detached from the upper end of the pending core (Fig. 6). This procedure created a smooth concave surface on a core preform. Sometimes platforms were further modified with pecking and grinding (see “[Extra: The Pecked and Ground Core Platform](#)”).

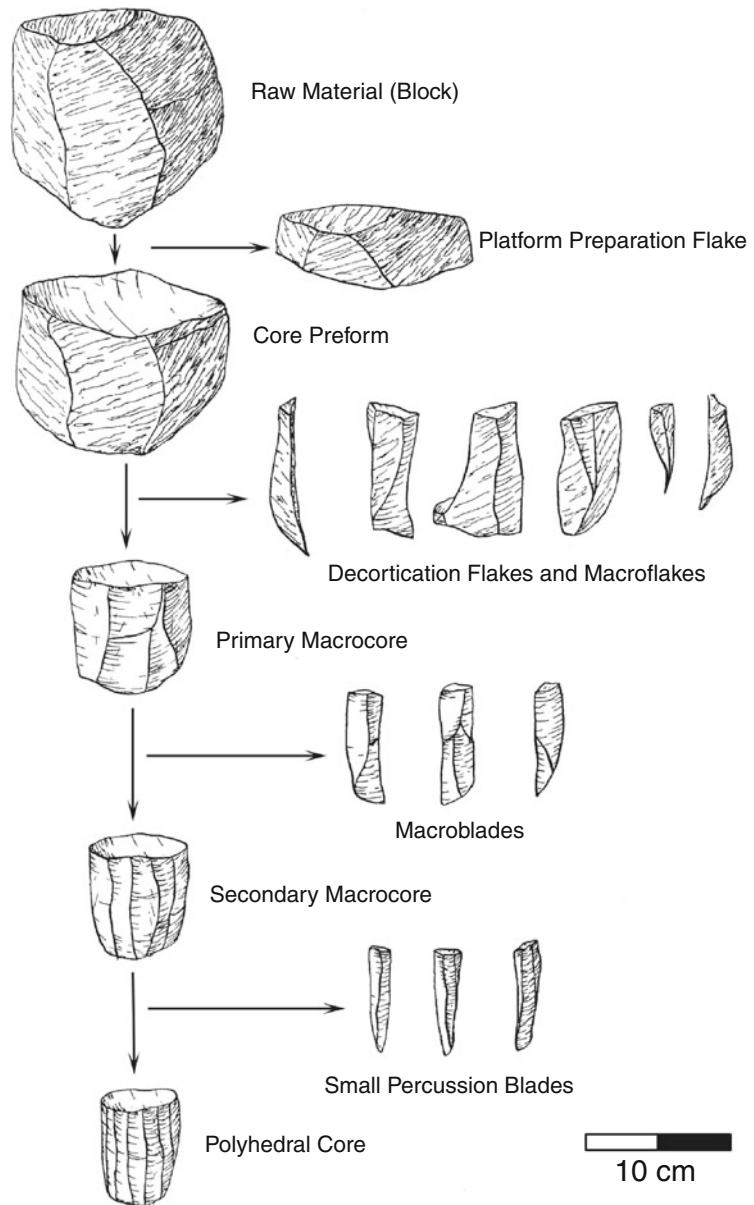
Next, relatively large decortication flakes and macroflakes were detached from the lateral sides of the core preform (Fig. 6). Decortication is the removal of the cortex or weathered surface of the stone. Additional macroflake detachments gave the preform more symmetry, resulting in a primary macrocore with irregular ridges on its lateral facets. Some of these macrocores are immense measuring more than 40 cm in length (Fig. 7), although most of them fall in the 15–20 cm range. After initially shaping the macrocore, macroblades were removed from the primary macrocore to make a secondary

macrocore (Fig. 6). Macroblades were relatively long, parallel-sided items with one or more dorsal ridges. These blades were roughly 2.5 cm wide and more than 1 cm thick. By themselves, macroblades were sturdy cutting implements, but they were also further shaped into more specialized biface tools (Fig. 8). Macroblade removal created a series of parallel, irregular ridges running the length of the core. Next, small percussion blades were detached to make the polyhedral core (Fig. 6). These blades are thinner than macroblades, with widths of less than 2.5 cm, and their removal created more regularized parallel ridges running the length of the core.

Most initial core shaping and blade-making activities were accomplished with direct percussion. Indirect percussion, however, was also probably used. This technique involved placing one end of an antler, bone, or wood punch on a platform and then striking the opposite end with a hammer stone; it permits more precise control over the transmission of force than direct percussion (Fig. 9). As a consequence, relatively standardized percussion blades can be made with indirect percussion. Although still a subject of debate (Pelegrin, 2003), the recovery of extremely symmetrical macroblades at sites like Kaminaljuyu in the Maya region (Fig. 1) suggests that indirect percussion was used in ancient Mesoamerica (Hirth, 2003).

The polyhedral core was reduced to make the delicate pressure blades that were common place in ancient Mesoamerica. The Aztec technique for making these blades has been reconstructed according to historic information and replication experiments (Clark, 1989c; Crabtree, 1968; Sahagun, 1963, plate 778; Titmus & Clark, 2003; de Torquemada, 1975; Tudela & Corona Nuñez, 1977). The reconstruction proposes that seated craftsmen secured cores against an immovable object with their feet and then used their stomach muscles and torso to “press” or push blades off with a long-handled wooden stick called an *itzcolotli* (Fig. 10). In some areas of Mesoamerica, however, pressure blades were also removed with a handheld technique (Flenniken & Hirth, 2003).

Stone Tools in Mesoamerica:
Flaked Stone Tools,
Fig. 6 Schematic diagram of the initial steps in core production (Illustration by author)



First-series blades were the initial pressure blades removed from a polyhedral core (Fig. 11). These blades eliminated irregular ridges left by the blades previously removed with percussion. Sometimes second-series blades were taken off after first-series blades depending on the shape of the polyhedral core. If the core was cone shaped, first-series blades often extended only part way down the sloping core face, resulting in a secondary polyhedral core.

In turn, second-series blades were removed to extend the parallel ridges the entire length of the core.

The product of first- and second-series blade detachments was the pressure core (Fig. 11). Pressure cores yielded third-series blades that are generally regular and consistent in shape (width and thickness) and have two dorsal ridges, thereby making them prismatic in cross section. The dorsal ridges were mechanically important



Stone Tools in Mesoamerica: Flaked Stone Tools, Fig. 7 Large macrocore from the Zaragoza-Oyameles obsidian quarry in the Mexican State of Puebla (Photo by Charles Knight. Used with his permission)

because they helped guide the transmission of force from the platform resulting in successful pressure blade removal.

Many pressure blades were further modified in a variety of ways. Most of them were snapped into sections and used for cutting activities. One parallel edge could be hafted in a piece of wood or bone, making the section easier to handle. A piece of wood or bone was incised deep enough to insert the blade section, which was then secured with a sticky adhesive composed of pine pitch and ashes.

Pressure blades were also made into specialized forms such as projectile points, lancets, and notched silhouettes of various forms. Small pressure blade projectile points were used for hunting and warfare. Many of these items were too small



Stone Tools in Mesoamerica: Flaked Stone Tools, Fig. 8 Broken macroblade biface tools discarded at a blade-making workshop at Teotihuacan (Photos by Alejandro Serabia. Property of the author)

to be propelled effectively with a spear thrower (Fig. 12a, b). Consequently, their size and minimal weight indicate that they were used to tip arrows propelled with a bow. This conclusion is interesting because small blade points occur in archaeological deposits that supposedly predate the Postclassic (AD 900) introduction of the bow in Mesoamerica (see [“Extra: The Bow and Arrow in Prehistoric Mesoamerica”](#)).

The slender needle-like, lancet blades (Fig. 12c–e) may have been used in textile production, but they were most important for blood-letting. Historic sources and ritual archaeological contexts where lancets have been found indicate that they were used to draw blood (Clark, 1989d, p. 314; Durán, 1971, p. 263; López de Cogolludo 1954; Motolinía, 1950; Nuttall, 1903; see Landa in Tozzer, 1941, pp. 113–114). Lancets are often portrayed in bloodletting rituals depicted on Mexican and Maya codices, Maya



Stone Tools in Mesoamerica: Flaked Stone Tools, Fig. 9 The indirect percussion technique (Illustration by Karen Andrews. Used with her permission)

monuments, and polychrome vessels. As an act of auto-sacrifice, this practice was essential for appeasing the gods by providing them with blood nourishment.

Silhouettes, usually referred to as “eccentrics,” were also made from pressure blades and occur in a variety of shapes including crescents and trilobal sections (Fig. 12f–h). Here, the term silhouette is preferred to eccentric because the latter literally means “without symmetry” – most of these artifacts have symmetry and should be referred to by terms more specific to their morphological, technical, and functional attributes (Alejandro Pastrana, personal communication, 2014). Pressure blade silhouettes may have functioned as ornamental elements, perhaps signifying social status, which were sewn on articles of clothing (Spence, 1996). Their symbolic significance is supported by their relatively high frequency in burials and ritual cache deposits.

The end by-product of the blade-making sequence was the exhausted pressure core, often measuring no more than 1.5 cm in diameter (Fig. 11). At some sites like the Aztec city of Otumba (Otis Charlton, 1993) and the pre-Aztec city of Xochicalco (Fig. 1), lapidary craftsmen used exhausted cores to make beads (Fig. 13). The slender cores were fractured into sections using bipolar percussion and then ground and polished to perfection.

Mesoamerican Biface Technology

Biface flaking techniques were used to make impressive biface and uniface items for domestic, military, and ideological purposes. Although probably made by individual households early on, by the Classic period (AD 300–900), many of these implements were being made in specialized workshops at the quarries or in the cities. One important utilitarian uniface artifact in Central Mexico was the maguey scraper (Fig. 14). The maguey plant (*Agave atrovirens*) was a valuable source of water, food, fiber, and fuel, among other things (Evans, 1990; Sauer, 1963; Sheehy, 2001). Near Teotihuacan, large maguey scrapers at the Aztec (AD 1350–1520) period site of Cihuatecpan were made of relatively coarse obsidian from the source of Otumba (Fig. 1). Maguey scrapers were used to process maguey fibers and to initiate the flow of a sticky liquid that was converted into a fermented drink called *pulque*. Evidence suggests that pulque was a valuable source of nutrition and potable liquid in large cities like Teotihuacan where sanitation was a serious problem (Sheehy, 2001, p. 265).

Large, impressive bifaces were used for combat and also may have had symbolic significance given the central importance of warfare, conquest, and human sacrifice that emerged during the Classic period (AD 300–900) (Fig. 15). These items occurred in many forms. At Teotihuacan (AD 100–650), evidence has indicated that the large atlatl points for the city’s army were made by craftsmen under the direction of state officials (Carballo, 2004, 2007). During the Epiclassic period (AD 650–900), evidence suggests that

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 10 Gene Titmus removing pressure blades using an Aztec *itzcolotli* (Photos by James Woods. Used with his permission)



numerous biface workshops in and around Teotihuacan may have supplied many consumers in the region and beyond (Andrews & Hirth, 2006, p. 249; Nelson, 2009, p. 160).

Like the small silhouettes made from pressure blades, the contexts in which their large counterparts are found indicate that they had symbolic significance (Gamio, 1966; Moholy-Nagy, 1989; Stocker & Spence, 1973). At Teotihuacan, some of the most impressive examples are the anthropomorphic silhouettes (Fig. 16). Other impressive pieces combine multiple symbols into one implement, such as a projectile point, a serpent, and a trilobal motif signifying blood droplets (Fig. 17). Many of these items were undoubtedly associated with warfare and sacrifice because they are often recovered in offerings with human sacrificial victims decorated as warriors.

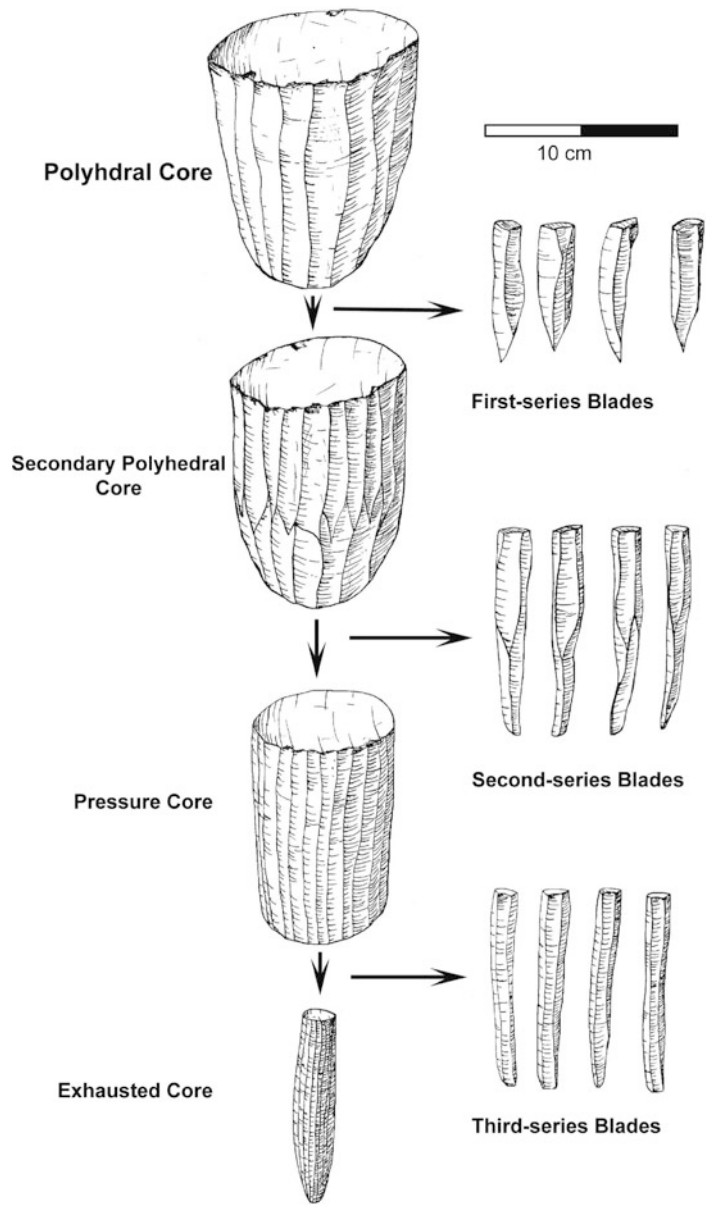
At Xochicalco, ten impressive silhouettes were found atop the site's major public pyramid.

They occur in several forms including circular uniface elements (Fig. 18). These artifacts were either used during public rituals conducted for the benefit of the masses or were the contents of dedicatory caches buried during the construction of the pyramid.

The stone tool technologies prevalent in pre-Hispanic Mesoamerica varied over both time and space. This discussion has provided a cursory overview of the flake stone tools prevalent from Paleo-Indian period (prior to 7200 BCE) until the Spanish conquest in the early sixteenth century. The Mesoamerican blade technology was the most important, enabling the production of prismatic blades that were further shaped into different types of tools. Overall, flaked stone tool production in Mesoamerica provided a remarkable variety of highly functional implements used for a variety of activities.

**Stone Tools in
Mesoamerica:
Flaked Stone Tools,**

Fig. 11 Schematic
diagram of pressure blade
production (Illustration by
the author)



Extra: Obsidian in Mesoamerica

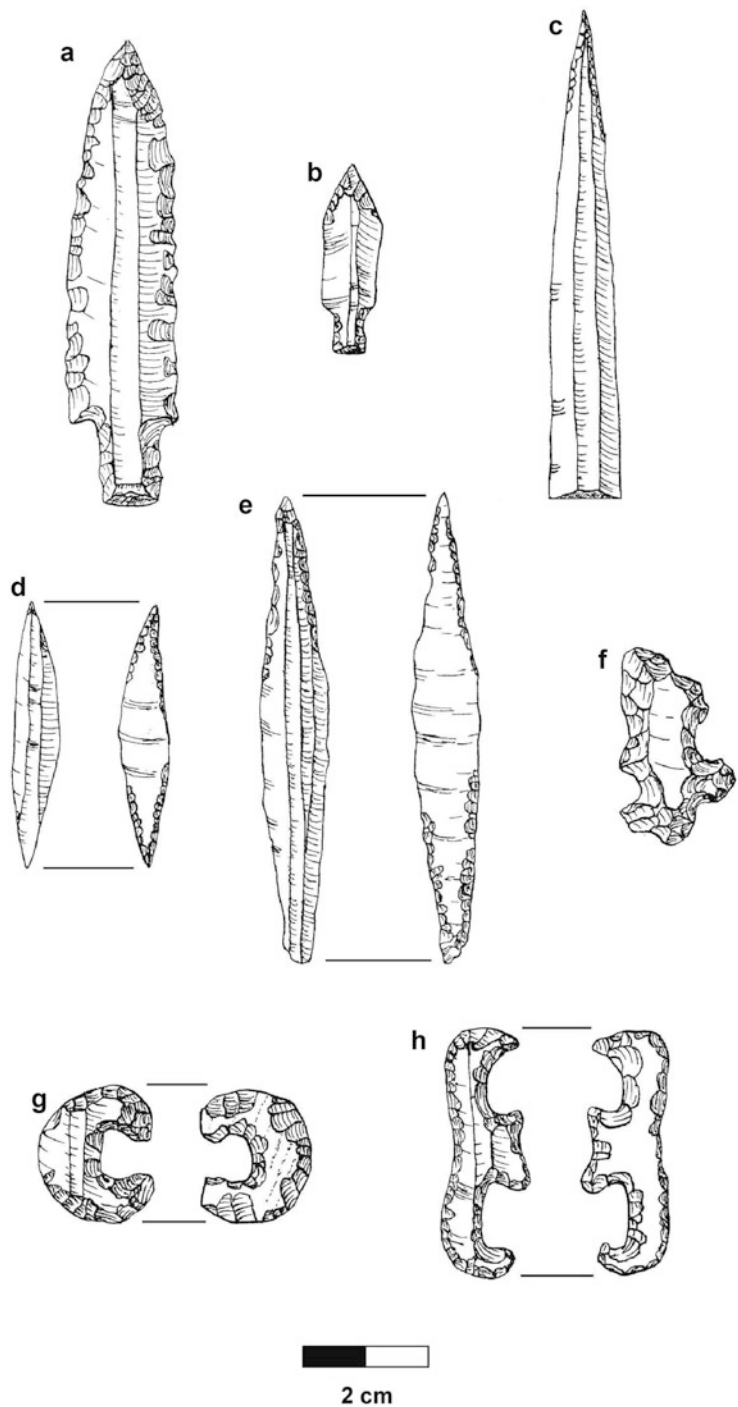
Obsidian is an igneous stone that is often described as “volcanic glass.” This siliceous material is created by the extremely rapid cooling of volcanic ejecta, a process that prevents the formation of crystalline structure. Obsidian is very smooth and glassy to rough or grainy in texture and is usually black to gray in color, but

it also can be red, brown, green, silver, and aqua-marine. This variation in color is the result of chemical impurities. Obsidian occurs in block or tabular form in large veins or as isolated chunks and cobbles in flows of volcanic material. It can also be found on talus slopes or alluvial streambeds in a “weathered” cobble form. Having eroded out of primary geologic context, the weathered cobble

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 12 Specialized tools made from pressure blades at the site of Xochicalco: (a, b) projectile points; (c–e) lancet blades; (f–h) silhouettes (Illustration by author. Property of Kenneth Hirth. Used with his permission)



surface exhibits tiny cones or fracture planes that are produced by rolling action. Obsidian is easy to work with because of its noncrystalline structure, and it produces an extremely sharp cutting

edge. One disadvantage of obsidian is that it is brittle, so that tools and tool edges can break more easily than other flakeable stone like chert and flint.

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 13 Beads in progress from the elite zone of Xochicalco, Mexico. Inset (Illustration by Luis Gonzalo Gaviño, property of the author)



Stone Tools in Mesoamerica: Flaked Stone Tools,

Fig. 14 Turtleback maguery scraper from the Aztec period Teotihuacan Valley (Photo by Susan Evans. Used with her permission)

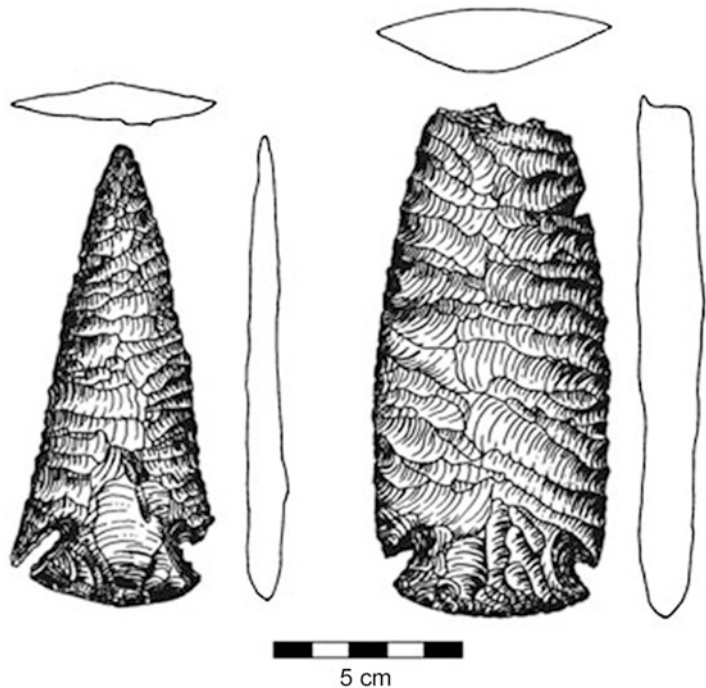
Throughout most of Mesoamerica, obsidian was the primary raw material used to make flaked stone tools. In the region, obsidian flows are found in two major zones of geologically recent volcanism (Glascok, Elam, & Cobean, 1988). One major zone is an east-west trending band of sources scattered from the state of Veracruz on the Gulf of Mexico to the western state of Michoacán bordering the Pacific Ocean; well-known sources in this zone include Pico de Orizaba, Zaragoza-Oyameles, Sierra de las Navajas (Pachuca), Otumba, Zacualtipan, Ucareo, Zinapécuaro, and La Mora/Teuchitlan (Fig. 1). The southern zone is located in Guatemala, El Salvador, and western Honduras; well-known sources in this zone include Jilotepeque, El Chayel, Ixtapeque, and Esperanza (Fig. 1).

Studies of obsidian artifacts from archaeological sites using techniques such as instrumental neutron activation analysis (INAA), X-ray fluorescence (XRF), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) have revealed that large quantities of these materials were transported across the landscape. By tracing the distribution of different sources, archaeologists have been able to reconstruct routes of obsidian trade and transport and how

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 15 Large biface projectile points from the site of Xochicalco (Illustration by Luis Gonzalo Gaviño. Property of the author)



Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 16 Anthropomorphic figurine from Teotihuacan (Photo from the Proyecto Pirámide de la Luna. Used with the permission of Saburo Sugiyama)



they changed over time (Asaro, Michel, Sidrys, & Stross, 1978; Boksenbaum, Tolstoy, Harbottle, Kimberlin, & Neivens, 1987; Braswell & Glascock, 1998; Cobean, Vogt, Glascock, & Stocker, 1991; Glascock, Elam, & Aoyama, 1991, 1994, Glascock, Neff, Stryker, & Johnson, 1994; Hirth, 2008; Knight & Glascock, 2009; Moholy-Nagy, 2003; Nelson, 1985).

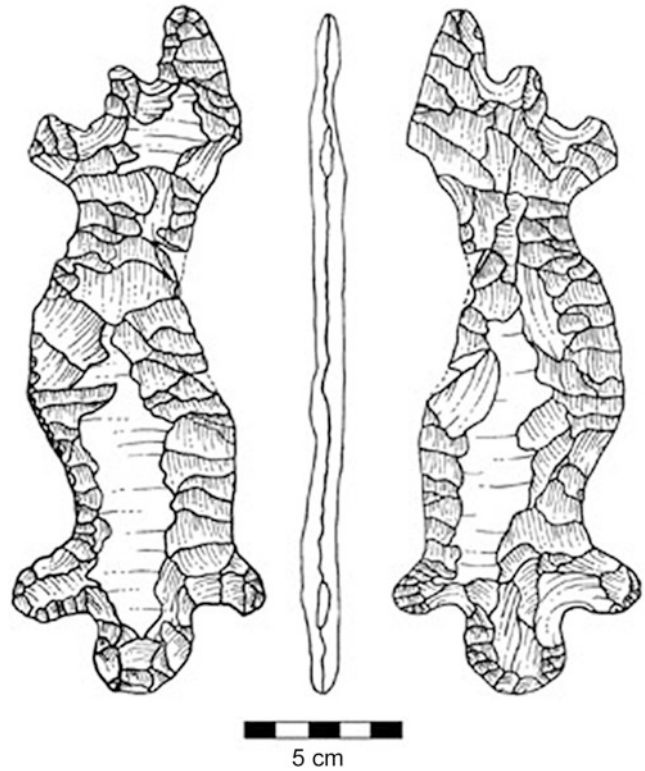
Extra: The Ideological Significance of Obsidian

Thus far, comparatively little attention has been given to research on the ideology related to obsidian flaked stone tool production. Ideology or belief systems are the most challenging for the archaeologist to reconstruct. But, the general theoretical perspective embraced by many archaeologists posits that technological and economic features of a society are linked to ideological aspects of culture (Erickson & Murphy, 2008). Even though obsidian provided essential tools,

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 17 Bifacial composite silhouette from an offering found in the Moon Pyramid at Teotihuacan. This artifact combines projectile point, serpent, and trilobal blood droplet elements in its design (Illustration by David M. Carballo. Used with his permission)



Stone Tools in Mesoamerica: Flaked Stone Tools,
Fig. 18 Crescent silhouette from Xochicalco (Photo by author)

it also had an extremely complex symbolic conceptualization in ancient Mesoamerica.

Often mined underground, obsidian was associated with the underworld, the land of the dead, and other valuable resources like water and precious metals (Pastrana, 1998, pp. 174–189). The Aztecs believed it was created when a bolt of lightning (male symbolism) struck a sacred cave (female symbolism) and thus represents a product of the union of heaven and earth. It had a similar origin story for the ancient Maya and was considered the Heart of the Earth (Heyden, 1988, p. 220). Human use of this sacred stone took on numerous forms of ritual significance. For example, warriors fought with weapons of obsidian, which meant they were metaphorically the ones who “carried divinity with them.”

One important god in the Aztec pantheon was *Tezcatlipoca*, who embodied four aspects represented by different colors, each one patron of a different part of the universe (Solís, 1994,

p. 185). Black Tezcatlipoca was related to the underworld, sacrifice, and of course obsidian, and his idols in the main temples were made of this material (Heyden, 1988, p. 222; Pastrana, 1998, p. 179). Associated with the night, sorcery, and warfare (Berdan, 2005), he was arguably the most respected and powerful of all the gods (Heyden, 1988, p. 222). Tezcatlipoca was the protector of rulers and ensured their strength – he spoke to the people through their rulers. Another symbol associated with Tezcatlipoca was the obsidian mirror, which had divinatory properties. Tezcatlipoca was referred to as Smoking Mirror, depicted with one on his forehead and his right foot. The obsidian mirror provided him with a reflection of everything that took place in the world.

Another prominent Mesoamerican deity was *Itzpapalotl*, the Obsidian Butterfly, an ancient goddess married to the hunting god *Mixcoatl*, revered by the Aztecs as a warrior who led soldiers into battle (Heyden, 1988, p. 220). Moreover, she and her obsidian knife were symbols for human sacrifice. Her title and importance may have been related to the belief that warriors who died in battle returned as butterflies.

A deified form of the Aztec sacrificial obsidian knife was the god *Itztli*, one of the nine principle gods of the Underworld. As such, the obsidian knives, at least those used for sacrifice, were considered supremely divine symbols of blood sacrifice, a practice that was essential for maintaining the stability of the Mesoamerican universe. Also, *Itztli* may have been the *Nahuatl* (language of the Aztecs) word for obsidian blades and is the prefix for the name of the prismatic blade removal tool (*Itzcolotli*) referred to in the text above.

The entire sequence of obsidian stone tool production and use also was associated with different gods (Pastrana, 1998, p. 190). Aztec miners who obtained obsidian from underground quarries were protected by the god *Ehecatl-Quetzalcoatl*. This god was associated with fertility and water, which was considered a resource that emanated from the underworld via the springs and caves of mountains. Interestingly, a sculpture of *Ehecatl-Quetzalcoatl* was

recovered from one Aztec mine at the Sierra de las Navajas (see Fig. 1) quarry in Central Mexico (Pastrana, 1998, p. 192). Craftsmen involved in the initial shaping of obsidian blade cores and bifaces at the quarries were protected by *Itzpapalotl*. Besides sacrifice, she was also associated with mother earth and possibly the mythical origin of obsidian (Sullivan, 1972). City-based craftsmen who further shaped obsidian implements were associated with *Papaloxahual-Xochipilli*. This deity was patron of the arts and perhaps craft guilds, especially those that produced sacred items like obsidian mirrors (Pastrana, 1998, p. 190). Not surprisingly, those involved in military activities were under the protection of Tezcatlipoca and *Itzpapalotl*, who was often depicted on the shields of warriors.

The symbolic significance of obsidian was extremely complex, and this brief summary provides a glimpse of how an important facet of material culture was tied to, or otherwise justified by, Mesoamerican ideology. Clearly, our understanding of this topic comes largely from ethnohistoric accounts of the Aztecs and Mayans recorded around the time of the Spanish conquest. The gods and symbols, however, have much greater time depth. Although we cannot assume the meanings were exactly the same for earlier societies like the Toltecs and Olmecs, ethnohistoric data and the archaeological context of artifactual symbolism can be used to infer the meaning of the latter. This realm of study is limited, but it represents an exciting new research focus that scholars are beginning to examine with greater interest (Levine & Carballo, 2014). It is important because it adds to our holistic understanding of ancient societies, a hallmark of anthropological archaeology.

Extra: Origins of the Mesoamerican Blade Technology

Hirth and Flenniken (2002, p. 123) have pointed out that research on the origins of the Mesoamerican blade technology has been limited. Initially emerging during the Middle Preclassic (900–300 BCE), by 700 BCE prismatic blades had become

the primary flaked stone tool from the Central Highlands to the Chalchuapa area of El Salvador (Aoyama, 1994, p. 174; Clark & Lee, 1984; Coe & Diehl, 1980, pp. 247–249; Grove, 1974, p. 33, 48; Marcus & Flannery, 1996; Pires-Ferreira, 1975, Table 5; Sheets, 1978b, Tables 3 and 5; Sweeney, 1983, p. 619).

William Parry (1994) and John Clark (1987) are two researchers that have addressed the emergence of this technology from a largely theoretical perspective. Their views are somewhat complementary, but they emphasize different factors. Parry (1994) suggests that the principal motivating factor may have been a demand for the production and exchange of many uniform, standardized implements. A blade technology enables such outputs, but a relatively high level of skill is required to make large batches of standardized blades efficiently. Hence, an increasing demand for blades during the Middle Preclassic created a need for blade-making craftsmen. These specialists supported themselves, at least in part, by exchanging blades at the regional and perhaps interregional level. He further notes that many blade workshops are found in large settlements with monumental architecture, sometimes quite distant from obsidian sources. Parry (1994, p. 94) tentatively states that this evidence may indicate that early craftsmen were attached or sponsored by the ruling elites in these large settlements.

Clark (1987) suggests that the widespread adoption of the Mesoamerican blade technology was related to the competitive elite behavior associated with ranked or chiefdom societies. These societies differed from the Archaic foraging groups (7200–2500 B.C.) in that people lived in larger sedentary communities that were socially hierarchical. Clark (1987) maintains that there was no real technological advantage to a blade technology because the expedient flake tools made during the Archaic period were functionally adequate. Moreover, the Mesoamerican blade technology required specialized training because it was difficult to learn. It also required the coordination of core production at the source and the transport of cores to the settlements where they were reduced. Consequently,

Clark (1987) suggests that the adoption of the Mesoamerican blade technology was complex enough to require the sponsorship of the elites who ruled the Preclassic ranked or chiefdom societies. Accordingly, these elites financed and organized the acquisition, production, and distribution of cores to blade-making craftsmen in large settlements.

Many researchers have debated various reasons why blade technologies arose in different space and time throughout the world. The Parry (1994) and Clark (1987) models for the emergence of Mesoamerican blade technology cannot be used to explain the adoption of blade technologies in societies that were less complex than chiefdoms (Hirth & Flenniken, 2002). World-wide examples include the Paleolithic and Neolithic blade technologies of Europe, Asia, and North Africa (Inizan & Lechevallier, 1990; Pelegriin, 1997; Tixier, 1976), the Paleolithic microblade technologies of Siberia and Japan (Flenniken, 1988; Kobayashi, 1970), and the microblade technologies of North America (Andrefsky, 1987; Arnold, 1985; Bradley & Yevgeny, 1996; Magne, 2004; Morrow, 1988; Parry, 1994; Rasic & Andrefsky, 2001; Reid, 1976; Yesner & Pearson, 2002). These societies ranged from highly mobile to relatively settled groups who probably never attained the level of social complexity typically associated with chiefdoms.

The adoption of blade tools in northwestern North America may relate to functional aspects of the technology (Yesner & Pearson, 2002). This argument recently summarized by Magne (2004, p. 94) states that microblades were a “response to any of several possible causes, such as lithic raw material shortage alleviated by efficient blade production, preference for composite slotted armaments, or resource uses for which microblade design is most efficient, such as slicing, peeling, piercing...” It has also been suggested that blade technologies may be best suited to societies where the tasks involved in food acquisition or production (subsistence tasks) were predictable (Rasic & Andrefsky, 2001, p. 77). Here the manufacture of standardized blade “replacement” parts for tools

repeatedly used for the same tasks would be technologically efficient.

The development of craft specialization and exchange (Parry, 1994) and the competitive elite behavior associated with emerging chiefdom societies (Clark, 1987) may have played a role in the adoption of the blade technology in some places of Mesoamerica. However, new empirical evidence from the Olmec site of San Lorenzo (Fig. 1), arguably the first large-scale Mesoamerican community with monumental architecture, indicates early blade production was independent of elite involvement (K. Hirth & A. Cyphers, personal communication, 2014). Its inhabitants had relatively equal access to obsidian, and the only evidence for blade production is found on the periphery of San Lorenzo Island, a great distance from San Lorenzo's elite-controlled center. Hence, if elites were not initially involved in the emergence of this technology, the functional argument that blades are better for economies with predictable subsistence tasks deserves consideration. The Mesoamerican Preclassic period (2500 B.C. – A.D. 300) was associated with a profound shift from small-scale foraging societies to larger settled chiefdom societies. Hence, compared to the nomadic foraging lifestyle during the Archaic period, the daily tasks associated with settled agricultural economies during the Preclassic were certainly more predictable because they were tied to the strict seasonal cultivation of specific crops. Moreover, the patchy distribution of obsidian across the landscape would have made a blade technology more effective for supplying the needs of large settlements with tools from distant sources. Craft specialists producing highly standardized blades for specific tasks would have been able to efficiently meet the needs of very large settlements.

Extra: Measuring the Skill of Ancient Blade-Making Craftsmen

In ancient Mesoamerica, obsidian blades were made by specialized craftsmen. Some researchers have attempted to measure the skill of these craftsmen as a means for identifying how much

time they devoted to blade-making activities (Andrews, 2003, 2012; Clark, 2003; Clark & Bryant, 1997; Hirth & Andrews, 2006). Defining the time spent making blades is important because it helps archaeologists infer how many blades were in demand and how much economic exchange there was between members of an ancient society. This kind of information reflects the complexity of a society's economy. Unlike the modern world where everyone specializes in a particular job, most prehistoric societies were primarily composed of people who provisioned themselves with all their daily needs. As societies became larger, people began to specialize in different occupations and exchanged their products for things they did not produce. Hence, the level of specialization in a society is a measure of economic interdependency (Durkheim, 1933).

Measuring craftsman skill is founded on the assumption that aptitude should vary according to the amount of time invested in blade production; in other words, highly skilled craftsmen should be those who made the most blades. Essentially, this assumption is based on the premise of practice makes perfect.

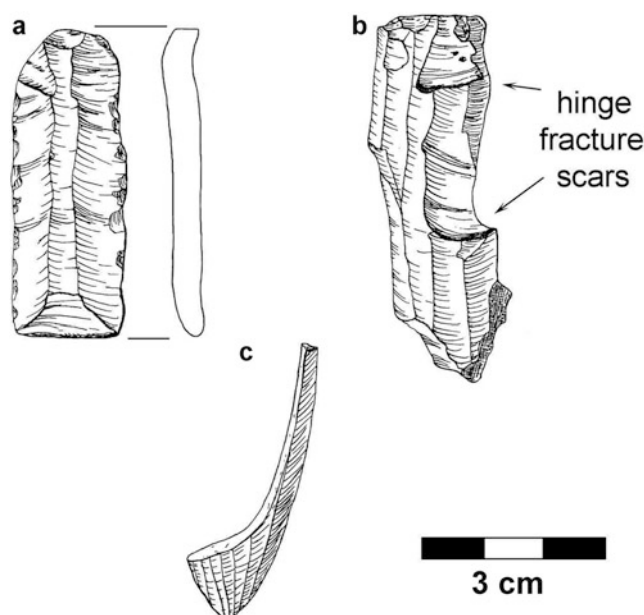
Measuring the skill of ancient blade-making craftsmen in Mesoamerica is quite a challenge. The one advantage to studying flaked stone artifacts is that they are made with a reductive technology. That is, flaked stone tools are shaped by reducing or removing pieces of stone from a larger stone until the desired form is achieved. The pieces that are removed are called by-products. Careful study of the by-products of Mesoamerican blade production has made it possible to identify those artifacts that are mistakes, items that represent one means for measuring craftsman skill.

Mesoamerican blade craftsmen usually made blades in household workshops. Several artifacts found at these workshops have been identified as mistakes; these items include the hinge-fractured blade and the plunging blade. A hinge-fractured blade is a blade that failed to extend all the way to the bottom of a core. The distal end of a hinged blade has a fracture plane that curves outward from its ventral to dorsal surface (Fig. 19a). These artifacts are mistakes because the

Stone Tools in Mesoamerica:

Flaked Stone Tools,

Fig. 19 Hinged and plunging artifacts from the site of Xochicalco: (a) hinged blade section; (b) core exhibiting severe hinge scars; (c) plunging blade section (Illustration by the author. Property of Kenneth Hirth. Used with his permission)



craftsman's intent was to remove a blade that extended the entire length of the core. Also, hinged blades leave behind a deep scar that inhibits the removal of subsequent blades from that part of the core (Fig. 19b).

A plunging blade removes the distal tip of a core. In contrast to the hinge fracture, a plunging blade's ventral surface curves inward at the bottom of the core thereby removing more core length than intended (Fig. 19c). This mishap reduces the length of subsequent blades, thereby reducing the overall amount of cutting edge that can be produced from a core. The forces resulting in the production of these mistakes are described in detail elsewhere (Andrews, 1999, 2003; Clark & Bryant, 1997; Santley, Kerley, & Kneebone, 1986; Sheets, 1978b).

It has been suggested that the frequency of mistakes in a collection of by-products should be useful for measuring the skill of flaked stone tool craftsmen (Clark, 1986, 2003; Sheets, 1975, 1978b; Torrence, 1986, p. 147). Consequently, comparisons of hinged and plunging blade frequencies from Mesoamerican blade workshops have been used to make comparative assessments of skill. Workshops with the highest level of skill have the fewest errors.

Preliminary assessments of craftsman skill at the immense Classic period (AD 100–650) city of

Teotihuacan and the smaller Epiclassic (AD 650–900) city of Xochicalco indicate that Teotihuacan's craftsmen made fewer mistakes (Andrews, 1999, 2012). Hence, based on the assumption that skill varied in relation to time spent in production, it appears that Teotihuacan's craftsmen made and exchanged more blades than the craftsmen at Xochicalco. This finding fits previous characterizations of Teotihuacan's economy as being highly complex, with many specialists throughout the city dependent to a significant degree on nonagricultural production for their livelihoods. In contrast, Xochicalco's economy appears to have been less complex, with more limited evidence of craft production and economic interdependence (Hirth, 2000). In this way, measuring the skill of flaked stone tool producers has contributed to supporting earlier inferences about economic complexity.

Extra: The Pecked and Ground Core Platform

Another source of variation in the Mesoamerican blade technology was core platform treatment. Sometimes single-facet platforms were pecked

and ground, creating a flatter, slightly rough surface. This type of platform became widespread during the Postclassic (AD 900–1519) period, but it emerged in the preceding Epiclassic (AD 650–900) period and perhaps was present even earlier in some areas of Mesoamerica. The pecking and grinding of platforms took place during different phases of the reduction sequence throughout the region. For example, at Tula (Fig. 1), the capital of the Toltec empire, platforms were pecked and ground at the macrocore stage, whereas at Xochicalco, an Epiclassic (AD 650–900) city, they were pecked and ground on small, already partially reduced prismatic cores.

The pecked and ground platform modification made blade removal easier for two reasons. First, the tiny fracture cones produced during the pecking stage made blade removals easier. Experiments indicate that less pressure force is needed because the tiny microfractures help to facilitate a macrofracture, permitting successful blade removal. This outcome of the process was extremely important, especially at sites like Epiclassic (AD 650–900) Xochicalco where blades were detached by hand from very small (>8 cm in length) prismatic cores (Flenniken & Hirth, 2003). Experiments have demonstrated that it is difficult to generate enough force with the handheld technique to produce successful blades using cores longer than 8 cm in length. Second, the pecked and ground surface reduced the risk that the pressure tool used to remove blades would slip off the platform. This outcome aided the craftsman in the precise application of force.

Extra: The Bow and Arrow in Prehistoric Mesoamerica

The date when the bow and arrow became prevalent in prehistoric Mesoamerica is still a subject of debate. The established date for the introduction of the bow in North America is sometime around AD 200, much earlier than what is generally accepted for Mesoamerica. Citing a lack of archaeological and iconographic evidence for the

bow, Hassig (1992) has suggested that it did not become common in Mesoamerica until the Postclassic (AD 900–1519) period. Other researchers, however, have suggested that the bow was present during the Classic (AD 300–900) period (Linné, 1934) or perhaps even earlier during the Preclassic (2500 BCE–AD 300) period (Tolstoy, 1971).

One reason for believing the bow was common in Mesoamerica prior to the Postclassic period is the presence of small projectile points (>3 cm in length, Fig. 12b) at many sites predating AD 900. Many of them were fashioned out of prismatic blade sections that were made with pressure. The use of these implements as effective tips for spears or *atlatls* (spear throwers) is hard to imagine because they are so small. Indeed, research indicates that many *atlatl* points average over 4.5 cm in length (Thomas, 1978, p. 469). As a result, it has been suggested that small points found in mortuary offerings at Classic period Teotihuacan may have had a ceremonial or ideological significance (Parry, 2002).

Although small points predating the Postclassic period may have had a ceremonial function, research at the Epiclassic (AD 650–900) city of Xochicalco suggests that such items were used to tip arrows (Andrews & Hirth, 2006). This conclusion supports earlier claims that the bow was present at Epiclassic Xochicalco (Sáenz 1961, pp. 40–43, 1967, p. 10, 14) and at the contemporary site of Cacaxtla (Fig. 1) in the modern state of Tlaxcala (Baus de Czitrom, 1986, p. 529). Most of the small points at Xochicalco have been found throughout the city in nonceremonial contexts. In addition, they comprise the entire collection of projectile points ($N = 83$) recovered in the city's public armory. Hence, there is little doubt that these points were used to tip arrows, and given the central importance of militarism and conquest at Xochicalco, they were probably used for combat.

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Stone Transport of the Olmec

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The legacy of large stones left by prehistoric societies has often led to debate, conjecture, and speculation that link cultural or belief imperatives to structural form and using materials moved from sometimes distant sources. Our uncertainty extends to explaining how ancient people moved these large stones or megaliths weighing many tons, using simple tools in contrast to today's modern equipment. Limited archaeological evidence encourages debate, and even when there is visual evidence, differing arguments and interpretations can be raised (Photo 1).

In Mesoamerica, stones moved by Olmec society during Preclassic times posed such a question, with megaliths, most weighing between 5 and 20 t, transported a distance of at least 80 km. The source for the stones included Cerro Cintepec near the Tuxtla Mountains in Veracruz state of modern Mexico. Besides the stones themselves, little archaeological evidence was available to understand or explain the transport process. The larger stones were used for sculptures known as *cabezas colasales*, or colossal heads, and also altars, and thrones with many smaller stones were used for other sculptures. The more likely method was considered to be water transport using a combination of sleds and raft configurations made of canoes or logs. Direct land routes held challenging obstacles of seasonally fast flowing rivers, extensive swamps, and floodplains and so were discounted (Fig. 1).

More recently this view of water transportation has been challenged, suggesting land transport was not only possible, but is in fact the more likely method. This research used a different research methodology and database of watercraft performance and behavior under load in seagoing conditions. These data were applied to human capability and physiology. To examine land

transport, analytical tools available with GIS technology were adapted to study the question. The parameters for this aspect of the study also utilized human physiology data. In doing so, the methodology overcame the limited application of replication experiments and has shown that applying this approach to existing data provides useful outcomes.

San Lorenzo Olmec and Stone Heads

When introducing the Olmec, researchers often refer to the Olmec as the “mother culture,” a title that is debated. What is not disputed is the Olmec “heartland,” a sphere of influence some 200 km long and 80 km wide (125 × 50 miles). At its heart during the period between 1200 and 900 BC known as the Preclassic was the San Lorenzo (SL) plateau, the political hub. Situated some 60 km (38 miles) from the Gulf of Mexico, the SL plateau is a partly man-made ridge around 1,200 m long and rising some 45 m above the extensive floodplains and swamplands, characteristic of the Rio Coatzacoalcas basin. Its position and elevation make the plateau a dominant feature over this area, underwritten by the agriculturally productive floodplains that supported the general population and its hierarchy comprising artisans and rulers. The latter resided exclusively on the SL plateau and initiated the manufacture of the stone and jade objects, found not only on the plateau but also elsewhere in the region. Jadeite was sourced from distant sites by trade or exchange, but volcanic stone was used for the larger sculptures including the colossal heads. These are apparently the likeness of different rulers, conferring value on the stone used, with at least one head originally an altar. Such value underwrites the need for a viable transport process and a favorable agricultural situation nurturing manpower resources required to transport the stones and carve the heads.

An early and valuable study by Velson and Clark (1975) established specific transport elements of water transport, including raft types, manpower needed, and possible routes. However, testing this work with updated analytical

Stone Transport of the Olmec, Photo 1 Colossal head at Xalapa Museum of Anthropology:
L. Hazell 2008



Stone Transport of the Olmec, Fig. 1 Hypothetical water transport routes (Drawn by L. Hazell 2008)

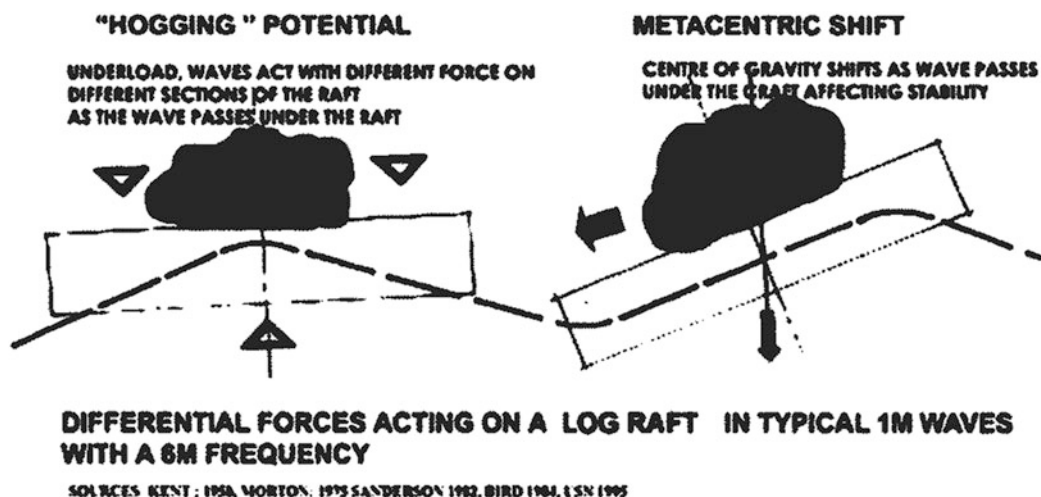


techniques, adopting environmental and maritime data as parameters, and applying them to human physiology subsequently redefined Olmec stone transport, in particular the unlikely use of open water routes and methods (Fig. 2).

The methodology determined prevailing wind speed and direction generated a wave size, frequency, and speed that would overcome canoe raft configurations, while ocean surface currents would be in excess of the ability of hypothetical Olmec crews to make progress. This power constraint also occurs traveling upstream to the SL. Increasing crew numbers would not overcome this nor would using known sail

configurations. The question of viable progress against current flows in both situations was even more pronounced with log rafts. As water transport was not practical, the previously dismissed land routes were reinvestigated.

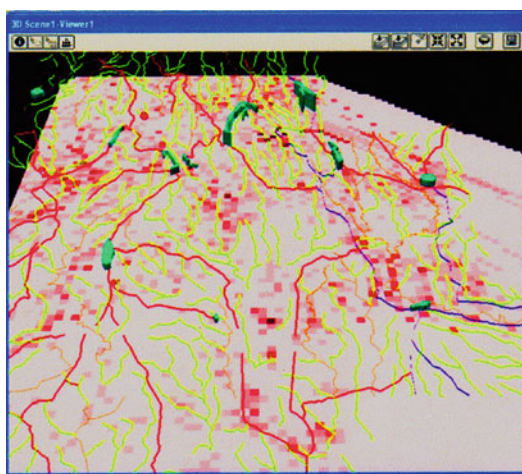
The challenge of the Olmec heartland terrain, in particular swamps, floodplains, and gradients, were constraints adopted as parameters. In practical and viability terms, these translate into the need of human power (drafting animal power was not a fact of Olmec life) and ingenuity to overcome, particularly to haul or control stones on slopes. In addition soils must be capable of bearing the load of the stones or at least being changed



Stone Transport of the Olmec, Fig. 2 Differential Forces. Drawn by L. Hazell 2008

so they could the required load. Human power is known from experimentation and replication. Ethnohistoric examples provide further data as well as an insight into possible methods. These examples show, as a parameter, a gradient value of 1:10 adopted in analysis defines human numbers needed for control and whose combined power can be effectively coordinated. Adopting these and a terrestrial database established by digitizing Instituto Nacional de Estadística y Geografía (INEGI) survey maps and using slope gradient analysis defined viable land routes within a corridor that also included a known workshop at Llano del Jicaro. Quarry sites were also included in this corridor even though the stones were not quarried in the accepted sense (Fig. 3).

The analyses also provided a starting point for pathways to cross the floodplains and swamp areas and ultimately access the SL plateau. These areas are seasonally inundated making crossing them apparently implausible. However, laboratory testing of soils found on the plains and tested as wet and dry samples was compared with both causeway and natural levee core samples. The results indicated the bearing capacity of the predominant alluvial silts (Barro Veteado) while theoretically a constraint to viable transport crossing, would not be so in reality.



Stone Transport of the Olmec, Fig. 3 Geographic information systems (GIS) slope gradient analyses: L. Hazell. Deep red pixels indicate steep gradients: modern roads generally follow lesser gradients indicated by pale pixels

The differences between wet and dry resistance suggested that a seasonal constraint on transport would apply though (Fig. 4).

This constraint could be overcome. Structural examples demonstrated that the Olmec were accomplished earth builders, possessing the knowledge to construct durable structures such as the San Lorenzo and Tenochtitlan plateaus,

TIPO DE	ESTADO DEL	ENSAYE	CARGA	AREA	PESO VOLUMETRICO WEIGHT	RESISTENCIA	RESISTENCIA
SUELO SOIL TYPE	ESPECIMEN STATUS OF SPECIMEN	TEST	LOAD		MAXIMO MAXIMUM	A COMPRESION COMPRESSION RESISTANCE	A COMPRESION COMPRESSION RESISTANCE
			(kgf)	cm2	kgf/cm ³	(kgf/cm2)	kPa
		1	196	25.13	2084	8	763
ARCILLA	HUMEDO WET	2	196	25.13	2083	8	763
		3	196	25.13	2084	8	763
			PROMEDIO AVERAGE			8	763
		1	3391	25.13	1846	135	13230
ARCILLA	SECO DRY	2	3391	25.13	1847	135	13230
		3	3384	25.13	1846	135	13205
			PROMEDIO AVERAGE			135	13221
		1	208	25.13	2119	8	813
ARENA	HUMEDO WET	2	228	25.13	2121	9	888
		3	196	25.13	2117	8	763
			PROMEDIO AVERAGE			8	821
		1	2240	25.13	1884	89	8742
ARENA	SECO DRY	2	2241	25.13	1883	88	8667
		3	2240	25.13	1883	89	8742
			PROMEDIO AVERAGE			89	8717
		1	208	25.13	1827	8	813
BARRO VETEADO	HUMEDO WET	2	215	25.13	1832	9	838
		3	208	25.13	1829	8	813
			PROMEDIO AVERAGE			8	821
		1	4068	25.13	1829	162	15872
BARRO VETEADO	SECO DRY	2	4094	25.13	1831	163	15972
		3	4094	25.13	1831	163	15972
			PROMEDIO AVERAGE			163	15939

Stone Transport of the Olmec, Fig. 4 Representative examples of wet/dry soil types with compressive testing results

S

earth mounds, platforms, and causeways. Modern civil engineering understands that structural deficiencies or durability limitations in soil properties can be overcome by mixing different soil types. From strata identified in known earth structures, the Olmec were apparently aware of this as well. The layering found in these structures combines soil of differing types and properties similar to that used on modern road building. This made earth structures a likely tool to move megaliths from the Tuxtla Mountains to San Lorenzo and

a logical application of strength or compressive resistance knowledge.

Yet even without applying this knowledge to causeways, silts found on the floodplains provided sufficient compressive resistance for their transport without using these additional materials. Nevertheless a constructed pathway of this soil is subject to seasonal conditions although without durability, a property not needed for singular or irregular megalith transport. Even so Olmec earth structure durability is clearly

Stone Transport of the Olmec, Fig. 5 Summary of soil strength calculations with applied megalith weight

Compression resistance of soil strata from lab tests:

Core 8 DRY: 12132kpa (average)

Core 8 WET: 124kpa (average)

$$\text{SL 1: weight 25.3 short tons} = 22947\text{kg} \times 73\% = \frac{39698\text{kg} \times 9.81}{6.58}$$

$$= 59.18\text{kpa}$$

$$\text{using a sled: } \frac{39698\text{kg} + 2034 \times 9.81}{2.49}$$

$$= 164\text{kpa}$$

Summary of soil strength calculations with applied megalith weight

demonstrated by the Potrero Nuevo causeway, on which the present-day village of Loma del Zapote is built.

Calculations using the laboratory data confirmed that a megalith transport process that involved sliding along the ground would not deform the soil, while a sled would do so, increasing resistance to hauling (Fig. 5).

By using these outcomes with slope gradient analyses, it was reasonable to assume that land transport was more likely, especially when this route held less risk than the uncertainty of watercraft performance and structural integrity in open waters. The same compressive resistance also defined methods to move the stones, as dragging the stones in contact with the path allowed the weight to be spread under the deformation level of the soil. Any other method such as a sled or using rollers to move stone around 20 t would exceed this point. Not all stones were this heavy though, and a method using a “y” frame for stones of around 1–2 t proved to be viable.

In refining Olmec stone-moving methods, the flattened rear of the heads appears to reinforce the notion of direct contact hauling. This shape allows stable hauling while minimizing deformation of the underlying road surface during the process (Fig. 6). Linking the combined power of the haulers is one further element in this equation, as rope is represented on the sculptures and known for the period. The numbers of haulers



Stone Transport of the Olmec, Fig. 6 Colossal head showing the flattened back: Xalapa Museum of Anthropology (Photo: L. Hazell 2008)

used varied depending on specific gradients and stone size, while the agricultural economy could support the numbers needed to haul megaliths.

These workers, combined with their artisan and Olmec hierarchal power, are components of Olmec megalith use and their transport, but a further element is the application of knowledge to build the structures that is still visible today. Research of the stone transport process with this methodology allows us to appreciate this knowledge.

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Stonemasonry of the Incas

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And what one admires most is that, although these [stones] in the wall I am talking about are not cut straight but are very uneven in size and shape among themselves, they fit together with incredible precision without mortar. (Acosta, lib. 6, cap. 14; 1962: 297)

Like Father Acosta in the seventeenth century, the modern traveler stands in awe before the Inca walls of huge stones, some weighing over 100 metric tons, tightly fitted together. They wonder about how people who did not know the wheel and had no iron tools transported and dressed stones of that size and mated them one to another in such a way that, as the saying goes, not even the blade of a knife could be inserted into the joints. Answers to these questions have been replete with speculations ranging from the intervention of extraterrestrial beings, the use of parabolic mirrors concentrating sunlight to cut the stone laser-like, to the application of an herb, the juice of which softened the stone, to the more prosaic investment of an immense labor force. Recent studies of Inca construction, however, demonstrate that the awe-inspiring, tightly fit megalithic masonry was well within the technological reach of the Incas (Protzen, 1985, 1986, 1993). It is to be hoped that the fantastic tales of extraterrestrial intervention will be put to rest once and for all.

Quarrying

The Incas did not practice quarrying in the proper sense. The stone is neither cut off a rock face nor is it detached from bedrock by undercutting. The Incas gained their building stone either by picking suitable blocks out of a rockfall or by prying it loose from fragmented rock faces. Large blocks of five or more tons were only minimally shaped in the quarries; all the fine work was done at the

construction site. Smaller building blocks were dressed on most sides in the quarries, and only the finishing and the fitting to other stones was reserved for the site.

The Incas chose the stones to be quarried with great care. Proper workability, texture, and color of the stone mattered a great deal. Rocks also had symbolic, even religious, significance for the Incas, which may explain why they often went far out of the way from a construction site, to quarry the appropriate stone. According to some chroniclers, stones from the andesite quarries of Rumicollca, some 30 km south of Cuzco, were not only used in the construction of Cuzco but were shipped all the way to Tomebamba in Ecuador, some 1,700 km to the north. Research by Dennis Ogburn (2004) lends credibility to this story: the petrological compositions of the stones at Tomebamba very closely match that of the stones from Rumicollca. To access the quarries and transport the stones, the Incas built well-engineered roads, 4–5 m wide. For example, to get a specific rose rhyolite for the so-called Sun Temple at Ollantaytambo and to reach the quarries of Kachiqhata, the Incas built enormous ramps, the total construction volume of which exceeded the volume of quarried stones by a factor of 40 or more. This is the price the Incas were willing to pay for a select stone.

Cutting and Dressing

To cut and dress stones, the Incas used simple river cobbles of various sizes as hammers. These tools and their fragments are found in abundance in the ancient quarries scattered among roughed out building blocks and in the quarrying waste. The hammerstones are easily distinguished from other stones by both their shape and their petrological characteristics; they are water-worn rounded stones of materials different from the quarried stone and the surrounding bedrock. The hammers come in different sizes; some are as small as an egg, others are the size of a football, and others still are two to three times the size of an American football. The largest of these hammerstones were used to break up and roughly

shape the raw stones, the medium sized to dress the faces of the building blocks, and the smallest to draft and cut their edges and corners. The technique involved is exactly as Garcilaso de la Vega “El Inca” described it: “The quarryfolks, . . . , who had no other instruments to work the stones, but some black cobbles they called *hihuana* (sic. for *hihuaya*), with which they dress the stones by bruising rather than cutting” (lib II, cap. XXVIII, 1976, p. 119, tomo I).

Indeed, when hitting the workpiece straight on with a hammerstone, one crushes the rock producing little more than dust. However, if one increases the angle of impact to about 15–20°, little chips can be torn off. By further increasing the angle to some 45° by imparting a twist to the hammer just before impact larger chips can be removed, thus accelerating the process considerably. The impact of the hammer leaves a small pitmark on the workpiece. Such pitmarks can be observed on every face of every building block in every Inca wall of cut stones, regardless of the building blocks’ material. Smaller, finer pitmarks found along the edges of the building blocks indicate that smaller stones were used to cut the edges. The particular technique in cutting edges requires that the edge be shaped by hitting the workpiece with grazing blows directed away from the workpiece, which results in corners with dihedral angles larger than 90°. It is these obtuse angles that account for the characteristic beveled joints of Inca cut stonemasonry and that brings about the *chiaroscuro* effect.

Extensive experiments have demonstrated that the process is relatively easy, effective and precise, and not as time consuming as one might assume. Twenty quarry people working side by side could dress a block 4.5 m long, 3.2 m wide, and 1.7 m high – the dimensions of one of the largest building blocks in the ancient quarry of Kachiqhata near Ollantaytambo – in less than 15 days.

Fitting

The most intriguing question about Inca cut stonemasonry concerns the precision fitting of

the blocks. It has been repeatedly argued that the Inca stonemasons ground the blocks into place using a mixture of sand and water. The evidence, however, does not support this hypothesis. Where walls have been dismantled or fallen apart, one finds the exact imprint of the stones which have been removed or fallen off. Very often the shape of the imprints determines a unique position for the stone it once accommodated. To grind in a stone, however, requires that the stone can move freely along a path in at least one direction. Thus, the ground stone would fit in any, and not just one, position along that path. Furthermore, if the stones had been ground into place, the joints should show signs of abrasion, but they do not. Instead one finds the typical pitmarks which result from pounding.

The imprints seen on dismantled walls indicate that when laying a wall, the Inca stonemasons left the top face of every new course uncut until it was to receive a new course. The bottom face of the block of the new course was cut first, and a suitable bed was carved out of the course already in place. A similar approach was used for the rising joints; it is the side of the block already in situ that was carved to match the pre-cut shape of its new neighbor. The technique used appears to have been one of trial and error. The masons started by outlining the shape of the new stone atop the course it was to be fitted to and proceeded to carve out a bed. By trying the fit time again and again, the masons obtained a perfect match. Granted, the trial and error technique is a tedious one and perhaps not very convincing if one considers megalithic building blocks of several dozens of tons. However, it works and does not postulate the use of tools and machinery of which no traces have been found. The Incas had plenty of time and manpower at hand. Since they moved huge blocks over many kilometers, it is not inconceivable that they were capable of setting up a stone several times to achieve the desired fit. It is of course also conceivable that the Inca stonemasons knew of another technique to transfer the shape of one stone to another without actually trying it in successive steps. Such a technique has in fact been proposed by Vincent Lee (1986). Inspired by log

cabin builders, Lee suggests that the shape of one stone was scribed onto the other with an ingenious but simple device consisting of a stick and a plumb bob. Although experiments have shown the technique to work, there is no evidence as of yet that the Incas actually used it.

Assemblage

When assembling a wall, the Incas often had several construction crews working simultaneously and side by side. Where two crews met in a course, the final gap in the wall was closed with a “wedge” stone introduced into the masonry bond from the front of the wall. Because in the last gap there is not enough room to maneuver the stones for the usual one-on-one fitting, the Inca stonemasons hit on the ingenious idea of the wedge stone that fits to its neighbors only along a very narrow band near the face of the wall. Once one knows what to look for, it is relatively easy to spot wedge stones in an Inca cut-stone wall and to determine its construction sequences. If scribing had been the predominant fitting technique, there would have been no need for wedge stones: even the last stone could have been scribed for a perfect match and lowered into place. But many wedge stones clearly were not lowered into the gap they were intended to fill, since they are generally wider at the bottom than at the top.

Transporting

Another vexing problem is how the Incas transported and heaved enormous building stones. Rough abrasion marks found on building blocks at Ollantaytambo suggest that the stones were simply dragged along the ground. From these marks it is even possible to determine the direction in which the blocks traveled. The dragging of big stones is consistent with chroniclers’ reports:

These Indians used to move very large stones with muscle power, pulling them with many long ropes of lianas and leaf fibers, . . . and they [the stones]

are so big that 15 yokes of oxen could not pull them” (Gutierrez de Santa Clara lib. 3, cap. 63, 1904–1929, p. 550). Dragging big blocks involves large transportation crews: “Four thousand of them were breaking stones and extracting stones; six thousand were hauling them with big ropes of hide and leaf fibers; . . . (Cieza de León cap. LI, 1967, p. 170)

Six thousand people dragging a stone is not unreasonable; many Old World transportation problems were solved with very large work forces. Engelbach (1923), for example, calculated that it would have taken 6,000 men to haul the unfinished obelisk at Aswan from the quarries to the Nile. The questions raised by a transportation crew as numerous as this, which remain largely unanswered, are how the crew was harnessed to the stones and how it negotiated turns on the narrow roads on the steep slopes of the Andes.

An experiment carried out in 1994 in the town of Ollantaytambo involved the dragging of a 14 metric ton heavy Inca building block a distance of about 150 m. One hundred and eighty-four people from the town, men and women, volunteered for the task. They were given no instruction regarding how the task had to be performed. They brought ropes, which they wrapped around the block like a net in such a way as to have six leading ropes extending from the stone in the direction it was to be pulled. The 184 people were distributed over the six leading ropes, which they grabbed and leaned into to drag the block the requisite distance with relative ease over a surface roughly equivalent to the roads from the quarries.

How smaller stones, like those from the quarries of Rumicollca, were transported remains uncertain. The general assumption is that the stones were either carried on litters or that they were suspended from poles carried on peoples’ shoulders.

To lift stone up onto a wall under construction, the Incas built ramps perpendicular to the wall and raised the ramps as the wall got higher. At Sillustani near Puno on Lake Titicaca, such a ramp leaning against an unfinished burial tower, called *chullpa*, can be seen today. According to the Jesuit priest Bernabé Cobo,

this practice was still in use in the construction of the cathedral in Cuzco. He reported that "... since they lacked cranes, wheels and engines to lift them [the stones], they made a steep ramp attached to the work over which they raised them; as the edifice was growing they raised the ramp; this device I saw in use at the cathedral of Cuzco that is being built; because the masons who work on this construction are Indians they let them ... use what they are accustomed to ..." (tomo II, libr. XIV, cap. XII, 1964, p. 262).

Antecedents

John Hemming argued emphatically that the high skills of the Inca stonemasons "cannot have been developed in the century or less of Inca ascendance. Architecture anywhere in the world evolves from precursors" (1980, p. 26). Here, the precedent is Tiahuanaco at the south end of Lake Titicaca, which reached its peak around 900 C-E. Tiahuanaco has some of the world's finest stonemasonry: carefully fitted rectangular ashlars [masonry made of large square-cut stones, typically used as a facing on walls of brick or stone] and exquisitely worked monolithic gates and statues. It is said that Pachakuti, the 9th Inca, was so impressed by this stonework when he first saw Tiahuanaco that he advised his architects to take careful note of how this masonry was made because he wanted Cuzco to be built in the same manner. It is also said that he imported Qolla laborers from the Lake Titicaca area to work on construction projects (Sarmiento de Gamboa cap. 40, 1943, pp. 111–112). But because Tiahuanaco culture developed at least a millennium before the Incas, and may have reached its peak some five to six centuries before Pachakuti's rise to power, and because nothing comparable has been built in the interim, one may question why the Qolla laborer should remember any of the ancient techniques. More recent research by Protzen and Nair (1997) shows that there exist significant differences between the architecture and stonemasonry of Tiahuanaco and that of the Incas, suggesting that,

although the Inca may indeed have been inspired by Tiahuanaco, their architecture and stonemasonry were authentic inventions.

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String and Stories

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Elizabeth Barber in her classic *Women's Work: The First 20,000 Years* made the profound observation:

We don't know how early to date this great discovery - of making string as long and as strong as needed by twisting short filaments together... Soft flexible thread of this sort is a necessary prerequisite to making woven cloth. On a far more basic level, string can be used simply to tie things up - to catch, to hold, to carry. From these notions come snares and fishlines, tethers and leashes, carrying nets, handles, and packages, not to mention a way of binding objects together to form more complex tools... So powerful, in fact, is simple string in taming the world to human will and ingenuity that I suspect it to be the unseen weapon that allowed the human race to conquer the earth, that enabled us to move out into every econiche on the globe during the Upper Palaeolithic. We could call it the String Revolution. (1994, p. 45)

Barber's insight that the capacity to join things together through lashing, binding, and knotting, with string or cordage, is what gave people mobility is of profound importance. It cannot, however, have occurred in isolation from two other essential capacities: bodily movement and communication. How and why human movement is accomplished is central to our understandings of the growth and transmission of culture and civilization and is thoroughly social and embodied. Movements are always performed by groups of people through the actions of their own bodies and are coordinated and motivated through ritual, music, dance, and stories. Movements through the landscape also create trails both cognitive and material. "We know *as we go*" (Ingold, 2000, p. 230). Historically stories, string, and trails were very likely coproduced with one another; they certainly inform each other mythopoetically through the fundamental commonality of narrative, journeying, and weaving.

Weaving and storytelling reflect a common origin in the derivation of text and textile from the Latin verb *texere* to weave.

The linguistic remnants of the body in movement and action can be dimly perceived in the root meanings of many terms closely associated with making meaning and knowing. Take, for example, understand – in Old English to grasp an idea by standing or placing the body in between. Similarly epistemology, the study of what can be known, comes from the Greek *epi* meaning over and near and *histasthai* to stand, that is, to know through putting oneself in a good position. Symbol – something standing for something else – comes from the Greek *bolein* to place or throw together. Likewise a metaphor was literally a device for being transported across space; in modern Greek a *metaphor* is a taxi. Theory originally meant to contemplate, from *theoros*; in modern Greek it is one who travels to see things, an ambassador. Travel was originally travail, to work, and method comes from *meta* and *hodos* – after the traveling way.

What weaving, stories, and string share is the complex duality of tension and connection, difference and similarity. Stories join ideas, string joins things together, and both are dependent on tension. String and cordage derive their connective capacity from tension in knots, binding, or twining, and tension derives from the Sanskrit word for string. Weaving and textiles depend on the tension between the warp and the weft.

Stories and narratives are dialogical and have an essential tension or irony that comes from the listener's implicit double recognition that the coherence, the order the storyteller imposes on the world, comes from linking things together while also recognizing that entirely contradictory orderings and associations are equally possible and that in relating one narrative in terms of another stories are told and understood against the background tradition of other stories. Stories are a way of dealing with the ontological multiplicity or "bothness" of life, the tensions and incommensurabilities between the contingent and the ordered, between the anomalous and the classified, between differing subjectivities, spatialities, and temporalities, and between the

personal and the theoretical, the concrete and the abstract, the essential contradictions, and the inexpressibility of human existence (Pelton, 1980, p. 258). The trickster myth, that is common to so many cultures, reveals the multiplicities and tensions in the way the human world is storied and performed through language. In Norse mythology, for example, the links are apparent in the role of Loki the trickster god of mischief and destruction who also taught mankind the art of netting (Turner & van de Griend, 1996). In Greek myth it was Athena the goddess of many things but especially love, procreation, wisdom, civilization, strategy, and weaving (Barber, 1994, p. 241).

Barber's insight that string, an almost invisible and seemingly trivial soft technology, gave humans the capacity to move requires a radical rethinking of the stories we tell ourselves about the origins and nature of human civilization and existence. Archaeology has, until now, celebrated early cultural development as basically lithic (related to stone) and technological, a process based in utilitarian stone tools and weapons, giving us a rather androcentric (centered or focused on males) picture of early man conquering the world with stone axes. Focusing on string brings into prominence the catching of small birds, animals, and fish through netting. It emphasizes the capacity for movement of humans by land and by sea. Most importantly it brings into visibility the early development of nonutilitarian ornamentation and symbolization. These capacities for enabling symbolic expression, mobility, and relatively low key methods of hunting and tracking give a very different perspective on the early development of technology and culture. But, there are profoundly differing views about whether all these constituted a "revolution" occurring in the Paleolithic period around 26,000 BP as Barber believed or whether they occurred considerably earlier and more incrementally. If so, string was not a human innovation but a hominin one.

There is now strong evidence that string was made by Neanderthals, and possibly even *Homo erectus*. Bruce Hardy and his team have found twisted fibers in a rock shelter very near the

Chauvet cave in France that they date at 90,000BP (Hardy, 2008; Hardy et al., 2013). Two key areas in which the early uses of string are evident are in very ancient shell beads and in new datings of the earliest movements by sea. Recent discoveries of clusters of beads and pendants with drilled holes reveal the necessity of the almost invisible technology of the string, thread, cord, or fiber to suspend them. At the same time they suggest the development of a capacity for reflection and symbolization, for abstraction and communication. Such capacities are normally taken to be prototypically human, but there are some archaeologists who date ostrich shell beads in Africa as far back as 200,000 years ago (Bednarik, 1997a, 1997b, 1997c). Recent finds, at Blombos in South Africa, of pierced shell beads showing signs of wear by threads or clothing are dated at around 75,000 years ago, and maybe as old as 280,000 (Douglas, 2004, p. 26). Dating disputes will always permeate archaeology, but it is clear that Neanderthals made necklaces implying symbolization and least protolanguage (Arsuaga, 2002). The other and most important development was traveling by boat across open-sea passages. Australian Aborigines were once thought to be the world's first sailors, arriving in Australia across an ocean gap of around 50 km at least 60,000 years ago. Water transport over this breadth of deep water would require string of some sort in the form of lashing and knots to tie together what was most probably a bamboo raft (Jones, 1989; Thorne & Raymond, 1989, p. 39ff). Now this claim has been supplanted by evidence of stone tools on Crete and Cyprus dated at over 100, 000 BP and on Flores at over 1 Ma BP (Brumm et al., 2010; Simmons, 2014; Strasser et al., 2010).

The earliest direct evidence we have currently for string as twisted plant or animal fiber and hence as the basic component of clothing or textiles is 26,000 BP, and there are figurines wearing string skirts which are dated around 20,000 BP. The use of twisted cords for weaving on looms has developed from the earliest times in cultures around the world from the Andes to China (Adovasio & Hyland, 2000), as has the

use of knots for mnemonics and decoration and the celebration of string in games and stories. Perhaps the most highly elaborated use of string was in the *quipu* of the Inca. Gary Urton's research suggests that these knotted strings were examples of how something as simple as string is capable of generating a hugely complex system of signification, codification, and narrative (Urton, 2003; Quilter & Urton, 2002; Salomon, 2004). Similarly Weiner (2001, p. 236) suggests that the *kirugu*, the sacred knotted cord of the Iatmul of the Sepik in Papua New Guinea, maps out the stories of their migrations.

String, stories, and trails, in their complex interactions and their multiple embodied skills and practices, now stand among the earliest of technologies and were developed by our hominid ancestors, all of which should give us pause in our contemporary storytellings that locate our cultural origins in developments of symbolic and social technologies around 35,000–40,000 BP. Our cultural origins now look much less gendered, much less modern, much less Eurocentric, and much less special to humans (Villa & Roebroeks, 2014). We and our ancestors created trails, traveled by water, and joined ideas and things together, making ourselves and our world.

See Also

- [Beads](#)
- [Quipu](#)
- [Textiles in South America](#)

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Suanxue Qimeng

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The *Suanxue qimeng* (*Introduction to Mathematical Studies*), the first book composed by Zhu Shijie, a Chinese mathematician of the Yuan dynasty, was published in 1299 (Du, 1966; Ho, 1970–1980). It differs from his second one, the *Siyuan yujian* (1303), in that its mathematical content presents a stronger continuity with the Chinese mathematical tradition. Most of the topics treated in it can be traced back to the Han classic which founded this tradition, the *Jiuzhang suanshu* (*The Nine Chapters on Mathematical Procedures*, hereafter called *The Nine Chapters*), probably completed in the first century AD. Indeed, Zhu Shijie deals there with the rule of three, the distribution into unequal parts, and their composition or reiteration along the lines

opened by the sixth of *The Nine Chapters*. He also describes how to perform the same computations with fractions and presents algorithms to obtain areas and volumes, even though he considers some forms not found in *The Nine Chapters*. The rule of excess and deficit, which was transmitted to the West where it became known as the rule of false double position, receives in his *Suanxue qimeng* a presentation as complete as in *The Nine Chapters*, even though it had been partially forgotten and sometimes transmitted in an imperfect state during the time elapsed since the composition of the latter (Chemla, 1997). Moreover, Zhu Shijie devotes a chapter to an improved presentation of the algorithm for the solution of systems of simultaneous equations given by *The Nine Chapters* and comparable to the so-called Gaussian pivot method (Chemla, 1992, 1996).

In addition to this, the *Suanxue qimeng* includes the treatment of topics that had emerged in the previous decades in Northern China, Zhu Shijie's homeland, such as the "procedure of the celestial unknown," a technique that puts into play polynomial algebra to obtain an equation to solve a given problem (Du, 1966).

Yet, in contrast to *The Nine Chapters*, Zhu Shijie, in the first part of the book, makes clear which algorithms can be used to perform the basic arithmetical computations on the counting surface and includes new procedures for such computations when particular numbers are involved. It is interesting that some of the procedures he described could be used later without change when the abacus replaced the counting surface. In this respect as in others, such as the treatment of topics like the summation of all kinds of series, the inclusion of tables of unit conversion, a style of practicing mathematics in close contact with the problems of socio-economic life, or the use of certain new technical terms, the *Suanxue qimeng* repeatedly evokes the writings of Yang Hui, a mathematician who had lived slightly earlier in Southern China (Lam, 1979). Indeed, in contrast to the period before the unification of China under Mongol rule, when mathematics seems to have developed independently in the north and the south of China, the time of unification when Zhu Shijie

worked might have allowed the partial merging of these two traditions; his book may be our first reflection of this (Du, 1966).

See Also

- **Computation: Chinese Counting Rods**
- **Jiuzhang Suanshu**
- **Zhu Shijie 朱世傑**

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Sugar in Latin America

Judith Vidal

The sucrose from sugar cane is identical to that in beet sugar and other sugars such as glucose, dextrose, fructose, levulose, and lactose. The chemical formula for sucrose is the oligosaccharide C₁₂H₂₂O₁₁. After refining, sugar is 99.9 % pure.

Sugar cane was first cultivated and processed in India thousands of years ago. Gradually, medieval trade routes brought the product and its cultivation to the Mediterranean basin and Madeira where it languished on a small scale until its introduction to the Caribbean and Brazil. Columbus took it to Hispaniola on his second voyage in 1493. Cortés took it to New Spain, Balboa to Central America, and Pizarro to Peru. It was in Brazil, however, that the efforts of Duarte Coelho Pereira converted his captaincy of Pernambuco into a prosperous sugar-producing center fashioned after the *engenhos* (sugar works) of Madeira from whence the first cuttings and processing technology came. This became the model for an industry so vital to Portugal they courted Dutch capital to finance the African slave trade to supply the necessary labor. In exchange, the Lowlands received the crude sugar for refining and distribution. So profitable was this arrangement that the Portuguese eventually abandoned their enterprises in the Far East for the Brazilian milk cow, as Emperor João III fondly referred to the flourishing colonial sugar industry.

Aside from the introduction of large-scale cultivation and processing, the techniques of sugar production changed little since the early days of Venetian and Dutch refining and trading monopolies. Cultivation was usually from small cuttings or ratoons planted in evenly spaced furrows and allowed to mature for periods from 6 to 18 months – depending on the type of cane, the time and amount of rainfall or irrigation, temperature, storms, quality of soil, disease, and pests.

Plantation owners and managers were constantly alert for crop dangers and began to employ technicians to advise them. They experimented with irrigation systems, tested new strains of cane from both seed and ratoon, and tried crop rotation. Harvest had to follow immediately upon maturation. Normally this was by hand-held machetes wielded by slave laborers. Sometimes they used slash-and-burn techniques.

Harvesting was simultaneously accompanied by manually loading the syrup-filled stalks into mule-drawn carts for transport to the sugar houses. The cane was then handfed through the

vertical or horizontal cylindrical presses which were originally adapted from wooden olive presses. These were two- or three-roller, metal-clad, devices with gears powered by humans or animals (*trapiches*) or water (*engenhos*). The extracted syrup flowed through wooden troughs or, in some cases where capital and topography permitted, through Roman-style aqueducts to the boiling sheds. Large *engenhos* comprised thousands of acres with thousands of residents in self-sufficient hacienda communities. More modest enterprises relied on hand-carrying the crude syrup to nearby pots for boiling.

Early production systems were ecologically complete, for the crushed stalks (or bagasse) were dried and used as fuel to fire the boiling vats. The ashes and extraneous leaves and stalks were tilled back into the soil as fertilizer and also served as animal fodder. Slaves found that unprocessed molasses from pieces of stalk that were not disposed of quickly underwent inversion and began fermentation; this primitive rum was used as currency to reward slaves and keep them cooperative but was not recognized as a commercial product for export.

Until the nineteenth century, the juice from the raw cane went through a series of open-pot boilings at extremely high temperatures. This process was watched very carefully to avoid fire and to avert burning the sugar. Slaves ladled off the scum of debris which flocculated with animal grease at the top; other impurities settled to the bottom in sedimentation. Lime was then added to help clarify the syrup. This purification, also known as defecation, removed the maximum number of impurities. The clear syrup was then placed in evaporating pans. The sludge of megasse sugar was next scooped into hanging clay cones with open bottoms to allow the heavy brown molasses to drip out. The resulting crude sugar was about 96 % pure and fit for transport in casks or in loaves.

Shipped to European ports, crude sugar was sometimes sold directly, but most was transshipped and refined by a process of reheating in huge vats to which water and bone carbon filters were added. After a series of washings, the clear liquid was evaporated in copper pans

and allowed to crystallize or granulate – the finer the quality, the whiter the crystal. As with the processing of raw sugar, refining would remain unmodified until the nineteenth century introduced steam vacuums and centrifuges to the finishing processes.

Throughout the colonial period, every finishing process was done by the mother country or its agents, usually in the Lowlands. Therefore, refining always occurred in Europe. The most efficient refineries were scattered around Antwerp which remained the capital for finishing sugar until war razed the production centers and blockaded trade. Britain, France, and Germany then built their own refineries. Long before Britain took possession of sugar-producing lands, England monopolized refining and distribution industries. This availability of mass production coupled with a growing popular taste for sweetened coffee and bread with treacle (molasses) provided an amenable consumer base for the confection in England and on the continent which demanded the colonial product.

Having pirated the rattoons and seeds of Brazilian and Spanish haciendas, European powers sought to monopolize refining and trade. In 1662 Catherine of Braganza married Charles II of England; her dowry included former East Indian territories such as Bombay and Tangiers and also a taste for tea which swept the court with exceeding popularity and would eventually displace both coffee and cocoa as England's hot, sweetened beverage of choice.

The Caribbean was an entrepôt of plantation islands. England, Spain, Portugal, France, and Holland all engaged in slave trade with Africa, and all quickly learned the commercial value not only of sugar but also of its intermediary byproducts, molasses and rum. After the molasses dripped off the crude muscovado sugar, the syrup was fermented and distilled into rum on the islands as early as 1530 and used as currency to purchase African slaves. Molasses was shipped directly to North American ports where New England distilleries enjoyed a burgeoning business. From the time of the capture of Jamaica in 1655, rum was regularly issued to British sailors, for it lasted longer than the traditional ale on high

seas at certain temperatures. In 1754 it was watered down to grog and freely rationed until the 1960s. The sugar interest monopolized parliament and led to colonial uprisings which reshaped the empire.

Britain and its competitors consolidated their territories and introduced technological advances. As early as 1794, steam was used to power a three-roller press in Jamaica. A similar steam-driven mill operated in Cuba in 1797 – 10 years before the first successful steam-boat. These machines were neither uniformly nor extensively adopted and operated imperfectly. Early fixed iron rollers often clogged or broke when the woody stalks of older cane were fed through the press. Shutdowns were costly, for the syrup in cane spoiled if not processed within 3 days of harvest. Mechanical repairs and waiting for replacement parts also impeded production.

The vacuum pan was invented by Edward Charles Howard in England in 1813, but it was not introduced to the colonies until 1835. This pan admitted steam through holes in the pan's bottom which was lined by a filtering cloth and capped by a dome connected to an air pump with a condenser. Interior heating coils were added by Daniel Wilson, and in 1828 Louisiana planter Valcour Aime implemented these improvements in his sugar houses and also introduced the use of the polarimeter to value raw sugars in cane. Despite patent disputes a system of multiple evaporation in six to ten successive pans was widely adopted and diversely adapted throughout the world. Penzoldt's centrifugal machine invented in Germany in 1837 for drying wool was modified for sugar by Sir Henry Bessemer. Cane-processing technology was adapted for beet sugar. In London the Fairrie family experimented with decolorizing agents for their refinery and discovered animal charcoal.

With the mechanization of sugar in the latter nineteenth century came the professionalization of technical advisors and managers. Technical assistants had to know how to assemble equipment correctly, keep it in good repair, and operate it. Agricultural experts were consulted to identify the best strains of cane for a particular climate or soil. Hawaiian planters of the 1850s maintained

an experimental station which offered soil analyses, pathology reports, and pest controls. Entomological research at the British Museum identified natural predators and prescribed counter parasites.

The first mechanized harvests were successful in Australia. In the 1960s, Cuba contracted with Soviet engineers to develop a combine harvester. The self-propelled model ruined the ratoon and the ground for several seasons. Eventually the Cubans developed a harvester but technical problems diverted its production to Australia in 1984.

The sucrochemical industry experimented with research and development. Cane sucrose sales were eroded by beet sugar, high fructose corn sweeteners (HFCS) in processed foods, and synthetic sweeteners. New applications included gasohol, furniture, paper, and plastics. Brazil was the only successful producer of commercial gasohol although Australia and the US successfully converted their sugar industries to gasohol production during World War II.

The original sugar-producing countries of Latin America and the Caribbean still produce their crops of precious cane, but unstable governments, lack of capital, natural disaster, and inefficient management hinder technological growth.

See Also

► [Crops in Pre-Columbian America](#)

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Śulbasūtras

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Sometime around the sixth century BCE, new forms of knowledge began to evolve in parts of northern India, aimed at preserving and cultivating the Vedic wisdom, worldviews, rituals, and practices. The body of knowledge thus produced was called *vedāṅgas* (organs/limbs of the Vedas) and classified under six distinct categories: phonetics (*śikṣā*), grammar (*vyākaraṇa*), metrics (*chhandas*), etymology (*nirukta*), astronomy and calendars (*jyotiṣa*), and rites, rituals, and sacrifices (*kalpa*). The last of these comprised prescriptive texts concerning ethics, morality and conduct (the *Dharmasūtras*), household affairs (the *Gṛhyasūtras*), and rituals (the *Srautasūtras*). Included in some of the *Srautasūtras* were guidelines for the construction of various fire altars (*citis*) and the arithmetic and geometrical formulae behind the process. These manuals were perhaps called *rajju samāsa* (“joining the measuring cord”). In course of time, they came to be identified as the *Śulbasūtras*.

Śulba, literally “string,” refers to the measuring cord, and *sūtra*, literally “string” again, means an aphorism in the Sanskrit technical vocabulary. We have information about 11 such “aphorisms of the measuring cord”: the *Baudhāyana*, the *Āpastamba*, the *Mānava*, the *Kātyāyana*, the *Maitrāyaṇa*, the *Hiraṇyakeśi*, the *Vādhūla*, the *Varāha*, the *Laugākṣi*, the *Satyāśadha*, and the *Maśaka*. The first eight of these are now extant. Later Vedic texts like the *Brāhmaṇas*, the *Āraṇyakas*, and the *Upaniṣads* were, as a rule, affiliated with one of the three Vedas. This was also the case with the *Śulbasūtras* or the *Srautasūtras* to which they were attached. The *Maśaka Śulbasūtra* belonged to the *Sāmaveda*, and the eight extant *Śulbasūtras* to the *Yajurveda* with the *Kātyāyana Śulbasūtra* pertaining to the *Śukla* (white) *Yajurveda* and the rest to the *Kṛṣṇa* (black) *Yajurveda*. *Śulbasūtras*

of the *Rgveda*, if they existed, have not come down to us.

The *Rgveda* speaks of fire as *triṣadhaṣṭha* or “dwelling in three places” (3.20.2). This might be a reference to *Gārhapatya*, *Āhavanīya*, and *Dakṣiṇā*, the three fires every household was expected to maintain. In premodern India, as in the rest of the premodern world, it was not possible – or at least not feasible – to produce fire everyday as it was a time-consuming process involving several hours of labor. Maintaining fire was the Vedic people’s answer to this challenge. They came up with the idea of maintaining a surplus of three fires in every household. The science of altar-construction doubtless developed to address this challenge. In course of time, the rituals evolved out of this functional matrix to become complex symbolic systems represented by rituals like the *agnicayana*. In response to this, the *Śulbasūtras* laid down guidelines for constructing such fanciful altars as the *rathacakra citi* (the chariot-wheel shaped altar), *śyena citi* (the falcon shaped altar), and the *kūrma citi* (the tortoise shaped altar). The symbolic significance of these rituals is so lost to us today that one scholar, Frits Staal, found them wanting in semantic content.

The *Śulbasūtra* mathematics is not very complex. It contains formulae for constructing basic geometrical figures like right angles, squares, rectangles, and trapezia. The construction of a square or a rectangle equal in area to other geometrical figures like a circle or a rhombus is of special interest to these manuals.

One such formula in the *Baudhāyana Śulbasūtra* describes how a circle is converted into a square, i.e., how a circular altar is rearranged to form a square altar of equal area. This is done by dividing the diameter of the circle into eight parts and an eighth part into a further 29 parts, from which 28 parts are removed in addition to a sixth part of it and an eighth part of the sixth part. The formula to convert a circle of diameter d into a square of length l will then be

$$l = d - \frac{d}{8} + \frac{d}{8 \times 29} - \frac{d}{8 \times 29} \left(\frac{1}{6} - \frac{1}{6 \times 8} \right) \\ = 0.87868d$$

Therefore, the area of the square is $l^2 = (0.87868d)^2 = 0.77208d^2$. The original area of the circle, with a π value of 3.141593, was

$$\pi r^2 = 3.141593 \left(\frac{d}{2}\right)^2 = 0.7854d^2$$

The area of the square and the circle ($0.77208d^2$ and $0.7854d^2$, respectively) are almost the same, the latter being larger by a mere 1.7 %.

The *Baudhāyana Śulbasūtra* gives a formula to arrive at the value of $\sqrt{2}$. Increase the length of a square by a third and the third in turn by a fourth. Reduce this by its 34th part. Thus,

$$\sqrt{2} = 1 + \frac{1}{3} + \frac{1}{3 \times 4} - \frac{1}{3 \times 4 \times 34} = 1.41422$$

which is a very close approximation to the correct value.

It is generally believed that mathematics in India evolved out of the *Śulbasūtras*. This, however, is not borne out by evidence. There is no influence of, or historical continuity or even a logical connection, between the *Śulbasūtras* and the later-day works of mathematicians like Āryabhaṭa, Mahāvīra, Bhāskara I, or Bhāskara II. The *Śulbasūtra* tradition came to an end by the turn of the millennium. This was due in large to the fact that the construction of altars for maintaining fire had outlived its historical destiny. Massive expansion of agriculture, which depended upon the availability of the bull and therefore the cow, facilitated surplus production of ghee (clarified butter) on a hitherto unprecedented scale. The production of oil, which was not heard of in the age of the *Ṛgveda*, was another concomitant development in the wake of agrarian expansion. Together, these enabled the maintenance of fire through the relatively easier means of perpetual lamps made of stone, clay, or metal. Not surprisingly, the three fires, consuming large quantities of smoke-producing fuel like wood, vanished from the households, taking away with them the science of the *Śulbasūtras*. Several centuries later, the Nampūtiri brāhmaṇas of Kerala revived the *agnicayana* and other sacrifices. But we do not know the context in which this revival

took place, or the meanings the Nampūtiris attached to the sacrifices, although they continue to offer glimpses of what transpired in the course of the sacrifices.

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Sun Simo

Fabrizio Pregadio

The Chinese physician and medical author Sun Simo (alternative spelling: Sun Simiao) was a native of Huayan, in modern Shensi. His biography is so much a composite of fact and legend that it is even impossible either to substantiate or invalidate his traditional dates (581–682). From official, autobiographical, and hagiographic sources it emerges that he retired at an early age on Mount Taibai, not far from his birthplace. He repeatedly declined imperial summonses and official titles, but was almost certainly in Emperor Gaozong's retinue from 659 to 674, when he retired on account of illness. He seems to have spent an extended period in Sichuan, which may explain why many legends that concern him are located in that area. After his death he was venerated as *Yaowang* or “King of

Medicine” (by which he is still known) in temples dedicated to him.

Sun Simo is the author of two of the most important Chinese medical compilations, the *Qianjin fang* (Prescriptions Worth a Thousand or, Remedies Worth their Weight in Gold), also known as *Beiji qianjing yaofang* (Important Prescriptions Worth a Thousand, for Urgent Need), and the *Qianjin yifang* (Revised Prescriptions Worth a Thousand). The former, in 30 chapters, was completed soon after the middle of the seventh century (apparently in 652). The latter, also in 30 chapters, dates from the late seventh century. Both works are preserved in editions derived from versions published in the eleventh century, when they were edited to be used as textbooks in the Imperial Academy of Medicine. In these texts, Sun provides an extended compendium of contemporary medical knowledge, arranged in sections dealing with such subjects as pharmacology, etiology, gynecology, pediatrics, dietetics, acupuncture, ► [moxibustion](#), and specific diseases. Both texts include a wide selection of prescriptions (about 5300 in the *Yaofang*, about 2000 in the *Yifang*).

Among the many points of interest in these compilations, three deserve special mention. The first is the priority that Sun Simo accords to gynecology and pediatrics, the two branches of medicine with which he deals first in both works. The second is the importance given to medical ethics, reflected in this well known passage from the first chapter of the ► [Qianjin yaofang](#): “When someone comes to look for help, a doctor should not question rank or wealth, age or beauty, nor should he have personal feelings toward that person, his race, or his mental capacities. He should treat all his patients as equal, as though they were his own closest relatives.” The influence of Sun’s medical ethics spread beyond China, reaching Korea and Japan through quotations of relevant passages in texts of these two countries.

A third aspect is Sun’s relationship with Daoism (Taoism) and Buddhism. The nature of his involvement with the Way of the Celestial Masters (*Tianshi Dao*, one of the main traditions of liturgical Daoism) is debated. In the two chapters entitled *Jinjing* (Book of Interdictions)

of the *Qianjin yifang*, Sun quotes formulas used in exorcist rituals by the Celestial Masters. This raises the issue of how he gained access to them. His interest in Daoism is also reflected in the chapter on “Nourishing the Vital Principle” (*Yangxing*), and in another extant text on physiological disciplines which is attributed to him, the *Sheyang zhenzhong fang* (Pillowbook of Methods for Nourishing [the vital principle]).

Another source which points to Sun’s relationship with Daoism is the *Taiqing danjing yaojue* (Essential Instructions from the Books on the Elixirs of the Great Purity). This text -available in an excellent English translation – consists of a collection of alchemical methods, probably derived from the Six Dynasties compilations centered around the now lost *Taiqing jing* or Book of the Great Purity, one of the main early alchemical canons. Although Sun’s authorship cannot be definitively proved, we know from his own witness that he was involved in the compounding of elixirs around AD 610. Among the medical disorders which he experienced, of which he left a first-hand account in his medical works, is intoxication due to elixir ingestion.

In addition to Daoism, recent research has pointed out Sun Simo’s close connection with Buddhism. For example, he refers to Indian massage techniques, and mentions methods for the treatment of beriberi from works edited by Buddhist monks. Perhaps under the influence of Tiantai disciplines, he also introduced meditation in his medical practice. Moreover, the above mentioned “Jinjing” section of the *Qianjing yifang* includes incantatory formulas in Sanskrit. The main factor behind these Buddhist elements may have been Sun’s interest in the doctrines of the Huayan school. Some passages of his texts, especially those on medical ethics, acquire new meaning if read in this light.

See Also

- [Acupuncture](#)
- [Alchemy in China](#)
- [Medical Ethics](#)
- [Medicine in China: Forensic Medicine](#)
- [Moxibustion](#)

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Sun Tzu

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The Chinese military general, strategist, and theorist Sun Tzu was a notable historical figure in the late Spring and Autumn Period (770–403 BC) of ancient China. His birth name was Sun Wu (孫武), and he originated from a military family in the state of Qi (齊). His book *Sun Tzu: The Art of War* (孫子兵法) has been considered the most important military treatise of China, which laid the foundation of Chinese strategic thought and military dialectic and is widely applied in numerous fields worldwide today.

Despite his uncertain historicity, Sun Tzu was believed to be a contemporary of Lao Tzu (Lao Zi) and Confucius. Due to political upheavals in Qi, Sun Tzu moved to the state of Wu (吳). In 512 BC, Sun Tzu presented the King of Wu *The Art of War* (in 13 chapters) and was later appointed as a general. He played a major role in the war planning against the state of Chu (楚), Wu's arch-enemy. In 506 BC, Wu launched major offensives against Chu. Wu forces

commanded by Sun Tzu won a stunning victory and crushed Chu's main forces in the Battle of Boju (柏舉之戰) and captured Chu's capital, Ying (郢), as a result.

There was almost no historical record of Sun Tzu after the conquest of Chu. It was believed that Sun Tzu subsequently left Wu's court and chose to live in seclusion. Nevertheless, Sun Bin (孫臏), an alleged descendant of Sun Tzu who wrote *Sun Bin: The Art of Warfare* (孫臏兵法), emerged on the historical scene about 150 years later in the early Warring States Period (403–221 BC). In order to distinguish between the two, Sun Tzu was called "Wu Sun Tzu" (吳孫子, as he served the state of Wu) and Sun Bin "Qi Sun Tzu" (齊孫子, as he served the state of Qi).

The Art of War was written at a time when China was undergoing a period of tremendous changes that had led to the revolution in strategic thought. Sun Tzu's famous concept "war is the Tao (Way) of deception" marked the end of and departure from the old aristocratic way of war that was based on military rites. By recognizing "war is the Tao of deception," Sun Tzu developed various schemes to grasp the entirety of the situation for decision-making purposes as well as to precondition, manipulate, and eventually control the enemy.

Sun Tzu identified the presence of contradictions between phenomenon and essence in war as a result of the use of deception and stratagem. And accordingly, he devised a method to grasp the phenomenon that can help to infer the essence upon which strategists and generals can make their judgments and decisions. That is why Sun Tzu used so many contradicting pairs in *The Art of War*, including win–lose, strong–weak, attack–defense, vacuity–substance, numerous–few, and courage–fear, to represent any situation or circumstance so that generals and strategists can discern the abstract patterns and dynamic relations quickly and more easily (Li, Zehou, 2006, pp. 76–83).

One major theme of *The Art of War* is its emphasis on winning without fighting – "subjugating the enemy's army without fighting is the true pinnacle of excellence." This is made possible by exploring nonmilitary means in both

wartime and peacetime. “The highest realization of warfare is to attack the enemy’s plans; next is to attack their alliances; next to attack their army; and the lowest is to attack their fortified cities.” Even if a battle had to be fought, Sun Tzu advocated utilizing the dominant psychological/cognitive dimension in war by manipulating the enemy before entering a battle. He was against the idea that victory is solely decided by the battle itself – “the victorious army first realizes the conditions for victory, and then seeks to engage in battle. The vanquished army fights first, and then seeks victory.”

A dominant feature that contrasts *The Art of War* with Western military and strategic theories is its treatment of the relationship between theory and practice. Chinese strategic thought is not affected by the theory–practice relationship. It was modeled on no fixed model but water. Sun Tzu’s “water metaphor” – “the army’s disposition of force is like water . . . The army’s disposition of force avoids the substantial and strikes the vacuous. Water configures its flow in accord with the terrain; the army controls its victory in accord with the enemy” – rules out any possibility of predetermining events in accordance with a more or less definitive plan worked out in advance as an ideal to be realized (Jullien, 2004, p. 20). Nothing is essential except the demands of the situation, and the work of generals and strategists is to adapt to unfolding circumstances. As a result, they can avoid becoming bogged down on the one hand and can produce patterns that are never definite on the other hand.

Apart from being the cornerstone of the Chinese School of the Military (兵家) among other schools of thought, *The Art of War* constitutes an important basis for Chinese pragmatism and rationalism, which had influenced the development of Taoism and Legalism (Realism) significantly (Li, Zehou, 2006, pp. 83–106).

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Sun Zi

Ang Tian Se

Of all the mathematicians in ancient China, we know the least about the life of Sun Zi. The fact that he was given the honorific designation of *Zi* (Master) after his surname led some people like Zhu Zunyi (AD 1629–1709) to identify him with Sun Wu, a celebrated tactician in the sixth century BCE. Then Ruan Yuan (AD 1764–1849) assigned him to the late Zhou period of the third century BCE. With regard to the text written by Sun Zi, Dai Zhen, the eighteenth century scholar and mathematician, citing from internal evidence, argued that the text could not have been written earlier than the Han dynasty at the turn of the Christian era. Though this text by Sun Zi was listed in all the bibliographical chapters of the *Sui Shu* (Standard History of the Sui dynasty), the *Jiu Tang Shu* (Old Standard History of the Tang Dynasty), and the *Xin Tang Shu* (New Standard History of the Tang Dynasty), there was no mention of its author. This shows that as early as the middle of the seventh century AD, no one seemed to know who Sun Zi was.

Sun Zi had neither high political position nor influential social standing to merit a place in official history. He appeared to be merely a scholar with some Buddhist inclinations as is

evidenced in a problem mentioning the length of a *sutra*. The mention of *wei qi* (encirclement chess), and the taxation in terms of silk floss in other problems indicates the text of Sun Zi could not have been written earlier than the third century AD and later than the fifth century. Thus we assume he lived around AD 400.

Sun Zi Suan Jing is the earliest existing text to provide a description of the rod numerals and their operations. It also gives the names of large and small numbers, tables of measures for length, weight, and capacity, as well as densities for metals. The most famous problem is the oldest example of the remainder problem which reads as follows:

Now there are an unknown number of things. If we count by threes, there is a remainder 2; if we count by fives, there is a remainder 3; if we count by sevens, there is a remainder 2. Find the number of things.

The problem has since evolved into what is now known as the Chinese Remainder Problem. Written in modern form, the problem can be expressed thus:

$$N \equiv 2(\text{mod}3) \equiv 3(\text{mod}5) \equiv 2(\text{mod}7).$$

It appeared that Sun Zi's solution of the remainder problem had been extensively employed by the ancient astronomers to perform complicated computations of the calendar. By the thirteenth century, the problem was fully developed by ► [Qin Jiushao](#) with a sophisticated method of solution which also tackled the difficult case where the moduli were not relatively prime.

See Also

- [Computation: Chinese Counting Rods](#)
- [Qin Jiushao](#)

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Sundials in China

Edoardo Proverbio

The measurement of time has a long history in China. Besides clepsydrae and water clocks, sundials and incense clocks were the only timekeepers employed in the epoch preceding the introduction of mechanical timepieces.

The earliest form of timekeeper used in China appears to be the sundial. Although the use of a simple vertical pole, employed to determine the epoch of solstices by measuring the length of the sun's shadow, appears to go back to Shang times (ca. 1500–1000 BCE), it is more difficult to establish the epoch in which the shadow of a simple style was used in China to measure time. Perhaps the most ancient reference is the one made by Joseph Needham et al., contained in the *Shi Ji* (Historical Record), which goes back to the beginning of the fifth century BCE. This reference, as well as those in subsequent epochs, makes no mention of the typology of these ancient sundials. Among later apparent references to the building of sundials of the equatorial type, there is the one contained in the *Sui Shu* (History of the Sui Dynasty), which refers to a “graduated sundial” the shadow of which reproduced the motion of the heavens. It was built by Ge Heng, a master of astronomical learning and instrument maker active in about the middle of the third century AD. One of the first descriptions of a Chinese equatorial sundial that has come down to us is contained in the *Duxing Zazhi* (Miscellaneous Records of the Lone Watcher) by Zeng Minxing (ca. AD 1176) in

which, among other references, it is stated that Zen Nanzhong, master of astronomy and a highly skilled instrument maker, who was active in Chiangsi province, invented and built many water clocks and sundials: “he also made two wooden dials with diagrams on them. One was set upon a wooden support for reading (the hours by) the sun’s shadow” (cited in Needham, Ling, & de Solla Price, 1986).

But the only extant ancient objects that appear to have been built and used as accurate timekeepers are the two so-called Han sundials, dated as former Han, perhaps going back to the second century BCE. These two objects have been interpreted in different ways. The most probable interpretation is, however, the one proposed by White and Milman in 1938. According to them the base-plate of these sundials was inclined in the equatorial plane, and the central gnomon was not a style but a rectangular plate connected with a perimetral T-shaped gnomon by a bronze bridge. Time would thus be shown by the position of the shadow of the peripheral gnomon in line with the bridge according to the graduation engraved on the face of the sundial. The season would be shown by the height of the shadow of the T-shaped gnomon on the central rectangular plate. Upon these ancient, supposedly equatorial solar timekeepers the graduations appear on one face only.

The most remote mention of the existence of Chinese equatorial sundials with surfaces graduated and a gnomon extending both above and below the equatorial plane plate appears to go back to the twelfth century. The *Duxing Zazhi*, mentioned above, reports the following passage: “So at Yunchang (Chiangsi province) he (Zeng Nanzhong) made a *Gui Yingtu* (diagram of the sun shadow) and constructed a sundial (*gui*). The dial was supported on posts so that it was high toward the south and low toward the north (i.e., in the plane of the equator). The gnomon pierced the dial at the center, one end pointing to the north pole and the other to the south pole. After the spring equinox, one had to look for the shadow on the side facing the north pole, and after the autumn equinox one found it on the other (the under) side” (Needham et al., 1986). Numerous

examples of late (Ming and Ching dynasties) Chinese equatorial sundials graduated on both sides have come down to us. The dials existing in the imperial palace at Beijing are of this kind.

Besides fixed equatorial sundials, two portable equatorial sundials made of lacquered wood, with inscriptions in red and black, or black only, were constructed in China, at least as far back as the Sung period (tenth to twelfth centuries). The largest production of these portable sundials appears to have been concentrated somewhere around the nineteenth century. Their construction is quite simple. They are generally composed of a rectangular piece of wood as a base plate with a compass needle having an azimuth graduation for meridian orientation set in it. A second, mobile lunette (the plate dial) is connected to the board at the middle.

The lunette is thus half the size of the base plate. The plate dial is graduated and may be raised or lowered to any desired angle so that the gnomon, fixed at right angles at the center of the graduation, may point at the pole whatever the latitude of the observer may be. The dial is then fixed in position by means of a ratchet prop. It is interesting to note that the latitude scale materialized by the position of the ratchet is given not in degrees or by the names of cities, but by the 24 fortnightly periods (*chi*) into which the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course) was subdivided in traditional Chinese astronomy. The hour lines of the equinoctial dial plate are also expressed in the so-called Chinese “double-hours” associated with the 12 ideograms of the duodenary cycle. In fact, despite their everyday, popular origin, these timekeepers seem to embody elements of the long tradition of Chinese geomancy or topomancy, divination by means of configurations of earth.

So we must believe that Chinese equinoctial sundials belong to the pure Chinese chronometric tradition, an interpretation that takes us back to the origin of the Chinese science known as *Feng shui* (geomancy, wind and water), based on the use of the geomantic compass, and of the ancient divinatory system based on the *Yijing* (I Ching, Book of Changes).

The first portable (and fixed?) horizontal solar time pieces were introduced into China starting from the end of the sixteenth century by Matteo Ricci and other Jesuit missionaries. Indeed, Father Ricci himself, in the preface to his memoirs, wrote: “As for their clocks, there are some which use water, and others the fire of certain perfumed fibers made all of the same size; besides this they make others with wheels which are moved by sand, but all of them are very imperfect. Of sundials they have only the equinoctial type, but do not know well how to adjust it for the position (i.e., the latitude) in which it is placed” (cited in Needham). The structure of these Chinese horizontal sundials which have come down to us is perfectly similar to that of the European “diptych” sundials, whose center of diffusion in Europe appears to have been Nuremberg in the late sixteenth century. Chinese horizontal sundials were not constructed before the end of the Ming dynasty (second half of the seventeenth century), and we have significant evidence showing that this kind of sundial was also employed more for geomantic purposes than as simple timekeepers.

Besides the two types of portable sundials so far mentioned, few specimens of a third kind of sundial, probably horizontal, consisting of a rectangular ivory plate, each one ruled for a different latitude, with hour and declination lines engraved, exist in China. The time of day and the period of the year were presumably indicated by the shadow of a style fitted into a central hole.

Unfortunately, given our still insufficient knowledge on the latter, as on other Chinese sundials previously discussed, it is often difficult to know exactly on what working principle they were based and the precise uses for which they were constructed and put to use. Even more uncertain is the epoch in which many portable Chinese sundials, still extant in museums and on exhibition, were built, where they were built, and by whom.

See Also

► [Clocks: Astronomical Clocks in China](#)

► [Fengshui](#)
 ► [Geomancy in China](#)

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Sundials in Islam

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During the seventh century, Arab and Persian scholars discovered Greek astronomy. Their expansion in the Greco-Roman world put them into contact with sundials and astrolabes, both of which share the same history. After a period of assimilation, these scholars brought back improvements to the gnomonic, and the sundial was put to the service of Islam. Islam changed the perception of sundials. These objects were not only rough indicators of the day as with the Romans; Arab Persian astronomers wanted those sundials to indicate accurately the times of prayer in a specific location. So it was out of the question to have merely empirical and approximate plots or to use a sundial calculated for another city. It needed accuracy, and this could

only be accomplished by using sophisticated mathematical and astronomical methods.

It is likely that the astronomical tables played a key role in this evolution. We know that many astronomers knew the work of the great astronomer of antiquity, Ptolemy (II century AD). In particular, he wrote a short treaty *On the analemma*, which can be considered as a treatise on descriptive geometry and should not be confused with the method described by Vitruvius in his *De architectura*, although the process has some similarities. The Ptolemy treatise contains no practical application for the construction of a sundial. We know from various sources, including the philosopher Proclus (410–485), that analemma (in astronomy, an analemma is a curve representing the changing angular offset of a celestial body from its mean position on the celestial sphere as viewed from another celestial body) dates back at least to the first century BC and at that time, Diodorus from Alexandria, a famous gnomonist, would have written about this method. The fact is that the analemma method was likely well known during ancient times, and it is then an important step in the calculation of sundials with trigonometric tools. Among others, the method is used by Thābit ibn Qurra (cf. below). The analemma method is essentially a trigonometric projection method: depending on the date, time, and latitude, one can calculate the position of the Sun, especially its horizontal coordinates (azimuth, altitude), project them onto a plane, and tabulate the basic parameters of a sundial (unequal length of time, length of the shadow, angle between the shadow direction and a geographic axis, solstices curves, etc.).

According to the *al-Fihrist* bibliography of al-Nadīm (d. 987), there is a long list of prestigious scholars who wrote in the first centuries of Islam about sundials and their purposes; this list includes Habash, Banu al-Sabbah al Farghānī, and al-Mahali. Al-Bīrūnī (973–1050), a scholar famous for the richness of his astronomical work, wrote a short study about the trajectory of the end of the shadow of a gnomon, using the tangent function. Much later, there are also numerous Mamluk authors who dealt with sundials.

Among them, there is al-Marrakushi who worked in Cairo in the thirteenth century with his famous *Treaty of astronomical instruments*, a major work of the Arab gnomonic. There are also the gnomonic tables of his contemporaneous al-Maqsi or Ibn al-Sarraj, one of the greatest specialists of these time measurement instruments. In their writings, these authors discuss a wide variety of dials: horizontal, vertical, inclined, cylindrical, and conical. Many of these treatises are in libraries waiting to be studied one day.

Arab Persian gnomonic also produced portable sundials, one of the most well known being the copper specimen that belonged to warlord Syrian Nūreddin (1117–1174), called “locust’s leg.” Like most portable dials belonging to the cylinder height type, known since Greco-Roman antiquity, the principle is to determine the time from the height of the Sun above the horizon during the day. The use of these dials to determine prayer times was mostly anecdotal.

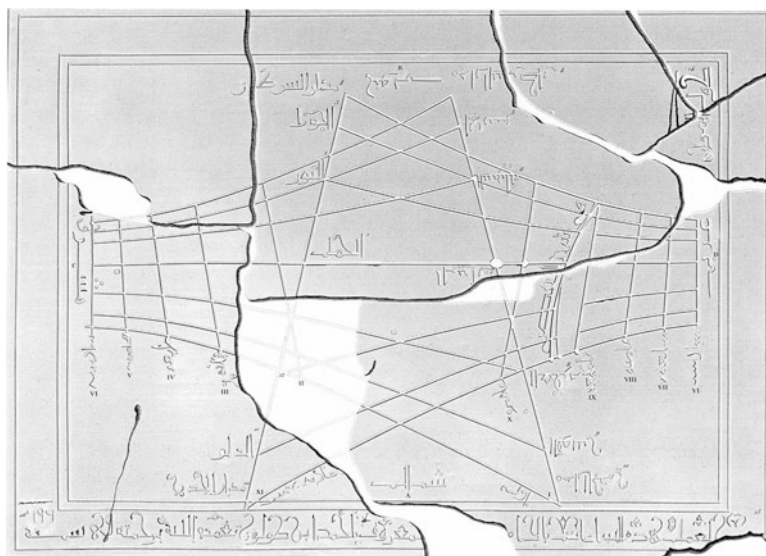
Early in history, the mathematical study of sundials was a well-established discipline whose practitioners were marked out by a dedicated word (*Ashab al-azlal* in the words of Ibn al-Haytham) and recognized as craftsmen. So we have from the ninth century, tables and books dealing with the calculation of dials, like the ones of Baghdad astronomers al-Khwārizmī (780? -850?) and Thābit ibn Qurra (836–901). The work of the latter, *Works of astronomy*, contains two important chapters on gnomonic that make it one of the oldest treatises in Arabic on the subject. Thābit ibn Qurra considers plane dials with a perpendicular gnomon and looks for plotting hour lines on their surface depending on time, date, and place. He looks at the classification of meridian planes, the horizon and the first vertical – as did Ptolemy – but also adds other cases and finally considers one of the inclined and declining dials, indicating that it works as a horizontal dial in another place (equivalent latitude theory).

Everything indicates that one has to wait until Ibrāhīm ibn Sinān (909–946) for the first substantial writing about sundials with his treatise *On shadows instruments*. Ibn Sinān there develops

a unified theory of these instruments, based on strong geometric bases. In particular, he underlined the problem of uneven hour lines that are not straight lines – as already written by his grandfather Thābit ibn Qurra – but curves. In the first centuries of Islam, one drew unequal hour sundials (as on antique Greco-Roman dials) which resulted from the division by 12 of the time interval between sunrise and sunset. These hours have varying durations that depend on time and place. Equinoctial hours, lasting 60 min, were the only ones used by astronomers in their calculations and were later superseded by uneven hour sundials. Thābit ibn Qurra, in his book, gave the possibility to draw equinoctial hours. The most famous Arab Persian dial with equinoctial hours is the horizontal sundial found in the Umayyad mosque in Damascus, built by astronomer Ibn al-Shāṭir around

1371–1372. It has two features: first, it is a masterpiece in the complexity and comprehensiveness of its drawings. But more importantly, it has a polar gnomon that is seldom seen in an Islamic dial; this was so far the oldest known of its kind. Does this mean that dial with polar gnomon are an Arab Persian invention? Everything leads us to believe it.

The project of Ibn Sinān was resumed by Ibn Haytham (965–1039), who wrote two books about sundials. One was dedicated to mathematicians, entitled *On the hour lines*, and the other was dedicated to sundial craftsmen and entitled *On horizontal sundials*. In the first book, Ibn Haytham went back to the problem of temporary hour lines geometry. Ibn Haytham, as did Ibn Sinān, wrote application books so that craftsmen would be sufficiently enlightened to build sundials, since that is the purpose of his second book



Sundials in Islam, Fig. 1 Sundial of the Ibn Tulun Mosque in Cairo. Very faithful reproduction of a beautiful sundial disappeared, published in the *Description de l'Egypte* prepared by scholars who accompanied Bonaparte in Egypt. This is a horizontal sundial cut into two parts nested. Dated from the late thirteenth century, it indicated unequal hours represented by the inclined lines, framed by two arcs of hyperbolas solstices. The entire route is cut by the right of the equinoxes. Between the 9th and the 10th hour is the curve of the *Asr* prayer. Cadran solaire de la mosquée d'Ibn Tulun du Caire. Reproduction

très fidèle d'un magnifique cadran solaire disparu, parue dans la *Description de l'Egypte* préparée par les savants qui accompagnaient Bonaparte en Egypte. Il s'agit d'un cadran solaire horizontal coupé en deux parties imbriquées. Daté de la fin du XIII^e siècle, il indiquait les heures inégales représentées par les droites inclinées, encadrées par les deux arcs d'hyperboles des solstices. L'ensemble du tracé est coupé par la droite des équinoxes. Entre la 9^e et la 10^e heure se trouve la courbe de la prière *asr*



Sundials in Islam, Fig. 2 Sundial in the Cairo Citadel (Egypt). Remarkable multiple sundial, vertical declining southwest dated eighteenth century. There are five sundials each operating with their own gnomon. The sundial indicates the equinoctial hours, *Asr*, *Zuhr*, and *Maghrib* prayers, and has curves for *Isha* and *Fajr* twilights.

Remarquable cadran solaire multiple, vertical déclinant sud-ouest, daté du XVIII^e siècle. On y trouve five cadrans solaires fonctionnant chacun avec leur propre gnomon. Le cadran indique les heures équinoxiales, les heures de prière de *asr*, *zuhr*, *maghrib* et comporte les courbes pour les crépuscules de *isha* et *fajr*.

on horizontal sundials where he explains in particular how astrolabes were used to draw sundials.

It is believed that thousands of dials were built since the ninth century in the Islamic world, but many have disappeared (like the one of the Ibn Tulun Mosque in Cairo, which dates from 1296 and which is only known thanks to an etching) or are not inventoried; Figs. 1 and 2.

This abundance is a major feature of the Arab-Islamic sundial which demonstrates its strong links with religion, a link that comes from the definition in Islam of prayer time in terms of variation in the length of shadow. Thus, there was a need to include on sundials some *asr* or dusk curves, but also to draw the equivalent italic hours to know how much time is left before the Sun sets. The first *asr* curves seem to appear on Arab dials in the eleventh century (Vth Hegira). The *asr* is the moment when the shadow of a gnomon of length a is equal to its meridian length increased by its own length; by defining φ the latitude and δ the declination of the Sun,

this corresponds to a height h of the Sun given by $\cotan h = 1 + \tan(\varphi - \delta)$. One finds, for instance, in the treatise of al-Marrakushi lots of explanations and tables to plot these curves.

The expansion of the gnomonic Arab Persian in Europe via the Maghreb resulted in a sort of revival of sundials manufacture between the thirteenth and fourteenth centuries in Andalusia as reflected, for example, by the treatise of Ibn al-Raqqūām which dates from the fourteenth century and uses the analemma methods.

The architecture during the Mamluk and Ottoman periods has many sundials adorning the walls and courtyards of mosques, a tradition that lasted until the end of the nineteenth century. Many of these prayer dials are works of prestige, as reflected by their smart engraving and their geometry and ornament. A very special feature of these dials is manifold: it is almost a gnomonic block where there are several dials and therefore several gnomons (one that indicates *zuhr*, one for *asr*, one for *maghrib*, one for the time remaining before the dusk prayers). Their relative disposal

obeys criteria that combine aesthetics and astronomical necessity. Their fine sculpture, the calligraphy of embossed Arabic letters, and their mathematical accuracy make these sundials incomparable masterpieces that must be preserved.

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Surgery in Ancient Egypt

Hedvig Györy

In ancient Egypt, because a majority of the population had to endure hard physical toil, bone abnormalities such as arthritis, inflammation of the joints, bone attrition, kyphosis, osteoarthritis, or tuberculosis were a common occurrence. None of these conditions were, however, considered surgical cases. The surgical repertory was limited. Both physical remains and written sources support the notion that operations were sporadic and minor, and that the emphasis was on physical treatment of fractures or dislocations, with a few cases of incisions or cuts into certain regions of the body. There were also various external organic alterations like abscesses, boils, fistulas, hemorrhoids, ulcers, and some superficial growths. Malfunctions of the nose, ear, and teeth were treated in this manner only occasionally. In treatment, the anatomical knowledge applied was taken from earlier medical observations and theories, not from the science of mummification. Good examples of this are the mummies examined by Regöly-Mérey: in 17 cases, the brain was removed transnasally, in 8 cases the frontal and facial sinuses were removed, and in 5 cases the pterygoid sinus had been opened up. Thus, these sinuses had to be penetrated with a hook, but none of these sinuses is ever mentioned in the medical treatises.

Sources

If we consider surgery (from the Greek *cheirurgia* meaning "hand work") as a medical specialty that treats illness by operative manual and instruments, its most important characteristic is wound management. Looking at the ancient Egyptian word for physician, we find the *swnw* written with an arrow-shaped hieroglyph. It has been suggested that the arrow shape has its origin in the fact that the primary occupation of

physicians was treating injuries received in combat. Physicians were experienced in removing arrows, similar to the god Thot, or perhaps they used arrowheads to lance abscesses. But a very limited number of pictures and only relatively few passages in the medical papyri describe surgical wound management in ancient Egypt. The Ebers papyrus (855–77), Hearst papyrus (217–27, 245, 260), London papyrus (29, 43–4) and, the most extensive, a complete scroll – the Edwin Smith papyrus – all contain descriptions.

References to surgical cases interspersed among prescriptions in the above-mentioned first 3 scrolls suggest that surgery was considered as part of any healer's art. This conjecture seems to be relevant for all three types of healers – physicians, priests, and magicians – since they are all named in the Smith papyrus when speaking about the examination of the patient's pulse. Ancient Egypt was, however, very advanced in medical specialisation and thus there might be a distinction among physicians dealing predominantly with surgical cases – as the priests of Sachmet are believed to have been specially trained surgeons (even for animals). Early distinction between surgery and pharmaceutical medicine is the most pronounced when looking at treatments of internal versus external cases: practically all the operations are directed at repairing external parts of the body, mostly for already existing damages.

The Smith papyrus was a manual for use by an army surgeon or practitioner for treating accidents or for teaching purposes. It is essentially a treatise on wounds, internal pathology, and bone surgery with meticulous clinical observations. It lists 48 cases of injuries and lesions along with the appropriate treatments. It follows the *a capite ad calces* (from the head to the calves) method, common in Western medicine until the Middle Ages. It starts with skull lesions, continues with caudal lying injuries on the head, in the neck, the clavicle, the humerus, the sternum, and the shoulders, and finishes with a description of the region of the spinal column, where it stops abruptly in the middle of the case of the fourth thoracic vertebra. But it was not the only ancient book in this field. It mentions, for instance, in case 5,

another one, with the title “On Wounds,” the structure of which could be similar to that of the Smith papyrus. It contained case studies for medical treatment with explanatory glosses, but it might also have been a teaching book for anatomical and physiological features, since it is quoted as an explanation of a physical condition that results when the skull is splintered. The Smith papyrus is matter of fact and sober and would even fulfil today's requirements. The inductive process that deals with these cases is the oldest known example.

Case Study

The surgeon elicited information by questioning the patient or directing him to attempt certain movements or postures. His own ocular, olfactory, and tactile observations were then added. For case studies, conditions were closely observed, symptoms described and effective treatments noted in a remarkably scientific manner. These procedures were, however, accompanied by an equally important religious/magical rite, known from different sources. For instance, the ancient Egyptians believed that the illness passed into the bandage (called *trap* in Eb. 2) and thus, with the removal of the bandage, the illness was also thought to be removed.

Wound Repair

The ancient Egyptians regarded symptoms of infection as part of the recovery process. They also realised pain, but interestingly, they never mention anaesthesia for use in surgical interventions, although they had means for it. The silence can be the consequence of both its non-existing (e.g., holding the patient down) or having methods which were trivial – e.g., being drunken. Its only possible occurrence is an Old Kingdom circumcision scene (see a comprehensive description in the article ► [Wound Healing in Ancient Egypt](#)).

Ancient practitioners were more deeply concerned with arresting haemorrhages, since

the *mtw* (Eb. 871), tumours (Eb. 875), and wounds were susceptible to bleeding. The main wound repairing methods were bandaging with an ointment or poultice, scorching (Eb. 872, 876) and surgery. In doubtful cases, enforced bedrest and normal diet were often recommended to the patient until he reached the decisive moment when the healer could give either a positive or negative prognosis.

In many cases, as mentioned in Eb. 510–42, injury treatment was restricted to various medicaments. For instance, a typical first-day treatment was to put raw meat on the fresh wound, which induced haemostasis. A suppurating wound was likely to be cured by honey (Eb. 513), which is hygroscopic (capable of easily absorbing moisture) and stimulates the production of white blood cells, or by astringent herbs such as acacia leaves (Eb. 527). They also used wound dressings which combined, for example, honey and *snt* (incense, Eb. 515) or wax and *mrḥ.t* (grease/oil, Eb. 518), providing protection and promoting healing. Discharge and suppuration might also be treated by fat, ground peas and fermented barley bread, causing an antiseptic and hygroscopic effect (Eb. 522) – and, in the case of bread, possibly yielding penicillin. These last materials were given in sequence: (1) ox fat on the first day to induce the wound to become foul; (2) barley bread for drying it; then (3) several other things alone or in combination on the following 4 days. Thorn pricks (Eb. 726–32) were treated with poultices or ointments. Similar treatments could also certainly be applied to artificial wounds.

We do not know the criteria the surgeon used to determine the place for an operation, i.e., *d w-^c* – “knife-treatment.” Neither is a special operating theatre mentioned thus far, which may mean that the operation was performed at the patient’s home.

Main Surgical Categories

Trauma (By Accident or Combat)

Based on many relatively good healing settings, we can assume that ancient Egyptian bone setting

was advanced. Among the skeletal remains from ancient Egypt, there are innumerable completely healed limbs with good realignment of the bone, but most other bone settings often show gross shortening and misalignment. Since fractures of the femoral bones often healed without complication, it may indicate, on the one hand, that the virulence and incidence of pyogenic pathogens was lower than they are today, although their existence is proved by the frequency of osteomyelitis. On the other hand, based on the skeletal remains of pyramid workers and other Egyptians, it is obvious that fractured limbs were splinted using an advanced technique suitable even by modern standards. Cleverly, if only one of the bones of the lower leg or forearm was broken, the remaining intact bone could serve as a splint for the broken one, and healing was satisfactory. In instances where the damage was so severe, however, amputation was an alternative course of action.

Representations of injuries are relatively infrequent. Two of them are accurate enough to mention: the accidents drawn on the wall of the tomb of Ipui which happened in the joiner’s shop and the pictures of the battle of Qades in various temples. Moreover, medical papyri, especially the Edwin Smith papyrus, are very accurate and detailed in the description of various types of injuries and their treatments. They tell us that the healer was able to characterise the most important types of injuries, impressive even by today’s standards. They differentiated among various types of swellings, fractures, and joint injuries.

Besides the superficial wound (*wbnw*), they cured the *wbnw kft* – a deep gaping wound, as, for instance, in Sm. 28, where the most important clinical sign for an open oesophagus, drinking water regurgitating through the wound, is mentioned. The axillary could also be open (Sm. 47). The most common complaints, swelling and fever, indicate that wounds were often infected. In the special case of perforation, the word *thm* is used. Wounds were often surgically treated by suturing with *jdr* stitching (Sm. 3, 10, 14, 23, 26, 28, 47) and/or bandaging (Sm. 2, 9, 10, 27, 47). Basic medicaments for curing were honey

and fresh animal meat, but, in specific cases, many other ointments and poultices were also applied (Eb. 510–42). Sometimes a sequential approach was used (Eb. 522).

In the case of fractures, the ancient Egyptians differentiated a simple closed *sd*-fracture, where the bone is broken in two, from a commuted compound or impacted *pšn*-fracture, where the bone is broken in several places. As a diagnostic clinical sign of fracture, *nhbhb*, meaning, in all probability, “crepitation,” is mentioned. The standard procedure for the reduction of fracture was traction (Sm. 12, 35, 36). And, indeed, many humeri were found in graves still set in splints. The first procedure was, after realigning the broken limb, to set it either with a splint wrapped in bandages, or encased in a healing poultice cast that could be made of various (often unidentified) materials; as, for instance (just to mention some known substances), cow’s milk mixed with barley (H 219) or acacia leaves bound together using gum and water (H 223). For reducing a fracture of the clavicle (Sm. 35), the ancient Egyptians also used a method still applied, but first described among Greek physicians by Hippocrates, by stretching the patient “on his back with a folded cloth between the shoulder blades” and pulling “on his two shoulders until the fracture falls into position.” Among the neurological complications, as in the case of an impacted fracture of the cervical vertebrae (Sm. 33), aphasia, unconsciousness and tetraplegia, are mentioned.

Concerning injuries to joints, dislocations (*wnh*) and sprains (*nrw.t*) were treated. In the tomb of Ipuï in Deir el-Medineh, there is a picture of industrial accidents. Among them the use of Kocher’s method for dislocated shoulders can be clearly discerned (For information on Kocher’s method, see <http://www.tki.unibe.ch/theodor.htm>). Other methods are described in the Smith papyrus, e.g., treatment for the dislocation of a jaw (Sm. 25). For neurological complications resulting from the dislocation of a cervical vertebra the inability to move the limbs, priapism, urinary incontinence, and intestinal dilatation with gas secondary to paralytic ileus are given (Sm. 31). In another case, a positive Lasague sign is described, i.e., pain due to a sprain of the

vertebral column when the legs are extended (Sm. 48), which indicates a prolapsed lumbar intervertebral disc with nerve involvement.

Based on two ivory slabs bearing the names of kings Aha and Djer (both first Dynasty), some specialists assume the use of tracheotomy, a procedure that opens the airways to maintain breathing. The slabs represent a man kneeling, with his hands tied behind his back and with a pointed instrument directed at his throat. As the man holding the tool is seated, the scene is unlikely to be a battle scene, and, since the process is not repeated in later representations and the situation is not described in later medical texts, an interpretation of ritual execution (?) is also possible.

Skull Surgery and Trepanation

According to the Edwin Smith papyrus, the ancient Egyptians recognised brain disorders and performed skull repair. They were also the first in the history of medicine to identify the inner parts of the cranium, as *tpw*, the falx cerebri, or protruding dura mater (The dura mater is the tough fibrous membrane covering the brain and the spinal cord and lining the inner surface of the skull. It is the outermost of the three meninges that surround the brain and spinal cord) – based on the description, or as *ntnt*, the meninges (Sm. 6). They also provided vivid descriptions of the brain and cerebrospinal fluid.

Parallel to the development of weapons, the number of head injuries increased (Fig. 1), thus causing a discussion of the many cranial injuries in the Smith surgical treatise. The dominant factor in healing, however, seems to be the *vis mediatric naturae*, the expectant healing power of nature. This is also manifest by the signs of treatment on heads with cranial injuries found by Elliot Smith, Wood Jones, Courville, and, recently, Nerlich, which are far from adequate if any medical treatment’s sign is present. A successfully recovered head injury to Amenemhab, who saved Thutmosis III from an attacking elephant in Nij/Mitanni, is known from literary tradition, while Breasted published the results of a palaeopathological examination of the mummy of General Ossi-numph-neferu, with a 7.5-cm long, caved-in, but completely



Surgery in Ancient Egypt, Fig. 1 Head of Seqenenre Taa II, showing multiple injuries acquired in battle (Source: LECA, A–P. *La médecine égyptienne au temps des pharaons*, Paris 1971, Fig. 94, p. 372)

healed, left side frontotemporal bone wound. This recovery is a great achievement even by current standards of surgical knowledge.

Craniotomies were well known in ancient Egyptian practice. A special treatment was trepanation, which is essentially making a hole in the skull without damaging the cerebral membrane. Today, only a few unquestionable cases are known of perfect healing at the edges that testify to a longer life, and, based on its absence in the Smith papyrus, it was certainly not regarded at that time as a medical treatment. But many other interventions were considered surgical, and some of them are given in the Smith papyrus with a modern scientific approach of clarity and diagnostic accuracy.

The first 8 cases in the Smith papyrus deal with various injuries of the skull (for details, see *Wound Healing in Ancient Egypt*). Pathological descriptions give clues to the identification of symptoms such as meningeal irritation, cerebral prolapse, nuchal rigidity (stiff neck), trismus

(lockjaw), tetanus, contracoup (brain injury), or hemiplegia (weakness on one side of the body). Complex case studies indicate a basic medical understanding of the function of the brain. They also knew their limits very well – when a cure was hopeless, palliative treatment was undertaken.

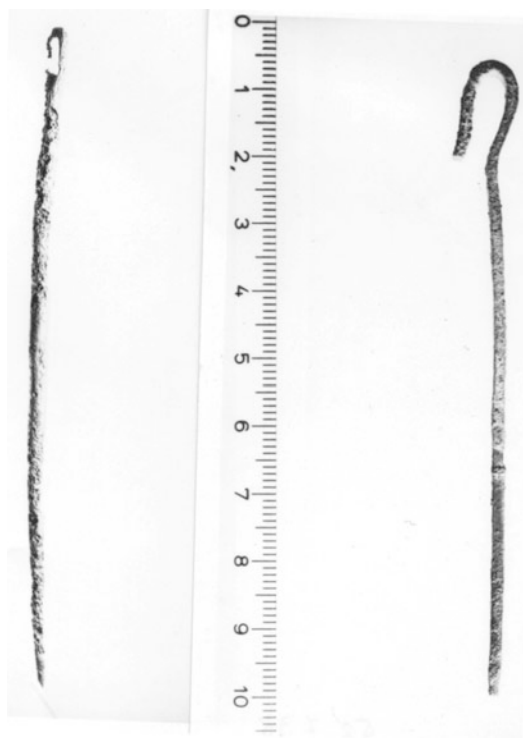
Plastic and Prosthetic Surgery

In some cases, wound treatment meant not only the healing of the wound but also the reconstruction of an earlier structure. Typical examples are Sm. 11–2 cases with plastic surgery of the nose. Besides the treatment of the fractured bone, by the usual means of application of *mrh.t* (oil/grease), honey and fibres, two fabric *ads* soaked into *mrh.t* were introduced into the cavity and applied to the bridge of the nose. Then the nose was bandaged above two linen pads, which protected the nostrils from distortion. The same reasoning led to the fixing of the auricle by means of a small cushion after the suturing of the ear in Sm. 23. Following local applications, a supportive bandage was also recommended for an ear wound in Eb. 766.

A surprising innovation in ancient Egyptian medicine was the use of prostheses (artificial limbs). We know that long ago there was a post-mortem nose prosthesis, for instance, on a Ptolemaic period Gamhud mummy, clearly shown by the fact that the straps are above the mouth and the chin, which then go to the base of the cranium where they are tied in a knot. Consequently, for a long time it was thought that restorative surgery was only used by embalmers to maintain physical integrity for eternal life.

There were doubts about the earliest prosthetic contrivance, two 4th Dynasty teeth fixed together by a golden wire, found in the Gisa cemetery. After a long debate, the conclusion seems to be that it was made for a dead person (The next artificial teeth, the holding of a maxillary bridge by a silver wire, were found in the Ptolemaic period.).

A prosthetic big toe, however, recently discovered in Thebes on a mummy of the 21st/22nd Dynasty in Tomb 95, was certainly made for a living person (Fig. 2). The linen-wrapped



Surgery in Ancient Egypt, Fig. 2 Hook and needle in the Egyptian collection of the museum of fine arts, Budapest

foot and leg show evidence that the amputation was cleaned and prepared for this device. The amputation is completely healed, and the wooden prosthesis, made up of three separate components, is worn on the sole, which indicates that the owner lived long using the prosthesis after the accident (As a reason for amputation of the toe, ischaemic gangrene has been suggested.). Another (in this case cartonnage (Cartonnage was papyrus or linen soaked in plaster, shaped around a body. It was used for mummy masks and coffins)) toe prosthesis from Thebes around the same period, kept in the British Museum, was applied also to a living person; again, wear and subsequent refurbishment can be observed.

Pathological Extensions

Pathologies were well differentiated: several sorts of tumours, abscesses, cysts, swellings, boils, etc. (*hn̄hn.t.t*, *sft*, *nw.t*, *šfw.t*, *hsd*, *tw.w*, *bsj*, *hm*, *sh*, *bnw.t*, *wnm-snf*) are mentioned in the

Ebers, Hearst and Berlin papyri, with very brief medical instructions. These might have been treated in the following ways:

- Medicaments, for instance, Eb. 51–581, 855–62, H 41, 132–33, 136–39, Bln. 52–7 or the last step in Eb. 877;
- ... treat it similar to the treatment of the *s-hmm* “(firebolt?-man)” for scorching the skin-like flesh-protrusion in Eb. 863 or the (umbilical or epigastric?) hernia in Eb. 864.
- *thn* – piercing with the *Hmm* as in Eb. 865 for the ascites (fluid in the abdomen);
- *dw*-“knife-treatment,” meaning, probably, excision, as in Eb. 866 for a vascular tumour (haemangioma?), Eb. 867 for a presumably subcutaneous lipoma; Eb. 868 for a possible sebaceous tumour with metastasis (*tnts*); Eb. 869 for an abscess; Eb. 870 for a swelling, the identification of which has several possibilities, such as a dermoid cyst lined with skin appendices, pilonidal sinus located in the mid-line or sebaceous cyst of the scalp, as, for instance, atheroma; Eb. 871 for an abscess in the axillary lymph glands;
- *dw*-“knife-treatment” with heated (*sšmm*) knife as in Eb. 872 for a probable haemangioma;
- Either excision or scorching according to the state of the tumour, as in the first 2 cases in Eb. 876; or
- The tumour was left untreated, as Eb. 874. This might have been leprosy, or in Eb. 873, a possible cavernous haemangioma, or a twisted vascular swelling forming knot (in this case, however, the *mtw* should be straightened). The first 2 steps in Eb. 877 are still unidentified although cancer, cutaneous leprosy, bubonic plague, or neurofibromatosis have already been suggested. In the last step in Eb. 876, the ball-shaped extensions have tentatively been identified by Regöly-Mérei as varicosities.

In all the above cases, procedures are not described and thus nothing definite is known. The only complex and detailed surgical process is given in the Ebers papyrus (Eb. 875) – with

various knife and forceps devices – and is, in all probability, the month-long treatment for dracunculiasis (Dranunculiasis, also known as Guinea worm disease, is a painful and debilitating infestation contracted by drinking stagnant water contaminated with Guinea worm larvae that can mature inside a human's abdomen until the worm emerges through a painful blister in the person's skin) (which may be the origin of the caduceus, the medical emblem with snakes), and thus a very atypical surgical invention.

Circumcision

Herodotos (II.37) wrote: "They practice circumcision for cleanliness, for they set cleanliness above seemliness," but we find no mention of it in any medical or iatromagical text, and its two representations hint at a sort of feast for ritual initiation, probably for procreative purposes. Conceivably, the traditional practitioners had religious ties, and were most probably priests, since the fulfilling of the cleanliness doctrine was the most important one for temple workers. Based on a representation of the tomb of Ankhmahor, it was performed by a scalpel or some sort of blade. Following the Ptolemaic rule, physicians could do it, too, as later the use of Roman instruments, such as forceps and scalpels, was common in this field.

There is only one mention in the First Intermediate Period stele of Uha of circumcision being performed on females in Pharaonic times, where a crowd of men and women are participating in the cultic rites that accompanied the procedure. It seems, based on this mention of a communal feast, that female circumcision was also primarily ritualistic and it has been hypothesised that it was also associated with temple activities, although I think it was primarily the same sort of fertility rite as that for men – at least the above communal feast hints at it. We do not know, however, how popular the act was, or when, how or why it came into existence. In any event, it must have lost its festive side, as it never appeared again as a public act. It must not have been obligatory, since virgins were also referred to as *m'.t*—"uncircumcised," from the Middle Kingdom on. Based on the state of preservation

of the pubic area on mummies, the fulfilment or non-fulfilment of the act of circumcision cannot be definitively determined. According to written sources, however, in Graeco-Roman times, nymphotomy/clitoridectomy seems to have been a widespread custom in Egypt. Soranus (second century B.C.E.) first recommended the process for girls with excessively large clitorises. He gave as the reason for the operation the shame that results from its erection and the girl's excessive desire for sexual indulgence caused by the abnormality. According to Aetios, who used Hellenistic and Roman imperial sources, the ancient Egyptians excised the clitoris especially around the time when the girl was about to be married.

Burns

In the Ebers papyrus, there is a complete book on wounds originating from burns: 482–509. No. 482 lists a sequence of remedies which, it says, should be applied consecutively. In other cases, remedies applying an ointment or a bandage are the same during the entire treatment. Similar to cases in the London papyrus (15–21, 46–8, 53–61) and also among the Ebers papyrus prescriptions (482–500), magic spells had to be cast, referring to Horus having been burnt in the desert. According to the incantation of Eb. 499 which had to be recited with mother's milk, Isis used "water in her mouth" and "Nile springing between her thighs." Mother's milk, gum, and ram-fur (having a high cholesterol content) were put on the burnt wound. As for surgical procedures, Eb. 504 speaks about opening a blister with a sharp thorn, and Eb. 501 mentions an incision on a blister sandwiched between two prescriptions, but, as usual, without any details.

Various Types of Bites

According to the Brooklyn herpetological papyrus, snakes and the effect of their bites were accurately identified, and their bites treated with rational medical care. The treatments comprised the application of a bandage with salt and natron, (Natron was a salt (sodium carbonate and sodium bicarbonate) that was used in the mummification process to dry out the body of the deceased in order to assist in its preservation) both being

antiagglutinant (An antiagglutinin is a substance that makes particles (such as bacteria or cells) stick together to form a clump or a mass) and antihaemolytic (Haemolysis is alteration, dissolution, or destruction of red blood cells in such a manner that hemoglobin is liberated into the medium in which the cells are suspended, e.g., by specific complement-fixing antibodies, toxins, various chemical agents, tonicity, or alteration of temperature) thus impeding the absorption of the venom; drinking of emetic remedies with various material to get rid of venom by vomiting; fumigation as adjuvant; magical spells for general and specific divine help and/or the *ḏw*-^c “knife-treatment” and the *tštš*-incisions in the swelling.

Other types of bites, such as those from crocodiles (Eb. 436, H 239–40, 243), lions (H 244) and humans (Eb. 432–35, H 21), were treated like any other wound, preferably by applying fresh meat on the first day and, subsequently, honey, wax, and *mrḥ.t* as in Eb. 435 or by using other herbal remedies, occasionally with the addition of some animal ingredients.

Dental Surgery

Dentistry is among the earliest medical fields in ancient Egypt. Even the first known Egyptian physician, Hesira, was a dentist. A wide range of dental treatments is listed in the medical papyri, such as filling teeth, treating gums or abscesses, and reducing halitosis. But no surgical inventions are mentioned, although an alveolar process using piercing to drain an abscess under the first molar has already been found in a mandible from the fourth Dynasty. Neither is tooth extraction described, and, based on the many abscesses and cysts found on mummies, was rarely, if ever, practiced.

Surgical Devices

There were several specialised surgical devices (Fig. 3), as various types of knives for cutting tumours, needles for suturing, several types of spatulas for applying the medicaments, “fire drills,” and metal cauteries for operations and disinfection. They made splints and bandages



Surgery in Ancient Egypt, Fig. 3 Prosthetic big toe from Thebes

very skilfully, having specialised books on this topic – primarily for the embalmers, but as the Smith papyrus says, physicians used them as well. Hooks and forceps were probably also often common with the embalmers, although such devices as the small leather forceps, called *hnw(h)* must have been a surgical speciality. They also used several natural objects, such as acacia thorns for cutting up blisters and the bulrush knife for removing elastic foreign bodies. Seemingly they were adapted to the various functions surgeons had to accomplish during the various stages of different types of operations. Parts of the instruments were also used for cosmetics; ointments were made and applied the same way for both purposes. The execution could have been of different quality according to the demand, although they are mostly primitive. The problem is, however, that only a few surgical devices survived (often unprovenanced), and representations are missing – the Kom Ombo temple relief originates from the Roman times, so ancient Egyptian and Roman medical instruments are

already mixed. We do not have detailed knowledge of pharaonic surgical devices.

Surgeons

The practitioners of all the above procedures might have been very different people. Surgeons, i.e., medical practitioners specializing in surgery, seem not to have existed in the modern sense during Pharaonic times. Operations were performed by the practitioners, dentists, priests, or magicians. For combat/battle injuries there was a military physician, problems with teeth were handled by a dentist, complications of the ear or nose were treated by the specialist or by a general practitioner. For bites, the *hꜣp Srdt*, the “controller of Selket” was responsible, while circumcision might be the task of the *kz*-priests.

Surgical procedures are, however, attributed by Egyptologists most often to the priests of the lioness goddess, Sechmet, who were veterinarians (as the ancient Egyptian said: “one who knows bull”) too. Aha-nakht, a colleague of the *swnw* Hery-shef-nakht, of the Middle Kingdom introduced his picture in his Hatnub graffito with the words: “The scribe of the hall of judgement, Aha-nakht. I am a wab priest of Sekhmet, capable and skilled of his brotherhood, who places hand on a man when he knows it (i.e., the illness), skilled in examining strongly and one who knows bulls,” thus attesting to a medical connection for these priests. The *dw*-‘- knife-treatment, however, is said in Eb. 501 to belong only to the *swnw* physician as the secret knowledge of the beating of the heart belongs as well to the *swnw* as to the *wꜣb* priest of Sekhmet and to the magician.

The account given in this article represents the state of surgery during the New and, probably, the Middle Kingdom periods in Egypt, since our sources date mainly from these periods, but it was probably not very different during the preceding and following periods. Wound management has always been an important part of human life and thus probably the first medical books (see ► [Medicine in Ancient Egypt](#), especially the note on Egyptian Medical Papyri) already contained

appropriate instructions. It is unknown, however, how much they differed from the Middle Kingdom methods, where the latest research places the original of the texts of the Smith papyrus. The concept was probably the same, as we find in the few New Kingdom Berlin papyrus prescriptions for bite and the very complex 30th Dynasty (?) Brooklyn Museum herpetological papyrus. A great transformation seems to have taken place only later, with the gradual fusion with Greek medicine via the Alexandria School.

Surgery would be used in ancient Egypt only if a cure could not be achieved by means of prescriptions or other methods, and if the patient was not in a terminal condition, when only palliative steps were taken. And, indeed, it was often the best solution as success would certainly not be guaranteed even in standard operations, in spite of the relatively advanced methods, due not only to imperfect anatomical knowledge, but also to the lack of both effective anaesthetics and of antiseptics and the low level of hygiene, which could lead to septicaemia.

See Also

► [Hair in Egypt](#)

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Surgery in Ancient India

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The *Rgveda*, the earliest account of ancient Indian civilization, makes mention of the Ashwini Kumaras, known as *dev vaidya* (doctors of the gods). They were the chief surgeons of the Vedic period who had performed rare legendary surgical operations. Without entering into the complicated references of ancient texts on this, the latest simpler version is provided by Ahuja and Mishra (2014) in a brief overview mentioning the legendary surgeons and ancient Indian Ayurvedic surgical practices.

The *Rgveda* says that the Ashwini Kumaras performed the first plastic surgery to rejoin the head and trunk of saint Chyavana when Dakshya cut his head. Their other classic works include: an eye operation of Reejashva, the implantation of the teeth of Phushna in his toothless mouth, the transplant of the head of a baby elephant on

Ganesha whose head was cut by Lord Shiva in a rage of disobedience, rejoining the head of Lord Brahma and saint Dadhichi severed by demon Bhairava, and transplant of the head of a horse on the body of *Dadhyancha* preserved through *madhu vidya* (honey method). In addition, they transplanted an iron leg on Bispala, the wife of king Khela, who had lost her leg in war; they also operated and repaired the excised head of Yagyana by Rudra. In other words and on the face of it, the Ashwini Kumaras were doing both homo- and heterotransplantations at the very ancient time of *Rgveda* 5,000 years ago!

Such miraculous magical surgical skills of the *Rgvedic* time may seem mere legends or mystery to modern medical science and we may not even believe that. Nevertheless, they do reflect some special surgical skills which laid down the foundation of the *Āyurveda* – the fifth Indian Veda – the classical medical system of India.

However, the realistic and systematic earliest compendium of medical science of ancient India compiled by Caraka is known as *Carakasamhitā*. It describes the works of ancient medical practitioners, like Acharya Ātreya and Acharya Agniveśa of 800 BC, and contains the *Principles of Āyurveda* that remained like a standard textbook of *Āyurveda* almost for 2,000 years. They were followed by Acharya Suśruta around 600 BC, who was a specialist in cosmetic, plastic, and dental surgery, called *Sandhan Karma*. He treated numerous cases of *Nasa Sandhan* (rhinoplasty), *Oshtha Sandhan* (lobuloplasty), and *Karna Sandhan* (otoplasty). He is therefore known as the “Father of Surgery,” and his works are compiled in the *Suśrutasamhitā*, which describes over 120 surgical instruments and 300 surgical procedures and classifies human surgery into eight categories. He described 60 types of *Śāsti-Upakrama* (treatments for wounds).

Considering the great surgical skills achieved by ancient Indian surgeons, right from the Ashwini Kumaras, Chyavana, Dhanvantri through Ātreya, Agniveśa, and Suśruta, brain surgery (craniotomy) was likely practiced in a more sophisticated way which had very much improved upon the protohistoric trepanation then in vogue elsewhere in the world. It is quite

likely that the trepanation gave way to early ancient Indian surgical practices which eventually developed into the modern scientific surgical skills of the Āyurveda much before they spread elsewhere and got assimilated with similar indigenous traditions, such as Greek, Unani, or Hikmat.

Trepanation

Ancient Indian surgical knowledge is expected to have evolved quite early from the Bronze Age and Neolithic traditions of trepanation then performed by flint, copper, and bronze instruments. The advancement came with mastery of iron smelting that produced not only iron weaponry but also various kinds of surgical instruments for craniotomy. At the same time, there were refinement and new discoveries of better and safer anesthetics and pain-killers to use during surgery.

Of course, trepanation, also called trephination or trephining, in which the brain was exposed by drilling or cutting through the skull vault, was a very primitive surgical practice common in the Neolithic, Chalcolithic, and Bronze Ages. It was used both for medical and magico-religious reasons, done either on the living person (antemortem) or just after death (postmortem). We view such surgical intervention on the human brain case frightening even today with modern technology, so we can imagine how terrifying trepanation was for the patient when done by ancient surgeons as early as 5,000 years ago with archaic implements like flint knives, shell scrapers, and drills using crude anesthetics and pain-killers! The survival of the patient depended much on the ability of the medical practitioner. Trepanation has aroused great interest among historians of medicine and religion, anthropologists, archaeologists, and the general public.

Historical Background

In the global context, this author (Sankhyā & Robbins Schug, 2011) presented a glimpse of the

history of trepanation, and more recently Comşa and Sankhyā (2014) elaborated on various types of trepanations and their expansion, techniques, and complications. It is still unknown where the first trepanation was performed. Squier (1863) and Broca (1867) were among the first to draw attention to this practice in Peru. Piggott (1940) thought that it had begun in Europe around 5,000 years ago. In Asia, trepanation is evident from around 4,000 years ago in the Bronze Age of Jericho in Palestine (Giles, 1953; Parry & Starkey, 1936). In Europe, there are good examples of trepanations (Andrushko & Verano, 2008; Bennike, 2003; López, Caro, & Pardiñas, 2011; see Comşa & Sankhyā, 2014 and Erdal and Erdal (2010) for more references) from the Neolithic sites of France and Germany. In Africa, Egyptian skulls show trepanation; the Kabyles, Berbers, Kisii, and Masai are said to still follow trepanation as a medical practice. In Asia, the use of trepanation is known from Afghanistan, the Indian subcontinent, China, southern Siberia, and Japan. It is also known from Oceania in the Polynesian Islands, Bismarck, New Britain, New Ireland, Tahiti, and Melanesia. The North American continent presented a few cases, but most come from South America, especially in the Andean Mountains of Peru, Paracas, Huarochiri and Jauyos, and Cuzco. In Bolivia, trepanation sites date between the fifth and sixth centuries AD.

In India, the earliest trepanations are known from Neolithic Burzahom ca. 4300 BP and Harappa, whereas their last occurrence is seen in a 2,000-year-old Iron Age megalithic skull at Maski in Karnataka (Sarkar, 1972). However, there is general lack of evidence of trepanation in ancient India, probably due to the practice of cremation of the dead which was widespread right from Vedic times, and the evidence, if it ever was present, is lost forever. Moreover, the non-tribal mainstream or semi-urbanized ancient Indians also had access to the advance Ayurvedic surgery which the tribal populations did not. This is the reason that trepanation remained in vogue in many isolated tribal groups of the world as mentioned above who stay away from mainstream civilization and follow their traditional beliefs and practices.

Trepanation Methods

In prehistoric times, the flint or obsidian blades were used for such a purpose. Later, copper then iron scalpels were developed. The skill of the surgeon was necessary for the survival of the patient during this awesome operation that involved cutting off the skin and flapping of the scalp and exposing the brain *dura mater*. The ancient surgeons decided on the equipment and methods according to each case, which varied from scraping, gouging, sawing to drilling, and also combinations of these. A canoe-shaped rectangular depression is seen in Peruvian, French, and Palestinian sites (Brothwell, 1994). The Inca in Peru made “grit-like” or reticulated trephinations for healing cephalalgias, abscesses, tumors, or mental illnesses by “crosscut sawing” techniques identified there in 1936; it is rarely found in the Old World (Brothwell, 1994). There are instances where this technique was applied on living patients, in Troy VI Ikiz Tepe and in Lidar Höyük in Turkey (Erdal and Erdal, 2010), and on patient who survived several years. Other similar cases come from Palestine, at Tell Duweir operated by the crosscut sawing technique. The “scraping-cum-incision technique” was applied in some cases on Bohemian skulls. Another technique called “linear cutting” was common in the central highlands of Peru.

Trepanation for Medical Reasons

Many scholars, notably Ullrich (1971), Anda (1951), Verano (2003), Ortner and Putschar (1985), and Bereczki and Marcsik (2005), observed that most of the trephinations in Neolithic and Bronze Age Germany were used for treating and had pathology followed by cranial and postcranial trauma. The patients felt relieved after the bone splinters were removed and the wounds were healed. Other indications for trephination were osteomyelitis, osteitis, periostitis, convulsions, melancholia, epilepsy, paralysis, tumors such as osteomata, cancer metastasis, myeloma, osteosarcoma, meningioma,

echinococcosis, Hand-Schüller-Christian illness, eosinophilic granuloma, lymphogranulomatose, and cerebral abscesses. Certain troubles in the spine and skeletal parts were also treated by trephination, including neurological disorders and mental retardation. Trephinations were also done in certain acquired disorders, metabolic and endocrine malfunctions, tumors, tuberculosis, syphilis, infections, neoplasm, and cysts (Comşa & Sankhyani, 2014).

Large trepanning holes were made in cases of fracture or trauma and the trepanned area was protected in various ways. The Inca, for instance, employed tree bark, golden plaques, or bone fragments. In Melanesia, the cut was covered with banana skin, coconut, or tree bark. The cranial vault bone is not elastic so its healing is not easy and depends more on the metabolic condition, environment, and age of the patient. Therefore trepanation intervention was carried out upon an individual in full health, by a skillful person. The regeneration layer results from conjunctive tissue and not from bone. But, gradually, the bone edges get rounded and eventually fuse together covering the wound.

Magico-religious Trepanations

Scholars have reported many cases where trepanations were also done for the bony roundels or bone disks or roundels to serve as amulets to ward off evil spirits. They were taken from an individual in order to take over the spiritual powers of a dead person as a trophy or amulet. The ancient people wore amulets made of human skulls or other bones believing they transferred the spiritual powers of the dead to them and could protect them against evil spirits. Trepanations for roundels were usually performed postmortem. The roundels appear to have played a significant role in ancient times. The interpretations of the archaic communities around the world were mostly connected with the unknown forces of nature, and this is why the magical-religious practices were very important for those people. Another argument is the fact that, although the

cutting off of such a bone roundel was an act that demanded a lot of care and precision, the amulet had to meet certain criteria. Since the ancient people were mostly practical, we do not see any reason they would have made such amulets or trophies of human skulls or pieces, unless they were considered to be highly important.

In Eastern and Central Europe, we have some good examples of such roundels, from Raklo in Bulgaria or from sites like Nynice, near Plzeň (Hallstatt); Prosmyky, near Lovosice; Tuchoměřice, near Prague (La Tene) in the Czech Republic; or Kunzig-Ost in Germany (Comşa & Sankhyan, 2014). Modern astrologers still suggest that people wear precious stones to gain magic and healing properties.

Pseudo-trephinations

These are sometimes confused with simple holes of different dimensions formed due to physiological, metabolic, and endocrine malfunctions, tumors, infections, syphilis, cultural mutilations, or taphonomic agents, formed antemortem or postmortem (Comşa & Sankhyan, 2014).

Trepanations in India

Roy Chowdhury (1973) opined that trepanation was done on two Bronze Age Harappan skulls from Cemetery R37, namely, Nos. H 802/B and H 796/B. He, without specification, also regarded the presence of trepanation on one Kalibangan skull – at a Harappan site. Sarkar (1972) mentioned that trepanations were also done around 2,000 years ago in the Iron Age megalithic skull (M30) from Maski in Karnataka, South India. He explained that the two circular holes of 22 and 15 mm, respectively, on the either side of the sagittal suture of the vertex (the top of the head) are indicative of trepanation. He also attributed a squarish hole on the right temporal skull of a child of 9–10 years from Lothal, another Harappan site in western India. Sankhyan and Weber (2001) and Sankhyan and Robbins Schug (2011), however, confirmed and described two true surgical trepanations, multiple on a Neolithic Burzahom skull (SKL 7, BZH-3) from the Kashmir Valley (ca. 4300 BP) and one on a Harappan skull, No. H796/B. However, other cases of the claimed trepanations are needed to be confirmed by X-rays or scanning (Fig. 1).

Surgery in Ancient India,

Fig. 1 The author showing the Harappan (Right) and Burzahom (Left) trepanned skulls in his laboratory



Trepanated Harappan (Left) & Burzahom (Right) Skulls in Palaeoanthropology Laboratory of the AnSI Kolkata

Harappan Trepanation

The Harappan trepanned skull (H 796/B) comes from cemetery in Square R37 located on slightly raised ground to the south of the preserved fractional burial with the head turned on the cheek and the skeleton of burial oriented in N–S direction. All the three skulls, Nos. 796, 796A, and 796/B, form one burial (Gupta, Dutta, & Basu, 1962).

The Trepanned Harappan Skull

The authors of *Memoir No. 9* (Gupta et al., 1962) have studied the Harappan skulls and correctly allocated the No. 796/B to a 25–30-year-old adult male in sub-mesocranic category with the LBI = 75.84, who had a cranial capacity of 1336.67 cc. But, they have made no mention of any cranial trauma and trepanation done on it or other skulls. Therefore, except for Roy Chowdhury's (1973) preliminary mention but without any image, it was not until 2011 that I made the first illustrated highlight of the trepanation at Harappa in the journal *Current Science* (Sankhyan & Robbins Schug, 2012) with a few passing remarks.

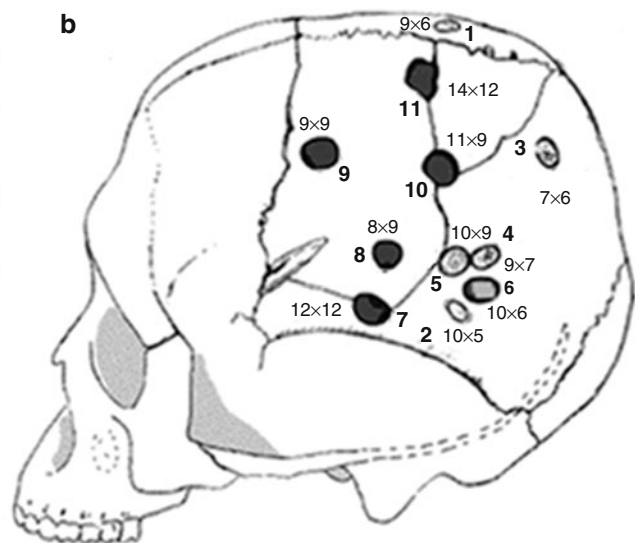
The trepanated Harappan skull possesses two depression fractures on the right parietal close

together, as if fused by healing. A fracture superior to and running parallel with the temporal line caused plastic deformation and upheaval of the bone from the coronal suture to the parietal eminence. A second fracture runs perpendicular to the first, from the sagittal to the squamous suture. This fracture caused a linear depression with cracked margins visible on the parietals probably resulting from a severe blow using a strong wooden club. The trepanation was obviously carried out to remove the bone splinters and blood clotting or hematoma and clean the wound as a surgical operation. Whether the man survived the operation may be debated, and the senior author in Robbins Schug et al. (2012) desires computed tomography for confirmation of sclerosis.

However, even further examinations (Fig. 2a) under 20× magnifications show that a thin membranous growth is still visible on the inner margins of the trepanated circular hole despite the preservative coat applied on the skull by the excavators or later workers. Mishandling at the time of excavation (the first reporters were ignorant of the presence of trepanation) and later by many workers, the delicate rejuvenated part might have been damaged and lost. Hence, now we may not expect a prominent evidence of sclerosis even through scanning. Nevertheless, the



- Trepanned hole Measurement in mm
- Trepanned depression



Surgery in Ancient India, Fig. 2 (a) Enlarged view of the trepanned hole in Harappan skull H796/B. (b) Trepanned Burzahom skull SKL 7 showing trepanation process

trauma stands as unequivocal cause and witness of a surgical operation done on this skull.

Burzahom Trepanation

The Site and Burial

Burzahom is in the heart of Srinagar City in the Kashmir Valley which is a cup-shaped Himalayan valley surrounded by high mountains. The site was excavated during 1961 and 1968, which yielded ten human skeletons of different cultural stages: Neolithic, Neolithic–Megalithic, and early historic cultures. It is the Neolithic Phase II which has yielded seven human skeletons in the burials, and the trepanated skull (SKL7, BZH-3) is one of them, dated between 4300 and 4000 BP. The burial of the skull had animal bones, antler, horn pieces, and a circular soapstone disk associated with it. The skeleton was in its primary articulation and found in a crouching position, oriented NE–SW and at a depth of 7 ft 4 in. (2.24 m) from the surface level (Basu & Pal, 1980). The skull was reportedly covered with red ochre. The trepanned side of the skull was lying upward, facing the surface.

The Trepanned Skull

The trepanned skull is of a female aged 26–30 years and hyperdolichocranic (very long head), with a long nose and greater calvarial (skullcap) height; the face is narrow and the cranial volume is 1,353 cc, with good dental condition and medium tall stature at 159.1 cm. The forehead is low and slightly receding, with a distinct postglabellar (the space between the eyebrows) depression. Greater affinity is shown with the mature Harappan from Cemetery R37) as well as the modern Punjabi people of northwest India. The cranium shows left-sided swelling or exaggeration/hypertrophy.

Trepanation Process

The Burzahom trepanation was first noticed by Allchin and Allchin (1968) but ascertained by Roy Chowdhury (1973) for medical reasons. However, Basu and Pal (1980), who studied the skeletal features, accepted the presence of

trepanation but considered it a purely postmortem attempt for extracting the roundels as votives/amulets for magico-religious purposes and not for medical reasons. My detailed examination of the original skull, however, leads me to conclude that the trepanation on the Burzahom skull was done for medical reasons.

Although the skull shows multiple trepanations, I think the reason for trepanation was a head injury since the vault is fractured, having a clear fracture line connecting the three larger trepanned holes. In all, there are 11 attempts at trepanation probably done in different stages. The shallow and elongated depressions where only the outer table of the bone is removed probably were for the initial treatment of the patient, and then three actual trepanned holes were made for bloodletting, apparently in a triangular fashion to cover the maximum area to remove the blood. The patient could have not survived since there is no clear evidence of healing of the bone (osteogenesis and sclerosis) visible inside or outside the punctured holes. Roy Chowdhury, however, believed that there is evidence of a ring of sclerosis (callous) around one hole but did not specify the hole. Basu and Pal (1980) also did not recognize any evidence of sclerosis and came to the conclusion that it was not a surgical operation either performed while alive or after death.

I recently reviewed the earlier study and reclassified the 11 perforations into five depressions (1–5) and six trepanned holes (6–11). In the first sitting, the surgeon started his treatment of the patient with a gentle stroke given on the top of the head with a view to see if the patient could be relieved of the pain and chronic ailment and return to normal. This stroke caused a small depression (1) on the top of the cranium. With the same intention, the surgeon gave the second stroke but this time down below on the left parietal bone (2). The third stroke was tried on the posterior extreme (3). All the three strokes were probably given in a single sitting after brief intervals, which resulted in three impressions or shallow depressions (2–3) on the cranial vault. In the second sitting, when the patient could not get any relief from the earlier treatment, the surgeon gave two greater strokes on another site which caused

deeper depressions (4 and 5), followed by another and bigger one that removed the outer table of the bone into the diploe space by perforating the skull slightly but leaving the inner table intact (6). Again, when the patient showed no sign of relief, the surgeon thought of real deeper interventions in the third sitting, which perforated the cranium and formed two complete holes (7 and 8) made close by possibly for bloodletting and taking out the degenerated blood tissue. They are almost of the same size and outline and were made very neatly and carefully made by the same instrument. Finding no relief to the patient, the surgeon made another trepanation in the fourth sitting, which was probably his last effort on the living patient when a single neat rounded hole (9) was made. However, the patient perhaps succumbed to death in this attempt, so that the remaining two holes (10 and 11), which are bigger in size and uneven in shape, were most likely a postmortem study trial to ascertain the cause of the pathology and for a simple demonstration/training to a future surgeon. There are fracture lines emanating from these big perforations indicating that the patient had suffered from a trauma. Because she had no cure, she might have turned insane or epileptic and wandered here and there and likely fell down and got the head injury evident from the cranial trauma. This trepanation was therefore necessitated for surgical reasons to treat the injury.

No special instruments that could have been used in trepanation were found in the trepanated burial site except some animal bones, antler, horn pieces, and a soapstone circular disk. It is possible that the antler piece or animal bones could have been used as drills of various diameters for trepanation. Erdal and Erdal (2010) observed that only the drilling technique with flint or bone drills was practiced during Neolithic times, whereas the cutting and scraping techniques were developed later with bronze instruments during the Bronze Age, followed by iron instruments during the megalithic period. With this background, although trepanation is the job of a specialist, the possibility of a Bronze Age Indus surgeon speculated by George Weber earlier (Sankhyān & Weber, 2001) seems unlikely.

I concur with Basu and Pal (1980) about the extraction of the roundels from the Burzahom skull except in the postmortem trepanation. I consider it less likely that the Burzahom skull was intended for extracting roundels which are possible through a cutting technique and not by the drilling evident at Burzahom. The drill would rather damage the bone and push that inside the skull making the piece irretrievable. Human skulls and bones are used by sorcerers and magico-religious experts in spiritualistic treatments, yet there is no direct evidence to support the idea that the Burzahom trepanation was intended for extracting roundels as votives. There could have been spiritualistic treatments of the patients, but trepanations were attempted with a surgical motive, even though the patient could not survive the procedure. The retrieval of cranial roundels could only be the last thought after the postmortem operation but lacks evidence.

Who Was the Burzahom Surgeon?

If it was a case of surgical operation, then who performed the surgery is the mind-boggling question. In this quest, I recently re-scrutinized the craniometric data of 10 skeletons and noticed homogeneity, except the cranium of skeleton 6, which stood at a contrast. Although (Basu and Pal, 1980) had diluted its significance by attributing the differences to individual variation within a community and not due to any migration to Burzahom, I believe that he could have been the man brought to the community as a medical and spiritual healer – a shaman. He was a very robust man of an age between 51 and 55 years. His skull is mesocranic (round or as broad as long) with LBI (74.9) and receding and low forehead (frontal). His face was very broad with large bizygomatic diameter (150 mm) and the nose also similarly very broad (hyperchamaerrhine, nasal index 68.0). All these features made him a person of phenotypically very distinct population since all other skeletons of Burzahom collection are of long-headed (dolichocranic) to very long-headed (hyperdolichocranic) people with long and narrow faces and longer noses. Burzahom men were also taller (SKL 1 = 176.4 cm,

SKL 9 = 178.5, SKL 10–177.1 SKL) than the “robust” man (173.4 cm). There is great paucity of comparative data, but the craniometric data table of Basu and Pal (1980) lists one such very similar skull (NGK 7) in contemporary Neolithic Nagarjunakonda (Andhra Pradesh). How could he have come from such a distant place as South India to Kashmir? Either the seminomadic people of Burzahom had some information about this man or he was a crazy tourist who walked over to visit the Himalayan paradisaical Kashmir Valley. He was accepted by the Burzahom community for the treatment of their young women, first spiritually and then medically and finally surgically. For his acts of kindness, he was allowed to stay with others, and the valley attracted him to spend his life there. So he was buried in their settlement.

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Surveying

Frank J. Swetz

Surveying is the mathematical science that incorporates the application of geometric principles with concepts of measurement in order to delineate the forms, position, and extent of terrestrial features or man-made structures. It is an ancient activity that has been used by all urbanized societies. The establishment and maintenance of land boundaries, the construction of walls, and the lay out of irrigation systems and aqueducts rely on the use of some kind of surveying. Extent structures such as Stonehenge in England, the Great Wall of China, Machu Picchu in the Andes of Peru, the Great Pyramids of Giza, or the temples of Angkor in Cambodia testify to their builders' knowledge and use of surveying. However, all too often, in the ancient world, surveying activities were the closely guarded prerogative of an elite, members of a priestly or bureaucratic class. Knowledge of their mathematical discipline was usually transmitted orally from master to student. Such practices, combined with the ravishes of time, account for few existing documented records of old surveying practices and techniques. Therefore, much of what can be gleaned about surveying in early non-Western societies is speculative in nature and rests on extant archaeological and architectural evidence.

The most basic of surveying activities include the determination of straight horizontal and vertical lines and the establishment of a level plane

upon which structures can be erected or reference slopes established. Instruments to achieve these goals are strikingly simple: straight horizontal lines can be obtained through the use of sighting poles or stakes and retained by the use of stretched cords or ropes; straight vertical lines are obtained by the use of a plumb bob, a weight suspended from a string, and a level plane can be constructed with the assistance of a leveling device such as a water-filled trench.

Rope Stretching

Herodotus (ca. 484–425 BCE), the Greek historian, attributed the origins of geometry to the Nile Valley of Egypt, where priest-surveyors stretched ropes to mark out land boundaries. These “rope-stretchers,” or as Herodotus called them *harpedonaptae*, are the first historically recognized surveyors. Rope stretching activities also took place in Babylonia where ancient clay tablets mention the act of “stretching a field,” that is using a rope to determine the dimensions of an agricultural field and denoting a particular individual as “the dragger of the rope,” a surveyor. It appears that these early Egyptian and Babylonian land measuring activities were prompted by the need for royal levies. However, in the early Indus Valley civilization, rope stretching served another need. The *Śulbasūtras* (Rules of the Cord), compiled between the fifth to eighth centuries BCE, supply geometric prescriptions for the construction of ritual altars. These prescriptions were based on rope-stretching and were carried out by the Vedic priests. Later Pali literature makes mention of “rope holders” (surveyors) in reference to land measurements. In all early urbanized societies, rope stretching provided the basis for surveying.

Egypt

Surveying activities in Egypt certainly preceded the fifth century BCE observations of Herodotus. An inscription on the Palermo Stone dating from

the Old Kingdom period of Egyptian history (ca. 3000 BCE) notes the existence of land surveys. Tomb inscriptions of about the same period mention the existence of land registry offices. A wall scene in the tomb of Menna at Thebes depicts surveyors at work. The scene shows two men measuring a field of corn with a long cord on which knots are marked at intervals of about 4 or 5 cubits. A standard measuring cord or rope of this period was 100 cubits (52.5 m) long. To obtain accurate vertical lines as well as to sight over long distances, Egyptian surveyors use the *merkhet*. This instrument also existed in Egypt from the earliest times; it consisted of a short plumb-line and plummet hanging from a holder that contained a sighting slit. Thus alignments could be made on distant objects. Merkhets were employed in the orientation of temples in a process called the “stretching of the measuring cord.” Egyptian surveyors also employed two types of levels, the water level via a water filled trench which was suitable for large scale leveling, and the plumb-bob level erected with the aid of a wooden, right isosceles triangular frame work. Modern surveys have affirmed that the ancient Egyptians obtained very accurate results using their simple tools: the foundation for the Great Pyramid of Giza is almost perfectly level; boundary markers on the sides of the Nile River are aligned over long distances and a very accurate system of nilometers (flood gauges), were established along the Nile from its delta to the First Cataract, a marvelous feat of leveling.

Babylonia

Large scale construction projects existed in the Tigris-Euphrates region as early as 2300 BCE. The accomplishments of Gudea of Lagash, an engineer or architect of this time, is commemorated by statues which depict him holding a tablet containing scaled plans for a structure. These plans are superimposed on a rectangular grid. Both the use of scaling and a rectangular reference grid indicate the existence of a high level of surveying skill at this time. Further, extensive systems of irrigation channels relied on the

establishment of adequate gradients or slope determined by leveling techniques. Fragments of Babylonian clay astrolabes dating back to the second millennium BCE have been found. With such instruments, observers of the time could determine angles of inclination; however, it is believed that these astrolabes were employed for astronomical sightings rather than terrestrial surveying.

Ancient India

Archaeological evidence from such sites as Mohenjo-Daro and Harappa, cities of the early Indus civilization (3500–2500 BCE) indicate that city planning principles were followed. Buildings were uniform in appearance, and roads were laid out at right angles to each other. The existence of sewerage systems as well as flowing aqueducts testify to a knowledge and use of leveling principles. Builders of the cities of Mohenjo-Daro and Harappa knew surveying. Linear measuring scales found at excavation sites in the region indicate the early Indus peoples employed a decimal system of measurement. This system was based on a “Mohenjo-Daro inch” of 0.67 cm. Further, at Lothal, the remains of a sighting instrument were found. The instrument consists of a hollow shell with four slits cut into its sides. These slits are situated at right angles to each other and allow for perpendicular sighting as would be necessary in surveying a rectangular road system. During the later *Śulbasūtra* period (800 BCE), ► [bamboo](#) poles, *saṅku*, were used for measuring and laying out circular regions, and a standardized chain or measuring rope, *rajju*, was employed. The *Śulbasūtra* texts describe an extensive mathematics supporting its rope stretching surveying techniques. Included in this mathematics was a theory of similar triangles.

While works of later Indian mathematical authors primarily concerned applications of mathematics to astronomy, some also included mathematical information for surveyors. Āryabhaṭa I (476–550) in his *Āryabhaṭīya* (ca. 499) discusses procedures for finding areas and volumes of plane figures and solids.

► **Brahmagupta** (ca. AD 628) in his *Brahmasphu-tasiddhānta* (Correct Astronomical System of Brahma) provides much information relevant to the needs of surveyors including specific computation procedures necessary for working with a shadow gnomon, a sighting staff employed for inclined sightings, thus incorporating a concept of angle into surveying activities.

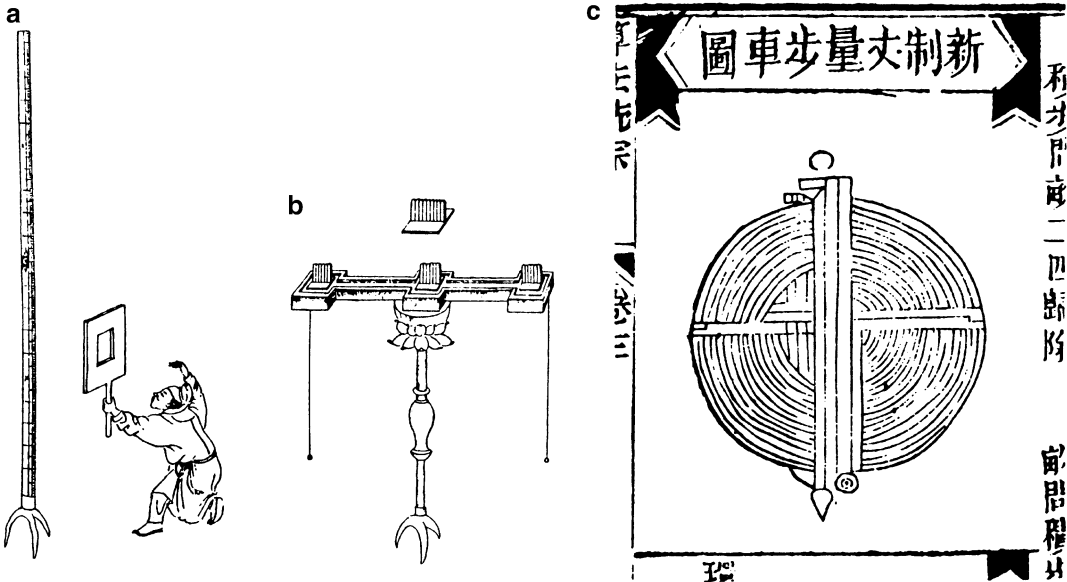
China and the Far East

Early Chinese society was river based. Settling along the banks of the Yangtze and Hwang Ho rivers, the Chinese people harnessed and controlled the rivers by a system of dikes, canals, and irrigation channels. These construction projects required a knowledge and use of land surveying. Surveying was openly recognized as an important societal activity; folk hero Fu Xi and legendary emperor-engineer Yu the Great were often depicted holding surveying instruments.

Discussions and illustrations in extant texts and reference works provide some knowledge of the instruments used by early Chinese surveyors.

Calibrated sighting poles, *biao*, were used in conjunction with sighting tubes, *wang tong*, or sighting boards, *ce shi pai*. A water level, *zhun*, was employed for leveling and a bamboo measure tape, *bu che*, devised for chaining land. A primary surveying instrument was the L-shaped set square or gnomon, *ju*. The earliest documented reference to surveying is found in the ► **Zhoubi Suanjing** (The Arithmetical Classic of the Gnomon and the Circular Paths of Heaven, ca. 100 BCE–AD 100) where in a fanciful conversation between Zhou Gong, a duke of the Zhou dynasty (ca. 1030–221 BCE) and the Grand Prefect Shang Gao, the duke advises the Prefect in the use of the set square. More substantial information on the mathematics of surveying is supplied in ► **Jiuzhang suanshu** (The Nine Chapters on the Mathematical Art, ca. 100 BCE). The work contains nine chapters on specific applications of mathematics. Chap. 1, “Field Measurements”; Chap. 5, “Construction Consultations” and Chap. 9 “*Gougu*”(right-triangle) are directly concerned with surveying computations (Fig. 1).

In AD 263, the scholar-official Liu Hui wrote a commentary on the *Jiuzhang* and revised much of



Surveying, Fig. 1 Classical Chinese surveying instruments. (a) *Biao*, calibrated sighting pole; (b) water level, *zhun*; (c) *bu che*, a bamboo measuring tape (From Frank

Swetz, *The Sea Island Mathematical Manual: Surveying and Mathematics in Ancient China*. Penn State University Press, 1992. Used with permission of the author)

its contents. He paid particular attention to the ninth chapter and extended its collection of problems to allow for more surveying situations which involved the obtaining of measurements to inaccessible points. Liu stressed a technique called *chong cha* (double difference) requiring two distinct sighting observations from separate locations. At the beginning of the Tang dynasty (AD 618–906), Liu's problems involving double differences were separated from the *Jiuzhang* and made into an independent mathematical work on surveying, the *Haidao suanjing* (Sea Island Mathematical Manual). In AD 656, the Royal Academy established an official curriculum to be used for the training of state officials. The *Haidao* was included among the ten mathematical works to be studied. Later, this curriculum was adopted in Japan and Korea where the instructions of the *Haidao* provided the basis for surveying. One of the most accomplished feats of early Chinese surveying was begun in the year 724 when the State Astronomical Bureau of the Tang dynasty initiated the first meridian survey in the ancient world. Under the supervision of the scholar Yixing, 13 observation stations were established near the meridian 114°E and between latitudes 29°N and 52°N. Observations were taken over a period of several years. The expedition determined the angular attitude of the north celestial pole above the horizon and recorded the length of shadows at noon for the summer and winter solstices and equinoxes.

The *Haidao suanjing*'s problems became the basis of later works which considered surveying computations. In 1247, the mathematician ► [Qin Jiushao](#) published ► [Shushu jiuzhang](#) (Mathematical Treatise in Nine Sections). Three of its nine chapters concerned survey applications: Chap. 4 was entitled "Surveying"; Chap. 7, "Architecture"; and Chap. 8, "Military Matters" which concerned the use of surveying techniques for observing an enemy from a distance. His contemporary, ► [Yang Hui](#) wrote *Tian mu bi lei cheng chu jie fa* (Practical Rules of Arithmetic for Surveying). Toward the end of the Ming dynasty, Western influence began to penetrate China. In 1582, the Italian Jesuit Matteo Ricci arrived in Macao and eventually

made his way to Beijing where he used his mathematical and scientific knowledge to win favor with the court. Ricci collaborated with the scholar Xu Guangqi to publish *Celiang fayi* (Essentials of Surveying) (1607–1608). This book introduced contemporary European survey and land measurement methodology to China. Xu himself was a skilled surveyor and wrote an appendix to the *Essentials of Surveying*. It appeared in 1608 under the title *Celiang i tung* (Similarities and Differences [Between Chinese and European] Surveying Techniques). From this period onward, surveying in China combined both European and traditional theories and practices.

The Islamic World

Islam did not emerge as an intellectual and political force until about AD 726 with the establishment of the 'Abbasid Caliphate. From their capital in Baghdad, the early 'Abbasid caliphs patroned the collection of scientific works and used this acquired knowledge to consolidate their religious and political empire. Their era was marked by the building of new canals, bridges and aqueducts and by the reconstruction of old Babylonian irrigation systems. Surveying was used in this work. While Muslims became the heirs of Babylonian, Egyptian and Greek surveying theory, they soon became accomplished practitioners and innovators in their own right. Religious prescriptions required daily prayers toward Mecca; in turn, mosques had to be constructed facing Mecca. Thus determining the *qibla*, or direction of Mecca from a given location, became an important task for surveyors.

Muslim surveyors used several methods of leveling: the plumb-bob level was employed as well as leveling poles. ► [Al-Khāzinī](#) (ca. 840) and Ibn-al- 'Awwām wrote on the use of leveling poles. The latter wrote a handbook for farmers that included the layout of fields. Right angles were laid out with the use of an L-shaped square, *kunija*. Abu'l Wafā (940–998) wrote about the use of such a square. The most complete early Muslim treatise on surveying was written by Muḥammad ibn al-Hassan al-Hasib ► [al-Karājī](#)

(ca. 1000). It was entitled *Kitāb al'ūqūd wa'l abniyah* (Of Vaults and Building). Al-Karajī discussed both the mathematical and practical aspects of surveying and provided specific instructions for the surveying of tunnels and underground aqueducts, ► [qanat](#). Later writer Abū Saqr al-Qabisi introduced trigonometric methods into surveying computations.

The one area of surveying in which Muslim scientists and craftsman excelled was the design and utilization of measuring instruments. Their knowledge of the astrolabe was obtained from the works of Ptolemy. The first noted Muslim maker of astrolabes was al-Fazārī (d. ca. 777) who worked under the patronage of al-Mansur. By the end of the eighth century a number of scholars were producing works on the construction and use of the astrolabe. The most famous of these scholars was Māshā'allāh (762–ca. 815), a Jew who worked under Islamic patronage. His *Kitāb sana'at al-asturlāb wal-'anal bihā* (Book of the Construction of an Astrolabe and Its Use) became the authoritative reference of its time. At a later date (ca. 1380), Chaucer used Māshā'allāh's theories in his European introduction of the astrolabe as a scientific instrument. It was Muslim efforts that resulted in the astrolabe becoming a valued instrument in land surveying activities. Similarly, the Jacob's staff, a popular medieval instrument for determining planar angles, is believed to have reached Europe via Muslim sources and may have had its origins in navigational methods used by early Muslim traders. The oldest actual description of this instrument comes from a navigator's manual, the *Mohit*, written by Sidi al-Chelebri, captain of the Turkish fleet under Sultan Suleimann in 1554.

Pre-Columbian America

Although no written records exist to document the surveying knowledge of early native American civilizations, archaeological sites testify to these peoples' application and understanding of surveying techniques and principles. The city planning and construction carried out by the Olmec, Maya, Teotihuacan, Toltec, and Aztec

peoples of South and Central America indicate that they undertook some surveying activities. For example, the Aztec capital of Tenochtitlan was laid out according to a grid system. It contained markets, palaces and streets and canals and held a population of approximately 200,000 people in the year 1521. Temples and ball courts were oriented to the four cardinal directions. Aqueducts brought fresh water into the city from many miles distant. Some of the Aztec surveying instruments are known by name; plumb line, *temetzlepilolli*; the water level, *atezcath*; set square, *tlanacazanimi*; measuring scale, *tlahuahuanoloni* and the construction compass, *tlayolloanaloni*.

See Also

- [Abū'l-Wafā](#)
- [Al-Karajī](#)
- [al-Khāzinī](#)
- [Āryabhaṭa](#)
- [Astrolabe](#)
- [Brahmagupta](#)
- [Jiuzhang suanshu](#)
- [Māshā'allāh](#)
- [Qanat](#)
- [Qibla and Islamic Prayer Times](#)
- [Qin Jiushao](#)
- [Śulbasūtras](#)
- [Zhoubi Suanjing](#)

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Surveying in Ancient Egypt

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The English verb “to survey” refers to a variety of activities, two of which will be discussed here with an emphasis on the way in which these were practiced in Ancient Egypt. The first can be provisionally defined as the techniques to reduce reality to fit onto a map or a model and the second as the techniques to transfer the information and

ideas reflected on a plan or a model to the real world. Up until very recently, a surveyor would go into the field with two instruments, one to measure angles, such as a transit or a theodolite, and one to measure distances, such as a measuring tape or an electronic distance measuring device (EDM). Modern technology has combined these two instruments into one, and they are referred to as a “total station,” which can perform both functions. The underlying principles of surveying, and the fact that these are based on the accurate measurement of angles and distances, were already mostly understood in Ancient Egypt. It must be kept in mind that the Ancient Egyptian civilization lasted for more than 3,000 years and did change slowly but continuously. The technology and methodology of surveying will have been different during the various periods of Egyptian history (Table 1). From the available evidence, it is not possible to determine an exact chronology of the discipline of surveying in Ancient Egypt, and the following discussion will be thematic rather than sequential.

This evidence comprises a number of preserved ancient tools that were likely used for surveying, several plans and maps from various periods, inferences from marks and modern measurements in extant structures, and a few surviving texts on the subject. The Moscow (or Golenishchev) Mathematical Papyrus, probably written during the eleventh dynasty (unknown provenance, now in the Pushkin State Museum of Fine Arts in Moscow), discusses a series of problems of the area and volume of complex shapes, including a curved surface (problem 10) and a truncated pyramid (problem 14). The Rhind (or Ahmes) Mathematical Papyrus, written around 1550 BCE but claiming to be a copy of a twelfth dynasty text (found in Luxor, now in the British Museum in London), deals with a series of problems of area and volume, including the area of a triangle (problems 4 and 51), a rectangle (problems 6 and 49), and a circle (problems 38 and 50) as well as the volume of a cylinder (problems 41 and 43).

Surveying would have been needed in Ancient Egypt, from the Old Kingdom onward, for at least

Surveying in Ancient Egypt, Table 1 The chronology of Ancient Egyptian civilization following Baines and Malek (2000, pp. 36–37)

Period	Dynasties	Date
Early Dynastic Period	1st–3rd Dynasties	2950–2575 BCE
Old Kingdom	4th–8th Dynasties	2575–2150 BCE
First Intermediate Period	9th–11th Dynasties	2125–1975 BCE
Middle Kingdom	11th–14th Dynasties	1975–1640 BCE
Second Intermediate Period	15th–17th Dynasties	1630–1520 BCE
New Kingdom	18th–20th Dynasties	1539–1075 BCE
Third Intermediate Period	21st–25th Dynasties	1075–715 BCE
Late Period	25th–30th Dynasties	715–332 BCE
Greco-Roman period	Macedonian and Roman rulers	332 BCE–395 CE

two important applications. First was the construction of the famous tombs, temples, and pyramids, some of which still stand today and testify to the accuracy of the measurements. Second, and with a larger impact on daily life, were the measurements to restore the outlines of the agricultural fields after the yearly inundation of the Nile in July and August. The maximum height of the inundation, measured in nilometers at several places, differed from year to year and with that the area of arable land. The available land needed to be redistributed each year and taxes were levied accordingly (Shaw and Nicholson, 1995; Harrell, 2001). This is attested in the following remark of the Greek historian Herodotus, who traveled through Egypt in the fifth century BCE.

The King would send men to inspect and measure the loss of cultivated land in order that from then on some of the tax, proportionate to the report of the loss, might be remitted. I attribute the invention of geometry to this cause and from Egypt it spread to Greece. (Herodotus, *History* 2.109, translation Shore, 1987, p. 125)

Measuring distances in Ancient Egypt was done in the same way as it is still mostly done today: by comparing the unknown with a known distance indicated on a tape measure or a ruler. Several ancient measuring rods have been preserved, most of them dating to the New Kingdom or later. Two were found in the tomb of Kha, the architect of the Pharaoh Amenhotep II (Eighteenth Dynasty), in Deir al-Medina (near Luxor) and are now kept by the Museo Egizio in Turin. One was gilded and probably a gift not meant for daily use; the other is hinged and was most likely used by its owner during his work (Arnold, 1991). Longer distances were measured with a rope that had knots at regular distances, an activity known as “stretching the cord” (Shore, 1987). This rope, reminiscent of “Gunter’s chain” used by seventeenth- to nineteenth-century surveyors, is often depicted ending in the ram’s head of the god Khnum, the creator god, indicating the importance attached to the measurements and their accuracy. A depiction of land surveyors in action can be found on the top register of wall 5 in the tomb of Menna, an administrator who lived during the reign of Pharaoh Tuthmosis IV or that of his successor Amenophis III (Eighteenth Dynasty) (Fig. 1).

No single Ancient Egyptian unit of length can be given, as this not only varied over time but also by purpose and place. Several systems existed simultaneously, as they did in Europe until very recently (the Convention of the Metre was signed in 1875 and the International System of Units in 1954, but neither are implemented, or even adopted, by all countries). The basis for the Ancient Egyptian unit of length was the cubit, the length from the elbow to the tip of the middle finger (Arnold, 1991; Gillings, 1982; Skinner, 1954). A cubit was divided into seven “palms” and 28 “fingers” (one palm being four fingers). Two cubits seem to have been in use, the “royal cubit” and the “short cubit”; the former was most often about 524 mm (20.6 in.) and the latter 449 mm (17.7 in.). A finger was therefore either approximately 19 mm (0.74 in.), when taken from the royal cubit, or approximately 16 mm (0.63 in.), when taken from the short cubit (Gillings, 1982). It is possible that at times, the



Surveying in Ancient Egypt, Fig. 1 Fragment of the top register of wall 5 of the 18th Dynasty tomb of Menna, showing land surveyors in action (photograph by Robert

L. Mond and Ernest J. Mackay, 1914–1916, used with the kind permission of the Griffith Institute, Oxford, UK)

Surveying in Ancient Egypt, Table 2 Overview of the most important Ancient Egyptian units of length

	Fingers	Cubits	mm	Square (cubits ²)	Square (mm ²)
Remen	19.5	$1/2 \times \sqrt{2}$	371	$1/2$	137,288
Cubit	28	1	524	1	274,576
Double-remen	39	$\sqrt{2}$	741	2	549,152

short cubit was divided into only six palms and 24 fingers (Skinner, 1954). The royal cubit would then be close to one short cubit plus four fingers (one palm) long. A hundred cubits, 52.4 m (171.9 ft) in length, was called a *hayt*, a *khet*, or, in the Greco-Roman period, a *schoenia*. An area of 100×100 cubits (a square hayr, khet, or schoenia) was called a *setat* or, in the Greco-Roman period, an *arura* (Neugebauer, 1954; Shaw and Nicholson, 1995).

A remarkable additional unit was the *remen*, defined as half the diameter of a square with sides of one royal cubit in length. The length of this diameter is $\sqrt{2}$ cubits, which cannot be written as the sum of reciprocal fractions (such as $\sqrt{2} = 1 + 1/3 + 1/13$, etc.), the notation system used in Ancient Egypt, but only as an unending decimal fraction (like $\sqrt{2} = 1.41421\dots$). A remen would be about 371 mm (14.6 in.) or, by coincidence, almost exactly 19.5 fingers (Table 2). The advantage of the remen was that it allowed areas of land to be halved, or doubled, while preserving the proportions simply by

changing the unit, much like the ISO system for paper sizes. A square with sides of a cubit, for instance, has twice the area of a square with sides of a remen and half the area of a square with sides of two remen (a “double remen”). To calculate the area of a circle, π (pi) was approximated as $(2 \times (1 - 1/9))^2 = 16^2/9^2 = 256/81$, which equals 3.16049... (whereas the correct value of $\pi = 3.14159\dots$ and 355/113 would be a better approximation).

Less is known about how angles, the second basic element of surveying, were understood in Ancient Egypt. There is ample evidence of the use of plumb bobs, often combined with a set square or another device that could have served as a sight, which essentially create a 0° angle with the vertical (and a 90° angle with the horizontal). Some of these instruments were apparently used to establish levels (Arnold, 1991; Lehner, 1997). Marks representing different elevations are preserved in several structures among which are the Fourth Dynasty Mastabet al-Fara’un, the burial complex of Pharaoh Shepseskaf, in Sakkara (near

Cairo), the Fifth Dynasty pyramid of Niuserre in Abusir (near Cairo), and the Eleventh Dynasty temple of Mentuhotep in Deir al-Bahri (near Luxor). It has been suggested that water in channels cut for this purpose was used to create a level plain (Edwards, 1993), which can be considered a 0° angle with the horizontal (and a 90° angle with the vertical).

It is unclear how a right angle on a given base line, essential for many surveying tasks, was constructed. There is no evidence that the special case of the Pythagoras theorem, which proves that a triangle with sides of 3, 4, and 5 units will have one right angle, was employed (Gillings, 1982). Over short distances, a right angle could have been constructed by sighting over a set square (Arnold, 1991; Edwards, 1993). The accuracy of this method could be improved by several techniques, but probably not sufficiently to account for the results evident from the surviving structures. Another way to construct a right angle is by establishing two large equilateral triangles with one side and two corners in common. The diagonals of the resulting rhomboid, one of which would correspond with the base line, will be at a right angle (Arnold, 1991). What techniques were used to achieve the observed level of accuracy with the tools available at the time remains enigmatic, but the ancient surveyors could draw on generations of experience with the layout of agricultural fields and canals.

There is some archaeological and textual evidence about angles other than 0° and 90° , relating to the inclination of pyramids, pylons, and the walls of buildings. This includes a set of preserved marks in the foundation trenches of Old Kingdom mastaba number 17 in Maidum (Arnold, 1991) and problems 56–60 of the Rhind Mathematical Papyrus (Gillings, 1982). The angle of the face of a structure was described using the *seket*, which can be defined as the length of the setback of the building from the vertical at a height of one cubit or, in modern terms, as the cotangent of the angle of the wall with the horizontal (Gillings, 1982). A vertical wall has a *seket* of zero, and a wall with an inclination of 45° has a *seket* of one cubit. The

Great Pyramid in Giza, built by Pharaoh Khufu (Cheops) of the Fourth Dynasty, rises at an angle of $51^\circ 52'$ with the horizon and consequently has a *seket* of 0.79 cubit (about five palms, two fingers). The measurements by the ancient surveyors were sometimes transferred to the structures under construction by elaborate means, such as the mudbrick walls under the outer court of the Twelfth Dynasty pyramid of Senwosret in Lisht, believed to indicate the desired level to which the court had to be built up, or the lines of rock-cut postholes surrounding the Great Pyramid (Arnold, 1991).

Measurements were not only needed to ensure a practical and secure structure but often also to make it correspond to religious beliefs or cultic necessities. Despite a dearth of concrete information, the latter has become subject of much speculation. Many proportions of structures and angles of shafts are assumed to have had a special meaning, but these are rarely fully understood. The orientation of the pyramids according to the cardinal points is generally thought to have been motivated by stellar elements in the Ancient Egyptian religion. This orientation was most likely achieved by astro-surveying, performed by priests rather than surveyors. One instrument that was probably used for this is the *bay*, part of a palm rib with a slit at its base through which stars, or the sun, could be observed. A bay was used in combination with a merkhēt, which doubled as a plumb bob and a sundial. A set of these instruments (now in the Staatliche Museum Charlottenburg in Berlin, found in Abydos?) once belonged to Hor, a priest of the Twenty-Sixth Dynasty. According to the inscription on the merkhēt, it "... knows the motion of the two discs (sun and moon) and every star..." (translation Wells, 1999, p. 37). An inscription on the bay indicates that it is "... for indicating the commencement of a feast..." (translation Wells, 1999, p. 37). With these relatively simple instruments, it is possible to observe, through the slit in the bay, the passing of a star across a vertical line, established by the plumb bob attached to the merkhēt. In the day, the bay would cast a shadow that could be aligned

rather accurately because of the slit in the top. Either could be used to find true north, for instance, by bisecting the angle of the rising and setting of a celestial body over a horizontal plane (Edwards, 1993; Lehner, 1997) or by observing the alignment of a pair of selected stars (Spence, 2000). Surveyors would then again be needed to transfer the observations to the actual building under construction.

Celestial observations were also used for the first known attempt to calculate the circumference of the Earth, by Eratosthenes during the reign of Ptolemy III Euergetes (246–221 BCE). Eratosthenes was born in Cyrene (Libya) and brought to Egypt as a tutor for the son of Ptolemy III and a librarian of the library of Alexandria (with about 500,000 “books”). Alexandria was the capital of Egypt during the Greco-Roman period and, at the time, the most powerful and influential city in the region. Thanks to the patronage of the Ptolemaic rulers and the renowned library, scholarly and scientific knowledge advanced greatly. Basing his calculations on the difference, on the same day, in the height of the sun in Alexandria and in Aswan, Eratosthenes came surprisingly close to the actual figure (Berthon & Robinson, 1991); an achievement that took about 1,500 years to surpass (Neugebauer, 1954).

See Also

- [Maps and Mapmaking in Ancient Egypt](#)
- [Mathematics](#)
- [Nilometer](#)

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Sūryasiddhānta

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The *Sūryasiddhānta* is a complete work on Hindu astronomy and is more popular and widely studied in North India than in the South. In order to enhance its prestige and antiquity, it is stated in the text itself (1.29) that it had been communicated by a representative of the Sun God to Maya, several 1,000 years ago. However, both internal and external evidence shows that the work was composed between AD 600 and 1000. In about 500 verses, distributed through 14 chapters, the work deals with all aspects of Hindu astronomy,

K. V. Sarma: deceased

and also cosmology, geography, astronomical instruments, and time-reckoning. It follows the midnight day-reckoning.

The contents of the work are comprehensive. Chapter I speaks about the circumstances that led to the composition of the work, the aeons and aeonary revolutions of the planets, the principles underlying the computation of the planets and the nodes, the position of the planets at the beginning of the current aeon, the prime meridian and local time, and the inclination of the orbits of the planets. The time units given in the work are more in conformity with the *Purāṇas* than with other texts on Hindu astronomy. Chapter II deals with the computation of the true motion and the true longitudes of the planets. Chapter III is devoted to the determination of the directions, place and time, and also the calculation of the precession of the equinoxes. It is noteworthy that the *Sūryasiddhānta* is the earliest available Indian text which contains a discussion of the calculation of the precession of the equinoxes. Chapters IV and V deal in detail with lunar and solar eclipses and their computation. Chapters VII and VIII are concerned with the conjunction of one planet with another, and a planet with a star, including their observation. Chapter IX deals with the determination of the heliacal rising of the planets and Chap. X with the phases of the moon. Chapter XI is concerned with the phenomenon of *pāta*. Cosmology and geography of the worlds and of the earth occur in Chap. XII. The construction of the armillary sphere and its working and a mention of the main astronomical instruments form the subject matter of Chap. XIII. Chapter XIV enumerates and defines nine types of reckoning time, such as lunar, solar, sidereal, tropical, etc.

The *Sūryasiddhānta* is indebted to earlier astronomers like Āryabhaṭa (b. 476) and Brahmagupta (b. 598) in certain matters like the inclination of the planetary orbits, the tabular sines, etc. It is also to be noted that the *Sūryasiddhānta* does not include chapters on arithmetic, algebra, or astronomical problems, which are generally included in texts of this type.

The popularity of the *Sūryasiddhānta* is clear from the very large number of manuscripts of the work found throughout the land. About 35 commentaries on the work, written by scholars from different regions of India, and about 20 works, including planetary tables and manuals, based in the *Sūryasiddhānta*, have been identified. The popularity of the work is also reflected by the number of almanacs prepared on the basis of the *Sūryasiddhānta*.

See Also

- [Armillary Spheres in India](#)
- [Āryabhaṭa](#)
- [Astronomical Instruments in India](#)
- [Astronomy in Medieval India](#)
- [Brahmagupta](#)
- [Precession of the Equinoxes](#)

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Suśruta

Guy Mazars

Suśruta is not the original author of the medical ‘Compendium’ which bears his name, the *Suśrutasaṃhitā*, which constitutes the major source

of information about ancient Indian surgery. The treatise is supposed to contain the teaching of the god Dhanvantari, who was incarnated as Divodāsa, a king of Benares. Therefore it is not the personal work of Suśruta who had only recorded an already constituted medical tradition. The date of its redaction is not known. The basic text is supposed to have been revised and enlarged by an author called Nāgārjuna, which adds to the confusion, since there are several people named Nāgārjuna in Indian literary history. It is possible that the attribution of this name to the reviser of the text is but an echo of the legend which had the great Buddhist philosopher Nāgārjuna (first to second centuries AD) as a physician and alchemist. In any case, the teaching of Suśruta must already have been fixed at the time of the *Carakasamhitā* which refers moreover to the disciples of Suśruta for surgical treatment. The ‘Suśruta’s Compendium’ was the object of very elaborate commentaries whose purpose was to clarify and add precision to the contents. The principal commentaries of the *Suśrutasaṃhitā* are those of Jejjāṭa (before the ninth century), Gayadāsa (eleventh century) and especially that of ḍalhaṇa (eleventh to twelfth centuries) entitled *Nibandhasaṃgraha*.

In its present form the *Suśrutasaṃhitā* consists of 186 chapters which are divided into six large sections (*sthāna*):

1. Forty-six chapters in the *Sūtra* section deal with general questions such as medical training, diet or surgery.
2. Sixteen chapters in the *Nidāna* section deal with the diagnosis and prognosis of important ailments.
3. Ten chapters in the *Śārīra* section deal with the creation of the universe, embryology and anatomy.
4. Forty chapters in the *Cikitsā* section deal with therapy.
5. Eight chapters in the *Kalpa* section deal with poisons.
6. Sixty-six chapters in the *Uttara* section deal with diseases of the eye, ear, nose, and throat,

paediatrics, seizures by evil spirits, dentistry and internal diseases in general.

The *Suśrutasaṃhitā* describes surgical operations which reveal the skill and the daring of the surgeons of that period: the lowering of cataracts with a needle, grafts for repairing the nose and the earlobe, procedures for the removal of stones in the urinary tract, resections of scrotal elephantiasis, Caesarean sections and surgical removal of a dead foetus from the womb.

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Swidden

Karl H. Schwerin

Swidden, also known as “slash and burn,” “long fallow,” and *roça* in Brazil, is a system of agriculture that involves clearing small areas within a forest, burning the slash (Figs. 1, 2, 3, and 4), and planting for 1–5 years (Figs. 5 and 6). The plot is then abandoned for 25–200 years – long enough



Swidden, Fig. 1 Mamo: uncleared swidden. Mamo, Venezuela. Uncleared farm plot thick with trees and undergrowth. Karinya Indians, March 1962 (Photo by Karl H. Schwerin)



Swidden, Fig. 2 Cachama: Field of Francisquito Martinez ready for burning. Cachama, Venezuela. Karinya Indians, February 1962 (Photo by Karl H. Schwerin)

for the forest to reclaim the cleared area. In contemporary Latin America this system may support as many as 50 million people.

In spite of the labor involved in clearing the forest, it is less than that required in clearing brush or turning under grass sod. This explains why fields are abandoned until the forest has regrown. In the tropics most nutrient and organic matter is locked up in the plants and trees, rather than in the soil. Thus, ash from the burned slash also frees nutrients for the crops.

A typical swidden planting mimics the diversity of the forest, with a variety of crops interspersed among each other, or planted in closely spaced zones within the field. In the Amazon-Orinoco drainages one may encounter 10–15 crops being grown together (Fig. 7). Once crops are planted, they require only one or two weedings before harvest (Fig. 8). In the tropics, harvest can extend over many months; just enough is taken from the field to provide for a few days or a week at a time. In a sense, then, the crop is stored in the field, rather than in a storehouse (Figs. 9, 10, and 11). The labor required in swidden is minimal, averaging 2–4 h a day



Swidden, Fig. 3 Cachama: Francisquito Martinez setting fire to field. Cachama, Venezuela. Karinya Indians, February 1962 (Photo by Karl H. Schwerin)



Swidden, Fig. 4 Cachama: burning field of Francisquito Martinez. Cachama, Venezuela. Karinya Indians, February 1962 (Photo by Karl H. Schwerin)



Swidden, Fig. 5 Mamo: planting manioc. Mamo, Venezuela. Juan Guevara planting a manioc cutting with his machete. Karinya Indians, March 1962 (Photo by Karl H. Schwerin)

(though perhaps concentrated into 5 or 6 h two or three times a week).

Swidden crops are often limited to starchy staples, vegetables, and fruits, producing little protein. Thus subsistence is typically supplemented by fishing and/or hunting. Only in Mesoamerica, where beans are important, is the need for supplementary animal protein reduced somewhat.

Swidden agriculture is often characterized as unproductive and destructive of soil fertility. In fact, during the first 1–3 years it is generally more productive than most permanent fields. The ash provides ready nutrients and there is little competition with other plants. The return on labor investment is even more rewarding.

After a few years productivity typically declines. Traditionally this was blamed on exhaustion of the soil. Extensive research indicates that this is due not so much to declining soil fertility, as to invasion by weeds and grasses which compete with crops for space and nutrients. A further motivation for abandonment is that this tangled growth becomes a magnet for vermin, insects, and

Swidden, Fig. 6 Manioc planting. Kuri, Honduras. Recently planted manioc stem; from this a new plant will grow. Miskito Indians, January 1981 (Photo by Karl H. Schwerin)





Swidden, Fig. 7 Mamo: bananas, manioc, curagua. Mamo, Venezuela. A mixed planting. A strong fiber is extracted from the leaves of the curagua (*Brocchinia* sp.). Karinya Indians, April 1962 (Photo by Karl H. Schwerin)



Swidden, Fig. 8 Mamo: weeding field. Mamo, Venezuela. Juan Guevara weeding field with machete and garrabato. Karinya Indians, March 1962 (Photo by Karl H. Schwerin)



Swidden, Fig. 9 Cachama: Teresa Tamanaico pulling up manioc tubers. Cachama, Venezuela. Karinya Indians, July 1962 (Photo by Karl H. Schwerin)

disease. Thus the farmer logically seeks out a new spot in virgin forest to clear another plot free of problems (Fig. 12).

Contrary to popular belief, this does not necessitate periodic village movement. Robert Carneiro has shown that 500 people practicing swidden agriculture could subsist permanently on 6,000 acres located within a 3-mile radius of their village. Other explanations based on social, political, or religious factors must be sought for the practice of moving villages.

There is much debate about the “backward” and “deleterious” effects of swidden agriculture. When practiced by a sparse, widely dispersed population, it does not seem to harm the ecosystem, and may in fact prove beneficial by opening up the forest canopy and stimulating new growth. Some ecologists believe that the equilibrium state under aboriginal conditions was grounded on periodic swidden clearing. On the other hand, when population growth intensifies clearing to a point where the forest can no longer regenerate itself, the result will be widespread environmental degradation. Throughout Latin America recent programs of development



Swidden, Fig. 10 Cachama: harvesting manioc. Cachama, Venezuela. Miguel Tamanaico and Delia Tamanaico harvesting manioc tubers. Karinya Indians, July 1962 (Photo by Karl H. Schwerin)



Swidden, Fig. 11 Cachama: Delia and Teresa Tamanaico stripping manioc tubers. Cachama, Venezuela. Karinya Indians, July 1962 (Photo by Karl H. Schwerin)

have led to widespread deforestation, replacement of swidden agriculture with more extensive systems such as livestock pasturing or machine cultivation, and resulting ecological degradation.

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Swidden, Fig. 12 Mamo: swidden cleared and uncleared. Mamo, Venezuela. Field of Juan Guevara with cleared ground in foreground, second growth of

1 year in middle ground, and uncleared wooded area in background. Karinya Indians, March 1962 (Photo by Karl H. Schwerin)

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Tabiyah

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Ṭābiya, often called succinctly yet inaccurately “rammed earth,” has long been traditional architecture’s versatile alternative to concrete. The structures are strong, durable (given scheduled maintenance), and noncombustible, with a high thermal mass. They absorb heat during the day and radiate it at night. The embedded clays modulate interior humidity – the walls “breathe” better than concrete, with fewer condensation issues. As with cast-in-place concrete, the *ṭābiya* construction process involves shaping an initially ductile or pliable material. Instead of being poured as a slurry and left to set, a damp homogenized mix of low-clay (5–15 %) loamy earth, aggregate, and additives such as lime stabilizer and ash is compacted (tamped) in successive layers into a double-wall (box) formwork.

What makes the *ṭābiya* technique distinctive is its reusable modular wooden formwork that assembles by means of soft quick-connectors (traditionally mortise and tenon, wedges, pegs, tourniquet rope). Not all construction using earth as a component is *ṭābiya* fashion. The technique is a parallel invention of ancient origin, with antecedents reaching back to c. 5,000 BCE. Mundane as well as sacral structures and fortifications attests its use in various parts of Eurasia (notably China), the Middle East, Africa,

and the Mediterranean (Gandreau, Delboy, & Joffroy, 2012). In the Iberian Peninsula, *ṭābiya* is found in both pre-Roman and Roman contexts, but there is little evidence of significant use in Roman or Visigothic urban fortifications (Algorri García, Vázquez Espí, & de las Casas, 1996; Gurriarán Daza & Sáez Rodríguez, 2002).

The *ṭābiya* technique is inherently flexible and was always responsive to local availability and cost of materials as well as to project purposes. The implicit ecological benefit of traditional *ṭābiya* is that subsoils are typically used to obtain material, leaving leftover topsoil available for agricultural reuse. The ingredients in historically documented *ṭābiya* varied, as did workmanship and quality. Unlike with concrete, placing the ductile mix in the formwork was only a first step – expert and attentive compacting was key, and usually was left to the most experienced workers (even though the overall process is much less dependent on trained labor than masonry).

Terminology

Ṭābiya is an ambiguous term (as are the cognates *tapia* (Castilian), *taipa* (Portuguese), tappy, tabby (English), etc.). The relevant English language literature dating back to the 1980s and 1990s often offered, quite unfortunately, a truncated technical and historical context or operated with awkward renderings of foreign terms. This is particularly true of studies dealing with

derivative historic *tābiya* such as the “tappy” (“tabby”) of the Southeastern United States (northern Florida, Georgia, parts of South Carolina) (Davis & Taylor, 2006; Gritzner, 1978). The most comprehensive recent literature dealing with *tābiya* in the Mediterranean area and South America continues to be available mainly in Spanish, Catalan, or Portuguese only (for extensive bibliography, see, e.g., Graciani García, 2008; Gurriarán Daza & Sáez Rodríguez, 2002; Pavón Maldonado, 2012).

The primary meaning of *tābiya* is quite clear in Arabic sources as prominent as Ibn Khaldūn’s *Muqaddimah* (Ibn Khaldūn, 1967, Chap. 5, Sec. 24), which reserve the term for formwork processes and associate it with the noun *ṭawwāb* – “brick- or tilemaker,” the maker of *ṭūb* – an artisan often skilled in *tābiya* work as well. The association is not surprising. Where possible, the soil chosen for *tābiya* comprised fair to good potter’s or brick clay. The person best qualified to recognize suitable soils and guide their preparation was an expert *ṭawwāb*.

Tābūt (Arabic) (“coffer,” “box”) is the wooden (or modern metal-and-plywood) formwork as such, also referred to in the Western Maghrib as *lūh* (Standard Arabic *lawh*, “plank” or “board”). In Iberian technical usage, *tapia* (Castilian) (Portuguese *taipa*) mostly applies to the finished structure and *tapial* (Castilian) (Portuguese *taipal*) to the formwork (Graciani García, 2008; Pavón Maldonado, 2012; Torres Balbás, 1985). In the vernacular, the distinction formwork/structure often vanishes – *tapia* may denote any kind of wall (Castilian *pared*), just like *tābiya* may mean “fortress.” Other related terms (e.g., *pisé* and *pisé de terre* (French)) are equally problematic, especially now that PISE has become an acronym for “pneumatically impacted stabilized earth,” a mix of soil, Portland cement, and water (terrocement), sprayed from gunite machines against single-wall forms and rebar grids (Barbeta i Solá, 2002).

***Tābiya* Formwork, Ergonomics, and Work Flow**

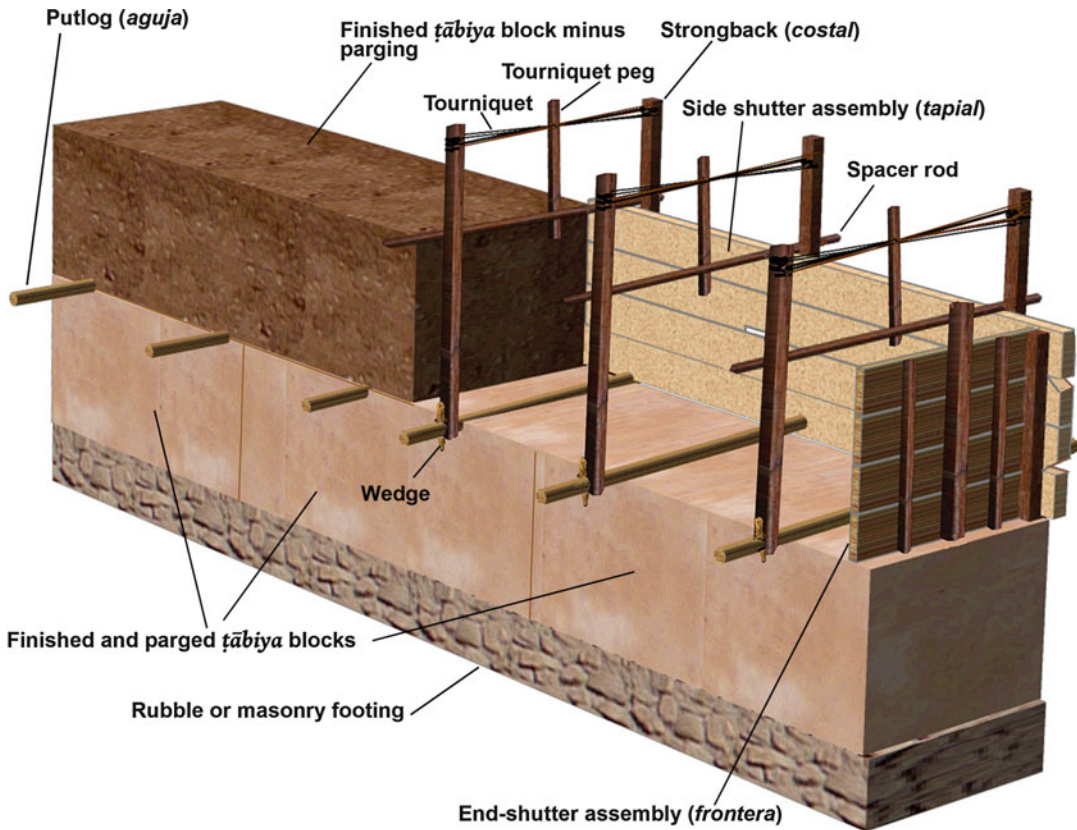
Tābiya formwork typically includes the following basic components (Figs. 1 and 2). The

majority are reusable; those marked with an asterisk are expended in each setup:

- (a) Three putlogs* or three reusable “putlog” rods/needles (*aguja* (Castilian), *agulla*, *risell* (Catalan), *gato*)
- (b) Six main strongbacks (*costal* (Castilian), *cárcel* (Castilian), *aro* (Castilian), *travesaño* (Castilian), *barra* (Catalan))
- (c) Two side shutter assemblies (*tapial* (Castilian), *tapieres* (Catalan), *taules* (Catalan))
- (d) One end-shutter assembly (*frontera* (Castilian), *captauló* (Catalan))
- (e) Three tourniquet ropes (*soga* (Castilian), *soga* (Catalan)) and/or yokes (*brochal* (Castilian))
- (f) Ten or more assorted wedges
- (g) Three (optional) tourniquet pegs
- (h) Two or three (optional) spacer rods (*bastón* (Castilian), *bastó* (Catalan))

Historic types of formwork and many pre-1980s traditional ones were made entirely of wood (nails could be substituted with wooden dowels). Where available, tamarisk (gen. *Tamarix* (*tamariz*, *taray*)) was often used, particularly the larger of its 50–60 species. Tamarisk has a long history as a renewable source of utility lumber in drought-prone areas. Its drawback, however, is the limited gauge of lumber obtainable, particularly from deciduous species. The genus, native to the drier parts of Eurasia and Africa, can also become dangerously invasive (the salt cedar varieties are deemed an invasive species in the United States, where tamarisk spread artificially between the 1800s and the 1930s, as an ornamental and to inhibit erosion).

Putlogs were the only nonreusable parts of historic *tābiya* formwork. They generally remained embedded in the finished work (e.g., Figs. 1, 2, and 3) and were cut off flush once no longer required as formwork support. Mortar or other render (parging) protected the cut ends. Instances of putlog extraction for reuse, however, are not uncommon. In older or cheaper *tābiya* work, the putlogs were usually round (natural timber). From the mid-twelfth century, above all



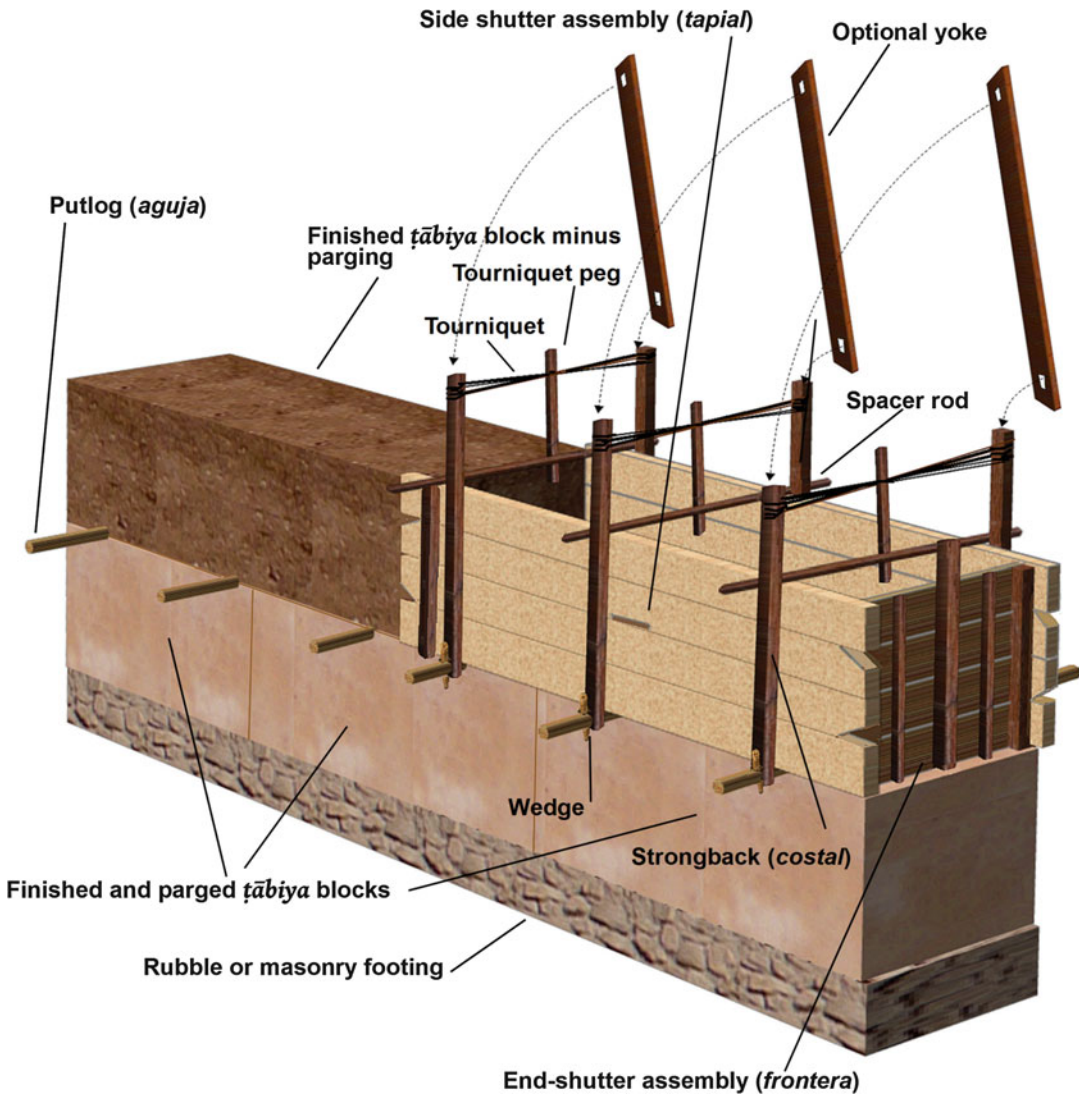
Tabiyah, Fig. 1 Schematic model of basic *tābiya* formwork assembly using tourniquets (shuttering along the side facing the viewer omitted)

in the Maghrib and in the Iberian Peninsula, lumber with rectangular cross sections began to appear. In massive walls, e.g., fortifications, short putlogs only c. 45 cm long were used. These required special solutions to lock them in place. Wall thickness was flexible with short putlogs, and using squared lumber saved setup time, yet time was also lost in safe installation.

Subsequently, in Early Modern *tābiya*, particularly in the Iberian Peninsula, putlogs were gradually replaced in upscale construction by metal rods (*aguja*, *agulla*, *risell*, “needle”). These either passed straight through the work using holes left by spacer rods (*bastónes*) or were inserted halfway from each side (if equipped with eyelets). Coated with grease and fine sand before material was pitched in and tamped, *agujas* were more easily extracted and redeployed. The transition to metal rods saved

material and mitigated structural issues arising from the degradation of putlogs inside finished walls (Villanueva, 1827).

Formwork strongbacks (the vertical components that brace the shuttering) (Figs. 1, 2, 3, and 4) tended to be around 5 × 10 cm or heavier, roughly 1.3 m long. The lower end was shaped either to (a) straddle (fit *over*) the lumber or metallic putlog/needle or (b) to fit *into* the latter’s mortise or eyelet. Different local systems were devised. Where eyelet-equipped metal *agujas* were used, it was enough to whittle down the strongback’s tip to make it sit tight. If the tip was predrilled, in addition, to accept a safety peg below the eyelet, the peg locked the strongback in position. Alternatively, a tenon at the strongback’s end fitted into a mortise in the putlog. One might also mortise the strongback, to sit saddle-wise over the *aguja*, or drill it, to slip

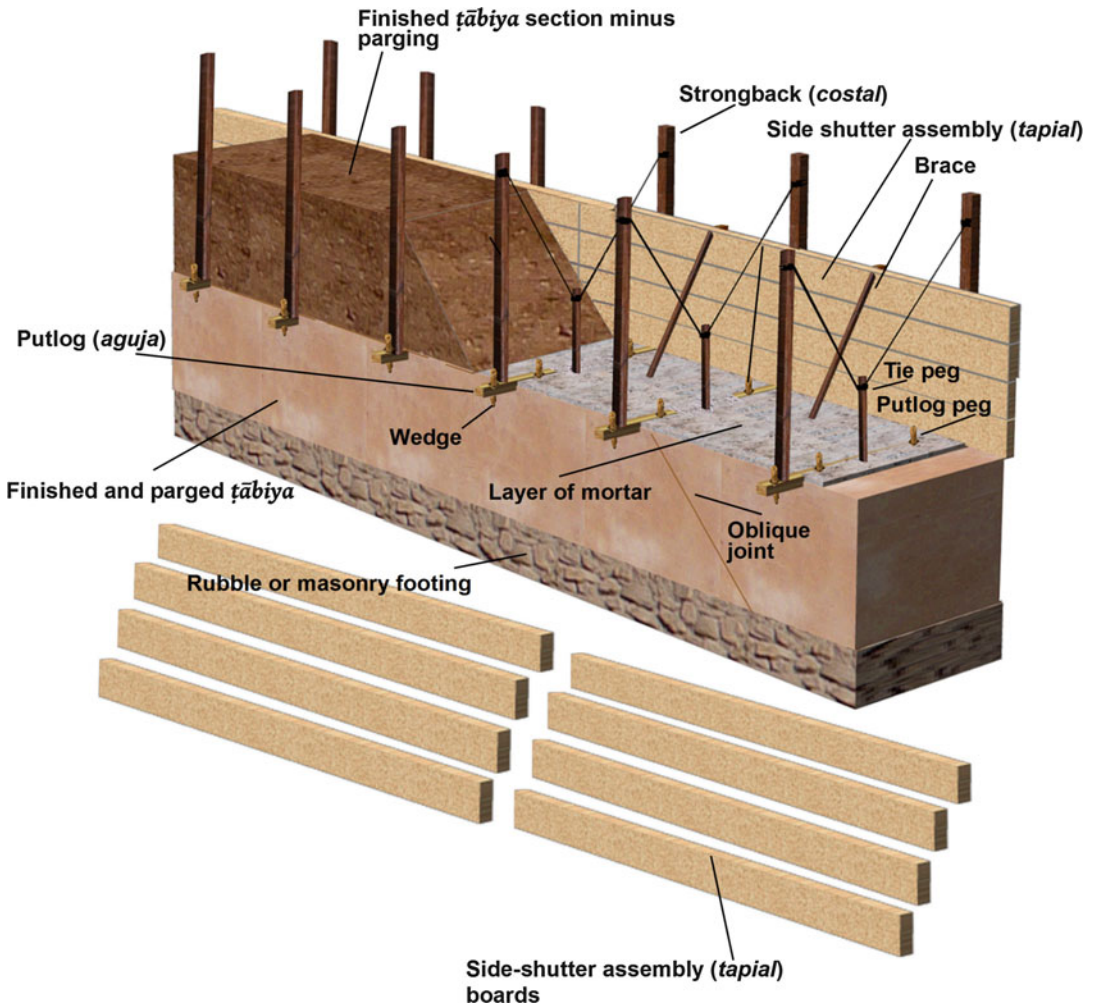


Tabiyah, Fig. 2 Schematic model of basic *tābiya* formwork assembly using tourniquets and optional yokes (shuttering along the side facing the viewer included)

onto a round metal *aguja*. All the solutions required in principle a wedge fitting into a slit in the putlog/*aguja* (eye of the needle), to lock the strongback against the shutter.

The upper ends of the strongbacks took a variety of patterns (rope channel, knobhead, slight crook, end peg). All were designed to either (a) accommodate a rope tourniquet or other equivalent device and prevent it from riding up and coming off or (b) accommodate a wooden yoke. Tourniquet and yoke were not mutually

exclusive: the rope might be used to pull the strongbacks together as tight as needed and the yoke then installed for true rigid interlock. Either way, once the strongbacks were in position, wedged, or otherwise fastened below and under tourniquet tension or yoke interlock, they held the shuttering tight – at one end (in overlap) against the just finished block (also known as “lift”) and at the other end against the end shutter. The result was an empty rectangular compartment.

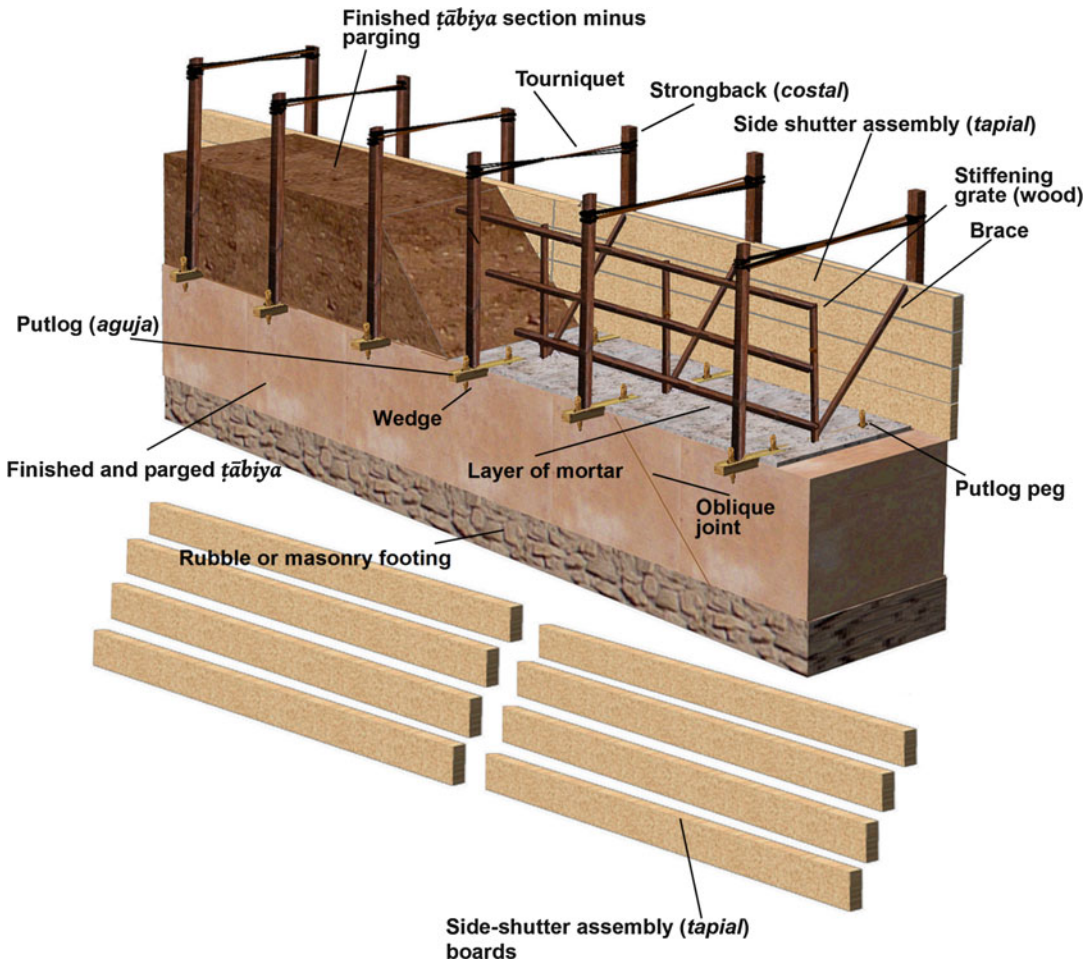


Tabiyah, Fig. 3 Schematic model of continuous-run *t̃ābiya* formwork assembly using braces, tie pegs, and short putlogs (based on hypothetical reconstruction in Graciani García (2008–2009, Fig. 8))

The side shutters most often comprised four boards each. Typically, the boards were 2–3.3 cm thick, 21–23 cm wide, and 2–3.3 m long. Ibn Khaldūn’s *Muqaddimah* gives 2 cubits as the most common module, which, if we suppose that the reference cubit was the *ma’mūnī* of 45 to 47 cm, would mean shutters at least 90 cm high and 1.9 m long, a little too high to be ergonomic (Ibn Khaldūn, 1967, Chap. 5, Sec. 24). The shuttering was held together by two small pieces of strongback (*montantes* (Castilian); c. 7.5 × 4.5 cm in cross section) nailed across the boards close to each end of the assembly, on opposing faces (Villanueva, 1827). Gaps of 2–3 mm

separated the boards, to let liquid expressed by tamping seep out and to allow for expansion from humidity saturation of the boards throughout a workday. A few simple cutout handholds at the ends and in the middle of the shutters (Fig. 2) made handling easier.

The end shutter was assembled using vertical or horizontal boards and a varying number of strongbacks, but one vertical board or strongback was usually left longer, as a handle. End shutters with arched tops were also common. Hammering on the handle or the arch reseated the shutter if it rode up in the course of tamping or unstuck the shutter if it did not come free readily during



Tabiyah, Fig. 4 Schematic model of continuous-run *tābiya* formwork assembly using braces, internal embedded grating, and short putlogs (an alternative to the hypothetical reconstruction in Graciani García (2008–2009, Fig. 8))

disassembly. End shutters of different sizes were used for different jobs. Together with the length of the putlogs/needles, they governed formwork width, unless short putlogs were used that did not traverse the work.

The width of the formwork was rarely an issue, unless the wall was so narrow that working high above ground, without added falsework (such as scaffolding) or safeties, became hazardous. Minimum wall width is normally governed by the formula $E = \text{height/width}$, where E should lie between 5 and 8, with 10 as the last safe value for non-reinforced one-story walls. Other calculations apply with a second or third story. Historic *tābiya* widths tend to range from 20 to 35 cm in

simple house walls (35 cm is preferred to facilitate compacting) to c. 80 cm in the walls of hollow fortification towers, for instance, and 2 m or more in massive curtain walls of urban fortifications (Graciani García, 2008; Graciani García, 2008–2009; Graciani García & Tabaes Rodríguez, 2003; Pavón Maldonado, 2012).

The keys to the ergonomics of *tābiya* were elbow room and weight of the components (Barbeta i Solá, 2002). If the weight of each side shutter is kept around 25 kg, assembly, disassembly, and moving the components to the next position can be a one-man task. Light shutters also permit skinnier putlogs. The shutters are in fact lifted entirely off putlogs only when work

comes to a corner block. In a straight wall run, placing the next batch of putlogs and moving the strongbacks is sequenced so that the shutters simply slide forward on the putlogs while remaining restrained by partially loosened strongbacks. The round timber putlogs or round metal *agujas* are slick – like the shutter itself – with seeping mud and liquid, making this an easy operation.

The optimal weight factor constrains shutter length/height and board thickness. Length also has to be balanced against the minimum number of strongbacks required. These would preferably have to be added in modular increments, at 0.75–0.85 m spacing. The spacing, just like optimal height for standard formwork (max. 0.85 m), was namely calibrated to the elbow room required by a worker wielding an old-style manual rammer and to the muscle fatigue from raising the rammer repeatedly to a given height. The most common traditional arrangement was a fairly optimal one. Typically, there were three strongbacks a side, spaced c. 0.75–0.85 m on center (Barbeta i Solá, 2002). Archaeology has documented, however, a gradual increase in the distance between strongbacks (and thus putlogs) in the Iberian Peninsula, from c. 0.5 m on center in early *ṭābiya* work to c. 0.85 m from the middle of the twelfth century CE (Graciani García & Tabales Rodríguez, 2003) (Table 1, Fig. 5).

Materials and Preparation

The basic ingredients are low-clay loamy earth, aggregate, and controlled quantities of stabilizer. Various optional additives were used or experimented with in different historic and regional contexts. Estimating the required volume of raw earth must factor in losses incurred

in sifting and premixing, transport, and compacting (around 30–45 % for the latter alone). The material should not contain stones larger than a fist and should be free of all vegetable matter. Greasy material (excess clay) tends to stick to the formwork and shrinks too much. Sticky formwork can take patches of material out of the finished surface when being dismounted. Finished blocks that shrink excessively also develop fractures and deformations (Gurriarán Daza & Snacel Sánchez, 2014; Villanueva, 1827).

The prepared material must be kept moist (not wet) and should be pitched into the formwork at more or less optimal stiffness. The traditional test was to squeeze a fistful of the material – if it did not stick to the hand and kept the imprinted shape, it was good to go (Villanueva, 1827). Technically, the optimal point stands around 12 % TEO on a Proctor test. Too little moisture prevents adequate homogenization; too much moisture results in blocks with lower compression strength that also abrade easily (Barbeta i Solá, 2002). Part of the moisture is expelled through compacting. As stabilizer, lime or animal blood was used. Alternatives and modern replacements include lime, cement, or various asphalt emulsions. The latter entail commonly recognized drawbacks.

Each block was built up inside the formwork incrementally. Material was pitched in and spread in a layer 7–25 cm deep (7–10 cm being optimal) and compacted to about 50 % of the original loose depth. Traditional tamping was manual, using wooden rammers. This is labor intensive and requires both endurance and adequate care, and fatigue can produce uneven compacting. Once a block has been completed, it is sturdy enough and has already lost enough

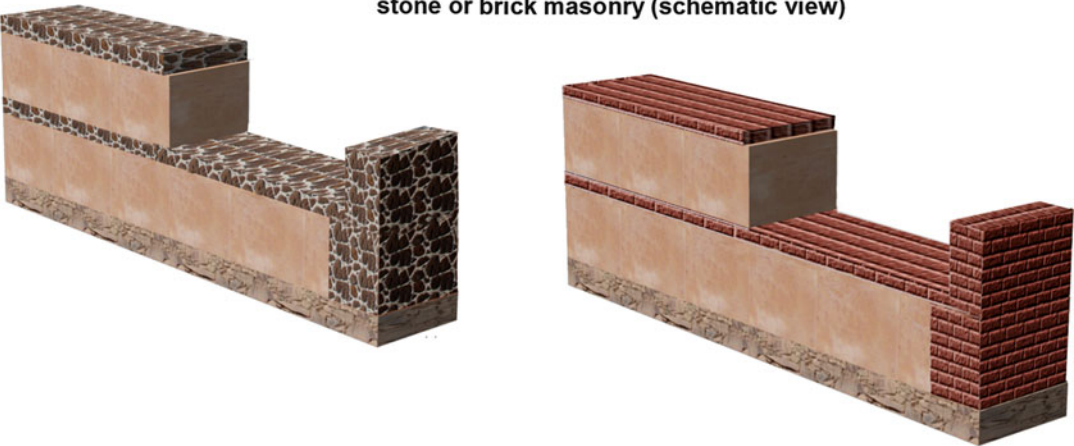
Tabiyah, Table 1 Basic formwork dimensions in historic and traditional *ṭābiya* preparation

	Height	Length	Traditional base unit
<i>Standard (Maghrib and al-Andalūs)</i>	≤0.80 m		<i>rassāsī</i> cubit (54.07 or 58.8 cm)
<i>Oversize (Maghrib and al-Andalūs)</i>	0.90–0.94 m	2.25–2.50 m	two <i>ma'mūnī</i> cubits (2 × 45 to 47 cm)
<i>Traditional (optimal)</i>	c. 0.81 m	2.20 m	
<i>Traditional (reported)</i>	c. 0.84–1.19 m	2.46 m	
<i>Theoretically ergonomic</i>	max 0.75–0.85 m	max 2.00 m	–

Finished wall with leveling courses (*verdugadas*) of stone or brick (schematic view)



Finished wall with leveling courses (*verdugadas*) and corner blocks (pilasters) (*cadenas*) of stone or brick masonry (schematic view)



Tabiyah, Fig. 5 Schematic model of finished *tābiya* wall segments with leveling courses (*verdugadas*) and masonry blocks (*cadenas*)

moisture for the formwork to be removed almost immediately and set up for the next block. Workflow is continuous. No setting-in-the-form period is involved, unlike with concrete. The surface usually becomes too difficult to work within the hour, and any texturing (texturing to improve the bonding and adhesion of a sealing coat) must be done as soon as the formwork comes off (Barbeta i Solá, 2002).

It was common procedure to flip the side shutters end for end once a corner was reached, i.e., when the shutters were being lifted entirely off. The flipping ensured that shutter faces were exposed to humidity and pressure from inside the formwork evenly over a workday. In principle,

formwork should never be left mounted overnight, to prevent warping the boards. Incidentally, as the two pieces of strongback (*barzones* in Castilian) that hold the boards together and also serve as end shutter stops are nailed across opposite faces, one of these will automatically end up on the outside (permitting a snug flat fit to the side of the just finished block), while the other will be on the inside, to serve as a stop. The process thus differs from modern concrete forming by means of treated plywood shutters – the vast majority of standard premade shutter assemblies (on wood or metal frame) normally always expose the same working side of the plywood sheet to the concrete (Barbeta i Solá, 2002).

Compressive strength of a finished *ṭābiya* wall and associated components increase gradually with drying and curing. Complete curing may take up to 2 years or longer, depending on materials. The results of compressive strength tests on various samples from historic *ṭābiya*-made structures range widely, from 25.5 kg/cm² (362.7 psi) for household and utility walls to between 184 and 213 kg/cm² (2,617.1–3,029.6 psi) for high-grade fortifications (e.g., Barbeta i Solá, 2002; Graciani García, 2008, pp. 144–145). *Ṭābiya* that incorporates lumber, bamboo, lime concrete, brick, stone masonry, or in modern versions steel rebar reinforcements, in various configurations, offers superior structural resilience and limited anti-seismic properties.

Varieties of *Ṭābiya*

A raw finished *ṭābiya* wall, just like raw finished cast-in-place concrete, displays formwork marks (mostly horizontal raised lines at the seams between formwork sections). In addition, a sequence of horizontal strata from the layered compacting is often visible. Weathering may accentuate the inherent pattern. Some of the standard observed patterns are useful for initial historical and structural diagnosis as well as for dating *ṭābiya*-made monuments. The following key types are for the most part readily identified through preliminary surface pattern and texture analysis:

- (a) Plain clayey earth *ṭābiya* (*tapia de tierra* or *tapia ordinaria* (Castilian)) without optional additives and even without stabilizer.
- (b) Stabilized homogeneous block *ṭābiya* (*tapia estabilizada en masa* (Castilian)) using gypsum or lime as binders (in particular kiln lime with various degrees of hydraulicity) and aggregate ranging from sand to pebbles, pieces of rock, crushed ceramic tile, and brick rubble. In transatlantic contexts (Brazilian and early American colonial “tabby” or “tappy”), lime was often obtained not from limestone but from seashells.
- (c) Reinforced block-joint *ṭābiya* (*tapia de tierra y cal* (Castilian)), in which the horizontal and vertical joints between blocks formed by compacting consist of lime or gypsum mortar (in the latter case, the finished product is a *tapial de tierra y yeso* (Castilian)).
- (d) Reinforced crust/casing *ṭābiya* (*tapia de tierra crostada*, *tapia calicastrada*, or *calicostrada* or *acerada* (Castilian)), in which a layer of mortar ranging in thickness from 1.5 to as much as 15 cm is applied on both sides to the forming boards, up to the estimated height of the first layer of clayey earth mix to be compacted, and then the process is repeated for each successive layer until block completion. The result is a *ṭābiya* block encased in tight-bond mortar coating. In cheaper varieties, only the exterior face of a wall would be so treated, not the one facing the building’s interior.
- (e) Reinforced crust-and-layer *ṭābiya* (*tapia crostada con juntas de mortero de cal*) in which the process of making a reinforced crust/casing *ṭābiya* is further enhanced by spreading a horizontal layer of mortar on top of each compacted layer of earth mix. The mortar crust and the layers of mortar separating the earth-mix layers interlock as they cure, enhancing rigidity and offering greater erosion resistance.
- (f) Reinforced *ṭābiya* with mixed-material structural components (various types of *tapia mixta*, *tapia verdugada/encadenada*, or *tapia de fraga* (Castilian)). These types of *ṭābiya* represent a logical high-cost extension of the crust-and-layer design. They feature (a) highly visible distinctive horizontal leveling courses of masonry (rough stone, ashlar, brick, single course to as thick as triple course) between the compacted *ṭābiya* blocks and (b) vertical masonry blocks (*cadenas*) either reinforcing structural corners or flanking and separating the *ṭābiya* blocks (the latter type of construction is usually called *de cajones únicos*). The *cadenas* play a structural role similar to the vertical ashlar blocks in Carthaginian and Roman *opus africanum*. Leveling courses alone, *cadenas*

alone, leveling courses with corner *cadenas*, and leveling courses with massive *cadenas* and homogeneous blocks of *tābiya* fill have been used in varying combinations. Specific combinations permit approximate dating of historic structures.

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Takebe Katahiro

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Takebe Katahiro was born in 1664 at Edo (now Tokyo). His father, Takebe Naotsune, was a *Yuhitsu* (secretary) of the Shogun. In 1676, when he was 13 years old, he and his elder brother Takebe Kataaki (1661–1716) became pupils of SEKI Kowa (d. 1708) and studied mathematics.

The Takebe brothers and ► [Seki Kowa](#) were colleagues in the Shogun's government, and their families were the same rank: 300 *koku*. (His annual salary was 300 *pyo* (1 *pyo* was 60 kg of rice), which is the same as a landlord of 300 person village.)

Takebe's mathematical works are in three fields. One concerns completing the *tenzan-jutsu* or *endan-jutsu* (lit. addition and subtraction methods, Japanese algebra system), which was created by Seki Kowa. In the second work Takebe created the *tetsu-jutsu* (inductive methods). Using these methods he obtained the formula of $(\arcsin \theta)^2$. In the third, for computing the approximate value of fractions, he solved the Diophantine equations using the *reiyaku-jutsu* (continual division method). Takebe also worked in astronomy and geography.

In 1683, Takebe wrote his first work, *Kenki Sampo* (Studies for Mathematical Methods). The book provided counter-arguments for Saji Ippei's *Sampo Nyumon* (Introduction to Mathematical Methods, 1680). Saji had criticized Seki Kowa's *tenzan-jutsu* system in the *Hatsubi Sampo* (Mathematical Methods for Finding Details, 1674) and solved Ikeda Masoki's problems in the *Sugaku Jojo Orai* (Textbook of Mathematical Multiplication and Division, 1672). Takebe made good use of the *tenzan-jutsu* method for solving Ikeda's remainder problems.

Takebe commented on Seki Kowa's *Hatsubi Sampo* and published the *Sampo Endan Genkai* (Commentaries for Japanese Algebra System), in 1685. This is one of the best books for studying the *tenzan-jutsu* method.

Chinese mathematicians in the Song and Yuan dynasties used counting rods to solve higher degree equations of more than the fourth degree. There were two color symbols in the counting rods: red rods were plus and black were minus. They had no symbols to express power; the position of the rods on the counting board indicated the powers. Therefore, the system could not indicate complex expressions. For example, $1/(x-1)$, that is $(x-1)^{-1}$, was very difficult to indicate by that system. Seki Kowa abandoned the counting rods system and created algebraic symbols, which used Chinese characters for

calculation with figures. This might be the first example of creating Japanese mathematics from the Chinese.

Takebe commented on the most important Chinese algebraic text in Japan at that time, *Suanxue Qimeng* (Introduction to Mathematical Studies, Zhu Shijie, 1299). He published the *Sangaku Keimo Genkai Taisei* (Complete Works of Commentaries on Suan Xue Qi Meng) in 1690. Seki Kowa and the Takebe brothers started to compile an edition of the mathematical works of *Seki-ryu*, Seki Kowa's school. After Seki died, Takebe Katahiro continued this work and published *Taisei Sankyo* (Complete Mathematical Manual) about 1710.

Takebe's main work is the *tetsu-jutsu* method, a sort of inductive method. He computed small natural numbers and then predicted infinite numbers. The computation was helped by the algebraic symbols of the *tenzan-jutsu* method. Using these methods, Takebe obtained the formula of $(\arcsin \theta)^2$. He computed the length of curve AB (hereafter s) using the diameter d and the length of straight line AB (h).

Takebe set up $d = 10$ and $h = 10^{-5}$. Then letting the half point of straight line AB be C_2 , and the half point of curve AB be B_2 , he computed the length of AB_2 (h_2). Then he computed the length of AB_4 as h_4 , and continued to compute h_8, h_{16}, h_{32} and h_{64} . Takebe computed h_∞ using a sort of infinity series *zoyaku-jutsu* (extra division method), and obtained h_∞ .

$$\begin{aligned} \left(\frac{s}{2}\right)^2 &= 10^{-4} \times 1.000\ 000\ 333\ 333\ 411\ 111 \\ &\quad 225\ 396\ 906\ 666\ 728\ 234 \\ &\quad 776\ 947\ 959\ 587 \\ h(AC_2B) &= 10^{-5}, \\ d(B_2OD) &= 10^1. \end{aligned}$$

Second, he indicated this value using h and d . The power 10^{-4} is h by d , and the approximate value of the coefficient is 1. Therefore,

$$\begin{aligned} \left(\frac{s}{2}\right)^2 &= 1hd + 10^{-10} \\ &\quad \times 0.333\ 333\ 511\ 111 \dots \end{aligned}$$

Then he used the same method. The power 10^{-10} is h^2 , and the approximate value of the coefficient is one-third using the *reiyaku-jutsu* method,

$$\left(\frac{s}{2}\right)^2 = 1hd + \frac{1}{3h^2} + 10^{-16} \\ \times 0.177\ 777\ 992 \dots$$

Takebe continued to compute as above, and he set the series as

$$\left(\frac{s}{2}\right)^2 = A_0 + A_1 + A_2 + A_3 + A_4 + \dots$$

He obtained

$$A_0 = hd, \quad \frac{A_1}{A_0} = a_1 \left(\frac{h}{d}\right), \\ \frac{A_2}{A_1} = a_2 \left(\frac{h}{d}\right), \quad \frac{A_3}{A_2} = a_3 \left(\frac{h}{d}\right), \dots \\ a_1 = \frac{1}{3}, \quad a_2 = \frac{8}{15}, \quad a_3 = \frac{9}{14}, \quad a_4 = \frac{32}{45}, \dots$$

He expanded them to the general series of a_n , which was

$$A_n = \frac{2n^2}{(n+1)(n+2)}.$$

Therefore Takebe obtained the formula

$$\left(\frac{s}{d}\right)^2 = 2 \sum_{n=0}^{\infty} \left(\frac{(n! \times 2^n)^2}{(2n+2)!} \times \frac{h^{n+1}}{d^{n-1}} \right).$$

Takebe had no notion of triangle functions. However, if we set

$$\theta = \sqrt{\frac{h}{d}},$$

we can obtain $\arcsin \theta = s/(2d)$. Therefore, his formula has the same value as the formula

$$(\arcsin \theta)^2 = 2 \sum_{n=0}^{\infty} \frac{(n! \times 2^n)}{(2n+2)!} \times \theta^{2n+2}.$$

This work was described in the *Fukyu Tetsu-jutsu* (Inductive Methods) in 1722, and the special manuscript was sent to Shogun in 1730.

The key method of *tetsu-jutsu* was computing the approximate value of decimal fractions. He named it the *reiyaku-jutsu*, which used the Euclidean algorithm to compute the value of continuing fractions. For example, to try to compute the approximative value of π using this method, we set;

$$\pi_n = 3.1415926, \quad \text{or} \quad 3 + \frac{1,415,926}{10,000,000}.$$

First, divide 10,000,000 by 1,415,926; the quotient q_1 is 7 and the remainder r_1 is 88,518. Next, divide the former divisor 1,415,926 by the remainder r_1 ; the quotient of q_2 is 15 and the remainder r_2 is 88,156. Next, divide the former divisor r_1 by the newer remainder r_2 , and the quotient q_3 is 1 and the remainder r_3 is 362. Continuing this algorithm, the quotients are:

- $\{q_1, q_2, q_3, \dots, q_n\} = \{7, 15, 1, 243, 1, 1, 9, 1, 1, 4\},$
- $p_1 = 3 + 1/7 - 22/7 > \pi_n,$
- $p_2 = 3 + 1/(7 + 1/15) = 333/106 < \pi_n,$
- $p_3 = 3 + 1/(7 + 1/(15 + 1/1)) = 355/113 > \pi_n.$
- $p_{2k} = q_0 + 1/(q_1 + 1/(q_2 + 1/(q_3 + 1/(q_4 + \dots + 1/q_{2n} + 1)))) < \pi_n,$
- $p_{2k+1} = q_0 + 1/(q_1 + 1/(q_2 + 1/(q_3 + 1/(q_4 + \dots + 1/q_{2n} + 1)))) > \pi_n.$

The value of p_1 and p_2 had already been computed by the Chinese mathematician, ► [Zu Chongzhi](#) (429–500). Takebe concluded that Zu Chongzhi also invented the same method as his own *reiyaku-jutsu* and Zu Chongzhi's significant figures were seven decimal places, the same as the above computation. He admired Zu Chongzhi and named his book *Fukyu Tetsu-jutsu*; the title was connected with Zu Chongzhi's *Zhui Shu*.

In 1723, Takebe made a map of Japan under the order of Tokugawa Yoshimune, the eighth Shogun, this map is now lost. That year Takebe became a *Yoriai* (adviser) of the Shogun.

Shogun Yoshimune already permitted the import of foreign scientific books in 1720,

if they were not related to missionaries. Knowledge of Western astronomy was imported in some Chinese translations. Takebe and his student, Nakane Genkei (1662–1733) translated Mei Juecheng's *Li Suan Quan Shu* (Complete Works of Calendar and Mathematics, 1723) and sent the manuscript (Japanese name *Rekisan Zensho*) to Yoshimune in 1733. It was published and read by many Japanese scholars. Kepler's newest opinion, the elliptical orbit of planets, however, was hidden by the missionaries who advised Mei Juecheng. It became known to the Japanese after ► [Asada Goryu](#) (1734–1799) translated Kepler's (Part 2 of) *Li Suan Quan Shu*.

Takebe was held in honor by Yoshimune, and he became a *Hoi* (Knight), and held successively better positions. In 1733, he retired, and he received a life annuity of 300 *pyo*. He died on July 20, 1739 (August 24, 1739 in the present calendar) at Edo.

Takebe was one of the best mathematicians in Japan. The Mathematical Society of Japan has presented the Takebe Katahiro Prize since 1996.

See Also

- [Asada Goryu](#)
- [Computation: Chinese Counting Rods](#)
- [Mathematics in Japan](#)
- [Seki Kowa](#)

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Tang Shenwei

Hong Wuli

Tang Shenwei was a medical practitioner of the eleventh century. He was a native of Chongqing, Sichuan Province with the surname Shenyuan, and later he moved to Chengdu in the same province. He was born to a family of many generations of physicians and was an expert in medical science. During the Yuanyou period (1086–1094) of the Song Dynasty, his tutor was Li Duanbo. Tang inherited his tutor's medical knowledge and became quite adept at treatment. He was very virtuous, also he responded to any patient's call and never refused to see a patient, whether rich or poor. The only payment he asked was knowledge about a certain herb or an effective recipe (Tang, 1957).

He was especially conversant in the herbal art. He compiled a 32-volume *Materia Medica of Classified Syndromes* which was based on the combination of two other existing herbological works, the *Jia you ben cao* (*Jiayou Materia Medica*) and *Tu jing ben cao* (*Illustrated Classic of Materia Medica*). He added a large amount of new material extracted from the classics of philosophy, history, and other branches of the natural and social sciences, as well as the Buddhist canon, with a total number of 1,746 herbal drugs (Tang, 1904). In the field of traditional pharmacology, in addition to absorbing the knowledge inherited from earlier practitioners, he was full of initiative and creativity. Most of his experience was derived from his own long-term practice. He enriched the traditional herbological work by adding processing methods and effective recipes for each herb. Meanwhile, he was also a proficient clinical physician. He created a new style of combining medical practice with herbal knowledge to form the principle of “verifying the drug by recipes,” which was quite helpful to clinical practitioners, thus pushing medical science forward a step further. His work was treated as an officially promulgated book on materia medica

and circulated for several hundred years (Shang et al., 1989). His working methodology and epistemology were praised and copied by later scholars in the same field. Tang exerted an especially profound influence on the work of the great naturalist of the Ming Dynasty, ► [Li Shizhen](#).

See Also

- [Li Shizhen](#)
- [Medical Ethics in China](#)

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Tao Hongjing

Fabrizio Pregadio

The Daoist (Taoist) master, alchemist, and pharmacologist Tao Hongjing was born in 456 near modern ► [Nanjing](#). He served in various positions at the courts of the Liu Song and Qi dynasties until 492. In that year he retired to Mount Mao, the seat of Shangqing or Supreme Purity, a Daoist tradition based on meditation and visualization techniques. The retreat he built on the mountain was to remain the center of his activities until his death in 536.

After his initiation into Daoism around 485, Tao set out to recover the original manuscripts, dating from about one century before, that contained the revelations at the source of the Shangqing tradition. Tao authenticated and edited the manuscripts, and wrote extended commentaries on them. This

undertaking resulted in two texts completed in ca. 500, the *Zhengao* (Declarations of the Perfected) and the *Dengzhen yinjue* (Concealed Instructions on the Ascent to Perfection, only partially preserved). These and other works make Tao Hongjing the first systematizer of Shangqing Daoism, of which he became the ninth patriarch.

Since the establishment of the Liang dynasty in 502, Tao enjoyed the favor of Emperor Wu (r. 502–549), on whom he exerted remarkable influence. Shortly after, he began to devote himself to alchemical practices under imperial patronage. His main biographical source, written in the Tang period, has left a vivid account of these endeavors. Along with scriptural sources they testify to the importance of alchemy within the Shangqing tradition, which represents the first known instance of close links between alchemy and an established Daoist movement.

A third text on which Tao Hongjing worked during his retirement on Mount Mao was the *Bencao jing jizhu*, a commentary on the earliest known Chinese pharmacopoeia, the *Shennong bencao*. The original text contained notes on 365 drugs. To these Tao added 365 more, taken from a corpus of writings that he refers to as “Separate Records of Eminent Physicians.” Tao’s arrangement of the materia medica was also innovative. He divided drugs into six broad categories (minerals, plants, mammals, etc.), and retained the three traditional classes of the *Shennong bencao* only as subdivisions within each section. In a further group he classified the “drugs that have a name but are no longer used [in pharmacology].” Tao’s commentary discusses the nomenclature, notes changes in the geographical distribution, and identifies varieties; it also includes references to the Daoist *Xianjing* (Books of the Immortals) and to alchemical practices. With the exception of a manuscript of the preface found at Dunhuang, the *Bencao jing jizhu* is lost as an independent text, but has been reconstructed based on quotations in later sources.

See Also

- [Alchemy in China](#)

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Taqī Al-Dīn

Sevim Tekeli

Taqī al-Dīn, Muḥammad al-Rāšid ibn Ma'rūf, was a mathematician and astronomer. He was born in Damascus in 1521 and died in about 1585. He wrote several books on mathematics, astronomy, optics, and theology.

The most important of his books are: *Jabr wa'l-Muqābala* (Algebra), *Bughyat al-Ṭullāb min 'ilm al-Ḥisāb* (The Desire of Students for Arithmetic), *Sidrat al-Muntahā fī al-Afkār* (The Nabk Tree of the Extremity of Thoughts), and *Ālāt-i Raṣdīya li Zīj-i Shāhinshāhīya* (Observational Instruments of the Emperor's Catalogue), *Al-Kawākib al-Durrīya fī Bengamāt al-Dawrīya* (The Brightest Stars for the Construction of Mechanical Clocks).

From the point of view of the history of Ottoman science, the most important event of the sixteenth century was the foundation of the Istanbul Observatory, which Taqī founded under the sponsorship of Murād III (1574–1595). This observatory was an elaborate building which

contained dwelling places, a library, and offices for the astronomers. It was conceived as one of the largest of the observatories of Islam and was comparable to Tycho Brahe's (1546–1601) Uraniborg Observatory built in 1576, equipped with the best instruments of his time in Europe. There is a striking similarity between the instruments of Tycho Brahe and those of Taqī al-Dīn.

The instruments of the observatory included the following. First there were those originally constructed by Ptolemy: the armillary sphere, the parallactic ruler, and the astrolabe. Then there were those invented by Muslim astronomers, such as the azimuthal and mural quadrants. Taqī al-Dīn invented the *mushabbaha bi'l manāṭiq* (sextant, an instrument with cords for the determination of the equinoxes), which was also an important invention of Tycho Brahe. In addition, he built a wooden quadrant for the measurement of azimuths and elevations, and clocks for the measurement of right ascensions of the stars. The latter was one of the most important discoveries in the field of practical astronomy in the sixteenth century, because in the beginning clocks were not accurate enough to be used for astronomical purposes.

In *The Astronomical Instruments of the Emperor's Catalogue* the author says, "The ninth instrument is an observational clock." The following statement is taken from Ptolemy: "I could have freedom of action if I were able to measure the time accurately. Now our master Taqī al-Dīn, with the help of God, upon the instructions of the Sultan, planned the observational clocks." In *The Nabk Tree of the Extremity of Thoughts* Taqī al-Dīn says, "We constructed a mechanical clock with three dials which show the hours, the minutes, and the seconds. We divided each minute into 5 s." On the basis of his observations, Taqī al-Dīn prepared astronomical catalogues and books.

Hipparchos (second century BCE) used the intervals of seasons for the calculation of the solar parameters. But the variation of the declinations around the tropics in 1 day rendered difficult the correct determination of the beginning of the seasons. In spite of this difficulty, the method was used for a long time.

After him, ► [al-Bīrūnī](#) (d. ca. 1048), Copernicus (1473–1543), and Tycho Brahe were interested in this subject, and used a new method called “three points observation.” Taqī al-Dīn, a contemporary of Tycho Brahe, says the following in *The Nabk Tree*: “The moderns follow the method of three points observation, two of them being in opposition in the ecliptic and the third in any desired place.” This method was an important contribution to astronomy. By using this method, Copernicus, Tycho Brahe, and Taqī al-Dīn calculated the eccentricity of the orbit of the Sun, and yearly mean motion of the apogee. According to Copernicus the eccentricity is 1p 56′; according to Tycho Brahe it is 2p 9′, and according to Taqī al-Dīn it is 2p 0′ 34″ 6''' 53''' 41'''' 8''''' . As compared to modern calculation, Taqī al-Dīn’s is the most accurate value. According to Copernicus the annual motion of the apogee is 24″; to Tycho Brahe it is 45″, and to Taqī al-Dīn it is 63″. Its real value is 61″. As far as world astronomy is concerned, Taqī al-Dīn’s results can be said to be the most precise in the calculation of solar parameters.

The next important contribution of Taqī al-Dīn concerns the use of decimal fractions, the system of numerals formed from initial letters, used in the Hellenic world. This system hindered the development of algebra.

► [Al-Khwārizmī](#) (d. 801) presented the decimal system which was inspired by Indians to the Islamic world. The application of this to fractions started with Abū’l-Ḥasan Aḥmad ibn Ibrāhīm al-Uqlīdīsī and continued with al-Kāshī (d. 1437). But its application to astronomic and trigonometric tables was realized by Taqī al-Dīn. Thus the tables of his ► [zīj](#) named *Kharīdat al-Durar* (*unbored pearl*) and a *zīj* were prepared using the decimal system and decimal fractions.

See Also

- [Astronomical Instruments in the Islamic World](#)
- [Clocks and Watches](#)
- [Observatories in the Islamic World](#)
- [Ottoman Science](#)
- [Quadrant](#)

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Tattooing in China

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Evidence for the practice of tattoo in early China can be found in a number of texts that date from the mid-first millennium BCE to the nineteenth century CE. These works include *Shangshu* 尚書 (*Hallowed Documents*); *Liji* 禮記 (Record of Rites); *Zhuangzi* 莊子; dynastic histories starting with the *Shiji* 史記 (*Records of the Historian*); literary anthologies such as *Wenxuan* 文選 (*Selections of Refined Literature*); dynastic penal codes; and informal narrative collections

such as *zhiguai* 志怪 (records of anomalies) and *biji* 筆記 (note-form records).

In these texts at least six types of tattoo are mentioned: tattoo marking a people as different from the majority population, tattoo as punishment, tattoo of slaves, tattoo in the military, figurative tattoo, and textual tattoo. These types sometimes overlap; a formerly branded slave or criminal might join the army and be marked with his regimental brand. Later he might voluntarily have his body tattooed with complex figures or texts. After leaving the army, he might join a gang of street toughs and further tattoo his body.

The terms used for tattoo are varied and inconsistent; neither tattoo as punishment nor as decoration is always called by the same name, even in the same time period. Some of the terms encountered in these early texts are *qing* 黥 (to brand, tattoo), *mo* 墨 (to ink), *ciqing* 刺青 (to pierce [and make] blue-green), *wenshen* 文身 (to pattern the body), *diaoqing* 雕青 (to carve and [make] blue-green), *juyan* 沮顏 (to injure the countenance), *wenmian* 文面 (to pattern the face), *limian* 斲面 (to cut the face), *huamian* 畫面 (to mark the face), *loushen* 鏤身 (to engrave the body), *louti* 鏤體 (same), *xiumian* 繡面 (to embroider [or ornament] the face), *kenie* 刻涅 (to cut [and] blacken), *niezi* 涅字 (to blacken characters), *cizi* 刺字 (to pierce characters), and so on. These terms are sometimes used together, and there are numerous further variations.

In almost all of the textual sources, tattooed people are stigmatized as defiled or uncivilized. Mainstream, educated Chinese society never accepted the practice as normal or acceptable. This opprobrium was partly due to the association of tattoo with somewhat “barbaric” people on the periphery of society, whether foreigners, prisoners, or military men. Also, in the traditional Confucian worldview, it is unacceptable for a person to defile the body given to one by one’s parents.

Several early sources mention the tattooing practices of peoples in the areas surrounding the central kingdoms. Among others, the records refer to Man 蠻 or Yi 夷, broad terms that refer to various tribes located mostly south of the Yangzi River, from what are now Guangdong

and Vietnam to the south, to Zhejiang and Jiangxi to the north. Other peoples that are described as tattooed are the people of Wo 倭 (present-day Japan) and Liuqiuguo 流求國 (modern-day Taiwan). The various “others” in these passages are often described as being tattooed with animal patterns or fish scales, presumably as apotropaic aids to avert the danger from ferocious creatures in the wild, mostly riverine areas where they lived. The specific customs described by Chinese literati in these texts vary, but the purpose of most of the passages is to highlight the differentness of the tattooed peoples. This sense of otherness is strengthened by the mention of activities such as eating raw meat or eating with the hands and going about naked; from the point of view of a civilized Chinese person, these are habits hardly different from those of animals. Tattoo is portrayed as the epitome of uncivilized practices since it renders the human body patterned like the skin of an animal or water creature.

Tattoo, like the other corporal punishments, was an effective means of punishment in China for most of recorded history, due to the shame that a criminal felt upon reentering society with parts of the body either mutilated or even removed, permanently marking him or her as untrustworthy. From early times until recently there has been a strong stigma attached to failing to preserve one’s physical body. By not keeping the body intact and undefiled, one has failed in one of the most important filial duties and has brought shame on one’s family –past, present, and future. In the very beginning of the *Xiaojing* 孝經 (*Classic of Filial Piety*), Confucius tells his disciple Zengzi 曾子 that filial piety is the thing most necessary for civilized society and that the basis of filial piety lies in avoiding injury to the skin, hair, and body that one receives from one’s parents. The existence of this kind of social pressure must have made punishments such as the injuring of the skin by tattoo or branding particularly fearful.

Although tattoo theoretically was abolished, along with the other mutilating punishments, by Emperor Wen 文帝 (r. 179–155 BCE) in 167 BCE, it was continued as a punishment during the Han 漢 (206 BCE–220 CE) and the

following period of disunion. There is no mention of tattoo in the Tang 唐 (618–907) penal code though examples of the actual continuation of the practice are to be found in the histories and in *zhiguai* texts. It was reinstated as a legal form of punishment after the Tang, and there are many references to it in later dynasties. It was often combined with exile, as a way to ensure that the defiled person be removed as far as possible from law-abiding, civilized people. For example, the “punishment treatise” of the *Songshi* 宋史 (*History of the Song dynasty*) states that there are 200 crimes punishable by tattoo and banishment. Among these, in the case of relatively minor offenses, the punishment might be lightened to banishment alone, but if the criminal were to commit another crime, he would be tattooed at once and enlisted in the military.

A few special types of tattoo pertain naturally only to slaves, such as the facial brand of ownership or the forehead brand identifying a person as someone who had attempted escape. In addition, there are some records that describe women forcibly tattooing the faces of their slaves or their husband’s concubines, to render them unattractive to males in the family.

It is likely that a large percentage of tattoos after at least the Han dynasty were in some way connected with the military. In some eras there was a practice of branding soldiers with post and rank to prevent escape and absenteeism and as a way to mark prisoners of war. Tattoo was likely a method of identifying bodies on the battlefield as well. Also in at least one time of upheaval, ordinary citizens were seized and tattooed as slaves of the armies. When these people escaped, they were forced to form gangs of bandits to survive until a general amnesty allowed them to return to their villages.

One kind of military tattoo is the oath, whereby a soldier could tattoo dedication to a certain cause. An entire regiment could be tattooed with a symbol or a short phrase, or individual soldiers might tattoo themselves. The most famous example of the latter was the Song General Yue Fei 岳飛 (1103–1141), heroic subject of many plays and stories focusing on his attempts to recapture northern China from the Jurchens.

His biography says briefly that he had a tattoo on his back reading “Jin zhong bao guo” 盡忠報國 (serve the nation with absolute loyalty). A *chuanqi* drama about this story vividly portrays Yue Fei’s mother crying as she pierces her son’s skin with an embroidery needle and rubs ink into the wounds.

Perhaps not so unlike the military soldiers and heroes, lovers sometimes tattooed their skin to represent an oath of shared commitment. And, like these oath tattoos, various other kinds of representative tattoos were sometimes done voluntarily. There is evidence that all manner of people practiced tattoo, in spite of the stigma. These included emperors and outlaws, street thugs, and robed officials.

The best-known literary treatment of tattooed men is that found in the sixteenth-century vernacular novel *Shuihuzhuan* 水滸傳 (*Outlaws of the Marsh*). The story features five tattooed men in the band of outlaws that gathers under the leadership of Song Jiang 宋江 at Liangshan Marsh; Song Jiang’s tattoo is a facial brand, and the others are figurative. Shi Jin 史進, for example, is known as the “Nine-Patterned Dragon” 九紋龍, after the nine dragons tattooed on his shoulders, arms, chest, and belly. It is likely that the cultural practice of full-body decorative tattoo in Japan has continued since the seventeenth or eighteenth century to the present day directly because of the popularity of this novel (called *Suiko den* in Japan). The responsibility lies with a painter named Katsushika Hokusai 葛飾北齋 (1760–1849) and a woodblock printing artist Utagawa Kuniyoshi 歌川国芳 (1798–1861). In illustrating various editions of the novel, these craftsmen gorgeously decorated more heroes with tattoos than those originally described as such in the novel. The illustrations in the Japanese editions of the novel fueled a tattoo craze in Japan (which, incidentally, might have helped fuel the current craze for tattoo in modern China, several centuries later). The link below is to an image of the Nine-Patterned Dragon of Shi Jin from an eighteenth-century Japanese woodblock illustrated version of the novel. <http://artofrezumi.tumblr.com/post/13301892145/utagawa-kuniyoshi>

One rarely read but important source of information of tattoo practice in China is the ninth-century miscellany *Youyang zazu* 酉陽雜俎 (*Miscellaneous Morsels from Youyang*), by Duan Chengshi 段成式 (c. 800–863), particularly because of the eleven entries in which this amateur ethnographer records in astoundingly meticulous fashion some of the pictorial and textual tattoos that he saw. These eleven entries reveal that people of various social ranks, even officials, were extensively tattooed with pictures or with literary texts or both. Duan was ever on the lookout for odd things in ordinary society, and he records not only tattoos that were commonly seen on the streets of cities in his own time, but he also tells of special visits he and his friends made to the homes of tattooed people to admire the body work in person. He describes the official reaction to some tattooed people, particularly ruffians who prowled the streets making trouble (some of whom were associated with the military), as violently negative; he mentions one government crackdown in which thirty tattooed men were beaten to death and their bodies exposed in public to discourage others from becoming tattooed.

The vivid picture that Duan paints of the streets of major Chinese cities such as Jingzhou and Chang'an is not seen elsewhere; mention of such subversive activities is not a topic of interest for most educated literati. For this reason, we owe a debt of gratitude to Duan Chengshi, who did not shirk from any subject, no matter how unsavory others might have found it. In fact, Duan's descriptions seem anything but negative; at times his descriptions are neutral and detached, but at others he openly acknowledges the artistry and beauty in the tattoo that he sees. Duan pricks the reader's imagination with these entries, particularly in cases like the man who holds a respectable official position, but under whose concealing robes lies a full-body tattoo of an undulating snake. When the man is drunk at parties, his friends convince him to disrobe and pretend to scare the entertainers with his tattoo. As Duan possibly intended, the reader cannot help but wonder if there were other officials like this man or if he was an anomaly

in his social class. Duan also tells us that he visited the home of a policeman to see his tattoos. The man disrobed and revealed a body entirely tattooed with poems by his favorite poet, Bai Juyi 白居易 (772–846). This is not the only example of literary text used as tattoo, but it is certainly the most tantalizingly unusual one.

The robed official's tattoos perhaps represented and expressed his hidden animal nature, which reminds us of one of the reasons the stigma was so strong in the first place among Han Chinese. Of a higher and presumably more acceptable social register, the policeman's second skin allowed him to identify with and honor his beloved poet. Other bearers of tattoos felt endowed with supernatural strength, like the man whose back was graced with a Buddhist deity; twice a month he would have his wife and daughter worship the deity and offer milky gruel to it, to ensure that he could continue to lift heavy weights. In other entries it appears that pictorial tattoos might have been considered effective apotropaic devices.

In a few entries, Duan describes the fine quality of the tattoos that he saw: "On his chest and belly appeared mountains, pavilions, parks, ponds and kiosks, grass and trees, and birds and animals. There was nothing that wasn't included. The tattoo was so fine that it was as if it had been painted on with repeated fine washes of color." He does not describe the techniques by which such complex figurative tattoos were created, but in another entry he outlines a simple means by which people could instantly be tattooed on the street. "In Jingzhou, during the *zhenyuan* era (785–805), there were tattoo vendors in the street. They had imprinting stamps into which they would press needles closely together into the shapes of all kinds of things, such as toads and scorpions, mortars and pestles, or whatever people wanted. Once they'd imprinted the skin (with this needle stamp), they would brush (the pricked area) with black lead. After the wound had healed, the tattoo was finer than that on the patterns from which the customer had originally ordered." It is clear that tattoo was readily and openly practiced during Duan's lifetime and that there was a high demand for it. It is possible that

the roadside customers were former criminals or soldiers, but it is also likely that there was a good deal of interest in tattoo among the general population and possibly even among the upper classes.

References

- Most of the information in this article can be found in expanded form, with detailed notes, translations, and complete citations in my two articles below.
- Reed, C. E. (2000a). *Early Chinese Tattoo* (Sino-Platonic papers number 103, pp. 1–52). Philadelphia: University of Pennsylvania.
- Reed, C. E. (2000b). Tattoo in Early China. *Journal of the American Oriental Society*, 120(3), 360–376.

Tea in India

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The story of how tea cultivation was brought to the South Asian subcontinent and gradually established there as a major industry (said to be contemporary India's second largest employer, after the railways) is notably marked by experimentation, innovation, and scientific and technological advances that were subsequently adopted by tea producers in other parts of the world. The initial impetus for this came from afar in the immense thirst for tea that developed among the population of the British Isles beginning in the late seventeenth century. Brewed with leaves imported from China, the beverage was at first a luxurious and medicinal privilege of aristocrats, but during the next century, as its import gradually increased and its price declined, it spread to the middle and eventually the working classes. By the end of the eighteenth century, tea, usually served with milk and heavily sweetened with sugar produced by slave labor in the Americas, had become a staple of British life.

The commercial entity most involved in this process was the East India Company, which had acquired virtual hegemony over the Indian subcontinent by the mid-eighteenth century. Using India as an entrepot in the China trade and opium cultivated there as an exchange commodity, the Company was able to ship tea profitably back to the motherland. Yet by the 1780s, its directors worried about the Chinese monopoly over this now-essential commodity, the cultivation and processing of which was treated as a state secret by the Qing imperial regime. In the nineteenth century, as Britain fought two Opium Wars to keep the tea trade profitable, they began investigating the possibility of its cultivation in the vast subcontinent under their control. Ingenious and clandestine attempts to smuggle plants and seeds out of China met with little success, as *Camellia sinensis* mostly failed to thrive under Indian conditions (Rose, 2010; Griffiths, 1967, pp. 42–50). But in December, 1834, a robust plant from the forests of Assam in northeast India was definitively identified, after nearly a decade of horticultural debate, as a broader-leafed variant of the Chinese plant (var. *assamica*) – a discovery promptly and portentously hailed by the Governor-General's recently appointed Tea Committee, as "...by far the most important and valuable that has ever been made on matters connected with the agricultural or commercial resources of this empire" (Griffiths, 1967, p. 41). An initial shipment of eight chests of its dried leaves, processed with the aid of Chinese informants, created a sensation on the London auction market in 1839 and precipitated a virtual tea rush, as investors envisioned a burgeoning industry in British-controlled lands (Fig. 1).

Yet conditions in Assam differed greatly from those in China, where tea had been produced for more than 1,500 years as a cottage industry by small growers who shared local and likewise small-scale processing facilities. Assam, which had come under Company control in 1826, was thickly forested and thinly populated. To produce tea on a scale sufficient to meet British demand would require the clearing of thousands of acres of jungle and the creation of large plantations

Tea in India, Fig. 1 A sign planted among tea bushes on an estate in northern West Bengal points, both literally and figuratively, toward the tea garden's mechanized hub, where the freshly picked leaves of *Camellia sinensis* var. *assamica* are processed into dried, black "CTC" tea (Photo by the author, December 2010)

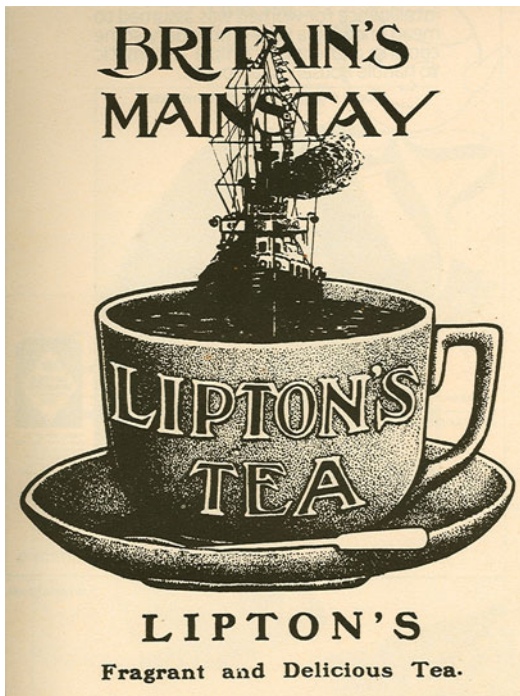


(euphemistically called “gardens”) on the model of those that produced other cash crops elsewhere in the colonized world. Following the abolition of slavery in the British Empire in 1833 (extended to India a decade later), a workforce for these tracts was secured by importing hundreds of thousands of indentured laborers – mainly landless, impoverished people from central India, many of whom perished due to the unfamiliar climate, unhealthy living conditions, and harsh work regimen to which they were subjected (Moxham, 2003, pp. 127–189). Despite this and despite market conditions that did not always favor the new Assam product (a darker, black or fermented tea that only gradually won acceptance over the largely green Chinese varieties), Assam growers began realizing significant profits by the 1850s. Cultivation and harvests expanded dramatically in succeeding decades, and by 1888 India overtook China as the principal supplier of tea to the United Kingdom (Fig. 2).

Although most of it passed through the auction houses and port of Calcutta, growers and traders had little interest in selling it to Indians, who showed – even well into the twentieth century – similar disinterest in drinking it. Many who were drawn to the Independence struggle regarded it as an exploitative, imperialist product, but most Indians simply had no experience of it. That India is today not only one of the world's leading producers of tea (with a crop of roughly 1.2 billion kilograms in 2013) but also its single

biggest consumer (accounting for more than 80 % of its own crop) reflects a history in which technological and marketing innovation shares the spotlight with economic and political developments.

From the beginning, the large scale of tea cultivation in Assam, difficulties in securing labor, as well as the distinctive qualities of the local plant led owners to experiment with cultivation and manufacturing methods that differed from traditional Chinese practice. Since tea leaves must be processed rapidly after plucking, most gardens had their own factories, and efforts to mechanize these, with a view to reducing both manpower and processing time, began almost immediately. Many of the pioneer planters – who were once as romanticized in colonial narratives as they are now maligned in postcolonial histories – were amateur inventors who devised machines, some of which would eventually be patented and manufactured, to accelerate and standardize the three basic stages of leaf processing for black tea: initial withering or wilting, rolling (manipulation of the leaf to break down cellular structure and expedite the oxidation process – the latter often erroneously called “fermentation”), and drying. In place of the shallow baskets in which the Chinese withered small batches of leaves, Assam planters devised huge troughs lined with wire mesh, around which, in time, air was mechanically circulated at a controlled temperature and humidity



Tea in India, Fig. 2 A World War One-era newspaper ad (from an English-language daily in India) suggests the centrality of tea, produced by poorly paid colonial labor, in the British imperial and military project (Image courtesy of Urban History Documentation Archive, CSSSC Kolkata)

in a process that could require 12 hours or more (Fig. 3).

Hand rolling, another Chinese practice, was replaced by the 1870s by machines like the Nelson Roller, in which large batches of leaf were massaged for a fixed period between rotating metal plates and which “reduced by 75 % the time required for the hand-rolling process” (Griffiths, 1967, p. 493). For drying, the Chinese practice of pan firing in outsized woks was supplanted by the 1880s by drying machines, which were large ovens heated by coal – so that India’s coal reserves became as crucial to tea growers as they were to its railways and steel mills.

These technologies, largely in place by the end of the nineteenth century, contributed to enormously increased production. The 1880 crop of 43 million pounds was doubled less than a decade

later and then rose to 197 million pounds by 1900 (Moxham, 2003, p. 114; Griffiths, 1967, p. 128). Expanded acreage only partly accounted for this increase. Constant improvement in horticultural techniques (including the gradual elimination of introduced Chinese strains, which had initially been favored and had hybridized with the Assam variety, a process eventually recognized as undesirable) would see per-acre yields rise from 100 to 200 lb in the early decades of cultivation to 1,500 lb by the mid-twentieth century. Such improvements and the control of diseases and pests were initially the main concerns of a well-equipped Experimental Station financed by growers through the Indian Tea Association (ITA, established in 1881), which opened at Tocklai, Assam, in 1913 and thereafter reported on its research at the Association’s annual meetings (Detailed Report, 1914, p. iv).

Yield itself would eventually help drive renewed innovation, especially as India had to compete in international markets, after the 1880s, with other black tea industries in Ceylon (Sri Lanka) and Java. Bumper harvests worldwide coincided with decreased consumption during the First World War and the Great Depression of the 1930s, leaving Indian growers – even after ITA-mandated reductions in output – with an annual unsold surplus of more than a hundred million pounds of tea, which sparked interest in creating a domestic market for this export crop (Fig. 4).

This required innovative marketing, and in the largest such effort ever mounted on the subcontinent, the Indian Tea Market Expansion Board (ITMEB), established in 1936, began a massive campaign to convert the population to the tea habit through eye-catching advertising and signage, model tea shops in railway stations and bazaars, and traveling tea vans that demonstrated tea making and passed out tens of millions of free cups of the beverage (Fig. 5).

The ITMEB also borrowed the packaging and sales methods formerly used to promote tobacco, creating tiny one-pice packets on perforated chains that were sold for the smallest unit of currency and intended to appeal, once the habit had taken hold, to poor consumers as pay-per-use

Tea in India, Fig. 3 Tea leaves fill huge troughs in a multistory “withering house” on an estate in northern West Bengal. An overhead cable system is used to transport bags stuffed with leaves to the next stage of their processing (Photo by the author, December 2010)



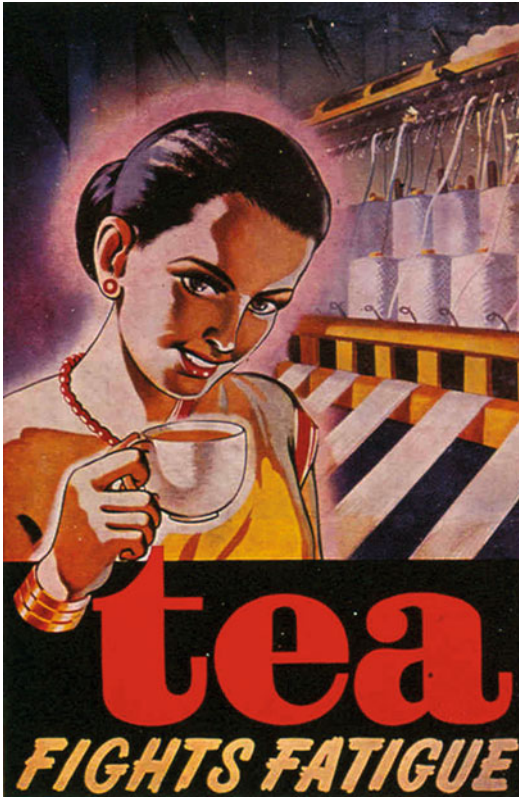
Tea in India, Fig. 4 The cover of a Bengali-language brochure produced circa 1938 for the Eid festival by the Indian Tea Market Expansion Board shows the “journey of tea” from garden to middle-class couple, emphasizing the modern, industrial stages in its manufacture and transport (Image courtesy of the Urban History Documentation Archive, CSSSC Kolkata)



doses (Bhadra, 2005, pp. 19–26; Collingham, 2006, p. 187–208; Indian Tea, 1936–37). Somewhat hampered by the Second World War and the final phase of the Independence struggle, promotion continued after 1947, when British growers and packers began selling their businesses to Indian entrepreneurs and when the ITMEB became the Tea Board, a division of India’s Ministry of Commerce.

The gradual creation of a large domestic market eventually led to further technological

innovations to protect the industry’s profit margin, since most Indian consumers could not afford to pay the prices that tea fetched overseas. The basic machinery for tea processing had changed little since the late-nineteenth century, although a few estates experimented, beginning in the mid-1920s, with devices such as the Legg Cutter. Adapted from tobacco processing, this was used in humid areas such as the Dooars region of northern Bengal, where proper withering was difficult to achieve during monsoon



Tea in India, Fig. 5 An ITMEB poster from 1948 by commercial artist Annada Munshi, created as part of a campaign to encourage factory and mill owners to offer “tea breaks” to workers on the argument that it would improve their productivity (Image courtesy of the Urban History Documentation Archive, CSSSC Kolkata)

months. By slicing large, unwilted Assam leaves into tiny strips, the device accelerated oxidation, though many tasters did not favor the resultant product. By the mid-1960s, Legg Cut tea would be superseded by another and more widely adopted processing innovation.

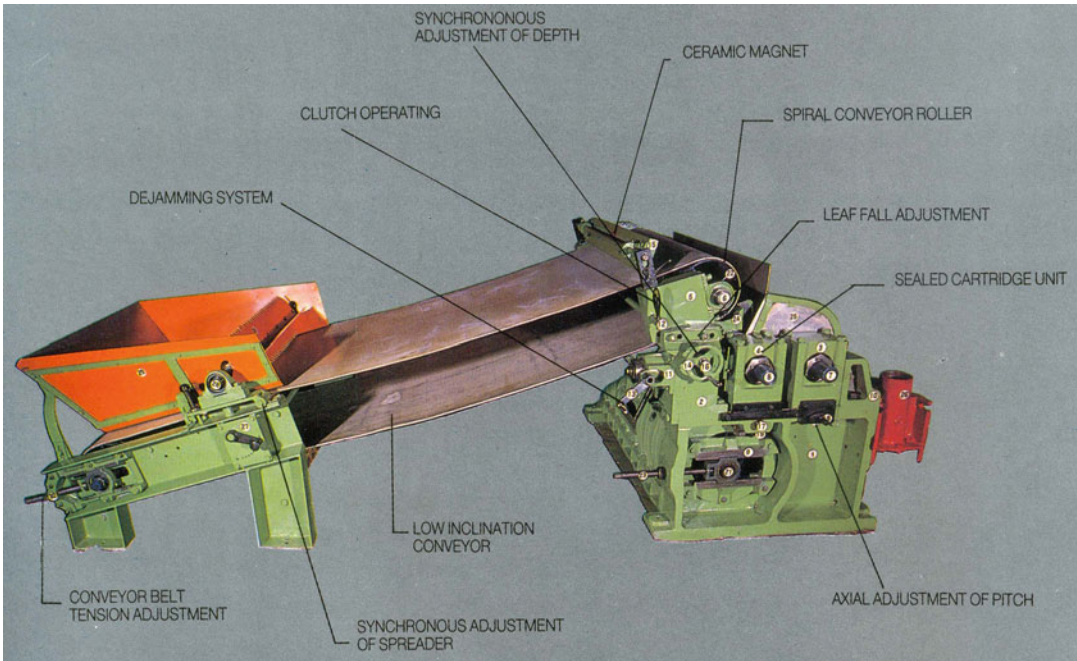
In 1931, William McKertcher, Chairman of the Amgoorie Tea Estate in Assam, had invented a machine to crush, tear, and curl lightly withered leaves using steel rollers studded with sharp teeth. Dropped between two such rollers rotating at different speeds, leaves were torn into tiny fragments that oxidized rapidly. Tea produced by this process became known as CTC, as opposed to the rolled, full-leaf product that was now dubbed Orthodox. The CTC process

produced a tea of exceptionally strong liquor that held up well to copious amounts of milk and sugar – suiting Indian tastes – but, like most growers of his period, McKertcher still had the export market in mind, specifically the new American penchant for teabags that required just such a product. In any case, his machine was cumbersome, expensive, and difficult to clean, and its widespread adoption was delayed for nearly three decades (Dutta, 1992, pp. 126–129).

After Independence, India’s share of the international trade continued to decline, while its growing domestic market, so assiduously cultivated in previous decades, demanded a yet more affordable product. The ITA, recognizing that it had invested too heavily in horticulture and insufficiently in industrial capacity, appointed a Senior Research Engineer to its scientific staff at Tocklai in 1955. Thereafter, annual reports spoke excitedly of progress in the quest for continuous manufacture, in which all stages of tea processing would be fully mechanized. Attempts to develop harvesting machines to replace hundreds of thousands of mainly female tea pickers met with little success, in part because of the topography of Indian gardens. But in 1957, Tocklai introduced the McTear Rotorvane, named for its engineer-developer – an elaborate grinder to mash partly withered leaf into *maal* (Hindi for “raw product”) ready for rapid oxidation on a conveyer belt (Detailed Report, 1958 p. 107).

The most important breakthrough, however, came at the end of the decade, when Indian engineers in Calcutta (now Kolkata) redesigned McKertcher’s 1931 device as a sliding-block CTC machine. This machine was cheaper, more efficient, and more easily serviced because its heavy steel rollers could be slid in and out with relative ease (Fig. 6).

Its sharper steel rasps also led the machine’s acronym to be redefined (by those in the know) as cut, tear, and curl. Patented by the Small Tools Manufacturing Company but quickly pirated by others, the improved CTC machine gradually spread throughout Assam and Dooars gardens, and then far beyond. The device revolutionized the industry and finally made possible the vast



Tea in India, Fig. 6 An improved “sliding-block” CTC machine, circa 1965, produced by the Small Tools Manufacturing Company of Calcutta (Image courtesy of Anik Palchoudhuri)

Tea in India, Fig. 7 A streetside chai shop in north Kolkata that serves up a blend of water, rich buffalo milk, and CTC tea leaves, mildly spiced (at the customer’s request) with fresh ginger (Photo by the author, April 2011)



expansion of its Indian consumer base, for it inexpensively produced a strong-liquoring product that became beloved of Indian merchandisers and consumers since it also doubled

cuppage – the number of servings obtainable from a given weight of dry tea (Lutgendorf, 2012, pp. 21–24). Over the next four decades, CTC came to dominate the Indian industry,



Tea in India, Fig. 8 Conveyor belts move leaf fragments through successive “cuts” by CTC machines to large, rotating “googhy” drums in a tea factory in northern West Bengal (Photo by the author, December 2010)

comprising roughly 90 % of production by the beginning of the twenty-first century and becoming the obligatory ingredient in *chai*, the ubiquitous national beverage, produced by boiling tea particles in a mixture of water, milk, and sugar, occasionally with the addition of spices like ginger and cardamom (Fig. 7).

By contrast, the full-leaf and expensive Darjeeling Tea that is prized internationally, produced at higher elevations from a plant that is closer to the introduced Chinese strain and processed by the (similarly mechanized but less complex) Orthodox method, now accounts for only about 1 % of the Indian crop.

Today, in realization of the once-futuristic dream of continuous manufacture, CTC machines are generally used as one component in a largely automated production process (Fig. 8). Withered tea leaves fall through a chute into some variation on the Rotorvane (for initial crushing of the leaf) and then, after passing through three to four cuts between CTC rollers, tumble through googhys (huge rotating aluminum drums that give the leaf fragments a characteristic curl to produce a granular



Tea in India, Fig. 9 An automated and coal-fired drying machine for “flash-firing” CTC tea particles at high temperature; the flues on the left are used to extract “tea waste” (Photo by the author, December 2010)



Tea in India, Fig. 10 The author contemplates a (possibly) lifetime supply of just-dried CTC granules, awaiting packing in the warehouse of a tea factory in northern West Bengal (Photo by the author, December 2010)

product). Then they are moved along continuous bed fermentation belts, to finally drop into giant ovens that flash-fire them at 225° Fahrenheit, halting oxidation and removing all but 3 % of their moisture, while also sucking out, through huge ducts, the sawdust-like chaff of stem fragments (Fig. 9).

Sorting machines then sift out various grades of tea, from larger broken orange pekoe leaf fragments to the finest dusts (the latter often highly valued in Indian markets), which are then packed in moisture-proof bales or containers. The whole process of production – from picking to packing – generally takes less than 18 h, and its end product may go up for auction in Guwahati or Kolkata within days or weeks. Speed of processing and delivery, no less than mechanized efficiency, is important to an industry and consumer base that prizes freshness in tea and that maintains, even for cheaper grades, surprisingly high standards of connoisseurship (Fig. 10).

As a postscript, it may be noted that the chaff expelled by modern drying machines – so-called tea waste – is actually not wasted at all. It is largely shipped abroad for the manufacture of

instant and flavored teas, products that (to the wonder and amusement of Indian tea industry insiders) are now valued by consumers in certain countries of the postindustrial West.

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Tea in Japan

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West Indies

Tea and Tea-Drinking Customs

There are three different stages of tea drinking in the history of Japanese society. Tea – as a form of beverage – and the social custom of drinking it, and, possibly, even the plant *Camellia sinensis* itself, were first introduced in the late ninth century by Buddhist monks who had made a pilgrimage to Tang-era China. As it was a precious commodity, its consumption was limited to the inner circle of the imperial court, and it was employed mainly for religious ceremonies (Murai, 1989; Shimaō, 2014).

The second stage of the custom of tea drinking in Japanese society was the end of the twelfth century. Eisai, a Buddhist monk who had made a pilgrimage to Song China, introduced a new type of tea – *matcha*, which is ground or powdered green tea – and a new method of preparing it (Hashimoto, 2013).

Finally, a new method of making tea – steeped leaf tea – was introduced from Ming China and a new manufacturing technique was invented in Uji. This type of tea became a popular commodity in the urban areas by the mid-seventeenth century (Yoshimura & Wakahara, 1984).

The Historical Developments of Tea Cultures

Drinking Tea at the Imperial Court

When the custom of drinking tea was first introduced to Japan, the imperial court initially

accepted it as part of religious ceremonies, such as the seasonal sutra reading rituals held every spring and autumn at the imperial court (*Kinomidokkyo*) (Murai, 1979, 1989; Uruma, 2001). However, tea itself was not central to this religious ceremony. Rather, tea was offered after the seasonal mass to relieve the fatigue of the priests in attendance on the day of the ceremonies (Murai, 1979).

It is commonly understood that the tea during this period was made from a tea brick in which the tea leaves were steamed, packed in moulds, pressed into block forms, and then toasted. The brick tea was then grounded into powder, decocted, and flavored with salt and spices such as raw ginger and arrowroot before serving (Murai, 1979; Shimaō, 2013). The beverage was served to reward the priests at the annual mass. The use of tea during this period was medicinal rather than epicurean (Murai, 1979; Shimaō, 2013).

When tea was first introduced to the imperial court in the late ninth century, Emperor Saga appears to have ordered the cultivation of the plant *Camellia sinensis* to meet the demand of the semiannual use at the imperial court, so tea was an entirely private and strictly limited phenomenon (Hashimoto, 1999). In fact, neither the production nor consumption of tea seemed to have been a part of the lives of courtiers even though a small amount of tea seemed to have been continuously cultivated on the premises of the imperial court and at some Buddhist temples (Murai, 1979).

Powdered Green Tea and Zen Monasteries

Even after the new form of powdered green tea and a new tea-making method were transmitted to Japan from China by a Buddhist monk at the end of the twelfth century, access to tea was still limited to the small circle of the ruling class, namely, the members of the imperial court and religious institutions, and its purpose remained ceremonial. Only a modest amount of tea was cultivated on the premises of temples and shrines.

Powdered green tea became essential to the monastic life of Zen monks. The tea was made and served on various occasions during the rituals

and annual ceremonies outlined in the *Shingi* (*Qinggui*) – the written codes of conduct regulating all aspects of monastic existence – from the form of organization to the conduct of daily life, including rituals and ceremonies (Hashimoto, 2013). Through the implementation of *Shingi* at various temples, tea was an essential part of the life of Zen monasteries (Shimao, 2014).

The custom of drinking powdered green tea has been strongly associated with the Zen Buddhist practices since Eisai introduced it, and he has long been understood as the founder of one of the Zen sects, Rinzai. However, as the work of religious historians since the 1970s has shown, the Buddhist orthodoxy in medieval Japan was *Kenmitsu* – the coexistence of exoteric and esoteric Buddhism – and the Rinzai sect in its early stages was a consolidation of Zen and esoteric Buddhism (Hashimoto, 2013). Moreover, the cultivation of the plant and manufacturing of tea was not limited to Zen temples. On the contrary, the tea plants were first cultivated on the premises of exoteric-esoteric Buddhist temples such as Kozanji of Mount Togano-o (Hashimoto, 1999). In other words, as Hashimoto makes clear, the custom of drinking powdered green tea was not exclusive to the Zen monasteries. Thus, the custom of tea drinking was first introduced to the exoteric-esoteric Buddhist temples and then emulated by members of the secular world (Hashimoto, 2013).

Playing with Tea

Tea was still a luxury good and a favored gift, because the supply was very limited. Temples in Kyoto and Nara were the only places where tea was cultivated and manufactured, and it was distributed only through personal channels (Hashimoto, 1999, 2013). However, with the rise of military power and the relocation of the political center to Kamakura in the east, tea drinking and the cultivation of tea spread to the temples in Kamakura through the circulation of goods and people between the capital and the new political center.

With the expansion of tea cultivation, although its distribution was still limited and

private, the custom of drinking tea finally spread outside the religious institutions and developed into a form of entertainment: tea matches (*tōcha*) were played by the military elite, the emerging new social power, by the mid-fourteenth century (Murai, 1979). Although the cultivation and manufacturing of tea remained private and its distribution was made only through personal channels, tea cultivation was gradually transmitted to religious institutions in Kamakura and then to the wider society (Hashimoto, 2013; Murai, 1979).

Gathering for Tea in Shogun's Audience Hall (Shoin)

In the fifteenth century, during the rule of the Ashikaga shoguns, the political center was again relocated to Kyoto. Tea drinking now developed into a more elaborate social practice that required more refined space and aesthetics, as it was performed at the Shogun's residence. The audience hall was decorated with a number of *karamono*, the objects which were brought back from China and beyond by Buddhist monks to Japan, and turned into a space where the authority of the ruler was displayed. Additionally, elaborate rituals performed at the Shogun's residence developed a refined style called *karamono suki*, producing both art connoisseurs serving the shoguns as cultural advisors (*Dōbō*) and written instructions for decorating the hall, such as *Kundaikansōchōki*.

Tea Gathering as Political Theater

Eventually, by the sixteenth century, the custom of drinking tea had developed into a form of art, which we now identify as *chanoyu*, or the Japanese tea ceremony. By the time of Oda Nobunaga and Toyotomi Hideyoshi, tea gatherings served as opportunities for political theater for military leaders. As a result, the production of tea was encouraged and patronized by the military leaders to ensure both the quantity and quality of the supply. With the increase in demand for a stable supply of tea, new regions emerged as tea plantations, such as Uji, a village near Kyoto (Yoshimura & Wakahara, 1984).

Gathering for Tea in the Cities

The practice of tea gathering was not exclusive to military leaders. Wealthy town commoners in prosperous cities such as Kyoto, Nara, and Sakai also began practicing the elaborated tea-drinking ritual in the fifteenth and sixteenth centuries (Murai, 1979). They themselves developed an individual style of *chanoyu* that differed from the practices of the Ashikaga Shogun.

A New Invention: Steeped Leaf Tea

By the mid-seventeenth century, another type of tea – steeped leaf tea – became more popular and began to circulate in the urban markets. This type of tea is called *sencha*, the beverage made by steeping tea leaves that are dried and roasted in metal kettles in hot water. The legend is that the Chinese monk Yunyuan Longqi, who established the Manpuku-ji temple on Mount Ōbaku, introduced this new type of tea from Ming China. However, tea plantations in Kyushu had a long history of producing roasted tea and claim that their manufacturing method was introduced from Ming China in the fifteenth century during Hideyoshi's invasion of Korea (Yoshimura & Wakahara, 1984).

Tea producers in Uji invented a new tea-manufacturing method, which was rapidly transmitted to tea plantations outside the area so that *sencha* became the most popular beverage among the city dwellers (Yoshimura & Wakahara, 1984). Consequently, a tea-manufacturing industry developed during this period, producing tea that was ever more accessible though tea as a commodity was still limited to the urban population.

Tea in the Rural Areas

Before the transmission of the custom of drinking tea from China, and for villagers more generally, decoctions of various herbs like persimmon leaves appear to have been the favored beverage for both the elite and common folk alike (Uruma, 2001). Furthermore, villagers are known to have been drinking roasted tea, or *bancha*, since the medieval period. This beverage was made from *Camellia sinensis* that was privately cultivated or collected from mountain areas (mountain tea) but

processed differently from what the elite consumed (Hashimoto, 2013; Nakamura, 2013). There remains a debate as to whether or not *Camellia sinensis* is native to Japan, though the majority of historians agree that it was imported from China at some time in history (Terada, 2013).

In the Modern Period

The production of green tea was encouraged by military rulers like the Shogunate and other lords during the Tokugawa period. However, the system of tea production has changed dramatically since the 1850s. With the opening of Japanese ports to foreign trade and the fall of the Tokugawa Shogunate that followed, tea producers and manufacturers changed their business structure to fit the new world of a market-oriented economy. The leaf tea processed using the Uji method became one of the key commodities that were viable for export.

By the early 1980s, 80 % of green tea in the Japanese market was manufactured using the Uji method noted above (Yoshimura & Wakahara, 1984). While Uji-method green tea has become a popular everyday beverage in contemporary Japan, the drinking practice of *matcha* (powdered green tea) is viewed as a cultural practice that is deeply associated with Japanese tradition.

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Technology

Arnold Pacey

The development of technology has usually been socially determined, changing in direction as different social formations have emerged. For example, there are important distinctions to be made between, first, small communities of farmers or dispersed groups of hunters with technologies outstanding chiefly for their adaptation to local *environments*; second, the larger kingdoms and empires, whose technology tended to be *engineering-centered*; and third, trading communities and merchants or entrepreneurs with *production-centered* technologies.

An initial problem in discussing technologies of the first kind is nomenclature. Weiner, who has discussed the remarkable protective clothing developed by the Inuit for life in the Arctic, has described these people as “the great pioneers of microclimatological bioengineering.”

This tribute to the control of body heat loss achieved by Inuit clothing is well deserved but places the skills of Arctic people within the wrong frame of reference. Their technology was environment-centered, not engineering-centered. On the one hand, they were adapting to a very demanding environment; on the other, they were making very efficient use of environmental resources. Thus, the animals hunted for meat were also a source of oil for lamps, bone for making needles and other tools, and the skins, intestines, and fibers from which clothing was made.

Archaeological evidence suggests that the invention of tailored skin clothing adequate to enable people to winter in the Arctic was accomplished in Siberia around 2000 B.C.E. After that, it was several centuries before oil lamps, houses built of snow, and dog sleds were developed by the people of the Dorset Culture, based on Baffin Island. Later still, improved boats and harpoons were developed by the Alaskan Inuit.

All these inventions, quite clearly, were the work of small, dispersed groups without centralized organization, and all were responses to an exacting environment. Perhaps what we ought also to remember is that for the Inuit, as for most non-Western peoples, the environment was endowed with personal and spiritual meanings, and with magical qualities. It was not merely the object of detached, if concerned, analysis that it has become for most Westerners. Thus, their technology was based on an organic world view.

The same points can be made about peoples inhabiting other environments, such as rainforests, deserts, steppes, or coastal and island situations. The efficiency with which resources were used by such people is illustrated by the estimate that in A.D. 1500 the Amazon basin supported a somewhat larger population than it did in 1990, yet without the extent of destruction of forest and fishery resources now taking place. Fruits, nuts, leaves, seeds, and roots were gathered for use as food and medicine. Fish and animals were caught, often using poison tipped spears, but with less ecological disturbance.

In some rainforests, notably in Central America as well as in Asia and Africa, people developed a form of agriculture in which a great variety of

crops was raised while extensive tree cover was retained. Cereals such as corn in the Americas or rice in Southeast Asia were grown in forest glades with shade tolerant vegetables under trees. Those trees that were left unfelled or were newly planted would be selected according to whether they produced fruit, nuts, timber, fodder, or *materia medica*. Thus, an artificial rainforest was formed in a system often referred to as forest farming, forest inter-culture, layered gardening or, more recently, agroforestry. The key point – whatever the name – is that there would always be tree cover, and usually other vegetation, to protect the soil from erosion and to retain plant nutrients. By contrast, where rainforest is cleared for conventional western style agriculture, soils become degraded very rapidly.

In Africa, rainforest crop production became widespread only after the banana and Asian yam were introduced on the east coast by Indonesian traders and colonists around A.D. 400–500. In quite a short space of time, these crops were adopted by many gardeners across the continent, enabling populations in forested areas to increase considerably. In Central America, archaeologists have now shown that the Maya culture used forest farming with high yielding nut trees and manioc (cassava) as major crops around A.D. 600–900.

Other environment-centered technologies were those of people living in hot, dry, semidesert conditions who evolved sophisticated water conservation techniques. Some of these made use of small structures, such as check dams in gullies and spreader dikes on flatter ground – for example, in northern Mexico and Arizona – or else stone lines on contours (in the African Sahel). Others practiced the careful planning of fields in relation to rainwater catchment areas, and the construction of bunds to channel water and hold it on the land. Among the most elaborate ► [rainwater harvesting](#) systems of this kind were those of Nabataean farmers in the Negev Desert in Israel from about 200 B.C.E., and comparable systems in Morocco and elsewhere in North Africa. Small dams, river diversions, and the Persian ► [qanat](#) (wells linked by a tunnel) were other means of providing irrigation water to crops on a small scale.

Consideration of environment-centered techniques such as these offers a distinct perspective on early technology quite unlike the conventional view based on the materials from which tools were made, namely, stone, bronze, and iron. That view seeks to discover a pattern of tool use and metal-working skill common to all human societies, and ignores the environmental particularism emphasized here. It parallels the modern assumption that the principles of technology are independent of cultural values and underestimates the different ways in which human societies explored the varying surroundings in which they lived. By contrast, a perspective based on environmental adaptation allows one to recognize the extraordinary sophistication of some peoples who nominally remained in the “Stone Age” even in the early twentieth century, including the Inuit and some rainforest communities.

Viewed from another angle, however, the Neolithic period in the later Stone Age does seem to have been a time of particularly important innovation, at least for western Asia. It is associated with the first domestication of crops and livestock, and hence the invention of agriculture, probably associated with the earliest use of some of the water conservation techniques previously discussed. Complementing these innovations were others, such as pottery (and soon after, the potter’s wheel), grain milling, tool-making, and textiles (with the looms on which they were woven). Many of these innovations relate to the domestic sphere of life, and it is likely, therefore, that many of the inventors concerned were women.

It would be a mistake, however, to assume that the invention of agriculture, the domestication of plants, and the appearance of pottery or textiles were unique events, each occurring only once in human history, in one part of Asia and then diffusing to other regions. Independent inventions undoubtedly occurred, just as different crops were domesticated in various places and at different times. For example, about 1500 B.C.E., corn (i.e., maize) and pottery were both known in Mexico, but not in Peru, where beans and peppers were cultivated. Thus, the two cultures may have developed agriculture independently of one

another. Moreover, some plants were still being newly domesticated in the twentieth century, for one reaction to deforestation in Africa has been to cultivate a number of fruits and vegetables that people had collected from the wild until the loss of forest cover threatened their existence. Reports from Kenya show how modern gardeners, usually women, have selected from wild varieties and have produced strains adapted for garden conditions.

Engineering-centered technologies developed in a very different context. They were characteristic mainly of kingdoms or empires whose labor resources and administration made large scale construction works possible. One view of the origins of engineering is that once agriculture was established, irrigation became necessary in many of the warm, dry countries of western and southern Asia to produce sufficient food for growing populations. The dams and canal systems necessary for irrigation could not have been constructed, it is argued, without recruiting a large labor force, and that in turn could not have been done except in centrally organized kingdoms. In this view, the need for irrigation canals and other hydraulic works dictated the formation of centralized government administrations with the coercive power and management skills needed to organize large scale construction works.

This theory about how hydraulic civilizations evolved does not apply everywhere, however, since empirical evidence shows that in many areas where irrigation was practiced, farmers did the essential earth moving and engineering work themselves, or with their neighbors through local systems of cooperation, but without central organization. This seems to be true for rice culture in China, according to Francesca Bray. Some of the biggest centrally organized engineering schemes prior to A.D. 605, involving thousands of laborers, were not for irrigation but for construction of transport canals for carrying grain to the capital. However, flood control and irrigation in north China did depend on large scale works, so the evidence is not clear cut.

In Mesopotamia and Egypt, much early irrigation was also on a small scale, dependent on manually operated water raising devices such as

the *shaduf*. The type of crops grown and the seasons of cultivation meant that water requirements in early agriculture were much less than after the agricultural revolution of the Islamic period (after A.D. 700), when crops that demanded more water (including rice) were more widely grown. In Mesopotamia, large scale works were needed at an early date, but in most places it is hard to argue that the requirements of hydraulic management were sufficiently exacting to determine the development of centrally organized states. On the contrary, the prior existence of centralized political power made possible a wide range of construction programs that included fortifications, monuments, and temples, as well as hydraulic works, and it is impossible to say which kind of engineering came first. One of the earliest sites to provide evidence is Jericho, where defensive walls, but also big water tanks, have been found dating from before 6000 B.C.E. The pyramids of Egypt were among the largest construction projects ever conceived when they were begun about 2600 B.C.E. But a comparable amount of labor may have gone into embankments and canals built at about the same time for flood control and irrigation by the Sumerians in Mesopotamia. Thus, the evidence does not give a clear picture of hydraulic requirements, rather than other construction works, forcing the pace in either administration or engineering.

That brings us to a second hypothesis about how engineering-centered technologies evolved, suggested by Lewis Mumford and some like-minded commentators. This is the view that such technologies were related to the invention of institutionalized warfare. In early societies, conflicts were sometimes wantonly violent, but some groups had customs that enabled one side to signal a surrender before serious injuries were inflicted. Among a few isolated peoples in Africa and Oceania, conflicts between communities were still like this until recently, and observers note that, if somebody was killed, the combatants were so shocked that fighting immediately stopped. A ceremonial burying of spears and an exchange of cattle or captives would then settle outstanding issues.

Organized, lethal warfare had to be invented, perhaps during the Neolithic period, and possibly following the invention of agriculture, since agriculture made possible denser populations within which tensions could be greater. Also, agriculture produced the economic surplus needed to pay for arms and fortifications. The suggestion is that military institutions evolved from about this time and provided a model of how large bodies of men could be recruited, disciplined, and supervised while constructing fortifications, pyramids or hydraulic works. Many instances can be quoted of the administration of hydraulic installations based on military routines. In later times, at Marv in northern Iran, a water storage dam below the city was looked after by 400 “guards” who minutely regulated and recorded all outflows of water. The head of the water office had more authority than the local police chief, and when repairs to the dam or canals were necessary or when new works were needed, he could call up 10,000 people to do the work.

The development of warfare provided much other stimulus to engineering-centered technology. Mechanized fighting may be said to have begun with the clumsy, four-wheeled Sumerian chariot of about 2400 B.C.E. The Hittites, whose empire overlapped Asia Minor and Syria, invented some of the first effective siege engines around 1600 B.C.E. and introduced the first iron weapons soon after. Horses were initially used mainly for drawing chariots, their full potential for warfare only emerging much later with the invention of the stirrup and its associated harness. This freed the rider’s arms to use weapons while he remained securely in the saddle.

The most famous of military inventions was, of course, ► [gunpowder](#), known by A.D. 900, used in rockets by about 1100, and in guns before 1288. These inventions, developed within Chinese military institutions, were stimulated by earlier Indian discoveries about the chemical behavior of saltpeter, and by the use of incendiary weapons for naval warfare in Southeast Asia. The latter often depended on petroleum, obtained from surface oil seepages on the island of Sumatra. Although guns evolved more rapidly in Europe after 1300, China was the

source of many ideas for gunpowder siege weapons used in the Arab world, and there were transfers of Chinese firearms technology to Korea and Thailand.

Considerable resources were needed for manufacture of the heavy cannons that had become widespread by 1500, and only the larger Asian empires could afford them in any number – but those that could were then able to expand their territory and consolidate their power. In India, the Mughal Empire’s arsenals and gun-casting capability were important for its expansion between 1526 and 1700. In Persia also the new technology had a centralizing, consolidating influence during the reign of Shah Abbas (1587–1627), though his empire depended less on guns than did the powerful Ottoman or Turkish Empire, an exporter of guns and know-how. Given that most cannon were cast in bronze, McNeill has called this period a “second bronze age”, referring to “gunpowder empires” not only in connection with Turkish, Persian, and Mughal rule, but also in relation to China and the Russian Empire in Asia.

The ships used in naval warfare and trade in Southeast Asia were of sewn construction, with rattan fiber holding together carefully fitted timbers in a flexible hull suited to landing on sandy beaches. They usually had outriggers and tripod masts to support sails, and regularly crossed the Indian Ocean. The Chinese, meanwhile, were building larger ships whose wooden hulls were held together with iron nails and had watertight bulkheads. China was also developing inland water transport on a large scale. The canals had ramps and spillways for moving boats between one level and another, but also incorporated the first pound locks and lock gates, introduced in A.D. 983 (a precisely dated invention).

One Western bias in understanding technology is a tendency to focus on the wheel and machines using wheels. But wheels did not always mean progress. Wheeled vehicles were used in the north and west of Africa around 500 B.C.E., regularly crossing the Sahara Desert. Yet they went out of use later when the camel was introduced, because camels provided much more efficient means of transport in a region with sandy deserts

and no paved roads. For parallel reasons, wheeled vehicles were not much used in southern Asia. In Central America, rollers and wheeled toys have been found, but in a region where there were not animals capable of pulling carts, no purpose could be served by developing such devices.

The potter's wheel (and later lathes working on similar principles) were probably the first machines, around 3000 B.C.E., to use the wheel. Much later, a basic water powered corn mill evolved, with a vertical axle and propeller like blades below the millstones. One view is that this was a Greek invention made about the time of Alexander the Great. Another view, however, is that it arose out of the Hittite tradition of engineering which had earlier pioneered so much military equipment. After the Hittite empire collapsed around 1200 B.C.E., some aspects of its culture survived in Syria, and itinerant craftsmen perhaps reached Mesopotamia and Iran. It was probably in one of these countries that water mills originated. Since the same type of mill appeared in China not long afterwards, one might reasonably look for its origins close to trade routes with China. As for the introduction of the mill into Greece, this could be a by-product of Alexander's expedition through Iran to the Indus River in 330–323 B.C.E.

Some thousand years later, Iran was certainly where an early type of windmill was invented. It worked in much the same way as the vertical axle water mill, though mounted in a tower with vents in the walls to catch the wind.

Mumford sees these inventions as part of the tradition of innovation stemming from small dispersed communities rather than from centrally organized states. However, at Baghdad, which had about one million inhabitants in A.D. 1000, corn milling was carried out by a series of floating mills on the Tigris River which operated continuously, night and day. The water wheels were of the later undershot type, driving millstones through wooden gears. Other uses of water power in Iraq and Iran by A.D. 1000 were in sugar cane crushing mills, fulling mills, and mills for preparing the pulp for papermaking. Paper manufacturing had been introduced at Baghdad in A.D. 794, probably with the help of

Chinese workmen, and pulping was water powered from about A.D. 950.

In all these instances, it would seem, we are no longer dealing either with the environment-centered technology of dispersed communities, nor with the labor intensive engineering of powerful centralized states. Rather, we are seeing the emergence of production-centered technologies in expanding industries. An even more striking example can be cited from northern China, associated with the use of blast furnaces for iron production. Methods of achieving high temperatures in furnaces were highly developed in China's porcelain industry as well as in metal smelting. Chinese iron masters had pioneered blast furnaces capable of melting large batches of metal, and output rose steadily to a peak in A.D. 1078. Moreover, the furnaces were owned and run by independent entrepreneurs whose market oriented, proto-capitalist operations are seen by McNeill as marking a turning point in world history.

More evidence that technology in China was moving into a new phase is provided by the great flowering of mechanical devices that were introduced there in the three or four centuries prior to 1250. They included spinning wheels, silk winding machines, and most striking of all, water-powered mills for spinning and winding thread of a local type comparable to linen. Some improvements in textile technology were due to women innovators, and many businesses were run in an independent, entrepreneurial style.

By contrast, much manufacturing in the major Asian empires was directed toward meeting state requirements for armaments, or the needs of royal palaces for luxury textiles, porcelain, and furniture. The most characteristic unit of production was the royal factory or *karkhana* in Mughal India, or the specialist porcelain factory or arsenal in China. At one time, 4,000 silk workers were employed in karkhanas in Delhi. Some may have been conscripted, and the factories were run in rather the same way as the labor intensive, state-run engineering works mentioned previously. Such factories were highly successful in meeting government requirements for arms or the court's demand for luxury goods, but could not respond readily to a varying market demand.

Production for purposes of trade, and especially for export, flourished most markedly where merchants and other entrepreneurs could function independently. By 1700, India had become the world's greatest exporter of textiles, sending its cotton cloth to Europe, Africa, and many destinations in Asia. Both Indian and foreign merchants were involved, sometimes financed by the many Parsi and Gujarati bankers to be found in ports such as Surat.

It should not be thought, though, that proto-capitalist industrial organization was always favorable to the use of machines, water powered or otherwise. The high quality of Indian textiles was achieved by painstaking handwork and a very fine division of labor. British observers noted that cotton cloth would sometimes be worked on by four people for every one employed on the same tasks in Europe. Thus, the remarkably fine muslin produced in Bengal was the result of many detailed processes which would be simplified and reduced to a single operation in the West.

Indian cloth was also noted for the fastness and brilliance of the colors with which it was dyed, mostly using vegetable dyes, such as indigo and madder. However, some inorganic substances were also needed as mordants, and this gave rise to a significant chemical industry. For example, the alum used in madder dyeing was produced in Rajasthan by processing broken shale tipped as waste around copper mines. The shale was steeped in water. Aluminum compounds were separated from copper salts by differential crystallization. Then a reaction with saltpeter produced the alum. These chemical processes were operated on a substantial scale but using labor intensive methods and minimal equipment. Merchants and banks had ample funds to invest in the textile trade, but because wages were low, there was little advantage in financing better production equipment. Instead, most of the capital available was put into building ships to carry exported cloth. Thus, Indian shipbuilding developed to a very high level in the eighteenth century. Ships were built for Indian merchants and foreign traders, and from 1800 for

the British navy. Meanwhile, cotton cloth, dye-stuffs, and chemicals continued to be produced by laborious manual techniques.

Similarly in China, there were many flourishing industries, often organized on proto-capitalist lines, but the interest in mechanization evident before 1300 was not sustained, and indeed, some machines went out of use. Silks, porcelain, and cotton goods were produced in quantity, but mainly by labor intensive methods in an economy where wages were tending to fall. But, as in India, the production technologies involved are of considerable interest. Moreover, they are quite distinct from the environment-centered and engineering technologies discussed earlier. It is of particular relevance to observe that printing evolved as a production technology in China, and by 1600 had export markets in Korea and Japan. But the content of the books being printed was dominated by the literary interests of the bureaucrats who served the imperial government. Thus, relatively few books were of significance for the dissemination of technical information. It is worth recalling, though, that the first known printed book, the *Diamond Sūtra*, an extract from the Buddhist scriptures, dates from A.D. 868, and that by the eleventh century a few books on agriculture were being printed. In A.D. 1044, Zeng Gongliang published the *Wujing zongyao* (Collection of Military Techniques) that quoted the formula for a weak [gunpowder](#) mixture, and in 1313 a remarkable work appeared – *Nong Shu* (Treatise on Agriculture) by Wang Zhen – which, among other things, described water powered spinning mills.

But whatever limited writings there were on technical subjects, either in Islamic manuscripts or Chinese printed books, technology depended far more on knowledge, skill, and technique passed from one craft worker to another through processes of observation, personal contact, and apprenticeship. Nonverbal habits of thought and of getting the “feel” for how a process should work were undoubtedly central for innovation and learning.

Nonverbal communication, often in the form of a visual or experimental dialogue, was also the

means whereby techniques were passed from one community or culture to another. Confronted with an unfamiliar product or process, a craft worker would not always copy it directly, but would “question” it to try and work out how the same result might be achieved by more familiar means, or how it might be reinterpreted to suit his or her community’s culture or resources. Moreover, this dialogue or questioning approach could at times prompt entirely new lines of thought or innovation. For example, between the sixth and tenth centuries A.D., the Chinese picked up ideas from India and Persia about chemistry, dyestuffs, textile printing, windmills, suspension bridges, and other matters. These were developed in entirely new ways as a result of being questioned and reinterpreted rather than being copied, and so contributed to some of the best known of Chinese inventions, including gunpowder and printing.

Between 1100 and 1800, and especially after their voyages of discovery began around 1450, Europeans were continually picking up ideas from other cultures: about water clock mechanisms, chemistry, cooking, and glassmaking from Islamic sources; about gunpowder, firearms, printing, and porcelain manufacture from China; and about metallurgy, cotton textiles, and dyestuffs from India. Few of these techniques were directly copied in any detail, but they became part of a dialogue in which Westerners did most of the questioning and learning – and in which they reinterpreted many techniques in terms of the Western enthusiasm for machines and mechanization.

This source of stimulus contributed significantly to the technology of the European industrial revolution, but that in turn brought a change in attitudes and relationships. A sense of technological superiority coincided with a tendency to use non-Western countries as markets for factory made goods and as sources of raw materials. Local manufactures in many parts of the non-Western world therefore declined. One striking feature of the late twentieth century has been a new openness in the West for dialogue with the environment-centered technologies practiced in the rest of the world. But, again, Westerners

are reinterpreting everything they learn in terms of their own outlook, discarding the organic and holistic world views of other peoples and fitting everything into an analytical, scientific frame of reference. Thus, Inuit technology has been discussed in terms of “ice alloys” and “bioengineering” whilst indigenous rainforest technologies are being reinvented as “ethnobotany” and “agroforestry”.

See Also

- [Colonialism and Science](#)
- [East and West](#)
- [Ethnobotany](#)
- [Gunpowder](#)
- [Paper and Papermaking](#)
- [Qanat](#)
- [Western Dominance](#)

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Technology and Culture

Claude Alvares

General accounts of the history of science and technology (or, more narrowly, of inventions) are scarce. The few that are available are also of fairly recent origin: obviously, the idea of a history of science (where science has been identified with Galilean science) and technology (identified with industrial technology) could not have appeared much earlier than this century. Not many people even know that the word "scientist" was first used by William Whewell in 1833.

Also, most available histories have remained the work of western scholars. This has not been an entirely happy circumstance. On the contrary, it has afflicted these histories with certain methodological and other infirmities which have had the effect of reducing them to mythological works. This is especially so when they are studied with regard to aspects of the history of science, technology, and medicine in the non-Western world.

One of the first is a history of technology and engineering written by Dutch historian Forbes. Forbes's work appeared in 1950 under the title *Man the Maker*. In it, he conceded that technology was the work of humankind as a whole, and that "no part of the world can claim to be more innately gifted than any other part." A few years thereafter, Forbes produced his rich and prodigiously detailed *Studies in Ancient Technology* which set out a remarkable description of the different technologies of Asia, Africa, pre-Colombian America, and Europe. However, it is in *The Conquest of Nature* that his Eurocentric assumptions came to the fore: in that work (as the title itself indicates), Forbes went on to subsume the technological experience of people from diverse cultures under a philosophical anthropology that was unmistakably Western, if not Biblical – the domination of nature myth originating in Genesis. And after a discussion about the grievous consequences of a seriously flawed

modern technology, he ended his book promising redemption from the technological genie through the Christian event of Easter. How does one prescribe a text like this to Hindu, Chinese, or Arab readers?

Another influential work of about the same period is *A History of Western Technology* by a German scholar, Friedrich Klemm. In it, Klemm provided a picture of technological development in the West in which non-Western ideas and inventions had no hand at all. The English translation which appeared in 1959 barely mentions Joseph Needham's work on China in the bibliography. Klemm could not have substantiated his interpretation of Western technological development unless he consciously played down non-Western technology. In fact, the only quote on Chinese technology in Klemm's book is from the *Guan yin zi*, the work of a Daoist mystic of the eighth century AD: Klemm used it to prove why the alleged religiously colored oriental rejection of the world in China could not have provided a stimulus for the emergence of science and technology in that country.

This distorting Eurocentric perspective continued to hold sway even over the more standard (five volume) *A History of Technology* edited by Charles Singer, Holmyard and Hall. The first volume of this work appeared in the same year as Joseph Needham's *Science and Civilisation in China*, and the editors themselves acknowledged that up to the period of the Middle Ages in Europe, China had the most sophisticated fund of technological expertise. Three of the Singer volumes dealt with preindustrial technology, where logically China (and India) should have been given major space and Western technological development would have appeared in proper perspective in the nature of an appendix. However, Chinese, Indian, and other technologies were ignored and Western technology made the focus of the exercise.

In addition to manifesting such ignorance of non-Western science and technology, these histories suffered from another methodological limitation: they restricted themselves to a record of artifacts and machines disembodied from the latter's social and cultural contexts. The problem

was eventually recognized by some Western scholars themselves.

These histories are evidence that the western scholars associated with them proved incapable of stepping out of their cultural cages, either knowingly or involuntarily. Either way, this eroded the credibility of their work as it exhibited both their lack of objectivity and their general incompetence when called upon to deal with societies other than theirs.

They show that our dominant descriptive and evaluatory ideas of technology and culture both in the Western and non-Western world have been formulated over the past couple of centuries with reference to the West's experience of these phenomena. Concepts and categories reflected from a limited area of human experience have been indiscriminately used to explain and assess the rest of the world.

New frameworks are therefore inevitable. We are in the posttraditional, postcolonial, and post-modern age. But unless the outmoded intellectual environment that engendered this subjective and tunnel-visioned output is rigorously dissected, analyzed, and then jettisoned, the new frameworks needed for the alternative histories and encyclopaedias intending to take their place are in danger of turning into copies of the old.

There are two preliminary aspects of this intellectual mal-development that need elucidation. First, there is the perception of humankind as *homo faber*, a tool-making animal, which is basically a reflection of fairly recent Western experience with the machine. Fascinated by the bewildering profusion of tools and machines, Western historians began to look at the ability to produce these as a special field with its own history and set out to create a distinct species of man in the image of *homo faber*. This scholarly creation had its repercussions in encouraging the overestimation of the singularity or uniqueness of Western culture in comparison with others (although all cultures are unique and incommensurate). The elaborate, embarrassing exercise in culture-narcissism soon became routine since it was not to be challenged for nearly a century. (It is important to point out that the *homo faber* idea is quite recent to humankind: it is

consistently absent in not just other cultures, but even within a large part of the West itself).

For instance, it was taken for granted that the system of production that got generated in the last century and a half in the West was the only one with any significance simply because in the light of the present – and to all appearances – it had apparently emerged as the dominant one. Therefore, its past was the only one worth considering. This notion was in turn bolstered by another: a self-generating model of technological development in which the historian attempted to trace the evolution of modern science and technology by working backward to the experiences and ways of thinking characteristic of Mediterranean antiquity. Thus the roots of modern technology were shown to be exclusively founded on the work of Greek and Roman thinkers, mathematicians, engineers, and observers of nature with no input from any other culture areas or people.

This brings us to the second aspect we have alluded to above, and this concerns the relationship between knowledge and power and the impact of this on interpretations of technology and culture. Throughout history, knowledge has generally remained closely linked with interests. Even when encyclopaedias, for instance, have traditionally sold themselves on the Francis Bacon principle that “knowledge is power,” they too have continued to reflect an undeclared, equally influential, political principle – that “power is knowledge.”

The intrusion of Europeans into non-European societies and the gradual establishing of political dominance and inequality between societies stimulated the inauguration of a new discourse about such societies. Political dominance came to be as routinely and unabashedly expressed in the form of knowledge as it was through the barrel of guns. Edward Said has already written on the invention of the discourse on “Orientalism” and its direct political uses. But there are less controversial discourses that have had even larger repercussions only now being acknowledged. As a result, much academic knowledge in the Western world about the non-Western world, particularly the latter's technology traditions, remains not only distorted or contaminated by the ethnic

concerns, goals, theories, obsessions, and peculiar assumptions of Western scholars and universities; it is still largely defined, legitimized, and decided by them irrespective of whether there is any concurrence from the non-Western world.

The combination of these two aspects proved deadly: the emerging conception of Western man alone as *homo faber*, once it took firm roots within the situation of political dominance, rendered any appreciation of technique elsewhere – technique not necessarily reflected only in tools or machines – difficult and often impossible. In fact, the combination helped inaugurate its very own dark age. For it generated among Western (and not a few non-Western) scholars several major assumptions concerning technology and culture. We shall discuss three of these.

The first emerged in relation to Western man's attitude toward the past, particularly with regard to preindustrial technology. *Homo faber* exercised his new found power over the past by deriding it: this is reflected in the rewriting of history from today's perspective in which the past is seen as mere prelude to the present. Earlier technological innovations are considered primitive precursors of later developments. Here we have a good example of the parochialism of the modern/Western mind as it proceeds to take experiences of technology and culture exclusive not just to the late twentieth and early twenty-first centuries but to extremely small segments of the world population and makes these the basis for investigating, analyzing, assessing, and judging the general activities of human societies over hundreds of years. This was the case even when such societies were not so technologically enamored, dependent, or controlled as some of them seem to be now.

The second assumption relates to humankind's so-called unique propensities for technology when compared with that of the animal world, an uncritical theory best summed up in a single word: speciesism. After deciding on the issue of the comparative technological competence of all living species in its own favor, the West came to the conclusion that the rest of

creation, because inferior, was expendable if so required to further its own scheme of things.

But it is the third assumption that concerns us most seriously here: it is the idea that Western man can be equally distinguished from non-Western societies as well on the ground that the latter, like the animal and other "lower" species, also lacked technological development as it emerged in the West.

This idea was appropriately reflected in academia in the emergence of two new sciences: the discipline of sociology, which focused on so-called advanced societies and their flair for technology; and the subject of anthropology which occupied itself with non-Western cultures, limited to primitive or preindustrial tools. Anthropology's political origins have been blandly asserted by Claude Levi-Strauss in his controversial Smithsonian lecture:

Anthropology is not a dispassionate science like astronomy, which springs from the contemplation of things at a distance. It is the outcome of a historical process which has made the larger part of mankind subservient to the other, and during which millions of innocent human beings have had their resources plundered and their institutions and beliefs destroyed, whilst they themselves were ruthlessly killed, thrown into bondage, and contaminated by diseases they were unable to resist. Anthropology is daughter to this era of violence: its capacity to assess more objectively the facts pertaining to the human condition reflects, on the epistemological level, a state of affairs in which one part of mankind treated the other as an object.

It is within such an imperialist context that the histories and technological experience of non-Western societies could be written off or ignored: the latter, after all, were conquered peoples. When technology is seen through an anthropological prism, the emerging picture is bound to be far removed in character from a scenario that emerges from a sociological perspective. What is more, it is bound to be even more far removed from reality itself.

Some impression of that reality is discernible in the period before political dominance began to corrupt the objectivity of knowledge. Before the so-called "voyages of discovery," though non-Europeans were conceived as fantastic, wild, opulent, even monstrous, they were rarely

considered inferior or backward; and even the actual European encounter with the scientific, technologic and medical traditions of non-Western societies was different from what eventually became the stuff of politically directed myths. In fact, from the day that the Portuguese mariner Vasco da Gama landed in India until almost three centuries later, Asia had a larger and more powerful impact on Europe than is normally recognized. Donald Lach has appropriately titled the first volume in his *Asia in the Making of Europe* "The Century of Wonder." It was not without reason that an Englishman of the time addressed the Indian Emperor by describing himself as "the smallest particle of sand, John Russel, President of the East India Company with his forehead at command rubbed on the ground." Nor can we forget that the first presents offered by da Gama to the King of Calicut included some striped cloth, hats, strings of coral beads, wash basins and jars of oil and honey. The king's officers naturally found them laughable.

It would take a few more decades before the Europeans landing in the Indian subcontinent would notice anything beyond gold and spices. But by 1720 and for a period of up to a 100 years, a new category of observers came visiting, some from newly formed learned societies in England. Their detailed reports were a result of the European quest for useful knowledge in different fields.

In his pioneering volume, *Indian Science and Technology in the Eighteenth Century*, the Indian historian Dharampal includes several accounts from these observers which describe among others the Indian techniques of inoculation against smallpox and plastic surgery. (While the first was eventually banned by the English, the latter was learnt, adopted, and developed). The accounts also document Indian processes like the making of ice, mortar, and waterproofing for the bottoms of ships; water mills, agricultural implements like the drill plough, water harvesting and irrigation works, and the manufacture of iron and of a special steel called *wootz*.

More techniques (like those involved, for instance, in the manufacture of Indian textiles) are described in *DeColonizing History* (Alvares,

1991) and *Science and Technology in Indian Culture* (Rahman, 1984). But even this documentation, impressive as it is, is now recognized to be but the tip of the proverbial iceberg.

The Chinese, like the Indians at Calicut, had a similar experience with an embassy and its gifts from London. The edict of Qian Long to the embassy is worth quoting: "There is nothing we lack, as your principal envoy and others have themselves observed. We have never set much store on strange or ingenious objects, nor do we need any of your country's manufactures" (Fairbank, 1971).

Immediately after the encounter, the graph of European reaction rises with esteem and wonder; and then, as political conquest and overlordship increase, the graph alters course and begins to record increasing denigration. A remarkable transformation of image thus takes place as the political relationship between Europe and non-European societies changes to the advantage of the former, rendering the Europeanization of the world picture almost an act of divine will.

By 1850, political dominance over the non-Western world was clearly installing distorted ideas not only about that part of the world but rebounding to distort Western man's image of himself as well. Already by 1835, for instance, the British had acquired a flattering notion of their own civilization (Victorian England was seen to be at the top of the pyramid of civilization) and a thorough-going contempt for Asia.

This contempt finds expression in the famous Minute of Lord Babington Macaulay:

I have never found one amongst them (the orientals) who could deny that a single shelf of a good European library was worth the whole native literature of India and Arabia. . . It is, I believe, no exaggeration to say that all the historical information which has been collected from all the books written in the Sanskrit language is less valuable than what may be found in the most paltry abridgment used at preparatory schools in England. In every branch of physical or moral philosophy the relative position of the two nations is nearly the same.

Dharampal has produced an interesting record of these assessments of science and technology in India among Western observers as the

relationship between India and Britain changed to Britain's advantage.

Regarding the question of Indian astronomy, he discusses the case of Prof. John Playfair, Professor of Mathematics at the University of Edinburgh and an academican of distinction. Playfair studied the accumulated European information then available on Indian astronomy and arrived at the conclusion that the Indian astronomical observations pertaining to the period 3,102 years BCE appeared to be correct in every text. This accuracy could only have been achieved either through complex astronomical calculations by the Indians or by direct observation in the year 3102 BCE. Playfair chose the latter. Opting for the former would have meant admitting that "there had arisen a Newton among Brahmins to discover that universal principle which connects, not only the most distant regions of space, but the most remote periods of duration, and a De La Grange, to trace, through the immensity of both its most subtle and complicated operations."

Similar attitudes prevailed concerning the knowledge of how Indians produced *wootz*. Heath, founder of the Indian Iron and Steel Company and later prominently connected with the development of the steel industry in Sheffield, wrote "... iron is converted into case steel by the natives of India, in two hours and a half, with an application of heat that in this country, would be considered quite inadequate to produce such an effect; while at Sheffield it requires at least four hours to melt blistered steel in wind-furnaces of the best construction, although the crucibles in which the steel is melted, are at a white heat when the metal is put into them, and in the Indian process, the crucibles are put into the furnace quite cold."

However, Heath would not admit that the Indian practice was based on knowledge "of the theory of operations," simply because "the theory of it can only be explained by the lights of modern chemistry."

By the beginning of this century, the Western mind had already convinced itself that Western science and philosophy were the only approach to metaphysical truth ever attained by the human

species and that the Christian religion provided wisdom and insight incumbent on all people everywhere to believe.

The result is reflected in the output of academia: a "history of art" turned out to be nothing but a history of European art and a "history of ethics" a history of Western ethics. While European music was music, everything else remained mere anthropology. The contemporary evaluation of human activity in the West as compared with the non-Western world was unabashedly provided by the late Jacob Bronowski in the *Ascent of Man* in words almost echoing Macaulay in 1837:

We have to understand that the world can only be grasped by action, not by contemplation. The hand is more important than the eye. We are not one of those resigned, contemplative civilizations of the Far East or the Middle Ages, that believed that the world has only to be seen and thought about and who practiced no science in the form that is characteristic for us. We are active; and indeed we know, as something more than a symbolic accident in the evolution of man, that it is the hand that drives the subsequent evolution of the brain. We find tools today made by man before he became man. Benjamin Franklin in 1778 called man a 'tool-making animal' and that is right.

Now, there were obviously perverse consequences of such a view: scholars in several non-Western societies, schooled in an educational system imposed on their societies through the colonial establishment, readily incorporated similar ideas about their own histories. In an article in *Nature* 35 years ago, Joseph Needham had to chide a native scholar of Thailand for claiming that his own people had not made any contribution to science despite compelling evidence to the contrary. Nevertheless, the colonization project succeeded in convincing many non-European intellectuals and scholars that only the West was active. They facilely accepted the idea that activity per se was desirable compared to judicious or necessary activity; that only the West was capable of thinking in the abstract sense. If this opinion were carried to its logical conclusion, it would appear that if the rest of humankind had survived for hundreds of years, this must be due to some form of manna falling providentially from the heavens.

The damage done by these years of extremely ideological scholarship and a ruinous ethnocentrism to the history of technology was bad enough. Predictably, the impression of an empty technological wilderness invented by Western scholarship about non-Western societies had a parallel, simultaneous, destructive impact on the assessment of their cultures as well. So insidious was the nature of this outrageous assumption regarding Western and non-Western abilities, that even Joseph Needham, Mark Elwin, Abdur Rahman and a host of other scholars participated in pointless debates which often took it for granted. One major debate, for example, focused on why China (and India) did not produce either modern science or an industrial revolution on the European pattern, especially since Chinese technology had already reached a level of sophistication not yet attained in any other part of the world as late as the fifteenth century.

Attempted answers compared and contrasted the internal conditions within Chinese society with those within Europe; the argument eventually succeeded in establishing the conclusion that no scientific or industrial revolution occurred in China because the social conditions in China were not the same as those within Europe. Thereafter, a host of cultural and social factors were dragged out of context and labeled probable "obstacles" either to the development of technology or modern science.

A critique of the three assumptions we have surveyed above therefore becomes compelling and inevitable, if we are to eschew their myriad fallacies in future. We shall take each in turn.

The idea that the past was merely a prelude, and a primitive one at that, may come naturally to anyone who has begun to feel that the present era of technical change is inevitable. Yet future societies may assess their past (our today) basing themselves on values other than those celebrating mere technical change. Already mindless technical change and built-in technological obsolescence have been assaulted by several global thinkers on the ground of ecological unsustainability and resource scarcity. It would also be wrong to think that because man did not have technology as he now does, he was

necessarily impoverished. If there is anything the past gives us it is this positive impression of survival in all kinds of environmental scenarios. There is also evidence of more widely dispersed creativity when man was not submerged by technology than there is today. In many areas of human experience, we are yet to match even the technological achievements of the past which were driven by values other than mere complexity for its own sake or profit.

A similar argument may be used against the assumption that humankind is the only tool-making species there is. Several naturalists and ethologists have documented the diversity of nature's schemes at fabrication; most notably, Felix Paturi in his *Nature, Mother of Invention* and Karl von Frisch in *Animal Architecture*. Scholars like Lewis Mumford have gone further in stating quite bluntly that in their expression of certain technical abilities other species have for long been more knowledgeable than man.

Insects, birds and animals, for example, have made far more radical innovations in the fabrication of containers, with their intricate nests and bowers, their geometric beehives, their urbanoid anthills, and termitaries, their beaver lodges, than man's ancestors had achieved in the making of tools until the emergence of homo sapiens. In short, if technical proficiency alone were sufficient to identify and foster intelligence, man was for long a dullard, compared with many other species.

Niko Tinbergen, another ethologist, after years of close observation of other species, has come to the following conclusion: "It was said that (1) animals cannot learn; (2) animals cannot conceptualize; (3) cannot plan ahead; (4) cannot use, much less make tools; (5) it was said they have no language; (6) they cannot count; (7) they lack artistic sense; and (8) they lack all ethical sense." All of these statements, says Tinbergen, are untrue.

It cannot be said therefore that, in contrast with other species, humankind alone is a tool-maker. Thus the attempt to distinguish man from other living species because of his tool-making capacity is now seen to be a result of limited knowledge and unwarranted assumption

of qualitative discontinuities between human beings and other species. It will also be useful to recall here that the ability to fabricate and organize is not a singular human trait – it is an intrinsic feature of nature since nature can exist only in a given form, whether at its most primary constituents at the subatomic level or even at the level of crystalline structures or the multiple tiers of a primary forest.

However, it is the third assumption – concerning the West's genius for technology and the rest of the world's incompetence in the same department – that contains the greatest mythological component of them all.

As we shall presently see, such an assumption has not only no historical basis, it is in fact contrary to historical and even to contemporary evidence. As for the gift of Greek rationality, suffice it to say that for 2,000 years it gave no technological advantage to those who had it over those who did not. On the contrary, major scientific concepts, technological artifacts, tools, and instruments emerged in cultures that had nothing to do with either Greece or Rome.

The other problem with this assumption is it cannot even cope with the long established view that the science and technology traditions of most societies, particularly so of the West, are in significant ways mixed traditions. Even the little that we know about it indicates that the cross-cultural borrowing of technics and technology is impressive. Thus a very large number of critical inventions from both India and China helped fill significant gaps in the technological development of the West. A simple example from Francis Bacon's work will suffice to illustrate this point. He wrote:

It is well to observe the force and virtue and consequences of discoveries. These are to be seen nowhere more conspicuously than in those three which were unknown to the ancients, and of which the origin, though recent, is obscure and inglorious; namely, printing, ► [gunpowder](#), and the magnet. For these three have changed the whole face and state of things throughout the world, the first in literature, the second in warfare, and the third in navigation; whence have followed innumerable changes; inasmuch that no empire, no sect, no star, seems to have exerted greater power and influence in human affairs than these mechanical discoveries.

Now all these three mechanical discoveries were Chinese. Yet here again Western scholars have found it hard to acknowledge their origin. Borrowing of techniques from India is easily documented as well.

The documentation of technology in other cultures is only beginning. For example, it was only in 1974 that Sang Woon Jeon's *Science and Technology in Korea* appeared. There is as yet no major record of technology in Africa or South America though there is now available a large volume of documented evidence that both areas were rich in tools and techniques, from metallurgy to textiles.

In India, the other large storehouse of useful and appropriate tools (some still in productive use), the most extensive documentation of technology has only recently commenced, sparked in part by Dharampal's *Indian Science and Technology in the Eighteenth Century* and the work of scholars like Abdur Rahman.

The immediate impact of these reinvigorated investigations, stimulated largely by political independence, is a fresh debate over the issue of technology and culture: the old assumption of one technology and one culture in which others are seen to make a few, presumably inconsequential, contributions, is in tatters. Whatever its own pretensions to be the only viable culture, the West is finally being seen by non-Western societies as only one among several: a certain balance between cultures gets restored even though economic inequality persists. In fact, in some cases the pendulum has swung to the other side with cultures unabashedly resuming their traditions. There has naturally been a reverberation in the climate of ideas.

Changes in perception of this kind have already come about in other academic disciplines. To cite just one example, world histories were once written as if Europe were the center of the planet, if not the cosmos. There has been progress since: Geoffrey Barraclough and Leon Stavrianos, for instance, have both succeeded in producing comprehensive histories which avoid the older Eurocentric perspectives.

But even assuming we are able to produce, culture by culture, a fairly objective and

comprehensive record of science, technology, and medicine, we would still be uncomfortably close to the pet obsession and perception of the present epoch. If there is anything the recent past has shown us, it is that we can be all too zealous judges in our own cause. We continue to celebrate uncritically our technological feats even when we know that the principal criterion of success for any species (and the human species is no exception) is primarily its ability to survive.

Therefore, it may be best not to get trapped in the debates on what is basically a subhistory: the history of slave-machines or automation or the recent machine-propensity of some cultures. After all, the *homo faber* concept is itself a distorted reflection of the natural endowments of the human species, an example of reductionist thinking. We know now that reductionism readily distorts knowledge, often pauperizes it, but rarely enhances it.

What is required in the circumstances then is a paradigm shift. I would like to suggest this can be achieved by replacing the heavily loaded term "technology" (too close identified with externalized objects) with the more neutral word, "technique." Technique has a larger ambit than technology and does not necessarily express itself only in the form of tools or artifacts. For the moment, we may define it briefly as every culture's distinct means of achieving its purposes. The natural propensity of human beings is to rely on technique, not technology, for while it has been proven that we can survive without technology, we cannot survive without technique.

Thus there can be no technique without culture, no culture without technique. An investigation into a culture's techniques is bound to be considerably more difficult than the recording of a culture's artifacts. The important gain here would be that we would begin with a more democratic assumption: that there is no culture without a system of techniques. Such a postulate would inoculate us effectively against methodological, ethnocentric, and other fatal flaws the *homo faber* concept was both parent and heir to. It would nip in the bud any undesirable future forays into cultural narcissism or ethnocentric discourse.

If this is indeed so, the more logical assumption would be that every culture has relied on a corresponding system of techniques that has guaranteed survival. Understood in this way, it makes far better sense to talk of Western technique (even though today largely expressed in the form of technology), or African, Indian, Chinese, Maya, or Arabic techniques of survival (in which technology may not be given that importance for fairly valid reasons). But even a relatively low importance given to technology could never mean a poverty of technique. The idea that the human species is technique-natured could be empirically falsified if a human society could be found that lacked technique – and not just machines or artifacts.

Technique, then, is nothing but the permanent but dynamic expression of an individual culture. Cultures can only express themselves or survive through technique: the alternative is chaos. Nonhuman species may be guided in the exercise of technique by inflexible inborn patterns of behavior. But the human world is as rigorously bound by the controls imposed by the symbolic universe that emerged as a substitute for weakened instinctual patterns. Myth, for instance, is technique. Interaction with (or manipulation of) nature may take place either through myth-making, scientific construction, and myriad other ways. All are expressions of the symbolic universe human beings inherit because they are human beings.

Thus we share the necessity of functioning through technique – not just through tools – with other living species – from the mammoth geobiological processes of Gaia to the cross-pollination of the rice plant to species of bird and animals, some of which, like the bower bird, are more prone to technology than others. Thus the so-called potter-wasp is known for its technique in constructing what we human beings culturally recognize as pots: however, the small vessels are the conclusion of technique: without it, there would be no "pot," no propagation and, therefore, no survival.

This will also explain why so-called primitive societies are often more complex in their socio-cultural arrangements – their rich fund of

botanical knowledge, slash-and-burn techniques, elaborate myths are as much an expression of technique – than modern societies.

Our new paradigm – based on a thoroughgoing analysis of technique – will enable us to concentrate more effectively on those aspects of human experience in non-Western societies where there may be appropriate development of technology (as in India and China) but a superabundance yet of technique. A large number of these, particularly in India or in the Islamic cultures, may be located squarely within the domain of the sacred. They would be unintelligible outside such a framework of understanding.

We shall also observe in such societies that even where there is sophisticated technology, it retains an unobtrusive (not invasive) character. This can be seen from the merged outlines of Arab architecture to the irrigation works of South India or Sri Lanka.

An encyclopaedia of non-Western science, technology, and medicine may restrict its scheme to a bare description of the evolution of machines or artifacts incompetently covered by earlier conventional Western works, but it must do so guided by the background of the larger canvas of technique. Here the scholar will eventually examine theories of language in the same detailed manner as he would the culture and preparation of food or the control of breath – all extremely detailed sciences in India and China; he would examine irrigation and animal husbandry techniques, the domestication of cultivars of crop plants, record the elaborate knowledge of plants and of the human body, and seek to understand theories of cosmic phenomena and of the behavior of annual events like the monsoons.

The aim of the historian is to describe the nature of this individual system and not place it within a hierarchical ordering of societies. His task is to document this immense richness, not endeavor to swamp and drive it into oblivion on the questionable assumption that Western technology is the only direction that human technique will take. The growing anxiety over Western technology is closely associated with the threat it is perceived to pose to the fate of the planet and to survival. We may have to examine its history

clinically to diagnose why it has generated the kind of problems it poses for humankind. Here, only a proper study of technique and culture within non-Western societies (and not as Forbes hoped, the event of Easter) will bring some balance and provide urgent clues to the origins of what Jamal-ud-din described as the illness of occidentosis, the plague of the West.

See Also

- [Colonialism and Science](#)
- [East and West](#)
- [Ethnobotany](#)
- [Technology](#)

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Technology and Environment

Arnold Pacey

The development of technology has usually been socially determined, changing in direction as different social formations have emerged. For example, there are important distinctions to be made between, first, small communities of farmers or dispersed groups of hunters with technologies outstanding chiefly for their adaptation to local *environments*; second, the larger kingdoms and empires, whose technology tended to be *engineering-centred*; and third, trading communities and merchants or entrepreneurs with *production-centred* technologies.

An initial problem in discussing technologies of the first kind is nomenclature. J. S. Weiner, who has discussed the remarkable protective clothing developed by the Inuit for life in the Arctic, has described these people as “the great pioneers of micro-climatological bioengineering”. This tribute to the control of body heat loss achieved by Inuit clothing is well deserved but places the skills of Arctic people within the wrong frame of reference. Their technology was environment-centred, not engineering-centred. On the one hand, they were adapting to a very demanding environment; on the other, they were making very efficient use of environmental resources. Thus, the animals hunted for meat were also a source of oil for lamps, bone for making needles and other tools, and the skins, intestines, and fibres from which clothing was made.

Archaeological evidence suggests that the invention of tailored skin clothing adequate to enable people to winter in the Arctic was accomplished in Siberia around 2000 BCE. After that, it was several centuries before oil lamps, houses built of snow, and dog sleds were developed by the people of the Dorset Culture, based on Baffin Island. Later still, improved boats and harpoons were developed by the Alaskan Inuit.

All these inventions, quite clearly, were the work of small, dispersed groups without centralized organization, and all were responses to an exacting environment. Perhaps what we ought also to remember is that for the Inuit, as for most non-Western peoples, the environment was endowed with personal and spiritual meanings and with magical qualities. It was not merely the object of detached, if concerned, analysis that it has become for most Westerners. Thus, their technology was based on an organic worldview.

The same points can be made about peoples inhabiting other environments, such as rainforests, deserts, steppes, or coastal and island situations. The efficiency with which resources were used by such people is illustrated by the estimate that in 1500 CE the Amazon basin supported a somewhat larger population than it did in 1990, yet without the extent of destruction of forest and fishery resources now taking place. Fruits, nuts, leaves, seeds, and roots were gathered for use as food and medicine. Fish and animals were caught, often using poison tipped spears, but with less ecological disturbance.

In some rainforests, notably in Central America as well as in Asia and Africa, people developed a form of agriculture in which a great variety of crops was raised while extensive tree cover was retained. Cereals such as corn in the Americas or rice in Southeast Asia were grown in forest glades with shade-tolerant vegetables under trees. Those trees that were left unfelled or were newly planted would be selected according to whether they produced fruit, nuts, timber, fodder, or *materia medica*. Thus, an artificial rainforest was formed in a system often referred to as forest farming, forest inter-culture, layered gardening or, more recently, agroforestry. The key point – whatever the name – is that there would always be tree cover, and usually other vegetation, to protect the soil from erosion and to retain plant nutrients. By contrast, where rainforest is cleared for conventional western style agriculture, soils become degraded very rapidly.

In Africa, rainforest crop production became widespread only after the banana and Asian yam

were introduced on the east coast by Indonesian traders and colonists around 400–500 CE. In quite a short space of time, these crops were adopted by many gardeners across the continent, enabling populations in forested areas to increase considerably. In Central America, archaeologists have now shown that the Maya culture used forest farming with high yielding nut trees and manioc (cassava) as major crops around 600–900 CE.

Other environment-centred technologies were those of people living in hot, dry, and semi-desert conditions who evolved sophisticated water conservation techniques. Some of these made use of small structures, such as check dams in gullies and spreader dikes on flatter ground – for example, in northern Mexico and Arizona – or else stone lines on contours (in the African Sahel). Others practiced the careful planning of fields in relation to rainwater catchment areas, and the construction of bunds (embankments or dikes) to channel water and hold it on the land. Among the most elaborate ► [rainwater harvesting](#) systems of this kind were those of Nabataean farmers in the Negev Desert in Israel from about 200 BCE, and comparable systems in Morocco and elsewhere in North Africa. Small dams, river diversions, and the Persian ► [qanat](#) (wells linked by a tunnel; Fig. 1) were other means of providing irrigation water to crops on a small scale.

Consideration of environment-centred techniques such as these offers a distinct perspective on early technology quite unlike the conventional view based on the materials from which tools were made, namely, stone, bronze, and iron. That view seeks to discover a pattern of tool use and metalworking skill common to all human societies, and ignores the environmental particularism emphasized here. It parallels the modern assumption that the principles of technology are independent of cultural values and underestimates the different ways in which human societies explored the varying surroundings in which they lived. By contrast, a perspective based on environmental adaptation allows one to recognize the extraordinary sophistication of some peoples who nominally remained in the “Stone Age” even in the early twentieth century, including the Inuit and some rainforest communities.

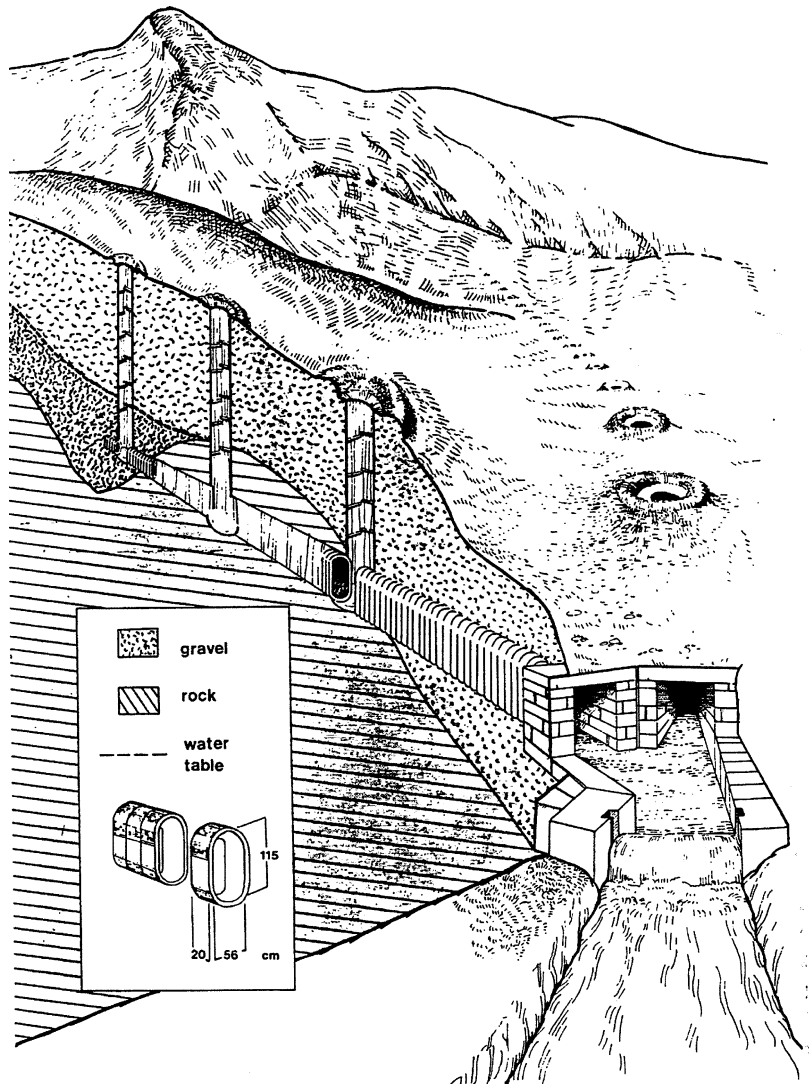
Viewed from another angle, however, the Neolithic period in the later Stone Age does seem to have been a time of particularly important innovation, at least for western Asia. It is associated with the first domestication of crops and livestock, and hence the invention of agriculture, probably associated with the earliest used of some of the water conservation techniques previously discussed. Complementing these innovations were others, such as pottery (and soon after, the potter’s wheel), grain milling, tool-making, and textiles (with the looms on which they were woven). Many of these innovations relate to the domestic sphere of life, and it is likely, therefore, that many of the inventors concerned were women.

It would be a mistake, however, to assume that the invention of agriculture, the domestication of plants, and the appearance of pottery or textiles were unique events, each occurring only once in human history, in one part of Asia and then diffusing to other regions. Independent inventions undoubtedly occurred, just as different crops were domesticated in various places and at different times. For example, about 1500 BCE, corn (i.e. maize) and pottery were both known in Mexico, but not in Peru, where beans and peppers were cultivated. Thus, the two cultures may have developed agriculture independently of one another. Moreover, some plants were still being newly domesticated in the twentieth century, for one reaction to deforestation in Africa has been to cultivate a number of fruits and vegetables that people had collected from the wild until the loss of forest cover threatened their existence. Reports from Kenya show how modern gardeners, usually women, have selected from wild varieties and have produced strains adapted for garden conditions.

Engineering-centred technologies developed in a very different context. They were characteristic mainly of kingdoms or empires whose labour resources and administration made large-scale construction works possible. One view of the origins of engineering is that once agriculture was established, irrigation became necessary in many of the warm, dry countries of western and southern Asia to produce sufficient food for

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Fig. 1 Two *qanat* tunnels in a typical landscape, where rainwater running off mountains replenishes groundwater beneath the sand and gravel of the lower slopes (water-bearing gravel is shown darker than the dry gravel layer above). The ground penetrated by one of the *qanats* is shown in cut-away section to demonstrate how the tunnel gives access to water trapped by impervious rock. The section also shows how the tunnel is lined with earthenware rings when passing through sand or gravel layers which might otherwise cave in. *Qanat* tunnels were excavated from the bottoms of a series of well shafts, with the “mother well” at the upstream end dug first to prove the existence of water. The tunnels were sometimes several kilometres long with their route evident on the surface from the line of well shafts, as on the right of the picture (Illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey, 1990, p. 86)



growing populations. The dams and canal systems necessary for irrigation could not have been constructed, it is argued, without recruiting a large labour force, and that in turn could not have been done except in centrally organized kingdoms. In this view, the need for irrigation canals and other hydraulic works dictated the formation of centralized government administrations with the coercive power and management skills needed to organize large-scale construction works.

This theory about how hydraulic civilizations evolved does not apply everywhere, however, since empirical evidence shows that in many

areas where irrigation was practiced, farmers did the essential earth moving and engineering work themselves, or with their neighbours through local systems of cooperation, but without central organization. This seems to be true for rice culture in China, according to Francesca Bray. Some of the biggest centrally organized engineering schemes prior to 605 CE, involving thousands of labourers, were not for irrigation but for construction of transport canals for carrying grain to the capital. However, flood control and irrigation in North China did depend on large-scale works, so the evidence is not clear-cut.

In Mesopotamia and Egypt, much early irrigation was also on a small scale, dependent on manually operated water-raising devices such as the *shaduf* (a device consisting of a long suspended pole weighted at one end and having a bucket at the other end). The type of crops grown and the seasons of cultivation meant that there were fewer water requirements in early agriculture than after the agricultural revolution of the Islamic period (after 700 CE), when crops that demanded more water (including rice) were more widely grown. In Mesopotamia, large-scale works were needed at an early date, but in most places it is hard to argue that the requirements of hydraulic management were sufficiently exacting to determine the development of centrally organized states. On the contrary, the prior existence of centralized political power made possible a wide range of construction programs that included fortifications, monuments, and temples, as well as hydraulic works, and it is impossible to say which kind of engineering came first. One of the earliest sites to provide evidence is Jericho, where defensive walls, but also big water tanks, have been found dating from before 6000 BCE. The pyramids of Egypt were among the largest construction projects ever conceived when they were begun about 2600 BCE. But a comparable amount of labour may have gone into embankments and canals built at about the same time for flood control and irrigation by the Sumerians in Mesopotamia. Thus, the evidence does not give a clear picture of hydraulic requirements, rather than other construction works, forcing the pace in either administration or engineering.

That brings us to a second hypothesis about how engineering-centred technologies evolved, suggested by Lewis Mumford and some like-minded commentators. This is the view that such technologies were related to the invention of warfare, for indeed, organized lethal warfare had to be invented, and this may have happened during the Neolithic age, possibly following the invention of agriculture. The reasoning here is that agriculture made possible denser populations within which social tensions were inevitable and from which large bodies of fighters could be recruited, while at the same time, agriculture

produced the economic surplus needed to pay for arms and fortifications. It is suggested, also, that centralized governments and military institutions began to evolve about this time, and provided a model of how large bodies of people could be organized and supervised, not only in combat, but also in constructing fortifications – or dams, canals, and pyramids.

Needless to say, the development of warfare provided other stimuli to engineering-centred technology. Mechanized fighting may be said to have begun with the clumsy, four-wheeled Sumerian chariot of about 2400 BCE. The Hittites, whose empire overlapped Asia Minor and Syria, invented some of the first effective siege engines soon after. Horses were initially used mainly for drawing chariots, their full potential for warfare only emerging much later with the invention of the stirrup and its associated harness. This freed the rider's arms to use weapons while he remained securely in the saddle.

Engineering-centred technologies in ancient civilizations can appear to be focused very largely on large-scale hydraulic works and on military engineering. In addition, one bias in the western understanding of technology is a tendency to focus on the wheel, and on machines using wheels, such as the early chariots just mentioned. But wheels did not always mean progress. Wheeled vehicles were used in the North and West of Africa around 500 BCE, regularly crossing the Sahara Desert. Yet they went out of use later when the camel was introduced, because camels provided much more efficient means of transport in a region with sandy deserts and no paved roads. For parallel reasons, wheeled vehicles were not much used in southern Asia. In Central America, rollers and wheeled toys have been found, but in a region where there were no animals capable of pulling carts, little could be gained by developing such devices.

The potter's wheels (and later, lathes working on similar principles) were probably the first machines to use the wheel, around 3000 BCE. Much later, a basic water-powered corn mill evolved, with a vertical axle and propeller-like blades below the millstones. One view is that this was a Greek invention made about the time of

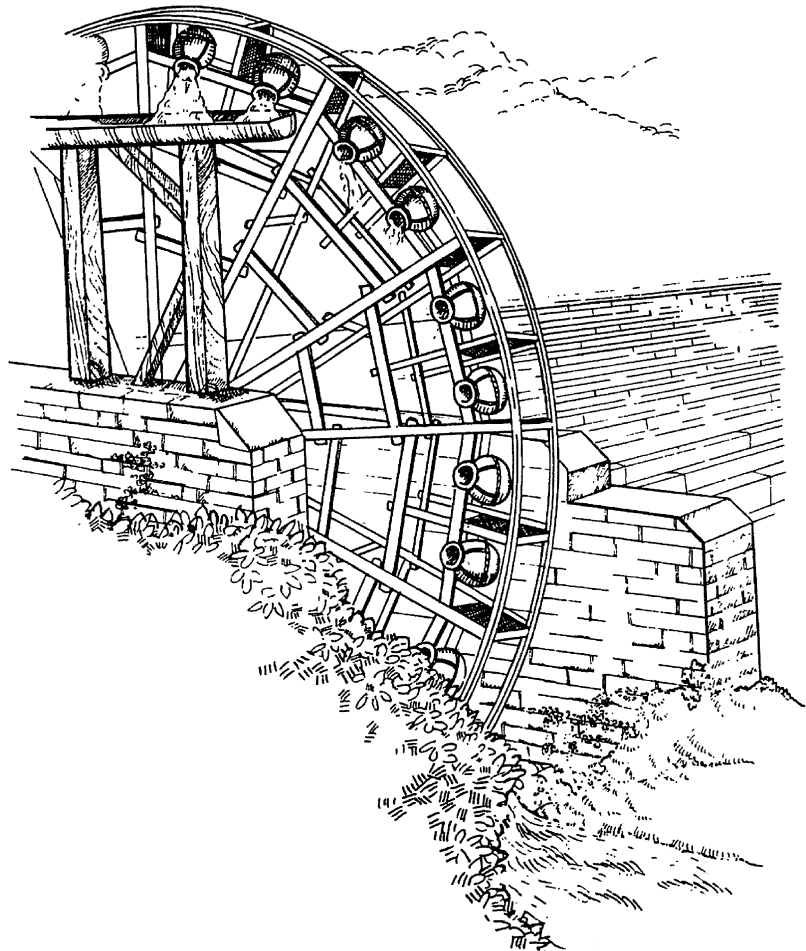
Alexander the Great. Another view, however, is that it arose out of the Hittite tradition of engineering which had earlier pioneered so much military equipment. After the Hittite empire collapsed around 1200 BCE, some aspects of its culture survived in Syria, and itinerant craftsmen perhaps reached Mesopotamia and Iran. It was probably in one of these countries that vertical-axle water mills originated. Since the same type of mill appeared in China not long afterwards, one might reasonably look for its origins close to trade routes with China. A related invention of the same period was the water-raising wheel or *noria*, a basic water wheel with a horizontal axle and pots or buckets attached to its rim in which water could be raised (Fig. 2).

Some thousand years later, Iran was certainly where an early type of windmill was invented. It worked in much the same way as the vertical-axle water mill, though mounted in a tower with vents in the walls to catch the wind (Fig. 3).

In both Iran and Iraq extensive use was made of water wheels of several types, and some large dams were erected. Other uses of water power in this region around the year 1000 CE were in sugar cane crushing mills, fulling mills, and mills for preparing the pulp for paper-making. Paper manufacturing had been introduced at Baghdad in 794 CE, probably with the help of Chinese workmen, and water wheels were used to work hammers that made pulp from 950 CE.

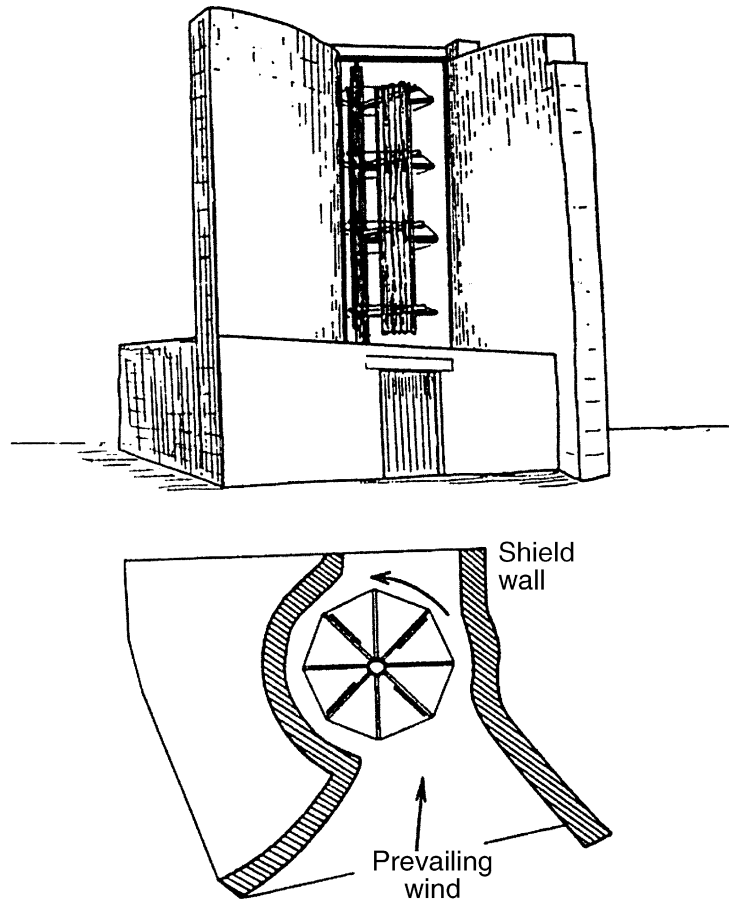
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Fig. 2 Water-raising wheel of the type known as the *noria*. This is an undershot water wheel, driven by the flow of water in the stream running underneath it. The jars tied to the rim fill from the stream and then empty into the trough at the high level (Illustration by Hazel Cotterell; reproduced from Pacey, 1990, p. 11)



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Fig. 3 Persian-type windmill showing how shield walls were designed to funnel wind onto the sails, which rotated on a vertical shaft. The way the mill worked is most clearly seen from the plan (*lower illustration*). The perspective view shows how the shield walls of later mills formed a towering open structure built of sun-dried bricks with a small room containing the millstones underneath. The earliest mills seem to have been of different design with the millstones supported by the shield walls at the top of the structure (Illustration by Arnold Pacey, based on photographs by Dick Day of a windmill in Afghanistan; reproduced from Pacey, 1990, p. 12)



Production-centred technologies can be said to include devices such as corn mills, or iron smelting, or the porcelain industry which developed in China. Other evidence of production technologies in China includes several inventions that first appeared there in the three or four centuries prior to 1250. They include spinning wheels, silk-winding machines, and water-powered mills for spinning and winding thread.

Much production of pottery and textiles would be carried on in a domestic context, but there were also instances of large-scale production, of which the most characteristic unit in South Asia was the *karkhana* of Mughal India, or the specialist porcelain factory in China. At one time 4,000 silk workers were employed in karkhanas in Delhi, some of them conscripted.

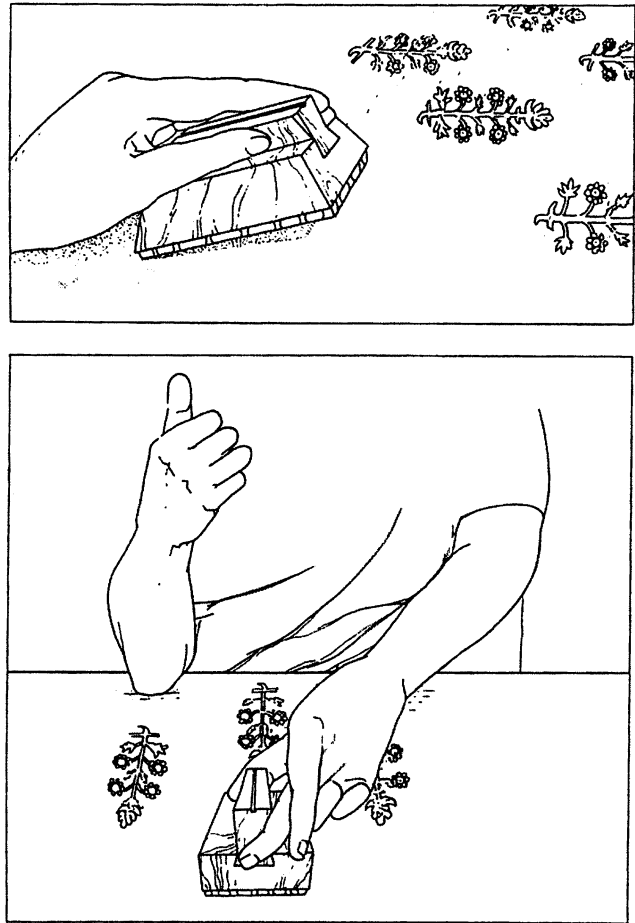
Production for purposes of trade had to be more flexibly organized and flourished most

markedly where merchants could function independently. By 1700, India had become the world's greatest exporter of textiles, sending its cotton cloth to Europe, Africa, and many destinations in Asia. Both Indian and foreign merchants were involved, sometimes financed by the many Parsi and Gujarati bankers to be found in ports such as Surat.

It should not be thought, however, that proto-capitalist industrial organization was always favourable to the use of machines, water-powered or otherwise. The high quality of Indian textiles was achieved by painstaking handwork, as in the printing of designs on cloth (Fig. 4), and sometimes by a very fine division of labour. British observers noted that cotton cloth would sometimes be worked on by four people for every one employed on the same tasks in Europe. Thus the remarkably fine muslin produced in Bengal was

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Fig. 4 Indian technique for printing designs on cloth using a wooden block, applied by hand to transfer a mordant (rather than the dye itself) to the cloth. Mordants are chemical substances that made the cloth receptive to dye. First the wooden block carved with the flower pattern being printed is carefully placed in position (*top*), and then it is struck sharply with the right hand to transfer the mordant solution from the block to the cloth (Illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey, 1990, p. 85)



the result of many detailed processes which would be simplified and reduced to a single operation in the West.

Indian cloth was also noted for the fastness and brilliance of the colours with which it was dyed, mostly using vegetable dyes such as indigo and madder. However, some inorganic substances were also needed as mordants, to help dyes bond with textile fibres and often modifying the colour, and this gave rise to a significant chemical industry. For example, the alum used in madder dyeing was produced in Rajasthan by processing broken shale tipped as waste around copper mines (Fig. 5). These chemical processes were operated on a substantial scale but using labour-intensive methods and minimal equipment. Merchants and banks had ample funds to invest in the textile trade, but because wages were

low, there was little advantage in financing more productive equipment.

Technology is too often equated with engineering and hence with structures, machines, or equipment. However, a deeper understanding of technology in non-Western cultures demands awareness of subtleties in responses to the environment by which human survival was guaranteed in very varied conditions, and subtleties in the use of materials (such as dyes and mordants) by which high-quality production was achieved without machinery.

Thus while engineering-centred technologies that are easy to illustrate with pictures of machines are central to most people's image of what technology is about, a more fundamental view of technology must take account of responses to the environment that cannot easily

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Fig. 5 Alum production in Rajasthan, India, about the year 1800 CE. Shale tips associated with copper mines provided the raw material and can be seen in the background on the right. Shale was steeped in water in rows of pots on the tips. The liquid was then brought to the boiling house seen to the left where some water was evaporated off and the pots left to stand. Blue crystals of copper sulphate formed and were removed. After decanting the liquid and boiling it again, saltpetre was added. The alum was formed by reaction of the saltpetre with aluminium salts in the solution, and crystallized at the bottom of the pots (Illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey, 1990, p. 122)



be illustrated, such as ► [rainwater harvesting](#) or agroforestry where there are no machines to illustrate.

See Also

- [Colonialism and Science](#)
- [East and West](#)
- [Ethnobotany](#)
- [Gunpowder](#)
- [Military Technology](#)
- [Paper and Papermaking](#)
- [Qanat](#)
- [Western Dominance](#)

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Technology in the Islamic World

Donald R. Hill

Hydraulic engineering was the most important technology of medieval Islam. Irrigation schemes supported a thriving agriculture and such schemes involved the construction of canals and *qanats* (see below), dams and water-raising machines. At the other end of the chain, water power was needed to process the raw agricultural products. In this article, we will begin with a survey of hydraulic engineering which will give us an overview of many of the significant aspects of Islamic technology.

Following this, a brief summary of a few other technologies will help us to appreciate the richness and diversity of Islamic material culture. The brevity of this summary is because of limited space and should not mislead readers into thinking that these technologies were insignificant, either in the social life of Islam or in the history of technology.

In Egypt, basin irrigation was in general use. This consists of leveling large plots of land adjacent to a river or canal, and surrounding each plot by dikes. When the river reaches a certain level the dikes are breached, allowing the water to inundate the plots. It remains there until the fertile sediment has settled, whereupon the surplus is drained back into the watercourse.

The regime of the Nile, with the predictable arrival of the flood, made Egypt particularly suitable for basin irrigation. Elsewhere in the Islamic world, however, perennial irrigation was, and is, practiced extensively on all the major river systems. As the name implies, it consists of watering crops regularly throughout the growing season by leading the water into small channels which form a matrix over the field. Water from a main artery – a river or a major canal – is diverted into supply canals, then into smaller irrigation canals, and so on to the fields. In many cases the systems operate entirely by gravity flow, but water-raising machines were used to overcome obstacles such as high banks, whether they were

natural or artificial. Perennial irrigation from wells, again using water-raising machines, is also extensively practiced in the Islamic world.

After the advent of Islam a number of existing systems were extended in order to cater for the needs of newly founded cities. Completely new systems were also constructed. In central Iraq the Muslims inherited the network constructed by their predecessors, the Sasānid dynasty of Persia. The major expansion occurred after the foundation of Baghdad in AD 762. The great Nahrawān canal, which left the east bank of the Tigris a short distance below Takrīt, was extended southward.

The rivers ʿUzaym and Diyāla, which discharge into the Nahrawān from the east, were dammed by the Muslim engineers to provide water for a huge irrigated area. Further south, to the west of the Shaṭṭ al-ʿArab, the city of Basra was founded in the seventh century. Originally it was simply an army encampment consisting of reed huts, but soon it grew into a great city which had no rival in Islam before the foundation of Baghdad. Gradually, in the last decades of the seventh and the first decades of the eighth centuries a vast network of canals was constructed to serve the demands of a thriving agriculture.

Other important systems were based upon the rivers in the province of Khurāsān, then much larger than the eastern Iranian province of the same name. Some of the most impressive networks were based upon the river Murghāb, upon which stands the city of Marv. In the tenth century the system was controlled by a specially appointed Amir who had 10,000 men under him, each with an appointed task. This Amir is said to have had more authority than the prefect of Marv. Other important schemes in the east were those centered on the cities of Bukhārā and Samarqand and on the lower reaches of the Amu Darya (Oxus) river.

In Spain, the Muslims greatly extended the irrigation schemes that had been constructed by the Romans and Visigoths. Syrian irrigation technology – large contingents of the conquering armies were from Syria – was applied in Spain, where the climatic and hydraulic conditions of the rivers of the north were very similar to those

in Syria. The irrigation systems, such as those along the Guadalquivir river and those in the province of Valencia, were the basis of the agricultural prosperity of Muslim Spain. Indeed, systems such as that in Valencia, basically unchanged since Islamic times, continue to serve the needs of the province to the present day.

A particular technique, originating in Armenia about the eighth century BCE, and still in widespread use in modern Iran, was the ► [qanat](#), an almost horizontal underground conduit that conducts water from an aquifer to the place where it is needed. For the preparatory work an experienced surveyor carefully examines the alluvial fans, the terrestrial equivalent of a river delta formation, in the general location of the proposed *qanat*, looking for traces of seepage on the surface and often for a barely noticeable change in vegetation, before deciding where the trial well is to be dug. When a successful trial well has been excavated, it is now known as the mother well. The surveyor levels from this point to the outlet of the *qanat*, marking the positions and levels of the proposed ventilation shafts at 30–50 m intervals. These shafts also provide for excavation of the spoil. A skilled artisan (*muqanni*) then begins work with his assistants by driving the conduit into the alluvial fan, starting at the mouth. At first the conduit is an open channel, but it soon becomes a tunnel. Another team sinks ventilation shafts ahead of the tunnelers, and laborers haul up the spoil to the surface through these shafts by means of a windlass. The tunnel is about 1 m wide by 1.5 m high; in soft soil hoops of baked clay, oval in shape, have to be used as reinforcement. As the work nears the mother well, great care has to be taken in case a *muqanni* misjudges the distance and strikes the full well, in which case he might be swept away by the sudden flow.

The construction of canals, *qanats*, and other public works required the assistance of skilled surveyors. The earlier methods of leveling were rather slow and tedious. This involved stretching a string between two staffs divided into graduations and held vertically. A level was suspended to the center of the string. One type, for example, was an inverted isosceles triangular frame suspended by hooks to the string. Fixed to the

center of the horizontal leg was a plumb line. One end of the string was moved up or down the staff until the plumb line passed through the inverted apex of the triangle, at which point the string was level. The difference in level between the two staffs was noted. In the eleventh century a level was introduced akin to our modern instrument but without, of course, any telescopic or electronic aids. A thin copper tube rotating on a circular plate that was suspended to a “gallows” was aimed horizontally on to a level staff. The reading gave the difference in level between the two points. The rises and falls along the route of the survey, summed algebraically, gave the level difference required. Triangulation, by which the heights and distances of objects, whether accessible or not, could be determined was usually carried out by the astrolabe. Quantity surveying methods were very similar to those in use today. The amount of excavation for a canal, for instance, was first calculated. Then, by applying known unit rates, the engineer worked out the number of excavators, laborers, foremen, and supervisors. From these results he prepared a Bill of Quantities which was used for measuring progress and paying the contractor.

The main purpose of dams was to divert water from rivers into irrigation systems. Our knowledge of Muslim dams comes from two sources: reports in the works of Muslim geographers, and the examination of Muslim dams which have survived to the present day. In the east, one of the most impressive dams, known as the Band-i-Amir, was built in 960 over the river Kūr in Iran, between Shirāz and Persepolis. As described by the tenth-century geographer ► [al-Muqaddasī](#), it was used to irrigate 300 villages. At each side of the dam, downstream, were ten water-raising wheels and ten water mills, all given extra power by the head of water impounded behind the dam. The dam was constructed throughout of masonry blocks, and the joints were made of cement mortar strengthened with lead dowels. The dam still exists and it is not surprising, given the solidity of its construction, that it has had such a long and useful life.

Also in Iran, at Kebar, about 15 miles south of Qum, is a dam which is very important in the history of dam construction. Built in the thirteenth century, it is the first known example of the true arch dam. It did not depend for its resistance to water pressure on gravity but was built as an arch, its convexity pointing upstream, and its sides were anchored securely into the rocky sides of the gorge in which it was built. The forces were transferred to the abutments, and it was considerably more slender than a gravity dam across a similar river.

A number of important Muslim dams were built in the Iberian peninsula. These included the dam at Cordoba with an overall length of 1,400 ft. Downstream from the dam were three millhouses that each contained four mills, as the geographer ► [al-Idrīsī](#) reported when he saw them in the twelfth century. Also below the dam is a large waterwheel. There are a series of eight dams on the river Turia in the province of Valencia. They are very securely built in order to withstand the sudden dangerous floods to which the river is subjected. They are also provided with desilting sluices, without which the canal intakes would soon become hopelessly choked.

These dams and their associated canals continue to provide for the needs of the province at the present time. It has been shown in modern measurements that the eight dams and their associated canals have a total capacity slightly less than that of the river. This, of course, raises the question whether or not the Muslims were able to gauge a river and then design their dams and canals to match. There seems no reason to doubt that they indeed had that capability.

Given that dam building had been an established practice since the times of the Sumerians and ancient Egyptians, it is not easy to isolate those elements that were Muslim innovations. On present evidence, it seems certain that the introduction of desilting sluices, the arch dam and hydropower were all Muslim inventions. The Muslims also probably perfected the technique of gauging rivers.

All the main water-raising machines were in existence in the Middle East before the advent of Islam. These included the Archimedean screw,

the well windlass, the *shādūf*, the *sāqiya* and the *norīa*. Because of their survival right up to the present day, and/or their importance in the development of machine technology, the last three of these are the most significant. The *shādūf* is illustrated as early as 2500 BCE in Akkadian reliefs, and it has remained in use throughout the world until now. Its success is due to its simplicity and its efficiency. It can be easily constructed by the village carpenter using local materials, and for low lifts it delivers substantial quantities of water. It consists of a long wooden pole suspended at a fulcrum to a wooden beam supported on columns. At the end of the short arm of the lever is a counterweight made of stone or clay. The bucket is suspended to the other end by a rope. The operator lowers the bucket and allows it to fill. It is then raised by the action of the counterweight and its contents are discharged into an irrigation ditch or a head tank.

The *sāqiya* was invented in Hellenistic Egypt, probably in the third century BCE. It is operated by an animal, usually a donkey, walking in a circle. On its shoulders and neck the animal wears a collar harness that transmits the power through two traces to a double-tree fastened to a drawbar. The drawbar passes through a hole in an upright shaft. This shaft carries the lantern-pinion, which is a type of gear-wheel consisting of two wooden discs separated by pins, the spaces between the pins being entered by the cogs of a vertical gear. This vertical gear has the cogs on one side of its disc and these protrude from the other side to form the wheel that carries the chain-of-pots, or potgarland. The component is therefore known as the potgarland wheel. It is erected on a horizontal axle over a well or other water source. The pots fill with water at the bottom of their travel and discharge at the top, like the shadoof, into a head tank or irrigation ditch. The *saqiya* was transited by the Muslims from the Middle East to Spain and eventually to the New World. In some areas it has retained its popularity to the present day.

The *norīa* is perhaps the most significant, from a technical viewpoint, of the traditional water-raising machines. Being driven by water, it is self-acting and requires the presence of neither

man nor animal for its operation. Essentially it is a large wheel constructed of timber. At intervals, paddles project outside the rim of the wheel, which is divided into compartments. The noria is provided with an iron axle and this is housed in bearings that are installed on columns over a running stream. As the wheel is rotated by the impact of the water on its paddles, the compartments fill with water at the bottom of their travel and discharge their contents at the top, usually into an aqueduct.

The point of origin of the noria is unknown, but it was certainly known in the Roman world and in China by the first century BCE. There is a possibility, therefore, that it was invented somewhere in the highlands of southwest Asia. The large noria at Murcia in Spain is still in operation, as are norias in various parts of the world, where they are often able to compete successfully with modern pumps.

Water wheels, as used in mills, were of three types: vertical undershot, vertical overshot, and horizontal. The first type was a paddle wheel mounted directly in a running stream. In the overshot wheel the rim was divided into compartments into which the water was directed from above, usually from an artificial channel or leat. Both vertical wheels required a pair of gears in order to transmit the motion of the water wheel to a vertical axle that led up to the millstones. In the horizontal type a jet of water from a reservoir was directed on to the vanes of the wheel, on the top of whose axle the millstones were installed. Various methods were used to increase the power and hence the output of mills. The wheel could be located in the piers of bridges or on boats moored on rivers, in both cases to take advantage of the increased rate of flow in midstream. In the Basra area in the tenth century there were mills that were operated by the ebb tide – about a century before the first mention of tidal mills in Europe. Apart from the production of flour from grains, water mills were also used for industrial purposes such as papermaking, the fulling of cloth and the crushing of metallic ores.

Bridges of all types were important in the Islamic world not only for communications but

also for protecting the banks of canals from damage due to fording people and animals. In the mountains of Central Asia, such as the Tien Shan and Hindu Kush ranges, both cantilever and suspension bridges were used for crossing ravines. The great rivers of Egypt, Iraq, and Transoxiana were usually crossed by bridges of boats. In many cases, however, rivers and other obstacles were crossed by masonry arch bridges built of dressed stone or, sometimes, especially in Iran, of kiln-burnt bricks.

Two bridges in western Iran, built in the tenth century, are constructed with pointed arches. This type of arch, which was to be such an important element in European Gothic architecture from the twelfth century onward, had appeared in Syria and Egypt during the seventh and eighth centuries, but only as a decorative feature. These Iranian bridges are the earliest known occurrence of the pointed arch as a load-bearing component.

Chemical technology was a highly developed profession in medieval Islam. The most important writer on the subject was Muḥammad ibn Zakariyyā ► [al-Rāzī](#). Although he wrote a number of alchemical books, his major work, *Kitāb al-asrār* (The Book of Secrets), written early in the tenth century, leaves us with the impression of a powerful mind, much more interested in practical chemistry than in theoretical alchemy. *The Book of Secrets* contains a comprehensive list of pieces of equipment, many of which are still in use today. The chemical processes described or mentioned by al-Rāzī include distillation, calcination, solution, evaporation, crystallization, sublimation, filtration, and amalgamation. Arabic works were undoubtedly an important influence upon the development of European chemistry. Evidence for this influence is the abundance of Arabic words in the chemical vocabularies of European languages. Examples in English are alkali, alchemy, alcohol, elixir, naphtha, and many others.

Mining played an important part in the economic life of the Islamic world. Spread throughout this vast area were mines for all the important metals, precious stones and essential commodities such as salt, coal and petroleum. The oilfields at Baku were exploited by the Muslims on a

commercial scale by the ninth century. In the thirteenth century Marco Polo reported that a 100 ship-loads could be taken from Baku at one time.

Iron and steel were, of course, the most important metals for many industrial and military purposes. Cast iron was described about 1040 by the great scientist ► [al-Bīrūnī](#) – it was exported to many countries as a raw material. There was also an extensive steel industry which produced, among other grades, the famous Damascus steel. As far as we can ascertain at present, this came from a number of Islamic centers in the Middle East and Central Asia. But it was certainly produced in Damascus itself.

We have been able to mention only the more important areas in which Muslim engineers and technologists were pre-eminent for several centuries. In many cases Islamic ideas were transmitted to Europe, but it is important not to evaluate Islamic technologies only with regard to their contribution to their European counterparts. Technologists in the Islamic world were responding to the needs of society and were extremely successful in a number of fields.

See Also

- [al-Karajī](#)
- [al-Muqaddasī](#)
- [Dams and Irrigation in Ancient Arabia](#)
- [Qanat](#)
- [Surveying](#)

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Technology in the New World

Aaron Segal

The indigenous peoples of the New World were excellent builders. Although their construction tools were limited they managed to produce pyramids, temples, and other public buildings in the Andean Highlands, the lowland jungles of Central America and the Yucatan, and the central highlands of Mexico. There were ceremonial ballcourts built throughout the Caribbean as well as in what is now Mexico, Guatemala, and Belize. Construction in North America included the mound sites of the Midwest and the Southeast and the cliff dwellings of the Southwest. While estimated populations at these sites varied from the hundreds to the thousands these were all urban societies and civilizations.

These master builders relied on their own concepts, designs, craftsmen, and techniques. In spite of claims of trans-Pacific, trans-African and other exogenous contacts, the evidence is sparse and less than convincing. The civilizations of the New World evolved on their own with only limited contacts with one another over space and time. Their achievements as well as their failure are entirely their own, including matters of technology.

The New World societies concentrated on identifying, applying, and improving instrumental technologies, whether for agriculture, irrigation, construction, crafts, or other utilitarian uses. The legacy that has survived is one of warrior-kings, royal courts, artisans cum farmers, priests and scribes, builders and artists.

The peopling of the New World began approximately 15,000 years ago when climatic changes made migration from Siberia and East Asia possible across the Bering Straits. It took another 8,000 years for these small wandering human bands to reach Patagonia and spread throughout most of Middle and South America. Somehow they managed to keep fertility above infant mortality as they diffused on foot

throughout the New World. Hunters and gatherers, they relied on stone age worked flint edges to kill, strip, and consume their prey. Their principal weapon, originating in Asia, was the *atlatl* or spear thrower improved with flexible sheets and stone weights. Bows and arrows were introduced later, also perhaps from Asia via the Arctic, and became a favorite weapon for hunting bison on the Great Plains. When the Tainos paddled island by island from Lake Maracaibo up the Caribbean Archipelago (A.D. 1000–1400) they were armed with an array of bows, arrows, stone, bone, and flint knives, *atlatls* and other weapons.

Those who undertook the Great Journey throughout the New World survived through environmental adaptation as they fanned out across two continents. Those who adapted to the Amazon Basin continued in a hunter-gatherer mode, learning the skills needed to survive in the tropical rain forest. The Arawaks, Tainos, and other voyagers to the Caribbean also relied primarily on hunting and gathering adapted to coastal fishing. Latecomers who remained in the Arctic or sub-Arctic turned to hunting, fishing, shelter, and other technologies to survive harsh winters.

Agriculture probably arose about 3000 B.C.E. simultaneously in the Andean highlands and Central Mexico, first as a supplement to hunting and gathering and as a response to growing populations. Gatherers observed which seeds yielded what plants and began to cultivate on a trial and error basis. Teosinte, a high-protein precursor of corn, was first cultivated in Mexico, while potatoes were an early ecologically suitable cultigen in the colder Andes. The list of cultivated edible plants soon expanded to include manioc, squash, peppers, pineapples, and other New World originals, especially several varieties of beans. The Tainos learned to grow tobacco and to cure it as snuff in their Caribbean islands, which became valuable trade items.

Agricultural technologies evolved to include the use of digging sticks, irrigation canals, terracing and ridging, intercropping, and seed beds. Lacking draught animals fires were set to clear new land. The most sophisticated technique was

that of the *milpas* practiced by the Aztecs who built silted mounds of fertile run-off materials.

Food processing and storage technologies were also innovated and widely diffused. The stone *metate*, or mortar and pestle, became the basic Mesoamerican tool for crushing corn. Ethnobotanical experience produced a variety of herbs, spices, and for the Mexicans chocolate to add to largely vegetable diets. As towns and cities grew, especially in the Andes and Mesoamerica, hunting declined in favor of limited domestication of chickens, turkey, pond fish, and small animals. However, animal protein was hard to come by in all the predominantly agricultural societies which relied on trade and food storage to supplement local corn, beans, manioc, and other staples.

Transport was a severe obstacle for all the New World peoples. Dogs were used to pull sleds and traverse with limited loads in the Arctic and on the Great Plains. Alpacas and llamas were semidomesticated and used for limited local transport in the Andes. However, everywhere terrain was rugged, surfaced roads were few and far between, and runners and head-loads were the primary mode of transport. Sailing vessels were unknown and the canoes of the Tainos and others had to hug shorelines for safety. Although the concept of the wheel was known, and toy wheels were used in the Andes, the lack of roads and the natural obstacles impeded the development of wheeled vehicles. The Spanish introduction of the horse and the cow revolutionized transport in the New World. Trade previously was confined to what could be carried on men's backs. Thus the Aztec long-distance traders, *pochotes*, specialized in high-value items such as jewelry, ceremonial feathers, and weapons.

Confined to limited home markets, New World societies tended to invest their agricultural surpluses in exquisite crafts. As royal courts developed around ceremonial centers so did specialized artisans capable of meeting quality demands, as well as items for daily use. The oldest discovered textiles date back 3,600 years to the Peruvian coast and were made of cotton with intricate woven designs. Dyed cotton for personal clothing became widely diffused with

pendants and ornaments often added. Excavation of Andean and other tombs has revealed the importance attached to clothing and jewelry and the high skills of the artisans. The Olmecs of the Mexican Southeast were the first to work in jade and turquoise as well as to create massive stone carvings. Metallurgy, especially in the form of masks, was highly accomplished in Mexico as well as among the peoples of what is now Costa Rica, Colombia, and Peru.

Ceramics and basket and gourd work were closely associated with the emergence of agriculture. Initial demands were for items used for carrying and storage. However, in the Andes and Mexico, as techniques improved, ceramics became an important ceremonial art form. Funerary jars, urns, water carriers, ceremonial masks, and other items are regularly depicted in sculptures and paintings and found in Aztec, Maya, and other tombs. Pre-Incan and Incan Andean societies also took pride in their varied and elaborate ceramics, baskets, and gourds.

Ceremonials were held largely outdoors, while palaces were for storage purposes. Most common people, including craftsmen, lived, ate, and slept in simple mud and brick dwellings. Their lords and masters lived in larger and more solid enclosures but with similar creature comforts. Building skills were directed at large-scale public constructions to honor the deities and/or fortresses for defense purposes. While kings lived in palaces with a few of their retainers many members of the court had to accept more humble accommodations. The benign tropical climate of the Caribbean contributed to nearly everyone's relying on hammocks and huts made of straw.

The Aztecs alone tackled the sewage and other waste disposal problems of man-made cities. They instituted barges along the canals of their capital at Mexico City, and also made an effort to keep water potable. At the Inca capital of Cuzco public hygiene was minimal as it had been in the Maya city-states. It may have been the scarcity of domesticated animals that reduced disease vectors in these highly crowded urban sites.

As builders the peoples of the New World concentrated their efforts on specific times and places. These included the Olmec

(1000–600 B.C.E.), Tectihuacan (A.D. 0–650), Toltec (1000–1300 B.C.E.), and Aztec (A.D. 1400–1530) civilizations in Mexico, the Mayas (A.D. 0–900) in Guatemala and Mexico, and the Moche (A.D. 0–600), the Nazca (A.D. 0–600), the Chimú (A.D. 1300–1420) and the Inca (A.D. 1400–1530) in Peru. They were able to construct magnificent and lasting buildings in environments as different as lowland jungles and highland mountains. They moved massive amounts of stone and carved and fitted it exactly with simple tools, as well as working with wood. Their architects designed vast open spaces and compelling interiors. Their multistory edifices reached up to the heavens, and served sometimes as astronomical observation sites, while commanding the world below. Their equivalents are neither the medieval cathedrals of Europe nor the Acropolis of Greece. Instead they are the most significant continuing testimony to the uniqueness of these New World civilizations and peoples.

While we can directly experience and marvel at these sites it is much more difficult to penetrate the intellectual worlds of their builders. The Mayas, prior to their collapse in A.D. 800–900, had a sophisticated writing system which was lost, as were many of their ideas about astronomy and mathematics. Similarly, the Nazcas of coastal Northern Peru who vanished around A.D. 600 may have had more advanced ideas about astronomy than their predecessors. The unevenness of historical experience and its inherently nonlinear nature is one of the sobering lessons of the history of science and technology in the New World. The Mayas alone invented a writing system which took nearly 450 years after the European Conquest to decipher. The Incas adapted a system of counting called the *quipu* for purposes of accounts and storage but never extended it into a mathematical base. The Aztecs excelled at urban planning, irrigation, and public health but showed little interest in writing.

The peoples of the New World were builders, agriculturalists, and craftsmen rather than scholars or theologians. The European conquerors came from an age of iron and steel with wooden ships, navigation, steel swords, guns, explosives, and literacy. They brought horses,

cattle, and smallpox, measles, diphtheria, trachoma, whooping cough, chicken pox, bubonic plague, typhoid fever, scarlet fever, amoebic dysentery, and influenza.

See Also

- [Animal Domestication](#)
- [Mathematics](#)
- [Nazca Lines](#)
- [Quipu](#)
- [Stonemasonry of the Incas](#)
- [Swidden](#)
- [Technology](#)

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Telescope

Julian A. Smith

The telescope is an optical instrument used to make distant objects appear nearer and larger; it

consists of one or more tubes with a series of lenses, mirrors, or both (refracting, reflecting and catadioptric models, respectively), through which light rays are collected, brought to a focus, and magnified. Despite their great variety, all telescopes have two basic parts: the objective, which intercepts and focuses the incoming light, and the mounting, which supports the objective. The telescope, which revolutionized astronomical research in the seventeenth century, is usually considered to be a European invention, though parallel discoveries occurred elsewhere, and some of its elements were developed earlier by other cultures.

The traditional Western account of the telescope's invention is quite complex. The use of hollow sighting tubes without lenses to observe stars had been known to the ancient Greeks, being recorded by Aristotle (384–322 BCE) and the geographer Strabo (ca. 63 BCE–ca. 19 AD). Lenses are mentioned by the playwright Aristophanes (ca. 450–388 BCE), and mirrors were investigated by Heron of Alexandria (ca. 60 AD). The geometer Euclid (ca. 300 BCE) and the engineer Archimedes (ca. 287–212 BCE) studied both. The investigation of lenses, mirrors, and sighting tubes continued throughout the Medieval period. The invention of spectacles, an important telescope precursor, occurred between 1285 and 1300 by an unknown Italian glassmaker, but Alexandro della Spina (d. 1313) and his friend Salvino d'Armati (d. 1317) are most often credited. Meanwhile, English Franciscan friar Roger Bacon (1211–1294) wrote extensively of spectacles and other optical devices, and influenced many later scientists with his research into the laws of reflection and refraction.

An enormous number of sixteenth century figures developed various combinations of perspective glasses and mirrors to enlarge distant objects, including the English father and son surveying team of Leonard (ca. 1520–ca. 1571) and Thomas Digges (1546–1595), mathematician William Bourne (d. 1583), Italian natural philosopher Giambattista della Porta (1534/1535–1615), and Dutch mathematician Cornelius Drebbel (1572–1634). But the lack of

documentary evidence has thus far left historians divided over whether these instruments were true telescopes or just magnifying glasses.

The first unambiguous accounts of the European telescope come from Holland around 1608. Most credit the Middleburg spectacle maker Hans Lippershey (ca. 1570–1619) with the first refracting telescope; but there are rival claims by Middleburg optician Zacharias Jansen (1580–ca. 1638), and Alkmaar inventor Jacob Metius/Adriaanzoon (1571–1635).

Early telescopes were first applied to military operations. But over the winter of 1609–1610, Italian physicist and astronomer Galileo Galilei (1564–1642) dramatically improved Lippershey's primitive device and turned it to the sky. His announcements of lunar valleys and mountains, sunspots, the phases of Venus, the moons of Jupiter, and much more (published in the March, 1610 *Sidereal Messenger*) thoroughly shook the ancient earth-centered cosmology of Alexandrian astronomer Claudius Ptolemy (ca. 150 AD). Similar observations were made between 1609 and 1612 by English polymath Thomas Harriot (1560–1621). The word "telescope," meanwhile, was coined in 1611, and was first printed in Julius Caesar Lagalla's (1576–1624) *Lunar Phenomena* of 1612.

Early Galilean telescopes, with one biconvex and one biconcave lens, suffered from both chromatic and spherical aberration, which left blurry images. The German astronomer Johannes Kepler (1571–1630) designed the improved Keplerian telescope of two biconvex lenses in 1611, but problems remained. It was not until 1636, when the Minorite friar Marin Mersenne (1588–1648) suggested replacing lenses with mirrors, that real progress could be made. Reflecting telescopes were designed by Scottish mathematician James Gregory (1638–1675) in 1663, and built a few years later by both Isaac Newton (1642–1727) and French physicist Guillaume/Nicholas Cassegrain (fl. 1672); these models (Newtonian and Cassegrain) are still widely used today.

During the period 1610–1650, the telescope was carried by European explorers to all regions of the earth; frequently Jesuit missionaries

exported it to non-Western cultures. However, there is evidence that other societies developed both the telescope and its various parts independently of Europe. Glass originated in Egypt about 3500 BCE and was first produced on a large scale by the Phoenicians, and lenses dating back to pre-Greek times (2000 BCE) have been discovered in Crete and Asia Minor/Mesopotamia.

Meanwhile, Arabic astronomers played a significant role in paving the way for the telescope. The mathematical laws of optical reflection and refraction in glass and other media were thoroughly investigated and extended by the physicist-astronomer Ibn al-Haytham (Alhazen, 965–ca. 1040). Ibn al-Haytham knew how to use spherical glass segments to magnify objects, and was familiar with spherical aberration and techniques to calculate the focal lengths of lenses and mirrors. Much of this knowledge was subsequently transmitted to Europe through Latin editions of his work, and especially through the texts of his Polish disciple, Witelo of Silesia (ca. 1230–ca. 1275). Bacon also learned much from Ibn al-Haytham.

Sighting tubes were also early employed by Arabic astronomers; ► [al-Battānī](#) (858–929) used them in his Raqqa observatory. ► [Naṣīr al-Dīn al-Tūsī](#) attached one to a sextant at his Maragha observatory in 1259 to study the sun.

Meanwhile, Needham argues that Chinese opticians may have discovered the elements of the telescope either before, or parallel to, the Europeans. Though glass was developed fairly late (ca. 500 BCE), quartz rock-crystal had been in use since ancient times and lenses of both materials were employed to focus solar rays to start fires. Needham also claims the Chinese used smoky rock-crystal to observe sunspots and eclipses. An important text of Tan Qiao (the *Hua Shu* or Book of Transformations of about AD 940) records the use of planoconcave, planoconvex, biconcave, and biconvex lenses to make objects larger, smaller, upright, and inverted. Spectacles have often been considered a Chinese invention, but this is based on a garbled text; they were brought overland from Europe by 1300. As for catoptrics, Mohist opticians of the

fourth century BCE studied both concave and convex mirrors, and were familiar with real and inverted images, focal points and refraction in different media. The use of concave mirrors to ignite tinder by focusing sunlight goes back to the Chinese Bronze Age; one of the earliest citations is dated 672 BCE.

Chinese sighting tubes made of ► [bamboo](#) are similarly old; the most important early reference is the (approximate) sixth century BCE *Shu Jing* (*Historical Classic*). By the *Huiai-Nan Zi* (*Book of Huai-Nan*) of 120 BCE, they were widely used in land surveying and triangulation; and by the twelfth century, they were standard navigational equipment for taking astronomical observations aboard ships.

Though many of these developments were contemporaneous with European discoveries, there are two parts of the telescope in which Chinese scientists can claim undisputed priority: the invention of equatorial mounting, and the development of clock drives, both of which are standard equipment on today's telescopes.

Astronomer Guo Shoujing (fl. 1270) developed the equatorial mounting now used on all modern telescopes for his “simplified instrument”, which was basically a dissected armillary sphere related to the torquetum, an Arabic invention which had been recently imported (ca. 1267) to China from Persia. With an equatorial mounting, a rotation about only one axis (one parallel to the earth's polar axis) was needed to follow the curved paths of the stars.

Chinese physicists and engineers anticipated the fourteenth century mechanical clocks and clock-driven astronomical instruments of Europe by over a 1,000 years. Mathematician, geographer and astronomer Zheng Heng (ca. 78–ca. 142) constructed what Needham calls the “grand ancestor of all clock drives,” a rotating bronze armillary sphere powered by a system of gears attached to a waterwheel. This device was used to predict the positions of various stars and planets. The later clock-driven armillary sphere of Su Sung (AD 1090) added a sighting tube to permit direct observation of a star as it moved over prolonged periods, resulting in a true “clock drive” for astronomy.

But despite Chinese priority in clockwork and mounting, just as in Europe, it was not until the seventeenth century that the disparate elements of the telescope were joined together. Though Chinese texts describe European telescopic discoveries from 1615 onwards, and Jesuit Father Terrentius/Johannes Schreck brought a telescope to China in 1618, Needham maintains that enough documentary evidence exists to assert a parallel, independent discovery by Suchow opticians Po You and Sun Yun Qiu. Between about 1620 and 1650, this pair constructed not only early telescopes, but also compound microscopes, magnifying glasses, searchlights, magic lanterns, and other instruments. Meanwhile, Sun Yun Qiu wrote a text on these and other optical devices, entitled *Jingshi (History of Optick Glasses)*. But the first Chinese book on the telescope specifically was the *Yuan Jing Shuo (Far Seeing Optick Glass)* of Tang Ruo-Wang (Adam Schall von Bell) in 1626. *Yuanjing* became the standard term for the telescope, and by 1635 it was being widely used by Chinese artillery in battle.

Telescopes appear to have come to Indian astronomers fairly late. Indian craftsmen made glassware, lenses, and mirrors throughout the ancient and medieval periods. And *gola yantra* or armillary spheres, first mentioned in the *Āryabhaṭīya* of Āryabhaṭa I of Kusumpura (b. 476 AD), had clock-drives (powered by clepsydra) for stellar observation by the *Bhatadipika* of Parameśvara (ca. 1432).

But it was not until the seventeenth century that primitive telescopes were used in India. The celebrated astronomer and instrument-maker Sawai Jai Singh (1686/1688–1743) employed telescopes to “show that Mercury and Venus get their light from the Sun as the Moon does” (*Zica-i Muhammad Shahi*); and though they revealed Saturn to be an irregularly shaped “oval,” these telescopes were apparently not good enough to resolve the rings, which had already been accomplished by Dutch physicist Christiaan Huygens (1629–1695) several decades previously, in 1659. Indian achievements in this area thus far appear to be rather derivative, but much research still needs to be done in this area.

See Also

- ▶ [Al-Battānī](#)
- ▶ [Āryabhaṭa](#)
- ▶ [Clocks and Watches](#)
- ▶ [Guo Shoujing](#)
- ▶ [Ibn Al-Haytham \(Alhazen\)](#)
- ▶ [Jai Singh](#)
- ▶ [Marāgha](#)
- ▶ [Naṣīr al-Dīn al-Ṭūsī](#)
- ▶ [Parameśvara](#)
- ▶ [Zhang Heng](#)

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Temples in Ancient Egypt and Archaeoastronomy

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During the last 5 years, the Egyptian-Spanish Mission on ancient Egyptian astronomy and

archaeoastronomy, conducted under the auspices of the Egyptian Supreme Council of Antiquities, has been performing an ambitious scientific project with the aim of studying the cosmovision of the ancient civilization of the pharaohs. Part of the project consists of a reanalysis of the iconographic and historical sources that has allowed a reassessment of the calendar theory (Belmonte, 2003), challenging old-fashioned paradigms, or a new proposal for the sky maps of ancient Egypt (Lull & Belmonte, 2006).

However, the most expensive part of the project, in time, effort, and resources, has been the five campaigns devoted so far to measuring the orientation and studying the spatial location of ancient monuments across the Nile Valley and beyond. More than 500 pyramids, hypogea, chapels, sanctuaries, or small and large temples have been measured so far. The fieldwork in successive campaigns was organized geographically but also with the intention of testing previous results with new exercises. Four papers have been published about the temples in which we

have analyzed the relation of temple orientation and their location within the local landscape, understanding landscape in its broadest meaning of both terrestrial (basically the Nile) and celestial (astronomical orientations) aspects. Our studies demonstrate that both components were necessary and intimately correlated.

Figure 1 shows the location of the sites where we have assembled the data of the temples along the five campaigns. We have taken measurements in almost every archaeological location within Egypt. These include very well-preserved temples, such as the one of Horus in Edfu, or monuments where just a few walls of the foundations were visible. The orientation has always been taken from inside looking outside, from the sanctuary of the temple to the gate, seldom across several halls, courts, and pylons. In a few occasions, the opposite direction has also been considered or even the perpendicular to the main axis.

We were not seeking extreme-precision alignments. Our main task was to measure as many

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Fig. 1 Map of Egypt showing the location of sites, from the Western and Eastern Deserts to the Nile Valley, where the orientation data yielded by our five field campaigns have been assembled. Dots stand for sites with just one or a few (two or three) sanctuaries on site. Ellipses stand for imposing archaeological sites where several temples, sometimes as much as ten, could be measured within a single location



sacred buildings as we were able to, giving a similar weight to those exceptionally well preserved and to temples where not more than a few walls are visible. We obtained our measurements using a high precision compass, correcting for local magnetic declination which is not expected to suffer alterations in Egypt, mainly a limestone and sandstone land, and a clinometer, both as isolated instruments or enclosed within a single tandem device. The instruments permit a theoretical 0.25° precision for both kinds of measurements. However, owing to various considerations, an error close to 0.5° in both azimuth and angular height is probably nearer to reality. This would signify a mean error of order $\pm 0.34^\circ$ in the determination of the corresponding declination. For the latitudes of Egypt, a precision of 0.5° is perhaps the best we can expect in solar, lunar, or very bright star observations near the horizon, and in the case of fainter stars, the errors in estimating the azimuth can range from more than one to several degrees. We consider our altazimuth data to be of good enough quality to pursue our main quest, i.e., to demonstrate the importance of certain families of astronomical alignments in ancient Egypt.

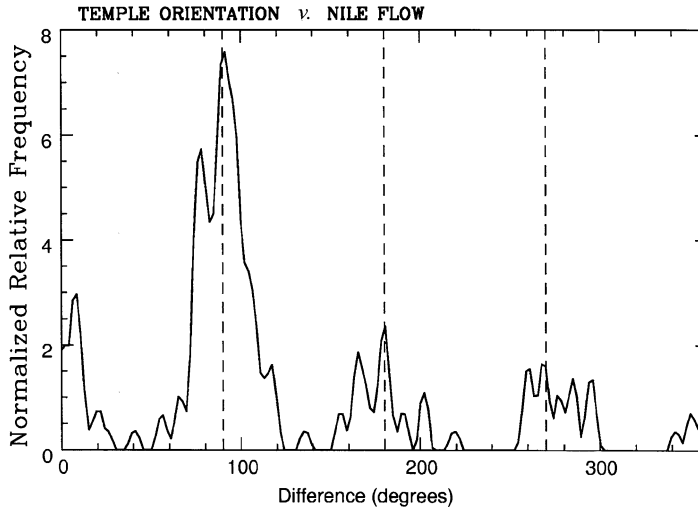
Testing Nile Orientations: The Null Hypothesis

The majority of Egyptologists have traditionally considered ancient Egyptian temples to be orientated with respect to the Nile. On several occasions, this preconceived notion has precluded any serious or systematic attempt on the part of the Egyptological community to study the orientations of the temples, and most efforts up to a few years ago had come from dedicated archaeoastronomers, like Hawkins (1973) or Krupp (1988), whose conclusions were not always assimilated. Indeed, we have heard this opinion several times, even being asked by some reputed scholars why we were devoting so much effort to a question that was crystal clear. So, from the very beginning of our project, one of our primary objectives has been to test the Nile hypothesis in order to check if so many scholars

could be wrong. We demonstrated that they were indeed correct and that in Upper Egypt the Nile was the main source of inspiration for orientating sacred buildings, but that it was not the only one. We tried to falsify the Nile hypothesis by performing fieldwork in a land with no river, the oases of the Western Desert, and we found that when the Nile is absent, astronomical orientations certainly dominate the situation. Figures 2 and 3 repeat those exercises but with a larger amount of additional data obtained in later campaigns.

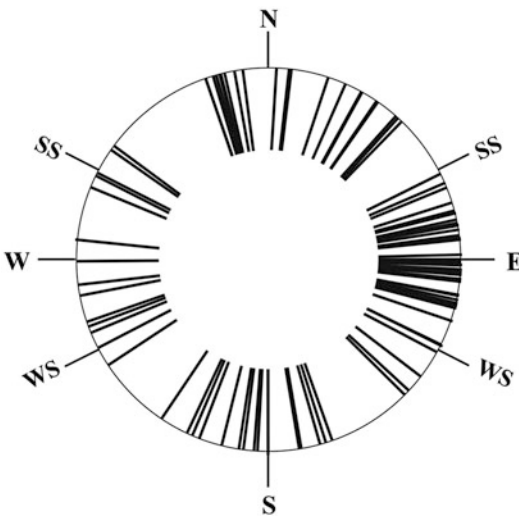
Figure 2 shows a histogram where the difference between the orientation of the temple and the course of the Nile versus frequency is presented. The histogram has been produced with the data of 170 temples in Upper, Middle, and Lower Egypt, with the particularity that in the Delta the difference is with respect to the closest river branch. The plot clearly demonstrates that temple orientation with the main gate located in front of (axis perpendicular to) the Nile is the most common way of orientating the buildings. Furthermore, axes nearly parallel to (at $\sim 0^\circ$ or 180°) or perpendicular to the river, but facing the other way ($\sim 270^\circ$), were also common. This demonstrates beyond any reasonable doubt that local topography (the course of the Nile) was very important at the moment of settling the foundations of the temples.

In contrast, Fig. 3 shows the orientation diagram of 95 temples in the deserts and oases of Egypt, where there is no river to justify the orientation. The diagram shows the typical form of a Maltese Cross which is probably related to a certain preference for solar and cardinal orientations that could not be obtained without a celestial reference. The answer to the controversy is fascinating, as both hypotheses should be correct. This is what we have seen during these years and demonstrated in previous works on the topic. Even more, we are almost convinced that certain places throughout Egypt had an especially sacred character because they presented double (topographic and astronomical) alignments, such as Karnak or Denderah, and some customs, like the selection of cardinal or quarter-cardinal orientations in certain regions, would follow a similar line of reasoning.



Temples in Ancient Egypt and Archaeoastronomy, Fig. 2 Testing the Nile hypothesis. Histogram representing the difference in orientation between the main axes of 170 temples of the Nile Valley and the average course of the river (or river branch in the case of the Delta) at their corresponding locations, for an interval of $\pm 1^\circ$, larger than our estimated error of $\frac{1}{2}^\circ$, allowing for probable historical changes in the river flow. Temple orientation with the main gate located in front of (axis

perpendicular to) the Nile is the most common way of orientating the buildings. Axes parallel to (at $\sim 0^\circ$ or 180°) or perpendicular to the river, but facing the other way ($\sim 270^\circ$), were also common. This demonstrates beyond any reasonable doubt that local topography (the course of the Nile) was very important at the moment of settling the foundations of the temples but was not the only factor to be considered. See text for further discussion

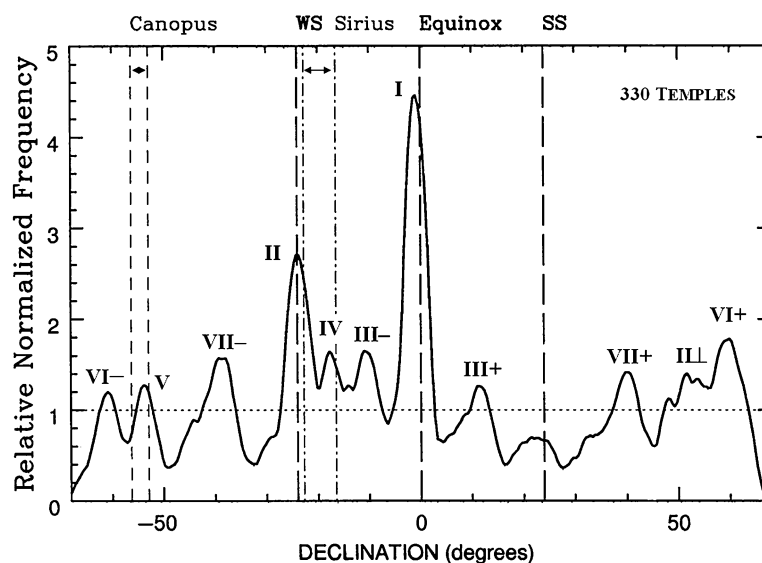


Temples in Ancient Egypt and Archaeoastronomy, Fig. 3 Falsifying the Nile hypothesis. Orientation diagram of the data assembled for temples measured outside the Nile Valley, where the river influence should be absent. Notice the Maltese Cross form of the diagram typical of astronomical orientations with a preference for cardinal and solar orientations

Challenging New Hypotheses: Astronomy in Action

During our campaigns, we tried to measure as many monuments as we were able to, in an attempt to put at our disposal as much statistical weight as possible. The idea was to put an end to the controversy about the question of whether the Egyptian temples were astronomically orientated or not. The results of the experiment are presented in Fig. 4 and are very suggestive. As a matter of fact, 11 peaks are significant in the plot and we believe that they correspond to seven possible different families of astronomical alignments of Egyptian temples. These could be classified as follows (same Roman numbers as in Fig. 4):

- (I) **The eastern (or “equinoctial”) family.**
The peak corresponds to a declination of $-1^\circ \pm 0.34^\circ$. This suggests an orientation to the equinoctial sun when the disk has



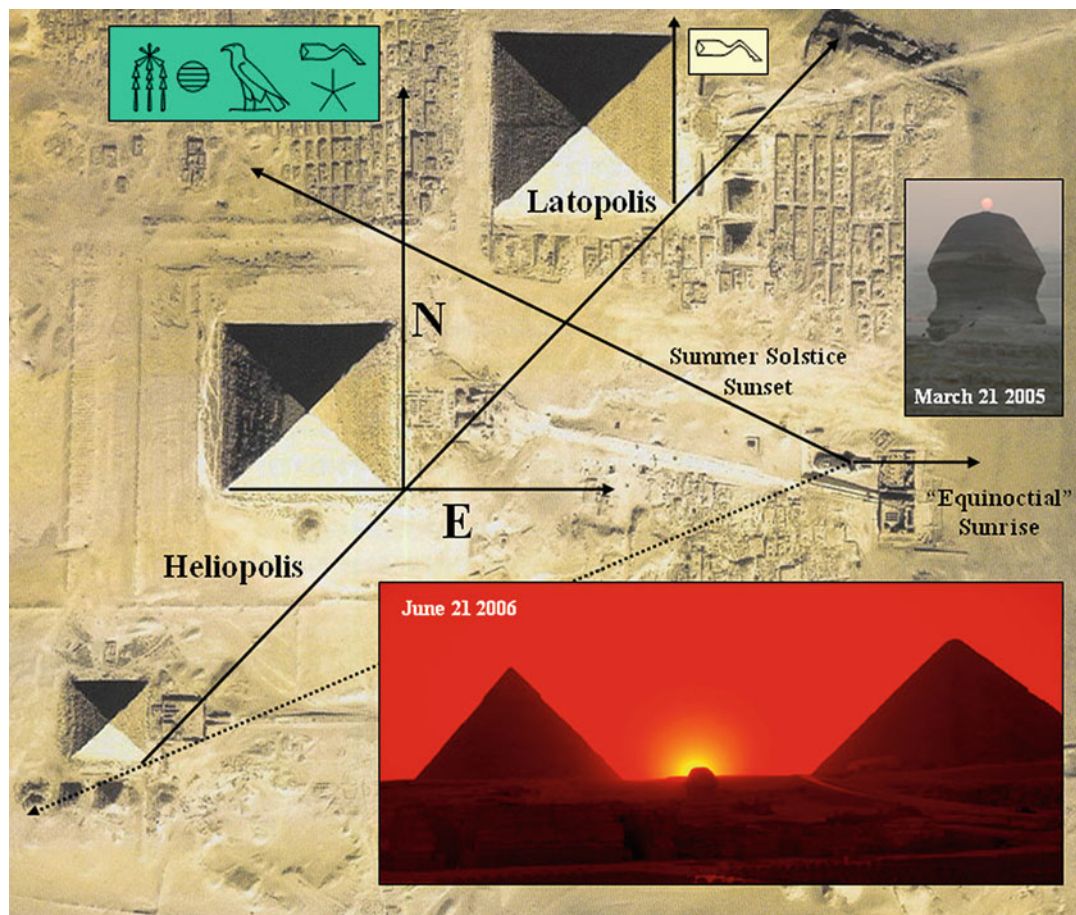
Temples in Ancient Egypt and Archaeoastronomy, Fig. 4 The core of the astronomical hypothesis. Declination histogram of some 330 temples of ancient Egypt obtained from the data measured in our five field campaigns across Egypt and their analyses as presented in Papers 1, 2, 3, and 4. Each peak is identified by a Roman numeral referring to each of the seven families of astronomical orientations as defined in Paper 3 and explained in detail in this work. Only peaks with values of the

frequency above the average (*dot line*) have been taken into account. Long-dashed lines stress the extreme and medium positions of the sun at the solstices and equinoxes, respectively. The lines for Sirius (*dot dashed*) and Canopus (*short dashed*) straddle the extreme declinations of these stars, the brightest ones of the skies of ancient Egypt, from the beginning to the end of her civilization. See the text for further discussion

completely risen above the horizon. This might imply that the ancient Egyptians were able to determine the day of the equinoxes with a reasonable precision. Another solution is that this family could be the result of an orientation in the Meridian line (probably to due north), and later the gate of the temple would have been open by establishing the perpendicular through standard topographic techniques. The pyramid complexes could be the paradigmatic example of such a procedure (see Fig. 5), where the N-S axis of the pyramid would have been the first element of the construction obtained in the foundation ceremonies (Belmonte, 2001; Spence, 2000). We can find arguments in favor of one or other alternatives, and the probable solution is that both kinds of monuments ought to be included within the group. These would include “equinoctially” orientated

monuments, such as the Sphinx or the solar temples of the 5th Dynasty at Abo Ghuorb, and 90° rotated axis temples such as those of the pyramid complexes of the Old and Middle Kingdoms.

- (II) **The solstitial family.** With a peak at $-24^\circ \pm 0.34^\circ$, this group is dominated by a series of temples orientated to sunrise at the winter solstice, although other solstitial orientations have also been documented. This is the dominating astronomical custom in the temples of Upper Egypt (see Paper 1 and Fig. 6) and was also found at many other locations within Egyptian geography. On the one hand, there has been discussion relating to the importance of the winter solstice with respect to the extended Mediterranean idea that the birth of the Sun happened exactly as this solar time mark. On the other hand, the summer solstice could have been important in



Temples in Ancient Egypt and Archaeoastronomy, Fig. 5 Schematic diagram where we show the astronomical and topographical relations between the different monuments erected in the Giza Plateau, notably the Sphinx and the pyramids, and certain elements of the sky or nearby geography. The relation with Letopolis and Heliopolis was first proposed by Goyon (1970). However, in this diagram, we additionally relate the original northern orientation of the pyramids, based on the observation of *Meskhetyu*'s Meridian transit (Belmonte, 2001), and the

similar name of the province which had the Letopolis as capital, the Bull's Foreleg. Astronomical connections of the Sphinx with equinox sunrise and summer solstice sunset (behind *Akhet Khufu*, the Horizon of Khufu, see Paper 3) are also stressed. However, another possible astronomical connection between the Sphinx and winter solstice sunset at the SE corner of Menkaure's pyramid (*dot line*) needs further evaluation (Photographs by Juan A. Belmonte)

ancient Egypt as a date close to the average arrival of the inundation. Besides, it has been argued that this time marker could be closely related to the origin of the 365-day civil calendar. Associated to this family, we have the peculiar $\Pi \perp$ peak. We are convinced that this group of temples, orientated to an interval of declinations centered at nearly 54° , includes monuments whose axis was obtained by rotating

90° anticlockwise, a previous orientation determined by winter solstice sunrise.

- (III) **The seasonal sun family.** This group of temples corresponds to monuments orientated to a peculiar interval of positive and negative declinations of $11.5 \pm 0.5^\circ$ and $-11^\circ \pm 0.34^\circ$, peaks III+ and III-, respectively. We speculate that this family had also a solar origin. One of the most interesting cases in this family is that of the

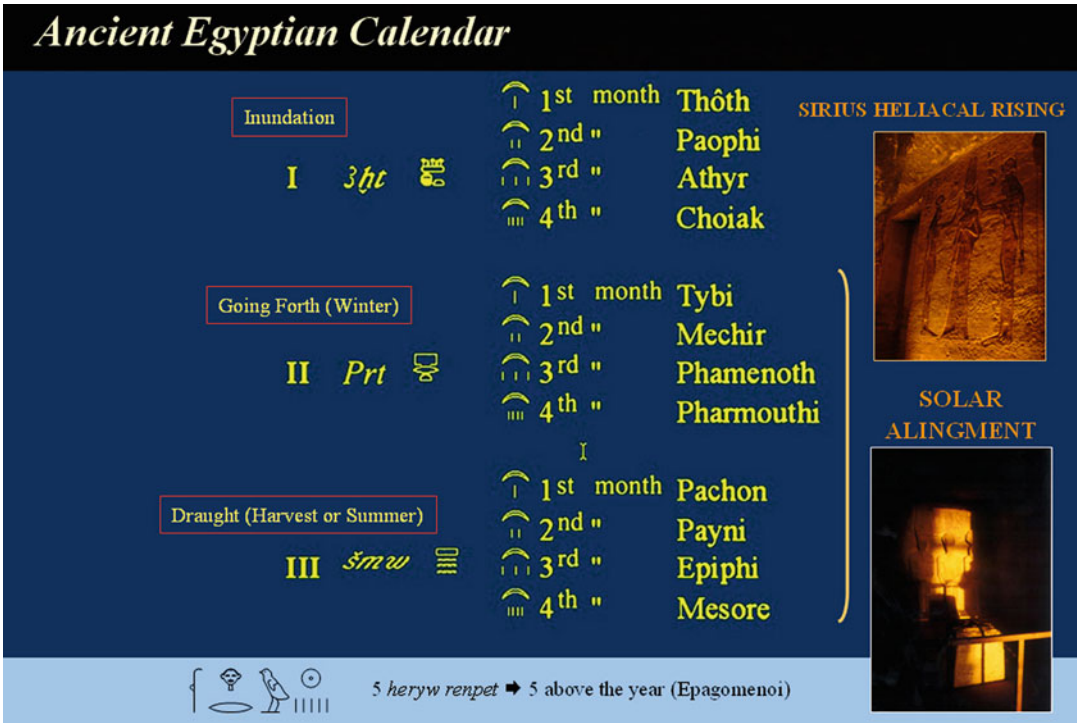
Temples in Ancient Egypt and Archaeoastronomy,

Fig. 6 Sunrise at the winter solstice in the main axis of the temple of Karnak. The phenomenon would have been more accurate 4,000 years ago when the temple was first aligned. This huge complex of temples was located at one of the few places in the Egyptian geography where the solstitial line, connecting winter sunrise and summer sunset, was at the same time perpendicular to the Nile. Solstitial orientations were very frequent in ancient Egypt, perhaps reflecting the importance of the solar cult in a way that we do not fully understand yet but that we are starting to envisage (Photograph by Juan A. Belmonte)



temples of Aton at Tell el-Amarna. One of these temples is clearly orientated to a distinctive notch on the eastern horizon similar to an *akhet* sign. Actually, it has been suggested that this geographical accident gave its name to the city, *Akhetaten*, the Horizon of Aton. Since the main gate of the temple is, at the same time, perpendicular to the Nile, the orientation and location of the temple of Aton could have simply been dictated by topographic features. However, there is a striking additional possibility. Sunrise at the *akhet* would have occurred on dates close to October 22 and February 20. Surprisingly, or not, these dates are similar to those when the famous sun-illuminating phenomenon occurs at the great temple of Abu Simbel (Fig. 7). For Abu Simbel, we have proposed a relation to the beginning of two of the seasons of the Egyptian calendar, *Peret* and *Shemu*, “Going Forth”

and “Drought,” respectively. In the reign of Akhetaten (c. 1352–1336 B.C.), the seasons of the calendar did not exactly correspond to the climate seasons (although this happened for Ramses II). However, these dates still divide the year in two periods, one of 120 days (exactly four Egyptian months of 30 days, or one calendar season) and another of 245 days, and they might have acted as harbingers of the real sowing and harvest seasons, respectively. Another temple complex of this family would be the sanctuary of the sun-god Re at Heliopolis, and as a matter of fact, it would be logical to expect a solar-related orientation for it. Hence, we have finally proposed the hypothesis that this group of temples would actually integrate a so-called seasonal sun family of orientations, with possible members all around Egypt. In fact, the “solstitial family” could be interpreted as a more specialized subgroup of this.



Temples in Ancient Egypt and Archaeoastronomy, Fig. 7 A diagram expressing the probable relation between the Egyptian calendar and the temples of Abu Simbel. On the one hand, the minor temple, dedicated to Queen Nefertari in her *Sopdet* dressing (upper right image), would be related with the heliacal rising of this star and the arrival of the inundation (although the temple is not orientated in the adequate manner), a coincidence

occurring for a period of years during the reign of Ramses II at the precise location of the temples. On the other hand, the splendid hierophany of the well-known solar illumination phenomenon in the sanctuary of the major temple (lower right image) would occur at the eve of the other two seasons of the civil calendar, the 1st day of the month of Thibi and the first of Pachon, respectively (Photographs by Juan A. Belmonte)

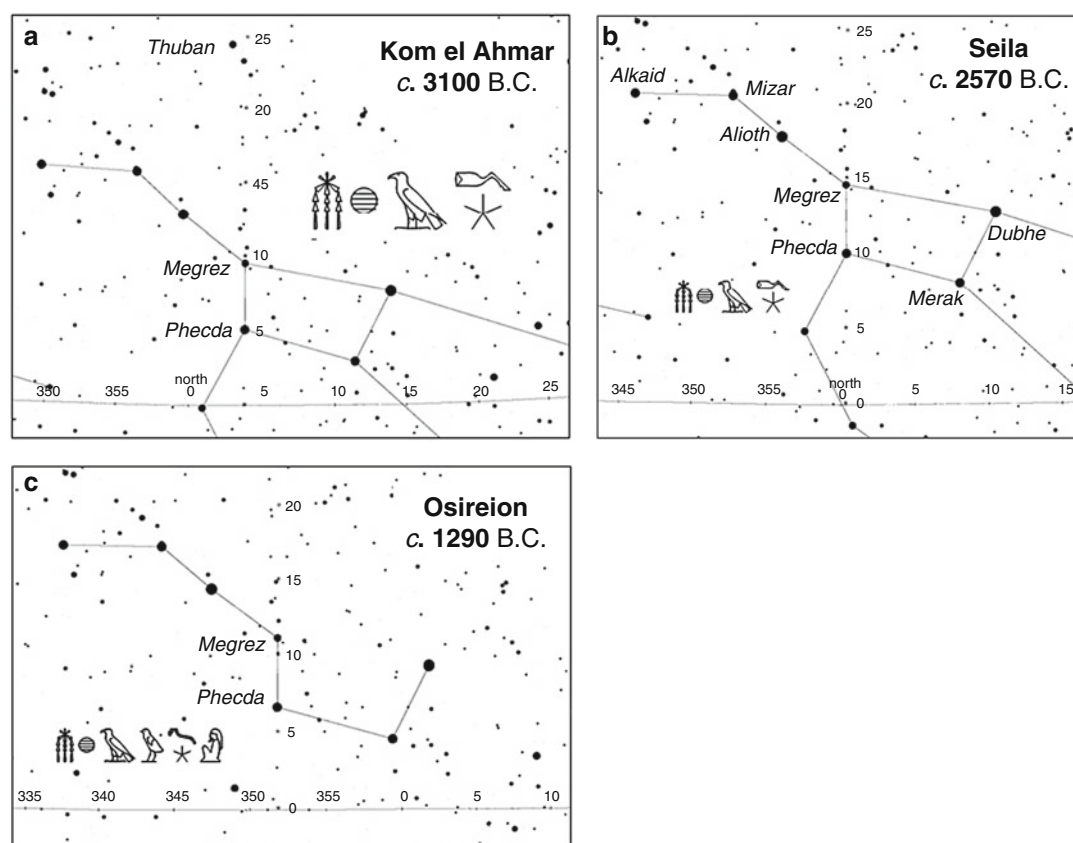
(IV) **The *Sopdet* family.** The main peak of this family would correspond to a declination of $-17.34^\circ \pm 0.34^\circ$, covering most of the period of the Middle and New Kingdoms. The star *Sopdet*, our Sirius, the brightest star of the ancient Egyptian skies, was very important as the harbinger of the actual flooding at least from the Middle Kingdom onwards, when the phenomenon of its heliacal rising (*Peret Sopdet*) is mentioned in the hieroglyphic texts on several occasions (Belmonte, 2003), although its name is also largely mentioned in the Pyramid Texts within the context of the stellar scatology of the Old Kingdom (Faulkner, 1969). This family of orientations would also have representatives all over Egypt.

(V) **The Canopus family.** With a peak at $-53.34^\circ \pm 0.34^\circ$, this stellar interpretation of this family is far more complicated because we cannot prove the importance of Canopus for the ancient Egyptians, notwithstanding the fact that it was their second brightest star in the sky (Allen, 1963). Canopus changed its declination from -56.25° to -52.5° during the course of Egyptian history and would adequately fit the data. However, in our present state of knowledge, we do not know how to justify this relation either from the religious, economical, or social point of view, in contrast to the case of *Sopdet*, which played a major role in Egyptian culture.

(VI) The Meridian (or northern) family.

With two major peaks, VI+ and VI–, located at declinations of $60^\circ \pm 0.34^\circ$ and $-61^\circ \pm 0.34^\circ$, respectively; these “peaks of accumulation” clearly speak of the great importance of near Meridian, not to say precise N-S, orientations in ancient Egypt. In fact, it is highly probable that families I and VI are the two sides of the same coin. Indeed, both are representative of the predominance of cardinal orientations according to the manner in which the

ancient Egyptians organized the cosmos. We support the idea that this northern custom was effectively achieved through orientations to certain configurations of stars near the celestial pole and that the circumpolar constellation of *Meskhetyu* would be the most appropriate target for this purpose (Belmonte, 2001) as shown in Fig. 8. *Meskhetyu*, the Plough, undoubtedly was one of the most important asterisms of Egyptian religion since at least the Old Kingdom, if not earlier, where it appears



Temples in Ancient Egypt and Archaeoastronomy, Fig. 8 The simultaneous Meridian transit (a particular astronomical configuration) of two stars of *Meskhetyu* (the Plough), notably *Megrez* and *Phecda*, as the possible reference for the northern orientation of three singular monuments pertaining to different periods of Egyptian history. (a) Predynastic structure HK29A at Hieraconpolis (Kom el Ahmar). The original north alignment was later rotated 45° clockwise so that this early sanctuary would also be almost perpendicular to the Nile at this particular

spot (family VII). (b) Precise N-S orientation of the minor step pyramid of King Snefru at Seila, in the heights to the east of the oasis of Faiyum. This procedure could have been followed to accurately orientate the pyramids of the 4th Dynasty for many generations (Belmonte, 2001). (c) The same case as (a) but almost 2,000 years later for the Osireion of the temple of Seti I in Abydos. Notice the displacement of the azimuth of the simultaneous transit versus time caused by precession

in the Pyramid Texts as the “imperishable star,” to the Ptolemaic Period when it is profusely mentioned in connection to temple orientation.

- (VII) **The family of quarter-cardinal directions.** This family is related to a peak located at a declination of $-39^\circ \pm 0.34^\circ$ (VII-) and asymmetric at some 40° (VII+). It would be defined by those temples with an orientation close to the SE-NW and SW-NE lines, and we believe that it is a subgroup of the cardinal superfamily. It is our contention that this orientation was achieved by the primary determination of a north alignment, which axis was later rotated by either 45° or 135° clockwise for temples open to the east side of the horizon, which are the most frequent, or anticlockwise for temples open to the west side of the horizon. By performing such an action, simultaneous astronomical and Nile orientations could be achieved in several cases. Some of the Million Year Temples of kings of the New Kingdom, especially in Abydos and Western Thebes, are good representatives of this group. However, the oldest temple excavated so far, whose plan has been partially recovered, structure HK29A at Hieraconpolis, would be the earliest example of the class (see Fig. 8).

In summary, by defining these seven families, we hope to have shown the importance of astronomical orientations in ancient Egypt. By analyzing the previous paragraphs, we might reach the conclusion that actually only three customs of astronomical orientations were present in ancient Egypt: cardinal (i), solar (ii), and stellar (iii).

- (i) The cardinal custom would be integrated by families I (in most occasions), VI, and VII and would be achieved by the observations of certain configurations (rising, setting, Meridian transit, maximum elongation, etc.) of stars in the north, predominantly, if not exclusively, stars of *Meskhetyu*. This procedure would initially give a near Meridian axis that would later offer various alternatives:

a gate opening north, a gate opening south, a gate opening east (or west), or a new axis by turning the original by 45° or 135° , with the gate opening near NE (or NW) or SE (or SW), respectively.

- (ii) The solar custom will be formed by families I, II, II $\perp$, and III and would basically be related to important points of the annual cycle of the seasons, or in some cases to special dates in the civil calendar such as *Wepet Renpet*, Egyptian New Year's Eve, or the eves of the other two seasons *Peret* and *Shem*. Paradigmatic examples would be the solar temple of Niuserre at Abu Ghurob (I), Karnak (II and II $\perp$), and Abu Simbel (III).
- (iii) The stellar custom would be represented by families IV and V. We have no doubts of the pertinence and relevance of the alignments to *Sopdet*. However, we have minor doubts if any of the presumable alignments to Canopus should be interpreted in a different way. In this case, it is difficult to see how new field data will provide a final answer. Hence, new epigraphic information confirming the importance of this bright southern star would be highly desirable.

A final point to discuss is how once an alignment was yielded by astronomical observations in a certain direction (e.g., Meridian or solstitial ones), the new axis at 45° , 90° , 135° (in both clockwise or anticlockwise directions), or 180° was obtained. The answer to this question could be encountered in a recent hypothesis (Miranda et al. 2008), which suggests that the sign of Seshat (the divinity mostly involved in temple orientation ceremonies, notably the stretching of the cord), carried by the goddess upon her head in all representations, might perhaps have been a schematic and symbolic representation of an archaic transit instrument that would have later become the emblem of the goddess. This instrument would have had eight radii and a viewpoint and could have been used at the “stretching of the cord” ceremonies since the dawn of Egyptian history, directly offering the eight directions under discussion from a single astronomical or topographical observation.

Conclusions

We wanted to demonstrate if the temples of Egypt were astronomically orientated or not. Epigraphic sources clearly mentioned solar and stellar targets as the references for temple orientations. However, the scientific community only agreed on the planning of orientations according to the Nile, and the relevant inscriptions were sometimes considered as mere remembrance of long forgotten practices. We have now measured 330 temples and shrines. This represents approximately 95 % of all the temples in any state of preservation still existing in the country, and our sample is statistically significant.

We want to stress a few results that are highlights of the analysis of the complete series of data, which should change the mind of the specialists with respect to Egyptian archaeoastronomical studies. These are:

- (i) The temples of the Nile Valley and the Delta were orientated according to the Nile as our data have clearly illustrated, but . . .
- (ii) The temples were also astronomically orientated beyond any reasonable doubt as all the successive analyses we have done to our data fully demonstrate. This means that the ancient Egyptians had to deal with special situations to accomplish both necessities. This problem was solved by the selection of appropriate orientations of one or the other class at different sites so that they would be more or less compatible with the Nile course (quarter-cardinal directions are a good example of this), or by the deliberate election of selected places in Egypt where the Nile prescription and a conspicuous astronomical orientation were simultaneously achieved, as in the case of the temple of Karnak.
- (iii) Among astronomical orientations, there were three kinds of targets. One was probably related to different celestial configurations of the stars of *Meskhetyu* in order to get a near or accurate Meridian orientation. This primary axis could have been rotated later by an eighth, a quarter, or half

a circumference to obtain any possible cardinal or quarter-cardinal direction (families I, VI, and VII). The second kind of target had a markedly solar character and was fundamentally related to important time marks of the annual cycle and/or the civil calendar (families I, II, II $\perp$, and III). Finally, the third group of targets was formed by the two brightest stars of the ancient Egyptian skies, Sirius and Canopus (families IV and V, respectively). These customs were present during most of Egyptian history and in different areas of the country, although some minor interesting peculiarities have been discovered.

At the turn of the century, the authors envisaged a project to answer a quite simple question. Were the ancient Egyptian temples astronomically orientated? Now, a few years later, we are proud of the quantity and variety of the results we have obtained. These have been the gateway for new questions. Indeed, much more work could be done. However, we consider our sample to be statistically representative, and we are convinced that new data will only serve to reinforce our results. This summary article clearly illustrates something that we could only have imagined at the very beginning of our project: ancient Egyptians undoubtedly scrutinized the sky in a permanent search for their correct orientation not only in time but also in space in a permanent effort to keep Ma'at on Earth.

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Temples of the Maya

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When Spanish Christian friars arrived in the Yucatan Peninsula in the sixteenth century, they saw Maya people in towns comprised of buildings where people lived and worshiped. In *Relación de las Cosas de Yucatán*, Fray Diego de Landa recounted the performance of New Year ceremonies at the cardinal directions with the purpose of renewing the community and the world (Taube, 1988, pp. 298–299; Tozzer, 1941, pp. 135–150). Such descriptions provide useful information for reconstructing Maya religious use of space in the sixteenth century and earlier,

but these commentaries are limited and biased by the writers' worldviews and desires to convert Maya people to Christianity. Over the course of subsequent centuries, new understandings of Maya temples have come to light. Archaeological excavations have exposed myriad structures and associated artifacts, epigraphic research has deciphered inscriptions about politics and religion, art historical analyses have shed light on Maya imagery, and ethnographic studies, as well as collaborations with Maya people, have deepened our understandings of Maya religion and society. Together, these forms of analysis and interpretation have revealed a wealth of new information about the physical qualities and symbolic values of ancient Maya temples.

Temple forms changed over the course of pre-Hispanic Maya civilization, but there also was remarkable continuity in the purpose and design of temples and associated imagery. Images and texts on temple exteriors frequently identify what the temples commemorate, marking them as mythological places and houses of gods and ancestors. Indeed, many convey that Maya temples were dedicated to deities (personifications of natural phenomena such as sun, rain, and corn) and revered ancestors (generally male rulers or queens), some who had merged with deities upon death.

Scholars organize Maya chronology into periods called the Late Preclassic (200 BCE–200 CE), Early Classic (200–600 CE), Late Classic (600–900 CE), and Postclassic (900–1521 CE) for the lowlands of southern Mexico, northern Guatemala, Belize, and western Honduras. Based on terms used for Classical Greece, this chronology was developed in the mid-twentieth century, when the Maya Classic period was understood as the florescence of civilization, with periods before deemed formative and those after characterized by decline (Proskouriakoff, 1950). Nonetheless, subsequent discoveries and analyses have demonstrated remarkable innovation and indeed florescence of art, architecture, and other aspects of civilization in all periods, most notably in the Preclassic, whose remains are continually being uncovered in new excavations across the Maya realm (e.g., Taube, Saturno, Stuart, & Hurst, 2010).

Temples of the Maya,

Fig. 1 Temple of the Sun,
Palenque, Mexico
(Photograph by author,
© Megan E. O’Neil)



Temple architecture – and Maya architecture in general – emphasizes both mass and open space (Miller & O’Neil, 2014, p. 46) (Fig. 1). The Maya frequently modified landforms and added fill to construct massive platforms upon which they built structures interspersed with plazas and courtyards, where both religious ceremonies and mundane activities took place. From the Late Preclassic to the Postclassic, builders constructed large pyramids, usually with terraced bases, that generally were solid but inside held tombs, offering caches, and remains of earlier structures (Fig. 2). Atop the pyramids were superstructures with one or more relatively small rooms. The size and shape of the superstructures are based on the traditional Maya house, which had thick lower walls made of wattle and daub and a thatched roof. Like the Maya house, temple superstructures frequently have one central doorway, usually with a wooden or stone lintel spanning the portal, though some have multiple doorways. Temple rooms are formed by corbel vaulting, whose arched interiors recall the pitched roofs of Maya houses (Fig. 3). Corbel vaults set parallel to each other allowed for multiple interior chambers and increased structural stability. Maya temples also could be single-story constructions that were set onto a platform.

Most pyramids had a central stairway, and some had stairways on multiple sides; the radial

pyramid, seen both in Preclassic Uaxactun and Postclassic Chichen Itza, had a central stairway on all four sides of the pyramid. These stairways gave access to shrines and also were places for processions and other performances. Indeed, the wide stairways of platforms and pyramids, in addition to the open plazas near temples, were essential spaces for Maya ritual performances, complementing the much smaller spaces of interior sanctuaries.

Pyramids were intentionally made large, certainly to emulate mountains, but the sizeable masses also grew over time with the accrual of construction layers, for which earlier structures were buried inside later ones. The presence of the earlier remains, particularly from named ancestors, gave additional significance to these buildings, ideas made explicit through inscriptions placed on later buildings, such as Copan’s Hieroglyphic Stairway (Structure 26), which was constructed over earlier buildings and whose stairway bears a lengthy text recounting centuries of dynastic history (Fash, 1998; McAnany, 1998) (Fig. 4). Such temples commemorate not only the latest structure and its patron but also the earlier structures and ancestors whose remains the building subsumes. Examples of large, layered buildings related to dynastic commemoration appear in Tikal’s North Acropolis, Copan’s Acropolis, and Uaxactun’s A-V platform (Fash, 1998).



Temples of the Maya, Fig. 2 Temple I, Tikal, Guatemala (Photograph by author, © Megan E. O'Neil)



Temples of the Maya, Fig. 3 Corbel Vault in Palace House A, Palenque, Mexico (Photograph by author, © Megan E. O'Neil)

Temples were oriented to plazas and other buildings, and they also were often built in relation to natural features such as mountains, caves, and water sources such as springs and *cenotes* (natural sinkholes). Furthermore, at times they were oriented to celestial bodies such as the sun and Venus on particular days of the year, such that doorways or windows frame the celestial bodies' presence in the sky or direct their light into the building (e.g., Tate, 1992, pp. 111–115). Indeed, temple engagements with natural phenomena were an inherent part of their symbolic value and the experience of these structures on a daily basis or on special days (Fig. 5).

Maya masons used locally available materials such as limestone, sandstone, and volcanic tuff for the construction of platforms, walls, piers, and lintels, though at Comalcalco, Mexico, they used clay bricks instead of stone. Across the Maya region, builders also used wood for beams and lintels. Exterior terraces and walls usually were covered with stucco, made by mixing crushed burned limestone with vegetal gums and water, for smoothing and decorating surfaces.



Temples of the Maya, Fig. 4 Hieroglyphic Stairway (Structure 10 L-26), Copan, Honduras (Photograph by Linda Schele, © David Schele, courtesy Foundation for the Advancement of Mesoamerican Studies, Inc., www.famsi.org)

Temples of the Maya, Fig. 5 Castillo on March Equinox with serpent in light and shadow, Chichen Itza, Mexico (Photograph by Mary Ellen Miller, 1976, © Mary Ellen Miller)



The stucco was often painted with mineral pigments in solid colors, such as hematite for a deep red hue, or with polychrome figural murals (Figs. 6 and 7). The Maya also created high-relief sculptures out of stucco and stone mosaic on

temple exteriors. Roof combs, which were erected on top of the corbel vault, held textual inscriptions or sculptures of rulers, deities, or zoomorphic mountains crafted in stucco, stone, or pigment (Fig. 8).

Temples of the Maya, Fig. 6 Castillo, Chichen Itza, Mexico (Rendering from a 3D model based on laser-scan data and remaining color, by INSIGHT, www.insightdigital.org and mayaskies.net. © Kevin Cain, INSIGHT)



Temples of the Maya, Fig. 7 Detail of painted flower on House E façade, Palenque, Mexico (Photograph by author, © Megan E. O’Neil)

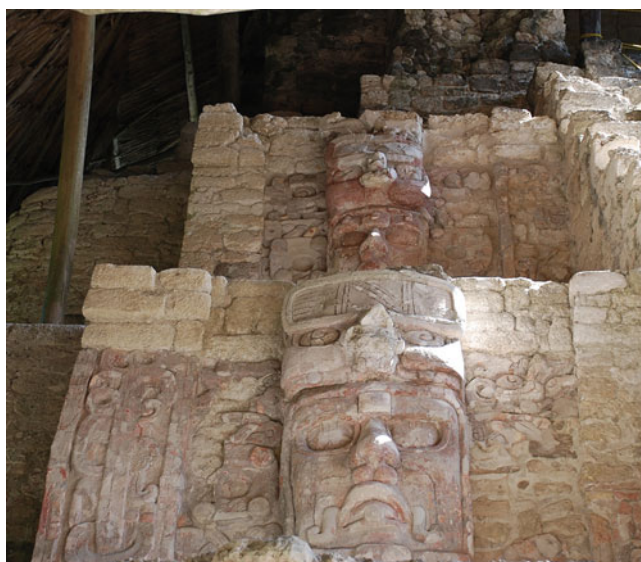
Early Maya constructions, particularly in the Late Preclassic and Early Classic, used abundant stucco decoration, for which stucco was shaped into friezes on building or platform exteriors. At multiple sites in Guatemala’s Department of the Peten, such as El Mirador, Nakbe, and Uaxactun, archaeologists have uncovered temples with monumental faces, modeled in high-relief stucco, with features denoting particular deities, such as K’inich Ajaw, the solar deity. This tradition continued in the Early Classic, most notably at Kohunlich, Mexico, and at El Zotz, Guatemala, where archaeologists discovered buildings with multiple heads of the solar deity (Skidmore, 2010) (Fig. 9).

Preclassic and Early Classic artisans also adorned temples with friezes portraying deities and ancestors in more dynamic compositions. At Calakmul, Mexico, archaeologists discovered a Late Preclassic temple whose central doorway was surrounded by a large stucco frieze, 20 m long, of the rain deity Chahk amidst supernatural birds and a cosmic crocodile (Delvendahl, 2008, pp. 29–30). At Copan, Honduras, archaeologists

Temples of the Maya,
Fig. 8 Structure
 33, Yaxchilan, Mexico
 (Photograph by author,
 © Megan E. O’Neil)



Temples of the Maya,
Fig. 9 Temple of the
 Masks, Kohunlich, Mexico
 (Photograph by author,
 © Megan E. O’Neil)



uncovered a building nicknamed Rosalila whose polychrome stucco decoration transformed the building into a mountain occupied by magnificent supernatural birds that are manifestations of the ancestor Yax K’uk’ Mo’ – whose tomb lay deeper within the building – as a solar deity (Agurcia Fasquelle, 2004).

In Late Classic Copan, use of abundant stucco gave way to cut stone decoration, and subsequently artisans crafted large-scale mosaics of

local volcanic tuff into friezes of high-relief and three-dimensional sculpture (Fash, 2011). These stone mosaic friezes, like the earlier stucco ones, transformed buildings into mythological places such as Sustenance Mountain, seen on Copan Structure 22, which held stone sculptures of the young dancing Maize God, which had been set with tenons into the building façade.

Analogous to Copan’s stone mosaics are the “Chenes-style” architectural facades on buildings

Temples of the Maya,

Fig. 10 Stone mosaic frieze around doorway of Structure 2, Chicanna, Mexico (Photograph by author, © Megan E. O’Neil)



from the seventh to ninth centuries in the Mexican states of Campeche and Yucatan. Around these buildings’ doorways are mosaics comprising massive zoomorphic mouths with prominent fangs that transform the doorway into a cave opening, an entrance into the sacred, animate earth, and the building itself into a cave or mountain (Fig. 10). Notably, the stucco tradition was not lost, for at Ek Balam, Mexico, archaeologists found a magnificently preserved stucco façade of a zoomorphic face surrounding a doorway into a room enclosing a royal burial (Vargas & Castillo, 2006). This sacred mountain thus honored both earth and ancestor.

Many Maya temples venerate deceased ancestors and hold their tombs, often inside the pyramid’s base on its central axis, as at Palenque, Tikal, Piedras Negras, and elsewhere, and associated sculptures and inscriptions may commemorate that ancestor. For example, the Temple of Inscriptions of Palenque is a terraced pyramid built over the tomb of the ruler K’inich Janahb Pakal (Fig. 11). Inside the tomb, the king’s carved sarcophagus portrays him being reborn from the jaws of the underworld as a manifestation of corn, lightning, and the rising sun, while his ancestors sprout from the ground in the form of fruiting trees (Schele & Mathews, 1998, pp. 95–132; Stuart & Stuart, 2008, pp. 166–184). Lengthy inscriptions on the walls of the superstructure

atop the pyramid position Pakal within a longer ritual history of his dynasty and its patron gods. The superstructure – and the building itself – was thus a place to commemorate both the ancestor and the dynasty through acknowledgment of past rituals and continuing ritual engagements within this sanctuary.

In contrast to temples honoring particular rulers or gods, some Maya temples commemorate calendar anniversaries, such as the *k’atun*, or 20-year period. In many sites, rulers erected stone stelae (freestanding sculptures) to commemorate *k’atun* endings, and at Tikal, rulers constructed temple complexes on large platforms with twin radial pyramids, an enclosure holding a stela and an altar, and a multi-roomed building (Harrison, 1999). These temple complexes, commemorating the passage of time and the ruler’s place within it, were certainly used for performing ceremonies in both the larger plazas and the smaller sanctuaries.

The sizes of structures, associated images and texts, and material remains give clues as to how Maya temples were used. At Yaxchilan, Mexico, carved stone lintels in temple doorways show men and women performing bloodletting rites that conjure deities, indicating that bloodletting and vision rites took place inside (Fig. 12). At Palenque, the Temple of the Inscriptions texts narrate the offering of vestments to deities (Guenther, 2007), suggesting that some temples



Temples of the Maya, Fig. 11 Temple of the Inscriptions, Palenque, Mexico (Photograph by author, © Megan E. O’Neil)



Temples of the Maya, Fig. 12 Lintel 24, Yaxchilan, Mexico. British Museum, AOA 1886-317, AN0 (Photograph by Charles Tilford, Creative Commons, CC BY-SA 3.0)

were used to care for and dress deity effigies. At Tikal, the presence of incense burners and blackening from burning inside temple sanctuaries is evidence that the Maya made fire offerings in these buildings, likely to ancestors buried inside (Coe, 1990; O’Neil, 2009). Furthermore, inscriptions reveal that the Maya performed fire ceremonies to dedicate structures (Stuart, 1998), and material remains indicate they performed ceremonies to terminate them (Agurcia Fasquelle, 2004), as if these temples were living entities that had to be brought to life and terminated.

Maya temples were thus created and used for multiple purposes, but for contemporary Maya people, worship and ritual happen both in buildings and in places in the landscape, such as caves, mountains, or springs. We see evidence for analogous practices in the archaeological record. Many constructed temples were named as mountains or marked as cave openings and effectively embodied their natural analogs (Brady, 2001). Furthermore, archaeologists have discovered offerings and remains of fires in caves, such as Balankanche, Mexico, and the cave system of Naj Tunich, Guatemala, contains offerings and



Temples of the Maya, Fig. 13 Offerings next to “World Tree” speleothem, Balankanche, Mexico (Photography by INSIGHT, www.insightdigital.org and mayaskies.net. © Kevin Cain, INSIGHT)

painted texts and inscriptions that demonstrate that individuals traveled from multiple locations to perform rituals in the cave (Stone, 1995) (Fig. 13). This cave system was an important place for worship and ceremony; the concept of the Maya temple thus also must encompass these natural places, where Maya people engaged with gods and ancestors through ritual performance, just as they did in constructed temples.

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Textiles in Africa

Gloria T. Emeagwali

Historians of African textiles now have at their disposal a wide range of oral and written documented sources. These describe significant centers of textile production over time, the raw materials, implements, and techniques used by the various cloth producers, varieties of fabric and techniques of dyeing and coloration,

symbolic expression as reflected in the finished products, and the many functions for which the latter were used. The process of technological transfer within various parts of the continent and the elaborate structure of guilds and schools of apprenticeship are also better known to us as a result of the systematic collection of oral history in some areas.

From the Northeast African Nile region to West Africa and elsewhere, travel reports, missionary reports, and even autobiographies have provided details about aspects of the development of cloth making techniques. Herodotus in his travels in Egypt as far as the first cataract obtained specific knowledge about the implements used by the Egyptians and the existing division of labor. Such information has complemented the archaeological evidence brought forward by teams of Egyptologists as they continue to come in contact with numerous reams of cloth in the mummified corpses and burial goods which the Egyptian nobility, like some of their counterparts in West Africa, sent along with the dead to the afterlife.

In the case of Ethiopia, travel reports by missionaries, explorers, and travelers such as Francisco Alvarez, Jerome Lobo, Charles Poncet, James Bruce and Henry Salt, provide direct and indirect information on the variety of textiles in the Axumite and post Axumite realm. For West Africa in the eighteenth and nineteenth centuries, Mungo Park, Barth, and Baikie complement the perspectives diffused in the missionary reports of Trotter, Allen, and Crowther, who emphasized that the people of Onitsha, Eastern Nigeria, like their counterparts elsewhere, "manufacture their own clothes generally plain or fanciful with cotton grown in their farms" (Crowther, 1968).

Archaeological reports have been no less useful than the eyewitness travel and missionary accounts cited. Reams of linen and cotton have been found in Egyptian tombs, and the Sudan, also one of the Nile Valley kingdoms, has yielded cloth and looms dating back to 500 BCE. The Igbo-Ukwu finds of Eastern Nigeria included thousands of artifacts, among which was cloth dated to the ninth century. The Bandiagara cliffs

of Mali have yielded textile products dated to the eleventh century. The evidence from the excavated pits complements the various collective recollections reflected in poetry, song, and narrative accounts no less than the honorific codes and titles and range of linguistic terms accorded textile specialists and their products. Some city states and towns in the African continent gave their names to a product line, as was the case of Akwete and Okenne in Eastern and Central Nigeria, West Africa.

Whether in renowned Nigerian textile centers such as Kano, Iseyin, Bida or Akwete and Okenne, or in the Wolof empire of Senegal, the Bambara kingdoms of Mali, the Mossi Empire of Burkina Faso, or the Baule polities of the Ivory Coast, we can identify some basic raw materials, production instruments and techniques, as well as common tendencies relevant to textile not only in West Africa, where the latter regions were located, but also in Central, East, and Southern Africa. Raw materials were derived from vegetable or animal products and generally involved wool, camel hair, flax, cotton, the leaves of the raffia palm (*Raphia rufia* or *Raphia vinifera*), silk from cocoons, and bark from the baobab tree. In all the above cases, with the exception of bark, which was hammered into shape, there developed over time sophisticated spinning, weaving, and dyeing techniques which included the gradual invention and improvement over time of vertical and horizontal frames, lower and upper beams, beaters, shed sticks, hecklers, shuttles, and templars, all various components of the horizontal and vertical looms produced across the continent.

African textiles, by the nineteenth century, included a wide range of fabrics, each influenced by the base material from which the thread was made, the texture of the thread, the width of the strip woven cloth, the alignment of the thread, and the intensity of inlays and the dyeing procedure, whether starch resist or not. Indigo, guinea corn stalk, the bark of the locust tree, the leaves of the tombolo tree, combined with ash potash and any of a long list of colorants were used to produce blue, red, buff, rust, or brown and other colors. Dyes were derived from experimentation

with vegetable and other products. The famous *Kente* cloth of strip woven silk (sometimes interlaced with threads of gold and very often confined to the Ashanti nobility), *Sanyan*, Western Nigeria's silk derived fabric, *Adrinkra*, the hand-printed cloth of the Ivory Coast, and *Sotiba* of Senegal, are some of the various types of textile products which have become household names in the continent.

A wide range of symbols was reflected in cloth through the representation of motifs of special shapes, figures, dimensions, and sizes. These were either impressionistically done by the use of geometrical shapes and symbols or were made to reflect naturalistic images derived from African cosmologies and indigenous belief systems. It was common for Dahomean quilts to portray images of the founding fathers of particular dynasties. A lion represented King Gelele and a buffalo King Gezo, whilst a representation of a ship was the symbol of King Agaza – all historic figures in the making of the Dahomean (Beninois) state. More recently, worldly events ranging from the American soap opera *Dallas* to statements about the prevailing economic reform programs have been coded into fabric. A study of African textile over the centuries yields information not only about changes in technical expertise and accretional gains made from the intraregional and interregional exchange of ideas, but also the prevailing lifestyles, philosophies, and world views of Africans in various parts of the continent. Textiles in themselves provide a rich source of historical information. They were associated with many activities and had many uses. They were a medium of exchange in barter, or units of currency in a wide range of commercial transactions. Tax payment was collected in the form of textiles and so too tribute. Since fabric differed in cost and the degree of technical expertise associated with various types, it was easy for it to become a symbol of wealth, extravagance, and conspicuous consumption. Cloth very often was a symbol of class affiliation. Saddle cloth and the overall accoutrements of the horse included specialized fabric, as did the panoply associated with Ashanti royalty. Cloth had special burial functions. Specialized fabric was associated

with shrines of the dead. Marital gifts, whether prenuptial or not, tended to include cloth as part of the expected dowry. Decorative and symbolic objectives were matched by functional and practical ones. Cloth was used for protective purposes against the elements, as sheets and covers, and also to make rice bags, purses, or tents.

The reproduction of knowledge systems was done through institutionalized apprentice systems of guilds, each of which adhered to strict codes of conduct and behavior. Fees in cash or kind were paid by the apprentice who was expected to “gain freedom” after periods agreed to in the context of elaborate ceremonies. These guilds themselves had a hierarchy of officials who in many cases were of significant political clout. The teaching and training of spinners, weavers, and dyers was therefore organized in the context of established custom and practice, even though there was a general tendency for specialization to be restricted to specific lineages within various regions.

There is evidence that Africans imported cloth in the context of the trans-Saharan trade as well as the trans-Atlantic, but these importations were complementary to a wide range of indigenous textile products. It was not unusual for various political elites to flaunt some of the imported textiles along with indigenous products, or for textile specialists to unravel an epic of imported fabric with the objective of isolating particular reams of thread. The British industrial revolution had specific implications for African textiles, given the fact that factory produced cloth was cheaper with the mechanization of spinning and weaving. The successful transfer of textile technology from India to Britain by the nineteenth century meant that the British factory system was able to churn out some relatively attractive textile products for the African consumer. This, however, did not lead to the destruction of the indigenous textile sector which continued to be a dominant component of the informal sector well into the twentieth century, despite some ill-intentioned legislation and policies during the period of colonial rule.

Contemporary Africa is home to a wide variety of indigenous textiles. Local factory-

produced cloth has had to compete with Taiwanese, Indonesian, and Dutch imports, most of which are imitations of indigenous African fabric. IMF and World Bank conditionalities tend to call for the removal of duties on imports and therefore undermine those local textile centers, some of which lack the productive capability to compete on the open market. In spite of these trends, however, there is every indication that African textile producers will continue to have a large share in the market and continue to experiment, innovate and produce the high quality textiles historically associated with the continent.

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Textiles in China

Dieter Kuhn

A textile is here understood as a woven fabric made from a wide range of raw materials. Some of these were silk, cotton, wool, and the bast fibers ramie (*Boehmeria nivea* L.), hemp (*Cannabis sativa* L.), and the bean- or vine-creeper (*Pueraria thunbergiana*), which possessed the greatest economic and cultural importance in pre-Mongol (prior to AD 1279) China. The development of textiles is described

here on the basis of archaeological evidence and from the view of its cultural importance.

The origin of weaving can be traced back to basketry and matting techniques from the Neolithic. Impressions on ceramic sherds and fragments from the archaeological sites of Banpocun near Xi'an in Shaanxi and from Hemudu in Yuyao county in Zhejiang prove that they existed in China as early as the fifth millennium BCE. The earliest finds of textiles are from southeast China. There is a complicated fragment of fabric, made of *Pueraria thunbergiana*, found at Caoxieshan in Jiangsu province and dated to the fourth millennium BCE. Its structure features a combination of hand twining and loom weaving techniques. A number of silk belts, a piece of silk, and a scrap of ramie cloth were discovered in a ► [bamboo](#) box excavated from the site of Qianshanyang in Wuxing in northern Zhejiang, dated to ca. 2750 BCE.

Small stone-cut and jade figures were found in various Anyang sites from the Shang period (sixteenth–eleventh centuries BCE). They clearly show “textile ornaments” which give an impression of Shang clothing and fashion. Apart from furs and leather, especially suitable as winter clothing and used for ceremonial occasions, hemp and silk were tailored. Tailoring does not mean cutting pieces of fabric so as to make them fit but simply sewing pieces of fabric together, only allowing a few corrections. It was probably the Shang people who introduced right side fastening and a hair-dressing style which could be distinguished from the barbarians. Most garments including lined garments were buttoned on the right side under the right arm. Very often the overlap of a robe was unbuttoned. *Obi*-like waist-belts kept the coat and the undergarments in position. Women's dress included a skirt. Women had their hair styled in a cylindrical shape, and flat rather high round caps were common. Upperclass people wore gaiters and shoes that curled upwards to the toe. Geometrically patterned fabrics (*T*-, *hui* and *lozenge*-patterns) were exclusively used as borders of garments, at the openings of the sleeves, at the collar, and along the overlap, for girdles and waist-belts,

caps and hats. Colorful painted and embroidered silk was available to the higher echelons of Shang society. Certain important weaving techniques were applied to produce silk fabrics as early as Shang times:

1. Tabby weaves with threads of almost identical diameter and a thread-count of warp and weft between 8:7 and 75:50 cm⁻¹;
2. Warp-faced tabby, also called rep or rib, where the number of warp-threads is roughly double the number of weft-threads per centimeter;
3. Monochrome tabby patterned with twill (3/1), very often named twill damask (*wenqi*). The ground weave is a tabby weave, and the pattern is woven in twill weave with the warp-threads forming the pattern;
4. Tabby crêpe (*zhou* or *hu*) with a thread-count of ca. 30:30 cm⁻¹. The warp-threads show a twist with 2,500–3,000 twists per meter. The weft-threads are twisted together from several threads in an *S*-twist showing 2,100–2,500 twists per meter. The strong twisting of the threads causes the crêpe effect;
5. Crossed-warp weave technology was known and used.

The most important and spectacular textiles of the Zhou period (1045–221 BCE) discovered so far are from central and southern China, especially from Jingzhou in Hubei and from the region of Changsha in Hunan. In Western Zhou times (1045–771 BCE) the *jin* brocade appeared, an outstanding weave which on the one hand was produced on a rather complicated loom and on the other hand asked for expert craftsmanship. This so-called brocade was a new type of warp-faced compound weave with the warp divided into at least two series, normally of different colors. Even picks of weft interlace with the warp either in tabby or twill. Although this weaving method produced polychrome silk fabrics with a colorful shiny and mostly geometric pattern on the surface, its repertoire was still limited by the weaving technology at the time. Weavers exhausted the technical possibilities of their looms and composed scenes and figures

which were evidently intended to be pictorial descriptions, but they are still symmetric with straight lines and cornered outlines. Embroidery helped to make the patterns of tigers, phoenix, dragons, birds, and blossoms appear more lively. The patterns were arranged in various ways adorning the silk robes of the fourth and third centuries BCE.

In 1972 outstanding textile fabrics and garments totalling more than 100 objects were unearthed at tomb no. 1 at Mawangdui in Changsha. The tomb belonged most probably to the Lady Dai (d. 168 BCE). Among the well preserved fabrics and garments there were more than a dozen robes of various make, such as 11 floss-wadded robes, 1 lined robe, 3 unlined robes, several blouses and skirts, 2 pairs of socks, 4 pairs of shoes, 3 pairs of gloves, pillow covers, 46 rolls of single-width silk fabrics, and many more items of daily life. The textiles exhibit an unrivaled excellence in weaving skills, the mastering of pattern design, and imagination in applying all sorts of patterning techniques. Favorite weaves were thin and loosely structured gauzes (*sha*) and lozenge-patterned leno (*luo*), a fabric of open structure which is made by cross-warp yarns.

The most sophisticated weaving techniques and looms were used to produce brocade with small geometric patterns. A new technical dimension of weaving becomes obvious with the pile-loop brocade, a velvet-like fabric with geometric patterns of different sizes. Forty silk garments are embroidered with the colorful and curvilinear designs of *xin qi* (abiding faith), *changshou* (longevity), *cheng yun* (riding on the clouds), and various plants and cloud patterns. Embroidery as a patterning technique lost some of its importance when by Eastern Han times (AD 25–220) the variety of weaving patterns was finally extended to include mythological beasts, birds, fishes, flowers, all sorts of four-legged creatures, and Chinese characters.

The brocade manufactured from Han to early Tang times (seventh century) was woven with warp-faced patterns. The colors of the previously dyed warp threads mounted on the looms dominated the patterns. The patterns could be as wide

as the width of the fabric (ca. 50 cm) but their length was rather limited. Probably during the eighth century of the Tang dynasty a dramatic innovation took place. The weft-faced patterning method as it had already been practiced in a few woollen textiles from Han times was now widely applied to silk weaving. The advantage of weft-patterning was that the colors of the pattern produced by the weft could easily be changed, which resulted in larger and more vivid pattern units. Furthermore the dressing of the loom was facilitated. After the Tang dynasty, the weft-faced patterning method gained predominance in brocades and in other weaves. At the same time the cultural influence of Central Asia became evident in textile patterns. Apart from several hundred fragments of silks unearthed in 1987 from the underground palace of Famen Temple near Xi'an, most textile finds from the Tang period were discovered in the dry desert region of Turfan (Xinjiang province) and in the cave temples of Dunhuang.

If satin weave (*duanwen*) is classified as an irregular twill (*xiewen*), then satin could have been created as early as Tang times. Whereas the interlacing points of warp and weft in twill weaves are arranged in a continuous oblique line, those points in satin do not form a line but are evenly distributed, thus allowing long floats of the threads which give the fabric a glittering and at the same time smooth appearance. The French name *satin* was derived from the word *zaituni* which was used by Persian merchants to name the city of Citong at the coast of Fujian, another name for the famous commercial center of Quanzhou in the Song period (AD 960–1279). Several well preserved complete sets of official robes, garments of various types, underwear, and other textile items were found in three Song tombs. The tomb of Huang Sheng (1226–1243) in Fuzhou in Fujian province, who was the daughter of an official and married to an imperial clansman, contained 354 textile items, of which 201 were articles of clothing. The textiles are of top quality. The weavers and textile printers made use of the most advanced techniques of their time in producing figured leno (*hualuo*), gauze (*sha*), crêpe (*zhou*), and figured twill silks (*ling*). Even a few

satin weaves (*duan*) are described. More than 30 textile items were discovered in the tomb of the student of the Imperial College Zhou Yu (1222–1261) in Jiangsu province, and the recently excavated tomb of Mme. Zhou (1240–1274) in Jiangxi province yielded 329 items of textiles. Among the many regional brocades produced, the pure red brocade from Sichuan (*Shu jin*), with a formidable array of realistically depicted designs, was most famous.

In northern China, where the Liao dynasty reigned from AD 916 until 1125, and in the Song empire, the use of various types of tapestry (*kesi*) became highly fashionable. Among the textiles recovered from the Liao tomb of Yemaotai, dated between 959 and 986, there was a shroud made of silk tapestry in gold threads with a powerful design of dragons. The forerunners of this *kesi* tapestry technique can be traced back to the *zhicheng* technique of Han times, an intricate inlaid pattern produced by the weft yarn employing the swivel weaving method. During the Yuan and the Ming dynasties the use of various types of weaves with gold threads (*jinjin*) increased. The weavers of Ming times, especially the craftsmen of the cloud pattern brocade (*yunjin*) from ► [Nanjing](#) mastered a swivel weaving method (*zhuanghua*) making use of colored wefts to form a pattern on a fabric of various weaves. In many cases a glossy satin served as ground for the colorful swivel weave.

Three types of pile fabrics were produced on a large scale in Ming and Qing dynasties. The *Zhang* satin, originally from Zhangzhou in Fujian, was a figured warp pile fabric. From early Qing times until the end of the eighteenth century its main centers of production were Nanjing and Suzhou. The *Zhang rong* was a velvet where in order to produce a pattern the loops in the pattern area were cut. Thus the velvet pattern stood out on a ground of loops. The *Jian rong* was a cut pile fabric made of black silk threads produced on looms in Nanjing.

For the dragon robes (*longpao*) of the imperial Ming and Qing courts, the formal Manchu court robes (*chaofu*), and the semiformal coats (*qifu*) all patterning techniques known at the time were employed. This applies especially to the robes

manufactured during the reign of the Qianlong emperor after 1759. Many of the old weaving techniques were handed down from generation to generation and can still be found in China.

See Also

► [Silk and the Loom](#)

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Textiles in Egypt

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Egyptian textiles during the Dynastic Era (3100 BCE–300 BCE) were primarily linen, although wool was not unknown. (Cotton and silk were introduced only later.) Linen was produced in three basic grades: royal or fine linen, thin cloth, and smooth cloth. Production of royal linen, the highest grade, was a palace monopoly. Its manufacture took place both in the royal palace and in workshops associated with state temples. These workshops were supervised from the royal harem and were obligated to provide specific amounts of linen annually for use in the royal household and in temple rituals. Presumably it was this highest grade of linen that was also used in international trade.

As is often the case, much of our knowledge of the processes for textile production, use, and care is derived from scenes portrayed in the funerary art of the social elite and tomb models showing textile workshops, coupled with the study of surviving textile examples (and Egypt's dry climate has helped to preserve many pieces of textile). These evidences reveal a remarkably sophisticated industry for the production of cloth and clothing. Modern archaeology increasingly realizes the importance of textile evidence in dating artifacts, as well as in offering invaluable evidence concerning the daily life of all classes of ancient Egypt society.

The typical color of Egyptian linen ranged from near white (when made from young, immature, flax plants) to golden brown (from fully mature flax). The Egyptians did not ordinarily color their linen because most of the dyes known to them were not colorfast. When one desired to dye either a finished piece of linen cloth or linen thread to be used in embroidery, it was necessary to treat the fabric first with a mordant (one of the several substances, such as alum, that would adhere to the fibers of the linen and facilitate chemical

bonding with the dyestuff) and then with the dye itself.

Tomb paintings show Egyptians harvesting flax by pulling it up by the roots, rather than cutting the stalks so as to produce the longest fibers possible. Since basic techniques of flax processing are never illustrated in scenes from ancient Egypt, we do not know the details of the Egyptian processes. The following steps would need to be done, however. After being dried, the stalks were drawn through a comblike device to remove the seeds (ripping). The stalks were then exposed to moisture and allowed to rot slowly (retting) so that bacteria could break down the pectin in the tough outer sheath. After drying, the stalks were beaten (breaking) and sometimes scraped (skutching) in order to separate the woody parts from the long, flexible fibers that would form the linen. A final combing (hackling) cleaned and prepared the fibers to be spun into thread.

In preparation for spinning, the flax fibers were rolled together, usually between the palm and the left thigh, forming a loosely twisted strand. These strands were wound into loose balls on a pottery reel and stored in clay or basketry containers until ready for spinning. Based on artistic representations, the Egyptians used three different techniques to rotate the spindles while twisting the thread together. The supported spindle was rotated by being rolled between the palm and the leg of the spinner (usually from knee to thigh). The grasped spindle was rotated between the palms. The suspended spindle was set spinning (again by rolling from knee to thigh) and allowed to drop and swing freely, its rotary motion being maintained by the weight of the whorl, the drum-shaped or dome-shaped stone, or ceramic attachment near the top of the spindle shaft, which acted as a kind of miniature flywheel. The dropped spindle produced the most constant tension on the thread, permitting a finer and more homogeneous thread to be produced.

The earliest looms were simple ground looms in which two parallel beams supporting the warp threads were placed on the ground and held firmly in place with pegs. At about the beginning of the New Kingdom (ca. 1550–1085 BCE), we also

begin to find portrayals of a vertical-framed loom in which the two beams were incorporated into a less portable rectangular wooden frame. Some have speculated that this innovation may have been introduced when Egypt was dominated by the “Sea People” or Hyksos (ca. 1700–1550 BCE).

When thread was ready for weaving, the warp threads were attached parallel to one another between the two main beams of the loom. In the simplest weaving, the weft thread was passed over and under alternate warp threads. On its return, the path of the weft thread was reversed, so that it passed on the opposite side of each warp thread. A stick or comb was often used to beat down and press the weft threads together. There are, of course, many variations on this basic tabby weave, some of them of considerable complexity. Various weaving patterns were used to provide some visual interest or decoration to the fabric.

Based on artistic evidence, it appears that men were most frequently involved in the cultivation and harvesting of flax and in the preparation of the fibers for spinning. Both men and women (and even children) are shown involved in the spinning of the fibers into linen threads. Women, however, seem to be the ones who work at ground looms, while men more often are shown working at vertical looms. Whether these representations reflect a true division of labor or only an artistic convention is unclear.

Woven cloth was cut either with a metal shears or a knife when the ancient Egyptian wished to fashion a piece of clothing. The pieces were sewn together using a linen thread and a needle of polished wood, bone, or metal (usually copper or bronze, but occasionally gold or silver). The pieces were held together during sewing with pins of the same composition. Both needles and pins tended to have larger dimensions than modern examples. Pins were frequently capped with a looped head, which may have served a decorative purpose. Seams and hems were frequently rolled and secured by a rather crude whipping stitch. Seams that might experience greater stress or wear might be joined instead with flat seams. There were, as today, many

experiments with decorative sewing in order to produce an aesthetic effect.

Considerable effort was often expended to repair damaged garments. Usually repairs were in the form of darning (reweaving), rather than patching. The more ordinary grades of linen, however, were repaired with considerably less effort. A frayed edge might be bound carefully with a whipping stitch, but more serious damage often led to the object being discarded and replaced. Sometimes outworn garments were torn into strips to use in wrapping mummies.

From as early as the Old Kingdom (ca. 3000–2700 BCE), there are indications that laundering was done for wealthy households and temples. Washermen often formed a kind of guild. In the New Kingdom, the Superintendent of the Washermen seems to have enjoyed nearly as much prestige as the sandal bearer within elite households. (In most households, the laundering would have fallen to women or slaves.) Clothing was collected from subscribing households, identified using specific markings and listed on *ostraca* (pottery shards or flakes of limestone), and taken to the riverside laundry. There it would be treated with natron or other types of surfactants, beaten with sticks or stones, rinsed, wrung out, and spread to dry and bleach in the hot Egyptian sun. When fully dry, it would be folded, bundled, and returned to its owners.

See Also

► [Dyes](#)

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Textiles in India

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India may be described as one of the ancient centers of the cotton textile industry, since early evidence of cloth has been found in prehistoric archaeological sites. The spinning and weaving of cloth was very much a part of everyday life in ancient India. The loom is used as poetic imagery in several ancient texts. The *Atharvaveda* says that day and night spread light and darkness over the earth as the weavers throw a shuttle over the loom. The Hindu God Vishnu is called *tantuvardhan* or “weaver” because he is said to have woven the rays of the sun into a garment for himself.

It is interesting to note that in the third or second century B.C.E., when the cotton industry in India was in a flourishing state, in Europe cotton was still virtually unknown. The Greek scholar Herodotus thought that cotton was a kind of animal hair like sheep’s hair. At the beginning of the Christian era, Indian textiles figure prominently in the trade with Rome. Arrian, the Roman historian, testifies to the export of dyed cloth from Masulia (Masulipatnam on the Coromandel coast), Poduca (Pondicherry), Argaru (Uraiyūr in Tanjavūr district, Tamil Nāḍu) and other places in south India. Legend has it that Indian cloth was purchased in Rome for its weight in gold. The quality of Indian dyeing too was proverbial in the ancient world, and in St Jerome’s bible, Job says that wisdom is more enduring than the dyed colors of India. Indian textiles even passed into

Roman vocabulary as is seen by the use as early as 200 B.C.E. of a Latin word for cotton, *Carbasina*, derived from the Sanskrit *kārpasa*.

The history of Indian textiles constitutes one of the most fascinating and at the same time tragic chapters in Indian history. In the sixteenth century the Portuguese first set foot on Indian shores and were followed in quick succession by the Dutch, English, and French. For the next hundred years “Indian cotton was king” and Europe was in the grip of what economic historians describe as “the calico craze.” Indian textiles were used in the Middle East, Africa, and Europe not merely as dress material but also as coverlets, bed spreads, and wall hangings. The joint English sovereigns William and Mary are described as having landed in England in 1689, resplendent in Indian calico. Daniel Defoe, the author of *Robinson Crusoe*, commented that Indian calico, which at one time was thought fit to be used only as doormats, was now being used to adorn royalty.

However, there was a dramatic reversal of fortune in the eighteenth century. The cotton revolution in England rendered redundant the products of Indian handlooms. The first ban on Indian textiles was imposed by the British crown in 1700 and repeatedly after that. By the end of the century, instead of Indian cloth being exported abroad, the Indian market was flooded by the machine-made cloth of Manchester and Lancashire. Around the same period, India was hit by one of the worst famines beginning in the late seventeenth century and continuing through the eighteenth century. The words attributed to Lord Bentinck, the Governor of India in the 1830s, that “the bones of the weavers are bleaching the plains of India” are a dramatic but apt description of the fate of the Indian weavers.

The eclipse suffered by the Indian textile industry lasted until the early twentieth century until its grand revival under Gandhi, who initiated the *khādi* movement. The *charkhā*, or Indian spinning wheel, and *khādi*, or homespun cloth, became symbolic of the Indian struggle for independence. Foreign cloth was burnt in the public squares and the Indian spinning wheel became a part of the home of every Indian patriot.

Since Independence, a sea change has occurred in the traditional Indian textile industry. The changeover to power looms and jet looms and the introduction of computer designs is setting new traditions in Indian textiles. In the course of its historical vicissitudes, the Indian textile industry has gone through a process of change as well as cultural assimilation.

Indian Textile Technology

The first process in the weaving of a cloth is warping and sizing, and in India this is done in the open. ► **Bamboo** sticks, about 120 in number, are fixed upright in the street or what is called the warping grove, at a distance of a cubit from one another. Rows of women walk up and down the line, each carrying a wooden spindle in the left hand and a bamboo wand in the right. As they walk, they intertwine the threads between the split bamboos. These threads are then stretched horizontally from tree to tree, evenly washed with rice starch and carefully brushed. The right amount of tension in the warp is required to prevent the yarn from breaking while on the loom.

In India spinning was and still is almost exclusively the occupation of women. More specifically, this was the sole occupation of destitute women and widows. It is interesting that this corresponds to the English notion of the “spinster” as one who has to spin for her livelihood since she has no one to support her.

The earliest looms in use in India were either the pit loom or the vertical loom. The *Atharvaveda*, probably compiled in the early pre-Christian era, says, “A man weaves it, ties it up; a man hath borne it upon the firmament. These pegs propped up the sky; the chants, they made shuttles for weaving... (sic).” However, the most common type of loom in use was the horizontal pit loom in which the loom is placed inside an earthen pit and is operated with foot treadles. By depressing the pedal with one foot and raising the other, one set of threads get depressed and the weaving shed is formed through which the throw shuttle is shot across

by hand. References to such looms are scattered throughout ancient and medieval inscriptions. Around the fifteenth century one begins to get reference to the draw loom. This would consist of several levers and so enable the weaving of complex patterns. The introduction of the fly shuttle in the 1930s toward the end of British rule in India resulted in the partial mechanization of loom technology and in another three decades this was followed by the introduction of the jacquard. Nowadays, partially mechanized looms, power looms, and jet looms are displacing the traditional Indian handloom.

Traditional Indian Costumes

Different types of cloth are worn and woven in the different parts of India, since this is a vast land with varying climates. Generally, men tend to wear a longish lower cloth of about one and a half yards in length, called *dhōti* or *lungi* in the north and *veshti* in south India, while the traditional upper cloth consists of a single piece of cloth called *aṅgavastra*. However, in hot weather, men generally go without the upper cloth. In many parts of northern India, men also wear a head gear against the dust and heat. This is especially true of desert regions like Rajasthan. The Indian women wear large skirts or loose trousers called *salwār* and longish or short jackets. Alternately, they wear a 6-yard piece called a *sāri* and a blouse for the upper part. In the colder parts of India, such as the Himalayan mountain ranges and Kashmir, the garments are thicker and more elaborate, including warm woolen shawls and heavy jackets. It is noteworthy that in antiquity, stitched garments such as shirts, trousers, and blouses were hardly ever worn in India. In the ancient sculptures and paintings such as the ones at Amarāvati or Brahādīśvaram, it is only the menials, palace attendants, common soldiers, and dancing girls, all of them belonging to the lower echelons of society, who are depicted wearing stitched garments. Such garments are never depicted on the upper classes or royalty nor on the images of gods and goddesses. A plausible reason may be the

association of impurity and pollution with stitched cloth.

Colors and Designs in Textiles

Traditional Indian textiles reflect the Indian ethos. There is an aura of religion and romance around Indian weaving. Everything is significant – the colors chosen, the motifs, and the wearing occasion. Crimson or shades of red are very auspicious and worn by women on the occasion of their marriage as well as by ceremonial priests in certain parts of India, such as the Madhvā Brāhmins of Karnāṭaka. White represents purity and ochre, renunciation, and these are the colors worn by Hindu widows as well as ascetics. Yellow and green denote fertility and prosperity and are worn in the spring. Black is considered inauspicious, although pregnant women in south India wear black, perhaps to ward off the evil eye. As late as the eighteenth century, coloring was done entirely through vegetable dyes such as madder and indigo, although now dyers have almost entirely switched over to chemical dyes except in the case of highly specialized textiles like the *kalamkāris*.

The earliest designs on Indian textiles seem to have been geometrical. A twelfth century Sanskrit text called the *Mānasollāsa* described textiles designed with dots, circles, squares, and triangles. The depiction of flora and fauna was related to religion and popular beliefs. The lotus, which has great spiritual significance in Hinduism, and the mango design are among the most popular Indian motifs. Swan, peacock, parrot, and elephant are also commonly depicted. The tree of life, which symbolizes fertility and prosperity, is another auspicious motif. All these designs are patterned on the loom itself and it may take a handloom weaver working on an ordinary frame loom as long as 30 days to weave an elaborate 6-yard *sāri* with designs and gold lace. As the weaver weaves, he also sings the special loom songs, a tradition which has now almost entirely died out except perhaps in some interior weaving villages in Uttar Pradesh or the remote south. These loom songs

tell of the glory of particular weaving castes or they are full of esoteric religious metaphors describing god as the eternal weaver, weaving the web of life, and the human body as the cloth he has woven.

Textile Varieties

Traditional Indian textiles are unique and unparalleled for their beauty. The *jāmdāni* is an elaborate textile which is woven with multiple shuttles and resembles tapestry work. Floral motifs called *bootis* in gold or silver lace are scattered over the body with heavy gold lace on the borders. The most striking of these designs is the *pannā hazāra*, literally a thousand emeralds, in which the flowers shimmer and gleam all over the sari. The Benarsi *sāris* called *Kimkhābs* woven in Uttar Pradesh are legendary for their loveliness, although Benaras in the north and Kānchipuram in the south were traditionally associated with pure cotton rather than silk. It was the British who introduced sericulture in Kanchipuram in the nineteenth century. Gadhwāl and Venkaṭagiri saris of Andhra and the Īrkāl saris of Karnataka specialize in rich gold borders and heavy panel-like *pallūs* (that portion of the *sāri* which is draped over the shoulder). Another variety is the tie and dye (called variously *bandini*, *ikāt*, or *chungdi*) produced in Rajasthan, Orissa, Andhra Pradesh, and Madurai where the fiber is tie-dyed before weaving. A unique Andhra textile is the *telia*, which was soaked in oil before weaving and catered exclusively to the West Asian market because it was woven to suit desert conditions. This textile appeared in the sixteenth century with Muslim rule and died out with the collapse of the Islamic empires. Another textile which became popular in the mughal period was the *mashroo* (also the *himroo*) in which cotton was used in the warp and silk in the weft. Initially these were used as Islamic prayer mats by the Mughal nobility who were forbidden by Islamic tenets to use any animal product. They therefore contrived the mashroo which enabled them to have their comfort without violating the religious tenet against the use of pure silk.

Textiles also form an important part of temple ceremonials such as the flag cloth hoisted in temples, the garments put on the deity, the cloth covering the chariots in which the deities are taken out on a procession and the ritual dance costumes. The *kalamkāri* cloth of Andhra, in which mythological stories are sketched minutely on cloth with a fine pen as well as the *Nādhadwāra pichwāis* of Rajasthan, are of this genre. In India it is also the practice among wandering groups of minstrels to render dramatic narrations of mythological stories, and the elaborately painted screens used on these occasions form an important aspect of traditional Indian textiles.

See Also

► [Colonialism and Science](#)

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Textiles in Mesoamerica

Carolyn Jones and Tom Jones

Because textiles are rare among the artifacts of cultures known to us only archaeologically, any analysis of them, or of the technology of their production, must be pieced together from indirect sources. In Mesoamerica, while archeological finds attest to the existence of various textile technologies at specific dates, much of our understanding of the subject comes from ancient Maya,

Mixtec, and Aztec books, stone sculpture, painted pottery, murals, clay figurines, European documents from the time of the Conquest, and modern textile traditions.

Though the physical environment of Mesoamerica generally precludes the survival of perishable artifacts, textiles have none the less survived from certain areas. The majority, mostly small fragments, have been found in dry caves in the arid regions of Mexico. In the humid southern lowlands very little has survived, some 2,500 carbonized fragments dredged from protecting mud at the bottom of the Sacred Well at Chichen Itza are the most important single find.

The oldest textiles to survive in Mesoamerica are cordage, netting, and basketry, worked in vegetal fibers other than cotton, with early examples dating to at least 7000 BCE in Oaxaca and to 5000 BCE in central and northern Mexico. Such textiles are fashioned from the leaves and stems of various plants worked without the benefit of a loom. In instances where fibers were extracted from their plant sources, they were probably spun by rolling them together between the hand and thigh, as no tools for spinning have been found. Spindle whorls and evidence of loom woven textiles appear much later.

The earliest evidence for loom weaving in Mesoamerica consists of fabric-impressed ceramics datable to 1500 BCE, at which time spindle whorls also begin to appear. Woven cotton fragments follow soon after. These early woven textiles are worked in plain weave and almost certainly were created on a backstrap loom. From these simple beginnings, a sophisticated textile industry developed.

The weaving process begins with the selection and preparation of suitable materials. The predominant fiber of woven Mesoamerican textiles was cotton, *Gossypium* spp., with both annual and perennial varieties reported at the time of the Conquest. Cotton was cultivated in at least two colors, white and brown, and traded throughout ancient Mesoamerica. Other fibers, generically termed istle (from the Nahuatl *ixtli*), were drawn from the leaves and stems of many plants of more local distribution, including *Agave* spp. and *Apocynum* spp. Both cotton and istle required

much preparation prior to spinning and weaving. Cotton was carefully picked over, its numerous small seeds and other vegetal debris removed by hand and the mass of fiber then fluffed or beaten to produce a uniform, smooth mass. Istle, on the other hand, was toasted, split, and scraped to remove the plant flesh from fibers which were then washed, dried, and combed. No animal fibers are known to have been used in ancient Mesoamerica. Textile headdresses incorporating human hair, however, have been found.

Both cotton and istle were spun on the spindle, a simple device consisting of a “whorl” wedged onto the end of a straight-tapered shaft. A mass of fiber was attached to the shaft, which was then twirled, imparting twist. The whorl helped the device to spin easily and for an extended time, and provided weight against which the fiber could be drawn out and twisted into thread. Different fibers required different types of spindles and sizes of whorls. Cotton, because of its very short fibers, was spun on a small spindle, the lower end of which was supported in a bowl or on the ground. The longer istle fibers required a larger, heavier spindle. Yarns of any size could be created and some as fine as 0.005 mm in diameter have been recovered. Yarns could be used singly, or two or more individually spun strands could be retwisted (“plied”) together. A mixture of cornmeal and water was likely applied to some yarn to smooth and strengthen it for weaving.

While there is little archeological evidence for the use of dyes, Post-Classic pictorial codices and reports of the *conquistadores* both attest to the vivid colors of Mesoamerican textiles. Plant dyes probably included indigo (*Indigofera anil*) for blue, brazilwood (*Caesalpinia* spp.) for red, logwood (*Haematoxylon campechianum*) for black or blue, annatto (*Bixa orellana*) for orange, and many other leaves, seeds, roots, barks, and fruits. Two animal dyes were important: on the Pacific coast, purple was extracted from small mollusks of the genera *Thais*, *Murex*, and especially *Purpura*, while in arid regions, cochineal (*Coccus cacti*, a scale insect of the order Hemiptera) was cultivated on the prickly pear cacti (*Opuntia* spp.). The beautiful red produced by cochineal

was much admired by the Spanish, and the dye-stuff became a major export to Europe following the Conquest. Mineral pigments, such as ochre, iron pyrite, cinnabar, carbon, copper sulfate, and “Maya blue” clay were known, and there is some evidence for the use of mordants which make dyes more permanent. Dyes and pigments were applied by painting, by stamping or rolling with figured clay implements, and by immersion dyeing. Patterns were produced during dyeing through the application of resists and through tying-off of sections to create undyed areas of yarn or fabric. Fabric incorporating tie-dyed warp, called *jaspe*, is still produced in Guatemala today.

Once suitable yarns were spun and dyed, the process of setting up the loom began. The *Florentine Codex*, a documentary of Aztec life and custom written by the Spanish friar Sahagún just after the Conquest, illustrates the weaver’s equipment, including spindle, warpboard, loom sticks, backstrap, and batten. It also describes the training of weavers, from the presentation of the newborn girl with miniature weaving equipment, to the day of a woman’s death when her loom and spindle were burned in the funeral pyre awaiting her in the afterworld. In the *Mendoza Codex*, created by Aztec scribes at the order of the first Viceroy of New Spain, there is a section devoted to a mother’s training of her daughter in domestic chores. It portrays the child’s instruction in spinning (Fig. 1) and weaving, from ages 3 to 14, her food rations, and punishments for unacceptable work.

Information about weaving is also contained in Maya books, whose almanacs provide endlessly repeating prognostications for the timing of certain quotidian activities. One almanac in the *Madrid Codex* depicts the process of preparing the warp for the loom (Fig. 2). The weaving goddess, named *Sak Na* in the accompanying hieroglyphic text, is shown seated cross-legged with her left hand against a horizontal frame supported by at least two vertical posts and with lines stretched between their projecting upper parts. Her raised right hand holds an inverted spindle from which thread reaches to the frame before her. While there have been varying



Textiles in Mesoamerica, Fig. 1 An Aztec woman instructs her 7-year-old daughter in the art of spinning cotton on a supported spindle. The child's ration of

one-and-a-half tortillas is shown between them (From *Mendoza Codex*, page 59; from a photo of the codex)



Textiles in Mesoamerica, Fig. 2 A Maya almanac illustrating the goddess *Sak Na* preparing her warp (From *Madrid Codex*, page 102; drawing after Villacorta)

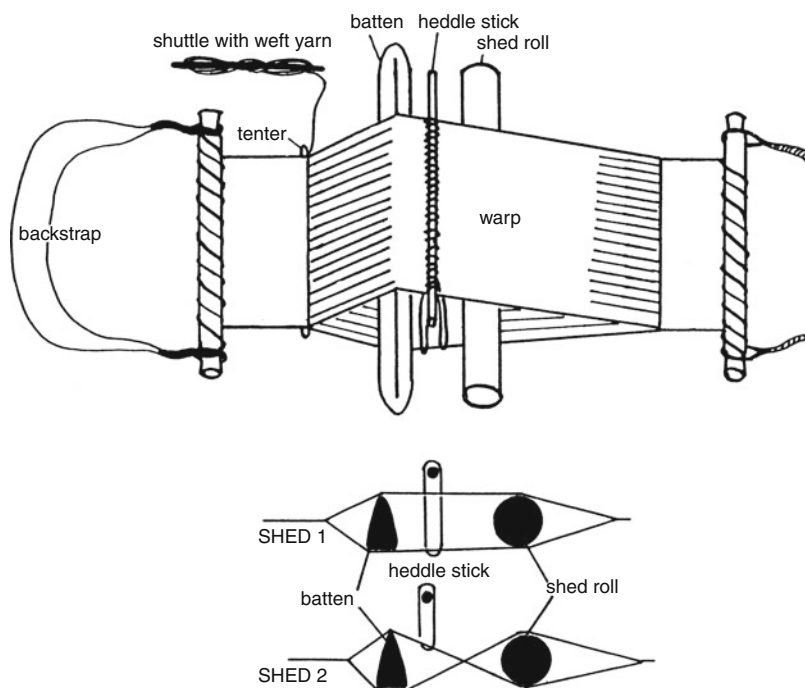
interpretations of the activity portrayed in this illustration, the overhead texts clearly read: *Sinah u chuch Sak Na*, or "She strings her warpboard, *Sak Na*," describing in ancient Mayan the process depicted. This manner of preparing the warp yarn, by measuring and stretching it between vertical posts on a warping frame, was in use at the time of the Conquest

and survives to this day. It is the initial phase of preparing a backstrap loom (Fig. 3) for weaving.

As the warp yarns are measured, they are wound alternately to one side and the other of a pair of vertical posts, thus creating a lease which maintains their order and allows the easy selection of alternate threads. Once wound,

Textiles in Mesoamerica,

Fig. 3 The structure of a backstrap loom, showing component parts and how they are used to create two sheds for weaving (Drawing by Carolyn Jones)



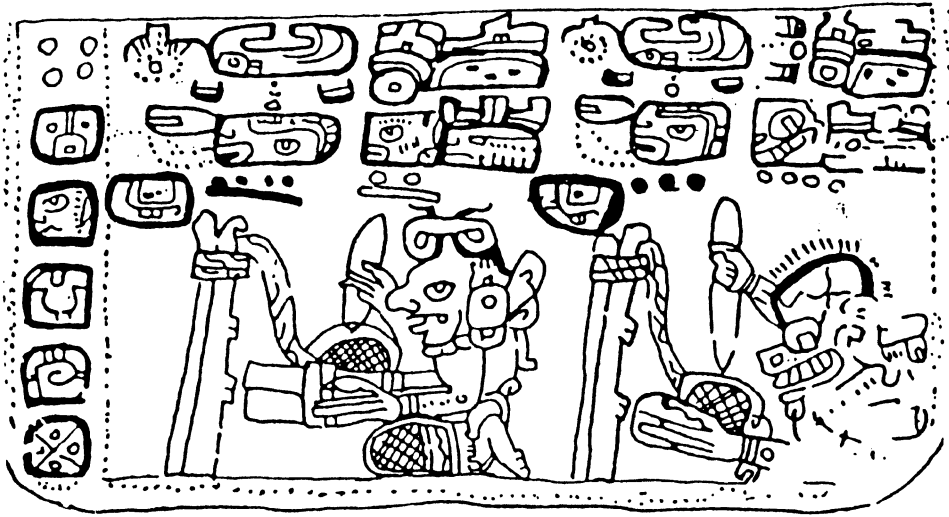
the opposite ends of the warp are secured to bars which form the ends of the loom, and a large, smooth, rounded stick (the shed roll) is placed through one side of the lease. The shed roll allows for the lifting of those threads which travel over it, one half of the total warp threads in alternating order, creating the first opening or shed. The remaining threads, which travel under the shed roll, are individually secured to a second stick (the heddle). By pushing the shed roll back and lifting the heddle, the other half of the warp threads are raised, creating the second shed. This is the mechanism by which Mesoamerican weavers created plain woven fabric.

Before the loom is ready for weaving, additional implements are required. A long, heavy, straight-sided wooden stick (the batten) which can be turned on its side to enlarge the shed through which yarn (the weft, carried on a shuttle) will pass, and which is used to beat that weft into place, is employed continuously during weaving. A thin stick (the tenter) is usually attached to the fore-edge of the weaving to regulate the fabric width. Finally, the far end of the

loom is tied to a tree or post, while the close end is attached to a strap which travels around the weaver's hips as she sits on the ground. By adjusting the position of her body, the weaver controls the tension of the warp of her loom.

This action is illustrated in the *Florentine*, *Mendoza*, *Matritense*, *Dresden*, and *Madrid Codices*, and in clay figurines from Maya burials on the island of Jaina. The *Madrid Codex* contains an almanac comprised of two episodes (Fig. 4). The first is illustrated with a crude drawing of a skirted female on her knees, her left hand supporting a backstrap loom, her raised right hand inserting the batten. Over the scene is an explanatory text that reads: *Och-i ti te' Ch'ul Na Che'el*, or "Divine *Na Che'el* (another name for the Maya weaving goddess) weaves at the post."

Simple in construction, the backstrap loom was well suited to the Mesoamerican woman's environment. Spinning and weaving were but two of her many daily chores, and the easy portability of the backstrap loom allowed its being rolled up for safekeeping when not in use, or set up when



Textiles in Mesoamerica, Fig. 4 A Maya almanac illustrating the goddess *Na Che'el* weaving at her backstrap loom (From *Madrid Codex*, page 102; drawing after Villacorta)

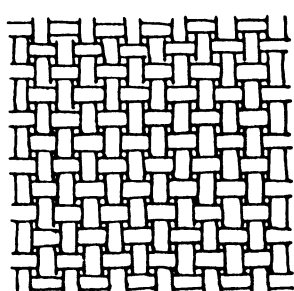
and where convenient. The simplicity of the equipment, however, did not preclude complex weaving. Extant fabric fragments display a wide variety of techniques. Among the simple weaves are plain, semibasket, basket, twill, and gauze. More complex weaves include supplementary weft brocade, tapestry, inlay, supplementary warp patterning and pile, warp interlock, and layer exchange double cloth (Fig. 5).

The structure of the backstrap loom determined several qualities of the fabric to be woven. The size of the finished cloth was determined when the loom was set up, and was limited in both width (by the weaver's armspan and her need to position herself at the center of the loom for proper tensioning), and length (the longer the warp, the more cumbersome and difficult it was to weave). When a large fabric was required, it was woven in small rectangles and pieced together, usually without cutting. Mesoamerican fabrics could include four finished edges and tended to show more warp than weft, with warp counts as high as 78 threads to the inch recorded.

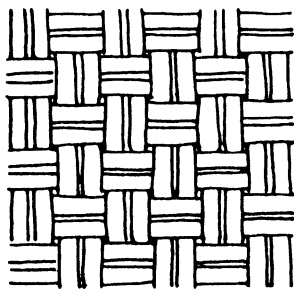
In addition to weaving, ancient Mesoamericans were familiar with twining, braiding, plaiting, knotted and knotless netting,

sewing, and embroidery. Methods for making leather, felt, bark cloth, and paper were known. At the time of the Conquest, new materials and techniques were introduced, including needle knitting and the use of sheep wool and silk. In some areas, the treadle loom came into use, and men entered the field of textile production. These different technologies survive side-by-side with backstrap weaving today.

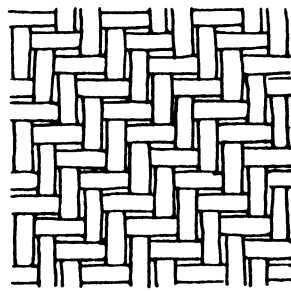
The importance of textiles, and particularly of weaving, to the ancient cultures of Mesoamerica must not be underestimated. Weaving was not simply a means of producing necessities of daily life, but was an expression of the Mesoamerican world view. The act of weaving was seen as a basic creative force, analogous to the original creation of the world in Mesoamerican myth. The symbolic significance of the act of weaving lives on in the complex patterns of the modern Maya woman's *huipil* (or traditional poncho-like garment), each of which is a cosmogram that places the weaver at the center of the universe. Many designs used today are notably similar to symbols depicted in carved stone representations of textiles from the ninth century, thus displaying remarkable continuity with a lengthy and rich Mesoamerican textile tradition.



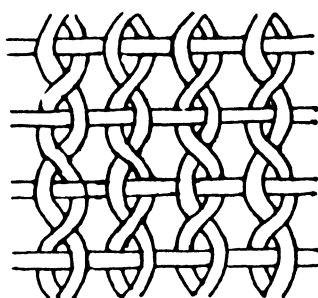
plain



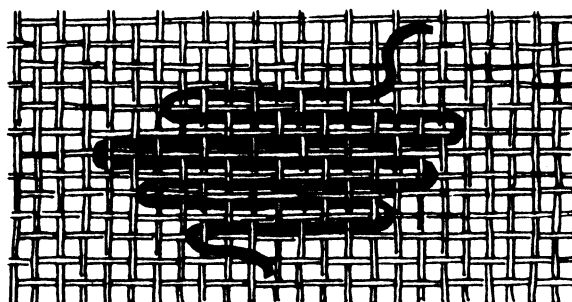
basket



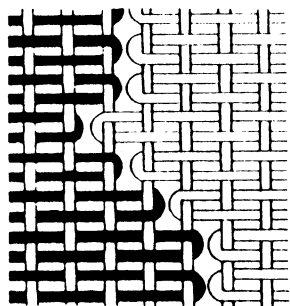
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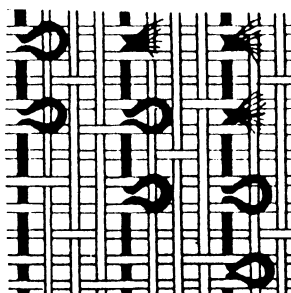
gauze



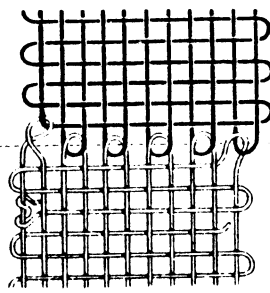
supplementary weft



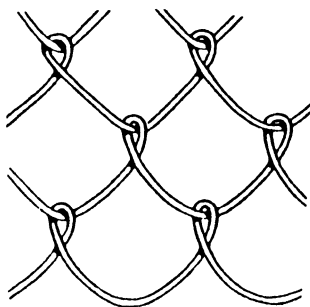
slit tapestry



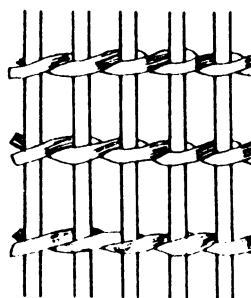
supplementary warp



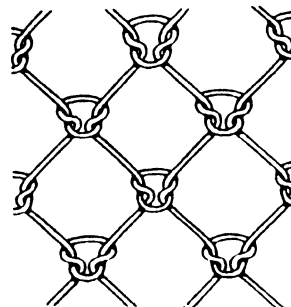
warp interlock



knotless netting



twining



knotted netting

Textiles in Mesoamerica, Fig. 5 Some structures known from ancient Mesoamerican textiles. The *bottom row* provides nonwoven techniques for comparison with

the loom-woven structures shown above (Drawing by Carolyn Jones)

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Textiles in South America

Amy Oakland Rodman

Unlike most parts of the world where discoveries of ancient textiles are unusual, the Pacific desert coast and dry western Andean slopes have preserved enormous quantities of textiles, wood, feathers, plant material, and other usually perishable artifacts. Most of the best preserved textiles were originally part of burial furnishings left in ancient cemeteries stretching from central Peru to northern Chile. The far north Andean coast (modern Colombia, Ecuador, and northern Peru) encounters periodic torrential showers which have destroyed most ancient remains. Few textiles have survived from the highland wet and dry climate or the rainforest regions of the eastern Andean slopes stretching to the Atlantic ocean.

It is apparent that desert conditions and the careful preparation of tombs are the two elements

most responsible for the preservation of ancient Andean textiles. Beginning around 3200 BCE and continuing until the conquest of the Andes in AD 1532, it is possible to reconstruct textile technology in coastal regions and occasionally to witness highland development through textiles preserved in coastal sites.

Archaeologists have designated the Cotton Preceramic (3200–1800 BCE) as a period when a variety of coastal cultures developed cotton twining, looping, and other nonloomed textiles before the use of the heddle loom or ceramics. Major discoveries at Huaca Prieta, La Galgada (a highland site with remarkable preservation), and in Asia have determined that not only were large quantities of cotton textiles used, but that some were elaborately patterned. Images on Preceramic cotton textiles include condors with outstretched wings, two-headed snakes, and humans or deities with splayed feet, all subjects with similar presentation to images which continue in the art of many subsequent Andean cultures. Designs are created through transposing twined elements, often combining a change in regular yarn movement with alternating colored yarns. Cotton dyes include indigo for blue and unidentified, red, yellow, and brown colors. Thicker plant fibers were twisted into sturdy twined mats, while cotton was used for looped caps and twined mantles.

Beginning in the Initial Period (1800–800 BCE) and the following Early Horizon (800–0 BCE), Peruvian textiles developed through the use of the heddle loom. Hundreds of painted Early Horizon cotton plain-weave textiles discovered near Karwa on the Peruvian south coast identified fabrics with designs very similar to stone carvings from the north highland pilgrimage site of Chavin de Huantar. This important and well-preserved painted ritual cloth provided evidence of the ways in which textiles were used to transport religious imagery throughout the Andes beginning in very early periods.

Camelid fibers, sometimes termed “wool” yarn, from the hair of the nondomesticated guanaco and vicuna or the domesticated llama and alpaca, were introduced into coastal weaving

during the Early Horizon. Camelid hair is more easily dyed than cotton and its introduction into coastal technology is usually based in its application in brilliant colors for weft-patterned structures. The first all-wool tapestry textiles appear in coastal cemeteries during this period and it is likely that these identify an ancient highland wool technology rarely preserved in the highland regions of natural camelid habitat.

The famous Paracas textiles were woven and embroidered on the southern Peruvian coast during the Early Horizon. On the Paracas Peninsula, elite individuals were buried with hundreds of embroidered shirts, skirts, mantles, feather fans, and golden objects all wrapped inside enormous plain woven cotton winding cloth. The multicolored wool embroideries depicted repeating human, deity, and animal images and were executed in stem stitch on plain-woven fabric. Paracas textiles also included a unique type of three-dimensional embroidery using the cross knit loop stitch to embellish borders with polychrome images. The technique was created with a single cactus spine needle as a continuous form of crossed looping.

The Nazca culture, which followed the Paracas on the south coast in the following Early Intermediate Period (AD 0–500), continued one of the most elaborate weaving technologies ever known, with textiles in double and triple cloth, warp and weft patterning, oblique interlacing, and fine garments woven with both discontinuous warp and weft. Andean loomed textiles are characterized in their tradition of four finished selvages. Individual finished cloth webs were sewn together to complete a garment and were rarely cut.

Very little is known of north coast weaving during the Early Intermediate Period, the time of Moche cultural development. The few surviving Moche textiles identify a technology principally based in the use of cotton and a narrow backstrap loom like that employed on the south coast. But structurally, Moche textiles are distinguished through the use of fine un-ply cotton yarns in twilled and weft-brocaded structures. Moche tapestry is woven with both cotton and dyed camelid fiber weft over a cotton warp using a

non interlocking weft which creates vertical slits between different color areas. Apparently slit-tapestry was common to coastal cultures both north and south.

Although known for only a handful of large weft-interlocked tapestries or tapestry fragments and triple-cloth narrow bands, the Early Intermediate Recuay culture of the Peruvian north highlands developed a distinctive textile tradition. Recuay tapestries were woven on a wide loom of more than 7 ft with a short warp of no more than 2 ft. Brilliantly dyed red and yellow wool yarns are characteristic of Recuay textiles, and tapestries use the highland weft-interlocked structure which leaves no openings between areas of different color. In the south central Andes, weft-interlocked tapestries uncovered on the Chilean north coast have been attributed to the Alto Ramirez culture of the southern highlands. Alto Ramirez textiles exhibit a decided preference for the use of blue and red dyed yarns almost certainly identifying an ancient source and knowledge of indigo dyeing in the southern highlands.

The following Middle Horizon (AD 500–1000) marks a break with previous cultural development. The Peruvian Huari culture located near the modern city of Ayacucho appears to have controlled the central Andean highlands and coast, while the south central Andes was allied to the site of Tiwanaku. Tapestry was the distinctive Middle Horizon medium woven in slit techniques with cotton on the coast and with interlocking camelid fiber wefts in the highlands. Local, coastal tapestry continued to be woven on the narrow backstrap loom. Highland Tiwanaku and Huari tapestries preserved in coastal desert burials identify the use of the wide loom with narrow warp like that used in Recuay tapestry. Huari shirts were woven in two parts and seamed down the center leaving an opening for the head and neck. The few Tiwanaku shirts discovered in northern Chilean desert cemeteries were patterned with similar images but were woven in a single panel with a neck opening woven through discontinuous wefts. Headgear was always used as an important Andean badge of identity. Huari and Tiwanaku

officials wore a knotted hat with four peaks or points on the top. Tiwanaku four pointed or cornered hats created polychrome designs in lark's head knots while similar Huari hats were patterned with knots with tufts of wool pile in each knot.

By AD 1000 the highland centers of Huari and Tiwanaku had collapsed and individual cultures began clearly to establish local identities noted in regional textile styles. Warp-patterned structures such as complementary and supplementary-warp weaves were commonly woven in the following Late Intermediate Period (AD 1000–1450). Textiles are often characterized as having repetitive, small-scale imagery in gauze, painted cotton, weft-brocades, and double-woven fabrics. South coast weavers shaped bags and shirts through the selective addition of warp yarns during the construction process. North coast weavers often wove exotic bird feathers into the cloth, creating shirts and other garments with one face completely covered with feather patterns. During this period coastal weaving especially exploited the full potential of natural native colored cottons which were woven in contrasts of white and natural red-brown, beige, and grey.

The highland Aymara weaving tradition was consolidated in the south central Andes during the Late Intermediate Period after the fall of Tiwanaku. Aymara textiles are characterized by elegantly striped warp-faced shirts, woman's dresses, head cloths, and mantles in natural colored camelid fiber yarns often dyed blue, green, and red.

The Late Horizon (AD 1450–1534) again marks the period when local cultures were brought under highland control, this time that of the monolithic Inca state with its capital at Cuzco in the southern Andes. Inca textile patterns are strictly geometric and nonfigurative and the most valued cloth was weft-interlocked tapestry woven on the wide tapestry loom with a short warp. Some of the best preserved Inca textiles have been discovered as miniature offerings covering gold and silver male and female figurines and left on the tops of Andean mountain peaks from Ecuador to Argentina. Male garments include a tapestry tunic, a mantle, a bag with a

carrying strap, and a large feather headdress. Female garments include a large wrap-around dress and a narrow, highly patterned belt. Most of these garments are woven entirely in camelid fiber and are colored with red and yellow dyes.

Following the conquest of the Inca state by European conquerors, European methods of textile manufacture were introduced throughout the Andes. The spinning wheel was adopted for workshop production, and the treadle loom was constructed for the manufacture of yardage to be sewn into non-Andean style tailored clothing. Needle knitting was introduced and is now regularly used for sweaters and knitted caps in local communities. Felting was introduced for wide-brimmed hats which have now become part of indigenous community dress in many regions.

While foreign clothing styles and techniques replaced local garment manufacture in coastal regions, European methods never replaced highland traditions in many indigenous communities in Colombia, Ecuador, Peru, and Bolivia. Today, some areas have maintained camelid-fiber spinning practices using the drop spindle and the backstrap loom or the staked ground loom to produce native four-selvedge garments. Men are the principal weavers in indigenous communities in Colombia and Ecuador, and women weave in Peru and Bolivia. In the southern Andes men weave on the European treadle loom. All community members spin, but spinning is generally considered women's work. Many communities continue to express local identities through handwoven patterns and specific color combinations which are worn daily or for community rituals. Traditional four-selvedged handwoven garments are also worn with European-style vests, pants, sweaters, or skirts in many areas. Some communities have specialized in the decoration of textiles with sewing machine embroidery.

Outside of the Andean region, a few Brazilian tribes and groups living in the Amazonian areas of Ecuador, Peru, and Bolivia, have continued lowland traditions using barkcloth, elaborate feather headdresses, and oblique-interlaced bags and narrow bands, textile traditions which may reflect ancient lowland origins never preserved in these wet regions.

South America continues as the native home to herds of guanaco, vicuna, llamas, and alpacas with an export industry in camelid fiber and manufactured textiles. Peruvian cotton is valued for its luster and is enjoying a revival in interest in native natural-colored cotton yarns.

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Thābit ibn Qurra

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Abū'l-Ḥasan Thābit ibn Qurra ibn Marwān al-Ḥarrānī al-Ṣābi' (836–901) was a Syrian mathematician, astronomer, physicist, physician, geographer, philosopher, historian, and translator from Greek and Syriac into Arabic. His scientific treatises were written primarily in Arabic and partly in Syriac. He was born in Kafartūtha near Ḥarrān (now Altınbaşak in Southern Turkey) and was a student in Ḥarrān. Ḥarrānians, the descendants of the ancient nation Mitanni in the Hellenistic age, were Hellenized, and their ancient religion of star worship was deeply connected to Greek philosophy. In the Arab caliphate,

Ḥarrānians called themselves Ṣābians since the Ṣābian religion was one permitted by the *Qur'ān*. Ḥarrān University was founded in the fifth century in Alexandria as a school of philosophy and medicine. After the Arab conquest, it was moved to Antiochia and later to Ḥarrān where, under the influence of Ḥarrānian traditions, astronomy and mathematics were taught, and it became a university.

At first Thābit ibn Qurra worked in Kafartūtha as a money changer. Here the Baghdad mathematician Muḥammad ibn Mūsā ibn Shākir met him and invited him to Baghdad, where Muḥammad and his brothers Aḥmad and al-Ḥasan, the Banū Mūsā, became his teachers. Later he worked at the court of the caliphs in Baghdad and in Surra man ra'a (Samarra) as a physician and astronomer. His position as the caliph's physician allowed him to keep his heathen religion. His son Sinān ibn Thābit and grandson Ibrāhīm ibn Sinān also were mathematicians, astronomers, and physicians in Baghdad.

Thābit ibn Qurra's contributions to science covered many different disciplines, from mathematics to philosophy. In mathematics, he was a translator or editor of translations of many works of Euclid, Archimedes, Apollonius, Theodosius, and Menelaus. Many of these are extant only in these translations. These translations, together with the geometric treatise of Thābit's teachers, the brothers Banū Mūsā, and his *Kitāb al-mafrūdāt* (*Book of Assumptions*), constituted the so-called middle books which were studied between Euclid's *Elements* and Ptolemy's *Almagest*.

Two of Thābit's treatises on parallel lines were first written in Syriac, the first under the title *Ktovo al-hay da-tren surte trishe kad mettapkin al bshir men tarten gonowoto dag'in bahdode* (*Book [in which is proved] that Two Lines Produced Under Angles Which are Less Than Two Right Angles Will Meet*). The second is called "the second book on the same topic." Both these treatises are extant only in the Arabic translations made by Thābit himself. The ideas of these treatises were further developed by Ibn al-Haytham (965–ca. 1050), 'Umar al-Khayyām (1048–1131), and Naṣīr al-Dīn al-Ṭūsī

(1201–1274) and later led to the discovery of non-Euclidean geometry.

Thābit's *Kitāb fī ta'līf al-nusub* (*Book on Composition of Ratios*) was devoted to the theory of compound ratios. This theory later led to the notion of real numbers and to the discovery of differential calculus.

Other works covered such subjects as a simple proof of the Menelaus theorem (the first theorem of spherical trigonometry), mensuration of plane and solid figures, and solutions of different problems of integral calculus. His books contained some proofs of the Pythagorean theorem and its generalization and dealt with the subject of amicable numbers, in which each number is equal to the sum of the divisors of the other.

In the field of astronomy, Thābit was the editor of the translation of Ptolemy's *Almagest* and the author of many treatises on the movement of the sun and moon, sundials, visibility of the new moon, and celestial spheres. In his treatise "On the Motion of the Eighth Sphere," extant only in Latin translation (*De motu octave sphere*), he added the ninth to Ptolemy's eight spheres and proposed the theory of "trepidation" to explain the precession of equinoxes. The fragments of Thābit's Syriac *Ktovo d'pulog d'yumoto d'shobo'o al koukbe shab'e* (*Book on the Subdivision of 7 days of the Week According to Seven Planets*) are extant in Bar Hebraeus' *Chronography*. In this book, the planets are designated by their Babylonian and Greek names; this subdivision was known to Romans and Indians and is the source of the names of the days of the week in many European and Asian languages.

Thābit also wrote books on mechanics and physics. His *Kitāb al-qarashūn* (*Book on Lever Balance*) discusses the conditions for equilibrium of different kinds of levers. In his *Kitāb fī masā'il al-mushawwiqa* (*Book on Interesting Questions*), Thābit tries to explain the phenomenon of the camera obscura. This attempt was erroneous, but it led Ibn al-Haytham in the *Book on Forms of Eclipses* and al-Bīrūnī (973–1048) in *The Exhaustive Treatise on Shadows* to the solution of this problem. He also studied the problems of acoustics in *Mas'ala fī'l-mūsīqā* (Question on

Music) which is an extant fragment of his great *Book on Music*.

In geography and medicine, Thābit revised works of Ptolemy (*Kitāb ṣūra al-arḍ*, *Book of the Picture of Earth*) and Galen. He was the author of the fundamental *Kitāb al-dhakhīra fī 'ilm al-ṭibb* (*Book of Treasure in the Science of Medicine*).

In philosophy, Thābit emphasized that integer numbers were abstractions of objects of counting and criticized Aristotle who rejected actual infinity. In his commentaries to Aristotle's *Metaphysics*, he considered the problem of the "first motor" and argued with Aristotle's opinion that the essence is immobile. Many of Thābit's treatises are devoted to problems of religion, in which he is critical of both Christianity and Islam.

See Also

- [al-Bīrūnī](#)
- [Banū Mūsā](#)
- [Ibn Al-Haytham \(Alhazen\)](#)
- [Ibrāhīm ibn Sinān](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Sinān ibn Thābit](#)
- [Umar al-Khayyām](#)

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Timber-Handling Technology in Japan

Conrad Totman

Japan has long been known for the ability of its artisans to construct gigantic, durable wooden structures, lesser wooden buildings of graceful design, and small objects of meticulous craftsmanship. One wonders how they were able to use the trees of their archipelago for these purposes when its topography made logging and timber transport so exceedingly difficult.

Preindustrial Timber Handling

Japan's earliest wood-handling technology was predictably simple. Stone – and later metal – hand axes, adzes, and chisels were used to fell and process tree trunks and ► [bamboo](#) to create rafts, dugout canoes, and plank-walled boats;

diverse hand tools, weapons, and other small objects; and post-and-beam buildings lashed together with vine and enclosed with thatch or wattle.

During the seventh century, however, major new architectural forms – grand wooden palaces and Buddhist temples that utilized stone foundations, mortis-and-tenon framing, board walls, and tile roofs – arrived from the adjacent continent. These new forms vastly increased the demand for timber and, as a consequence, produced changes in all stages of wood handling, from felling and transporting to final fashioning into the devices of daily life. In following centuries that technology was elaborated and refined, and its usage spread across the islands.

In the first stage, loggers used slender-hafted, narrow-bladed axes to fell and limb trees and cut them to length. By the sixteenth century blacksmiths were producing large saws with sufficient temper and consistency of thickness for use as crosscut saws, and for several decades woodsmen employed them in felling trees. During the seventeenth century, however, their use for felling was outlawed, evidently to prevent timber theft: the sound of an axe thwack carries much farther than does the swish of a saw, helping guide warden to miscreant. From then until the late nineteenth century felling was handled by professional axmen. To facilitate the felling of especially large trees, choppers gouged holes around the base, stuffed the wood chips back into them, and set them to burning, guiding the burn through the base so as to fell the tree in the desired direction.

Turning to transportation, in early centuries, when adequate timber was available within reasonable proximity of a construction site, logs could be carried to it on two-wheeled oxcarts. Or they could be floated downriver (or hauled upstream by man or animal power), snared and pulled ashore at a landing, and then loaded onto carts for overland transport.

Later, as lowlands were cleared and more and more timber came from steeply mountainous regions, the transport system became more complex. Skidding crews at the felling site used long-handled hooking tools, vine or woven rope, and,

where the situation required them, winches and sleds to role, skid, and sled pieces down to a log-assembly point. There (or sometimes at the felling site) axmen hewed the logs to form roughly rectangular pieces. This hewing reduced log weight, rendering sticks more manageable, and it made them more stable for the journey to town. In particular, when used to form rafts, hewn pieces were far less likely to twist and tear apart as raftsmen were negotiating rapids and turns in the river.

Depending on the terrain, workmen might use some of their squared sticks to form log trestles or trough-shaped chutes down which they could slide pieces to streamside. Or in the case of assembly beside a small mountain stream, they could construct splash dams and elevated chutes as needed to propel sticks on the flood down to where normal stream flow would float them freely.

Where felled trees were being converted to shingling or other small pieces, they commonly were split to portable size at the felling or assembly site or at a river landing. And material for conversion to charcoal was processed in kilns and the cooled charcoal bagged for transport. Both split pieces and charcoal were then carried overland to market by packhorse or floated out of the forest aboard log rafts.

The trip by water could be complicated. Most of Japan's rivers rush from mountains down to the sea, and given the frequency and unpredictability of downpours, freely floating logs risked doing damage to riverbanks or facilities, being stranded by high water at inaccessible sites, or even of floating out to sea and being lost. At convenient locations, therefore, river transporters constructed floating booms by lashing bamboo or logs together with vine and anchoring them to rock outcroppings, trees, or huge posts as the site allowed. These booms captured floating sticks, enabling workmen to beach them for temporary storage or processing or to assemble and bind them into rafts for the remainder of their journey.

On the largest rivers, the short initial rafts were beached at a midway point and several then joined end-to-end for the journey's final leg to a landing near the coast. At seaside, especially

large logs could be lashed to shipside or hauled astern to a port of destination. But most pieces were taken aboard for the trip.

At the lumberyard or work site, squared logs were left floating in the water until needed, or they were stacked on land for curing and sale or processing and use. To convert a log to boards or planking, sawyers positioned one end on a high A-frame and used wide-bladed saws to rip it to the specified dimensions. The saw teeth were shaped to cut on the draw stroke rather than the push stroke, which reduced the risk of kinking the blade. That design lowered the required level of temper and hence the cost of the saw, but it increased the frequency of sharpening.

Other workmen used regular axes or broad-axes to split sticks into staves, shingles, or fuel wood. And carpenters and craftsmen employed a handsome array of hammers, small saws, adzes, planes, chisels, rasps, and drills to shape pieces for final use, whether as building parts, cabinetry, tools, weapons, *objets d'art*, or whatever.

By the nineteenth century, then, Japan had a well-developed and complex system of wood provisioning. It was operated by an array of professionals – axmen, skidders, raftsmen, other rivermen, sawyers, and carpenters – most of whom were organized in guilds that protected their fields of expertise and employment. And timber merchants, who arranged and financed many of the logging and transport operations, also managed the lumberyards and handled most of the wholesaling, jobbing, and venture capitalization that the timber business entailed (Figs. 1, 2, and 3).

Industrial-Age Timber Handling

The world of preindustrial timber provisioning was thrown into turmoil during the 1860s when the established political order collapsed in the face of foreign encroachments. The new rulers set out to achieve rapid national self-strengthening, and that project entailed, among other things, sharply intensified exploitation of domestic resources, woodland included.



Timber-Handling Technology in Japan,
Fig. 1 Stacking wood at a lumberyard on Tatekawa Canal in a harbor side section of Edo (today's Tokyo). Men on the *left* stack split pieces of fuel wood; bales of charcoal are stored under thatch cover at their feet; sawyer

on right rips a timber to form planks; poles are stacked vertically to his *right*, partially obscuring Mt Fuji; plank-ing, boards, squared timbers, and long green bamboo poles are below him (Katsushika Hokusai, *Thirty Six Views of Mt. Fuji* (ca. 1820), in the author's possession)

Timber-Handling Technology in Japan,
Fig. 2 Sawyers rip a squared timber at Yamanaka in Tōtōmi Province, southwest of Mt Fuji, while another workman, seated before their temporary mountain hut, sharpens his saw, as family members look on. (Katsushika Hokusai, *Thirty Six Views of Mt Fuji* (ca. 1820), in the author's possession)



Those developments altered radically the techniques of felling, transporting, and milling timber.

Until around 1900 the organized guilds of axmen, raftsmen, and others were able to slow appreciably the inflow of new technology. But by then the use of crosscut saws – no longer

forbidden after 1868 – had become common, and they prevailed into the 1950s, until being displaced by chain saws. And in those areas, mainly in Hokkaido, where tractor-mounted mechanical saws are able to function, they and other similarly “high tech”

Timber-Handling Technology in Japan,

Fig. 3 Surrounded by his mallets and bamboo for hooping, a barrel maker smooths the inner surface of his staves at Fujimigahara in Owari Province, west of Mt Fuji (Katsushika Hokusai, *Thirty Six Views of Mt. Fuji* (ca. 1820), in the author's possession)



devices – feller-bunchers, skidders, processors, harvesters, forwarders, and tower yarders – have been introduced during recent decades in unsuccessful attempts to reduce labor costs enough so that the domestic timber harvest can compete with imports.

Rather similarly, raftsmen and rivermen retained their roles until around 1900, when timber began leaving the forest by tramway and railroad. By the 1930s nearly all flotation and rafting had ceased. But starting then, and especially after 1950, rails in turn gave way to roads as trucks and “Caterpillar” type tractors and sleds took over. In some interior valleys, moreover, highlines have come into use for carrying logs airborne from felling site down to assembly point, where they are yarded and loaded onto trucks or otherwise moved along for processing.

Sawmills had appeared in Japan by the 1870s, initially sash saws (vertically mounted, mechanically powered crosscut saws), subsequently circular saws, and eventually band saws (continuous ribbons of toothed steel driven at high speed by sheaves mounted above and below the saw carriage). The earliest were water and steam powered, but electric power, whether purchased or produced on site, came to prevail during the early 1900s. And internal-combustion engines later powered some portable mills. (Pulp,

plywood, and chip mills, technologies that are not discussed here, were introduced to Japan, respectively, in 1886, 1907, and 1957.)

The scale of Japan's sawmill technology has differed greatly from that found elsewhere. During the years ca. 1860–1920 the productivity of mills in Euro-America rose dramatically, tenfold or more. That rise was made possible by myriad technical improvements in saw types, power sources, and other aspects of mill equipment. But it also was premised on two conditions not found in Japan.

First, it presumed the existence of sprawling, richly stocked, flatland forests cut by leisurely flowing rivers that could float vast quantities of large, same-species logs to a sprawling sawmill site, flatland that would, a few decades later, provide easy terrain for the construction and use of roads and railways. Second, it presumed a system of woodland ownership that would allow a mill to obtain vast quantities of logs from large, more-or-less contiguous areas. In Japan, however, nearly all forests were on steep mountainsides, and possession was highly fragmented, about half being owned by smallholders with a few acres apiece, the other widely scattered half by government. Almost nowhere could a mill operator expect to obtain substantial quantities of large-scale timber from his immediate

environs for any extended period. In consequence, before World War II the most efficient technology did not fit Japan's circumstances, and the newest devices, band saws most importantly, were used in only a small portion of the country's sawmills.

During the first two decades after that war, great effort was made to introduce and refine the most up-to-date mill technology. However, from about 1970 onward, imported wood undermined the profitability of domestic milling, and the enthusiasm for technological change largely evaporated. Instead, sawmills gradually developed in two directions. Today large, highly integrated mills, which are set up at coastal sites near major markets expressly to handle imported logs, use elaborate, efficient, high-speed equipment to produce great volumes of lumber. Domestic timber, meanwhile, is mostly sawn at small mills set up in major timber-producing areas, where they use much simpler equipment to turn out high-grade, specialty lumber, but at rates comparable to those of American sawmills of the 1860s.

So today the timber-processing technology of Japan is used primarily to handle imported wood. And that situation seems likely to prevail for a few more decades, until destruction of the world's woodland drives global timber prices up enough to make Japan's mountain forests again competitive in the marketplace.

See Also

► [Forestry in Japan](#)

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Time

Henry J. Rutz

The dual classification of cultural systems of time as Western or non-Western is an oversimplification that limits our understanding of how time is created, represented, measured, and practiced in different cultures. The premises underlying dualistic thinking about time reveal its limitations.

First, dualistic thinking adopts the premise that Western time is linear (irreversible), abstract, quantitative, and homogeneous. In contrast, non-Western time is cyclical (reversible), concrete, qualitative, and heterogeneous. There is a tendency to draw too sharp distinctions based on characteristics presumed to be in opposition. Underlying these are further distinctions between *them* (Oriental, primitive, oral, preindustrial) and *us* (Occidental, modern, literate, industrial). Embedded in these implicit distinctions is the assumption that non-Western time is to be thought about within a conceptual frame that implicitly adopts Western time as a standard for perception and evaluation of non-Western time. In a word, dualistic thinking about time has been Eurocentric.

Second, dualistic thinking rests on the premise that Western and non-Western cultures are different and unrelated totalities, and that time is unitary within each. The Unitarian premise leads to generalizations such as believing that non-Western cultures have a cyclical as opposed to a linear concept of time. The result is that diversity is underreported and undertheorized.

Third, dual systems of culture and time suffer from an ahistorical and overly formal foundation to knowledge. Western societies have "history" and a consciousness of being in time, in contrast to non-Western societies which have "myth" and a sense only of relational time that renders events mere epiphenomena of structure. Myth is not about the causation of before and after but about a formal means for making all the elements and characters ever-present.

Fourth, the ahistoricist premise also leads to the view that non-Western societies have an awareness of themselves in time only to the extent that westerners bring such awareness to them, either in the form of historical consciousness or as a practical matter of the efficient and productive use of time as a resource.

Fifth, dualistic thinking rests on the premise that time is a thing that is either present or absent in a culture. A dichotomy between western *linear* time and non-Western *cyclical* time appears as real and coerces people to behave and think in a particular way. But the terms of this dualism are highly abstract and refer to no particular period, bounded space, social organization, or real people. The dichotomy bears little relation to the cultural construction of time in the everyday lives of people in a specific region, a particular period, or known conditions of migration, diffusion, and contact.

The situation is complex. While no cultural constructions of time have remained unaffected by European expansion, it is presumptuous to think that we know what aspects of European time (which varied in different periods and places) influenced a bewildering variety of religious communities, empires, and kin-ordered societies, each with its own historically constituted temporal rhythms. Indeed, examining the real complexities of culture and history raises important issues about temporal dynamics only to the extent that we abandon dualistic thinking.

An alternative perspective, one that anthropologists, historians, and archaeologists increasingly embrace, pays attention to multiple constructions of time in single social formations, the extent to which different times are articulated, and the temporal dynamics of development and change in the rhythms of everyday life.

While some languages lack a generic word for time, there is abundant evidence for the universality of concepts of duration and succession in the linguistic and cultural practices of every person. The French sociologist Émile Durkheim expressed the opinion that it is hardly possible to think about time "... without the processes by which we divide it, measure it or express it with

objective signs." These processes, he concluded, are social in origin. The anthropologist Edmund Leach, following Durkheim's lead, noted that "We talk of measuring time, as if it were a concrete thing waiting to be measured; but in fact we create time by creating intervals in social life. Until we have done this there is no time to be measured." To these ideas about time we need to add those of another French sociologist, Georges Gurvitch, who pointed out that every social formation has a multiplicity of times. Not only are there different collective representations of time among different cultures, but different time systems coexist within a single social formation.

These ideas, that time is culturally constructed, socially embedded, and multiple, have become guiding principles in cultural studies of time. The other articles on time in this encyclopedia illustrate the complexity and diversity of time systems from the multiplicity of time perspective. A brief comment on a number of issues will clarify the present direction in cultural studies of time systems.

1. Acceptance of the multiplicity of time within single social formations has led to the rejection of attempts to classify whole societies, not to mention a whole class of societies such as "Western" or "non-Western" by any single subsystem of time. Comparison remains important, but comparativists now recognize that they must seek out similar subsystems in different cultures. Leopold Howe, for example, disputes Clifford Geertz's conclusion that the Balinese calendrical system does not represent a flow by which the passage of time can be measured, that the calendar represents a concept of time that is nondurational, and that Balinese experience of time is of "islands" or points that are unconnected (an extreme form of discontinuity, imprecision, and noncountability). Geertz asserts that the particulate nature of days implies a nondurational concept of time. Such a description of Balinese time carries an implicit comparison with our own, based on dualistic assumptions that go unexamined in both. Howe provides

evidence that Balinese count days and are forever referring to past and future in terms of such counts. Geertz confused an attribute of members of a class with the class itself—each day is qualitatively different from others, but days fit into a succession that is endlessly repeated. Each name day partakes of being a day that *qua* day has the attribute of countability. The Maya had no such confusion. They viewed time as a flow that could be measured and also endowed days with qualities dependent upon the work of gods and men.

2. Recognition of the multiplicity of time shifts attention away from gross comparisons of presumed-to-be-different systems of time toward contextualized descriptions and similarities of subsystems in apparently different cultures. There has been a concomitant shift from classification to process, raising questions about temporal dynamics. How *does* time get constructed? What *are* the processes of development and change that account for the multiplicity of time and the degree of articulation among subsystems? Cultural studies of time have taken several directions, none of which is mutually exclusive. Nancy Munn challenges, from a phenomenological perspective, Evans-Pritchard's conclusion that Nuer time amounts to a creation of a static and nondevelopmental experience of time. His structural models of Nuer time overlook Nuer accounts of their bodily activity of procreation, their own subjective experience of time in terms of layers of ash on the fires, their ability to plan for events in the future, and other evidence of developmental constructs of time in their projects and practices. Peter Rigby, who has researched the age-set system of the pastoral Ilparakuyo Maasai in Kenya, challenges, from a historical materialist perspective, Evans-Pritchard's failure to address the degree of articulation of Nuer multiplicity of time. Had Evans-Pritchard taken into account the historical consciousness of Nuer, he would have found that all the elements of time-reckoning can be placed in a single conceptual frame arising from the historical development of Nuer within a specific social formation. Rigby, drawing on his own work and that of others, attempts such a synthesis for the Ilparakuyo Maasai.
3. Cultural studies of time that explore the underlying temporal dynamics of how a multiplicity of time is constructed have paid increasing attention to the politics of time. Cultural constructions of time are part of the political economy of development. The creation of time requires agents and agencies temporalizing their respective projects in struggles for power and legitimacy. Farriss' attempt to reconcile cyclical and linear concepts within the same calendrical system in Maya culture rests on an interpretation of Maya political transformation from city-states to rule by dynastic lineages. With the demise of Maya elites, subsystems of time wither and die.
4. The attention paid to the politics of time has raised anew issues about the reflexive study of time in different cultures. Johannes Fabian has criticized anthropologists for failing to recognize that theories which distance "other" cultures by placing them in an-other time unwittingly use time as an instrument of political domination. Apparently disinterested studies of difference are revealed to be interested studies of "the other", a form of cultural politics. The solution is to recognize that people of different cultures are contemporaries and use that as a point of departure for all conceptual frames concerning the politics of time. A reflexive approach to cultural construction of time would overcome Rigby's concern that most descriptions of time in "different" cultures are really implicit comparisons using hegemonic bourgeois time as a standard. Most of us reckon time in our daily lives by systems other than the formal-mathematical or chronological ones deployed by an army of scientists, historians, and anthropologists. Such reflexivity, or self-awareness, of our own multiple concepts of time would be salutary for advancing our understanding of the cultural construction of time in different cultures.

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Time in Africa

Henry J. Rutz

In every society, one source by which time is divided, measured, and expressed by objective signs is the mutual obligations and principles that structure social relations between persons and groups. Among the most important is kinship. In those societies in which kin communities encompass the widest range of social relations, time is expressed as duration and succession of kin-ordered activity. Perhaps the best-known case is that of the Nuer, a Nilotic pastoral people who live in villages of the upper reaches of the Nile in Sudan.

E.E. Evans-Pritchard has given us a rich account of ways in which village kin communities conceptualize and reckon time as an aspect of social structure. Among the multiplicity of times

apprehended by Nuer, three of the most important subsystems are (1) a series of social activities articulated with a series of ecological events by which one is used to measure the duration and succession of the other; (2) a series of age-sets that measures intervals and succession in the life cycle; and (3) a hierarchy of segmented kin groups that measures lapsed time, i.e., a form of collective memory of the “past” that constitutes the conceptual frame of Nuer history.

Nuer livelihood is based primarily on cattle herding and the cultivation of millet, a dual adaptation to vast stretches of marsh and savannah in a climate that necessitates a transhumant existence between village settlements on knolls during the rainy season and dry season cattle camps near rivers. A change of season is the objective sign for a change in settlement pattern, accompanied by changes in ceremonial and social activities. Most collective rituals, such as marriage and male initiation, take place in wet season villages, but the dry season cattle camps, when youth disperse to small camps in search of pasturage near sources of water, are viewed as a time of freedom and courting. In a rare comment on the experience of seasonal rhythms, Evans-Pritchard states that the pace of time speeded up during the wet season and slowed down during the dry season, an effect of the density of social activities and the significance the Nuer attributed to them.

Although the Nuer have no word for a generic “year”, they reckon cycles of wet and dry seasons, giving names to each, and divide the cycle into 12 named “moons” of unequal duration that mark the succession from wet to dry season and back again. The duration of months depends less upon lunar observance (though they are familiar with phases of the moon) than the agricultural and pastoral activities associated with ecological phases within seasons. Nuer adjust the series of ecological activities to fit social contingencies. If the Nuer were still in their dry camps, waiting for rain, then they would say that they were still in the named “moon” prior to the onset of rains. If they were still engaged in rituals associated with the wet season villages, then they would reckon the name of the moon by the social activities

appropriate to it. The result is an annual calendar embedded in a coordinated parallel series of ecological and social rhythms, the durations of which vary within and between cycles. Working one series against the other, Nuer rename months, skip months altogether, or even omit “years” in their recounting of socially significant events over a number of seasonal cycles.

Nuer can count seasonal cycles, months, and days (there is no “week”), but they tend not to. Chronology or a sense of lapsed time with respect to livelihood is culturally suppressed, giving the illusion of endless recurrence. Days, months, and seasons remain socially embedded and unarticulated as an abstract and numerical system independent of the concrete activities that lend the system meaning. The Nuer have no generic word for time.

Biological facts of individual maturation and aging, like ecological and physical facts, are given social significance in every society. But their division, measurement, and expression in objective signs are contingent and vary from one society to another.

Among Nuer, the reproduction of cattle, or cattle genealogies, is the basis of a concept of male personhood. Individual Nuer men are fiercely egalitarian and quick to defend themselves against perceived affronts to their manhood. The natural reproduction of cattle, combined with a culturally constituted series in the life cycle of male individuals—for example the transition from boyhood to manhood marked by the gift of a first cow, the transition to husband marked by a gift of cattle at marriage (a transfer from the groom’s to the wife’s kin), and a further transfer of cattle marking the transition to “fatherhood” with the birth of each successive child – regulate the rhythms of interpersonal kinship, articulating the pedigree of specific cows with the genealogy and life history of individuals.

Cattle genealogies mark the passage of time in the lives of individual male Nuer, a process that in its very nature is directional and irreversible. But Nuer also have organized individual male maturation as a collective problem of social significance. Village boys of comparable age

(between 14 and 16 years) are initiated into a named age-set during an open period. A “Man of the Cattle” is responsible for closing a period, “thereby dividing the sets.” The initiation consists of a painful ritual whereby each boy is cut to the bone across the forehead six times, producing deep scars called *gar*. His reward is a gift of his first cow and a taboo on milking. The only point of articulation between the seasonal and age-set time systems is the timing of the initiation, which occurs at the end of the wet season when food is plentiful. Proximate villages tend to coordinate periods despite independent declarations in each. Regions tend to share at least some age-set names (but vary the sequence), which differ from one part of Nuerland to another.

In pastoral Kenya and parts of Bantu East Africa, the age-set/generation-set system consists of age-sets organized into three distinct generation-sets of boys, warriors, and elders, with a pronounced taboo on warriors marrying. It is hard to avoid the conclusion that Nuer age-sets have something to do with the collective control of elders over young men. The military and administrative functions of Nuer age-sets, however, are attenuated and appear to have more to do with regulating the domestic obligations of manhood.

Nuer conceive of the age-set system as fixed at six living sets. Using a kinship idiom, they break the sets down into “brothers” who are equals, “fathers” who are elders in authority, and “sons” over whom they have authority. But age-set names are not repeated and Nuer do not perceive the age-set system as cyclical (some Bantu groups do). Age-sets whose members have died are not remembered or recounted. Even when a few old men of the most senior age-sets are still alive, junior age-sets are merging them with members of adjacent age-sets. The system is designed for the living, intended to mark lapsed time by the intervals between open and closed periods that define the age of one group of males relative to another in a weak form of gerontocracy. Like individual biography inscribed in cattle gifts and their genealogies, a sense of an irreversible flow of time is given in the fact that a named age-set “changes its position in relation

to the whole system, passing through points of relative juniority and seniority.”

All human communities develop collective representations of a past that embody a historical consciousness of the community *qua* community. Nuer have embedded their sense of historical consciousness in a model of a lineage system that creates the illusion of a fixed temporal horizon to events such as migration, tribal war, and territorial expansion that might otherwise be perceived as a succession of unique events in an irreversible “before and after” construction of past and future. The correct view of Nuer history is that it is ever-present and performative in the reciprocal rituals of lineage segments.

The segmentary principle of membership in a Nuer lineage is common descent through males from a recognized ancestor. The way Nuer think about tribal history is structured by how they think about the hierarchical relations between lineages, which also form the basis for claims to a division of territory. Reckoning political relations by lineages is relative because it depends on the particular person who is selected as the point of departure in tracing descent. The largest lineages, those which incorporate the widest latitude of members connected by descent from a common ancestor, are termed clans, and they in turn are comprised of lineages with several lines, each of which is a smaller lineage tracing descent through less distant ancestors to incorporate a narrower range of members.

The lineage system is employed by living Nuer to reckon their common past. Although every man is a potential founding ancestor, the social fiction is that the living are organized into segments in such a way that there are only 10–12 ancestors at the maximum social distance, and 3–4 at the minimum. This fixed system of reckoning is in contrast to the real events of Nuer history, which is one of human propagation inscribed in Nuer genealogical reckoning, expansion and contraction of territory, and the actual bifurcation and amalgamation of lineage segments. But the Nuer fit such events into a structure of lineages with a time depth of 10–12 generations when there is no reason to presume that they have existed for so short a time.

The Nuer express their political history as a fixed structure of relations between lineage segments. They prefer a stylization of history to a record of the endless march of unique events in an irreversible flow of time. The absence of writing and the strength of oral culture no doubt have something to do with it. The content of relations changes and is irreversible, no matter who the ancestors are or where a particular named unit fits into the hierarchy, but the structure remains constant. Eternal returns, with their prophecies of foretelling and fulfilment, or dynastic genealogies that record the unfolding succession of heroic deeds from some fixed starting point into a receding time horizon, are not the stuff of Nuer social history.

The Nuer are a tribal state without centralized authority. Their kin-ordering and genealogical reckoning are the key to their construction of time, which contrasts greatly with that of empires. In those states where imperial elites (military and religious) ruled over vast areas and innumerable village communities from imperial centres, there developed an awareness of time itself as an objective instrument of power and legitimation.

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Time in China

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Chinese methods of calculating time are of great antiquity. According to the *Shi Ji* (Book of Records), as early as 2254 BCE, Emperor Yao employed astronomers to calculate solstices and

equinoxes and predict seasonal change so that farmers would know when to plant crops. Oracle bones dating to ca. 1200–1181 BCE attest to the fact that Shang dynasty Chinese calculated time using a 60-day divinatory calendar that still is in widespread use. The early development of methods of measuring time was not entirely endogenous to China; cultures throughout the ancient world exchanged astronomical ideas and data.

Striking similarities exist between calendrical systems in widely separated regions, including parallels between the form and names of the Chinese and Maya divinatory calendars (Whittaker, 1990). At least as early as the first century BCE, the Chinese used a lunisolar calendar resembling the standardized Babylonian calendar developed in the fourth century BCE. The similarities suggest borrowing, and it is possible that the Babylonians were the original inspiration for the Chinese luni-solar calendar. In the Sui and Tang dynasties (589–960), Indian astronomers resided in China, and during the Yuan dynasty (1280–1368) Chinese collaborated with Persian and Arab astronomers. The technology of observation and measurement included an observatory built in Beijing during the Yuan dynasty. Contrasting with the astronomical system developed in Greek and medieval European astronomy, Chinese astronomy was polar and equatorial rather than ecliptic.

Although at times the Chinese borrowed astronomical ideas and technologies, these became incorporated into a system of time reckoning rooted in Chinese society. Sociologists have observed that time is a symbolic structure that represents a society's collective rhythms. In the Chinese calendar, some elements are based on astronomical cycles, while others have been shaped by the temporal rhythms of social life.

Chinese notions of the seasonal cycle are integrated into a system of classification based on the dualism of *yang* and *yin*. While *yang* and *yin* are often defined in terms of the complementary dualism of male and female, in Chinese they originally referred to sun and shadow, the very elements used to measure the changing seasons. For Chinese metaphysicians, *yang* and *yin* came

to denote primal cosmic forces that interacted to generate a cycle of five phases (*wuxing*) which were identified with five primary elements (wood, fire, metal, water, and earth). These phases and their associated elements were in turn identified with the seasons. Thus, Chinese classified spring with wood, summer with fire, autumn with metal, and winter with water, while earth was associated with the midpoint of the year.

This model of cyclical process associated the five phases with five colors (green, red, yellow, white, and black), directions (east, south, the center, west, and north), organs of the body, tastes, planets, virtues, passions, etc. Chinese elaborated rituals designed to control this cyclical process. Throughout the yearly cycle, the emperor performed rites to inaugurate the seasons, and his performance gave concrete expression to the association of season, direction, color, and ritual. Chinese thought that by means of these ritual performances, the emperor could ensure harmony in the universe and interpreted natural calamities as evidence of his loss of the “mandate of heaven” (Granet, 1934). The cosmological framework of *yin* and *yang* and the five phases also informed Daoist alchemy and still is fundamental to the Daoist rituals of popular religious culture (DeBernardi, 1992; Schipper 1993).

Chinese philosophers and scientists appreciated the importance of natural cycles and also linked the cycles of time with the cycles of human life. Not only they did link cyclic ideas of time to the liturgical calendar that regulated rites performed in the imperial court and its temples, but also they linked it to the microcosm of the body. In contrast with the taxonomic thinking that informs much Western science, Chinese explored patterns of function *through* time to make sense of various experiences, including ones related to health and illness. The associations of the five phases applied not only to the yearly cycle but also to the cycle of the month and the day. For example, Chinese medical practitioners thought that the “seasons of the day” could predict crisis periods for physical disorders affecting different parts of the body (Farquhar, 1992).

While cyclical time had key significance, Chinese also had a well-developed concept of continuous time. This concept found expression in “continuity history writing,” in which historians sought to chronicle causal sequences of events in history. While official historians recorded the objective facts of history, they also critiqued the past in a form of “praise and blame” historiography that sought to discern the logic of a *Dao* (path or way) that had its origins in Heaven. Thus, the rulers of China employed history, like divination, as a means to gain insight into the logic of events and as a guide to appropriate action.

In an agricultural society, charting seasonal change was crucial, and one responsibility of the emperor was promulgation of the lunisolar calendar. Since promulgation of a calendar was a political responsibility and privilege, astronomy was an orthodox Confucian science. Every year a Board of Mathematicians led by an Imperial Astronomer (who was a Minister of State) prepared the calendar. After the emperor approved the new almanac, high-ranking officials received it with great ceremony. The emperor, who had exclusive rights to promulgate the calendar, also bestowed the almanac upon China’s vassal states as a mark of favor. During the Qing dynasty (1644–1911) over two million almanacs were officially printed each year, and excess copies were available for sale. Despite this imperial monopoly, pirated editions circulated widely. Rebellious feudal lords sometimes expressed their withdrawal of allegiance by issuing a new calendar.

The Chinese used the calendar as an instrument to predict not only the best time for planting but also the best time to initiate action. As a consequence, astronomy was interwoven with astrology and divination. Details of the zodiac are still published in the almanac, and the Chinese may consult this source to predict dates that are propitious or unpropitious for human undertakings such as weddings.

The most ancient method of timekeeping is the 60-day divinatory calendar, evidence for which appears on oracle bones in the late Shang dynasty (ca. 2300–1181 BCE). The cycle is composed of two interlocking sets of cyclical characters that

are combined to form 60 unique two-syllable names. The “Ten Heavenly Stems” (*tian gan*) revolve in concert with the “Twelve Earthly Branches” (*di zhi*), and their combination generated 60 cyclical names. These 60 combinations were arranged in six 10-day groupings called *xun*. Since the first century BCE, years have been named after the consecutive days of the divinatory calendar, producing a repeating 60-year cycle. In the late Shang dynasty, the *xun* of the dyadic divinatory cycle was the basis for ordering sacrifices to royal ancestors. A full ritual cycle was completed in 360 days, increased to 370 by the addition of an intercalary *xun* every second cycle. This arrangement created a calendar that approximated the length of a solar year.

The Twelve Earthly Branches correspond to the 12 signs of the Chinese solar zodiac, which also name 12 constellations used to calculate the position of the sun every month. The zodiac animals (six wild or mythical and six domestic) are the rat, ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, cock, dog, and pig. They are divided between passive *yin* and active *yang* symbols and name the years in a repeating 12-year cycle. Chinese popular wisdom has it that persons who are born in a particular year have personalities shaped by the associated zodiac animal. Individuals should avoid marriage with persons born in the zodiac years of antagonistic animals and also seek to avoid having children during such years (Smith, 1991).

The task facing early astronomers who sought to invent a calendar for use in predicting the seasons involved reconciling lunar and solar cycles. The regular cycle of the moon provided a readily observed celestial clock, but the lunar year does not correspond with the seasons, since 12 lunar months produces a cycle of only 354 days. The yearly cycle of the sun produces a cycle of 365 1/4 days, but it does not predict the full moon. The 365-day Gregorian calendar follows the solar year alone, with an extra day added every leap year to adjust for the fraction. The Chinese, however, sought to reconcile solar and lunar calendars (Bredon and Mitrophanow, 1927: pp. 6-10).

By the eighth century BCE, Chinese could calculate and record eclipses, and they knew of the Metonic cycle. This was a 19-year cycle at whose beginning and end the sun and moon are in the same relative position to each other. Discovery of this cycle led to a system of coordination of lunar and solar cycles that resembles the Babylonian standardized calendar, and some authors have suggested that this system was perhaps borrowed rather than invented (for details of debates, see Needham, 1959, pp. 171–177).

During 19 solar years, there were 235 lunar months, and Chinese astronomers divided these into 12 years that were 12 lunar months long and 7 years that were 13 lunar months long. The 13-month years were produced by duplicating 1 month. The inventor of this calendar introduced that intercalary month in such a way as to ensure that the winter solstice always occurred in the eleventh lunar month, the summer solstice in the fifth, the spring equinox in the second, and the autumn equinox in the eighth. In addition, the introduction of an intercalary month ensured that the Chinese New Year always fell on the second new moon after the winter solstice, between January 20th and February 19th.

Before the adoption of the lunisolar calendar, Chinese dynasties inaugurated their reign by adopting a different month as the beginning of the civil year. The Manchus are said to have followed this tradition when Emperor Kang Xi in 1669 adopted the revised calendar proposed to him by the Jesuit Father Verbiest. The Republican Government expressed its break with imperial rule by adopting the Gregorian calendar, which was favored because of its universality. Its adoption also eliminated a powerful source of imperial authority, since monopolistic control of the calendar contributed to a mystification of Manchu power. Nonetheless, the traditional lunisolar almanac still regulates the cycle of community festivals and the rituals of ancestor worship.

See Also

- [Astrology in China](#)
- [Calendars in East Asia](#)

- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)
- [Five Phases \(Wuxing\)](#)
- [Geomancy in China](#)
- [Knowledge Systems in China](#)
- [Lunar Lodges in Chinese Astronomy](#)
- [Stars in Chinese Astronomy](#)
- [Yinyang](#)

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Time in Islam

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Islam is now a major global religion. It has its roots, however, in the Arabian Peninsula of the early seventh century. Its core elements were implanted in the early years and all later developments relate, one way or another, to that core.

In pre-Islamic Arabia some elements seem to have related to time (*dahr*) as fate, an underlying force directing human and natural destiny. It was conceived as a power existing eternally and responsible for the happiness or agony of humanity. Thus the *Qurʾān* refers to those who “say. . . ‘nothing but time can destroy us’.” [45:24/23]

While time was generally seen as an impersonal force, some people sought to identify God with time or, worse still by Islamic standards, to use this concept to deny God’s existence. The Apostolic Tradition (*ḥadīth*) records Muḥammad’s saying that Allah commanded men not to blame *dahr* “for I [God] am *dahr*.” Later there were various groups of radical thinkers, often only vaguely defined and known primarily from polemic references, who asserted “the eternity of the course of time.” Accordingly, because they denied both Creation and Judgment, the beginning and end of time, they were considered atheists. The term *dahrīya*, therefore, came to encompass a broad spectrum of dissenters advocating some form of atheism and/or hedonistic materialism.

Islam universally views time as created. It is God’s handiwork which, like all Creation, is under God’s command. God acts in and through history but, being eternal, time does not encompass him. Nature is also his Creation but, while it manifests his greatness, it in no way encompasses Allah.

According to al-Bayḍāwī (d. 1282) in the *Anwār at-tanzīl wa-asrār at-taʾwīl* (The Lights of the Revelation and the Secrets of the Interpretation), time consists of *mudda*, the period of revolution of the sphere from beginning to end (i.e., the totality of time); *az-Zamān*, a gross subdivision of *mudda* into long periods of time (e.g., specific historical eras such as dynastic reigns); and *al-Waqt*, a fine subdivision of *zamān* into definite points of time or short intervals (e.g., precise times of the five obligatory prayers).

There are some within the Islamic tradition who assert that time, begun at Creation, has no necessary end. Al-Ghazālī (1058–1111), speaking in the *Tahāfut al-falāsifah* (Inconsistency of the Philosophers) for the mainstream tradition,

teaches that religious dogma, for example the Day of Judgment, points to a finite end to time.

Measurement of Time

The two most significant historical eras, in the consciousness of Muslims, are the Age of Ignorance (*al-Jāhiliya*), the Dark Age in Arabia before the revelation of the *Qurʾān*, and the Islamic age stretching from the formation of the Islamic community in AD 622 until the end of history at Judgment.

There is evidence which suggests that most ancient Arabs followed a pure lunar calendar. About two centuries before the Prophet, apparently under the influence of Jewish civilization, many in Arabia adopted a lunisolar calendar. After Muḥammad’s transfer to Medina (the *hijra*), an absolute lunar calculation was mandated.

The *hijrī* year consists, in theory, of 12 months of 29 days, 12 h, 44 min, and 3 s. In fact, for various practical reasons, the lunar months are computed variously as having either 29 or 30 days. The *hijrī* year is about 11 days shorter than the solar year. There is no intercalation to the solar. Any particular *hijrī* date, over a period of approximately 33 years, will move through all four solar seasons.

A number of Islamic societies have introduced a solar or lunisolar calendar (e.g., pre-revolutionary Iran, Kemalist Turkey). None of these has achieved any universal acceptance among the world’s Muslims. It is accepted, further, that such a calendar has no support in the *Qurʾān* or the prophetic *Sunnah*.

Specific points in the yearly cycle are sanctified and celebrated in various ways. There are many local holidays and celebrations, and certain times are acknowledged as primary Muslim holy times. The first is the month of Ramaḍān during which the Muḥammad’s prophetic career was begun. For the entire month Muslims abstain from food, drink, smoking, and sexual contact. The fast

begins each day at the moment that there is sufficient light to distinguish white from black threads. It ends each night after the sun has completely set. Islam's "lesser feast," *'Id al-Fiṭr* (breakfast), brings release from the month-long abstention.

The "greater feast" is the *'Id al-Aḍḥā* (Feast of Sacrifice) on the tenth of Dhū 'l-Hijjah. It celebrates the end of the Holy Pilgrimage (*Hajj*) and reenacts Abraham's sacrifice of a ram in place of his son (*Qur'ān* 37:102). The primary sacrifice is made by the pilgrims in the valley of Minā, near Mecca. Muslims all over the world also offer such a sacrifice.

In Muḥammad's time the Arabs counted a 7-day week. There is evidence that this is a relatively late practice imported from Babylonia (or, perhaps, by way of resident Jewish communities who observed the weekly Sabbath). Earlier time flow was divided according to weather and similar seasonal changes. Under Islam the week was given significance by assigning a special status to Friday. It is not a day of rest but rather a day of communal prayer.

Time as a Moral Dimension

By [the token of] Time [through the Ages].
Verily Man is in loss.
Except such as have faith and do righteous deeds
and
[join together]
in the mutual teaching of truth and of patience and
constancy. (*Qur'ān* 103: 1–3)

There are numerous Quranic references to man's time and God's time. "He rules [all] affairs from the heavens to the earth: in the end will [all affairs] go up to Him, on a Day, the space whereof will be [as] a thousand years of your reckoning [32:5]." Creation, as well, is said to have been effected in 6 days [32:4]. Exegetes often emphasize that the days of Creation, before the placement of the sun, refer to God's days reckoned as a thousand man years (and, in 70:4, to 50,000 years). Muslim scholars reiterate that Allah is in no way bound by time; he is totally transcendent.

The point is that throughout the course of human history God maintains full control over his Creation. In his mercy Allah provided man with a window to his will and commanded him in the straight path. When time ends, at Judgment, man will face his time compacted to God's scale. "... In the immense future all affairs will go up to Him, for He will be the Judge, and His restoration of all values will be as a day or an hour or the twinkling of an eye; and yet to our idea it will be a thousand years" (Yūsuf Alī).

There is an implicit ambivalence as regards the pursuit of scientific and technological knowledge. In so far as the Muslim centers his consciousness on God, his greatness and omnipotence, he can easily succumb to a fatalistic acceptance of what comes to him. He then asserts God's absolute will and denies causality in nature. Without cause and effect there is no necessary natural order. In so far as man sees time as his sphere of action, he can hear the Quranic command to perceive God in his Creation. Exploration of the world becomes an act of moral compliance.

Time's purpose is to serve as an arena of moral action. It is the place which God has established for the exercise of will. Judgment and consequent assignment to paradise or hellfire will mean the end of time, its sole purpose being the setting for man's surrender.

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Time in Korea

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Timekeeping: Introduction

In the Confucianism-dominated ancient East Asia, following the practices of Emperors Yao and Shun became the ideal politics of royal statesmanship, which was believed to be a way to realize the rule of heaven. Therefore, “observing the heavens and granting the seasons” became a priority for all rulers. As a result, the armillary sphere, a basic instrument for celestial observation, was developed and made the calendrical system based on the observation results collected through this device. Chinese calendar, astronomical instruments and star maps, and timekeeping systems and timepieces were introduced to the Korean peninsula from remote antiquity. Timekeeping was both a royal duty and a royal prerogative in premodern Korea since the period of the Three Kingdoms (ca. 57 BC to 935 AD) of Silla, Baekje, and Goguryeo. In this period, Han and Tang Chinese-style sundials and clepsydras (water clocks) might have been introduced, although they developed fire clocks such as incense sticks at Buddhist temples. Baekje sent astronomers and calendar experts to Japan to teach calendar- and clock-making from 554 AD. It is believed that the clepsydra of Emperor Tenji (r. 661–671) deifying as God of Time in Japan was made in 671 AD by the Koreans coming across the sea. In 647, stargazing tower (*Cheomseongdae*), as its name implies, was built at Gyeongju during the Silla Queen Seondeok’s (r. 632–647) reign and has survived intact for more than 1,360 years. Actually, four different astronomical observatories have been referred to as *Cheomseongdae* in Korean historical records. The first one was located in Pyongyang, the then capital of the

Goguryeo kingdom. Unfortunately, the structure no longer remains. Another two, in Goryeo and Joseon kingdoms, still stand in the outskirts of Kaesong, North Korea, and in Seoul, South Korea. The one in Gyeongju is known as the oldest astronomical observatory in East Asia. In 718, the Silla government set up the Office of Water Clock and constructed a water clock at Hwangryong Temple, to assign doctors of astronomy and clepsydra. In 774, they cast a big bronze bell at Bongdeok-sa Temple, which tolled to announce the time for morning and evening prayers (Fig. 1).

During the Three Kingdoms period, they imported Chinese calendars, such as the “Great Expansion” calendar *Dayan-li*, “Chimer Virtue” calendar *Linte-li*, and “Extending Enlightenment” calendar *Xuanming-li* from Tang. They divided a full day into 12 double-hours and 100 marks and also divided a night into five night watches. Civilian time-announcing services were carried out according to the calendars employing water clock and bell (Nam, 1995).

The Goryeo dynasty (918–1391) kept a close relationship with the Yuan from the mid-thirteenth century and employed the “Season-Granting” calendar *Shoushi-li* distributed by the Yuan emperor in 1281 and the “Great Concordance” *Datong-li* from the Ming in 1370, respectively. These were major tools for the dual timekeeping. A full day was divided into 12 double-hours and 100 marks, a night subdivided into five night watches and 25 points. They ran the Astro-calendric Office *Seoun-gwan* which took charge of the astronomical, geographical, calendrical, and clepsydral timekeeping matters. They made water clocks and sundials (Nam, 1995). King Chungseon (r. 1298, 1308–1313) of the Goryeo collected the Neo-Confucian Song literature and the Mongolian and Islamic sciences in Yuan China and brought them to Kaesong. The al-Jazari’s (1206) book on the Islamic clock-making technology employing ball-powered transmissions might have been included in the king’s collections.



Time in Korea, Fig. 1 The Divine Bell of King Seongdeok (r. 702–737) the Great is also commonly known as the “Emille Bell,” a name related to child sacrifice legend. Some say that that bell, when struck, produces the sound of a baby crying (*em-ee-leh*). Today, taped recordings of the tolling bell have also been played on the hour to mark the time of day (Collection: Gyeongju National Museum, Gyeongju. Height: 375 cm, Weight: 19 tons. Photo by MH Nam (author), 1994)

The founders of Joseon dynasty (1392–1910) adopted Neo-Confucianism as the state ideology. The Neo-Confucian tenet of “observing the heaven and granting the seasons to the people” led to the production of calendars for farming and the reckoning of the time of day, which provided motivations to make accurate timekeepers. The Joseon rulers took over the Astro-calendric Office from the former dynasty and assigned astronomical, geographical, calendrical, meteorological, divinations, and clepsydral timekeeping duties. Ten engineers and craftsmen to make timekeepers and for timekeeping were assigned

to the Astro-calendric Office. The Prime State Councilor was appointed as the head of the office. Astronomy became the major discipline of the royal family.

The founder King Taejo (r. 1392–1398) built a bell tower *jongnu* in the downtown capital which announced the time provided by a newly cast night-watch clepsydra *gyeong-nu* in 1398. It was the first standard timekeeper in the capital Hanyang (now Seoul). The third monarch, Taejong (r. 1400–1418), was a scientifically inclined ruler who worked with his son, the future King Sejong (r. 1418–1450), to improve printing technology and clock-making. Assisting them in their works was the Court Engineer Jang Yeong-sil (ca. 1380–1445) who cast a new night-watch clepsydra *gyeongjeom-jigi*, the Striking Clepsydras, and various instruments.

After ascending the throne, Sejong commissioned his ministers to correct the calendar because of difficulties in measuring time with the Nanjing-based almanac in Seoul. Sejong decided to adjust the Season-Granting system according to the latitude 37.5°N of Seoul and saw that it required the installation of astronomical instruments and clocks to observe the heavens and to measure with accuracy the hours at Seoul.

The king began to equip the astronomical observatory from 1432 to 1438, and five astronomical installations and instruments were constructed and ten kinds of timekeeping devices were created. In the course of the project, Jang Yeong-sil invented and installed two Striking Clepsydras: the Striking Palace Clepsydra employed as standard timekeeper and the Striking Heavenly Clepsydra as an ideological instrument (see details below). In the portable water clocks, Traveling Clepsydras were carried by the Clepsydra Warden of the Astro-calendric Office for royal processions outside the royal palaces, rituals, and defenses at the military camps in the border.

The sundials mounting an equatorial-polar alignment and/or all thread-gnomons Scaphe-, Plummet-, Horizontal-, and South-determining

were new and used at the palace observatory, Astro-calendric Office, military camps, public places, and palaces. Among these, the upward-facing Scaphe sundial *Angbuilgui* was made for public use in 1434 and has been developed with various different types up to today (see details below). Two small simplified Armilla were employed to observe celestial bodies and time-keeping at the palace observatory and Astro-calendric Office, respectively. The sun-and-star time-determination instrument and its smaller version were created for measuring solar and sidereal hours. They were composed of a sun-and star-dial mounting an equatorial-polar alignment and thread gnomons. And most of these were installed on the west side of the *Gyeongbokgung* palace compound, and several instruments and timekeepers were at the Astro-calendric Office near the palace for regular observations. Calendrical undertakings ended in 1445 after more than 20 years of effort. The correction of the Season-Granting system fitted to the latitude of Seoul 37.5°N ended with the publishing of the *Calculations on the Celestial Motions of Seven Regulators Calendar Inner and Outer Volume* [*Chiljeongsan-nae-oe-pyeon*]. These provided a base for making timekeepers and keeping local time at Seoul for 200 or more years until the adoption of the Western-Style Temporal Model Calendar *Shixian-li* which was developed by the Jesuit missionaries and Chinese calendar experts of Beijing in the early seventeenth century.

In 1653, 17th monarch Hyojong (r. 1649–1659) promulgated adopting the Temporal Model Calendar. The traditional *Chiljeongsan*-based timekeeping system was changed to the Western time-reckoning system: 12 double-hours and 96 marks in a full day replacing the former 12 double-hours and 100 marks accordingly. The circumference of the circle 365 1/4 *do* (traditional Chinese degree) was changed to 360°. Several kinds of mechanical clocks were introduced through China and Japan from the 1630s. In 1669, a Court Engineer Yi Min-cheol (1631–1715) and a Professor of Astronomy Song I-yeong (1619–1692) made a traditional water-operated astronomical clock

and a Western-style astronomical clock driven by weights, respectively (see details below).

Timekeepers: Water Clocks, Mechanical Clocks, and Sundials

The Striking Palace Clepsydra

The Chief Court Engineer Jang Yeong-sil invented the Striking Palace Clepsydra *Jagyeok-gungnu* in 1433 under the order and commission of Sejong. It was installed at Announcing Clepsydra Pavilion *Borugak* in the *Gyeongbokgung* and the king assigned it as standard timekeeper from the first day of seventh lunar moon of 1434. The story on the making of the clock was written by Academicians of Hall of Worthies Kim Don (1385–1440) and Kim Jo (d. 1445) as the *Records of the Announcing Clepsydra Pavilion*. The records consist of memoirs by Kim Jo and inscriptions with preface by Kim Jo. The new clock was named after its housing as the Clock of the Announcing Clepsydra Pavilion *Borugangnu* officially or “palace clepsydra” *geumnu* literally.

According to the Kim Don’s memoirs, the Striking Palace Clepsydra consisted of three parts: (1) an inflow-type water-clock system with the dual-time-measuring and dual-time small-ball releasing mechanisms to mark the beginning of each double-hour and each night watch and their points. The system comprised three water-delivering vessels (reservoir, compensator, regulator) on the deck, an overflow receptacle, and two water-receiving vessels (time-measuring cylinders) to float indicator rods for daily changeover on the floor bed. On top of the measuring vessels, two rectangular-shaped dual-time small-ball releasing mechanisms (ball racks) are erected as shown in the left part of Fig. 2. The mechanisms cause dual-time small balls to fall, i.e., 12 balls for 12 double-hours and 25 for five night watches and their 25 points sequentially as time passes. (2) The Striking Palace Clepsydra also consisted of dual-time-announcing systems powered by dual-time large balls at the beginning of each double-hour and at each night watch and their points. The systems consisted of a dual-time



Time in Korea, Fig. 2 The Striking Palace Clepsydra. (Reconstruction) *Left*: An inflow-type water-clock system. *Right*: A dual-time-announcing system. *Middle*: Four dual-time small-ball receiving funnels and their ball transmission routes to connect the water-clock and the dual-time-announcing systems. The time-announcing mechanisms are as follows: Water trickles from the regulating vessel into a measuring vessel, to raise the indicating-rod float as time passes, to trigger the ball racks on top of the vessel, and to release the dual-time

small copper balls on the ball racks. The balls fall into the funnels on top of the vessel and travel through routes to enter to the dual-time small-ball-to-large-ball converters, to discharge hen-egg-sized iron balls to the double-hours and a night watch and their points machines under the converters. The large balls activate the machine controllers to sound the bell and to display a time tablet and to sound the drum and the gong by the corresponding figures (Length: 6 m, Height: 5.7 m, Width: 2 m. Collection of the National Palace Museum of Korea, Seoul)

small-ball-to-large-ball converter, the double-hour announcing machine, and the night watches and their points announcing machine as shown in the right part of Fig. 2. The double-hour machine consisted of a bell and a wooden striker on the pedestal and 12 time tablets (names of 12 double-hour animals) bearing wooden figures in the box which were linked to the double-hour machine controller in the box. When the bell rang at the beginning of each double-hour, then the corresponding time figure popped up to replace the former one sequentially telling the time. The night watches and their points machine consisted of a drum and a gong which are hit by wooden figures on the pedestal which were linked to the night watches and their points machine controller in the box. To announce night watches, the drum and the gong sounded for the number of night watch points. Two machine controllers were activated by hen-egg-sized large iron balls falling from the dual-time small-ball-to-large-ball converter. (3) There were four dual-time small-ball receiving funnels and their ball transmission

routes which were connected with the water-clock and the dual-time-announcing systems.

The clock was used as standard timekeeper to announce the time of the curfew alert *Injeong* (“people at rest”) in the evening and the removal of curfew *Paru* (“quit the clepsydra”) in the morning and mid-day drum *Ogo* (“quit morning services”) following the sunrise and sunset times in Seoul. The uniqueness of the clock was its capability to announce dual times automatically with visual and audible signals. The length of each night watch varies throughout a year and a night watch corresponds to about 2 h today. To match the variations of the 24 Fortnightly Periods with daily civilian life, the maker of the clock made an operating instruction *Manual on the Calculation and Usage of Clepsydra Indicator-rods Nuju-tongui* according to the sunrise and sunset hours of Seoul employing the *Calculations on the Celestial Motions of Seven Regulators* calendar *Inner Volume*. And then they calibrated night watch graduations with the double-hours on the water-clock’s float rods and made 11 pairs of

the indicating rods and the ball racks for sequential use throughout a year. The clepsydra warden began with the first pair of an indicating rod and a ball rack at the winter solstice and changed the pairs until the summer solstice (11th pair) sequentially at about 15 day intervals and then vice versa, from the 11th pair to the second one before the winter solstice. They used first and eleventh pairs for about 30 days each (Nam, 2014).

In 1536, under the commission of King Jungjong (r. 1506–1544), a court horologist, Park Se-ryong, made a copy of the Striking Palace Clepsydra of Sejong at *Changdeokgung* palace. The Sejong's Striking Palace Clepsydra was burnt down during the Japanese Hideyoshi's invasion of Korea in 1592. Fortunately, King Jungjong's 1536 clepsydra survived with some damages and it was restored in 1618 by Prince Gwanghae (r. 1609–1622) and housed at a new location in *Changgyeonggung* palace. It was used as the standard timekeeper and revived to the newly built clepsydra house on King Sejong's old *Borugak* site at *Gyeongbokgung* palace in 1863 and employed as standard timekeeper until 1895. Since then it was displayed outdoors for exhibition from 1908 and has been housed at *Deoksugung* palace since 1938 (Fig. 3) (Nam, 2000).

The Striking Palace Clepsydra is an integration of the traditional East-Asian inflow-float rod clepsydra and the Islamic ball-operated water clock (Needham et al. 1986). As we have seen above, the inflow-type water clock to measure dual time and the two ball-operated time-announcing machines to tell dual time were combined via a dual-time small-ball releasing mechanism on top of the measuring vessel, i.e., analogue to digital converter (A/DC) in a modern sense. King Sejong and his court scholars might have adopted the three-step inflow water-clock model of Wang Pu (AD 1135) of the Song dynasty in designing their water clock. And they got the ideas from the ball mechanisms of the Byzantine era and Islamic horology in designing discrete time-telling mechanisms (Hill, 1981). Early thirteen-century Islamic Engineer Al-Jazari's ball-operated Candle and Elephant



Time in Korea, Fig. 3 Remains of the 1536 replica of Sejong's 1434 Striking Palace Clepsydra are currently on the grounds of the *Deoksugung* palace. From the top, the water-delivering vessels (a reservoir, a compensator, and a regulator) are on the square-stone bases (mis-arrayed), and two dragon-ornamented inflow-float time-measuring vessels (2 m high, 32 cm in diameter, all bronze cast) are on the floor bed. In addition to the vessels, two turtle-shaped floats (copper plate machined) and an indicator rod are kept in the inflow vessels (Photo by the author MH Nam, 1994)

Clocks inspired them in designing the dual-time A/DC mechanisms and time-announcing machines (Al-Jazari, 1206; Needham et al., 1986). These innovative twofold power source methods enabled and secured accurate time measurement and effective time telling. Needham et al. (1986) argued that the transmission of ball-powered techniques of Islamic world came through China to Korea as follows:

The fact that in the fifteenth century automatically sounding clepsydias employing falling balls were in use across the entire span of the Old World, from Fez to Seoul, testifies eloquently to the ability of

ideas to travel far and quickly among the great civilisations of premodern times.

In 1437, Chief Court Engineer Jang Yeong-sil applied his experiences to make a functional astronomical clock the Striking Heavenly Clepsydra. He employed water-operated wheel mechanisms and ball mechanisms. The tradition of employing ball mechanisms was inherited by court engineers in making astronomical clocks in the seventeenth-century Korea (Nam, 2012).

The Striking Heavenly Clepsydra

In 1438, Chief Court Engineer Jang Yeong-sil completed his second Striking Clepsydra under the guidance of Sejong and installed it at the Respectful Veneration Pavilion *Heumgyeonggak* in *Gyeongbokgung* palace. So the clock was officially named the Clock of the Respectful Veneration Pavilion *Heumgyeonggang-nu*. According to the *Memoir of Respectful Veneration Pavilion Heumgyeonggak-gi*, written by the academician

Kim Don, they installed a sounding clock, a water-operated mechanical wheel, and a prime mover capable of revolving the golden model sun around a pasted-paper mountain once every day. In conjunction with the wheel, the ball mechanisms operated three kinds time-announcing mechanisms. In addition to these mechanisms, an inclining vessel was filled by overflowing water from the clepsydra. It was emptied when it was full and upright when it was half full. The mountain was surrounded by rural scenes of the four seasons depicting the farmers in rice fields. Figure 4 shows a visual image of the clock following Kim Don's memoirs.

The uniqueness of the clepsydra was its capability to demonstrate celestial movements and to announce the 12 double-hours and five night watches and their points automatically with visual and audible signals. As its name implies, it was used in conjunction with edifying Confucianism rather than observation. Kim Don said, "Everything was more ingenious and excellent



Time in Korea, Fig. 4 Artist's concept of the Striking Heavenly Clepsydra. A golden sun-model rotates along the peaks of a mountain that was surrounded by five-colored clouds once each day. Inside the pasted-paper mountain, a water-operated mechanical wheel which rotates by the trickling water which is supplied from the jade clepsydra. The wheel mechanisms are connected to the sun revolving device and three kinds of time-announcing mechanisms: (1) the Four Guardian Spirits (Eastern Blue Dragon, Southern Red Bird, Western White Tiger, and Northern Black Snake) and four female

jade time-announcing figures; (2) the 12 Spirit Generals [figures] of the Zodiac, occupying their respective positions, and 12 time tablet-bearing female jade figures on the level ground; and (3) at the southern foot of the mountain stands a high platform and four hour-jacks and bell, drum, and gong which are operated by ball mechanisms. South of the mountain stands an official figure who pours water into an inclining vessel. Around the mountain, there is rural scenery of the four seasons cited from the *Ode of Bin* depicting peasants working around the rice field, and there are wooden carvings of men, birds, and plants

than the traditional designs. All of these operations are performed automatically, without any human help. It seemed that the immortals operated the mechanisms; onlookers were struck with admiration and could not guess how it worked” (Annals of Sejong, 1438). This clock was an edifying instrument of royal prestige emphasizing the importance of observing the heavens and acknowledging the seasons and of helping agriculture and being aware of the Confucian moral tenet for all the people.

The clock was reconstructed twice in 1554 and 1614 after its destruction by fire. The last version was abolished in 1656. The clock had been maintained for 218 years, and the technical details might have been handed down and innovated upon to make subsequent astronomical clocks two decades later. Information related to design following astronomical clocks made it possible to conjecture plausible technical features (Hahn, Nam, Lee, & Lee, 2000). Detailed operational structures were not fully realized because of the dearth of technical information in the memoirs. In spite of this, the clock has its predecessors: the water-powered armillary sphere and globe tower of Su Song and Han Gong-lian in AD 1092 during the Northern Song, the Lantern Clepsydra of Guo Shoujing in 1272, the Palace Clepsydra of Yuan Shun-di during 1350s, and the Striking Palace Clepsydra, back to the al-Jazari’s Islamic water clocks. The clock inherited the East-Asian tradition of astronomical clock-making and became a forerunner of astronomical clocks of Yi Min-cheol and Song I-yeong in 1669 (Nam, 2012).

The Astronomical Clocks

Two decades after the abolishment of the Striking Heavenly Clepsydra in 1656, a magistrate, Choe Yu-ji (1603–1673), made a water-powered armillary sphere *seongi-okhyeong* in 1657. In 1664, King Hyeonjong (r. 1660–1674) ordered Yi Min-cheol and Song I-yeong to renovate Choe’s armillary sphere. In 1669, Song Jun-gil (1606–1672) submitted a petition to Hyeonjong to revive the Hall of Respectful Veneration of the Sejong. This caused Yi Min-cheol and Song

I-yeong to recreate the Striking Heavenly Clepsydra. Yi made a water-operated striking armillary sphere *honcheonui* employing a water wheel driving mechanism, an armillary sphere combined with model sun- and moon-carrying mechanisms, and a ball-operated carousel-wheel time-announcing mechanism (Annals of Hyeonjong, 1669, 17: 35ab; Hahn & Nam, 1997). It was installed by the side of the king’s chair as a symbol of kingship and then moved to Jejeong Pavilion in Changdeokgung palace after repairs in 1687.

Song I-yeong made a weight-driven striking armillary sphere called “self-sounding clock” *jamyeong-jong* employing Western clockwork. According to Kim Seok-ju’s (1634–1684) memoir, “The armillary sphere made by Song I-yeong was much same as that of Yi Min-cheol in general design, but he used the gear wheels of Western clockwork...” Both clocks employed a traditional armillary sphere with different driving methods: one was operated by a water-powered clepsydral mechanism and the other by weight-driven gear wheels, but both employed jackwork carousel wheels after the Striking Clepsydras. The jackwork figures were reduced in size and replaced by a disk time tablet and they added a ball-run mechanism incorporating a paddle wheel (Kim, 1907). It had been installed at the Office of Study Promotion and Special Advisors *Hongmungwan* until the fall of the Joseon dynasty. It was repaired under the order of King Sukjong (r. 1674–1720) by Yi Jin, and Choe Seok-jeong (1646–1715) and Oh Do-il (1645–1703) wrote *Inscriptions with Preface of Self-sounding Clock* in 1687 (Hahn & Nam, 1997). In the course of repair, Yi Jin might have adopted Christian a Huygens’ (1629–95) crown-wheel escapement and pendulum-type clockwork mechanism which was a state-of-the-art technology at that time. A small terrestrial globe showing a world map was incorporated instead of the telescopic mechanism of the armillary sphere.

Figure 5 shows the remains of Song I-yeong’s clock, showing a demonstrational armillary sphere on the left stand, two weight-drive clockworks inside the long rectangular case, and a time-announcing mechanism inside the right.



Time in Korea, Fig. 5 Outside view of Song I-yeong's astronomical clock. The armillary sphere incorporating a terrestrial globe is on the stand at left; the clockwork mechanism consisting of a striking train and two weights is inside the *long rectangular* space. The time-announcing

mechanism consisting of a moving train and the striking-release mechanism are inside the case at right. Case dimensions: 120 cm long, 98 cm high, and 52 cm wide (Photo courtesy: Korea University Museum, Seoul, Korea)

This clock was collected by Kim Sung-su (1891–1955, second vice-president of the Republic of Korea during 1950–1951) and introduced to the Western hemisphere (Jeon, 1963; Needham et al., 1986, pp. 115–152; Rufus & Lee, 1936). Needham stated, “The Song I-yeong/Yi Min-cheol clock deserves widespread recognition as a landmark in the history of East Asian horology” (Needham, 1986, p. 152). In addition, the clocks were the final versions of the Korean water-operated and weight-driven armillary sphere and the Striking Clepsydras of Sejong.

Scaphe Sundials

On the 2nd day of tenth lunar moon of the 16th year (1434) of Sejong's reign, two hemispherical concave sundials were set up in front of the Benevolent Government Bridge *hejeong-gyo* and on the southern side of the Royal Ancestral Shrine *Jongmyo* in downtown Seoul (Annals of Sejong, 61). These were the first public time-pieces in Korea, which were made of bronze in the shape of a kettle. This was a typical Korean Scaphe sundial called *Angbuilgui*. The name

came from the shape of the kettle directing toward the sky, which originated from the upward-facing instrument *yang i* of Guo Shoujing (1231–1316) of Yuan. A circular pole-pointing gnomon incorporated at the South Pole axis toward the North Pole and graduated with a reticular scale – 12 longitudinal hour-circle lines and 13 latitudinal solar-declination lines – was inside the semicircular hemisphere. To recognize common time, half of 12 of the double-hour Guardians of the Zodiac – Rabbit, Dragon, Snake, Horse, Sheep, Monkey, Rooster, and Dog – were drawn on the hour-circle lines with corresponding names of the animals as shown in Fig. 6a. Names of the 24 Fortnightly Seasons were inscribed on the 13 latitudinal solar-declination lines to know the seasons.

The pole-pointing gnomon axis is coplanar with the hour circles, and the planes of the solar-declination parallels are perpendicular to that axis. Thus, hour circles and the solar-declination parallels are perpendicular to each other. When the sun rose, the gnomon shadow indicated the Rabbit double-hour *myosi* and moved along to the hour circle via noon and to the Horse double-hour *osi* toward sunset and the



Time in Korea, Fig. 6 (a) The Scaphe sundial of King Sejong. Reconstructed by MH Nam (author), 1996, and collected by the Museum of Konkuk University, Seoul. (b) Remains of the eighteenth-century revivals of Sejong's Scaphe sundial. Collection of the National Palace Museum of Korea, Seoul (Photo: MH Nam, 1997). (c) The Scaphe sundial on its granite stand (Height:

136 cm) (Photo: MH Nam, 1995, *Deoksugung* palace, Seoul). (d) Portable Scaphe sundial made of ivory in 1873 by Kang Geon. Collection of the Seoul Museum of History. Length 6.5 cm; height 1.7 cm; width 4.2 cm (Photo: MH Nam, 2009). (e) A stamp with a Scaphe sundial (양부일구)

Rooster double-hour *yusi* in a day. At the winter solstice, the gnomon indicates a top solar-declination parallel and moves with the sun along the hour circles toward sunset the Rooster double-hours in a day. The shadow of gnomon moves downward following the seasonal change toward the summer solstice parallel and upward after the summer solstice toward the winter solstice; thus 1 year passed. When people read the shadow of the tip of the gnomon, they easily knew the present time of the day and the seasons, either.

As shown in Fig. 6b, Scaphe sundials were held up by four dragon columns standing on the

cross water grooves for orienting and leveling. On the lip were inscribed the directions corresponding to the 12 double-hours. Most of the Scaphe sundials of Sejong's reign were burnt down during the Japanese Hideyoshi's invasion in 1592 and restored at *Changdeokgung* palace in 1688 by King Sukjong (r. 1674–1720). Most of the extant Scaphe sundials were made early in the eighteenth century since the measuring of the latitude of Seoul as $37^{\circ} 39' 15''$.

The sundials were set up in front of major buildings in palaces such as the Council Hall *Sajeongjeon* where the king conducted daily affairs in *Gyeongbokgung*, the Queen's

Residence *Daejojeon*, and the Royal Library *Juhapnu* in *Changdeokgung*. Figure 6c shows the sundial on the beautifully sculptured granite sundial stand in front of the Imperial Residence in *Deoksugung* palace in Seoul.

The Scaphe sundials were made of ceramic, marble, and ivory in various types and sizes until the early twentieth century and the royal court sent several ivory or marble portable ones to Qing's court as gifts similar to those shown in Fig. 6d. Figure 6e shows a stamp with a Scaphe sundial which was issued to commemorate the 1988 Seoul Olympic Games by the Department of Post and Communication, Korea.

Hemispherical sundials were made and used for long time in the West, and in their usual form, only the solstices and equinoxes can be seen. And the gnomon was inserted on top of the hemisphere rather than the bottom in Sejong's Scaphe sundial. Korean Scaphe sundials were innovative and a conspicuous tribute to the public-spirited beneficence of the ruler (Needham et al., 1986, p. 81).

Supplementary Material

Korean Horary Systems

In ancient times, East Asians subdivided a calendar day into 12 equal intervals or "double-hours" (*si*, 時) and divided the day into 100 marks (*gak*, 刻), each mark equivalent to 14.4 min on a modern watch to tell the time at night using water clocks. Each double-hour was divided into a Beginning Half (*cho*, 初) and a Standard Half (*Jeong*, 正), and each length is 1 hour, the same as the modern hour, called "single hours." Each double-hour contained $8\frac{1}{3}$ marks of these intervals and each half-double-hour contained $4\frac{1}{6}$ marks. Before employing the Temporal Model Calendar (*Shixian-li* 時憲曆) by Qing, 12 double-hours and 100 marks timing system prevailed which was then changed to 12 double-hours and 96 marks, each mark equivalent to 15 min modern system.

The names of the 12 double-hours came from the names of 12 animals of the zodiac and read: Rat (*ja*, 子, 23–01 modern hour), Ox (*chuk*, 丑,

01–03), Tiger (*in*, 寅, 03–05), Rabbit (*myo*, 卯, 05–07), Dragon (*jin*, 辰, 07–09), Snake (*sa*, 巳, 09–11), Horse (*o*, 午, 11–13), Sheep (*mi*, 未, 13–15), Monkey (*sin*, 申, 15–17), Rooster (*yu*, 酉, 17–19), Dog (*sul*, 戌, 19–21), and Pig (*hae*, 亥, 21–23). Double-hours ran from 23 (子初) and the day began at midnight 00 (子正) half a double-hour later, not 23.

In the Season-Granting system (*Shou-shih li* 授時曆), a night is divided into five night watches which are five equal divisions of the duration divided from dusk (2.5 marks after the sunset) to dawn (2.5 marks before the sunrise). In Korea, the night watches were called *gyeong* (更) and each night watch is further subdivided into 5 points *jeom* (點).

See Also

- [Astronomical Instruments in Korea](#)
- [Time in China](#)

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Time in Maya Culture

Henry J. Rutz

Classic Maya culture developed from the second to the tenth centuries AD and expanded to encompass all of the Yucatan peninsula including the modern countries of Guatemala, Belize, and portions of El Salvador and Honduras. Unlike the

Aztec and Inca states, which developed highly centralized imperial cities, the Maya developed city-states. Elites intermarried, formed alliances, and shared a complex calendar.

While all empires have created multiple times to connect village community to imperial center, and earthly city to heavenly city, the historian Nancy Farriss has noted that “from their earliest recorded history, the Maya displayed an intense interest, bordering on obsession, in measuring and recording the passage of time.” Anthony Aveni (1989) observes, “The first bits of information in any Maya inscription are about time. What sets the Maya apart is not the number of time units they devised, or even their complexity; rather, it is their preoccupation with ‘commensurateness’ – perfecting the way time cycles interlock or fit together.” Over a millennium since the climax of classic Maya culture and five centuries after the Spanish conquest, Maya continue to practice their own time, albeit in modified form.

The Maya had a military state with a literate elite. Our information about their multiplicity of time comes from their own writings. Although Maya hieroglyphic writing died out, Maya elites were able to maintain an unbroken continuity from their system of writing to that of Spanish script. The language survived in many colonial documents from the sixteenth century on. Today two million people still speak more than a dozen dialects of the Mayan language.

The Maya calendar is the centerpiece of Maya concepts of time and its measurement. It consists of the conjunction of cycles upon cycles of time of long duration. Like the Gregorian calendar we use today, the Maya calendrical system was the culmination of many different cultural influences over millennia. The conception of time underlying the calendar is one of movement. Maya referred to time as a flow and perceived a need for both human and divine intervention in maintaining it. In Maya culture, people actively construct their sense of time, a point to which I return below with reference to daykeepers and their role in the regulation of everyday life.

The flow of time is incorporated into an all-encompassing cyclical pattern. Conjunction of complex forces mark cycles of different duration. The Body Count of 20 is the basic unit of Mesoamerican counting (10 fingers plus 10 toes). The classic Maya week consists of 20 named days, each propitious or unpropitious for particular activities. The 20-day week was combined with a separate series of 13 numbered days to create the Sacred Round of 260 days. Later, a Solar Year was calculated consisting of 18 20-day months plus 5 days. The solar year was articulated with the sacred round to create the Calendar Round of 52 years. The Maya also developed a Katun Round consisting of 13 20-year periods for a duration of 260 years. Despite an obsession with commensurability that led Maya priests into astronomy and cosmology, not all the cycles were articulated with each other. Late in the political development of pre-Conquest Maya culture a ► [Long Count](#) of five millennia appeared. Today, Maya daykeepers reckon the rhythms of everyday life by interpreting the solar and divinatory calendars.

Although Maya viewed time as a flow, it is also time with a content. Each day was named after a god and was qualitatively different from every other. Furthermore, the content of time was regulated by a conjunction of forces. Those days that were at the conjunction of different cycles had a greater force than other days. The larger the cycle, the greater the number of forces intermeshing from different subcycles. The Maya depicted time on stone carvings or drawings as weighty numbers carried by gods.

Intermeshing cycles produce a succession of days whose events are linear, unique, and irreversible. But this apparent linearity is an illusion because “no matter how unique a pattern of events may seem, no matter how long the sequence, it will eventually be repeated, when the governing forces of all the cycles of different dimensions coincide in one huge cycle” (Farriss, 1987).

Why these cycles? Maya observers were not disinterested observers of the heavens. Cosmic time links common people to rulers through the latters’ association with the cosmos.

The construction of cycles appears to be associated with the problems of legitimacy and political order. Returning to the same point, at least logically, is the ultimate form of reassurance against the reality of present conflict, chaos, and events that seem to be getting out of hand. As Farriss says, “Accounts of the famine in the books of Chilam Balam show less concern with starvation than with the fact that people flee into the forest to eat roots and other wild food . . . In other words, people cease to live in their customary fashion. . . Political conflicts are condemned because they disrupt the established hierarchy, and upstarts and invaders are vilified for breaking the rules.” Encompassing cycles provide a cosmic charter of legitimacy of a magnitude rarely conceived in the history of cultures.

The predictable order of cosmic time reckoning, unfortunately, depended upon human agency for execution. “It is unlikely that the Maya priests claimed to comprehend all the possible combinations of divine forces governing the subordinate movements of so immense a projection.” Past, present, and future are written in a single bound book, but one that admits of many interpretations.

How did the dual conception of cyclical and linear time work out in practice? Both serve as charters for sociopolitical arrangements, but each in its own way. It appears that classic Maya elites confined linear concepts to relatively short term duration out of choice (they possessed the literary or numeracy skills to create historical memory). Among the most important were the katun round and the chronicles written by members of Maya royal lineages during the colonial period.

The katun round, consisting of a recurring wheel (time is often depicted as a wheel in Maya stone carvings) of 13 20-year counts for a total of 260 years, recorded the important events of royal lineages. The interesting aspect of the katun round is its duality of both history and prophecy. Each year has its own name together with characteristic and appropriate events. The future is contained in the past, and therefore Maya could look to a record of the past as a guide to the future. The same pattern of events for a given year recurs every 260 years. In Chilam

Balam texts, logically associated events always occur in the same katun regardless of their inner chronology. It is as if all invasions were taken out of their chronological sequence and placed in their cosmological reckoning. Even references to the most recent “descent” – the Spanish conquest – are woven into the pre-Hispanic mix.

In addition to general reference to recurrent patterns of events there is also remarkable specificity to katun accounts, which name specific people and places, details of real famines, invasions, migrations, exiles, and rivalries. The specific content is about unique and irreversible events. The chronicles appeal to secular principles as the basis for claims to legitimacy, for example descent from previous rulers. The 20-year katun cycle may have served as a calendar for rotation and succession of ruling families in post-Classic Maya. In contrast, books of Chilam Balam that record cycles stress quality of time – joy, misery, abundance, and the place of cosmic and divine forces in their production. The sacred personages of the calendar rounds merge with their worldly actors.

There is some evidence that the Maya calendar evolved toward a dominance of linear over cyclical concepts of time during the post-Classic period as a consequence of the emergence of dynastic rule and its dominance over the more autonomous city-states of the Classic period. Unlike the calendrical system of cycles and their conjunction, which have no particular starting date, the ► [Long Count](#) system measured elapsed time from a starting point that would extend to a time horizon of 5,200 years before its repetition. This new calendar represented a radical shift from the dominance of cyclical time over linear time because its duration was long enough to encompass the ancient Calendar Round of 52 years and more recent katun round of 260 years. Specific details of human affairs accompany the Long Count and a new emphasis on written genealogies supports the hypothesis of a shift to dynastic rule.

If it is unlikely that ancient Maya priests could comprehend all the divine forces converging on particular days or years, how much less likely is it that ordinary people could use the Maya calendar

to take control of their own lives? A partial answer appears in the guise of Maya daykeepers. Barbara Tedlock (1982) has given us an account of time among Quiche Maya in the town of Momostenango, highland Guatemala. There daykeepers use an integrated solar year and the sacred round to divine whether a day is good or bad for particular activities. The appropriate determination of qualities to a day are specific to a particular client and require active participation on the part of both daykeeper and client.

Daykeepers use a set of practices referred to as “the speaking of the day” and “the speaking of the blood.” The qualities of the 20 name days are based on stipulated but vague mnemonic phrases that require interpretation by the daykeeper. Other factors specific to a client enter the picture, including the client’s character, part of which is determined by the particular day on which a child is born.

The daykeeper achieves understanding by sortilege or divination by lots. She or he mixes, grabs, and arranges piles of seeds and crystals into a pattern, all the while counting and interpreting the 260 days of the divinatory calendar. The blood is considered to be an active substance that sends signals or “speaks” to the daykeeper. The rapport between daykeeper and client is also thought to affect the divining of a day as good or bad for a particular activity. Clients come to a chosen daykeeper with a specific question about such probable occurrences as illness, accident, land disputes, building houses, inheritance, business transactions, travel, marriage, adultery, quarrels, dreams, births, deaths, and interpretation of omens. The divination is performed for the specific question posed by a particular client.

See Also

- [Calendars in Mesoamerica](#)
- [Long Count](#)
- [Mathematics](#)
- [Writing](#)

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Time in Native North America

Michael Zeilik

The Pueblo people of the United States Southwest believe in a cosmos in which nature functions with the active cooperation of humankind. The proper ceremonies must be carried out at the proper time so that the cosmic order is sustained. Traditional doctrines held that there were correct times for planting, harvesting, hunting, ceremonies, and many other activities – all embedded in a sense of sacred time. The right times for these crucial undertakings are established by astronomical observations to regulate the ritual calendar. The cycles of the sun and moon set the rhythm of Pueblo time.

Sacred time is ordered with different levels of periodicities. The longest appears to be the seasonal year. We have very little evidence – almost all ambiguous – that the Pueblos kept long counts or tallies greater than a year. Until the twentieth century, with the intrusion of European concepts of time, no indigenous interest appears in tracking cycles over many years. The yearly cycle is all important; after its end, a new, equally unique one begins. Within the seasonal span, ceremonies occur in a fixed sequence, in which the completion of one sets the stage for the next. The observation of the phases of the moon marked the subdivision of the year. Within a night, the start and end of some ceremonies are flagged by observations of the positions of certain stars, especially the Pleiades as seen from the

smokehole of a *kiva*, a structure used as a ceremonial room.

The shortest unit of time reckoned by the Pueblos is the day, which begins with sunrise. The day has vague subdivisions into loose “hours,” most of which are noted near sunrise and sunset by the color of the sky. About the only time of day noticed with any care is that of noon, which is typically observed by the length and directions of shadows cast by the edges of walls, buildings, trees, or sticks embedded in the ground.

A religious official has the responsibility and the authority to set the ceremonial dates within the ritual cycle. The crucial task entrusted to this official is the forecasting of the correct date by making anticipatory astronomical observations. The dates are announced ahead of time so that the people of the pueblo can enter into proper preparations (abstinence, practicing songs and dances, preparing costumes and special foods) so that the ceremony may be carried out with “good heart” and be effective.

Typically, one official – the Sun Priest – performs the sun-watching for the seasonal cycle, which includes the planting schedule. He does so from a sun-watching station that is usually located within or close to the pueblo. From this fixed spot, the Sun Priest keeps a horizon calendar (usually at sunrise using an observation of the first gleam) against the horizon profile. He knows from experience that when the sun rises (or sets) against a certain horizon feature, so many days will elapse until, say, the winter solstice. Then he uses tally markers (such as a knotted cord) to count down to that day, with an announcement made to the pueblo a few days ahead of the celebratory date. This anticipatory technique allows the Sun Priests to forecast the dates of the solstices to within 1 day of the astronomically correct date when the sun appears to “stand still” at its sunrise point. The observations made about 2 weeks in advance catch the sun when the angular speed of its sunrise position is large enough to be discerned by the naked eye on a day-to-day basis. Hence, this practice neatly solves both a cultural and astronomical problem.

Moon watching regulates timings between the seasonal and daily ones. The official responsible for tracking the phases of the moon generally is not the one who watches the sun. A Pueblo month begins with the observation of the first visible crescent and ends with the last. The days of invisibility are not typically counted. Calendar sticks were used to tally the observed months.

The months of the year are counted starting with the first before the winter solstice ceremony. The first five (or six) are named (usually after seasonal characteristics); then these names are repeated for the next five or six. The lunar calendar needs to be synchronized with the solar one, which is accomplished by adding an intercalary month (which can be as short as 4 days!) at the end of the regular count or after the winter solstice.

Although Pueblo people feared eclipses of the sun and the moon, they had no way to forecast them. In part, this lack was related to their disinterest in keeping counts longer than a year. We also find no evidence for knowledge of the 18.6-year lunar standstill cycle, even though the moon certainly was observed rising and setting. The historic Pueblo culture did not seem to attach any importance to this astronomical cycle so it was ignored.

The ancestors of the Pueblo people were the Anasazi, who inhabited what is now the greater Four Corners area of the US Southwest as a settled agricultural people. During the height of the classic Anasazi culture some thousand years ago, two major sites developed: Mesa Verde and Chaco Canyon. A regional center developed in the San Juan basin around Chaco by AD 1110; as many as 70 communities dispersed among 50,000 km² were integrated into a socioeconomic and ritual network connected by a road system.

How did the Anasazi regulate and track time? By using ethnographic analogy, we can generate hypotheses about Anasazi astronomy that can be checked against the archaeological record. The most important cycle of time for the Pueblos is the seasonal year, which is typically tracked by horizon calendars. Anticipatory observations are made about 2 weeks prior to the solstices. Of the

Anasazi sites field-tested so far, about one-third have reasonable horizon calendars.

A secondary strategy employed in the historic Pueblos used a special opening or window to cast sunlight on an opposing wall. The best Anasazi analogs to this type of interior observational technique occur in Hovenweep National Monument at Hovenweep Castle, Unit Type House, and the Cajon Group ruins with small portals. Hovenweep Castle and Cajon ruins work at sunset, Unit Type House just after sunrise. In all three locations, the horizon profiles lack the relief for tracking horizon calendars. For all, the throw from the shadow-casting edges is large enough so that the linear motion on the receiving wall is typically a few centimeters per day from the sun's angular positional change at sunrise or sunset. The evidence so far hints that interior light and shadow casting played an important role in Anasazi seasonal time keeping.

Exterior light and shadow casting was not an important time keeping technique in historic times. It may have been used more extensively by the Anasazi though perhaps more for ritual than calendric purposes. The three-slab site atop Fajada Butte in Chaco Canyon has been much investigated; so has the Holly site at Hovenweep. In both these cases, light and shadow cast by rock edges fall onto panels of rock art at important seasonal times of the year. These exterior sites generally suffer from a lack of resolving power for reliable calendric forecasting, if we apply the standard achieved by the historic Pueblo Sun Priests – within a day of the astronomical date of the solstices. Hence, these sites may have served as sun shrines for offerings to the sun with a light and shadow display that served a commemorative rather than a calendric function.

We have no firm evidence so far of prehistoric monthly lunar calendars, though such a count of days would have a unique sequence tied to the phases of the moon. No rock art in the Anasazi region has been demonstrated to display the measure of a lunar tally.

Occasional claims have been made that the Anasazi noted the 18.6-year standstill cycle of the moon. The hypothesis of attention to this interval has been put forth for the Fajada three-slab site and for Chimney Rock Archaeological

Area in Colorado (among a few others). The most convincing case is made for Chimney Rock, where the natural rock pillars (after which the site is named) act as a natural foresight when viewed from the site of Chimney Rock Pueblo, a Chacoan outlier, which was occupied from about 1075 to 1175.

The orientation allows a spectacular anticipation and forecasting of the major lunar standstills. For about two and a half years prior to the standstill, the moon rises between the pillars for 1 or 2 days per month. Starting after the summer solstice, the moon appears as a waxing crescent. Finally, near the winter solstice, the full moon stands between the pillars at around sunset. Hence, the priest in charge of the moon watching could forecast the date of the standstill and also the full moon nearest the winter solstice – an important conjunction among the historic Pueblos.

See Also

- [Astronomy](#)
- [Long Count](#)

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Time: Non-Western Views

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Time is a difficult notion, since time beliefs underlie a variety of seemingly unrelated areas like (1) scientific theory, (2) philosophy of

science, (3) religious beliefs about the nature of life after death, and consequently about the soul (4) human values and the (5) nature of language and logic, etc. These various time beliefs may or may not cohere with each other.

The structure of the English language, unlike that of the Hopi (American Indian) language, presupposes that time and space are entirely separate entities, and this makes it hard to understand the intermingling of time and space in relativity theory. As another example, the Buddhist Dhamma (ethics, way of life) is closely connected to the Buddha's concept of *paticca samuppāda*, or conditioned coorigination, the proper understanding of which requires the concept of a structured time, in which the instants of time are not featureless geometrical points. This notion of a structured time is incompatible with the two-valued logic assumed in Western philosophical discourse. In Buddhist thought, seemingly contradictory properties may coexist, as in the quantum-mechanical Schrödinger's cat who is both alive and dead at a single instant of time. Thus, the attempt to understand one aspect of a non-Western view of time, such as the Buddhist notion of *paticca samuppāda*, can force us to reconsider fundamental issues like the logic underlying Western thought.

Any attempt to provide an account of non-Western views of time is a very difficult enterprise, involving complex relationships across widely different areas of knowledge, and potential conflicts at a deep level with stock metaphysical assumptions underlying even the language and logic of Western discourse. This entire gamut of relationships between different pictures of time has been covered in the books *Time: Towards a Consistent Theory*, and *The Eleven Pictures of Time*, by this author, but it is too complex to be covered in the span of this one article, which will focus on only a single aspect related to the Western stereotype of non-Western beliefs about time.

The Western Stereotype: "Linear" Time Versus "Cyclic" Time

Non-Western views of time have typically been represented in Western literature and scholarship

by contrasting Western “linear” time with non-Western “cyclic” time. Linear time is endowed with a variety of positive properties: rationality, progress, free will, etc. while cyclic time is attached to a variety of negative properties: spirituality, stasis, fatalism.

The first step needed to understand non-Western views of time is to get rid of this stereotype.

For example, the time beliefs underlying scientific theory are not the same as those underlying the philosophy of science, and the two do not cohere, but both can be classified as linear time. Thus, scientific theory is today presented in the form of differential equations, such as Newton’s laws of motion, or the Hilbert-Einstein equations, or Schrödinger’s equation. These equations fix the state of the cosmos at any time, once its initial state is known. However, all these equations involve the mathematical notion of a derivative with respect to time – for example, velocity, or the rate of change of position, is the time derivative of position, and acceleration is the rate of change of velocity or the time derivative of velocity. On the existing Western mathematical understanding of the calculus, these derivatives with respect to time force us to suppose that time is a continuum, which can be represented using real numbers. That is, current scientific theory necessarily presupposes that time is like the real line, or that time is “superlinear”.

On the other hand, our reasons for believing in this or that scientific theory are (or ought to be) based on experiments, and this presupposes the belief that one can perform various experiments, the outcomes of which were not all determined beforehand, by the state of the cosmos at some moment in the remote past. That is, the philosophy of science presupposes a different belief about time: that the future of the cosmos is a consequence of human choices and actions, and not merely of its past state. One does not normally stop to think about such presuppositions because everyday human actions are premised on the same belief that human actions are powerless to change the past (“no use crying over spilt milk”) but that they do bring about the future in some small way (“if I don’t watch the milk it will

boil over”). Thus, the philosophy of science subscribes to the belief in “mundane time”.

These two types of time, superlinear and mundane, are both linear, but they are nevertheless incompatible and in conflict with each other. This conflict is a serious matter, for it pits scientific theory against the reasons for regarding it as valid. How is this conflict to be resolved? This would naturally seem to require a correction in one or the other picture of time.

However, the slightest alteration in one’s time beliefs can have profound consequences. Changing the picture of time in scientific theory fundamentally changes the type of equations used to formulate the models of physics. On the other hand, if one were to believe that the future of the cosmos has already been rigidly determined by its past, there would be little point to human action, and life itself would become meaningless, as in the theory of the Stoics, or in Nietzsche’s thought.

Since there are different notions of linear time, such as superlinear time and mundane time, which do not cohere with each other, so the very category of linear time is not meaningful. The category of cyclic time is not meaningful for similar reasons.

On the other hand, there need not be any particular conflict between a locally superlinear time and a globally recurrent cosmos. If the cosmos is restricted to a finite region, like a gas in a box, and evolves deterministically – according to Newtonian mechanics, say – then the Poincaré recurrence theorem tells us that, with probability one every state of the cosmos must repeat to an arbitrary degree of precision, infinitely often. Recurrence would similarly take place even if the cosmos evolves probabilistically rather than deterministically, so long as the future state of the cosmos depends only on its present state, an assumption more precisely formulated in current mathematics as the Markovian assumption for the evolution of a stochastic process. These recurrence theorems assure us that a recurrent cosmos, instead of being in conflict with superlinear time, is a logical consequence of it, under some rather general conditions, such as finiteness. In the above situations of cosmic recurrence, it could

be argued that time only seems superlinear because the time scale of cyclicity – the recurrence time – may be very large, just as the earth seems flat, although it is round, since it is very large. Thus, a linear picture of time, need not be in conflict with a cyclic picture of time.

This meaningless dichotomy of linear versus cyclic time has nevertheless been persistently used in the West to characterize non-Western thought about time. A non-Western historical perspective on the development of Western time beliefs is helpful in understanding the origins of this incorrect (but widespread) stereotype about time and its linkage to religious ideology.

Quasi-Cyclic Time and the Soul

Early notions of the soul (in India, for example) were based on the belief that the cosmos went through recurrent cycles, or, equivalently, that time was quasi-cyclic. It was believed that each cycle of the cosmos lasted for an enormous duration of time – billions of years – and that each cycle of the cosmos was approximately like the preceding one. Events repeated in approximately similar ways in successive cycles of the cosmos. Roughly the same people were reborn in successive cycles of the cosmos, and lived roughly the same lives, and died roughly the same death repeatedly, across cosmic cycles. This perceived state of affairs was described by saying that each individual has a soul, which persisted beyond death, and was repeatedly reborn (in successive cycles of the cosmos), until such time as it achieved deliverance.

The duration of a cycle of the cosmos is reckoned in the *Viṣṇu Purāṇa* as a day and night of Brahma, and amounted to 8.64 billion years. (An ordinary day and night amount to 86,400 s.)

This notion of a soul which persists across vast cosmic cycles is not a metaphysical notion, since it presupposes a cosmic state of affairs, which may or may not be the case. That is, this notion of the soul is a physical notion, since it involves a refutable or falsifiable picture of the cosmos.

It is a common error to confound quasi-cyclic time with eternal recurrence. It was not generally believed that these cosmic cycles were exact or eternal. The whole possibility of deliverance – *mokṣa*, *nirvāṇa* – was premised on the idea that these cycles were neither exact nor eternal. (However, the category of cyclic time encourages such an error by suggesting that various types of cyclic time are the same.)

In India, this was the traditional view of time and life after death held from before the time of the Buddha. The Lokāyata denied the belief in life after death as a fraud. An interesting feature of this denial is how Pāyāsi sought to establish the non-existence of the soul by performing some 37 experiments with dying men, and condemned felons. It is unlikely that such experiments were ever performed anywhere else.

The Buddhists did not deny this cosmic state of affairs. Indeed, popular stories like the *Jātaka* tales clearly accepted what was then the prevalent common belief about the world. What Buddhists denied was only the significance of cosmic recurrence, for they denied the existence of a soul or any continuity between two similar individuals across two cycles of the cosmos. In fact, they also denied that anything essential persisted between two similar individuals across even two instants of time: they maintained that the seed in the granary is a distinct entity from the seed in the ground, which is bloated. The seed in the granary cannot be the cause of a plant, because the seed in the granary remains a seed at the next instant. There is a similarity between the two seeds, and hence, due to the paucity of names, one gives the same name to both seeds. Therefore, in the Buddhist view it would not be proper to say that there is some essential sameness in an individual which persists from birth to death: in the Buddhist view, an individual exists (unchanged) only for a single instant.

This notion of quasi-cyclic time is incorporated in artistic or mythical representations, like the Wheel of Time, the Phoenix, or the Plumed Serpent of Central America, that are found from across the world, and certainly existed in Egypt. And, as Herodotus informs us, numerous ideas, customs, and religious beliefs were transmitted

from the Egyptians to the early Greeks. Therefore, it is not surprising that a similar notion of the soul is found in the works of Plato, and was subsequently developed by the Alexandrian Neoplatonic philosophers.

Indeed, it is little known that this belief in quasi-cyclic time was the anchor of early Christianity, as enunciated by one of its greatest real (as opposed to mythical) teachers, Origen of Alexandria (third to fourth century CE). This early Christian notion of cyclic time was remarkably similar to what is today known as the Hindu doctrine of *karma-samskāra*. According to this doctrine, the actions (*karma*) in one cycle determine the dispositions (*samskāra*) in the next cycle, and the objective of life is taken to be deliverance (*mokṣa*) from these repeated births and deaths.

Quasi-Cyclic Time, Immanence and Equity

Curiously, while cyclic time and *karma-samskāra* are today associated with casteism and inequity, in early Christianity, Origen argued in his *De Principis* that this notion demonstrated both equity and justice: equity, since God had created all souls equal, and justice, since souls were rewarded and punished in each cycle of the cosmos according to the merits or demerits they had earned from their good or bad actions in the preceding cycle. Origen's argument was not an isolated curiosity.

Thus, the notion of equity was related to immanence or the idea of divinity within man, and hence the importance of deep introspection. The discipline of Yoga (union) is not a physical exercise, but a technique of meditation or introspection to bring about the union of ātman with Brahman, inside man, and thence lead to deliverance. Mathematics (geometry) was perceived by early Greeks to be a technique, exactly like Yoga, to achieve the same goal. Thus, in Plato's *Meno*, Socrates demonstrated the slave boy's prior knowledge of mathematics, in support of his theory that all learning was but reminiscence of the prior knowledge of the soul. Likewise, Proclus

explained the etymology of mathematics (from *mathesis* or learning) as the science of learning, or the science of the soul, since he thought mathematics related to eternal truths, and forced one into an introspective state, which then aroused the immortal soul and induced it to recollect its past knowledge, which it had forgotten since birth.

Immanence related to equity, since all souls were regarded as being part of one God. This relation is well brought out by the following story. Śāṅkara was the founder of Advaita Vedānta, a philosophical system which asserts that ātman and Brahman are "not two" (but one). Śāṅkara was returning from his bath in the river, when he was accosted by a *candāla* (outcaste). By force of habit, Śāṅkara shrank back. After this the *candāla* taunted him, asking how Śāṅkara could maintain this distinction when both had an ātman one with Brahman, hence equal to each other. Realizing his mistake, Śāṅkara prostrated himself before the *candāla*. Almost every theorem of Euclid's *Elements* is about equality (not congruence), and this was unambiguously related to political equality as in the mystery story that there is "no royal road to geometry". The connection to political equality was made quite explicit in subsequent Islamic rational theology (*aql-i-kalam*). The lasting impact this had on Islam is obvious from the fact that religious-minded emperors like Aurangzeb, even though they ruled vast empires, worked to earn their livelihood – something observed with great astonishment by Europeans who had never known any ruler of this sort. In the early Christian version, Origen argued that not only were all souls created equal, but they would again become equal at the end of time, since all would ultimately achieve deliverance, as in *karma-samskāra*, and there would be a time when God would be all in all.

This notion of an immanent God was also essentially a celebration of the creativity of life. Man creates the future cosmos (at least a tiny part of it), just because God is in Man (and also other living creatures). All people are equal, just because all people are equally parts of one God. Since these notions involved a celebration of

creativity, they were associated with what have been called “fertility cults”, such as the worship of Bacchus or Dionysius. In India, various Tantric schools have many similar practices. The relation of equity to creativity is well brought out by the Lokayata festival, today known as Holi. On the one hand it is related to the harvest and is thus a celebration of creativity. The custom of throwing color on people was intended to erase the social distinctions that are displayed by means of clothes, and in fact to erase all individuality. The custom of taking bhang (marijuana) was intended to further creativity by heightening sexual passion.

Inequity as the Basis of Linear Time

After Constantine, this belief in the equity of all souls stood in the way of the political goals of the church, which now viewed the world from the imperial perspective of the Roman state: if all souls would be saved anyway what was the advantage to be gained by turning Christian? If God was within man, where was the need to fear God, and be obedient to the priest? Hence, theologians like Augustine proposed to erase equity and erect a transcendent God who would judge people and establish a simplistic moral division between good (Christians) and bad (non-Christians). In the revised picture proposed by state Christianity, all souls were NOT equal, so not all souls were eventually saved. Instead God established a permanent inequity in the world, sending some souls (those of good Christians) to heaven (forever), and other souls (non-Christians) to hell, as described in gory detail by Dante, for example. Reincarnation was accordingly changed to resurrection – life after death, just once.

Because the earlier notion of soul depended upon a view of life after death deriving from the belief in quasi-cyclic time, time beliefs were also compelled to change with this changed notion of the soul and of life after death. Time beliefs changed from quasi-cyclic time to linear apocalyptic time: the world, as conceived by Augustine, began a few thousand years ago, and would

soon come to an end. The notion of the soul became metaphysical.

Thus, the question of linear versus cyclic time is an issue that lies at the very foundation of Christianity (and the related historical notion of the West, as in Toynbee’s classification, used more recently by Huntington). Rejection of that view of (apocalyptic) linear time would amount to a denial of the entire religious ideology of state Christianity, as it is understood today. This explains the significance and importance to the West of the competitive stereotype of linear time versus cyclic, directed as much against early Christianity as it is directed against non-Western views of time.

The Western Misrepresentation of Quasi-Cyclic Time as Supercyclic

Augustine argued against Origen’s view, by misrepresenting “cyclic” time as eternal recurrence or a state of affairs where deliverance was available to none. He asserted that the cosmos would recur exactly, so that even Jesus Christ would be repeatedly reborn and repeatedly crucified, so that no one could be saved. “Heaven forbid that we believe this, for Christ having died once for our sins, rising again, dies no more”. Augustine then rejected this state of affairs on the grounds of “fatalism” (which, he quibbled, was different from “determinism”).

This was certainly a misrepresentation of non-Western views, where deliverance from the cycle of birth-death-rebirth was not only held to be possible, it was regarded as the ultimate aim of life. This was also a misrepresentation of Origen who explicitly stated:

And now I do not understand by what proofs they can maintain their position, who assert that worlds sometimes come into existence which are...in all respects equal. For...then it will come to pass that Adam and Eve will do the same things which they did before: there will be a second time the same deluge... So therefore it seems to me...that a diversity of worlds may exist with changes of no unimportant kind...in that age [world] which preceded this, Christ did not suffer... (*De Principis*, Book II, chapter III.4-5)

Augustine's misrepresentation of "cyclic" time may be presented thus: time was thought to be quasi-cyclic, whether in *karma-samskāra* or in Origen's teachings; however, Augustine misrepresented quasi-cyclic time as supercyclic time – a situation (of "eternal and exact recurrence") where no change is possible in the cosmos, which repeats mindlessly like a stuck record (this "repetition" being in some implicitly assumed notion of increasing time, external to the cosmos, perhaps in the mind of God). Most Western thinkers have fallen into the same Augustinian trap of confounding "cyclic" time with "eternal recurrence" because they lacked even the words required to make a distinction between different varieties of cyclic time.

Therefore, Augustine's misrepresentation of Origen's notion of "cyclic" time has confused a long line of Western thinkers like Nietzsche, who founded an entire philosophy on this misunderstanding of "cyclic" time as supercyclic time or "eternal recurrence of the same". The same confusion between quasi-cyclic time and eternal recurrence can be found in T. S. Eliot, or in Mircea Eliade's *The Myth of the Eternal Return*.

Starting from Newton, the same confusion about "cyclic" time persists in scientific theory to this day. For example, Stephen Hawking and G. F. R. Ellis, in their *Large Scale Structure of Spacetime*, argue against closed time loops (a third variety of partially cyclic time, distinct from quasi-cyclic time and super-cyclic time) repeating exactly Augustine's mistaken arguments. The first step of the argument confounds any sort of cyclicity with eternal recurrence, and the second step rejects eternal recurrence on grounds of fatalism. More recently, arguments in the scientific literature related to the Grandfather paradox of time travel, which involves a loop in time, have again endlessly repeated Augustine's wrong arguments. The confusion between quasi-cyclic time and eternal recurrence seems to reverberate eternally in Western thought: "cyclic" time represents "eternal recurrence" hence fatalism, and should be rejected. On the contrary, as this author has pointed out, such closed loops in time, being causally inexplicable from the past, are the way to have spontaneity, or

creativity, within the frame of current physical theory.

Thus, the Western stereotype of non-Western views of time involves a very deep-seated and long-standing confusion about the nature of time within Western thought, starting from Augustine and stretching down to people like Newton, Einstein, and Hawking.

There are a few other aspects of non-Western views of time that deserve at least a brief mention.

Discrete Versus Continuous Time

First, consider the issue of discrete versus continuous time. The belief that time is a continuum is forced in present-day physics, as we have seen, only by the Western understanding of the calculus, based on an idealistic understanding of mathematics. However, the calculus that developed in India incorporated a different understanding of mathematics, that could be called a realistic understanding. The difference between the two may be explained with reference to the Buddhist denial of the existence of the soul. The Buddhists (especially followers of Nāgārjuna's *śūnyavāda*) maintain that between two instants of time, an individual changes, and there is nothing "essential" in the individual that remains the same. In common parlance, and for practical purposes, we neglect or zero the differences as inconsequential, or non-representable, due to a paucity of names.

Let us now apply this understanding to a number like π , which denotes the ratio of the circumference of a circle to its diameter. No matter how we try to express this number, it cannot be specified – that would require a supertask. In idealistic (formal) mathematics, it is asserted that there really is such a number, although any actual representation of it will always only be approximate or erroneous. In realistic mathematics it would be asserted that calculations can only be done with an actual representation and not an idealized one. There is a paucity of names, and therefore we use a representation appropriate for a given practical purpose, zeroing certain things

treated as non-representable. The subtle difference between the two positions is brought out very clearly in the representation of such numbers on a computer; the actual numbers (floating point numbers) do not follow the same rules or “laws”, such as the associative law for addition that the ideal “real” numbers are supposed to obey.

This leads to a fundamentally different understanding of “infinitesimals” (as non-representable quantities discarded in a calculation), which presented such a problem for Newton and Leibniz. However, all practical conclusions drawn from the calculus use realistic mathematics and computation, rather than idealistic mathematics. Therefore, the idealistic point of view, which forces time to be a continuum in physics, involves the superposition of “extra baggage” from Western metaphysics, and there is no real need to believe that: time may well be regarded as discrete or atomic, provided one does the calculus with a different philosophy of mathematics. The point here is not to argue that time is, in fact, discrete, but rather that the discreteness or continuity of time should not be fixed purely from mathematical and metaphysical considerations, since these metaphysical considerations could be fundamentally different in the non-West.

Atomically Structured Time and Quasi Truth-Functional Logic

The second question concerns the link between time beliefs and logic. Time may be related to logic through Wittgenstein’s notion of logical worlds: the state of the physical world at an instant of time can be specified by specifying all the statements that are true at that instant of time. In the West it has been believed that if A is true at an instant of time, then its negation $\sim A$ cannot be true at that very instant. Certainly there are schools of thought in the non-West which also subscribe to this belief, but it is not universal. Buddhist and Jaina logics permit both A and $\sim A$ to be true at an instant of time. This involves the concept of an atomically structured time. The classical way to explain this would be to think of an instant of time as a microcosm. A modern

explanation for this state of affairs can be provided using microphysical loops in time.

Imagine that one has a time machine, and that one puts Schrödinger’s cat (now dead) on board the time machine and sends it back to the time of Schrödinger. The events here described from a future perspective would actually have been observed by Schrödinger somewhat differently: for Schrödinger, the “observed” sequence of events would have been that time spontaneously and inexplicably split into two streams (both part of this world), in one of which the cat is alive, and in the other it is dead. (At the microphysical level, one can actually “see” a somewhat analogous phenomenon of a photon or a particle of light splitting into an electron-positron pair, which may later recombine to produce back a photon. The positron has exactly the properties of an electron travelling back in time, so the process can also be described as an electron executing a closed circuit in time.) These two streams of time, witnessed (or rather inferred) by Schrödinger, are NOT “parallel” worlds, for the two worlds do meet, and the two cats would coalesce back into a single cat at the time we put the cat into the time machine.

In place of imaginary time machines, one can construct a more realistic desktop model involving parallel computing, although understanding this requires a little more technical knowledge. In parallel computing, a single process executing on parallel processors may be in multiple states at a “single instant” of time. Needless to say, “parallel” is a bit of a misnomer, since it is an essential feature of parallel computing that the processors (logical worlds, in the Wittgensteinian sense) and processes communicate with each other, and that they branch and collapse. Time, so to say, acquires a structure, and it is necessary to take into account this structure to understand the semantics of formal parallel computing languages.

Microphysical closed time loops enable us to understand how an atom of time can nevertheless have a structure, in the sense that multiple logical worlds are attached to a single instant of time. This structure is manifested not by further subdivision of the atomic instant, but by a change of logic. In such a situation of an atomically structured time, it is perfectly possible to have both

A and not-A valid at a single instant of time that cannot be further decomposed.

This notion of an atomically structured time or a structured instant is the basic unit of reality in Buddhism. It leads to the alternative notion of “causality” in Buddhism, called *paticca samuppāda*, or “conditioned co-origination”. The present is not the cause of the future, but the future cooriginates, conditioned by the past. *Paticca samuppāda* is identified by the Buddha as the key to his Dhamma. Thus, the use of a logic of four alternatives in Buddhism is not incidental to Buddhism but is integrally linked to its worldview, for it is only through an understanding of the causes of *dukkha* that one can remove it.

Ontically Broken Time

The common terminology of the laws of physics – for example, Newton’s laws of motion – is related to the theological idea that creation was a one-time process and that subsequent states of the cosmos were controlled by God using laws. This idea of a clockwork cosmos is denied in many non-Western systems of thought. Al-Ghazālī, argued from a different perspective, where the world is continuously created by God. In this situation, any causal connection becomes a restraint on the powers of God; al-Ghazālī denied the existence of causal connections. He conceded that there are observed regularities in the cosmos, but he explained them as arising from force of habit. God habitually creates smoke with fire; he is not obliged to do so. Of course, one does not know on what time scale God changes habits, but it could be imagined that the cosmos is such that not only would physical theories change, but physics itself would change, over a time scale of, say, a thousand years.

More to the point, this helps us to see the historical evolution of the idea of the laws of God. Thus, al-Ghazālī was speaking about an immanent God, the apparent restrictions on whose powers were all too obvious. When this was taken over in the West, as by John Scotus Duns, it created a problem, because it was supposed (at least by the opponents of this point of

view) that this description concerned a transcendent God. Under those circumstances, God would become a terrible tyrant, since one would never know what to expect next. Accordingly, God’s intervention was toned down, and his role limited to instituting laws. This led eventually to superlinear time.

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Tofuyo in Japan

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Tofuyo, fermented tofu (soybean curd) made by the complicated actions of *Monascus*,

Aspergillus, and *Bacillus*, is a traditional fermented tofu in Okinawa, Japan. Fermented tofu has been widely consumed in East and Southeast Asian countries for a long time. Its origin has been considered to be *red-sufu*, which is a traditional fermented tofu of mainland China and Taiwan, and it was brought to Okinawa from Fujian, China, during the period of the Ryukyu dynasty in the eighteenth century. In Japan, fermented tofu, *red-sufu*, has been called *nyufu* (*rufu*) or *funyu* (*furu*) (Ohta, 1965a, b).

Chinese *sufu* is prepared by overgrowing with a mold of *Actinomucor*, *Mucor*, or *Rhizopus* on the surface of tofu, and it is further fermented in a mixture of salt brine and rice wine (Han, Rombouts, & Nout, 2001; Su, 1986; Wang & Hesseltine, 1970). Although there are several kinds of commercial products of *sufu* in Taiwan (Fig. 1), *red-sufu* is colored with red mold rice (*red koji* or *beni koji*), which is prepared by growing the mold of *Monascus anka* or *Monascus purpureus* on cooked rice. For the variation of *sufu* products, other additives are frequently added into the brine solution, imparting either additional color or flavor to the various types of *sufu* (Wang & Hesseltine).

Red-sufu was brined and had a strong taste. At first, it was unpalatable to the Okinawan people (Yasuda, 1983). Hence the process of making it was improved so it became a refined tofuyo, by using awamori, which is a traditional distilled liquor, in place of using a large amount of salt. Tofuyo prepared by the improved method became an indigenous fermented tofu product of Okinawa with a mild flavor and low salt. In addition, it is highly nutritious with high-quality protein, fat, carbohydrates, and other nutrients. Therefore, it is both a low-salt and low-cholesterol cheese-like vegetable product.

During the Ryukyu dynasty, the Royal family and high society relished tofuyo as both a health and gourmet food; however, it was hardly known to commoners (Yasuda, 1983). Tofuyo has some beneficial properties such as the smooth cheese-like texture, being a valuable source of protein, and improving blood circulation. Thus, they took delight in eating it not only as a nutritious side dish but also as a health food. Traditionally,



Tofuyo in Japan, Fig. 1 Commercial products of *sifu* (*furu*) made in Taiwan



Tofuyo in Japan, Fig. 2 Tofuyo and awamori

tofuyo has been directly consumed as a dish eaten with awamori or as cakes served at teatime for ladies (Fig. 2).

At that time, the techniques of making tofuyo were handed on to the next generation among only a few people in high society until the end of World War II (Yasuda, 1983). Thus, awareness and production techniques were very limited

even in Okinawa. In order to develop the tofuyo manufacturing industry, we have investigated the features of its production and scientifically analyzed its characteristics (Yasuda, 1990). Although the scientific aspects of tofuyo have yet to be fully clarified, the outcomes have already been transferred to the local industry in Okinawa, and the market for tofuyo is now developing in Japan and other Asian countries. Recently, it has received a lot of attention as a health food, which has physiological activities derived from soybean and fungal metabolites (Kuba-Miyara & Yasuda, 2012; Yasuda, Tachibana, & Kuba-Miyara, 2012).

History of Tofuyo

Consuming traditional tofu in East and Southeast Asian countries is known as *toufu-ru*, *toufu-ju*, *furu*, *rufu*, *sufu*, *fuyu*, *tou-yu*, and *tau-zu* in mainland China and Taiwan, *tafuri* in The Philippines, *tau ju* in Malaysia, *tau-fu yee* in Thailand, and *chao* or *dau-phu-nyu* in Vietnam (Han et al., 2001; Shurtleff & Aoyagi, 1979). Interestingly, fermented tofu, known as tofuyo, has never been

found in the mainland of Japan and Korea. The history of tofuyo has been reported in Japanese (Yasuda, 1983) and also in the special report on the history of traditional fermented soybean foods written by Shurtleff & Aoyagi in English (Shurtleff & Aoyagi, 2007).

History of Fermented Tofu

The origin of tofuyo is believed to be *sufu*, which is the traditional fermented tofu of China and Taiwan, and its beginnings have been considered to be in mainland China (Katsura, 1996; Yasuda, 1983). However, the exact dates and location of this origin remain obscure. The first description concerning fermented tofu is found in the book *Peng Long Ye Hua* written by Li Rihua in the Ming dynasty (1368–1644). Fermented tofu is also described in *Pen Ts'ao Kang Mu* (*Honzo Kou Moku* in Japanese), which is a famous book on Chinese medicinal plants written by Li Shih-Chen in 1596. Interestingly, the preparation techniques of fermented tofu described in both books are different; the former was prepared with molded tofu, and the latter did not use the molding process. The term *rufu* also appears in the section on animals in this book, but it is not fermented tofu. In this case, it refers to milk curd (yogurt), which is produced from the coagulation of protein in milk under acidic conditions.

Coming to the Ch'ing dynasty (1644–1912), some records concerning the production of fermented tofu appear, indicating that the molding process became mainstream for *rufu* production. The molding procedure for fermented tofu is described in the book *Shi Xian Hong Mi* written by Zhu Yizun in 1644. In this record, there is an interesting notation that the fermented tofu was made with *red koji*, which is called *red mold rice*. This description is one part of the evidence that the origin of tofuyo derived from *rufu* (*sufu*). The guidebook on local production in China, *Jiang Nan Tong Zhi* written by Huang Zhijun in 1737, introduced *rufu* as one of the finest products in the district of Jiang Nan, China. In this guidebook, *rufu* was not animal milk curd but fermented soybean curd. The manufacturing procedure of

the fermented tofu recorded in *Xing Yuan Lu* written by Li Shi-Ting in the mid-Qianlong period (1757–1776) is hardly different from the modern methods. Moreover, the details of fermented tofu, *rufu*, regarding the white type, famous production sites, and other aspects were also described in *Sui Yuan Shi Dan* written by Yuan Mei (1782). From these descriptions, it can be concluded that development and spread of fermented tofu originated in the Ch'ing dynasty and became popular in the diets of people in mainland China and Taiwan. Fermented tofu established in China spread to neighboring countries in East and Southeast Asia, and it was given individual names in each country. One of them, *tofuyo*, which is Okinawa traditional fermented soybean food, was traditionally made in the home or in small cottage industries until recently.

Geographic Location and Special Features of Okinawa

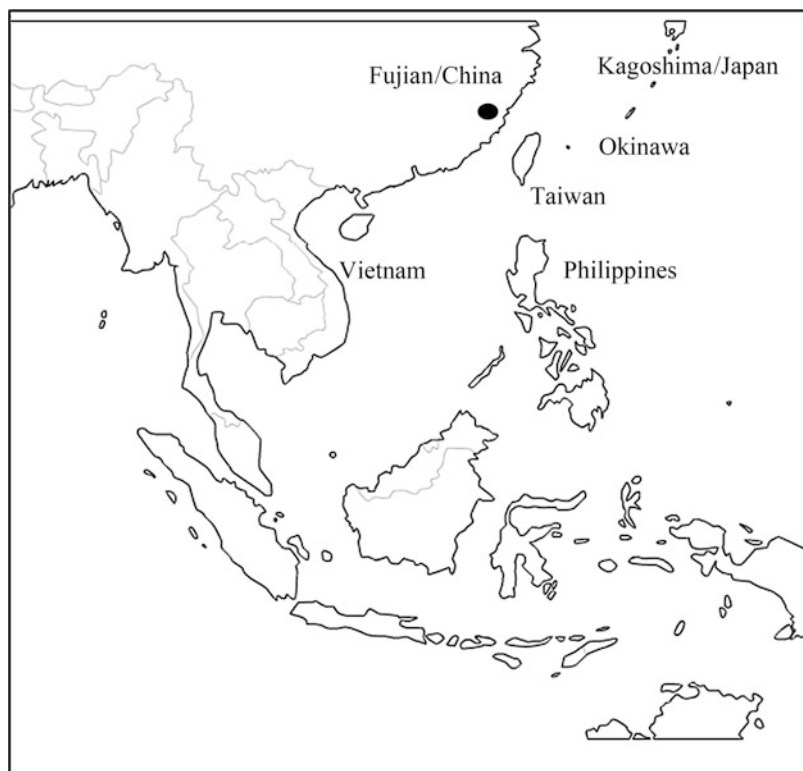
Tofuyo has a long and interesting history in Okinawa prefecture of Japan, and it has been passed down for a long period of nearly 200 years (Yasuda, 2011). There is no record that the tofuyo-like product was consumed in mainland Japan in the past; it is part of the distinctive history and location of Okinawa.

Okinawa is located at the most southern prefecture in Japan and is formed as an arch by a few hundred islands of the Ryukyu narrow islands extending from southwest Kyushu in Japan to Taiwan over a 1,000 km distance (Fig. 3). In the fifteenth century, the Ryukyu Kingdom (1429–1872) was established in Okinawa. The Kingdom thrived as a trading nation connecting with Japan, China, and Southeast Asian countries. The Ryukyu Kingdom existed until the Japanese Meiji government (1872) officially annexed it.

History of Tofuyo in Okinawa

The first description of fermented tofu products in mainland Japan is in the book *Tofu Hyaku Chin*

Tofuyo in Japan,
Fig. 3 Locality of
 Okinawa, Japan



Zokuhen (The Sequel to One Hundred Favorite Tofu Recipes) written by Ka Hitsu Jun in 1783. In this book, he gives instructions for how to make *red tofu* and *toufu-ji*. However, this description was similar to that of Chinese-style *red sufu*, also known as *red furu*, rather than that of *tofuyo*. Thus, it is thought that these fermented tofu products are more different than might first be surmised with *tofuyo* in Okinawa. Unfortunately, these fermented products have subsequently disappeared and can no longer be found in mainland Japan.

On the other hand, the Ryukyu Kingdom at the time maintained close commercial relations with mainland China, and that fact is formally recorded in the Ryukyu's Old Language Dictionary, *Kongo Kensyu*, in 1711 or in the book on the history of Ryukyu, *Ryukyu Koku Yurai Ki*, in 1713 edited by the Government of Ryukyu Ohfu (Royal Residence). Thus, it was believed that *sufu* and its production methods were brought to Okinawa from China (probably from Fujian, China) with the cultural exchanges. *Red sufu*

was likely introduced to the Ryukyu Kingdom during the late 1700s. However, even in these records, there is little detailed information regarding the fermented tofu, *red tofu*, *rufu*, *furu*, or *tofu-ru*. The brined product of *red sufu* had a strong taste and smell. For this reason, it was unpalatable for the people at that time and was recreated to suit their palate by using *awamori*. Thereafter, they were able to decrease the amount of salt in the original recipe and increase the shelf life without salt. In this way, the traditional *tofuyo* with an elegant, mellow, and delicious fermented soybean food was newly established.

At the present moment, the earliest known indirect reference regarding fermented tofu is found in the book *Account of a Voyage of Discovery to the West Corea and the Great Loo-Choo Island* written by Basil Hall in 1818. Hall and his party visited a Naha port on the way from China in 1816 and received a reception along with local cuisine and entertainment from the Government of Ryukyu Kingdom. In this

book, they described what happened at the reception. They ate something like cheese, and it is considered that the cheese-like food mentioned may be tofuyo.

Direct reference to tofuyo is found in *Gozen Hon Sou* written by Tokashiki Tsukan Pechin, who was a physician and high-ranking officer of the Ryukyu Kingdom in 1832. In this book, he introduced tofuyo, and according to his description, it was supposed to be delicious in flavor and have a favorable influence on the stomach. Moreover, as judged from the customs at the time, it was considered that tofuyo was consumed by the royal family and the upper classes as a side dish or a medicinal food in Okinawa. However, in fact, there was no reference to any record from 1832 until 1938 since it was a carefully guarded family secret.

From the early Showa era (after 1926) in Japan, preparation of homemade tofuyo began to be popular among the upper classes in Okinawa. However, its preparation method was not clarified at all. It is recorded that ladies ate it with tea and men took it with awamori. Typically, small tofuyo cubes were placed on a small dish and eaten with chopsticks or a toothpick. Even at that time, tofuyo was never widely consumed by regular people because it was only rarely made at home. In 1938, Baron Sho Jun, who was a descendant of the Ryukyu Royal Family and a well-known connoisseur of good food, wrote an article entitled “In Praise of Tofu” in the magazine *Monthly Ryukyu*. In this article, he said that tofuyo was one of the best rare and tasty foods in the world if not the best.

After World War II (after 1945), the technique of making tofuyo was passed on, and consequently, tofuyo came to be known to the common people. With the expansion of awareness of tofuyo, its industrialization came to be desired. However, in order to make tofuyo industrially, we were required to clarify features of tofuyo making that depend upon intuition and experience. To solve these matters, we revealed its features scientifically and then established the basic technology involved in tofuyo manufacturing (Yasuda, 1990). We transferred the outcomes obtained along the way to the local industry

during the 1980s. Subsequently, tofuyo, which reflects the food culture at the time of the Ryukyu dynasty, has been marketed. Nowadays, much attention has been paid to tofuyo as a health food that is both cholesterol free and low salt.

Making of Tofuyo

The manufacturing method of traditional tofuyo consists of three major parts: preparing tofu (soybean curd) and dehydrated tofu cubes, making koji, and soaking and ripening. A flowchart for tofuyo making is shown in Fig. 4.

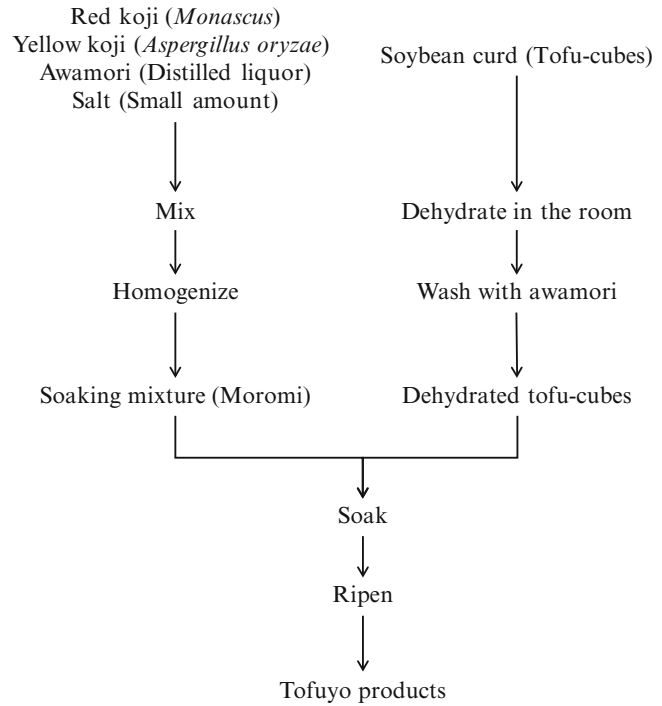
Processes for Making Tofu and Dehydrated Tofu Cubes

To prepare tofu, soybeans were first washed, soaked in tap water overnight, and then ground together with water. The mixture was heated and strained through a coarse cloth to separate the soymilk from the insoluble residues referred to as okara. The soymilk was then heated, and a coagulant was added into the heating soymilk to coagulate the soy protein. The coagulated soymilk was then transferred to a mold of a cloth-lined wooden box and pressed with a weight so as to remove the whey. Tofu appropriate for making tofuyo has to be hard, and its texture affects the quality of the product. The product has a suitable elasticity and fine texture during fermentation (Yasuda & Hokama, 1984).

For preparation of dehydrated tofu, the tofu prepared above was cut into 2 cm cubes, and the cubes were dehydrated for from 24 to 48 h. Since microorganisms such as bacteria grow on the surface of tofu cubes, their surfaces were washed with awamori (Yasuda et al., 1992). The resulting dehydrated tofu cubes were immersed in moromi, which is fermented broth prepared with koji, awamori, and salt. If the dehydrated tofu cubes were too soft, they would become mush during the ripening period. In contrast, if the cubes were too hard, it would be difficult to get a favorable texture.

Tofuyo in Japan,

Fig. 4 Process for making tofuyo



To establish a suitable texture of the tofu cubes for making tofuyo, we prepared different-hardness tofu cubes according to some dehydration methods and investigated their hardness values. We confirmed that the tofuyo prepared with tofu cubes dehydrated by mechanical methods such as by warm wind, in the oven, or under vacuum were not palatable and did not progress in the ripening. Therefore, the best quality of tofuyo was obtained with tofu cubes that were gradually dehydrated at room temperature (Yasuda & Hokama, 1984).

Some bacteria can grow on the surface of tofu cubes during dehydration. Some might produce high proteolytic and lipolytic activities due to its nutritional attribute. It suggests that the bacteria grown on the surface of tofu cubes may play an important role in “prefermentation,” which may affect the quality of tofuyo products. In fact, *Bacillus pumilus* TYO-67, which was isolated from the surface of tofu cubes during dehydration, produced abundant high secretory proteinase activity. In this research, we confirmed that the protein content of tofu cubes inoculated with

the bacterium during dehydration was lower than that of those uninoculated (Yasuda et al., 1992). In addition, we demonstrated that the inoculation of *B. pumilus* TYO-67 to the dehydrated tofu cubes shows faster maturation of tofuyo than that of uninoculation. Therefore, it was scientifically shown that the microorganisms grown on the surface of dehydrated tofu cubes may play an important role in “prefermentation” (Yasuda, 2003; Yasuda et al., 1992; Yasuda, Aoyama, Sakaguchi, Nakachi, & Kobamoto, 1999).

Processes for Making Koji

Koji, mold rice, is an important material for fermentation of tofuyo (Miyazato, 1977; Yasuda, Uechi, & Miyazato, 1981, 1983). For making rice koji, polished nonglutinous rice is used because it is essential that the mycelia of fungus quickly penetrate the rice kernel. Polished rice is soaked in water overnight, and the unabsorbed water is drained off. The swollen rice is cooked with steam at atmospheric pressure for 60 min,

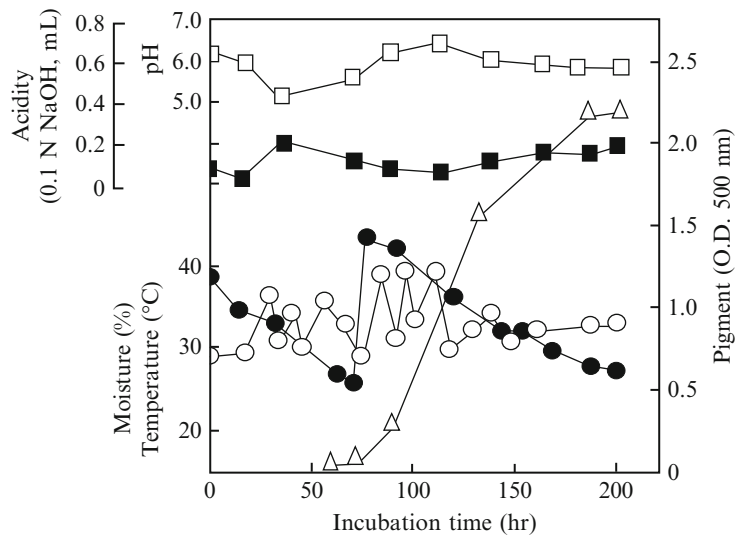
Tofuyo in Japan,

Fig. 5 Red koji. Red mold rice, “red koji,” was prepared with *Monascus purpureus*



Tofuyo in Japan,

Fig. 6 Changes in temperature, moisture, pigment, pH, and acidity of red koji during cultivation. *Monascus* was cultivated at 32 °C for the time indicated. The steamed rice was inoculated with seed containing *Monascus purpureus*, and cultured in an incubation box. Koji samples were taken for analysis at the indicated time. -○-; Temperature, -●-; Moisture, -△-; Pigment, -□-; pH, -■-; Acidity



cooled until near body temperature, and then inoculated with a starter of the genus *Monascus* or *Aspergillus oryzae*. The inoculated rice is placed in wooden trays and further grown with fungus. Red koji grown with genus *Monascus* was harvested after cultivation at 32 °C for 7 days (Fig. 5) (Yasuda et al., 1983). Yellow koji grown with *Aspergillus oryzae* was prepared by incubation at 32 °C for about 48 h (Yasuda et al., 1981).

During cultivation of koji, temperature, moisture, and aeration are extremely important factors and have to be rigidly controlled for preparation of high-quality koji without contamination.

Changes in temperature, moisture, pigment, pH, and acidity of koji during the cultivation are shown in Fig. 6 (Yasuda et al., 1983). After 40 h of cultivation, the material temperature increased to around 40 °C. The temperature of koji was controlled by hand mixing. After about 50 h of cultivation, the moisture level was reduced to 30 % or less, and the koji materials were moistened by a sterilized water sprinkle. Consequently, the fungus growth and koji pigment formation were markedly enhanced. The pH and acidity of koji were not greatly affected during incubation. After cultivation for 7 days, the koji prepared with the genus *Monascus* was harvested for

making moromi (Yasuda et al.). At this point, the production of proteinase, α -amylase, and glucoamylase activities were maximal after the inoculation of seed culture (Yasuda et al.).

Koji is a source of valuable hydrolytic enzymes for converting starch into fermentable sugars and proteins into peptides and amino acids. The features of koji suitable for making tofuyo are as follows (Yasuda et al., 1981, 1983; Yasuda, Matsumoto, Sakaguchi, & Kinjo, 1995). It has high hydrolytic enzyme activities such as protease, amylase, and glycoamylase. Another is that it provides a good flavor and taste. In order to enhance production of enzyme activities and pigments, we examined the effect of steaming methods and rice varieties (Yasuda et al., 1983). In the system of steaming under atmospheric pressure, enzyme and pigment production of glutinous rice koji was higher than those of nonglutinous and broken rice koji. In contrast, in the system of steaming under barometric pressure conditions, the productivity of koji prepared with nonglutinous rice was more abundant than that of broken rice or glutinous rice. Although glutinous rice is traditionally used as a raw material for koji preparation, we found that the highest production of the enzymes and pigment was obtained by employing autoclaved nonglutinous rice (Yasuda, 1990; Yasuda et al., 1983). Yellow koji by *Aspergillus oryzae* with high enzyme activities was also obtained in the same manner as the case of red koji described above (Yasuda et al., 1981).

Soaking and Ripening

The last process of making tofuyo is to soak and to mature the dehydrated tofu cubes into the moromi. To prepare the moromi (soaking mixture; fermentation broth), red koji and/or yellow koji, awamori (43 % alcohol concentration), and a small amount of salt are mixed and stored at 4 °C for from 24 to 48 h. The mixture is then ground with a blender until mushy, and the result is called moromi. The dehydrated tofu cubes are immersed into the moromi, and they mature at from 25 °C to 30 °C for 5 months. The ethyl

alcohol concentration in the moromi is finally around 20 %, and the pH is from 5.6 to 6.0 throughout the ripening period. The fermentation and ripening of tofuyo are accomplished under a high alcohol concentration derived from awamori. The quality of the tofuyo product is finally affected by the variety of koji and the liquor in the moromi. According to our investigations, we confirmed that the tofuyo product with red koji or the mixed koji with red koji and yellow koji was superior to that of only yellow koji with respect to color and flavor (Yasuda et al., 1995). Awamori has also important roles for giving tofuyo a pleasant flavor and preventing contamination with putrefactive bacteria. Using other liquors for making tofuyo such as whisky and shochu did not give such a desirable effect for the flavor fermentation of the product.

Characterization of Tofuyo

Chemical Changes in Tofuyo During the Ripening Period

To clarify its scientific characteristics, we investigated the chemical changes in tofuyo during the ripening period (Yasuda & Kobamoto, 1994; Yasuda, Matsumoto, Sakaguchi, & Kobamoto, 1993). The typical fermented tofuyo after 3 month ripening is as follows: 29.2 % crude protein, 21.2 % crude fat, 7.4 % crude ash, 0 % crude fiber, 24.2 % reducing sugars, and 3.2 % salt (on a dry weight basis). Crude protein and crude fat contents of tofuyo decreased along with ripening as time advanced, but sugar content increased. Sodium chloride content of the product was virtually constant (around 3 %) throughout the ripening period (Table 1).

Amino acids in fermentation products greatly contribute to flavor formation. We analyzed changes in the free amino acids of tofuyo, which was prepared by using red koji during the ripening period (Katsura, 1996; Yasuda, 2010), and the data are shown in Table 2. A dramatic increase in particular free amino acids is involved in the flavor formation of tofuyo products during the ripening period. Especially glutamic acid, alanine, aspartic acid, glycine, and serine may

Tofuyo in Japan, Table 1 Changes in chemical composition of tofuyo or moromi prepared by *Monascus* fungus during the ripening period

Ripening period (months)	Crude protein (%)	Crude fat (%)	Crude ash (%)	Crude fiber (%)	Reducing sugars (%)	NaCl (%)
Raw tofu	49.0	30.6	5.5	0	14.2	0
Dehydrated tofu	47.3	31.9	6.7	0	13.9	0
Tofuyo						
0.5	32.4	23.1	7.9	0	19.8	3.7
1	30.1	21.8	7.3	0	22.3	3.5
2	29.5	21.5	7.4	0	22.9	3.4
3	29.2	21.2	7.4	0	24.2	3.2
5	28.7	21.7	7.4	0	26.3	3.0
Moromi						
0	8.6	1.5	7.2	8.6	14.2	6.3
0.5	12.1	1.5	6.3	8.4	19.3	5.4
1	13.4	1.5	6.3	8.4	24.8	5.2
2	17.5	1.5	6.3	8.5	27.5	5.1
3	17.9	1.5	6.3	8.5	28.6	5.2
5	18.3	1.5	6.3	8.7	29.9	5.0

Tofuyo in Japan, Table 2 Changes in free amino acids of tofuyo prepared by red koji during the ripening period

Amino acid	Amino acid concentration (mg/100 g)					
	Raw tofu	Dehydrated tofu	Ripening period (months)			
			0.5	1	3	5
Aspartic acid	15	29	317	511	673	773
Threonine	23	26	33	78	143	148
Serine	10	53	78	209	410	481
Glutamic acid	20	56	283	609	864	881
Proline	9	49	85	83	86	147
Glycine	14	67	73	302	422	543
Alanine	24	90	219	414	676	702
Cysteine	0	0	3	5	6	9
Valine	15	19	38	88	145	124
Methionine	0	4	23	60	51	45
Isoleucine	3	15	40	85	126	137
Leucine	11	65	117	246	403	477
Tyrosine	0	10	51	114	153	150
Phenylalanine	14	50	65	128	200	173
Histidine	7	5	17	29	34	39
Lysine	8	4	13	78	152	216
Arginine	1	2	44	137	176	109
Total amino acids	174	544	1,499	3,176	4,720	5,154

contribute to the formation of a pleasant taste such as umami and sweetness. Furthermore, glutamic acid and aspartic acid contribute to produce a pleasant umami taste or savory enhancement in foods. In these data, the bitterness amino acids such as valine, isoleucine, leucine, tyrosine, phenylalanine, lysine, and arginine also gradually increased during fermentation, but the increased amount was much less than that of umami and sweetness amino acids.

Lioe & Yasuda (Lioe et al., 2004; Lioe, Apriyantono, Takara, Wada, & Yasuda, 2005) found that the presence of phenylalanine in savory fractions obtained from soy sauce is closely related to an enhanced umami taste in the fermented products. A potential synergistic effect of umami among free glutamic acid, salt, and phenylalanine was also observed (Lioe, Wada, Aoki, & Yasuda, 2007; Lioe, Selamat, & Yasuda, 2010). Furthermore, this phenomenon of umami or savory enhancement by subthreshold aromatic amino acids in soy sauce systems has been established by the model experiment system (Lioe et al., 2005). Although the efficacy of aromatic amino acids on umami or savory enhancement for the tofuyo product have never been investigated, the increment of these amino acids may seem to contribute to form the desirable taste and flavor of tofuyo.

Glucose is one of the major components apart from amino acids involved in the taste of the tofuyo product directly. The desirable taste of tofuyo is formed by interactions between these components. Glucose is produced by saccharification with the enzymatic actions of α -amylase and glucoamylase from koji (Tachibana & Yasuda, 2007). A similar phenomenon was also observed in the tofuyo products prepared using yellow koji and mixed koji (Yasuda et al., 1995, Yasuda, Matsumoto, Sakaguchi, & Kinjyo, 1994, 1995). Both α -amylase and glucoamylase produced by fungi had high activities throughout the ripening period despite the presence of high ethyl alcohol concentration from awamori. In fact, the reducing sugar contents of tofuyo increased with passage of the ripening period. Increase of glucose in the moromi is thought to be involved in the formation of its taste

components. Therefore, the saccharification ability by both enzymes also largely contributes to the formation of the desirable taste of the tofuyo product.

Recently, fermentation products have attracted attention as health-promoting foods. Especially peptides in fermentation products have the potential to prevent hypertension by inhibiting the angiotensin I-converting enzyme (ACE), which is a key enzyme for causing hypertension (Okamoto et al., 1995; Yang, Erdős, & Levin, 1971). Kuba, Tanaka, Tawata, Takeda, and Yasuda (2003) found ACE inhibitory activity (IC_{50} , 1.77 mg ml^{-1}) in extracts from tofuyo, and two ACE inhibitory peptides, IFL (IC_{50} , $44.8 \text{ }\mu\text{M}$) and WL (IC_{50} , $29.9 \text{ }\mu\text{M}$), were isolated to homogeneity. These peptides were expected to be easily absorbed by the gastrointestinal tract and to contribute to the antihypertensive effect via a transport system *in vivo* (Chun, Sasaki, Fujiyama, & Bamba, 1996; Kuba, Shinjo, & Yasuda, 2004; Kuba-Miyara & Yasuda, 2012). This finding suggests that previously unidentified bioactive compounds might be present in tofuyo and moromi. Therefore, tofuyo is expected to be beneficial as a health-promoting food.

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Tombs in Ancient Egypt

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An Egyptian tomb ideally comprised two basic parts. One was intended to house the body for eternity; the other was to act as the interface between this world and the next. These two elements could lie close to one another or could be separated by some considerable distance; they could also be of various constructional types and materials. However, the fundamental distinction remained between the mortuary chapel, or offering place, open to the public, and the burial chamber, intended to be sealed for eternity.

Theologically, since the dead were believed to dwell in the west, the western side of the Nile was the ideal place for a tomb. Accordingly, many necropoleis are to be found in this location. However, in a number of areas, this was not topographically practicable, tombs being placed on the east bank, in some cases with adjustments to ensure that the offering place of the public element faced west.

In the Nile Delta, however, the binary east/west bank division did not usually exist. Thus, while a cemetery might be placed to the west of the associated settlement, much depended on local topography, in particular the need to place cemeteries as far from the water table as possible. In a number of cases, particularly where a city hosted a royal cemetery, the necropolis was placed within the precincts of the principal local temple. This was also the case in some places in the Nile valley, in particular where the floodplain was particularly wide.

The public element of the tomb was usually focused on a stela, an inscribed slab that provided a point at which the two worlds met. It might be of simple form, bearing a depiction of the deceased (and perhaps his or her spouse) receiving offerings of food and drink, together with a ritual formula that guaranteed their eternal provision. On the other hand it might be an elaborately paneled “false door” (Fig. 1), making explicit the stela’s role as a portal between the worlds. In certain cases a statue of the dead person might replace or supplement the stela.

In many tombs the offering place comprised simply the stela, standing exposed, or with a very basic shelter carved out of the rock or built in brick or stone. However, in other cases the offering place was housed in a far larger structure, which could in turn be extensively decorated (Fig. 2). This structure may be referred to as a mortuary chapel or a mortuary temple, the latter term being generally used for royal examples.

For much of Egypt’s history, the decoration of such structures was concerned with food production, other motifs taken from the agrarian world,



Tombs in Ancient Egypt, Fig. 1 A typical false door stela of the Old Kingdom (British Museum EA682) belonging to Ptahshepses (ca. 2425 BCE) (Photo by author)



Tombs in Ancient Egypt, Fig. 2 The false door of Ptahhotep at Saqqara (ca. 2350 BCE) lies within a highly decorated chapel (Photo by author)

and the experiences of the deceased. In royal cases, this could include scenes of the gods and events of the reign. Tableaux in private chapels are often referred to as “daily life” scenes and provide an important source for our understanding of life in ancient Egypt. Their primary role was clearly to recreate magically the world the deceased had once enjoyed, as well as providing a further source of eternal sustenance. It seems likely, however, that they had other more esoteric significance, linked with concepts of regeneration and rebirth in the next world. From around 1250 BCE, these “daily life” scenes tend to be replaced by others of purely ritual type, with images of the gods and extracts from the various Egyptian funerary “books” that aided the dead person in his or her posthumous destiny.

As already noted, the form of the offering place varied. At one extreme, those of kings could be huge temples, either freestanding or, prior to the middle of the second millennium BCE, attached to a pyramid. Prior to the appearance of the pyramid, royal tombs seem to have

had a simple offering place adjacent to the burial chamber, and a large rectangular enclosure up to 1.5 km away, used during the funeral ceremonies, but dismantled afterwards. A mound of rubble or some other structure may have topped the burial place itself. At the beginning of the Old Kingdom (ca. 2650 BCE), these separate elements were united as a permanent monument in a single location, in the Step Pyramid complex of King Djoser at Saqqara. For perhaps the first time, all parts were built of stone, and a low square structure over the burial place was soon extended to form the basis of a six-stepped pyramid, the first of its kind (Fig. 3).

Only the very earliest pyramids were stepped, perhaps to provide a stairway to heaven for the dead king. They were soon replaced by smooth-sided structures (“true pyramids”), apparently intended as a recreation of the sun’s rays, along which the monarch might make his way to join with the sun god (Fig. 4). The very first step pyramids were surrounded by large rectangular enclosures holding ritual buildings (Fig. 5). However, these were soon superseded by a smaller enclosure with a mortuary temple on the east side of the pyramid. From this a causeway led to a “valley temple” on the edge of the desert (Figs. 6 and 7).

The free-standing temples that were adopted by the kings of the New Kingdom (1550–1070 BCE) after the royal abandonment of pyramids were all but indistinguishable from contemporary temples of the gods, the differences being in detail only (Figs. 8 and 9). Unlike earlier mortuary temples, the king’s spirit now shared the temple with Amun, the King of the Gods, and the sun god, Re, each of whom had his own separate sanctuary within the temple. They are thus often distinguished from the earlier temples by the description of “memorial temples.”

Private individuals’ mortuary chapels fall broadly under three headings. One type is built against or within *mastabas*, stone or brick structures shaped like low benches (“mastaba” means “bench” in Arabic). They are used throughout Egyptian history at sites with a flat basic topography, although the best-known date to the Early Dynastic Period and Old and Middle Kingdoms (ca. 3000–1700 BCE).

Tombs in Ancient Egypt,

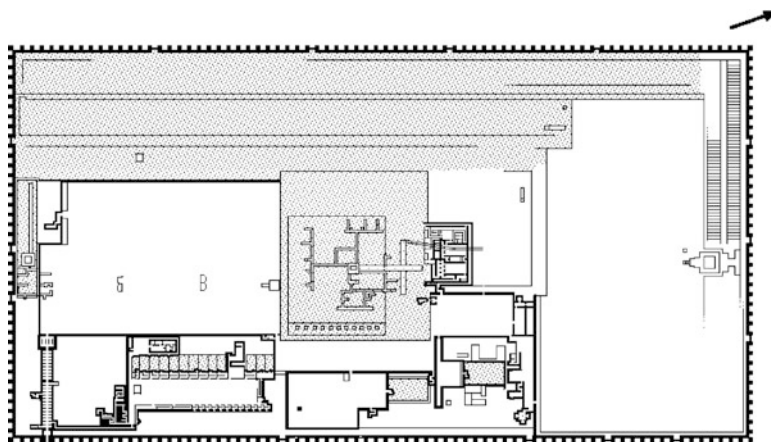
Fig. 3 The first pyramid – the Step Pyramid at Saqqara (Photo by author)

**Tombs in Ancient Egypt,**

Fig. 4 The finest examples of the true pyramid lie at Giza, belonging (*left to right*) to Kings Menkaure, Khafre, and Khufu (ca. 2550–2475 BCE) (Photo by author)

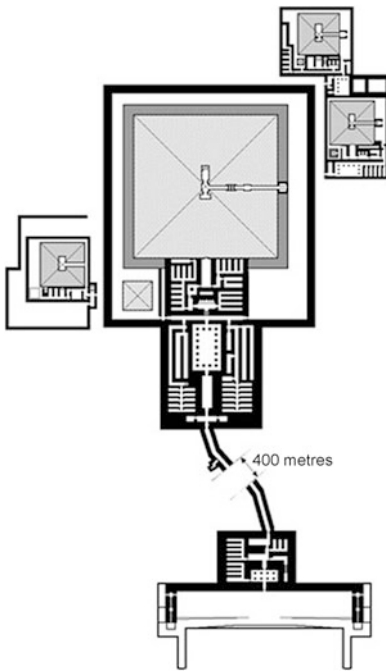
**Tombs in Ancient Egypt,**

Fig. 5 Plan of the Step Pyramid complex, showing the great expanse of ritual buildings (Plan by author)





Tombs in Ancient Egypt, Fig. 6 Typical of later pyramids is that of Sahure (ca. 2465–2450 BCE), with a mortuary temple on the east side (Photo by author)



Tombs in Ancient Egypt, Fig. 7 This shows the layout of the whole complex of Pepy II (ca. 2290–2180 BCE); the small pyramids belonged to his wives (Plan by author)

Mastabas of the earliest times usually had a paneled exterior, but from the Old Kingdom onwards, they tended to have flat, slightly sloping, sides, although paneling is occasionally found down into the Middle Kingdom (2100–1700

BCE). Chapels range from a simple niche at the southern end of the eastern face, holding the stela, to a complex of a dozen or more decorated rooms occupying much of the interior of the mastaba. Most usual is an offering place with one or two rooms (Figs. 10, 11, 12, and 17).

The next type of mortuary chapel is also employed on flat sites but comprises a freestanding building without an associated mastaba. Once again, these can vary considerably in size and elaboration, from little more than a shed around the stela to a miniature temple. The latter seem to appear first late in the Eighteenth Dynasty and are referred to as “temple tombs” (Fig. 13).

The final form of mortuary chapel is that which is cut into a rock face (Fig. 14). Such offering places first appear around 2500 BCE at Giza, and are found throughout the rest of Egyptian history. Plans are almost infinitely variable, although a number of fairly standardized plans are to be seen at Thebes during the New Kingdom (1550–1070 BCE). In particular there is the T-shaped tomb, with a broad but shallow hall running across the axis and a long corridor running from the middle of its back wall to the offering place, deep in the rock. This basic form could be greatly elaborated by the addition of columns and further chambers – one had no fewer than 70 columns.



Tombs in Ancient Egypt, Fig. 8 The earliest surviving New Kingdom royal mortuary temple is that of Queen Hatshepsut (ca. 1472–1457) at Deir el-Bahari (Photo by author)



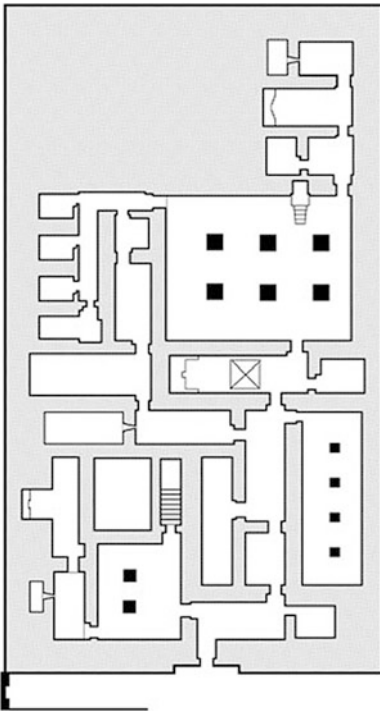
Tombs in Ancient Egypt, Fig. 9 Of rather different appearance but with the same purpose is the temple of Ramesses III (ca. 1185–1153 BCE) at Medinet Habu (Photo by author)

Tombs in Ancient Egypt, Fig. 10 The entrance to the now-ruined chapel of the paneled brick mastaba of Nefermaat at Meidum (ca. 2550 BCE) (Photo by author)





Tombs in Ancient Egypt, Fig. 11 A group of stone mastabas at Giza (ca. 2430 BCE) (Photo by author)



Tombs in Ancient Egypt, Fig. 12 The most elaborate chapel within a mastaba is that of Mereruka (ca. 2340 BCE) at Saqqara (Plan by author)

Of course, this division is purely for convenience, and many tombs exist that are a combination of more than one category. In particular, rock-cut mortuary chapels could have freestanding courtyards built in front of them (Figs. 15 and 16). Particularly elaborate examples date to the Saite Period (663–525 BCE).

In addition, after the abandonment of pyramids by kings, miniature examples often appeared above private sepulchres, of both built and rock-cut designs.

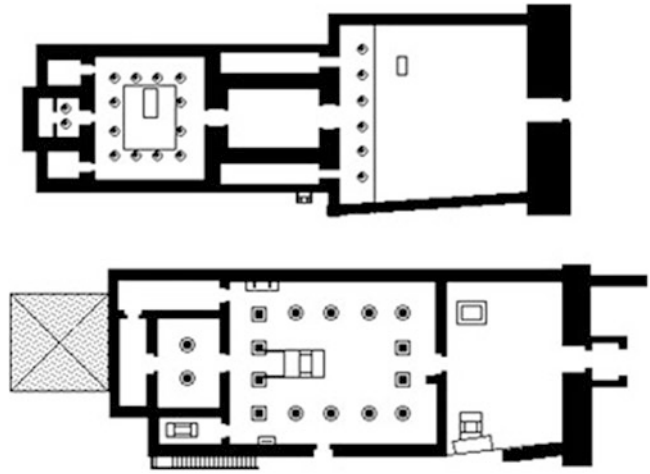
The burial chamber and its associated elements are collectively known as the “substructure.” The two key types are those approached via a vertical shaft and those accessed by sloping passage or stairway. A further consideration is whether the substructure has been tunneled out of the living rock or whether it has been constructed out of stone or brick in a cutting in the desert surface and subsequently covered over. There are, however, tombs that use more than one approach to various elements of their substructures.

In the vast majority of Egyptian tombs, the substructure lay close to, or directly under, the offering place. Many Old Kingdom mastabas had shafts descending from their roofs to burial chambers in the rock below (Fig. 17), while royal pyramids usually had their burial chamber under the center of the monument, approached via a sloping corridor from the center of the north face of the pyramid. In rock-cut mortuary chapels, sloping passages are found in the earliest examples, but later shafts are used as well.

Occasionally, the substructure lies some way from the offering place. The best examples of this are the royal tombs of the New Kingdom at Thebes, where the mortuary temples lay on the edge of the desert, but the tomb chambers were up to 2 km away in a desert valley. This is now known as the Valley of the Kings and also held

Tombs in Ancient Egypt,

Fig. 13 Plans of the “temple tombs” of Maya and Tjia at Saqqara, ca. 1340–1240 BCE. Note the pyramid attached to the rear of the lower sepulchre (Plan by author)



Tombs in Ancient Egypt,

Fig. 14 A classic group of rock-cut mortuary chapels are at Aswan, dating between ca. 2400 and 1850 BCE (Photo by author)



the burial chambers of a handful of highly placed nobles, whose rock-cut mortuary chapels lay a similar distance away.

Substructures took a variety of forms, ranging from a single chamber and approach shaft/corridor to a long sequence of corridors, pits, and halls. In the Nile valley, substructures were usually tunneled into the bedrock or constructed within trenches cut in the rock. However, in the Delta, where the bedrock was below the water table, constructed chambers were always used, sunk as deep as possible without getting too close to the water table, since damp was fatal to the preservation of the mummified body and its accompanying equipment.

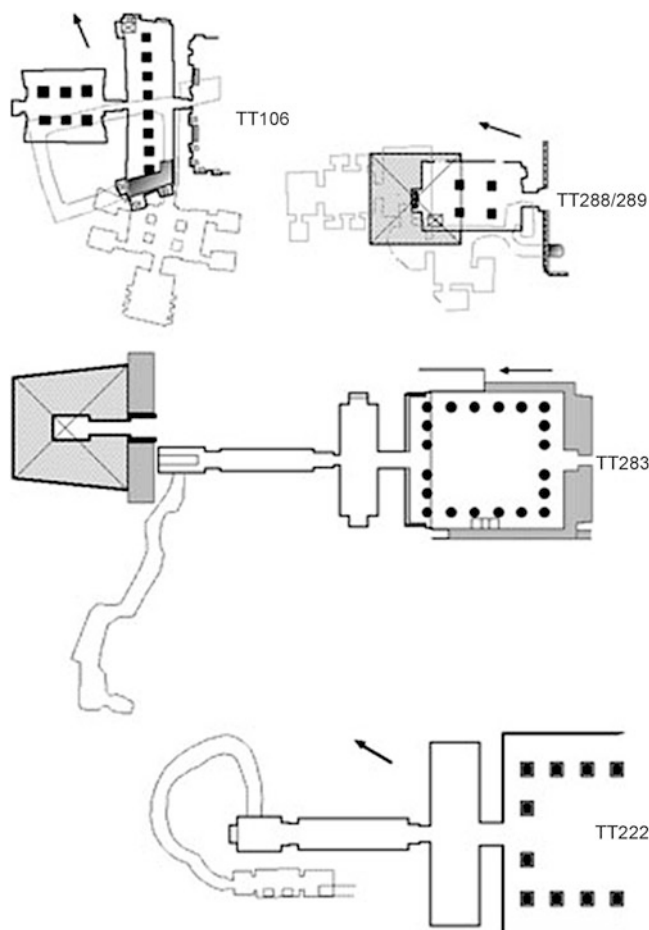
While most substructures were simple, with an approach shaft or passage leading to a room

whose door was simply blocked after burial, some included special security features, with sliding trap doors, hidden entrances, and/or burial chambers cut from single blocks of stone, closed with the aid of a “hydraulic” system using sand. Such elaborate features were first employed during the late Twelfth Dynasty (ca. 1800 BCE) and then revived over a millennium later, during the Saite Period.

Royal tombs were not surprisingly among the sepulchres with the most elaborate substructures, although certain private examples, particularly of the Saite Period, exceeded even them. Many earlier pyramids had a standardized substructure, built of stone in a shallow cutting, with a group of three chambers reached by a long corridor. This was blocked by three vertical portcullis

Tombs in Ancient Egypt,

Fig. 15 Plans of the private tombs of Paser, Setau, Roma-Roy, and Heqamaatrenakhte at Thebes during the middle of New Kingdom (ca. 1300–1150 BCE), showing the relationship between the mortuary chapel, in some cases pyramid, and the substructure (Plans by author)



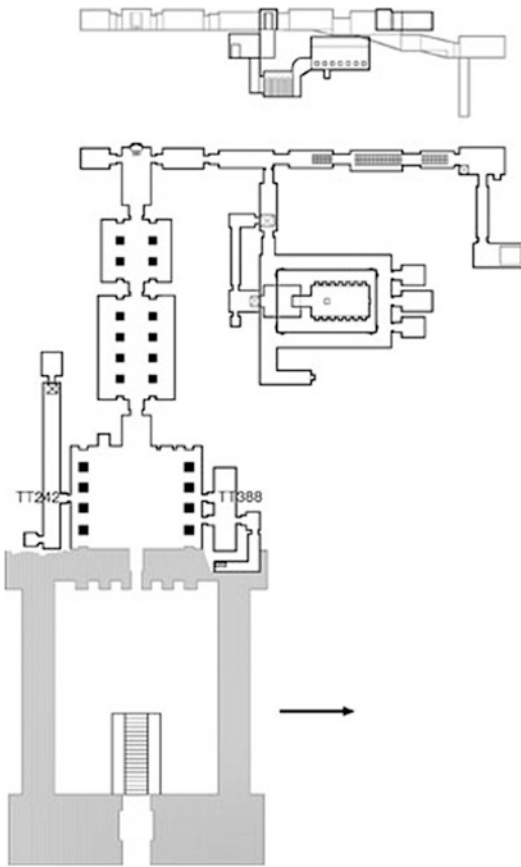
slabs of granite (Fig. 7). From the middle of the Middle Kingdom, however, changes were brought in to increase security. Entrance locations became random, and the aforementioned security arrangements introduced.

The security imperative probably also lay behind the separation of the royal burial chamber from the mortuary chapel early in the New Kingdom. The Valley of the Kings tombs generally take the form of a set of passages and stairways, leading to a pillared antechamber, and finally to a pillared burial chamber. A shaft in the floor interrupted progress down the tomb, probably with a dual role of hindering thieves and preventing storm water's penetrating the inner rooms (Fig. 18).

In contrast to the mortuary chapel or temple, which almost always had some form of

decoration, the substructure was usually completely plain. The principal exceptions were the royal tombs of the late Old Kingdom and the New Kingdom onwards, and a handful of private sepulchres of the Sixth Dynasty, Middle Kingdom, New Kingdom and Saite Period. In the late Old Kingdom, royal burial apartments were adorned with the *Pyramid Texts*, magic formulae intended to aid the king in the next world. They are the ancestors of a whole series of “books” that formed the basis for all later substructure decorations.

Royal tombs of the New Kingdom and later were principally adorned with various heavily illustrated compositions relating to the sun god's nocturnal journey through the underworld, in which the dead king would participate (Fig. 19). At first these works were a royal

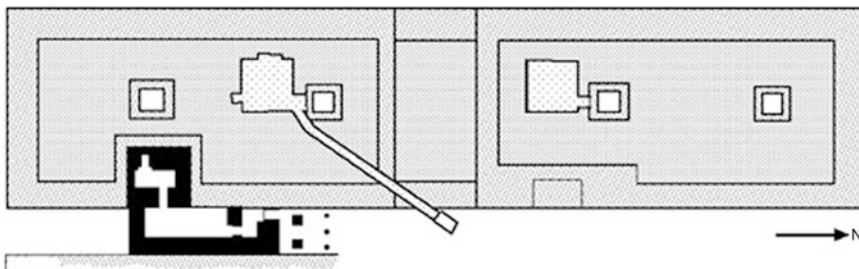


Tombs in Ancient Egypt, Fig. 16 One of the largest and most elaborate tombs in Egypt belonged to the priest Pedamenopet (ca. 600 BCE). It was partly built of brick and partly rock cut, with an extremely elaborate substructure. The burial chamber was carefully concealed and was approached from below (Plan by author)

prerogative, but by Saite times they could also be found in private tombs as well, which also revived the ancient *Pyramid Texts*.

The rare Old Kingdom decorated private burial chambers generally had illustrated lists of offerings on their walls. This was also the case in the Middle Kingdom, but in the New Kingdom the main decorative composition was the *Book of Coming Forth by Day* – better known as the *Book of the Dead*. This was essentially a guidebook to the next world and was more usually found on a papyrus placed alongside the mummy. Extracts are also found in mortuary chapels of the Nineteenth Dynasty and later.

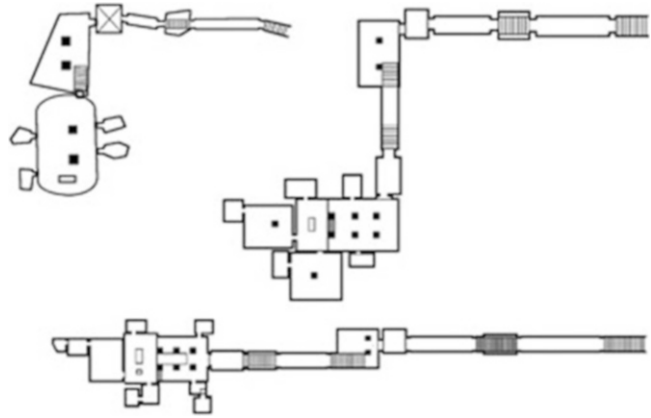
Following the Macedonian and Roman takeovers of the country, Egyptian-form tombs were supplemented by those in the classical tradition, in particular at Alexandria and in other areas with high levels of European settlement. However, even these sepulchres often included Egyptian features, especially in their decoration, where the native gods often appeared. A key difference between the two mortuary traditions was the blurring of the previous rigid distinctions between the chapel and the burial place. In classical tombs the body was placed in a sealed loculus in the wall of a generally accessible catacomb that might include both a chapel and a room for funerary feasts.



Tombs in Ancient Egypt, Fig. 17 Plan of the tomb of Kawab at Giza (ca. 2530 BCE), showing the burial shafts descending through the superstructure and the chapel built partly within and partly outside the mastaba (Plan by author)

Tombs in Ancient Egypt,

Fig. 18 Plans of the tombs of Kings Thutmose III, Amenhotep III, and Horemheb in the Valley of the Kings, showing the evolution from a “bent” to a straight plan between ca. 1450 and 1300 BCE (Plans by author)



Tombs in Ancient Egypt,

Fig. 19 The Book of the Earth, one of the numerous compositions found on the walls of New Kingdom royal tombs. Here it is seen in the burial chamber of Ramesses VI (ca. 1141–1133 BCE)



See Also

► [Embalming in Egypt](#)

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Tongren Zhenjiu Shuxue Tujing

Richard Bertschinger

The *Tongren Zhenjiu Shuxue Tujing* (Illustrated Canon of Acupuncture Points based upon the Bronze Figure) was written by Wang Weiji, and published in AD 1026. It has been a baseline in the identification of acupuncture points ever since. It is used not only in Chinese medicine, but also in acupressure as developed recently in the West, in *shiatsu* (pressure point massage) in Japan during this century, and in all acupuncture-related disciplines.

By the Song Dynasty (AD 960–1126), after much copying and recopying, the locations of the points and channels had become confused. Because of this and the greater stability brought about by the Song reunification of the empire, the medical scholar Wang Weiji reorganized and

collated all the then available material in order to locate and define the points precisely.

He produced a book which very quickly became the authoritative text throughout the country. It gave very detailed and accurate information concerning the points, the channels, the depths and effects of needling. The total number of points named in the ► [Huangdi Neijing](#) (Yellow Emperor's Canon of Medicine) had been 160; in the *Zhenjiu Jiayi Jing* (A-Z of Acupuncture and ► [Moxibustion](#)) it was 349. But now it was raised to 354. Not long afterwards, the full text of this book was cut onto two stone tablets, each some 2 m high and 7 m in length, which were erected in the Song capital, Kaifeng, where they could be read by everyone, or where ink-impressions could be made from them.

At the same time Wang Weiji directed the casting of two life-size bronze figures – hence the title of his book – which were completed in 1027.

These bronze figures are the very earliest of their kind. They were hollow and had the exact locations and names of the acupuncture points marked on their surface. It is noted in the Song histories that the purpose of the figures was for them to be covered in beeswax and then filled with water. When a student palpated and punctured a point correctly, a stream of water would flow out, reminiscent of the energy stream (or *qi*) tapped by that particular point.

The later history of these figures and tablets is also revealing. After 200 years, when the Yuan Dynasty moved the capital to what is now Beijing, the bronze figures and tablets were also moved, to take pride of place in the temple at the new Imperial Medical College. However, much use had been made of the figures, and the tablets were so worn that they were indecipherable. Reproductions were therefore made again. During excavations from 1965 to 1971 in Beijing, fragments of the original Song tablets were discovered, and their texts shows that the tradition has been faithfully and accurately preserved to the present day. This book is used as the foundation text for the listing of points in the *Essentials of Chinese Acupuncture* (Beijing, 1980) and other texts which have all been recently produced

in China and which are aimed at the interested acupuncture audience in the West.

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Tool Recycling in India

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Antiquity of Tool Recycling

Recycling of discarded utilitarian items as raw materials in fresh manufacturing is common in today's industrial world. And that the reusing of the discarded items for purposes different than they were originally used or for the same purposes, either by the same users or by altogether different users, is also common. Such evidences from the prehistoric past remained unknown until recently when it has been convincingly established that during the Stone Age, such practices not only happened but also were far more extensive and widespread, and they played quite significant role in prehistoric assemblage formation. In a Research Workshop organized by *The Israel Science Foundation* in 2013, several papers were presented on stone tool recycling during the early Stone Age (<http://earth911.com/tech/prehistoric-recycling/>). Evidence found in Fuente Nueva, southern Spain, although not very convincing, suggest that stone tool recycling may date as far back as 1.3 million years ago (Barsky et al., 2014).

Although the practice of tool recycling in prehistoric culture has only recently been

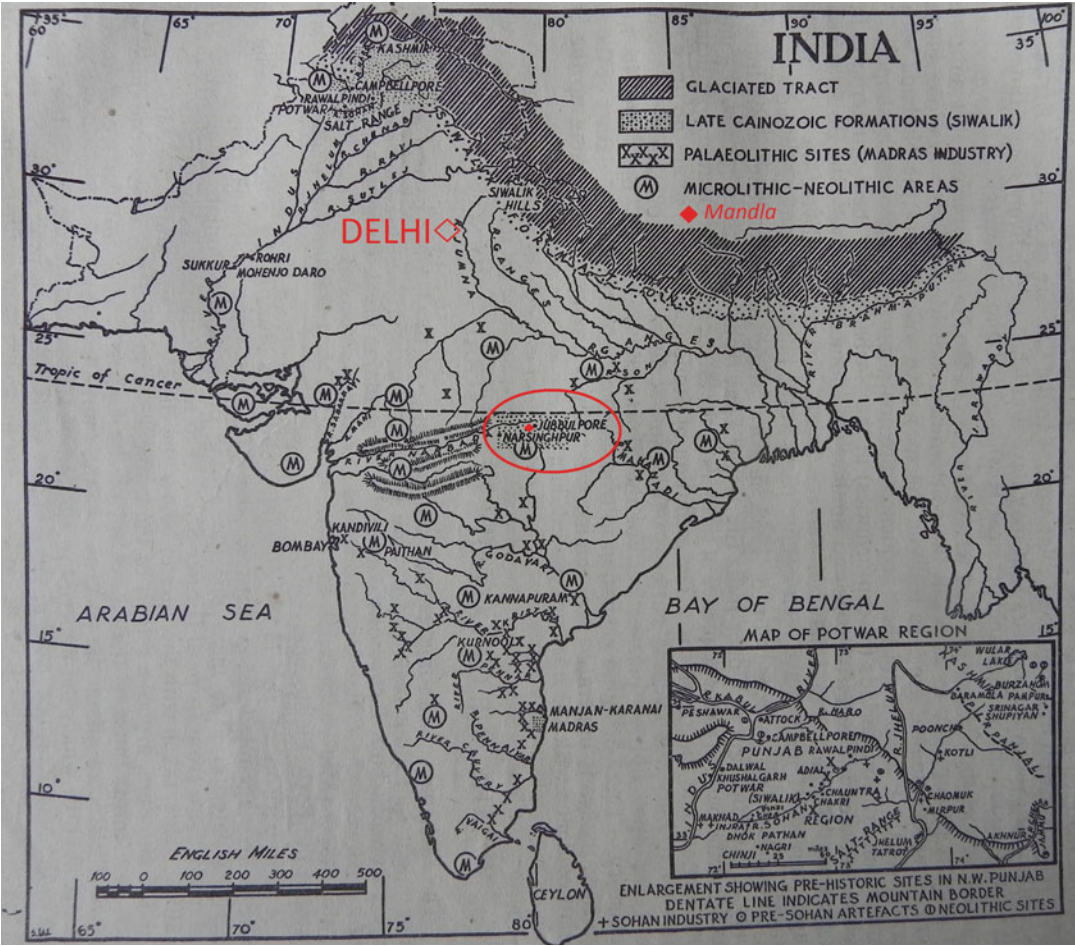
established, scavenging of stone tool remains, and their reuse by native Indians during the contact period all through the New World, by the Australian aboriginals, and by many native Indians in isolated pockets in Asia and Africa are now well established in prehistoric literatures (Cane, 1992, p. 26; Daniel et al., 2007; Galup, 2007; Goodyear, 1979; Kardulias, 2009; Sampson, 2009; Silliman, 2003). Scavenging of exposed prehistoric sites for suitable raw material by contemporary tribal people for modern uses (uses different from those of the original stone tools) is, however, a more commonly reported phenomenon from many parts of the world. The frequent uses of recycled stone tools collected from exposed prehistoric sites by contemporary tribesmen in several modern uses (e.g., strike-a-light set, folk surgery, etc.) are reported from many Southeast Asian regions, such as Borneo, Indonesia, India, and Sri Lanka (Brumm, 2006; Roy, 2009).

During the 1970s, Professor Lewis Roberts Binford (1931–2011) popularized the concept of “curation and recycling” in prehistoric archaeology. However, this issue generally has evaded serious archaeological interest until recently when convincing evidence established such prehistoric engagements to be far more extensive than ever realized, and their actual significance in archaeological interpretations is now understood. The problem of identifying the recycling evidences in prehistoric material remains perhaps was the main reason for not getting enough attention of archaeological investigation, which involves both the primary (reused in the same way as it was earlier either directly or by rejuvenating the cutting or working edge) and the secondary (the recycled material is put into altogether a different product, such as using as raw material for fresh knapping – striking a piece of stone to make weapons) recycling activities. In prehistory, both these conditions are difficult to establish. In the first instance, it is not easy to distinguish an existing tool that had been rejuvenated again and again during its lifetime by the user from that of a discarded tool that had been

reused/recycled by later users either immediately or after several years of disposal. In the second instance, the identification of recycling could be difficult in all such cases where the discarded tools of earlier age had been reused or recycled to shape completely new items destroying all obvious features of their earlier use.

Tool Recycling in Prehistoric India

A series of prehistoric archaeological sites bearing micros or microliths (very small size stone tools typically belonging to the Mesolithic period of the Stone Age) have been discovered in the district of Mandla (22° 12' to 23° 22' N, 79° 57' to 81° 45' E), Madhya Pradesh, in India during 2001–2002 (Roy, 2003, 2008, 2009, 2011, 2012). The Mandla findings are an important addition to the numerous prehistoric sites already discovered in the Chota-Nagpur belt (Jharkhand) and the adjacent geography now found across the States of Odhisa, Chhattisgarh, and Madhya Pradesh (Figs. 1 and 2). The discovery of the Mandla archaeological sites is significant for two reasons – first for having clear evidence of continuity of the microlithic tradition until recent historical time (late nineteenth or early twentieth Century) and second for convincing evidence of using recycled stone tools in prehistoric tool-making practices. This is the first time that evidence of stone tool recycling in prehistoric culture was reported from India. The evidence of patinated dorsal features (flake scars) from previous use along with comparatively fresh flaking marks on the same specimen confirmed recycling practices. Large tools discarded by earlier users were reused as raw materials for microlith production. It is often difficult to determine whether the old patinated surface is actually an earlier flake surface or is in fact a natural rock face. Moreover, historical contamination in case of open-air deposits, although all archaeological sites are now believed to remained exposed – at least for a brief period of time before undergoing stratification – can also make the situation



Tool Recycling in India, Fig. 1 Prehistoric sites in the Indian subcontinent in 1947. Since then more sites have been added, a large number of which come from the contiguous geography located across the adjoining States of Odhisa, Chhattisgarh, and Jharkhand. Mandla sites

discovered during 2001–2002 are further added to the list of prehistoric sites in India (Credited to V. D. Krishnaswamy, “Stone Age India”, Ancient India 3:11–57, 1947)

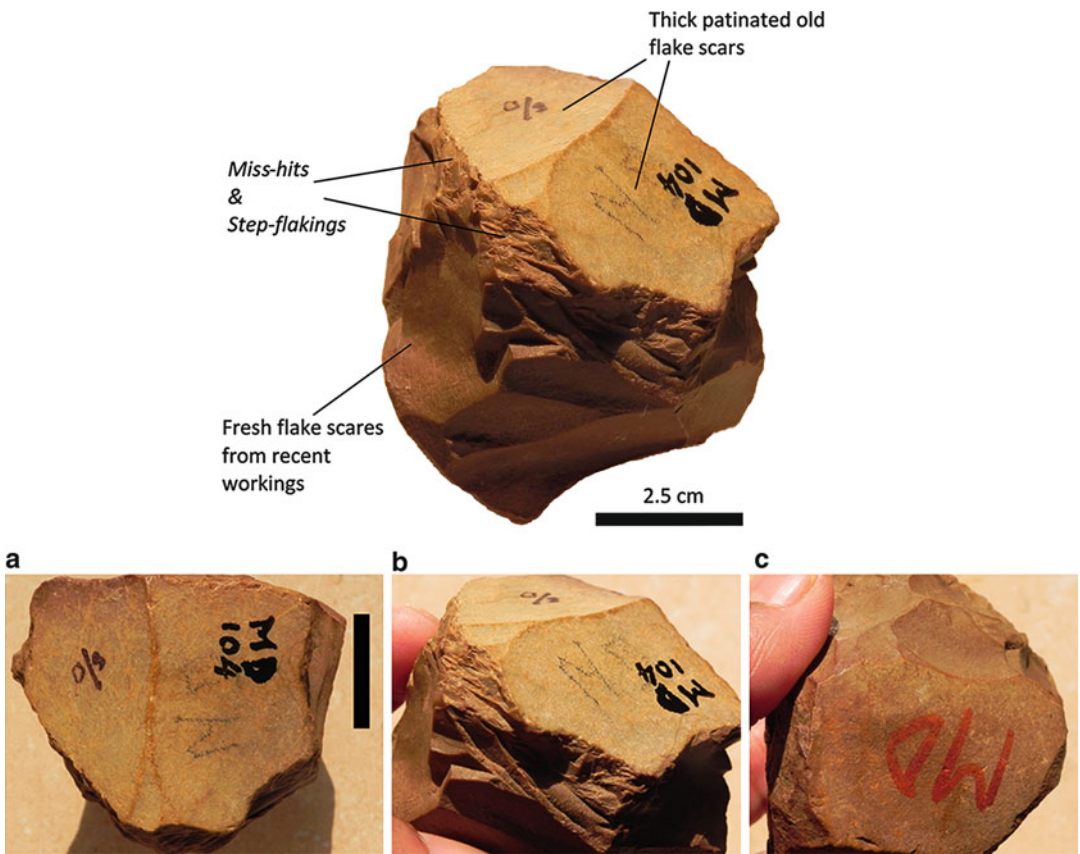
confusing. In Mandla, India, a core made on a recycled artifact is a confirmed case. The striking platform of the specimen undoubtedly bears old flake scars of an earlier artifact (Fig. 3). Once this was confirmed, several artifacts of Mandla findings, which were possibly made on recycled materials, were rather easily segregated (Figs. 4, 5, 6, and 7).

Tool Recycling: Implications in Prehistory

The Stone Age economy of using the easily available large tool remains as raw materials, particularly in subsequent small tool using cultures, has implications in our general interpretation of prehistoric cultures. The question is whether the

Tool Recycling in India,

Fig. 2 Partala prehistoric site in Mandla. The site abounds with natural pebbles and rocks scattered all around, a commonly occurring scenario in the district (*Inset*) Prehistoric artifacts are occasionally found in the open along with scattered natural pebbles and rocks



Tool Recycling in India, Fig. 3 An exhausted stone core on recycled material (secondary recycling) – (a) top, (b) side, and (c) bottom views (Scale: bar stands for 2.5 cm). The striking platform bears patinated flake scars from previous use. Relatively fresh flaking marks (miss-hits

and step flaking marks) from latest use are found around the edges of the striking platform (This and all other photographs/figures, if otherwise not mentioned, are by author)

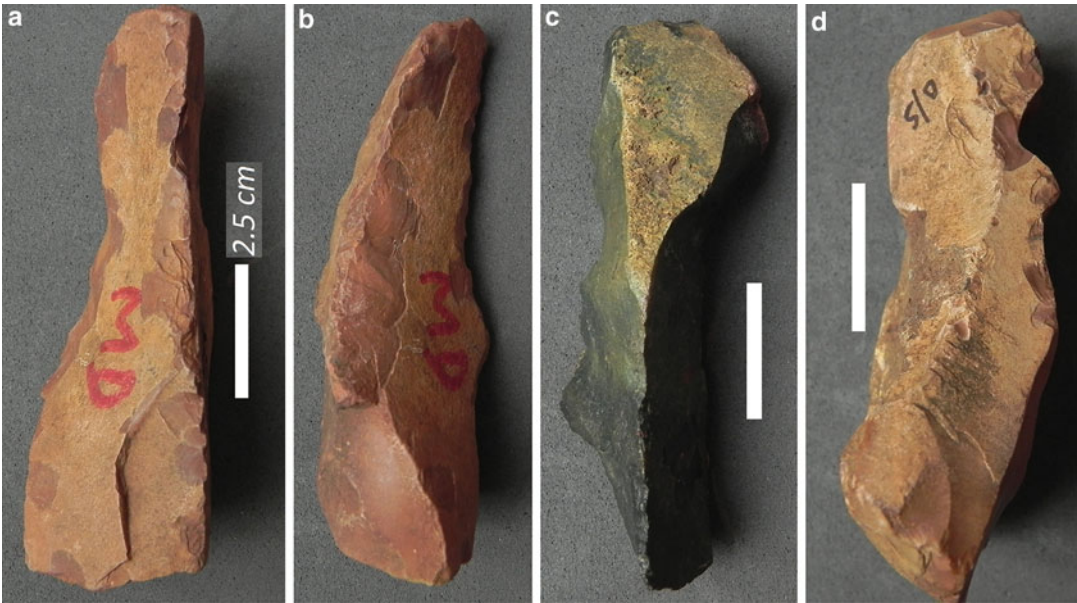
culture in question was largely or exclusively based on any earlier cultural ruins. Any prehistoric engagement must involve this particular issue, as the same may influence the reading of prehistoric records to a considerable extent. In



Tool Recycling in India, Fig. 4 Use of recycled tools by fresh trimming of the working edge (primary recycling). The recycling practice is confirmed by double patination – fresh and old of considerable time gap

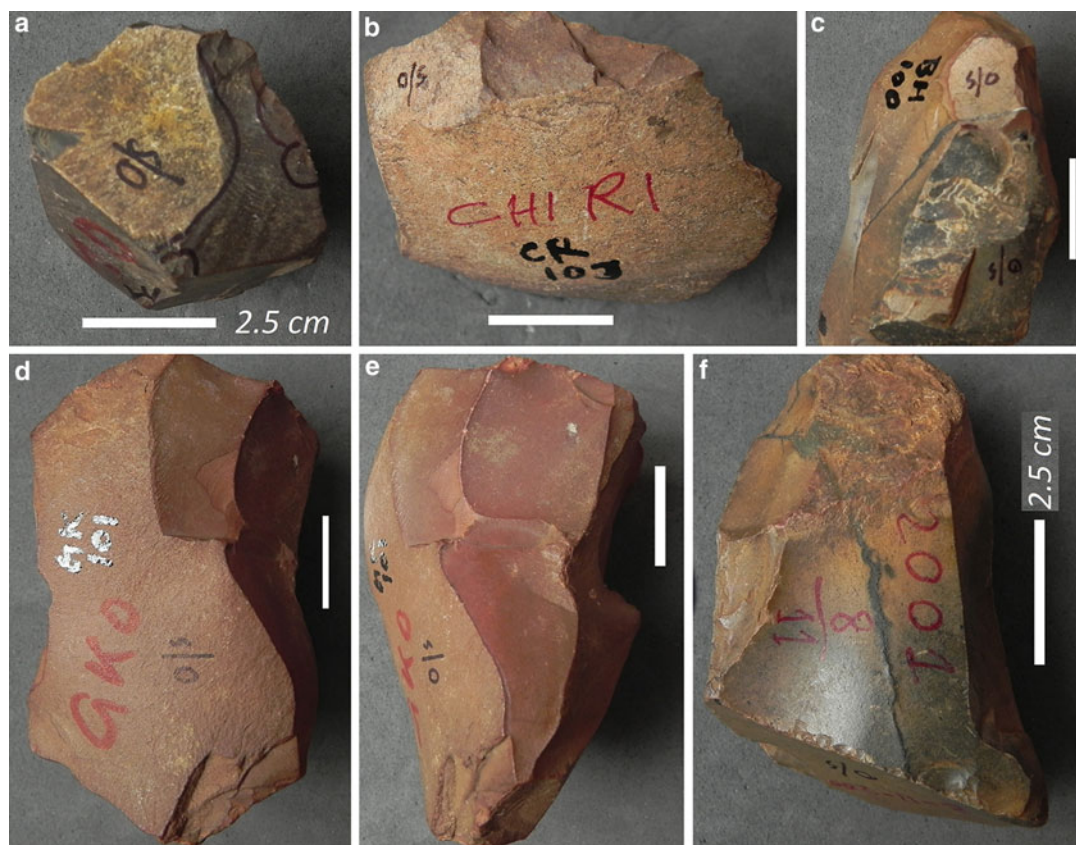
India, recycling evidence in prehistoric assemblage may not be so lacking, but has probably remained unnoticed in archaeological interpretations so far. The discovery of Mandla may influence further study in this direction. And since most of the prehistoric sites in India are exposed to the open air without reliable dating clues, the evidence of recycling may guide further understanding of the chronology problem.

How extensive the practice of using recycled large tools in small tool (micros) manufacturing remained in prehistoric practice might judge the extent of destruction of the large tool cultural remains by subsequent small tool makers. In Mandla, hundreds of stone tools have been recovered bearing signs of being prepared from recycled large tools of earlier times. Thus, the large tool cultural remains of earlier phase had possibly been destroyed by subsequent small tool makers. Archaeological sites or cultural remains whether are based on ruins of earlier cultures must be carefully investigated to understand the Stone Age history of a region or the local cultural



Tool Recycling in India, Fig. 5 Use of recycled tools after considerable reworking, such as the entire working edge made afresh (primary recycling). The recycling practice is confirmed by double or multiple patination of

considerable time gap. (a) and (b) are two sides of the same specimen, (c) fresh working edges, and (d) long flake tool recycled after reworking the working edge



Tool Recycling in India, Fig. 6 Use of recycled tools as raw material in fresh knapping (secondary recycling), (b) is a recycled flake used as side scraper by making the working edge fresh. The rest of the figures are cores made on recycled materials. Large tools of an earlier

phase were reused in fresh microlith manufacturing. The process destroyed the original specimen completely, rendering the original tool unidentifiable, particularly when the natural rock surface and the old knapping scars are not clearly distinguishable

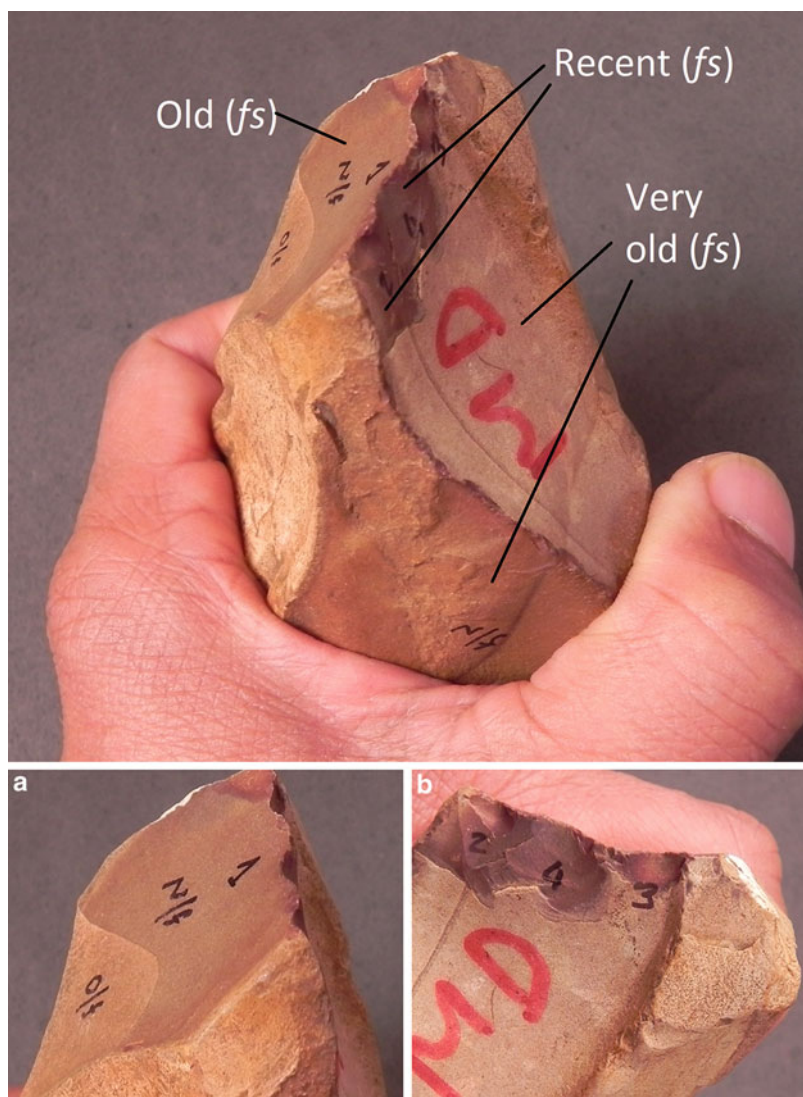
chronology. This has general methodological significance in the interpretation of archaeological records.

The evidence of using large tool remains from earlier tradition by subsequent small tool makers may not be easily found when the very process of small tool knapping would destroy any evidence of large tools being recycled in the process. In India, the microliths or small tool remains are found to be more numerous compared to the large tools of preceding periods. Is this due to a sudden increase in population during the microlithic time? Or might it be due to destruction of the earlier large tool remains by subsequent

microlith users? This will remain a challenge in coming years in Indian prehistoric engagements. The significance of “recycling” in prehistoric archaeological interpretation has received more attention in recent times, and several methodological approaches are suggested to address the inevitable problem in studying recycling attributes in prehistoric cultures. Analysis of bipolar technique, refitting, and analysis of spatial data are demonstrated to be useful in interpreting recycling behavior, which is now considered to have far reaching knowledge in prehistoric assemblage formation (Amick, 2007; Vaquero, 2011; Vaquero et al., 2012).

Tool Recycling in India,

Fig. 7 Successive reuses over a long time line is evident from multiple patination. The specimen bears at least three levels of patination formation – fresh working edge, old patinated flake scars (fs), and very old patinated body of the specimen (a) and (b) are close views of the working edge of the specimen.

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Tools Used in Ancient Egyptian Construction

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Building Materials

Most ancient Egyptian buildings were constructed of either mud bricks with wood elements or wattle-and-daub walls of intertwined poles packed with mud. These include all the houses and even the royal palaces. In the better-built structures, mud bricks were used for the foundations and walls with wood planks and poles employed for most everything else, including door and window frames, doors, window shutters, vertical supports (pillars) for roofs and upper floors, and horizontal supports for the mud-brick walls. Gypsum plaster was sometimes used to cover the interior walls and stone was also employed in these buildings whenever extra strength and durability were required, such as for door thresholds and pillar bases. The only buildings constructed largely or entirely of stone were the temples and freestanding tombs (pyramids and mastabas), although some of these were also built of mud brick, and many stone temples were surrounded by massive mud-brick walls.

Tools Used in Ancient Egyptian Construction, Table 1 Ancient Egyptian chronology

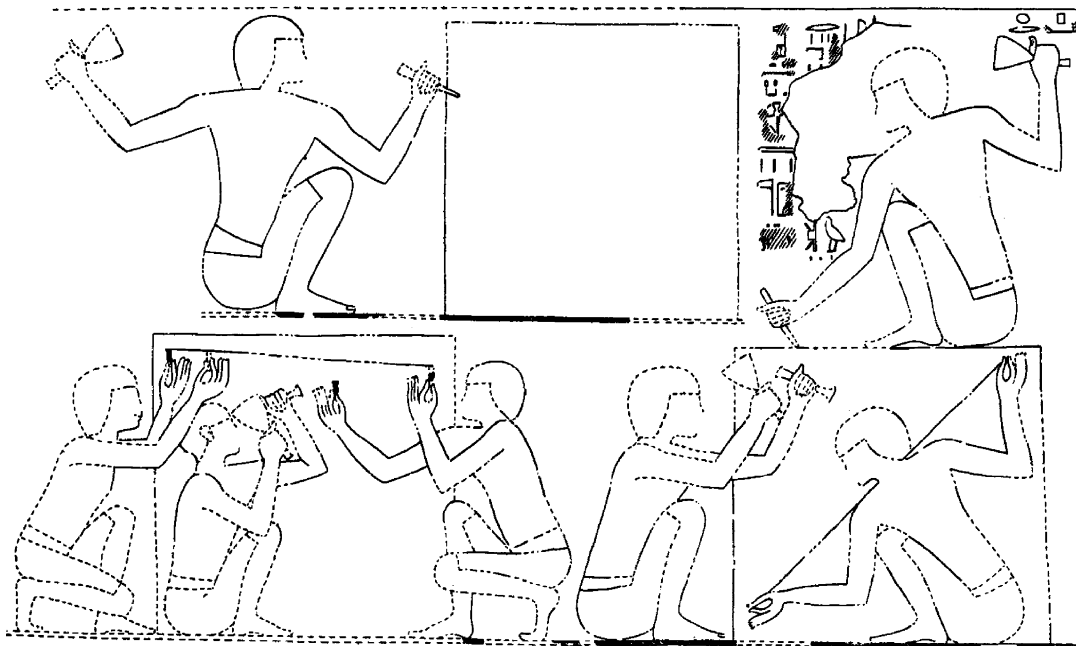
Predynastic or Neolithic period (5500–3100 BCE)
Dynastic or Pharaonic period (3100–332 BCE): dynasties 1–30
Early dynastic period (3100–2686 BCE): dynasties 1 and 2
Old kingdom (2686–2160 BCE): dynasties 3–8
First intermediate period (2160–2055 BCE): dynasties 9 to early 11
Middle kingdom (2055–1650 BCE): dynasties late 11–14
Second intermediate period (1650–1550 BCE): dynasties 15–17
New kingdom (1550–1069 BCE): dynasties 18–20
Third intermediate period (1069–664 BCE): dynasties 21–25
Late period (664–332 BCE): dynasties 26–30
Greco-Roman period (332 BCE–395 CE)
Ptolemaic period (332–30 BCE)
Roman period (30 BCE–395 CE)

The construction tools considered here were in use during Egypt’s Dynastic period (Dynasties 1–30), which ranged from about 3100 to 332 BCE (Table 1). The subsequent Greco-Roman period is excluded because many of the tool designs (and construction practices) were imported from the Greeks and Romans. Although there are no ancient Egyptian texts describing the use of construction tools, many of the tools themselves have survived, and there are also numerous carved reliefs and painted scenes on the walls of tombs showing the tools in use (Arnold, 1991; Clarke & Engelbach, 1930; Gale et al., 2000; Kemp, 2000; Petrie, 1917). Two such tombs are especially noteworthy in this regard, those of (1) Ti, an overseer of pyramids and temples under three fifth Dynasty kings (late Old Kingdom) at Saqqara near Cairo (Epron, 1939; Wild, 1966), and (2) Rekhmira, a vizier under two eighteenth Dynasty kings (early New Kingdom) at Qurna near Luxor (Davies, 1943). It is the art in these tombs that supplied the representations of tool use in Figs. 1–17. Another source of information comes from experimental archaeology, where facsimiles of ancient tools are made and then used to test their efficacy in various applications and materials (Stocks, 2003).

Measuring Tools

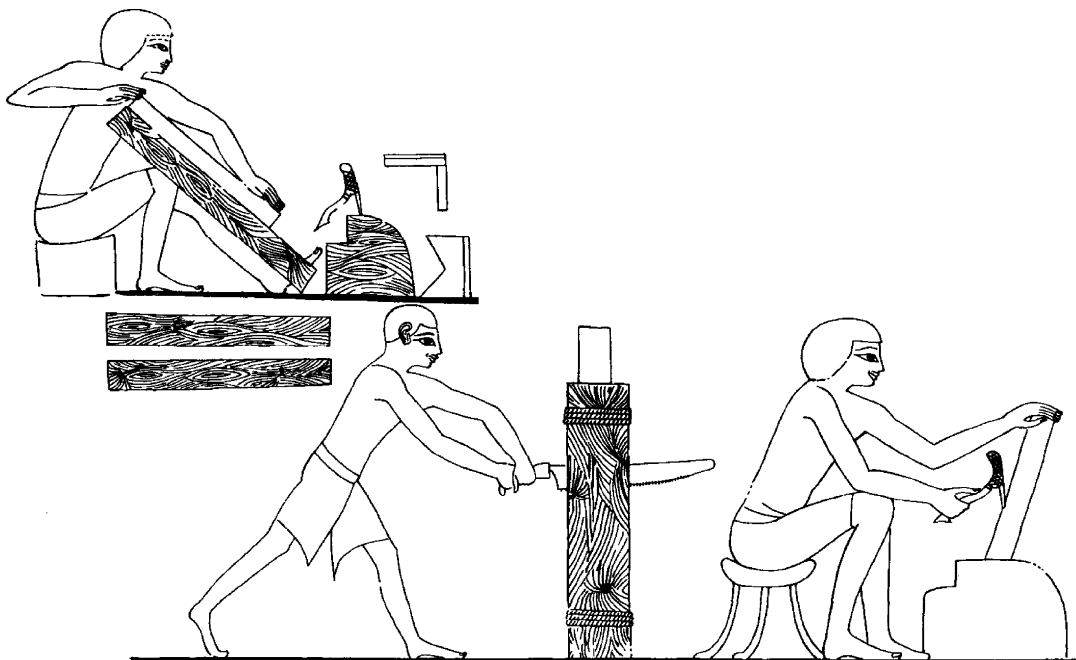
Construction, especially of the more elaborate stone structures, required the use of a variety of measuring tools, including ones for determining distance, slope, and flatness (for examples of these tools, see Pls. 47–49 in Petrie, 1917, Figs. 264–265 in Clarke & Engelbach, 1930, and Figs. 6.1–6.9 in Arnold, 1991). The Egyptians had cubit rods and measuring cords for determining distances. The cubit was a standard unit of distance that varied slightly during the Dynastic period but averaged 52.5 cm. It was divided into seven palms, each of which was further subdivided into four fingers. The working cubit rods were carved from wood (ceremonial ones were often of stone), and some could even be folded along hinges. Measuring cords were used to mark off both short and especially longer distances, and these were subdivided by knots tied at fixed multiples of cubits (Fig. 1).

Squared edges and corners were achieved through the use of a builder’s square, which consisted of two straight lengths of wood joined at their ends to form a right (90°) angle (Figs. 2 and 7). The square level combined a builder’s square with a plumb bob. It had two perpendicular sides of equal length that were joined by a crosspiece. At the apex, where the two joined sides met, there was an attached cord with a plumb bob suspended from the other end. The conical plumb bob was typically carved from stone. In use, the square level was placed upright on a surface (perpendicular to it), resting on the free ends of its two sides. By noting where the cord with the plumb bob lay on the crosspiece, the slope of the surface could be ascertained. Plumb bobs suspended from long cords were used to mark straight lines on vertical surfaces, check the verticality of walls, and measure vertical distances. A tool called a plumb rule was also employed to determine verticality. This consisted of a flat wood plank with two short shelves of equal depth at one end. A cord was attached to the end of the plank, just above the shelves, and this was threaded through a diagonal hole in the top shelf that exited at its outer edge. A plumb bob was suspended from the cord’s other end. To use



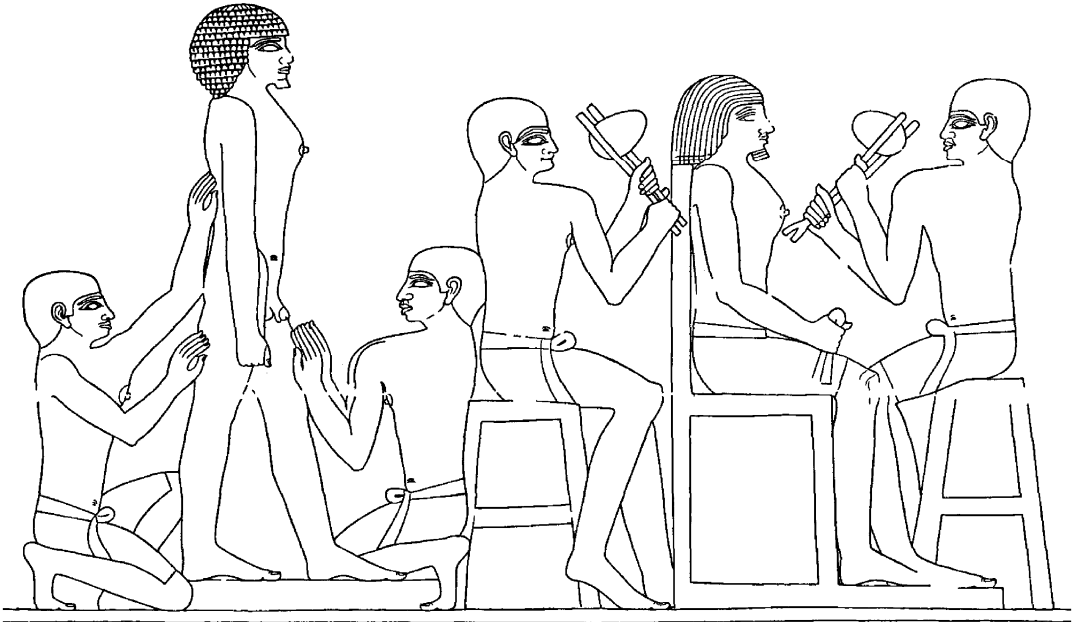
Tools Used in Ancient Egyptian Construction, Fig. 1 Stoneworkers using chisels struck by wood mallets, leveling rods (*lower left*), and a measuring cord

(*lower right*). Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 52))

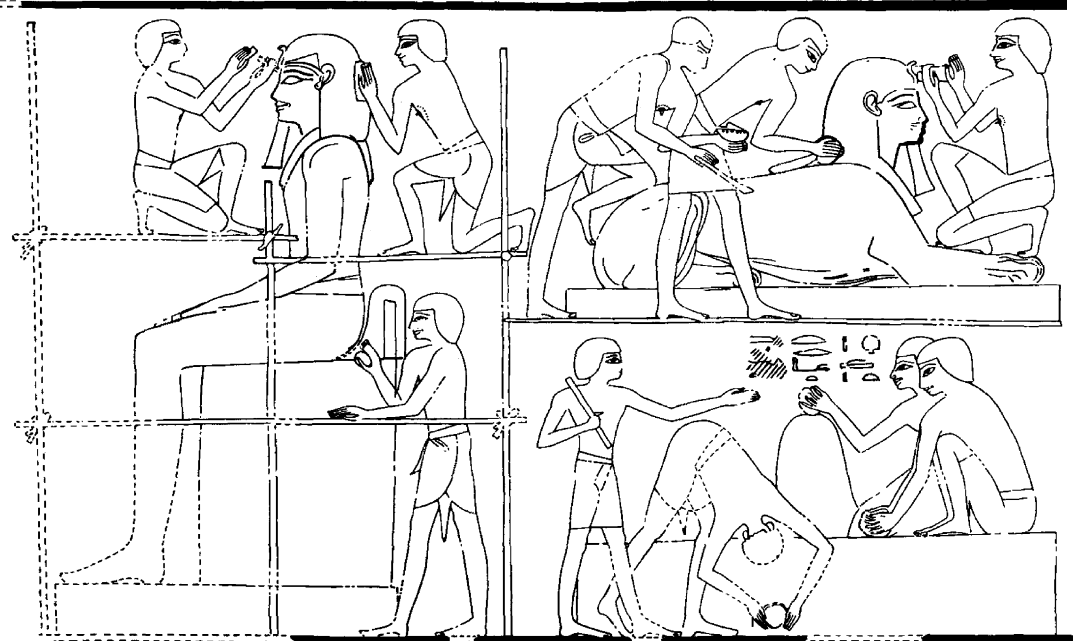


Tools Used in Ancient Egyptian Construction, Fig. 2 Woodworkers using a saw (*center*), adzes (*lower right* and *upper left*), and a straightedge (or perhaps a cubit rod; *upper left*). Note the builder's square just to the right

of the adze (*upper left*). Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 55))

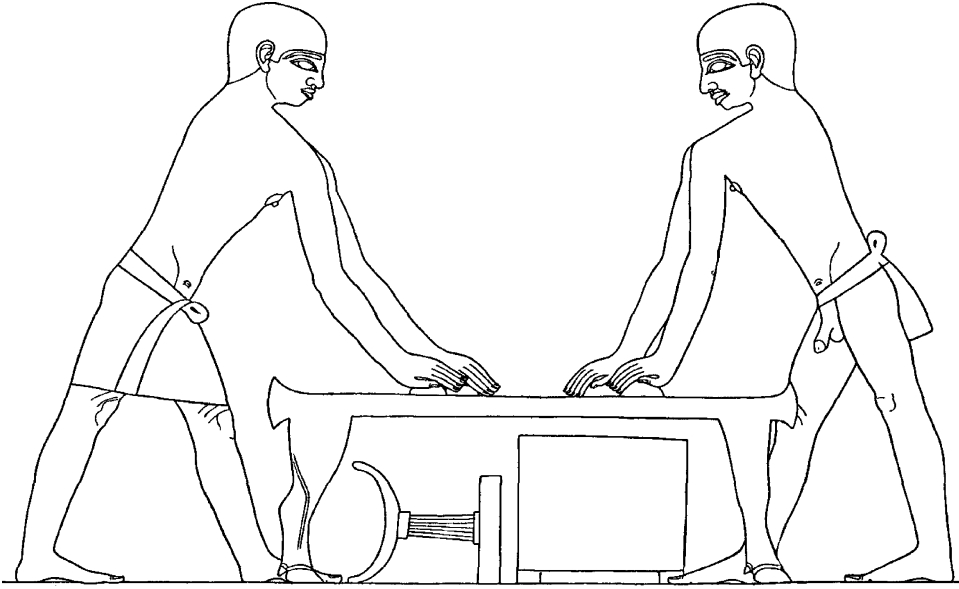


Tools Used in Ancient Egyptian Construction, Fig. 3 Stoneworkers using stone mauls (*right*) and possibly abrasive sand for polishing (*left*). Redrawn from a relief carving in the tomb of Ti (fifth Dynasty) (From Wild (1966, pl. 173))



Tools Used in Ancient Egyptian Construction, Fig. 4 Stoneworkers using rubbing stones (*left and upper right*), a chisel struck with perhaps a small piece of wood or stone (*upper left corner*), stone pounders

(*lower right*), and possibly abrasive sand for polishing (*upper right – man with cup and ladle*). Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 60))



Tools Used in Ancient Egyptian Construction, Fig. 5 Woodworkers using rubbing stones. Redrawn from a relief carving in the tomb of Ti (fifth Dynasty) (From Wild (1966, pl. 174))



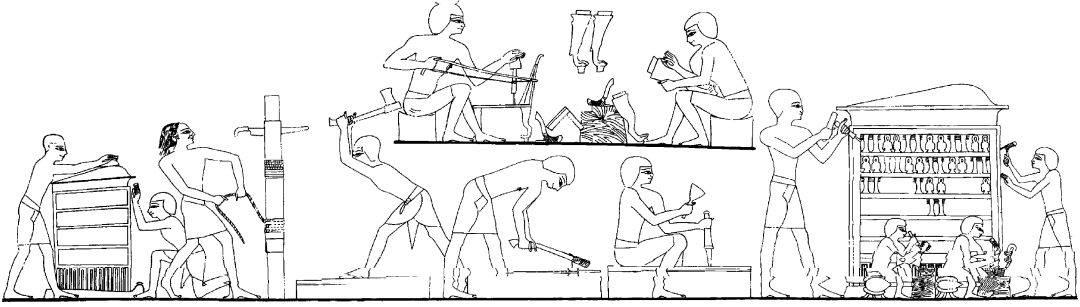
Tools Used in Ancient Egyptian Construction, Fig. 6 Woodworkers using rubbing stones (*upper left*), an adze (*far lower left*), a gouge (*lower left*), saws (*lower*

left and upper right), and a bow drill (*lower right*). Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 53))

the plumb rule, the back of the plank was pressed against a surface with the end bearing the attached cord and shelves oriented upward. The cord with the plumb bob was draped over the bottom shelf, and if the surface was vertical,

then the cord would just touch the shelf's outer edge.

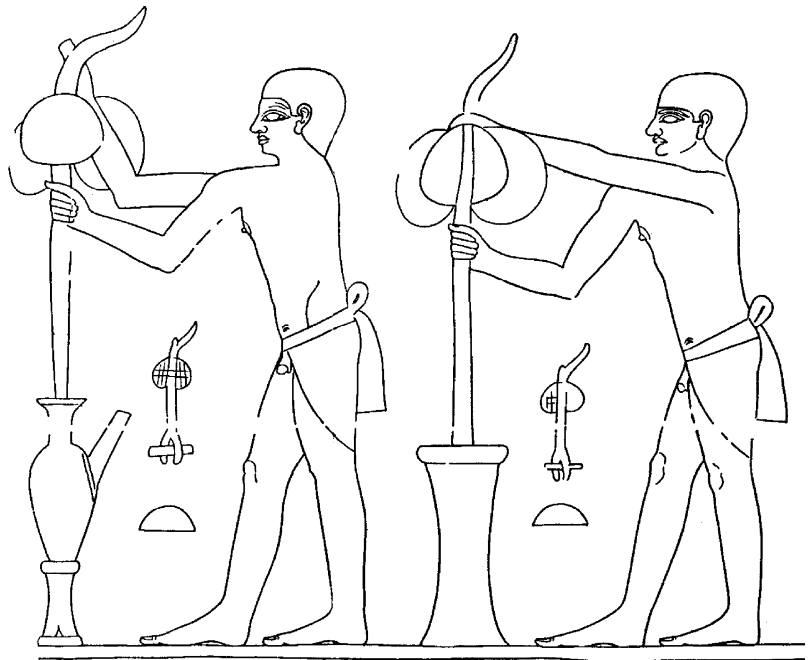
Marking cords were employed to draw straight lines on a surface. The cord was first dipped in a colored paint or powder (usually made from red



Tools Used in Ancient Egyptian Construction, Fig. 7 Woodworkers using rubbing stones (*far left*), a saw and axes (*lower center left*), mallet-struck chisels and adzes (*lower center right and far right*), a gouge

(*lower right*), and a bow drill (*upper center*). Note the builder's square between the adzes (*upper center*). Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 52))

Tools Used in Ancient Egyptian Construction, Fig. 8 Stoneworkers using hand-cranked drills with stone weights just below the handles. Redrawn from a relief carving in the tomb of Ti (fifth Dynasty) (From Wild (1966, pl. 173))



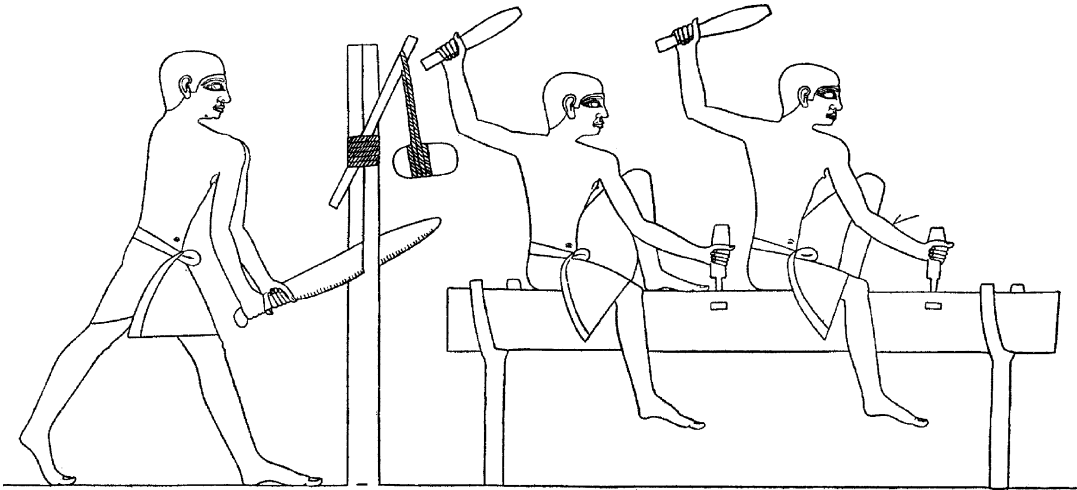
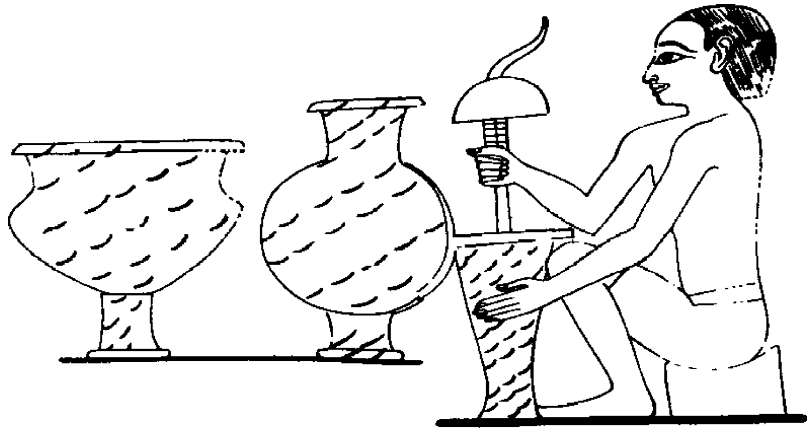
ochre) and then pulled taut across the surface. By flicking the cord against the surface, a straight line was marked off.

A set of leveling (or boning) rods was used to ascertain the flatness of a stone surface (Fig. 1). The set's three or four short wood rods were of identical length, and two of these were joined at their tops by a cord with the others left unattached. Two workers, each holding one of the joined rods, would place their rods upright

(perpendicular to) the surface and then pull the cord taut. With their free hands, or with the assistance of a third worker, the loose rods were placed upright on the surface and moved along the stretched cord. Wherever one of these rods fell below or rose above the cord, a departure from flatness was indicated. Areas that were too high were probably marked with colored paint or powder to show where additional dressing of the surface was needed. The degree of flatness of

Tools Used in Ancient Egyptian Construction,

Fig. 9 Stoneworker using a hand-cranked drill with a stone weight just below the handle. Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 54))



Tools Used in Ancient Egyptian Construction,
Fig. 10 Woodworkers using a saw (*left*; note the stone weight keeping the saw cut open) and mallet-struck,

wood-hafted chisels (*right*). Redrawn from a relief carving in the tomb of Ti (fifth Dynasty) (From Wild (1966, pl. 129))

a small surface could also be determined with a straightedge, which was a long piece of wood with a linear edge (Fig. 2).

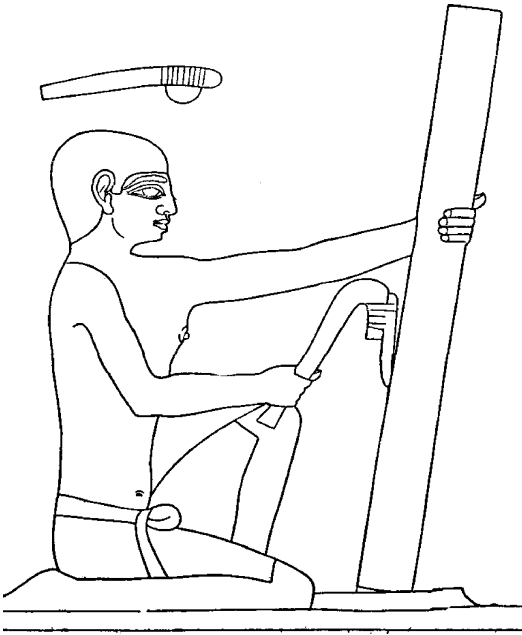
Cutting Tools

Stone Versus Metal

The first tools used in ancient Egypt, and volumetrically the most common ones employed throughout the Dynastic period, were made of stone. Tools requiring a hard, sharp edge or point were fashioned from chert (also known as flint), a rock consisting of microcrystalline

quartz. These were used to cut wood and also probably sometimes soft stones (limestone, sandstone, travertine, and rock gypsum). Hard stones with good impact-fracture resistance (notably anorthosite gneiss, dolerite, and silicified [quartz-cemented] sandstone or quartzite) were employed for pulverizing and grinding the hard stones, including anorthosite gneiss, basalt, granite, granodiorite, metagraywacke, and siliceous sandstone among a few others.

Copper tools, like those of stone, predated the Dynastic period. Because copper is a very soft metal, it could only be used to cut wood and soft stones and being much costlier than stone it was

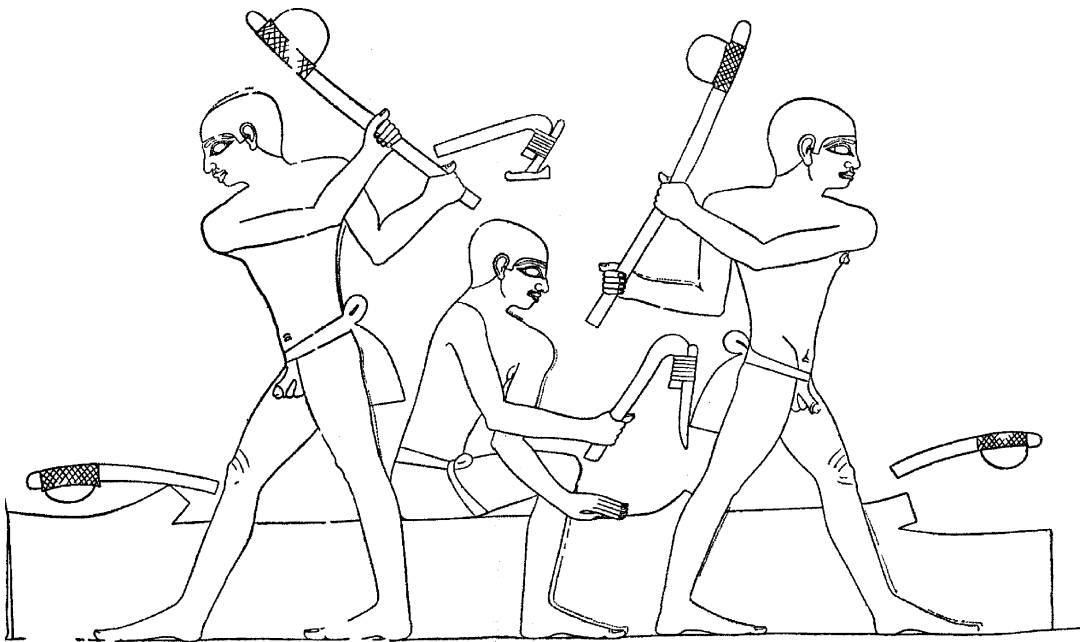


Tools Used in Ancient Egyptian Construction, Fig. 11 Woodworker using an adze. Redrawn from a relief carving in the tomb of Ti (fifth Dynasty). Note the axe at the top (From Wild (1966, pl. 174))

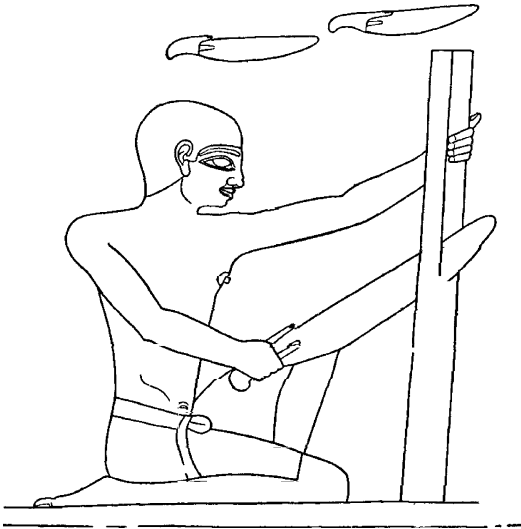
used sparingly for tools and then just for the more important projects. The much harder bronze metal (copper alloyed with tin) was first introduced during the Middle Kingdom and became the predominant material for metal tools beginning in the New Kingdom. Even though much harder than copper, bronze was still too soft to use on hard stones and for these the stone tools were still preferred. Iron tools first appeared in the Late Period. Although usually described as consisting of iron, these tools were actually made from either a primitive kind of steel (iron alloyed with carbon) or case-carburized wrought iron. Iron tools were strong enough to work the hardest materials and quickly replaced the stone tools formerly employed.

Stone Tools

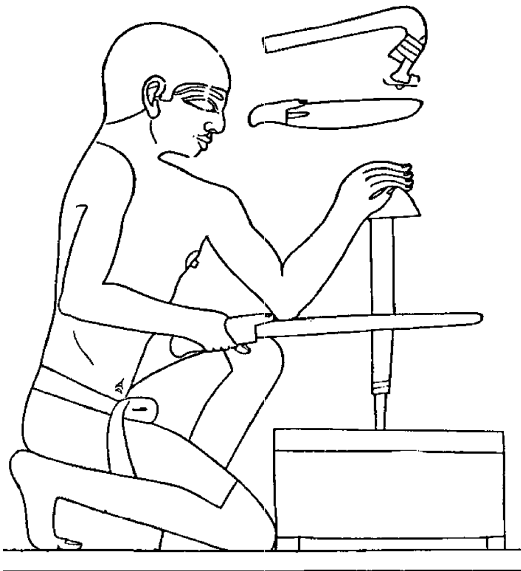
Stone mauls were elongated, generally roughly shaped pieces of hard stone with a blunt tip and a pinched waist where a wood handle was attached (Fig. 3). In contrast to this hammer-like tool, stone pounders were handheld, compact



Tools Used in Ancient Egyptian Construction, Fig. 12 Woodworkers using axes (*left and right*) and an adze (*center*). Redrawn from a relief carving in the tomb of Ti (fifth Dynasty) (From Wild (1966, pl. 129))



Tools Used in Ancient Egyptian Construction, Fig. 13 Woodworker using a saw. Redrawn from a relief carving in the tomb of Ti (fifth Dynasty) (From Wild (1966, pl. 174))



Tools Used in Ancient Egyptian Construction, Fig. 14 Woodworker using a bow drill. Redrawn from a relief carving in the tomb of Ti (fifth Dynasty). Note the adze and saw at the top (From Wild (1966, pl. 174))

pieces of hard stone that became well rounded and often nearly spherical after extended use (Fig. 4; for examples of these tools, see Pl. 53 in Petrie, 1917, Fig. 266 in Clarke & Engelbach,

1930, and Figs. 6.12–6.17 in Arnold, 1991). Both tools cut stone by pulverizing it. They were used to work soft as well as hard stones, but saw their greatest application with the latter.

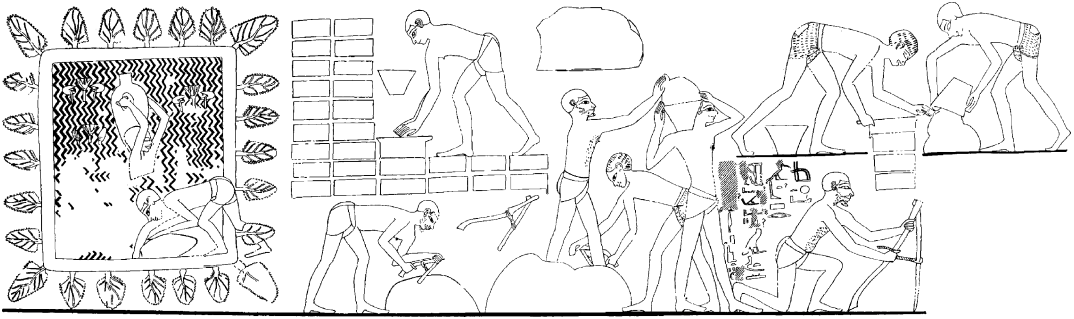
Rubbing stones were employed for smoothing both stone and wood surfaces (Figs. 4–7). These were the same hard stones used for mauls and pounders, but silicified sandstone was especially favored for this application. Only the harder stones can take a polish, and smoothing with rubbing stones was the first step. Producing a good, reflective polished surface required rubbing with an abrasive paste. Quartz sand was almost certainly the abrasive used, and this would have been applied with either a piece of leather or cloth (Figs. 3 and 4). Using progressively finer-grained sands would produce an increasing degree of polish.

Hand-cranked stone drills were used to hollow out the interiors of stone vessels and may have had some construction applications as well (Figs. 8 and 9). The drill consisted of a wood shaft with a forked end into which was lashed a bit of either silicified sandstone or, more often, chert. The other end of the shaft was bent to form a handle, and suspended just below this were stone weights that served to increase the downward cutting force of the bit. By cranking the handle back and forth, a worker could drill a cylindrical hole.

Chert is the only native Egyptian stone that can be shaped into a tool with hard, sharp points and edges. It was consequently widely utilized for a wide variety of nonconstruction applications, such as arrow and spear points and knife and sickle blades. In woodworking, chert was used for axe and adze blades, but it is unclear whether this stone was also used in stoneworking. It has been shown experimentally that chert pick heads, adze blades, and chisels can easily cut the softer stones (limestone and sandstone), and chert gravers (sharp-pointed inscribing tools) can be used to incise both soft and hard stones. Although there is no direct archaeological evidence for such applications, it seems likely that chert was employed for stoneworking.

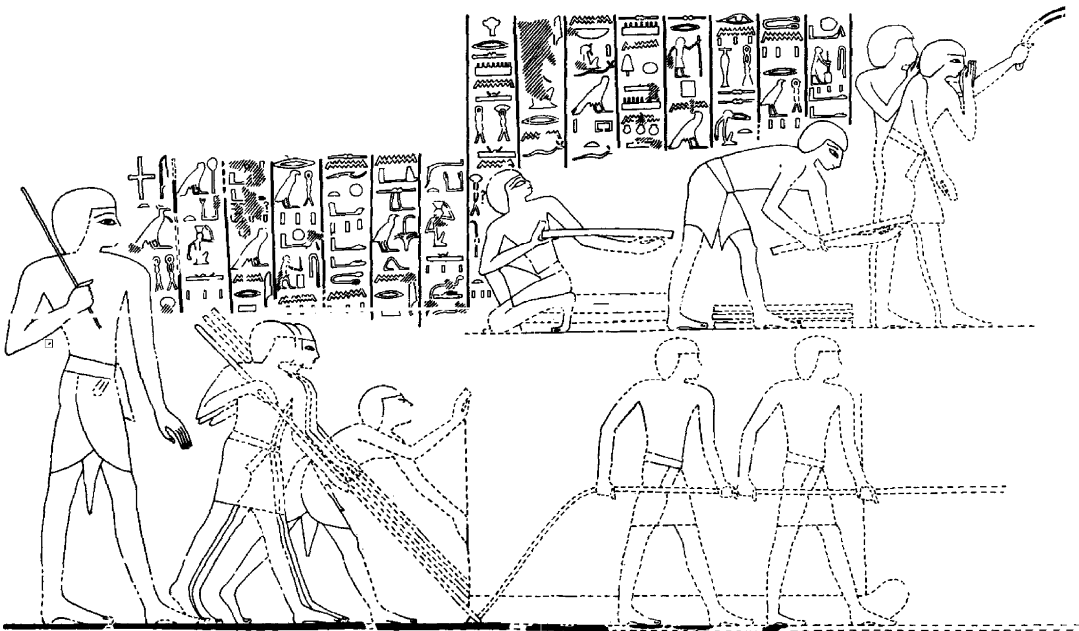
Metal Tools

The principal metal tool used for stoneworking during the Dynastic period was the chisel



Tools Used in Ancient Egyptian Construction, Fig. 15 Workers making mud bricks: obtaining water from a pond (*far left*), mixing the wet mud with hoes (*lower center*), and placing the mud in brick molds

(*upper center and upper right*). Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 58))

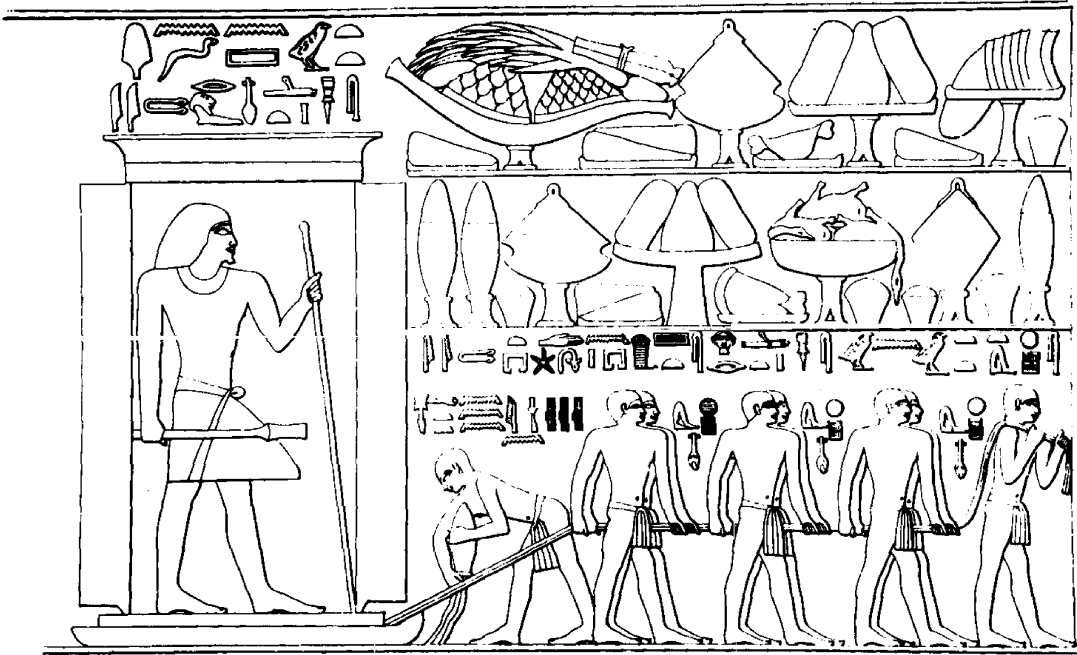


Tools Used in Ancient Egyptian Construction, Fig. 16 Workers with a sledge using levers behind it (*lower left*), pulling on a rope (*lower right*), and handling

sleepers (or rollers?; *upper right*). Redrawn from a painting in the tomb of Rekhmira (eighteenth Dynasty) (From Davies (1943, pl. 58))

(Figs. 1 and 4). Copper and bronze chisels were formed from stout cylindrical bars with either a pointed or flat-edged tip and were struck with a wood mallet (for examples of chisels and mallets, see Pls. 21–22, 46 and 49 in Petrie, 1917, Figs. 263–264 in Clarke and Engelbach, and Figs. 6.10 and 6.18–6.19 in Arnold, 1991). Some, especially for woodworking, were fitted

with a wood handle (Figs. 7 and 10). The chisels were used to dress soft stones and to cut holes and grooves in wood. Even for such soft materials, the tips needed frequent sharpening. It was not until the advent of iron chisels (and the first metal hammers) during the Late Period that the hard stones were worked with metal tools. Copper and bronze gads resemble chisels but were not used



Tools Used in Ancient Egyptian Construction, Fig. 17 Workers pulling a sledge with ropes while another worker pours water on the ground in front of the

sledge. Note the rounded front and chamfered rear of the sledge runner. Redrawn from a relief carving in the tomb of Ti (fifth Dynasty) (From Epron (1939, pl. 52))

for cutting. They were instead hammered into existing cracks and fractures within wood or stone in order to split these materials. The woodworkers also used a gouge, which was a small handheld, chisel-like tool for cutting grooves (Fig. 6).

Adzes are essentially flat chisels with a broad, straight cutting edge that were mounted on the end of a hooked wood handle (Figs. 2, 6, 7, 11, and 12; e.g., see Pls. 15–18 and 55 in Petrie, 1917). Blades of both metal and chert were employed. Adzes were used for trimming wood, and although direct evidence is lacking, they may also have been used for dressing soft stone surfaces.

Copper and bronze saws were employed for cutting wood and stone (Figs. 2, 6, 7, 10, and 13; e.g., see Pl. 50 in Petrie, 1917). Those with a serrated blade cut both wood and soft stone, whereas saws with smooth, nonserrated blades were used to cut the hard stones. In the latter case, the cutting was not done by the metal

blade itself (unlike the serrated blades used for softer materials) but rather by a quartz sand abrasive that was fed into the saw cut and over which the metal blade moved. Weights were normally attached to the ends of the longer saws of both types in order to increase the downward cutting force. Although iron saws eventually replaced those of copper and bronze, the basic designs did not change: serrated blades for soft materials and nonserrated blades for hard stones.

Bow drills with an abrasive bit (bit drills) were used to cut holes through wood and soft stones (Figs. 6, 7, and 14; e.g., see Pl. 48 in Petrie, 1917). The drill consisted of a wood shaft into one end of which was fitted a solid metal or chert bit. A bow strung with cord (similar to those wielded by archers) was used to rotate the drill shaft. This was accomplished by tightly looping the bow cord around the shaft and then moving the bow back and forth. While operating the bow with one hand, the worker used his other hand to hold onto a loosely fitting, hemispherical wood or stone cap

on top of the drill shaft. Such drills were much used in woodworking to produce the holes for doweled joints and lashings. In place of the solid bit, other bow drills were fitted with a hollow metal tube (tube drills). Unlike the bit drill, where the bit itself does the cutting, the tube drill used a quartz sand abrasive fed into the bottom of the hole. As with the nonserrated saw, it was the quartz sand that did the actual cutting, thus making the tube drill suitable for hard stones. Both types of drills originally had copper or bronze fittings with later ones made of iron.

An especially important tool for woodworking was the axe, which was used to chop and cleave wood (Figs. 7 and 12; e.g., see Pls. 1–7 in Petrie, 1917). Axes had either a subcircular or subrectangular metal blade that flared out into lugs on the dull side that were used in lashing the blade onto a wood handle.

Tools for Mud-Brick Manufacturing

Mud bricks were made from a mixture of fine-grained sediment (especially clay-rich mud), sand, chopped straw or other plant chaff, and perhaps also, as in modern-day Egyptian mud bricks, animal manure (Fig. 15). Excavation of the sediment and mixing the ingredients was done with the same hoe used by the ancient farmers. The wood blade of this tool had a narrow extension or tang on one side and this was fitted into a hole cut through one end of a short wood handle, with the two parts lashed together (Fig. 15; e.g., see Pl. 68 in Petrie, 1917). The mud mixture was typically packed into wood molds to produce bricks of uniform size (e.g., see Fig. 263 in Clarke & Engelbach, 1930). After drying and hardening in the sun, the bricks were ready for use.

Moving Tools

The construction of stone buildings required the lateral movement and lifting of stone blocks weighing anywhere from a few tons to tens (and exceptionally hundreds) of tons. Nearly all of this work was done with ropes, levers, and sledges

combined with a large measure of human muscle. The ancient Egyptians had ropes made from a variety of materials, including palm fibers, grasses, and papyrus and other reeds. Ropes up to several centimeters thick have been found and would have been strong enough for the heaviest loads. These were sometimes used in conjunction with grooved bearing blocks, which were carved from wood or stone and served as rope guides. By draping a rope around this device, the workers were able to pull from an angle (e.g., see Figs. 6.45–6.46 in Arnold, 1991). There were no pulleys in Dynastic Egypt.

Stout wood poles or beams were employed as levers for shifting stone blocks (Fig. 16). The largest were operated by teams of workers who would pull down on the elevated end with attached ropes. Stone blocks sometimes had small recesses (lever sockets or holes) cut along their sides where the lower ends of levers could be inserted (e.g., see Fig. 6.26 in Arnold, 1991). Wood or stone fulcrums were placed under the lower end of these levers, and wedge-shaped pieces of wood were pushed under the levered-up edge of a block to allow deeper insertion of the lever (e.g., see Fig. 267 in Clarke & Engelbach, 1930, and Figs. 6.42–6.43 in Arnold, 1991).

Sledges made from wood were employed for moving heavy loads around the construction site (Figs. 16 and 17). This conveyance consisted of two parallel runners joined by a series of crossbeams (e.g., see Figs. 6.35–6.36 in Arnold, 1991). Along the sides, on top of the runners, wood stakes or other attachments would have been present to restrain the load or anchor tie-down ropes. The front ends of the runners were rounded and angled upward to allow the sledge to ride up and over irregularities in the ground. The back ends of the runners were often chamfered (beveled) with a cut angling downward toward the front of the sledge (as in Fig. 17), and these allowed the insertion of levers to help move the sledge forward or adjust its direction. Using attached ropes, the sledges were pulled by teams of men or, less often, draft animals.

In order to reduce ground friction, the sledges were pulled over either wetted ground or wood beams (sleepers) laid crosswise along the

sledge's path (Fig. 16). It has been suggested that the sledges were also sometimes pulled over wood rollers, but this is unlikely as rollers would only be effective on ground that was hard, smooth, and relatively flat. Even though the Egyptians knew about the wheel from earliest Dynastic times, they had no wheeled wagons until the early New Kingdom. From this time onward, wagons may have been used for hauling stone blocks, especially the smaller ones, but sledges almost certainly remained the main conveyance for moving blocks around the construction site.

Wood rollers were apparently sometimes placed directly under stone blocks when these were being moved across hard, flat pavements (Fig. 16; e.g., see Pl. 49 in Petrie, 1917, and Fig. 6.31 in Arnold, 1991). Another tool thought to also assist in moving stone blocks is the so-called rocker. Made from wood, this device had two parallel, vertical sides that were joined by crossbeams as in the sledges (e.g., see Pl. 49 in Petrie, Fig. 89 in Clarke & Engelbach, 1930, and Fig. 6.29 in Arnold, 1991). The tops of the sides were flat and level, and their bottoms were rounded into a half circle or ellipse. There is much speculation on how the rockers were used, but it is generally agreed that a block of stone was placed on top of the sides, and then by rocking it back and forth, the block could be walked across a hard surface or pivoted to assist in its placement.

Extra: Wood or Iron Wedges?

In hard stone quarries dating to the latter part of the Late Period and especially the subsequent Greco-Roman periods, one sees lines of wedge-shaped holes on quarry faces and extracted blocks. It is a common misconception that these holes were cut to hold wedges of wood, which when wetted would swell and so split the rock along the line of wedge holes. In actuality, however, these holes were cut to hold iron wedges, which were struck with an iron sledgehammer to split the stone. This same method of splitting stone was also used in stone construction work toward the end of the Dynastic period.

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Transporting Stone Money in Micronesia

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The use of large stones or megaliths by ancient societies is often linked to construction or sculptures and associated cultural beliefs. But for one Micronesian society, stones were a form of currency. Known as stone money, or *rai*, Yapese society retrieved the limestone disks stones from Palau some 400 km away across open ocean waters, a process believed to have begun some 600 years ago. The stones varied considerably in size, with those moved in prehistoric times no larger than 2 m in diameter as determined by canoes of the time. A stone of this size would weigh over 2 t, but not all of the thousands moved were this big. Many men were involved in

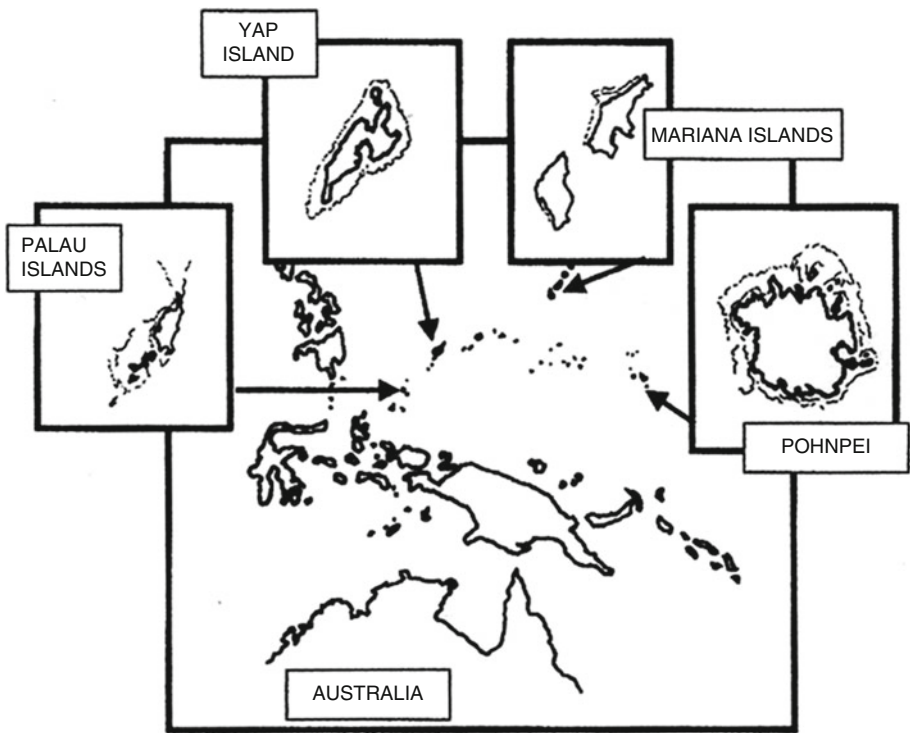
the retrieval of these symbols of power, wealth, and status. In this role, the disks were used in transactions, including marriage gifts and debt repayment. Years could pass between quarrying

on Palau and the eventual return to Yap. This extended time also involved fulfilling obligations associated with acquiring the stone from the Palauans (Figs. 1 and 2).

Research often describes open sea voyaging and exploration, but the circumstances of the prehistoric Yapese stone transportation process are unique and not easily explained or understood before European influences changed the traditional methods and numbers of stones transported. However, the prehistoric retrieval is a fine example of navigation, seamanship, and the use of watercraft technology, including sails, sailing techniques, watercraft viability, and thus knowledge. It exemplifies skills and determination to acquire the stone. The returning crews were carrying a symbolic and prestigious, but destabilizing, cargo. To understand how difficult the acquisition of the stones was, maritime, canoe performance, and human physiology data as constraints are used to study the process known by Yap society through oral tradition and legend.



Transporting Stone Money in Micronesia, Fig. 1 Source: <http://en.wikipedia.org/wiki/User:Marshman>

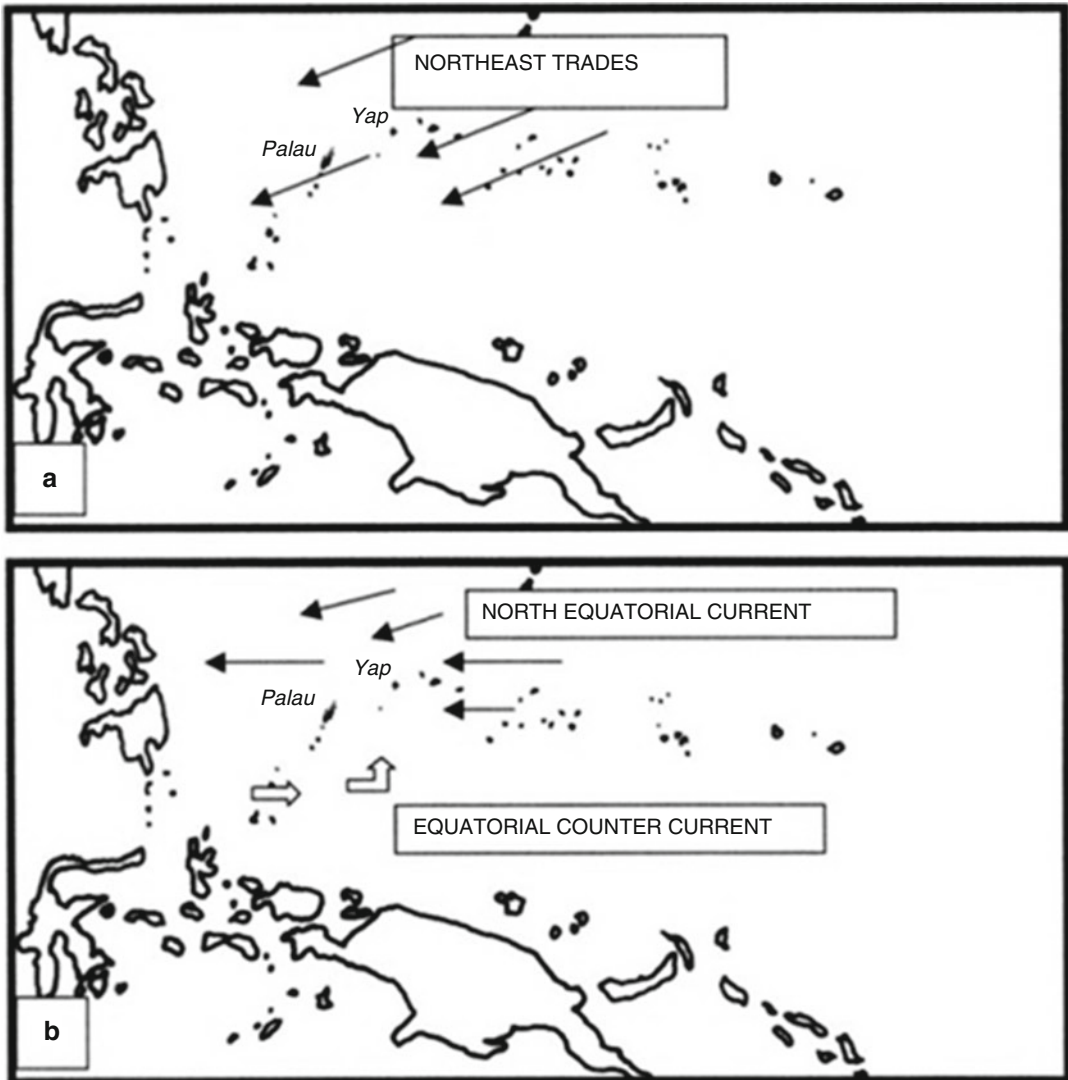


Transporting Stone Money in Micronesia, Fig. 2 Oceania region (Drawn by L. Hazell)

Geographic and Maritime Conditions

Yap and Palau form part of Micronesia, a Pacific region of some 3,000 islands occupying an ocean area of 7.4 million km². Yap is made up of four main islands, Yap, Gagil, Tomil, and Rumung, separated by narrow channels all surrounded by a fringing reef. The ocean expanse in which these remnants of volcanic action are situated is subject

to consistent wind patterns in particular the north-east trades. Their velocity is around 10 knots (18 km/h) during October through to May with a subtle variation in direction from northeast to east daily. Conditions such as these allow for 24 h sailing. In contrast, between July and October, only light winds occur, these being around 1.5 km/h. Ocean surface currents in particular the North Equatorial Current are also consistent

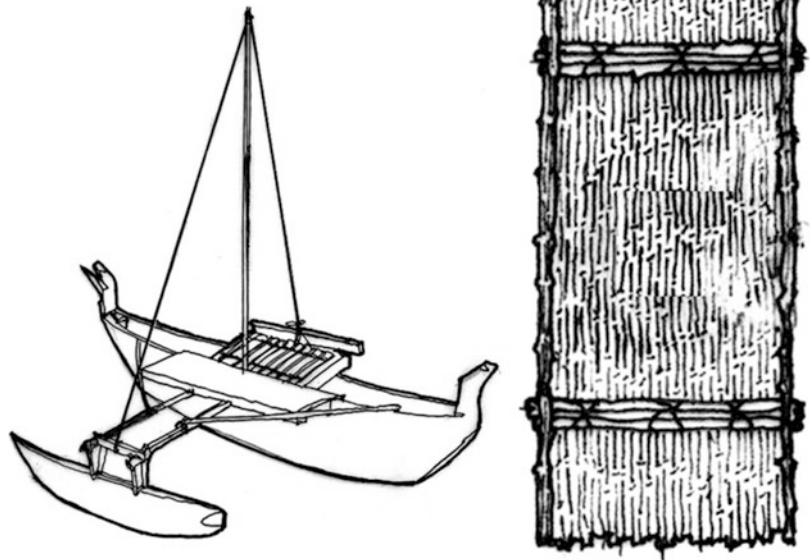


Transporting Stone Money in Micronesia, Fig. 3 (a) Prevailing winds: October to May, northeast trade winds (Sources: (Gatty, 1944; Morris & Rear Admiral, Hydrographer of the Navy, 1988; United States Navy [USN] 1995) Drawn by: L Hazell) (b) Ocean Surface Currents:

June to December, North equatorial current and equatorial counter current (Sources: (Gatty, 1944; Morris & Rear Admiral, Hydrographer of the Navy, 1988; USN 1995) Drawn by: L Hazell)

Transporting Stone Money in Micronesia,

Fig. 4 Tskupin sailing canoe and bamboo raft
(Drawn: L. Hazell)



between Yap and Palau, flowing west to east at around 1.25 knots or 2.5 km/h with a weaker NE set between August and October. There are variations to wind speeds and ocean currents noted in available records which would adversely laden craft (Fig. 3).

Open ocean conditions such as these determine the viability of ocean travel, particularly when undertaking the transportation of valuable loads. Meteorological and maritime data indicate these elements may hinder transport yet also provide power, if seasonal variations in conjunction with surface currents are taken into account. Analysis that includes human physiology and known watercraft and their performance has shown that this could be done.

Yapese Watercraft Performance and Power Options

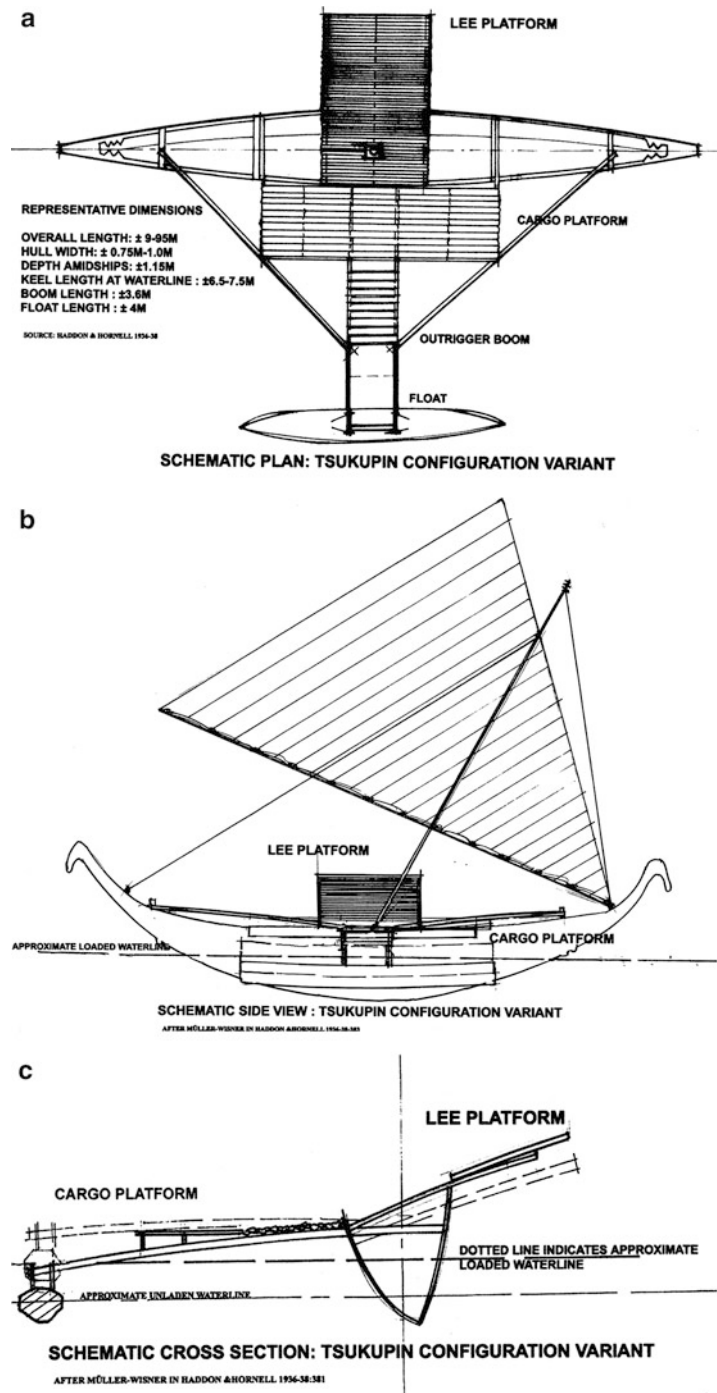
Yap oral tradition and legends of prehistoric origin describe bamboo rafts and, more recent data notes, outrigger canoes used for fishing, with both configurations possessing different sailing properties. Bamboo is readily available and buoyant

as replication experiments and calculations show. A raft made up of this material would be capable of carrying the largest disks. However, due to the need for continuous paddling to make progress against prevailing currents, this method as a singular option seems unlikely. In addition the effective life of cut bamboo is short and subject to borer attack, a weakness critical when under load. The legends though state that the rafts were loaded and set adrift to then be towed back to Yap when found (Fig. 4).

Conversely sailing canoes were not capable of carrying the larger stones. For canoes, this is a question of buoyancy with sufficient freeboard needed to prevent passing waves filling the hull. Sufficient speed to equal wave speed generated by the winds found in the region is also linked to this limitation. Sailing configurations of either raft or outrigger canoe would need to be capable of tacking as a method to overcome the opposing winds and currents. In doing so, the total distance would not be 400 kms but over 1,100 kms thus imposing an endurance or survivability constraint on the crews. Not all would have survived the rigors of this extended voyage. Indeed, it is likely this mortality added value to the *rai*.

Transporting Stone Money in Micronesia,

Fig. 5 Tskupin configuration variant schematics: (a) Plan. (b) Side view. (c) Detail cross section (After Muller-Wisner in Haddon & Hornell, 1936–1938, p. 381 All drawings by Leslie C. Hazell)



Tacking was originally understood to be a Western sailing strategy, but a technique in this region, known as shunting, allows similar progress against the wind. This technique

relies on a number of structural elements, an asymmetrical hull shape, the beam-to-length ratio, and an outrigger for stability under sail. This format also allowed its use as a cargo

platform. The construction of this canoe was flexible, with variations to suit fishing or other needs of the time (Fig. 5).

The *tskupin* is a Yapese single-outrigger canoe with sail and cargo-carrying capability. Its effective sail configuration, superior freeboard, and speed potential are derived from other attributes that have lesser resistance compared to a raft. With those features, it is able to sail closer to the wind. In one example noted by de Beauclair (1963), this canoe configuration achieved an average speed of 2.0 knots or 3.7 km/h over five days and covered 470 km. The limitations of speed and seagoing capabilities of both raft and canoe configurations under load with the prevailing conditions if combined can explain the process described in legends. With laden bamboo rafts adrift, the faster yet light capacity sailing canoe could catch them up and tow the disk-laden rafts back to Yap (Müller, 1917).

This may seem as a dangerous practice with such valuable cargo, yet the speed and maneuverability of the outrigger canoe could make up the difference in a day, depending on raft drift rates which are affected by the size and mass of the disk or total load. Analysis of the process indicates that this would have been the most successful option nevertheless (Hazell & Fitzpatrick, 2006). The prehistoric undertaking contrasts the lost status and value of the *rai* brought about by European traders transporting large numbers of these disks with cargo ships as part of a trading exchange. Their size and limited numbers retrieved in prehistoric times also emphasizes Yapese seamanship and maritime knowledge and confirms Yapese oral traditions.

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Trephination

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Perhaps one of the least understood surgical practices performed in ancient America concerns cranial trephination (also spelled “trepanation”), or the surgical modification of the skull. While much of the prevailing literature is largely dated, an older generation of theories tended to ascribe the practice to primitive wonderment and notions of spirit release and possession. This is despite a substantial body of technical evidence available from trephined specimens and a large and specialized body of surgical instruments and procedures documented in archaeological and contact-period historical contexts. According to medical historian Guido Majno, trephination was used as a cure for a number of ailments including skull fractures and related trauma, epileptic seizures, and insanity. In fact, many of those skulls examined to date bear evidence of blunt trauma or pathology that may provide a more direct indicator of why the practice was carried out in the first place.

While ancient Peru provides the largest body of trephined specimens available for study, and the clearest evidence of an established medical tradition in skull surgery, other important specimens have been reported from throughout the Americas. Documented examples, with evidence of osteitis, have been reported from the Mexican states of Chihuahua and Oaxaca, and archaeological sites in Lamy, New Mexico, and Accokeek, Maryland, in the United States, where trephined surgical openings are often no more than 2 cm in diameter. Reported trephined specimens from Columbia County, Georgia, archaeological zones along the Skeena River, and in the sites of Eburne and Lytton, British Columbia and Kodiak Island, Alaska, range between 3.8 and 6.0 cm in diameter. If all the putative cases of trephination reported in these examples are a reliable indication of areas in which the practice was known, then cranial trephination was quite widespread.

Majno has identified five primary techniques of trephination in specimens from both Peru and Mesoamerica. These include the most ancient method on record – the scraping-away of that bone just underlying the scalp – as well as other techniques such as grooving, boring, cutting, sawing, and rectangular intersection incision, the most predominant method employed, in which cut, sawed, or abraded grooves were used to perforate the skull in a rectangular pattern. Once the intersection incisions were connected to each other, a rectangular or octagonally shaped plate of bone remaining within the intersection was removed with a spatula-like device. Schendel (1968) notes that “the trepanning technique used in Mexico was to punch a series of small holes in the skull outlining the fracture, or the area to be removed, then to cut between those holes and lift off the depressed section of cranial bone.” After this initial procedure, the exposed brain was protected with a thin plate of hardwood and cotton pads. When trephination was not deemed suitable because of the extent of skull trauma, the damaged portion of skull was encased in a protective plaster cast. There were two types of plaster cast. The first was a mixture of feathers, egg whites, and resin, and the second was

prepared from a mixture of animal ash, blood, and egg whites.

Specialized tools and instruments employed by Inca physicians in the trephination of the skull included *tumi* knives crafted from alloyed and annealed, or metalurgically hardened, copper and bronze metals. The *tumi* knife consisted of a crescent-shaped blade, at the midpoint of which was attached a cylindrical metal handle or other appendage. *Tumi* knives used in trephination included razor sharp, serrated, or other saw-tooth-edged crescent-shaped scalpels. Additional instruments included bronze perforators, drills, and chisels. The basic surgical instrumentation utilized in cranial trephination long predated the rise of the Inca state, whose government came to sponsor and control this specialized field of medical endeavor (Burland, 1967). Cranial trephination, and both *tumi* knives and bronze perforators, are frequently depicted on the carved and painted surfaces of vessels of the Mochica civilization of the north coast of Peru (ca. AD 500).

In one collection of 273 skulls from Peru, 47 bore evidence of having been trephined between one and five times. According to Majno, the skulls studied thus far suggest that the survival rate was near 100 %. Only a few cases of osteomyelitis, or bone deterioration, were documented in the cranial collection he examined. Those cases appear to have been associated primarily with the size of the original injury, and whether or not the trauma was located at the base of the skull. Apparently, patients suffering blunt trauma over the cerebral cortex or brain stem were least likely to benefit from treatment by trephination. In other recent studies, projected survival rates, based on the examination of the presence of osteitis, range from 62.5 % in one study that found healing or evidence of osteitis in 250 of 400 skulls examined, to between 23.4 % and 55.3 % in other studies (Froeschner, 1992). These latter figures are questionable in that the studies cited by Froeschner do not distinguish postmortem trephination from that performed on severely traumatized patients. Froeschner's review also fails to acknowledge the existence of even the most basic metal instruments and surgical kits documented for the

practice of trephination in ancient Peru, claiming instead that "primitive tools" were the mainstay of the art of Inca trephining.

It is clear that specialized techniques and treatments contributed to the diversity and variation in surgical localities known from trephined specimens alone. In one analysis of a trephined skull collection consisting of 112 specimens (the Tello collection housed at the Peabody Museum of Harvard), 53.6 % of the skulls, or 60 specimens, bore trephined areas in the frontal area of the skull (26 of which were situated in the frontal bone, 12 in the region of the bregma, and another 12 crossing over the left coronal suture); 33 %, or 37 specimens, were trephined in the parietal area (18 of which bore surgical openings over the left parietal, while 15 crossed the sagittal suture), and 13.4 %, or 15 specimens, were trephined over the occipital area (with 7 in the region of the lambda, and 4 in the occipital bone). Most trephined specimens from the Harvard collection bear surgical openings within the frontal areas of the cranium, and again, trephined openings are most highly correlated with blunt trauma and other pathologies. The incidence of epileptic seizures among Inca era peoples was documented by both European-contact chroniclers and contact-era Inca scribes. This fact may provide directions for future inquiry into the origins of specific types of trephination among Inca and related peoples.

Based on a worldwide survey of ancient skull surgery, Majno has concluded that the Inca were the "Masters of the Art of Trepanning." He also noted that the survival rate for patients in Inca times was better than for such rates in modern times. He says that modern survival rates are the inverse of what they had been in earlier Inca times, and concludes that modern humans complicated the task of skull surgery by introducing new sources of infection and disease. In turn, modern physicians were trained to perpetuate otherwise antiquated traditions of skull surgery based on flawed nineteenth century assumptions and beliefs. European medical belief systems regarding infection, surgical procedure, anesthetics, and basic hygiene necessitated a constantly expanding and contracting repertoire of

experimental procedures which further complicated survival rates. As a result, the fledgling early twentieth century version of modern skull surgery suffered many casualties.

See Also

- [Medicine in Meso and South America](#)
- [Surgery in Ancient India](#)

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Tribology

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Tribology, the study of the phenomena and mechanisms of friction, lubrication, and wear of surfaces in relative motion, can be traced back to remote antiquity in China, where it developed significantly.

Sliding bearings were discovered in ancient mechanisms, especially in carts which operated at high speeds and carried great loads. In order to reduce friction and damage, Chinese mechanics lubricated bearings on their carts. This was recorded in the earliest poetry collection entitled *Bei Fen Quan Shu* (The Bei Wind and Spring Water) as follows:

- *The grease used is sufficient to lubricate the axle shaft.*
- *On the shaft end, we carefully check the pin bolt.*
- *Quickly, send me home driving the cart.*
- *Quickly, send me back to my Wei country town.*

It proves that before the book *Shi Jing* (Poems and Odes) appeared – before 1100–600 B.C. E. – lubricant was widely applied in China. Owing to their rhythmic quality, the verses were repeatedly quoted and talked about, and often appeared in later books as well.

By the time of the Chun Qui (Spring-Autumn) period (500 B.C.E.) in the Lu and Qi states, there was a group of special officers called *Jinche*,

whose duty was to check the pin bolts on the shaft ends. They were probably the earliest tribology supervisors. This demonstrates that the ancient Chinese already knew well that the better the lubrication, the faster and easier ran the cart.

Early lubricant was called *zhi* or *gao*. According to research on ancient characters, *zhi* was the fat of horned animals, and that of hornless animals was called *gao*. The lubricant used might be sheep oil, which was easier to get. Since *zhi* or *gao* is in a solid state at normal temperature, it had to be heated and melted before it was used. In 300 B.C.E. petroleum began to be used.

Metal bushes appeared in China quite early. There were relevant records about their use in *Wuzi Yebing* (Wuzi casting), which shows that they appeared not later than 400 B.C.E. The metal bush was made of two layers: outside and inside. The outer one was called *gong*, which turned together with the wheel, and the inside one was *jian*, which turned together with the shaft. Between them a kind of lubricant was provided, and the cart ran quickly and easily. In addition to carts, the metal bushes were applied in other mechanisms of antiquity, and they appeared in a variety of forms. In the Han Dynasty, they were already used quite widely. This is illustrated by the discovery of hundreds of mold sets of metal bushes in county Wen in Henan province. Most of them were still undamaged. They reflect the level of manufacturing as well as the scale of their production and application in the Han Dynasty.

The ancients took other measures to reduce friction and damage. Most mechanisms were made of wood. In the *Kao Gongji* (The Artificer's Record), three principles of wood selection were listed (1) the wood must be smooth, without joints; (2) it must be tough and wear-resistant; and (3) it must be thick enough and easy to revolve. In the sixteenth century a book entitled *Tian Gong Kaiwu* (Exploitation of the Works of Nature) was written, in which a further summary on the basis of experience was made. It analyzed the advantages and shortcomings of various woods, and provided an example: if wood works for too long, it gives out heat. In the field of structural design, the *Kao Gongji* and other books analyzed the relationship between the

axis path and the length of the shaft, and pointed out that when the cart and load were different, the interior axis of the wheel must keep a fixed proportion to the length of the shaft.

There was one other achievement of note in this field. In the Yuan Dynasty (thirteenth century) a ball bearing, which was circle-formed and consisted of four balls, was successfully applied to an astronomical instrument made by Guo Shoujing.

Trigonometry in Indian Mathematics

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Trigonometry offers one of the most remarkable examples of transmission of the exact sciences in antiquity and the Middle Ages. Originating in Greece, it was transmitted to India and, with several modifications, passed into the Islamic world. After further development it found its way to medieval Europe.

The very term “sine” illustrates the process of transmission. The Greek word for “chord” ($\epsilon\upsilon\theta\epsilon\iota\alpha$, literally “a straight line [subtending an arc]”) was translated into Sanskrit as *jīva* or *jyā* (“string of a bow”) from the similarity of its appearance. The former word was phonetically translated into Arabic as *jyb*, which was vocalized as *jayb* (meaning “fold” in Arabic), and this was again translated into Latin as *sinus*, an equivalent to the English sine.

It was by tracking back along this stream of transmission that the first chord table ascribed to Hipparchus (fl. 150 BCE) was recovered by Toomer (1973) from an Indian sine table (compare Tables 1 and 2). Toomer showed that some numerical values ascribed to Hipparchus in the *Almagest* of Ptolemy (fl. AD 150) could be explained by hypothesizing the use of this reconstructed table.

According to this reconstruction, Hipparchus used 6,875' as the length of the diameter (D) of the base circle, in other words, as the greatest

Trigonometry in Indian Mathematics, Table 1 Hipparchus' chord table reconstructed

Number	α	$R \text{ crd } \alpha$
1	7; 30	450
2	15	897
3	22; 30	1,341
4	30	1,779
5	37; 30	2,210
6	45	2,631
7	52; 30	3,041
8	60	3,438
9	67; 30	3,820
10	75	4,185
11	82; 30	4,533
12	90	4,862
13	97; 30	5,169
14	105	5,455
15	112; 30	5,717
16	120	5,954
17	127; 30	6,166
18	135	6,352
19	142; 30	6,510
20	150	6,641
21	157; 30	6,743
22	165	6,817
23	172; 30	6,861
24	180	6,875

chord subtending the half circle ($=R \text{ crd } 180^\circ = 6,875$). This number is the result of rounding after dividing $21,600'$ (360°) by the value of $\pi = 3; 8, 30$. (In this article we follow the convention: integer and fraction are separated by a semicolon, the former is in decimal form, and the latter is in sexagesimal form with commas to separate the places.) In India $3,438'$, namely, the rounded half of D , was used as the length of the radius (R), which is the largest "half chord" (*jyārdha* or *ardhajyā*).

Thus the relation between the Greek chord and the Indian sine can be expressed as

$$AB = 2AH, R \text{ crd } 2\alpha = 2R \sin \alpha. \quad (1)$$

Plane trigonometry was the essential tool for mathematical astronomy in India. All the astronomical texts in Sanskrit either give a kind of sine table or presuppose one. On the other hand, trigonometry was studied only as a part of astronomy

Trigonometry in Indian Mathematics, Table 2 Indian sine table with $R = 3,438$

Number	α	$R \sin \alpha$	Δ
1	3; 45	225	225
2	7; 30	449	224
3	11; 15	671	222
4	15	890	219
5	18; 45	1,105	215
6	22; 30	1,315	210
7	26; 15	1,520	205
8	30	1,719	199
9	33; 45	1,910	191
10	37; 30	2,093	183
11	41; 15	2,267	174
12	45	2,431	164
13	48; 45	2,585	154
14	52; 30	2,728	143
15	56; 15	2,859	131
16	60	2,978	119
17	63; 45	3,084	106
18	67; 30	3,177	93
19	71; 15	3,256	79
20	75	3,321	65
21	78; 45	3,372	51
22	82; 30	3,409	37
23	86; 15	3,431	22
24	90	3,438	7

and it was never an independent subject of mathematics. Furthermore, since they were not aware of spherical trigonometry, Indian astronomers developed the method called *chedyaka* in which the sphere was projected on to a plane.

Sine Table with $R = 3,438$

The earliest Indian sine table with $R = 3,438$ is found in Āryabhaṭa's book on astronomy, *Āryabhaṭīya* (around AD 500). It should be remembered that "table" here does not mean that the numbers are actually arranged in a tabular form, i.e., in lines and columns. As is usually the case with Sanskrit scientific texts, all the numbers are expressed verbally in verse. For brevity's sake, Āryabhaṭa gives only the tabular differences (Δ , the fourth column of Table 2). This is the standard sine table in ancient India.

Exactly the same table is found in the *jiuzhili*, a Chinese text on the Indian calendar written in AD 718 by an astronomer of Indian descent, but it did not have any influence on Chinese mathematics.

The values of sines were geometrically derived from $R \sin 90^\circ (=R)$ and $R \sin 30^\circ (=1/2 R)$ by two formulas:

$$R \sin (90^\circ - \alpha) = \sqrt{R^2 - (R \sin \alpha)^2}, \quad (2)$$

$$R \sin \frac{\alpha}{2} = \sqrt{\left\{ \frac{R - R \sin (90^\circ - \alpha)}{2} \right\}^2 + \left(\frac{R \sin \alpha}{2} \right)^2}. \quad (3)$$

It is worth noting here that the first tabular sine was equated with the arc $(3; 45^\circ = 225')$ which it subtends. This means that, when α' is small enough, the approximation $\sin \alpha' \approx \alpha'$ can be applied.

What is more remarkable in Āryabhaṭa is that he gives an alternative method for computing tabular differences by means of the formula:

$$\Delta_{n+1} = \Delta_n - (\Delta_1 - \Delta_2) \frac{J_n}{J_1},$$

where $J_n = R \sin n(3; 45^\circ)$. The formula, after several centuries of misunderstanding, was correctly interpreted by a South Indian astronomer Nīlakaṇṭha (born in 1444), one of the most distinguished scholars belonging to the Mādhava school (see below). When suitable values of $(\Delta_1 - \Delta_2)$ and J_1 are used, this formula produces very good values for the rest of R sines. It seems that Āryabhaṭa's sine values were computed by this second method rather than by the geometrical method. This means that the table with $R = 3,438$ is not a mere copy of the Hipparchan table, if ever existed.

Sine Table with $R = 120$

There is another kind of Indian sine table which uses $R = 120$. The table is found in the

Trigonometry in Indian Mathematics, Table 3 Comparison of the first four and last four values in the *Pañcasiddhāntikā* with those of Ptolemy

Number	α ($^\circ$)	Varāhamihira with $R = 120$	Ptolemy with $R = 60$
		$R \sin \alpha$	$R \text{ crd } 2\alpha$
1	3; 45	7; 51	7; 50, 54
2	7; 30	15; 40	15; 39, 47
3	11; 15	23; 25	23; 24, 39
4	15	31; 4	31; 3, 30
...	...	...	...
21	78; 45	117; 42	117; 41, 40
22	82; 30	118; 59	118; 58, 25
23	86; 15	119; 44	119; 44, 36
24	90	120	120

Pañcasiddhāntikā of Varāhamihira, a younger contemporary of Āryabhaṭa. This table is closely related to the Greek chord table with $R = 60$ which is offered in Ptolemy's *Almagest*. Because of the relation (1) given above, all the numerical values in the chord table with $R = 60$ can be transferred directly to the sine table with $R = 120$. Table 3 compares the first four and the last four values in the *Pañcasiddhāntikā* with Ptolemy's corresponding ones. The fractional parts after the semicolon in both tables are expressed sexagesimally. It seems that Varāhamihira's values were the results of rounding the numbers in the second fractional place of a chord table similar to that of Ptolemy.

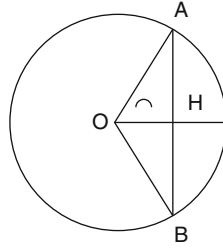
In these earlier Indian sine tables, only the 24 values in the first quadrant are given, with the interval of $3^\circ 45'$. Although Indians knew and used cosines (*koṭijyā*), they had no need of tabulating them because they knew that cosines could be derived from sines by the relation (2) above. On the other hand, they were interested in the versed sine (*śara* in Sanskrit, meaning "arrow" or *utkramajyā*, "sine of the reversed order," CH in Fig. 1) which is defined as

$$\sin \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \frac{\theta^9}{9!} - \dots$$

Using this relation, Brahmagupta (seventh century) simplified some formulas. For instance, formula (3) was rewritten as

Trigonometry in Indian Mathematics,

Fig. 1 Sine of the reversed order



$$R \sin \frac{\alpha}{2} = \sqrt{\frac{D \times R \text{ vers } \alpha}{4}}. \quad (3)$$

A table of versed sines can be easily obtained by adding Δs in Table 2 successively from the bottom upward (namely, in the “reversed order”).

Brahmagupta computed anew 24 sines with $R = 3,270$ in the *Brāhmasphuṭasiddhānta*. Elsewhere in this book and in the *Khaṇḍakhādya*, he offers a sine table with $R = 150$ and with the interval of 15° . This small table generates remarkably correct sine values when his ingenious method of second order interpolation is applied.

Bhāskara II

An improved version of the traditional sine table was prepared by Bhāskara II (b. 1114). In the chapter “Derivation of Sines” (*Jyotpatti*) of his *Siddhāntaśiromaṇi*, he introduces two new values:

$$R \sin 36^\circ = \sqrt{\frac{5 - \sqrt{5}}{8}} R,$$

$$R \sin 18^\circ = \sqrt{\frac{\sqrt{5} - 1}{4}} R.$$

With these two values and formulas (2) and (3) above, he obtains $R \sin 3n^\circ$ (where $n = 1, 2, 3, \dots, 30$). Further he combines them with the approximate value

$$R \sin 1^\circ \approx 60'$$

using the new formula

Trigonometry in Indian Mathematics, Table 4 Mādhava’s sine table

Number	α ($^\circ$)	$R \sin \alpha$
1	3; 45	0224; 50, 22
2	7; 30	0448; 42, 58
3	11; 15	0670; 40, 16
4	15	0889; 45, 15
5	18; 45	1,105; 01, 39
6	22; 30	1,315; 34, 07
7	26; 15	1,520; 28, 35
8	30	1,718; 52, 24
9	33; 45	1,909; 54, 35
10	37; 30	2,092; 46, 03
11	41; 15	2,266; 39, 50
12	45	2,430; 51, 15
13	48; 45	2,548; 38, 06
14	52; 30	2,727; 20, 52
15	56; 15	2,858; 22, 55
16	60	2,977; 10, 34
17	63; 45	3,038; 13, 17
18	67; 30	3,176; 03, 50
19	71; 15	3,255; 18, 22
20	75	3,320; 36, 30
21	78; 45	3,321; 41, 29
22	82; 30	3,408; 20, 11
23	86; 15	3,430; 23, 11
24	90	3,437; 44, 48

$$R \sin (\alpha \pm \beta) = \frac{R \sin \alpha R \cos \beta \pm R \cos \alpha R \sin \beta}{R}, \quad (4)$$

which is equivalent to the modern formula:

$$\sin (\alpha \pm \beta) = \sin \alpha \cos \beta \pm \cos \alpha \sin \beta.$$

Thus he could obtain sines for all the integer degrees of a quadrant. Formula (4) was unknown to Indians before Bhāskara II, while a chord version of the same formula was known to Ptolemy.

Trigonometry underwent a remarkable development in the early fifteenth century on the western coast of South India (the modern state of Kerala). The person who initiated this development was Mādhava (fl. ca. 1380/1420) of Saṅgamagrāma (near modern Cochin). His important works on astronomy and mathematics are now lost, but we know his achievements from the books of his successors. A sine table ascribed to him is quoted in

Nīlakaṇṭha's commentary on the *Āryabhaṭīya* (Table 4).

A couple of verses, which are often quoted by the students of the Mādhava school and which are ascribed to Mādhava himself by Nīlakaṇṭha, give the method of computing sines. The method can be expressed as

$$R \sin \theta = \theta - \frac{\theta^3}{3!R^2} + \frac{\theta^5}{5!R^4} - \frac{\theta^7}{7!R^6} + \frac{\theta^9}{9!R^8} - \dots$$

with $R = 1$ this is equivalent to Newton's

$$\sin \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \frac{\theta^9}{9!} - \dots$$

Similar power series for cosine and versed sine are ascribed to Mādhava.

See Also

- [Almagest: Its Reception and Transmission in the Islamic World](#)
- [Āryabhaṭa](#)
- [Brahmagupta](#)
- [Mādhava of Saṅgamagrāma](#)
- [Nīlakaṇṭha Somayājī](#)
- [Sexagesimal System](#)
- [Śrīpati](#)
- [Varāhamihira](#)

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Trigonometry in Islamic Mathematics

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Trigonometry is the connecting link between mathematics and astronomy, between the way calendars are calculated, the gnomon, and the sundial. In the Islamic world, the calculation of spherical triangles was necessary to carry out ritual customs. The *qibla*, the direction to Mecca, was indicated next to the hour lines on all public sundials.

The first trigonometric problems appeared in the field of spherical astronomy. Around the year 773, one of the Indian *siddhāntas* (astronomy books) was made known in Baghdad. The Indian astronomers Varāhamihira (fifth century) and Brahmagupta (sixth century) solved different problems in spherical astronomy by means of rules equivalent to a general sine theorem for a spherical triangle ABC with sides a, b, c and angles A, B, C (where angle A is opposite to side a , etc.), namely, $(\sin A / \sin a) = (\sin B / \sin b) = (\sin C / \sin c)$ and to the cosine theorem for the same triangle $\cos a = \cos b \cos c + \sin b \sin c \cos A$.

In the ninth century, Ptolemy's *Almagest* and Menelaus' *Spherics* were also translated, and commentaries were written to these works. Many trigonometric problems were solved in Ptolemy's *Almagest*, in which Menelaus' theorem on the spherical complete quadrilateral was used. The cases of this theorem used by Ptolemy are equivalent to the sine and tangent theorems for a right-angled spherical triangle. The *Almagest*, the *Spherics*, and the Indian *siddhāntas* formed the basis on which Arab mathematicians built their trigonometry.

The ancient Greek astronomers only used one trigonometric function, the chord of an arc. The "theorem of Ptolemy," which is equivalent to the formula for the sine of the sum of the angles, forms, together with the formula for the chord

of the half arc, the basis for the chord table in the *Almagest*. The Indian people replaced the chord with the sine, introduced the cosine and the versed sine, and compiled a small table of sine values. The Arabic mathematicians progressively made trigonometry into a science independent of its (astronomical) context.

Applications of trigonometry analogous to those in the Indian *siddhāntas* are found in the astronomical works of al-Khwārizmī. An analogous geometric construction for finding the azimuth according to the rule formulated in al-Khwārizmī's third treatise was provided by al-Māhānī (ca. 825–888) in his *Treatise on the Determination of the Azimuth at Any Time and in Any Place*. The rules equivalent to the spherical sine and cosine theorems were also used by Thābit ibn Qurra in his *Book on Horary Instruments Called Sundials*. With Ḥabash, the applications of the tangent and cotangent functions went beyond the usual applications in the theory of sundials. The introduction of the tangent and cotangent and their application in astronomy was a novelty. The names *zill* (shadow) and *zill ma'qus* (reversed shadow) apparently are translations from Sanskrit. In the case of a vertical gnomon, al-Ḥabash expressed the cosecant as the “diameter of the shadow” for a given height of the sun, i.e., as a hypotenuse. He computed a table for the cosecant with steps of 1° .

For a long time, the chord was used along with the sine. A theory of these magnitudes is found in the work of al-Battānī (ca. 858–929). In his astronomical work *Islāḥ al-Majisī* (The Perfection of the *Almagest*), he systematically employed the trigonometric functions sine and versed sine with arguments between 0° and 180° . Since the cosine is defined as the sine of the complement of the angle and since no negative numbers are used, the versed sine is defined in the second quadrant as a sum of two quantities. The elements of trigonometry are set forth in an even more systematic way in the *Kitāb al-Kāmil* (Perfect Book) of Abū'l-Wafā' (940–997/998). He defined several trigonometric functions in the circle with radius 1. The trigonometric tangent function is defined as a line on a tangent to the circle.

The proof of the general spherical sine theorem was given by Abū'l-Wafā' in his *al-Majisī* (*Almagest*), by his pupil Abū Naṣr ibn 'Irāq (d. 1036) in the *Risāla fī ma'rifa al-qisī al-falakiyya* (Treatise on the Determination of Celestial Arcs), and by al-Khujandī (d. ca. 1000) in the *Kitāb fī al-sā'āt al-māḍiyya fī al-layl* (Book on Past Hours in the Night). The history of the discovery of this theorem was described by al-Bīrūnī, the pupil of Ibn 'Irāq and al-Khujandī, in the *Kitāb maqālīd 'ilm al-hay'a* (Book on the Keys of Astronomy).

The use of trigonometry was expanded through al-Bīrūnī (973–1048). He is the author of the *Mas'ūdic Canon*, which is a summary of the results from the works of many predecessors and of personal observations and calculations. It comprises 11 books. Book 3 is dedicated to trigonometry. It has calculations equivalent to the formulas for the sine of the sum of two angles, the sine of the differences between two angles, and the sine of the double angle. It also includes the solution of cubic equations and the division of angles into three parts and the sine rule of plane trigonometry: $(\sin A/a) = (\sin B/b) = (\sin C/c)$. (The plane cosine theorem $a^2 = b^2 + c^2 - 2bc \cos A$ is equivalent to two of Euclid's theorems.)

Another important scholar in the area of trigonometry was Naṣīr al-Dīn al-Ṭūsī (1201–1274). His principal work was *Kitāb al-shakl al-qattā'* (Book on the Secant Figure, also known as *Treatise on the Complete Quadrilateral*). It was written in Persian and translated by the author into Arabic in 1260 possibly for the needs of the observatory of Maragha. In five books, it contains a full system of trigonometric formulas for plane and spherical triangles. If any three elements of such a triangle are given, the other three elements can be found by the theory explained in this work, which also contains the notion of the polar triangle $A'B'C'$ of a spherical triangle ABC ($A' = 180^\circ - a$, $B' = 180^\circ - b$, $C' = 180^\circ - c$). This work played an important role in the development of mathematics in Europe.

See Also

- [Abū'l-Wafā'](#)
- [al-Battānī](#)
- [al-Bīrūnī](#)
- [al-Khujandī](#)
- [al-Khwārizmī](#)
- [al-Māhānī](#)
- [Brahmagupta](#)
- [Naṣīr al-Dīn al-Ṭūsī](#)
- [Thābit ibn Qurra](#)
- [Varāhamihira](#)

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Ulugh Bēg

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Ulugh Bēg, Mīrzā Muḥammad ibn Shāhrūkh ibn Tīmūr Ulugh Bēg Guragān, 1394–1449, was the ruler of Samarqand (now in Uzbekistan) and an astronomer, mathematician, and poet. His nickname, Ulugh Bēg, means “great prince.” He was the grandson of the great conqueror Tīmūr. In 1417, as a pupil of Qādī Zādeh al-Rūmī of Bursa (Turkey), he opened in Samarqand the *madrassa* (school) where al-Rūmī was the teacher. In 1425, he founded an astronomical observatory and invited Jamshīd al-Kāshī to be its director. After al-Kāshī’s death, the head of the observatory became ‘Alī al-Qūshjī. Ulugh Bēg was killed by enemies of enlightenment. After his death, his observatory was destroyed, and al-Qūshjī fled to Turkey.

The main work of Ulugh Bēg was a book of astronomical tables known as the *Zīj-i Ulugh Bēg* or *Zīj-i jadīd-i Guragānī* (New Zīj of Guragan) written together with al-Kāshī, al-Rūmī, and al-Qūshjī. The tables are written in Persian and are extant in many manuscripts in Persian and Arabic translations. The work consists of four books of

trigonometrical, astronomical, geographical, and astrological tables.

Book I covered the subject of calendars, including the Muslim lunar calendar, the pre-Islamic Persian solar calendar, and the Chinese-Uyghur calendar. Book II dealt with spherical astronomy, covering sine and versed sine, shadows (tangents and cotangents), spherical coordinates on the celestial sphere (equatorial, ecliptical, and horizontal coordinates), geographical coordinates, as well as spherical distances between stars and the direction of *qibla* (to Mecca). In Book III Ulugh Bēg considered planetary and stellar astronomy, such as the motion of the sun, moon, and planets, the distances of the sun and the moon from the center of the world, and the equalization of astrological houses. Finally, Book IV dealt with astronomical calculations.

Ulugh Bēg also was the author of the mathematical *Risāla fī istikhrāj jayb daraja wāhida* (Treatise on the Determination of Sine of One Degree). Originally the treatise was wrongly ascribed to al-Rūmī; Ulugh Bēg’s authorship was established on the basis of the information in al-Bīrjandī’s commentaries to the *Zīj* of Ulugh Bēg.

See Also

- ▶ [al-Kāshī](#)
- ▶ [Observatories in the Islamic World](#)
- ▶ [Qibla and Islamic Prayer Times](#)
- ▶ [Zīj](#)

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Umar al-Khayyām

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‘Umar al-Khayyām (Ghiyāth al-Dīn Abū’l-Faṭḥ ‘Umar ibn Ibrāhīm Khayyām (al-Khayyāmmī) al-Naysābūrī (Nīshāpurī), 1048–1131) was a Persian mathematician, astronomer, philosopher, and poet. His scientific treatises were written primarily in Arabic; his poems were mostly written in Persian. The name Khayyām means “the tentmaker” – probably it was the profession of his father or grandfather. He was born and died in Nīshāpūr. Khayyām was a student in Balkh (now in Afghanistan) and worked at first in Bukhārā and Samarqand (now in Uzbekistan). In 1074 he was invited by Saljūq Sultan Mālikshāh Jalāl al-Dīn to the capital Iṣfahān to participate in the reform of the solar Persian calendar and to organize an astronomical observatory. The calendar reform was completed in 1079; the new calendar era was named according to the names of the sultan Māliki or Jalālī. In 1092, after Mālikshāh’s death, Khayyām fell into disgrace, and his observatory was closed. This was because of suspicions that some of his verses were anti-Islamic. To allay these suspicions, he made a pilgrimage to Mecca. Later he worked in Marw (now Marv in Turkmenistan) which was the new capital of the Saljūq sultans.

Two of Khayyām’s treatises are very important for the history of mathematics. One is the *Risāla fī’l-barāhīn ‘ala masā’il al-jabr wa’l-muqābala* (Treatise of Demonstrations of Problems of Algebra), written in Samarqand and dedicated to the judge Abū Ṭāhīr who had given him the opportunity to devote himself to the science. The topic of this work was the theory of cubic equations. Here the complete classification of cubic equations with positive roots was given, and for every type of equation, the solution by means of the intersection of circumferences,

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equilateral hyperbolas, and parabolas was also given.

The second work is the *Sharḥ mā ashkala min muṣādarāt kitāb Uqlīdis* (Commentaries on Difficulties in Introductions of Euclid's book). It was written in Iṣfahān in 1077 and contains the commentaries to Euclid's *Elements*. The treatise consists of three *maqālas*: (1) on the theory of parallels, (2) on the theory of ratios, and (3) on the theory of compound ratios. The ideas of this work were developed further by Naṣīr al-Dīn al-ṭūsī (1201–1274), John Wallis (1616–1703), and Girolamo Saccheri (1667–1733) (Khayyām's quadrangle is also called Saccheri's quadrangle).

Before the *Risāla fī'l-barāhīn*, Khayyām wrote the *Risāla fī taqṣīm rub' al-dā'ira* (Treatise on Division of a Quarter of a Circle) and *Mushkilāt al-ḥisāb* (Problems of Arithmetic). In the first, a geometric problem is considered. It is reduced to a cubic equation whose solution by means of the intersection of the circumference and equilateral hyperbola and an approximate numerical solution are found. Here the problem of classifications of cubic equations is formulated. The second work is not extant but is mentioned in the former as "the treatise on the demonstration of methods of Indians of extraction of square and cube roots and on generalization of these methods for determination of bases of square-squares, square-cubes, cube-cubes and so on as many as you like, what was not earlier." These words show that this work was devoted to the extraction of roots of n th degree, which was explained later in the arithmetic treatise of Naṣīr al-Dīn al-ṭūsī. Probably in this work, as in al-ṭūsī's treatise, "Newton's binomial formula" for $(a + b)^n$ for an arbitrary natural n was explained.

Khayyām also made many contributions to the study of astronomy and the calendar. His *al-Zīj Mālikshāhī* (Malikshah Astronomical Tables) is not extant, except for the catalog of fixed stars from this work. In Khayyām's calendar, there were eight intercalary days in 33 years. The error is 1 day in 5,000 years (in the Gregorian calendar, the error is 1 day in 3,330 years). After the closing of his observatory, Khayyām wrote the Persian historical treatise *Nowrūz-nāmeḥ*

(Book on the New Year) on reforms of the solar Persian calendar and on the Persian New Year holiday Nowrūz in pre-Islamic Iran.

In the field of physics, Khayyām wrote *Fī ikhtiyāl ma'rifa miqdāray al-dhahab wa'l-fidḍa fī jism murakkab minhumā* (On the Art of Determination of Quantities of Gold and Silver in a Body Consisting of Them) and *Fī'l-quṣṭāṣ al-mustaqīm* (On the Right Balance). Both of these works are included in the *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom) of Khayyām's student 'Abd al-Raḥmān al-Khāzinī, who worked in Marv. In this he explains a method to determine specific gravity.

Khayyām also made significant contributions to music and philosophy. He wrote a *Qaul 'alā ajnās allatī bi'l-arba'a* (Speech on Genera Which are [formed] by a Quarter) on the division of a quarter into three intervals in accordance with three genera of tonality – diatonic, chromatic, and enharmonic.

In philosophy, Khayyām was a follower of Aristotle and Ibn Sīnā (Avicenna). On the question of universalia, he was near to Peter Abelard. Many philosophical questions were considered in Khayyām's poetry, particularly in his well-known *Rubā'īyāt* (Quatrains).

See Also

- [Elements: Reception of Euclid's Elements in the Islamic World](#)
- [Naṣīr al-Dīn al-ṭūsī](#)

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Vāgbhaṭa

Guy Mazars

In the history of medicine in India, Vāgbhaṭa is the most celebrated author after ► [Caraka](#) and ► [Suśruta](#). It is not known at what period Vāgbhaṭa lived. We usually place him in the sixth century; he is in any case earlier than the tenth century. His identity has been the subject of unending discussion, and Indian critics hold that there was an “elder Vāgbhaṭa” in addition to “Vāgbhaṭa”, grandson of the former and son of Siṃhagupta.

Several treatises of Āyurveda (Indian medicine; see article in the encyclopaedia) are ascribed to him. The most interesting are the *Aṣṭāṅgasamgraha* and the *Aṣṭāṅgahṛdayasaṃhitā* which are probably two different versions of the same medical text whose teachings agree generally with those of Caraka and Suśruta. However the more commonly used text of Vāgbhaṭa is the *Aṣṭāṅgahṛdayasaṃhitā* or “Compendium on the Heart of Medicine” which is considered the greatest synthesis on Āyurveda ever produced. The Chinese pilgrim Yi Jing, who stayed in India from AD 673 to 688, spoke, without mentioning its name, of a work that was then recent and that summarised the eight branches of medicine. It is thought that he was referring to the work of Vāgbhaṭa, but he may also have been referring to

the *Yogaśataka*, “The Hundred Formulas”, which fits Yi Jing’s description perfectly. This work consists, as its name indicates, of a series of 100 therapeutic formulas distributed according to the eight theoretical divisions of Āyurveda. Its author is a certain Nāgārjuna, perhaps the same author who is reputed to have revised the *Suśrutasaṃhitā* but who is not necessarily the Buddhist patriarch of that name with whom he is nevertheless identified by the tradition.

The *Aṣṭāṅgahṛdayasaṃhitā* gives full expression to the richness and detail of the ancient tradition of Āyurveda. Numerous manuscripts of the work are extant in Indian libraries and the first printed edition appeared in 1874–1878 in Calicut. Since then, countless editions of the whole or of parts of the treatise have been published.

Vāgbhaṭa enjoyed early and widespread recognition. The *Aṣṭāṅgahṛdayasaṃhitā* was the object of numerous commentaries. The work is quoted in the *Firḍaws al-Ḥikma* or “Paradise of Wisdom” composed in AD 850 by the Persian physician ‘Alī ► [Ibn Sahl](#) Rabban aṭ-Ṭabarī who gives a very complete summary of the āyurvedic doctrines. The *Aṣṭāṅgahṛdayasaṃhitā* was also translated into Tibetan and incorporated into the immense Buddhist Encyclopaedia of the *Tanjur* between the years 1013 and 1055.

See Also

► [Medicine in India: Āyurveda](#)

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Vākyakaraṇa

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Vākyakaraṇa, apocryphally ascribed to Vararuci, is an astronomical manual produced in about AD 1300 which was very popular in South India, especially in Tamil Nadu and the adjoining regions. The work is so called because it was a *karaṇa* (astronomical manual) which used computational tables where the numbers are expressed in mnemonic sentences (*vākyas*), phrases, and words. It is also called *Vākyapañcādhyāyī*, because it contains *pañca adhyāyas* (five chapters). Until recently, when

the *Nautical Almanac* came to be used in South India for the computation of the Hindu almanac with its “five limbs” (*pañcaṅga*): the lunar day, weekday, asterism, *yoga*, and *karaṇa*, the *Vākyakaraṇa* was widely used for that purpose.

The author of the *Vākyakaraṇa* hailed from Kariśaila or Kāñchī in Tamil Nadu, as he himself states in his work. He also states that he based his work on the writings of Bhāskara I (AD 629), the exponent of the school of astronomy promulgated by Āryabhaṭa (b. AD 476), and the works of Haridatta (AD 683), author of *Grahacāranibandhana* and *Mahāmārganibandhana*. The *Vākyakaraṇa* was elaborately expounded by Śundararāja (AD 1500), who had contacts with the Kerala astronomer Nīlakaṇṭha Śomayāji. The date of *Vākyakaraṇa* is determined as ca. AD 1300, on the basis of epochs which the author gives for the computation of the planets.

In five chapters, the *Vākyakaraṇa* deals with all aspects of astronomy required for the preparation of the Hindu almanac. Chapter I is concerned with the computation of the sun, the moon, and the moon's nodes and Chapter II with that of the planets. Chapter III is devoted to problems involving time, position, and direction and other preliminaries like the precession of the equinoxes. The computation of the lunar and solar eclipses is the concern of Chapter IV. Chapter V is devoted to the computation of the conjunction of the planets and of planets and stars.

For the computation of the moon, the *Vākyakaraṇa* employs the 248 moon sentences of the ancient astronomer Vararuci. But for the five planets Mars, Mercury, Jupiter, Venus, and Saturn, the author himself computed 82 tables devoted to the different planetary cycles, containing, in all, 2,075 mnemonic sentences (*Kujādi-pañca-graha-mahāvākyas*).

The results obtained through the computations enunciated in the *Vākyakaraṇa* are not very accurate, going by modern standards, but they were accurate enough for the determination of auspicious times and other matters required in the routine life of orthodox Hindus. Besides, there

was the saving of much time and labor in working with the simple methods advocated in the work.

See Also

- [Āryabhaṭa](#)
- [Bhāskara I](#)
- [Haridatta](#)
- [Nīlakaṇṭha Somayājī](#)
- [Precession of the Equinoxes](#)

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Values and Science

Ziauddin Sardar

Is science value free? If “science,” as Lord Ruth-erford is reported to have said, “is what scientists do” then scientists would have to be superhuman to keep their values out of what they do in their laboratories. We cannot clinically isolate our cultural and ethical (and through them our historical) baggage from our human activities. Values play an important part in what we select to do or not do and how we actually do it. In as far as science is a human activity, it is subject to the strengths and weaknesses of all human activities.

However, in Western tradition, up to quite recently, scientists were seen as quasireligious supermen, heroically battling against all odds to

discover the truth. Also, the truths they wrestled out of nature were said to be absolute, objective, value-free, and universal. The idea of scientists as dedicated hermit-like lone researchers is now obsolete. Nowadays, science is an organized, institutionalized, and industrialized venture. The days when individual scientists, working on their own, and often in their garden sheds, made original discoveries are really history. Virtually all science today is big science requiring huge funding, large, sophisticated, and expensive equipment, and hundreds of scientists working on minute problems. As such, science has become a unified system of research and application, with funding at one end and the end-product of science, often technology, at the other.

Values enter this system in a number of ways. The first point of entry is the selection of the problem to be investigated. The choice of the problem, who makes the choice and on what grounds, is the principle point of influence of society, political realities of power, prejudice, and value systems on even the “purest” science. Often, it is the source of funding that defines what problem is to be investigated. If the funding is coming from government sources then it will reflect the priorities of the government – whether space exploration is more important than health problems of the inner city poor, or nuclear power or solar energy should be developed further. Private sector funding, mainly from multinationals, is naturally geared toward research that would eventually bring dividends in terms of hard cash. Some 80 % of research in the United States is funded by what is called the “military-industrial complex” and is geared toward producing both military and industrial applications.

Subjectivity thus enters science in terms of what is selected for research which itself depends on where the funding is coming from. But values also play an important part in what is actually seen as a problem, what questions are asked and how they are answered. For example, cancer rather than diabetes may be seen as a problem even though they may both claim the same number of victims. Here both political and ideological concerns, as well as public pressure, can make one problem invisible while focusing attention on

another. Moreover, if, for example, the problem of cancer is defined as finding a cure then the benefits of the scientific research accrue to certain groups, particularly the pharmaceutical companies. But if the function of scientific research is seen as eliminating the problems of cancer from society, then another group benefits from the efforts of research: the emphasis here shifts to investigating diet, smoking, polluting industries, and the like. Similarly, if the problems of the developing countries are seen in terms of population, then research is focused on reproductive systems of Third World women, methods of sterilization, and new methods of contraceptives. However, if poverty is identified as the main cause of the population explosion then research would take a totally different direction: the emphasis would have to shift to investigating ways and means of eliminating poverty, developing low cost housing, basic and cheap health delivery systems, and producing employment generating (rather than profit producing) technologies. The benefits of scientific research would go to the Third World poor rather than Western institutions working on developing new methods of contraceptives and companies selling these contraceptives to developing countries. Thus both the selection of problems and also their framing in a particular way are based on value criteria.

It can be legitimately argued that these factors are external to science, that within science, the scientific method ensures neutrality and objectivity by following a strict logic – observation, experimentation, deduction, and value-free conclusion. But scientists do not make observations in isolation. All observations take place within a well defined theory. The observations, and the data collection that goes with them, are designed either to refute a theory or provide support for it, and theories themselves are not plucked out of the air. Theories exist within paradigms – that is a set of beliefs and dogmas. The paradigms provide a grand framework within which theories are developed and make sense, and observations themselves have validity only within specific theories. Thus, all observations are theory laden, and theories themselves are based on paradigms

which in turn are burdened with cultural baggage. All of which raises the question: can there ever be such things as value-neutral “objective facts”? Studies of scientists working in laboratories have shown that the scientific method, by and large, is a myth. Researchers seldom follow it in the linear fashion that exists in the text books. Neither do they ascertain new “facts” suddenly out of the blue. And the same holds true of the laws of nature they are supposed to be discovering. It appears that scientists do not actually “discover” laws of nature; they manufacture them. Scientific knowledge advances by a process of manufacturing which involves thousands and thousands of workers assembling “facts” which through peer review and other procedures end as description or laws of nature.

Value judgments are also at the very heart of a common element of scientific technique: statistical inference. When it comes to measuring risks, scientists can never give a firm answer. Statistical inferences cannot be stated in terms of “true” or “false” statements. When statisticians test a scientific hypothesis they have to go for a level of “confidence”. Different problems are conventionally investigated to different confidence-limits. Whether the limit is 95 % or 99.9 % depends on the values defining the investigations, the costs, and weight placed on social, environmental, or cultural consequences. In most cases, the importance given to social and environmental factors determines the limits of confidence and the risks involved in a hazardous scientific endeavor. For example, when a chemical plant is placed in an area with an aware and politically active citizenry the risks are worked out to a high level of confidence. However, when one is located in an area where the citizens themselves are ignorant of the dangers and do not command political power, the confidence levels are much more relaxed. The people of Bhopal and Chernobyl know this to their cost.

But it is not just in its institutions and method that science is value laden. The very assumptions of science about nature, universe, time, and logic are ethnocentric. In modern science, nature is seen as hostile, something to be dominated. The Western “disenchantment of nature” was a

crucial element in the shift from the medieval to the modern mentality, from feudalism to capitalism, from Ptolemaic to Galilean astronomy, and from Aristotelian to Newtonian physics. In this picture, “Men” stand apart from nature, on a higher level, ready to subjugate and “torture” her, as Francis Bacon declared, in order to wrestle out her secrets. This view of nature contrasts sharply with how nature is seen in other cultures and civilizations. In Chinese culture, for example, nature is seen as an autonomous self-organizing entity which includes humanity as an integral part. In Islam, nature is a trust, something to be respected and cultivated and people and environment are a continuum – an integrated whole. The conception of laws of nature in modern science drew on both Judeo-Christian religious beliefs and the increasing familiarity in early modern Europe with centralized royal authority, with royal absolutism. The idea that the universe is a great empire, ruled by a divine logos, is, for example, quite incomprehensible both to the Chinese and the Hindus. In these traditions the universe is a cosmos to which humans relate directly and which echoes their concerns. Similarly, while modern science sees time as linear, other cultures view it as cyclic as in Hinduism or as a tapestry weaving the present with eternal time in the Hereafter as in Islam. While modern science operates on the basis of either/or Aristotelian logic (X is either A or non- A), in Hinduism logic can be fourfold or even sevenfold. The fourfold Hindu logic (X is neither A , nor non- A , nor both A and non- A , nor neither A nor non- A) is both symbolic as well as a logic of cognition and can achieve a precise and unambiguous formulation of universal statements without quantification. Thus the metaphysical assumptions of modern science make it specifically Western in its main characteristics.

The metaphysical assumptions of modern science are also reflected in its contents. For example, certain laws of science, as Indian physicists have begun to demonstrate, are formulated in an ethnocentric and racist way. The Second Law of Thermodynamics, so central to classical physics, is a case in point: due to its industrial origins the

Second Law presents a definition of efficiency that favors high temperatures and the allocation of resources to big industry. Work done at ordinary temperature is by definition inefficient. Both nature and the non-Western world become losers in this new definition. For example, the monsoon, transporting millions of tons of water across a subcontinent is “inefficient” since it does its work at ordinary temperatures. Similarly, traditional crafts and technologies are designated as inefficient and marginalized. In biology, social Darwinism is a direct product of the laws of evolutionary theories. Genetic research appears to be obsessed with how variations in genes account for differences among people. Although we share between 99.7 (unrelated people) and 100 % (monozygotic twins) of our genes, genetic research has been targeted toward the minute percentage of genes that are different in order to discover correlations between genes and skin color, sex, or “troublesome” behavior. Enlightened societal pressures often push the racist elements of science to the sidelines. But the inherent metaphysics of science ensures that they reappear in new disguise. Witness how eugenics keeps reappearing with persistent regularity. The rise of IQ tests, behavioral conditioning, fetal research, and sociobiology are all indications of the racial bias inherent in modern science.

Given the Eurocentric assumptions of modern science, it is not surprising that the way in which its benefits are distributed and its consequences are accounted for are themselves ethnocentric. The benefits are distributed disproportionately to already over-advantaged groups in the West and their allies elsewhere, and the costs disproportional to everyone else. When scientific research improves the military, agriculture, manufacturing, health, or even the environment, the benefits and expanded opportunities science makes possible are distributed predominantly to already privileged people of European descent, while the costs are dumped on the poor, racial and ethnic minorities, women, and people located at the periphery of global economic and political networks. Science in developing countries has persistently reflected the priorities of the West, emphasizing the needs

and requirements of middle class western society, rather than the wants and conditions of their own society. In over six decades of science development, most of the Third World countries have nothing to show for it. The benefits of science just refuse to trickle down to the poor.

But modern science is not only culturally biased toward the West: it represents the values of a particular class and gender in Western societies. As feminist scholars have shown, science in the West has systematically marginalized women. Women, on the whole, are not interested in research geared toward military ends, or torturing animals in the name of progress, or working on machines that put one's sisters out of work. But more than that, even the least likely fields and aspects of science bear the fingerprints of androcentric projects. Physics and logic, the prioritizing of mathematics and abstract thought, the so-called standards of objectivity, good method and rationality – feminist critique has revealed androcentric fingerprints in all. This is the case, for example, in the mechanistic model of early modern astronomy and physics, in modern particle physics, and in the coding of reason as part of ideal masculinity. The focus on quantitative measurements, variable analysis, impersonal and excessively abstract conceptual schemes is both a distinctively masculine tendency and one that serves to hide its own gendered character. Science has tried to hide its own masculine nature in other ways, by, for example, making women themselves objects in scientific investigation. It was not entirely accidental that sexology became a major science at the same time as women in the West were fighting for the vote and equal rights in education and employment. A number of studies have shown that scientific work done by women is invisible to men even when it is objectively indistinguishable from men's work. Thus, it appears that neither social status within science nor the results of research are actually meant to be neutral or socially impartial. Instead, the discourse of value-neutrality, objectivity, and social impartiality appears to serve projects of domination and control.

The history of science bears this out. The evolution of Western science can be traced back

to the period when Europe began its imperial adventure. Science and empire developed and grew together, each enhancing and sustaining the other. In India, for example, European science served as a handmaiden to colonialism. The British needed better navigation so they built observatories and kept systematic records of their voyages. The first sciences to be established in India were, not surprisingly, geography, and botany. Western science progressed primarily because of the military, economic, and political power of Europe, focusing on describing and explaining those aspects of nature that promoted European power, particularly the power of the upper classes. The disinterested commitment of European scientists to the pursuit of truths had little to do with the development of science. The subordination of the blacks in the ideology of the black "child/savage" and the confinement of the white women in the cult of "true womanhood" emerged in this period and are both by-products of the Empire. While the blacks were assigned animal and brutish qualities the white women were elevated and praised for their morality. While the blacks were segregated and enslaved, the women were placed in narrow circles of domestic life and in conditions of dependency. Racist and androcentric evolutionary theories were developed to explain human behavior and canonized in the history of human evolution. The origins of Western, middle class social life, where men go out to do what men have to do, and women tend the babies and look after the kitchen, are to be found in the bonding of "man-the-hunter"; in the early phases of evolution women were the gatherers and men went out to bring in the beef. Now this theory is based on little more than the discovery of chipped stones that are said to provide evidence for the male invention of tools for use in the hunting and preparation of animals. However, if one looks at the same stones with different cultural perceptions, say one where women are seen as the main providers of the group – and we know that such cultures exist even today – you can argue that these stones were used by women to kill animals, cut corpses, dig up roots, break down seed pods, or hammer and soften tough roots to prepare them for

consumption. A totally different hypothesis emerges and the course of the whole evolutionary theory changes.

Thus the cultural, racial, and gender bias of modern science can be easily distinguished when it is seen from the perspective of non-Western cultures, marginalized minorities, and women. The kinds of questions science asks when seeking to explain nature's regularities and underlying causal tendencies, the kinds of data it generates and appeals to as evidence for different types of questions, the hypotheses that it offers as answers to these questions, the distance between evidence and the hypothesis in each category, and how these distances are traversed – all have the values of white middle class men embedded in them. Put simply, this implies a relativism in science as in any other sphere of human knowledge. However, most scientists do not look kindly toward criticism, or sociological, philosophical, historical, and anthropological studies which highlight science's value laden nature. Relativism is anathema to scientists: many believe that they are engaged in revealing nature's absolute truths. Science, they argue, is special and different from any other body of knowledge: it is counter-intuitive and rarely a matter of common sense. Some propagandists for science have even suggested that the entire discipline of the sociology of knowledge is a conspiracy of the academic left against science.

The idolization and mystification of science, the insistence on its value neutrality and objectivity, is an attempt not only to direct our attention away from its subjective nature but also from the social and hierarchical structure of science. Whenever we think of "the scientists" we imagine white men in white coats: the sort of chaps we see in advertisements for washing power and skin care preparations, standing in a busy laboratory behind a Bunsen burner and distillation equipment telling us how the application of science has led to a new and improved soap or cold cream. This view of scientists is not far from reality. True power in science belongs to white, middle-aged men of upper classes. Everyone else working in science – women, minorities, black men, white men of lower classes, and third world

researchers – are actually basically rank and file laboratory workers. The social hierarchy within science by and large preserves absolute social status, the social status scientific workers hold in the larger society. The people who make decisions in science, who decide what research is to be done, what questions are going to be asked, and how the research is going to be done are a highly selective, tiny minority. These people have the right background, the contacts to get the necessary appointments, and then further contacts to secure funding for their research projects. The actual execution of scientific research, the grinding and repetitive laboratory work, is rarely done by the same person who conceptualizes that research; even the knowledge of how to conduct research is rarely possessed by those who actually do it. This is why the dominant (Western) social policy agendas and the conception of what is significant among scientific problems are so similar. This is why the values and agendas important to white, middle class men pass through the scientific process to emerge intact in the results of research as implicit and explicit policy recommendations. This is why modern science has become an instrument of control and manipulation of non-Western cultures, marginalized minorities, and women.

Even if we were to ignore all other arguments and evidence, the very claim of modern science to be value-free and neutral would itself mark it as an ethnocentric and a distinctively Western enterprise. Both claiming and maximizing cultural neutrality is itself a specific western cultural value: non-Western cultures do not value neutrality for its own sake but emphasize and encourage the connection between knowledge and values. By deliberately trying to hide its values under the carpet, by pretending to be neutral, by attempting to monopolize the notion of absolute truth, Western science has transformed itself into a dominant and dominating ideology.

See Also

- [Colonialism and Science](#)
- [Technology and Culture](#)
- [Western Dominance](#)

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Varāhamihira

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Varāhamihira, who flourished in Ujjain, in Central India, during the sixth century, was perhaps the greatest exponent of the twin disciplines of astronomy and astrology in India. A master of all three branches of the disciplines astronomy, natural astrology, and horoscopic astrology, he was a prolific writer whose works number more than a dozen, some of which are extensive.

Varāhamihira was born in Kāpithaka, present-day Kapitha, in Uttar Pradesh, known also as Saṅkāśya and mentioned as a great center of learning by the Chinese pilgrim Yuan Chwang as Kah-pi-t'a. He was the son of Ādityadāsa and a Śakadvīpī brāhmaṇa of the Maga sect, who were sun worshippers. His renown has caused several legends, both Hindu and Jain, being woven round his birth, growth, and predictive propensity. A legend has it that he was one of the nine luminaries of the court of King Chandragupta II Vikramāditya, but the definitively known date of Varāhamihira goes against this identification. Varāhamihira's patron has now been identified as King Mahārājādhirāja Dravyavardhana, who ruled over Ujjain during the middle of the sixth century. Varāhamihira also possessed great poetic talents, so that some of the later rhetoricians have extracted verses from his writings to illustrate poetic qualities. Indeed, the fame of Varāhamihira has even induced several places in India to be named after him.

K. V. Sarma: deceased

It is a characteristic of Varāhamihira that he produced larger and shorter versions of most of his works. His only work on astronomy is *Pañcasiddhāntikā* (The Five Basic Texts), being a redaction of select topics from the basic texts of five earlier astronomical schools: *Vāsiṣṭha*, *Paitāmaha*, *Romaka*, *Pauliśa*, and *Saura*, in 443 verses, in the form of a work manual.

Varāhamihira wrote several astrological works. In his *Bṛhajjātaka* (Large Horoscopy), also called *Horāśāstra* (Science of Hours), in 25 chapters containing about 400 verses, he treated all conceivable topics on the subject. This work has been a model for later works and is highly popular even today. In this work, Varāhamihira exhibits his understanding of Greek astrology and employs the Sanskritized forms of a number of Greek terms. His *Laghujātaka* (Shorter Horoscopy) is an abridged form of the previous work. On marriage and the prediction of auspicious times to marry, Varāhamihira composed two works: the *Bṛhadvivāha-ṣaṭṭala* (Larger Treatise on Marriage) and its abridgement, the *Svalpa-vivāha-ṣaṭṭala*. Prognostication on military marches and domestic journeys was treated in three works: *Bṛhad-Yoga-Yātrā* (Larger Course on Expedition), in 34 chapters, *Yoga-yātrā* (Course on Expedition), and *Svalpa-yātrā* (Shorter Course on Expedition).

On natural astrology, Varāhamihira's major work is the *Bṛhatsaṃhitā* (Large Compendium), the *Svalpa-saṃhitā* (Shorter Compendium), and *Vaṭakaṇikā* (Short Text), the last two known only through profuse quotations in later works. The *Bṛhatsaṃhitā*, in 106 chapters, is an encyclopedic compendium on numerous subjects relating to life and nature, such as physical astronomy, geography, calendar, meteorology, flora, portents, agriculture, economics, politics, physiognomy, engineering, botany, industry, zoology, erotica, gemology, hygiene, omens, and prognostication on the basis of asterisms, lunar days, etc. A fund of material on applied science, physical observation, and deduction on the basis of statistics and experimentation went into the production of this work, which is perhaps unparalleled in the early literature of the world. Varāhamihira's works, set

in precise terminology and in graceful language, have been models for writers of later times, not only in astronomy and astrology but in other disciplines as well.

See Also

- [Astrology in India](#)
- [Astronomy in Medieval India](#)

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Vaṭeśvara

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Vaṭeśvara, son of Mahādatta Bhaṭṭa, was a tenth-century Indian astronomer from a town in the Kashmir valley. Some accounts name Ānandapura as the place of his birth. He is the

author of the *Vaṭeśvara Siddhānta*, which he completed at the age of 24, in 904 CE (Śaka 826). Al-Bīrūnī refers to a work called *Karaṇasāra*, which he says was written by Viṭṭeśvara, son of Mihadatta. It is likely that this astronomer is the same as Vaṭeśvara. According to al-Bīrūnī, Viṭṭeśvara was born in Nāgarapura.

Although the *Vaṭeśvara Siddhānta* survives only in a solitary manuscript found at Lahore, it seems to have been a widely read work for a long time. Its influence is seen on major astronomers like Śrīpati, Bhāskara II, and Kamalākara Bhaṭṭa. Vaṭeśvara was an Āryabhaṭan by persuasion and adopted several stances taken by the great pioneer. For instance, most astronomers divide the *Mahāyuga* of 43,20,000 years into the four *yugas*, the *Kṛta*, *Tretā*, *Dvāpara*, and *Kali* in a 4:3:2:1 ratio. But Vaṭeśvara followed Āryabhaṭa and assigned a period of 10,80,000 each for the four *yugas*. In doing so, he made a strong attempt to refute Brahmagupta's criticism of Āryabhaṭa.

In 1,326 verses divided into eight chapters, the *Vaṭeśvara Siddhānta* covers a wide range of issues related to astronomy, including mean motion, true motion, calculation of aeonary days, corrections to mean planet, diurnal motion, eclipses, heliacal rising, lunar horns, and the conjunction of celestial bodies. The chapters are further divided into shorter sections devoted to different aspects of astronomy, which is not to be seen in any other astronomical treatise from India.

Vaṭeśvara set very high standards for the professional astronomer. For instance, he held that an ace astronomer must be able to determine the *ahargaṇa* (number of days elapsed in an era) on the basis of solar days alone, without taking recourse to lunar months, intercalary months, etc. The astronomer was also expected to find lunar days from civil days, solar days from lunar days, and sidereal days from solar days. Not only was the astronomer required to know how to arrive at the longitude of the sun and the moon but also determine the sun's longitude from the moon's and the moon's from the sun's! Vaṭeśvara offered a number of innovative methods and fresh interpretations, which along with its

encyclopedic character made his treatise an important source of reference for astronomers in India for a long time.

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Veterinary Medicine in India

Guy Mazars

A tradition of veterinary therapy developed very early in India. Modelled on Āyurveda, (Āyurveda is a holistic medical system that is explained in detail in an article in the encyclopaedia) this veterinary medicine is known through a specialised literature which tells us about the ancient methods of prevention and treatment of animal diseases in India before the advent of modern medicine (Mazars, 1994, 1999). Some of these treatments, as yet little known outside India, are still practised today.

The surviving texts are concerned mainly with the treatment of horses and elephants. The legends incorporated in these texts present knowledge regarding the medical treatment of horses and elephants as being directly revealed by the gods. This may be explained partly by the need to provide veterinary medicine with an origin similar to that of the Āyurveda, which is also presented as 'divinely inspired' knowledge. In fact, veterinary medicine developed from the ayurvedic model over the seven or eight centuries which preceded the Christian era. It is also known, from the inscriptions of Aśoka in the middle of the third century BCE, that this

Buddhist sovereign opened hospitals for animals (Schneider, 1978). Unfortunately, no actual veterinary records exist from this period.

The oldest Sanskrit text of veterinary medicine that has come down to us is a treatise entitled *Aśvāyurvedasiddhānta* (Complete System of Āyurveda for Horses) attributed to a certain Śālihotra (Mukhopadhyaya, 1926, pp. 356–399). This text is probably dated before the tenth century. There also exists a Tibetan version written at the beginning of the eleventh century, and the text was translated into Persian in the fourteenth century. Subsequently, various treatises on horses and diseases of horses were composed. The principal surviving ancient text dealing with elephant medicine is a treatise which tradition ascribes to Pālakāpya, a legendary person, also known as Dhanvantari, the father of Indian surgery (Mukhopadhyaya, 1926, pp. 400–424). The text, entitled *Hastyāyurveda* (The Āyurveda of Elephants), is divided into four parts. The first part is devoted to general diseases, the second to localised and minor ailments, the third to surgery and anatomy, and the last to the feeding of elephants and medicinal preparations. The text cannot be earlier than the Middle Ages, but it contains medical concepts and veterinary practices of long standing.

Specialised treatises are not the only source of existing information. The treatises of the Āyurveda sometimes refer to veterinary treatments. Thus, a passage in *Carakasamhitā* (Siddhisthāna, XI, 20–26) contains a list of ingredients for preparing enemas for elephants, camels, cattle, horses, and sheep (Sharma, 1983, pp. 665–666). There is also information on animal-borne human diseases. For example, rabies is described under the name *jalatrāsa* (hydrophobia) in the *Suśrutasamhitā* (from the beginning of the Christian era) (Bhishagratna, 1963, pp. 733–734). A small collection of therapeutic formulae from the eleventh century, the *Rājamārtanḍa*, contains a chapter devoted to the treatment of domestic animals (Misra, 1966, pp. 108–112). In addition, certain nonmedical texts contain information on the veterinary art. Some information regarding veterinarians is contained in the *Arthaśāstra* (Kangle,

1960–1963), a treatise of government traditionally attributed to Kauṭilya, possibly an adviser to Chandra Gupta (313–289 BCE), founder of the Maurya dynasty.

In the field of anatomy the knowledge of the ancient Indian veterinarians seems to have been quite extensive and is more accurate than that concerning the human body. Observations on animal carcasses were favoured by sacrifices, wars and other events. As regards the physiopathological conceptions in the Sanskrit texts of veterinary medicine, they are those of classical Āyurveda. According to these conceptions the health of both animals and human beings depended on the normal balance and proper functioning of the three vital principles: wind (*vāyu*), bile (*pitta*) and phlegm (*kapha* or *śleṣman*). Generalised diseases and localised ailments were linked to imbalance in these principles, or disturbances in the secondary forms of a single principle. Consequently, the name *tri-doṣa* (three troubles) was given to this triad of elements. Disorders in the functions governed by the three principles were themselves the outcome of multiple causes related to behaviour, character, feeding, mode of life, season, habitat, etc. In particular, equestrian texts often invoked a nutritional cause: food poisoning or unbalanced feeding.

Classification of diseases was broadly similar to the principles applied to human diseases but differed in detail, except in certain cases such as the diseases common to horses and human beings. The various conditions were classified according to their supposed origin, their apparent seat, or the nature of the symptoms. In the first category were diseases attributed to a disorder of wind, bile, etc. Diseases of wind were the most numerous, totalling 76 in the case of elephants. In the second category were diseases of the skin and the head, chest pains, etc. The last category notably included fevers, which were differentiated into many types according to the involvement of wind, bile or phlegm, and according to the other symptoms which accompany hyperthermia. One of the most detailed classifications is that of the *Hastyāyurveda*, which placed diseases of elephants in two broad groups. The first group was

endogenous diseases, including diseases attributable to disturbance of the vital principles. The second group was exogenous diseases, mainly traumatic injuries: accidental wounds and those caused by weapons, bites of wild animals, etc. However, identification of the diseases listed in the texts is often uncertain, and sometimes even impossible, due to a lack of information. The passage in the *Suśrutasamhitā* (Kalpasthāna, VII, 43–50) concerning rabies was translated as follows: ‘The bodily Vāyu in conjunction with the (aggravated) Kapha of a jackal, dog, wolf, bear, tiger, or any other such ferocious beast affects the sensory nerves of these animals and overwhelms their instinct and consciousness. The tails, jaw-bones and shoulders of such infuriated animals naturally droop down, attended with a copious flow of saliva from their mouths. The beasts in such a state of frenzy, blinded and deafened by rage, roam about and bite each other’. The text states further: ‘A person bitten by a rabid animal barks and howls like the animal by which he is bitten, imitates it in many other ways and, bereft of the specific functions and faculties of a human subject, ultimately dies...’ (Bhishagratna, 1963, pp. 733–734).

As in Ayurvedic medicine, prevention occupies an important place. It is based on general and dietary hygiene. The texts lay stress on the layout and maintenance of cowsheds and stables, the different sorts of foods with their qualities and their drawbacks, as well as on the dietary rules to be observed. They underline the importance of moderation in food for domestic animals and enumerate the undesirable consequences of an excess of food. Furthermore, like Āyurveda, the veterinary tradition of India emphasises methods aimed at strengthening the general state of health, notably by the use of tonics and stimulants (*rasāyana*), and aphrodisiacs (*vājīkaraṇa*). The latter, containing various constituents, which have been the object of little study to date, augmented the strength of enfeebled animals and those of poor virility. Sanskrit texts provide various recipes for potions enabling a stallion to mate repeatedly. The *rasāyana* (elixirs of long life) were prescribed to strengthen animals and were recommended for preventing

all sorts of illnesses. For example, a mixture based on aconite and three sorts of peppers was recommended for extending the life span of horses. The following plants were main constituents of such elixirs: *Asparagus racemosus* Willd., *Emblica officinalis* Gaertn., *Terminalia bellerica* Roxb., *Terminalia chebula* Retz., *Tinospora cordifolia* (Willd.) Miers and *Zingiber officinale* Rosc. Buffalo horn was also a valued ingredient.

Veterinary medicine is theoretically divisible into eight branches, corresponding to the eight divisions set out in the Āyurveda. Thus, hippiatry was divided into general surgery, general therapeutics, ophthalmology and otorhinolaryngology, care of foals (corresponding to Ayurvedic paediatrics), toxicology, fortifying treatments, demonology, and the use of aphrodisiacs. Apart from surgical operations, therapy consists most often in the administration of medicinal preparations by different routes and under different forms: mixtures of powders, decoctions, electuaries, ointments... The texts lay stress quite particularly on the benefits of using medicinal oils and butters in food, in external applications and in enemas. We find also various procedures intended to make horses sweat, techniques of cauterisation, bloodletting and several kind of enemas. Procedures of inducing sweating, eight in number, are indicated for treating the sicknesses due to wind and to phlegm. The texts of hippiatry distinguish between violent and mild sudorifics. They specify the method of use of each by indicating the most favourable periods for this type of treatment. Cauterisations with red-hot irons are reserved for the treatment of diseases which neither dietary regimes, nor errhines, nor enemas have been able to cure. The sites to be cauterised and the form and the number of the cauterisations vary according to the case to be treated. We are well informed also on the post-operative care and the precautions to be taken in the days that follow the operations. We note also the use of caustics. As far as bloodletting is concerned, the treatises on hippiatry tell us also about the contra-indications and indicate the food for ‘reconstituting’ the blood and the remedies to be administered if the bloodletting is substantial.

Since India gained its independence in 1947, the Indian Government, recognising the services rendered by traditional medicine, has given a new impetus to these practices. The study and practice of traditional medicine has been regulated, and training is provided at present by a large number of schools with associated hospitals and care centres. This movement has also benefited traditional veterinary medicine, which has undergone a revival.

Several Indian laboratories now produce preparations from ancestral recipes, which are packed under modern conditions and sold throughout India for the treatment of domestic animals. Traditional formulations produced on a large scale include tonics, fortifiers and digestives, as well as antiparasitic and antifungal products. Many of these medicaments are polyvalent, due to the multiplicity of ingredients used in their preparation. For example, a company in Bangalore produces a stomachic and tonic containing 59 ingredients. This preparation is recommended for treating digestive disorders (anorexia, dyspepsia, constipation, etc.) in cattle, sheep, goats, horses and dogs, in doses proportional to the size of these animals. The principal ingredients of vegetable origin include the following: *Aegle marmelos* Corr., *Aquilaria agallocha* Roxb., *Butea monosperma* (Lam.) Kuntze, *Centratherum anthelminticum* Kuntze, *Curcuma longa* L., *Ferula narthex* Boiss., *Moringa oleifera* Lam., *Piper longum* L., *Punica granatum* L., *Terminalia bellerica* Roxb., *Terminalia chebula* Retz., *Tinospora cordifolia* (Willd.) Miers, *Trachyspermum ammi* (L.) Sprague and *Zingiber officinale* Rosc. These ingredients were prescribed in Ayurvedic medicine for their aperitive, digestive, stomachic, carminative or anthelmintic properties. Another example is provided by an ointment against sprains and sores, prepared from the following plants: *Abrus precatorius* L., *Acorus calamus* L., *Celastrus paniculatus* Willd., *Hyoscyamus niger* L., *Moringa oleifera* Lam., *Nardostachys jatamansi* D.C., *Ocimum sanctum* L., *Saussurea lappa* C.B. Clarke and *Vitex negundo* L. To these oils are added extracts of seven other plants: *Anacyclus pyrethrum* D.C., *Colchicum luteum* Baker, *Curcuma amada*

Roxb., *Gloriosa superba* L., *Litsea sebifera* Pers., *Myrica nagi* Thunb. and *Nerium odoratum* Sol. All these plants have been investigated and their active principles are known. *Nardostachys jatamansi* is often combined with oil of henbane (*Hyoscyamus niger*) as an antineuritic. *Ocimum sanctum* and *Vitex negundo* are used as wound dressing. In traditional medicine, the root of *Curcuma amada* is applied to contusions and sprains. Extract of *Colchicum luteum* is applied externally as an analgesic (Mazars, 1994, p. 449).

Many plants of the Ayurvedic pharmacopoeia have been shown to be effective. Listing and identification of the many plant species used in preparing remedies described in the ancient medical literature was accomplished during the 1970s. Veterinary applications of these medicines were also taken into account. Despite the increase in chemical and pharmacological studies in recent years, there is still much to be done in evaluating the resources of India with regard to medicinal plants, which may be useful in veterinary medicine.

Long before the development of veterinary medicine in the West, the veterinary tradition of India had already originated a large body of theoretical and practical knowledge. Before the advent of modern medicine and the discovery of antibiotics, the knowledge of veterinarians in the West was not much further advanced than that of their Indian predecessors. Certain aspects of ancient veterinary medicine in India, neglected or unknown in the West, merit deeper study. These include the ideas regarding the feeding of animals, preventive methods and cauterisation techniques. Also of interest are the medicines derived from plants which are still in use, as well as those medicines which are no longer used but are fully described (together with indications, and mode of preparation and administration) in ancient texts.

See Also

► [Medicine in India: *Āyurveda*](#)

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Veterinary Medicine in Iran

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Veterinary medicine was known in Iran from the time of the Sassanids (212–652 AD). They treated useful animals with drugs or surgical operations. Veterinarians received wages and each animal had a tariff of its own. General practice was the same in human and veterinary medicine, but the duties of physicians and veterinarians have been separate since the Sassanid reign. Administration of a vast country like Iran with so many poor roads required the transport of army equipment to meet public demands. Domesticated draught animals, such as horses, mules, and camels, received special attention. This called for a disciplined veterinary organization. Veterinarians, especially army veterinarians, were celebrated figures in the country. In ancient Iran there were more veterinary clinics than in other countries of the world at that time (Elgood, 1974).

There were almost 70 important offices in the Sassanid government. One of the important offices related to horses and other domesticated animals and was administered by the head equerry (*Akhvarbadh* = *Hwrpt*). This head equerry was one of the key figures responsible for animal husbandry and veterinary organization. Another senior official was *Nhcyrpt* (master of the hunt) who was responsible for hunting affairs, breeding and treating hunter animals and birds or wildlife in modern-day terminology. The head equerry and master of the hunt had other responsibilities that sometimes were nonveterinary, but they were aware of veterinary

affairs and sometimes they were veterinarians. There were also second-class equerries who offered veterinary services especially to the horses. Ruminants were not paid equal attention. Experienced shepherds or rustic veterinary technicians treated them.

In the Sassanid reign, Becheshk Sotur (Quadruped Doctor) was the one in charge of treating army horses. He was an important figure. According to *Mafatih al-Olum* (Keys to Sciences) of Kharazmi, there were almost seven forms of writing for registering accounts and provisions. *Dad Dafira* was used for writing justice rules and *Ahur Hamar Dafira* was used for keeping the accounts of stables and horses. These forms of writings belonged to seven secretariats or ministries, and one of them was the Ministry of Stables that dealt with livestock affairs.

During the Sassanid era, veterinary medicine was separated from human medicine as a specialized art and profession, although it shared its roots with medicine. These two fields were unified to some extent in post-Islam Iran and some of the celebrated physicians of the time wrote independent treatises on veterinary medicine or allocated chapters of their medical collections to this field. Meanwhile, some of these people researched animal diseases and treated horses and birds of prey. However, there were certain people who practiced solely in the veterinary field during all the centuries since Islam. They had their own special clinics or offices and did not practice human medicine.

In Iran of the Islamic period and in other Muslim countries, they recognized the similarities between medicine and veterinary medicine, but at the same time they believed in their independence from each other. The most important duty of veterinarians was in treating and preventing equine diseases, because this animal was important to them in war and in performing the Hajj.

The Iranian state-run veterinary system was divided between the head equerry organization and the Investigation Department. The head equerry's organization was a well-organized department that took care of the health of animals in state studs and stables. In addition to these, the

investigating departments inspected the affairs of the stables, and cookery inspectors were busy with food hygiene inspection. Documents suggest that veterinarians headed all these practices.

Private veterinarians had their own special veterinary associations and veterinary regulations. They treated horses, mules, asses, and camels in their clinics or in their cottages. When there were disputes between the animal owner and veterinarian, the master of veterinarians or chief of the veterinary association intervened and reported the result to the market inspector for a final ruling. The final arbiter was the market inspector who also administered tests and issued certificates for veterinarians.

In the ancient Iranian and eastern world, people attached special significance to breeding and treating horses and birds of prey but not to ruminants. Perhaps one reason was the abundance of these animals, as there were vast ranges and low population densities. There was little need for treating ruminants, because these animals were religiously permitted meat, and so people slew them at times of probable danger and ate them if they were not rotten. But there was a dire need for horses, for protecting state borders, consolidating the ruler's power, and carrying food and ammunitions. People did not eat the flesh of these animals; they had to cure them.

The places and routes for keeping or trafficking horses, mules, asses, and camels, was chiefly in the cities, suburbs or probably in the studs, but the ruminants were kept in villages and suburban areas. Veterinarians and educated physicians depended on urban life and tended to work in developed areas. This is why, until the early twentieth century, rustic eastern communities had little access to physicians and veterinarians. People had to learn medicine, veterinary medicine, and midwifery through their own experiences.

Iranian Veterinarians and Hippologists

Fakhr Modabber, in his *Adab al-Harb*, alludes to a hippologist and horse master named Muhammad Marzbān, who visited Hadjaj, the ruler of

Iraq, in the company of Ibn Qerryah (d. 703) a great man-of-letters and horse master in Iraq. He said, "Marzban is the mother and father of this profession." That means that he is a master in hippology (the study of the horse). Ibn Qerryah was himself a student of Marzban. Marzban thought there was a direct link between the color and efficiency and physiological properties of horses. "A dark bay horse is good for war, a gray or white horse is good for plains, a piebald horse is good for hunting, a dun horse is good for visiting friends and walking, a colored horse is suitable for playing polo and a grass-green blond horse is the best for escaping." He then gave anatomical characters of the horse in great detail and in beautiful words. Marzban is a famous Iranian name meaning chief. According to the *Adab al-Harb* the title of horse master was attributed to a veterinarian skilled in raising horses.

The most renowned and best learned of the veterinarians of the first three centuries was Ibn Akhi Hozam, the chief of veterinary medicine and stockbreeding affairs of Motavakkel of Abbasids (d. 861). He was Iranian by birth and his father and uncles were all skilled veterinarians. His magnum opus lists the names of some notable veterinarians such as Abu Qoreh and Muhammad ibn Suleyman ibn Ghaleb, who was apparently a relative of Hozam.

Pre-Mongolian Veterinary Organization of Iran

In the administrative chart of Iran, the grand vizier or prime minister was second in administrative rank to the Sultan. The viziership was for some time hereditary in some families such as Jeyhani, Balami, and Nezam al-Mulk. There were almost ten tribunal courts in the office of the grand vizier, such as the Inspector's Court (*Divan Moshref*), *Mohtasseb*, *Saheb-e Barid* (which was responsible for mounted couriers), and the equerry office. This last was responsible for breeding horses, news dispatches, taking care of the pony express, veterinary medicine and inspecting livestock and food.

Breeding horses and training them for war were the chief responsibilities of the head equerry. The Moshref was in charge of animal health, administering veterinarians' affairs and other affairs related to animals. The inspectors' organizations and a number of other Seljukids administrative systems were in force until the end of the nineteenth century but changes occurred in the course of time in the nature and sometimes in the names and terms.

Any business, including medicine and veterinary medicine, had a chief of its own. These people, in addition to observing professional rules and regulations, were in charge of collecting taxes from the businessmen and industrialists. In some cases they defended the rights of their guild members against the government.

During the Ghaznavid dynasty, the head equerry was a distinguished title in the administrative system and army. It was the same during the Seljukid's reign. Ibn Abi Toba Nassir al-Din Kharazmi (killed 1,135), the Shafite vizier of Sultan Sanjar, was born in Merv and entered the court of the sultan upon learning the sciences of the time. He was skilled in inspecting the stables and food hygiene service and in veterinary medicine and stockbreeding. He served for a short time in the beginning. Twice he was appointed minister of Sultan Sanjar but was jailed following a conspiracy of one of the emirs of the Sultan and died in prison. He was a patron of scientists and authors. Ekhtiar al-Din Kushli was one of the head equeries at the court of Kharazmshah who fought in the Mongolian raid on Bukhara and was killed.

Veterinarians and Their Activities (Tenth to Thirteenth Centuries)

Veterinarians carried out their duties in the state veterinary service or as private practitioners. Some had veterinary offices. Veterinarian masters and sometimes master physicians, skilled in both medicine and veterinary medicine, wrote books on horses and their diseases. Abū Rayḥān Bīrūnī in his *Al-Tafhīm*, writing about of astrology from a Persian point of view, cited various

professions such as veterinary medicine and its relation with the stars. Fakhr al Din Rāzī in his *Djama al-Olum* in the *Treatise on Al-Baytara* wrote about the activities of the veterinarians.

Physicians Writing About Veterinary Medicine

Many physicians of Iran and the world of Islam have written about veterinary medicine and zoology. Ibn Baytar belonged to a family of veterinarians living in Andalusia. He wrote a book entitled *Kashf al-Vayl fi Marefat al-Amraz al-Khayl* (Detection of Afflictions in Horse Diseases) that showed his thorough knowledge of veterinary.

Veterinary Organization in the Mongolian and Timurid Periods

Veterinary medicine was a common profession during the thirteenth to fifteenth centuries. Many books were written on veterinary medicine and zoology in Persian or in Arabic, either independently or as chapters of general books. Some of these books are extant. They provide solid evidence about the education of veterinarians during this period.

In *Rozat al-Djannat*, falconers' treating birds of prey was explained. It says that Shams al-Din Kart, king of Herat who fell captive to Abaqa Khan, cured his beloved falcon in 1277. According to Shah-Qoli, the head equerry, Tamerlane was so skilled in veterinary medicine that he performed necropsy to find out reasons for the horse's death. Ibn Arabshah (1436) writes that Tamerlane, in his military march to Damascus, sent a number of veterinarians, physicians, industrialists, and scientists to Samarkand. Veterinary medicine was also a profession of high value in other states of the world of Islam. Ibn Monzer wrote the book *Kamel al-Sanaatayn* at the request of Nasser al-Din Qalavoon, King of Egypt (fourteenth century). Al-Malek al-Mujahed, King of Yemen and Arabia, wrote *Al-Aqval al-Kafia* on veterinary medicine.

Veterinary Organization in the Safavid Era (Sixteenth to Eighteenth Centuries)

Like previous periods, veterinary and animal husbandry affairs in the reigns of the Safavids, Afsharids, and Zands were a chief responsibility of the head equerry, hunt master and inspectors' court. A number of veterinarians cured sick animals in clinics or in the field. The head equerry was an army commander and the third most important person in the nation. According to Mirza Sami'a, he had thousands of men working under him, ranging in rank from second-class head equerry, *Baytar* (veterinarian), inspector of technical and financial affairs, horseshoe maker, cattle breeder, horse groom, technicians, and saddle keepers and setters. There were many organizations related to animal husbandry and wildlife organizations such as organizations for grooms (*Mehtarbashi*), head of cattle or horses (*Ramedarbashi*), head of herd of cows and sheep, grooms of mules and camels, grooms of lions, grooms of dogs, snake handlers, etc.

Investigation Department (*Eshraf*) or Veterinary Organization of the Safavids

There was an organization called *Eshraf* that supervised all governmental affairs both before and after the time of the Safavid reign. Part of their responsibility concerned the supervisors of the quadrupeds, camels, kitchens, etc. They also inspected the stables and studs of the horses and other animals producing food and dairy, and checked on taxes levied on animals. According to Chardin and Mirza Sami'a, the inspectors paid attention to the health of the camels and horses. Special officers studied animal corpses to identify causes of death.

There was a ministry called the head equerry organization that administered the affairs and inspected the health of the horses and other animals. Another organization called *Eshraf*, coequal with a modern-day veterinary organization, was responsible for treating and supervising the technical and financial affairs of the animal breeding sector of the monarchy. The chief of this

organization in the time of the Shah Abbas II was Nezam al-Din Ahmad.

The Veterinary Profession in the Time of the Safavids

Medicine and veterinary medicine in the Safavid reign inherited the traditions and knowledge of the Timurid dynasty.

Amin Ahmad Razi in *Haft Eqlim* (Seven Continents), written in 1601, mentions Romia or Constantinople, where there was a bazaar of veterinarians. There were special bazaars or marketplaces of veterinarians in other Muslim nations. Safavid kings, especially Shah Abbas I and II, paid special attention to breeding horses. At the order of Shah Abbas II, many veterinary books were written. Shah Abbas I used to go to the stables and inspect horseshoes; he knew about horse diseases and means of treatment.

Some of the great veterinarians of the period, as mentioned in the available manuscripts, treatises of falconry and hippology, are Hashemi, Saffi, Nezam al-Din Ahmad, Mohebbi Khan Khas, Majd al-Din bin Muhammad Shafi, Abdullah Khan Bahador, Arab Najafi and a few others.

Department of Veterinary Medicine in the Time of Qajars

In the time of Qajarids (until almost 1921), the department of veterinary medicine was part of the head equerry organization. The head of this department was the deputy chief of the head equerry organization.

Veterinary medicine was an independent job, and although many people contributed to it, as they did with humans, the veterinarians only were responsible for treating animals, especially horses. Another veterinarian and hippologist of the time of Nasser al-Din Shah was Haji Muhammad Qoli Beyq Turkman.

Since the middle of the Qajarid reign, Iranian veterinary medicine gradually lost prestige compared with Western veterinary science. Unfortunately Iranian ancient veterinary medicine

completely fell into oblivion, as did medicine. They could still use bleeding medicine, which is similar to Chinese acupuncture in some of its aspects, and use medicinal herbs observing rules of sanitation.

The political and social instability of Iran in the nineteenth century affected veterinary medicine. "Almost all of the veterinarians and the majority of the peddler physicians are Turkman. Veterinary is confined to a few diseases of horse and mule, and after cauterization and drainage they use purgatives. Since there are no sanitary police, sanitation measures, or veterinary establishments, deadly diseases have killed a greater number of animals making the tribal people poor" (Polak, 1865).

Comte de Gobineau, in his trips to Iran in 1855–1856, mentioned peddler veterinarians but did not attach significance to them. The fact that they said Iranian horses and sheep were the best of these animals in the world, shows that Iranian veterinary medicine must have been well developed.

The first faculty of veterinary medicine in Iran was founded in 1933 in Tehran and the German Dr. Damon, the French Le Louet and seven other German and Hungarian professors plus Iranian army veterinarians who had graduated from France, taught in this faculty.

In between the years 1926 and 1931, 15 civil students left Iran for France to study veterinary medicine. They studied at various schools of veterinary medicine and some of them passed specialized courses. On their return they taught at the Tehran Veterinary Faculty and they replaced foreign professors.

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Veterinary Practice in Nepal

Krishna Kaphle

Nepal is a landlocked country lying between 80°04' and 88°12' East longitude, and 26° 22' and 30° 22' North latitude. It extends over an area of 147,181 km² with an average east to west length of about 885 km. The north-south width is not uniform and it varies from a maximum of 245 km to a minimum of 145 km. Politically and geographically Nepal is located between two giant nations, China on the North and India on

Veterinary Practice in Nepal, Table 1 Status of livestock population by ecological zone, 1998/1999

Unit: ('000 no)							
Region	Cattle	Buffaloes	Sheep	Goats	Pigs	Fowl	Ducks
Mountain	809	317	368	870	101	1,250	11
Hills	3,453	1,970	382	3,435	468	9,830	84
Terai	2,769	1,184	106	1,899	256	6,717	326

Veterinary Practice in Nepal, Table 2 Percentage of households keeping livestock and birds by region, 1998/1999

								Unit: %	
Region	Cattle	Chauri	Buffaloes	Goats	Sheep	Pigs	Horses	Poultry	Ducks
Mountain	82.8	2.9	44.8	55.5	6.5	10.3	1.3	56.4	6.0
Hills	77.3	0.1	60.0	54.2	4.2	12.2	0.4	67.6	9.2
Terai	74.4	0.0	35.8	46.8	1.8	7.1	0.4	32.4	15.7
Nepal	76.6	0.3	48.5	51.3	3.4	9.9	0.5	51.9	11.6

the South. The country has three patterns of landscape: the mountains, mid hills and the plains. The plains and hills with valleys are the major sites of human settlement and major cities are located here. Nepal has a population of slightly over 23.15 million. Though the political boundary of Nepal was restructured by the British colonial era occupation in the Indian subcontinent, isolation from the world was almost total until the mid twentieth century. This isolation affected Nepal both in positive and negative ways. On the positive side, when ancient cultures and traditions were safeguarded, progress made elsewhere was slow to be. This has happened with veterinary medicine in Nepal. The tradition of ethno-veterinary medicine awaits revival, while the copied concept of western veterinary system has limited use. This short article describes the historical and contemporary situation of organized veterinary services in Nepal.

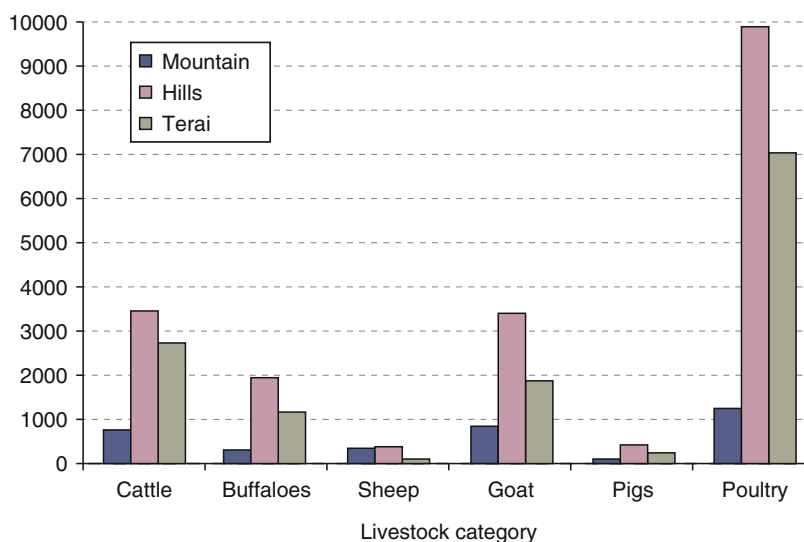
Agriculture, the only source of livelihood for most of the Nepalese people, is not only an occupation but also a way of life. About 85.80 % of the population live in rural areas and earn their living from farming, whereas only 6 % live in cities and are involved in non-farming occupations. Livestock is an indispensable part of agriculture, which provides employment to over 80 % of the country's population. Livestock is now looked upon with great expectations as playing a great part for the development of the nation, and attempts are made to boost production. The

efforts are seeing results, with farmers turning to commercial livestock farming which in the past was just a satellite component of agriculture, basically intended for manure production and domestic consumption (APP, 1995). However, in recent years dairy and poultry farming are turning into industries making a large contribution to the national gross domestic product (NGDP). Planners have identified three main ecological components of Nepal to implement various development activities (Carson and Sharma, 1992). The three ecological zones of Nepal have different distributions of livestock numbers, as illustrated in Table 1, with higher numbers in the mid hills. Almost every household in the villages has an animal. The percentage of households keeping livestock and birds by region is shown in Table 2. The status of livestock population by ecological region according to the reports of 1989/1999 as in Fig. 1 shows poultry population higher in the hills, but commercial poultry farms are located in plains and valleys. Poultry farming is the one most successful story of Nepal's transition of animal husbandry (Kaphle, 2000).

Situation of Animal Health Care Systems in Different Ecological Zones

The mountainous regions, ranging in altitude from 4,877 to 8,850 m above sea level, covers

Veterinary Practice in Nepal, Fig. 1 Status of livestock population by ecological region, 1998/1999



35 % of the country. This area is less developed and has only 6.97 % of the country's population. The mountainous topography makes it virtually cut off from other parts of the country; transportation is by foot and on the back of yaks and ponies, although there are some airstrips with irregular schedules. This region has the highest number of sheep, yaks, and chengras (hill goats). The population and economy of the mountain region is based on trade with Tibet and tourism, as well as support from animal husbandry. The demographic distribution is mostly people like the Tamang, Rai, Limbu, Gurung, and Sherpas famous for their mountaineering skills. The pastoral communities have been employing unique ethno-veterinary practices since time memorable. This region has 16 districts and each district headquarters has a government veterinary hospital. A veterinarian supported by junior technicians and some other staff mans these hospitals; their prime duty is to give outdoor health care support, monitor disease outbreaks, and implement and monitor government policy in the related sector. Private practitioners are out of question in these situations where farmers consult veterinarians as a last resort. Traditional veterinary practices like herbal medicines and bloodletting are used for simple cases; however parasites, foot rot, plant poisoning, and microorganism related diseases are

commonly encountered and they respond poorly to traditional medication. The region, with its rough topography and difficult communication networks, has a slow economic growth with livestock, tourism, and herb collection as the only path to greater income. Tourists in this area provide markets for local livestock products. Lack of proper technical and financing institutions with difficult communication and marketing opportunities can be viewed as the obstacles for livestock development. However if successfully harnessed, high altitude animal husbandry will flourish well and the standard of living of the people in this region can be raised substantially.

The hilly region comprises 42 % of the land area and 43.97 % of the total population of the country. This region has some major cities. The livestock health diagnosis aspect of this region is also controlled by the government veterinary hospitals with only a few private organizations and practitioners concentrated in the main cities. The government disease diagnosis mechanism is more concentrated in this region with the location of central veterinary laboratory and major regional laboratories. These laboratories are mainly concerned with large animal diseases and only the central veterinary lab at Tripureshwor, Kathmandu has some facilities for poultry disease diagnosis. This region is making progress, as roads linking to district

headquarters make the flow of goods and people easy and convenient. There are some milk collecting, chilling and processing centres in this region that are boosting dairy farming. As the genetic makeup of the livestock is being improved by upgrading with pure breeding males distributed by government or use of artificial insemination, so is the demand for commercial feed and health care attention. There was an early setback when pure Holstein and Jersey breeds of dairy cattle were introduced, as they could not receive optimum management and nutrition, they developed gynecological and metabolic disorders. Thus government policy has been to see that the genetic make up remains at 62.5 % so that increased productivity and the thriving ability of the animals are enhanced at the same time. The law forbids cross breeding of some indigenous cattle, buffalo and sheep species to preserve genetic composition. Poultry, goat and swine farming are gaining popularity with the effort of private entrepreneurs, government poverty elimination schemes and support of non-government organizations. Co-operatives and villagers' group formations, mainly for women, are encouraged, and facilities for providing loans are adopted to initiate cottage industry and livestock farming. Similarly leasehold forestry projects are implemented in some parts of the region which aim to provide the community a means to use and protect the forest and to help small unit livestock development and at the same time conserve the forest.

The plain region or the terai is the major centre for buffaloes, cattle and poultry. The terai and inner terai accommodate almost 50 % of the nation's population. The plains are densely populated, and migration from the hills and abroad are using up the fertile agricultural land for settlement purposes. There are private practitioners along with the government animal health care system; farmers are educated to a certain extent and like to be in touch with veterinarians for consultation. The supply of western drugs is also bountiful, with many veterinary drug stores located in this region. Farmers sometimes seek

the support of the Indian Veterinary Research Institute (IVRI) and other institutions in India as they have advanced technology for disease diagnosis. This region is developing fast and the livestock industry is making rapid progress. The extreme summer temperature, marketing facility and occasional disease outbreaks are hampering the established poultry and dairy industry. Lack of proper regulation in line with consumers health and public health concerns compounding with transportation to markets in cities is a major hurdle too (Joshi & Oleson, 1999).

History of Animal Disease Diagnosis Pattern in the Country

The government and the private sector both provide animal disease diagnoses. The history of the animal health care system in Nepal is not old; previously traditional health care practices dominated.

The first recorded establishment of a veterinary dispensary at Kathmandu was in the year 1950 B.S (beginning of the nineteenth century in the Julian calendar). In 1940 the present Central Veterinary Hospital was established at Tripureshwor, Kathmandu. The period from 1943 to 1957 saw the establishment of ten veterinary hospitals in different district headquarters of the country. In the year 1964 AD 14 zonal and 19 district veterinary hospitals (DVH), 21 veterinary dispensaries and 18 veterinary check posts were established. With the addition of 25 veterinary hospitals in 1981 and 16 in the year 1984, the country had a government veterinary hospital at all headquarters in the 75 districts. There are five regional laboratories set up to speed up disease diagnosis with special programs for epidemiologically important diseases. There are also regional training centres training farmers on recent techniques of management and primary health care, while selected candidates are given preliminary training to work as auxiliary village animal health workers (LSMP, 1993).

The private sector involvement in this regard is mostly concentrated with the poultry and dairy industry as they are commercially practiced. The share of the private sector in poultry health care is around 60 %, while the government jointly handles the remaining section. The central veterinary hospital and laboratory at Tripureshwor is the most refereed one in the country. It is equipped with modern laboratory facilities and manned by skilled personnel. The district veterinary hospitals and their sub-centres are limited in providing this service. Pet animal veterinarians are based in Kathmandu having their private clinics, while many government vets also have private practices outside their office hours. The military have five veterinarians in their service to take care of stud farms while in the police a single veterinarian looks after the health of the dog squad.

Most commonly encountered communicable diseases of livestock in Nepal are peste des petits ruminants (PPR), rinderpest, foot and mouth disease (FMD), rabies, brucellosis, haemorrhagic septicaemia, black quarter, anthrax, mastitis and swine fever. Infectious bursal disease, Newcastle disease, Marek's disease, infectious bronchitis, chronic respiratory disease and coccidiosis are common poultry diseases. Fasciolosis and infertility are other common diseases of dairy animals (Mathema & Joshi, 2000).

Traditional Animal Health Care Practices in Nepal

Ethnoveterinary medicine describes the traditional practices used by livestock raisers all over the world to keep their animals healthy and productive, and to treat and control diseases (Mathias, 1996).

Ethnoveterinary medicine is an effective means to safeguard the health of animals and the interests of the poorer communities around the world. Poverty and remoteness prevent access to conventional animal health care. To counter this, traditional animal health care has been reborn and now plays a greater role in the lives

of poor farmers. Traditional animal health care is cheap, readily available and safe for poor livestock keepers, but lack of information on its scientific validity, lack of policy support, and the negative attitude from modern veterinary practitioners has until recently limited its promotion. Ethnoveterinary practice in Nepal is a blend of Tibetan and Indian practices. The medicinal plants in the Himalayan range that stretches across the whole length of the country and the diverse ecological conditions have provided suitable grounds for traditional animal health care practices. Adding to that process was the late exposure of the nation to the outside world (~1950s), the fact of having no history of colonization and snail-paced industrialization of animal farming. All these shielded traditional animal health care knowledge from being overwhelmed by Western medicine. However, in recent times, with poultry and dairy farming using advance rearing practices, ancient ways are frowned upon. The consequences of Western medicine misuse in animal production from elsewhere in the world has yet to be learned by the Nepalese industrialists. However, there is a rising awareness to preserve ancient knowledge in the art of traditional animal health care. Encouraging the use of ethnoveterinary medicine, or preventing misuse of Western practices, is part of an important policy for the non-governmental agencies working with their international counterparts in the field of poverty elimination. Restrained if not total ban in use of chemical pollutants in the communities around the vicinity of wildlife reserves is gaining momentum. Nepal is at a crossroads, deciding whether to subsist in the safe ancient way of animal health treatment or to industrialize animal husbandry to meet the growing food challenge and leave the consequences for generations to come.

Animal husbandry is rapidly changing from the traditional system to an industrial form. There are ample opportunities for its growth, as it is deemed the only option for over 80 % of the national population. The small farmers relying on age-old traditional agricultural practices will not

be in a position to compete with cheap products from India, China and elsewhere. Tourism, a major source of foreign exchange, is also seeing its worst days with international terrorism. Thus with no other clear options available, livestock enterprise is making progress. The animal health care system is also making progress, but the speed is much slower. With around 400 veterinary doctors and slightly more junior technicians, the country is not able to meet its requirements. The Institute of Agriculture and Animal Science (IAAS), the only agriculture college, has started to produce around 25 veterinarians per year which is partially filling the growing demand. The lack of infrastructure and other factors makes the level of education below the global level. With advanced training to faculties and infrastructure development the future of the veterinary school at IAAS is bright. Research activities with the limited resources available have been a trademark of IAAS, and it will only get better. Some works on buffaloes (Dhakal & Salman, 1992) and poultry (Kaphle, 2000) have to great extent helped the farmers gain confidence and will to invest and upgrade their animal production activity. Commercialization of animal husbandry and increase in farmer's awareness will make animal health care an important factor, as can be evident from the hustling activities around IAAS, Chitwan. Thus, the nation needs to set up strict guidelines and regulations in implementing the policy of animal health care practices. At the same time, making service available to all the community at an affordable price and in a sustainable way should be the priority of the government (Lin et al., 2003). There should be a mandatory flow of information regarding epidemiological reporting from the field level to the concerned authorities and a rapid execution of appropriate steps. The reckless import of vaccines from foreign countries and reckless use of medicines like antibiotics and hormones should be controlled and a governing authority should look into the necessary criteria. Emphasis should be given to the preparation of vaccines from the local strain of pathogens within the country. Basic laboratory facilities should be developed for disease diagnosis in all district veterinary

hospitals. The school of veterinary medicine and animal science at Institute of Agriculture and Animal science should be strengthened. The manpower development program as well as faculty and student research activities should be initiated. One research area that has the potency to be of great use not only to Nepal but to the whole world is the research of medicinal herbs for various animal healthcare. Hence, in spite of the huge resources in form of traditional ethnoveterinary practice and bountiful medicinal plants, Nepal still needs to pull up its socks to learn from success stories of others, Taiwan being an ideal example (Kaphle et al., 2006).

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Village Defenses in South India

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Defense is an inherently reactive process. Given perceived threats to some valued entity or resource, one assesses the strength, technology, and probable tactics of these threats and then works to counter them. In the defense of premodern villages, the whole gamut of human, animal, and spiritual forces that acted on a village's well-being may be reflected in the built environment and the patterns by which the village arranged itself on the ground.

History shows that the simplest defense for the inhabitants of many small communities was to run away. Often effective, it left little, if any, trace in the archaeological record. The most enduring and visible archaeological evidence of village defense typically rests in walls, gates, towers, and ditches that protected a community from other people. The scale of such works tended to be proportional to the size and wealth of the community that built them. However, no village possessed the necessary means – weapons, training, manpower, leadership, and stores – to deal with extraordinary threats such as invading armies or regional famine. Faced with extreme dangers to its well-being, villagers could only submit or flee.

In South India, thousands of villages endured chronic threats to their peace and safety during the Early Modern period, or roughly between CE 1500–1800. The Vijayanagara Empire, which controlled most of India south of the Krishna River, began to collapse in the mid-sixteenth century. The ensuing political instability created an opportunity for other Indian and foreign powers to compete for control of the South. Local rulers and chiefs declared their independence from greater kings and contested similar claims made by their neighbors. Winners and losers alike often turned to plunder and they, along with marauder bands, laid waste to towns and villages in their path.

General patterns of Early Modern village defense in South India can be reconstructed from a wealth of archaeological and historical evidence. These patterns differ across South India's three major geographical divisions: the central plateau or *maidan*, much of which is semiarid scrub jungle; the rainy, forested mountains or *malnad* that flank the *maidan* to the west; and the coastal lowlands that border the Arabian Sea and Bay of Bengal.

Maidan

Maidan villages were among the most consistently fortified small communities of Early Modern South India. Although hill ranges covered in dry forest break its relief, much of the region is good country for cavalry. Throughout history, invading armies often chose it as a natural line of advance into the South. Robber bands also appreciated its many opportunities for looting, cattle lifting, and the relative ease of a getaway.

Each village typically comprised two main parts, a settlement core and the outlying fields and pastures. The settlement core contained homes, the temple of the main village deity, threshing ground, and storage facilities for grain, firewood, and animal fodder. Fields and pasture lands lay between the settlement core and the village's outer limits. The latter were defined by marker stones and posts, as well as by the shrines of lesser gods who guarded the village's ritual boundary. Beyond this boundary, and effectively beyond the village, lay the ritually unclean space that contained the village cemetery or cremation ground. Out there, one also found evil spirits, diseases, and ill fortune, all of which had been driven away by the village gods.

A thick bound hedge fence often surrounded the settlement core and acted as a village's first, if sometimes its only, line of defense. The bound hedge was a densely planted barrier of bamboo, prickly pear, and other plants selected for their thorns and other unpleasant characteristics. It was cheap, fast growing, easy to maintain, and effective against many animal and human threats. Gates guarded by village watchmen covered

roads into the village where they pierced the fence.

The main drawback to bound hedges was that they were inadequate to stop a large and determined attack. To supplement bound hedges, some small villages also chose to defend a strategic point, typically a tower or *hude*, within or near the settlement core, from which villagers threw stones and other missiles at their attackers. Often combined with a bound hedge, the *hude* gave village defenders the tactical advantage of high ground at relatively low cost. Nevertheless, the *hude* defense worked best, or perhaps only worked at all, if one's attackers were simply marauders for whom success was a quick raid and few casualties.

Larger or wealthier villages would defend a perimeter, either drawn around the oldest residential area and village deity temple compound in the settlement core or constructed adjacent to the village's living area. They fortified this perimeter with walls, bastions, and covered gateways made with mud, rubble, and locally quarried stone. Approaches to the village walls were protected by deep, wide ditches and, farther out, by bound hedge fences. Some villages worked the *hude* into their fortification plan. Other villages achieved the *hude*'s advantages of elevation by incorporating nearby isolated hills into their defensive works.

Malnad

In the rainy, forested mountains and deep valleys of the Western Ghats, which separate the central plateau from the coastal lowlands that border the Arabian Sea, village defenses differed fundamentally from those of the maidan. *Malnad* villages were commonly collections of neighborhoods scattered over a large area. Village ritual boundaries were similarly dispersed.

Many *malnad* villages depended for security on their relative isolation and the natural defensive strengths of the region's rugged terrain and dense forest cover. Rather than attempt to enclose one's village within walls dotted with bastions

and towers, *malnad* defenses focused on the lines of communication that led to the village. The reasoning appears to have been that if an attacking force could not reach the village, then it could not harm it.

Exploiting the *malnad* terrain as a potential force multiplier, the passes, roads, and trails that led to a village were defended in depth by earthworks, barriers, and breastworks collectively called *kadangas*. Many of these works were further protected by deep ditches, often filled with thorn bushes. Potential village threats would be confronted along the lines of communication and the village to which these lines led might appear to be essentially undefended. Should the defenses fail, the final option was always to scatter into the forest and return after the threat had passed.

Coast

Most of the rivers that drain South India's central plateau flow east and empty into the Bay of Bengal. The geographical transition from the maidan down to the coastal lowlands is through the Eastern Hills, broken ranges of low hills sparsely covered in patches of dry forest. Villages in the valleys, passes, and lower slopes of the Eastern Hills were laid out like those of the maidan region and were defended by bound hedge fences, walls, towers, gates, and ditches.

Beyond the Eastern Hills, the villages on the broad coastal plain and river deltas were as compact as found in the maidan, but they typically lacked defensive features. The East Coast villages were laid out in an open plan with houses aligned along regular streets. For the inhabitants of these villages, defense often meant scattering into the countryside or seeking the protection of nearby fortified towns.

On the other side of the peninsula, the high mountains of the Western Ghats reach nearly to the Arabian Sea. The lush, wet, coastal lowlands occupy a narrow strip of shore that reaches its maximum extent in the far south. Throughout this region, villages were dispersed entities – groups

of households in a loosely circumscribed locality – that more closely resembled malnad villages than the clustered communities of the maidan and East Coast.

West coast villages also took a different approach to defense. No attempt was made to defend the village per se or its lines of communication. Here, defense centered on individual household compounds, each of which was hedged around by mud or stone walls or a fence of bamboo and thorns. Gateways through these walls were also sometimes reinforced with guardhouses.

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Wang Chong

Fabrizio Pregadio

The Chinese philosopher Wang Chong was born in Shangyu (modern Zhejiang) in AD 27. According to his biographies, he came from a poor family and devoted most of his life to teaching, but also held minor posts in the state administration. Later he retired to compose the work by which we know him today, the *Lunheng* (Balanced Discussions). This extensive treatise in 85 chapters (1 of which is lost) was completed in AD 82 or 83, about 15 years before the author's death.

Wang Chong lived about one century after Confucianism had emerged as imperial ideology. In this process, the “rationalist” and socially minded philosophy taught by Confucius had been integrated with cosmological doctrines extraneous to the letter of his teaching. The school of thought to which Wang Chong belonged propounded, on the contrary, a reading of the classic texts devoid of esoteric interpretations.

In his work, Wang Chong analyzes, with a strongly skeptical and even iconoclastic spirit, ideas expounded by earlier thinkers and beliefs shared by the people of his time (e.g., the recourse

to divination, the belief in ghosts, the search for physical immortality, and the idea of an individual spirit that persists after death). Wang's typical procedure is to bring out contradictions in the anecdotes and accounts that he first quotes in full. Through an exemplary logical method, he often does not hesitate to take as true one detail that he has previously refuted, if this may serve to invalidate a different detail.

Philosophically, Wang Chong maintained that all phenomena arise spontaneously, and are not expressions of Heaven's will. Related to this was his opposition to the belief in prophecies and portents, through which Heaven was deemed to legitimate or censure rulers, and assent to or dissent from their policies. While Wang Chong rejected the blend of these forms of esoterism with Confucianism, he fully accepted the metaphysical and cosmogonical doctrines traditionally placed under theegis of Daoism. In this way, he anticipated some of the new developments in post-Han Confucianism.

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Wang Xiaotong

Ang Tian Se

There is no record of Wang Xiaotong's early life nor his year of death. We estimate that he flourished from the second half of the sixth century to the first half of the seventh century. The little we know of him is from a memorial he presented to Emperor Gaozu of the early Tang dynasty (A.D. 618–906) on the occasion of the submission of his mathematical text to the throne. The mathematical text he submitted was known as *Jigu Suanjing* (Continuation of Ancient Mathematics) and was subsequently selected as a prescribed text for imperial examinations in A.D. 656. In his memorial, which is now attached to his mathematical text, he mentioned that he had studied mathematics from a very young age. He studied the *Jiuzhang Suanshu* (Nine Chapters in Mathematical Art) thoroughly and had great admiration for Liu Hui's in-depth commentary on the text. On account of his mathematical acumen, Wang Xiaotong was appointed as an instructor in the Department of Mathematics, and later as a deputy director in the Astronomical Bureau. In A.D. 623, together with Zu Xiaosun, an official of the board of Civil Office, he was appointed to re-examine the adequacy of the current calendar.

Composed by Fu Renjun and promulgated for use since A.D. 619, the calendar had on several occasions been found to be losing accuracy in the predictions of solar and lunar eclipses. Based on the structure of the Kaihuang calendar composed by Zhang Bin of the previous Sui dynasty (A.D. 581–618), Wang Xiaotong

criticized the adoption of the *ding shuo* method and the precession of equinoxes in the current calendar. The critique sparked a 3-year debate between Fu Renjun and Wang Xiaotong, culminating in a submission of a proposal for rectifications consisting of more than 30 errors to the Astronomer-Royal. This does not necessarily reflect Wang Xiaotong's achievement in calendrical science. On the contrary, his view of adhering to the traditional model without taking into consideration the uneven apparent motion of the sun and the precession of equinoxes in calendrical calculations was a retrogressive one. His contribution lies in mathematics.

From the late Han dynasty in the first century onward, Chinese mathematicians were familiar with quadratic equations and their solutions. But it was not until the appearance of the *Jigu Suanjing* that equations of the third degree were presented. They arose because of the special needs of engineers, architects, and surveyors of the Sui dynasty. There are 20 practical problems in the *Jigu Suanjing* consisting of a problem (No. 1) on calendrical calculation, 6 problems (Nos. 2–6 and 8) on engineering constructions, 7 problems (Nos. 7, 9–14) on the volume of granaries, and 6 problems (Nos. 15–20) on right-angled triangles. The solutions of most of the problems involved equations of the third degree. For example, problem No. 15 says: "There is a right-angled triangle, the product of two sides of which is $706\frac{1}{50}$ and whose hypotenuse is greater than the first side by $36\frac{9}{10}$. Find the lengths of the three sides." Wang's solution amounts to the formation of the cubic equation as follows:

$$x^3 + \frac{S}{2}x^2 = \frac{P^2}{2S},$$

where P is the product and S the surplus. As a matter of fact, most of the problems in the last three categories involved the use of the equation

$$x^3 + Ax^2 + Bx = C,$$

where A , B , and C are positive numbers. Wang Xiaotong provided the rules for the arrangement

of the equations in all these problems but did not explain the procedure for arriving at such equations. He also did not discuss the equations of higher degrees. Numerical equations of degrees higher than the third degree occurred first in the work of ► [Qin Jiushao](#) around A.D. 1245.

See Also

- [Calendars in East Asia](#)
- [Jiuzhang Suanshu](#)
- [Qin Jiushao](#)

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- studied on his own since his youth. Despite both poverty and illness, Wang made unremitting efforts to observe the heavens, calculate planetary positions, and write about astronomy.
- Beginning in the late Ming Dynasty, Western astronomy had been disseminated intermittently into China, and subsequently it was adopted by the Qing (1644–1911) rulers. In 1646, a number of astronomical treatises, earlier written or translated by Western missionaries serving the Ming court, were published together by order of the Qing emperor under the general title *Xi Yang Xin Fa Lin Shu* (Astronomical Treatises of the New Methods of the West, 1646). Unfortunately, the “New Methods” introduced by the missionaries did not reflect the advanced achievements of modern astronomy in seventeenth-century Europe. Even worse, there were some defects and internal contradictions, especially in the parts dealing with the cosmological theory of planetary motions.
- In his *Xiao An Xin Fa* (New Method of Xiao’an, completed in 1633), Wang argued that all of the Western techniques could be reconciled with classical Chinese schemes and therefore could be used to revive the lost traditional astronomy of ancient China. By means of trigonometry, which was not used in traditional Chinese astronomy and mathematics, Wang created a series of methods to calculate ecliptic positions and predict planetary occultations. Forty years later, in his *Wu Xing Xing Du Jie* (On the Angular Motion of the Five Planets, completed in 1673), Wang criticized the contradictions in the *Xi Yang Xin Fa Li Shu* and proposed instead his own model of the planetary motions which differed from both the Aristotelian-Ptolemaic and the Tychonic geostatic models. In addition, he attributed the planetary motions to an attractive force radiating from the outermost moving sphere (i.e., the *primum mobile*). Wang also suggested that there were planets inside the orbit of Mercury which might account for the appearance of sunspots. All of these thoughts, along with some of his methods, were heuristic and had considerable influence on his successors.
- In general, Wang was one of a few pioneers who responded to Western science by

Wang Xichan

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Wang Xichan (July 23, 1628–October 18, 1682), sometimes known by his literary name, Xiao’an, was from Wujiang, Jiangsu province, China. When he was 16, the Ming Dynasty (1368–1644) collapsed and the door to social advancement through the imperial examination system was suddenly closed. After several unsuccessful suicide attempts, Wang abandoned his hopes for an official career and became one of the most distinguished Ming loyalists in his area. He seems to have survived by teaching literature, although his main interest was in astronomy, which he had

conscientiously studying it; he was open to critical acceptance of its major ideas when suitably reinterpreted for use in seventeenth-century China. Nevertheless, some of Wang's arguments were clearly exaggerated. For instance, he assumed that Western astronomy had in fact originated in ancient China, but such claims were due to his radical nationalism and traditional reluctance to recognize any innovations from the West.

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- the rockets also had a great cultural value in the Indian Hindu community during festivals like *Diwali* (festival of light).
- From the perspective of modern rocketry, the self-propelled mechanism is considered to be the most essential feature for differentiating rockets with any other nearby forms like arrow-assisted rockets popularly known as *Tir-a-Hawai* or *Agni-Bana* (fire arrows) used in the Indian continent (Iqtidar, 2004). The well-documented use of rockets in Indian warfare is listed during the time of Mughal Emperor Akbar (1556–1605). Rockets became an indispensable weapon in his artillery. One such rocket of the late seventeenth century is preserved at Victoria Museum, Kolkata (Dataa, 1986). This cylindrical rocket with a smooth orifice at the end has an outside diameter (O.D.) of 5 cm and length of 25 cm with a bamboo pool of 125 cm length for guidance during the flight. The shape of the rocket at the middle was slightly reduced in diameter. Mughal rockets were basically of two different types known as *kahak ban* and *Chandra ban*. However, the origins of these rockets are not entirely clear. They might have been a native invention with superior knowledge in the gunpowder alongside with the rich metallurgical background of caste-based India or a technology transfer from China, Mongol, or Muslim empires in the West. Such innovation was widespread for centuries afterwards among the military strongholds of different states in India taking the forefront of rocket weapon in the world. F. H. Winter (1979) listed the use of war rockets in Adhadanagars, Mysore, Jaipurs, Rohillas, Rajputs, Sikhs, Golcondans, Vijaynarans, Polygars, Vairagis, Marathas, Naga Sannyasis, and Bengal covering a vast geographical boundary of India.

War Rockets in India

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The history of war rockets in India raises debates about the exact time of its use and origin due to its presence in the popular myths dating back to the twelfth century (Haridas, 1963), lack of scientific documentation, and clear description of different firing projectiles. Apart from their military uses,

The tactical use of the rockets was focused on to create fire targeting the opponent's ammunition storage from distance unachievable by other means, panic against the progressing army, giving signals, and to destabilize the elephants, horse, or bullocks in the midst of commotion and flash fires (Jaim & Jaim, 2011). Both the British and French military had to face unfamiliar rockets from the mid-eighteenth century in Indian territories. In the first significant victory of the British East India Company in Bengal in 1757 at

Plassey, English soldiers encountered rockets from the Bengal side. With the passage of time, superior weapons in terms of accuracy and reliability dimmed the role of rockets in Indian warfare, which were mostly replaced by canons and guns – a sort of Western influence – and military exchange with the Islamic civilization. However, the southern state Mysore (in modern Karnataka state) revived the massive use of rockets in Anglo-Mysore wars with great decisiveness accompanied by desired control over propulsion. The greatest military feat by Indians using rockets, both historically and strategically, was inflicted by the king of Mysore, Tipu Sultan. Renowned for his bravery and boldness against the British expansions in the late eighteenth century, Tipu was considered to be the biggest enemy by the British in India and was known as the tiger of Mysore. Mysore was crucial for the British colonial expansion in India because of its strategic and economic aspects.

For several decades the British had to struggle with rockets in the hilly, rocky, and marsh battlefields during monsoons in the Seringapatam fort and nearby regions. It was a military necessity to deploy rockets because of the battlefield's topology, heavy canons of that time, and the mobility of troops. Both in-line attacks on the front enemy line and in ambushes, the Indians used wheeled rocket ramps firing 5–10 rockets almost simultaneously (Jaim & Jaim, 2011). Depending upon the target with a maximum range of 2.4 km, specific diameter-sized cylinder and angle of launches were selected. Rockets turned out to be the master weapon in the battle of Pollilur in 1780 in the second Anglo-Mysore war. They created trauma for the British troops as described by the various narratives of British officers. Even Colonel Arthur Wellesley, who defeated Napoleon at the Battle of Waterloo, suffered devastatingly in 1799 during the fourth Anglo-Mysore war; this also shows the inability of the British against rockets even facing it for decades. The swords attached to these rockets created enormous injury and terror by flipping around while landing due to the imbalance of the decreasing thrust and weight. These rockets survived even the



War Rockets in India, Fig. 1 Mysore war rocket at Firepower, The Royal Artillery Museum, Royal Arsenal Woolwich, London



War Rockets in India, Fig. 2 Mysore rocket, zoomed in

moisture of the monsoon season during two Anglo-Mysore wars because of their excellent gunpowder contents and compact sealing. Tipu's army had 5,000 rocket men and his father Hyder Ali had over 2,000 rocket men in their infantry with camels or horses for carrying them.

These wars and use of rockets are well documented, and specimens are preserved at Firepower, The Royal Artillery Museum, Woolwich, London (Fig. 1). Although there are only few surviving specimens of rockets of these kinds, variations are found in their sizes, weights, guiding stick lengths, and design features showing chronological development. These rockets were superior because they used metal in the rocket tubes instead of the boards or paper used in Europe, and they had better gunpowder. Soft iron metal cylinders ensured higher density of the gunpowder as explosives. It also reduced the chance of failures or breaking up in the middle of their flights. Multiple nozzle holes were pierced for propulsion to gain the reactionary force created by the burning explosives. Guidance and aerodynamic stability were ensured by different lengths of bamboo or steel like rods. One specimen had a metal cylinder of 5.8 cm O.D. $\times$ 25.4 cm long with 1.02 m long sword blade attached at the end, and another one had 3.7 cm O.D. $\times$ 19.8 cm long with 1.9 m long bamboo pole. These rockets weight around 2 kg (Narasimha, 1985).



War Rockets in India, Fig. 3 Mysore rockets displayed at Firepower, The Royal Artillery Museum, London (Photo by the author)

War Rockets in India,

Fig. 4 Mysore rocket man in late eighteenth century by Robert Home (Used with the kind permission of the Victoria and Albert Museum, London)



The fascinating fact of these advanced rockets is that these were not made by scientists or engineers. In fact most of these rocket artisans were illiterate, lived in a caste-based society in a closed community, and had no documentation of their recipes regarding them as secrets. It is believed that these productions were state sponsored and most probably developed within the fort area. The knowledge was orally transmitted to the next generation of artisans. This is a sharp contrast with Europe where patents and advertisement of firearms and other technologies were all over the competitive market. However, there were several military manuals like *Fathul Mujahidin* (The Triumphs of Holy Warriors) used by Tipu's army where chapters of rockets discussed their deployment techniques and organizations in the battlefield.

The glorious Mysore rockets ended with the defeat of Tipu Sultan in 1799. Rockets were still around India and appeared during the Sepoy Mutiny of 1857–1858 at Jhansi. Perhaps the restriction of military weapons and ammunition, except for the British and her allies, and their lack of sponsorship or need caused their gradual extinction (Fig. 2).

There had been efforts by Sir William Congreve to study these Indian rockets methodically and to sell them to British army and East India Company as a contractor (Werrett, 2009). Congreve rockets were not that accurate and decisive compared to Mysore rockets as was shown during the Napoleonic wars. The most famous one is the Anglo-American War of 1812 on Fort McHenry, near Baltimore, which inspired poet Francis Scott Key to write the “Star Spangled Banner,” later adopted as the US national anthem. Afterwards, following the impacts of Congreve rockets, rocket units appeared in most of the European and US militaries. The Indian rocket is an amalgam of rich military history and a story of technological diffusion throughout the continents across the globe. Moreover, it shows the superior nature of military weapons in a preindustrial society relying upon illiterate castes in India and opens the scope of reexamination as to whether the imperial power taught superior technology in the early industrial revolution to its colonies or whether it also benefitted from traditional innovations (Figs. 3 and 4).

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Water in India: Spiritual and Technical Aspects

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The content of the Vedas is astonishingly scientific, although much of it remains to be interpreted correctly. Knowledge of the Vedas is synonymous with knowledge of the science and metaphysics of creation.

The subject of water has been treated spiritually, philosophically, cosmologically, medically, and poetically in the ancient Indian literature comprising the *Veda(s)*, *Brāhmaṇa(s)*, *Upaniṣad(s)*, *Purāṇa(s)*, and *Smṛti(s)*. Water is regarded as the primordial substance from which the material universe came into being. Water occupies the highest place among the five gross basic elements of nature, called *pañcamahābhūta*. These are *ākāśa* (earth, substratum, space), *vāyu* (air), *teja* or *agni* (radiation, energy, or fire), *āpa* (water), and *pṛthivī* (Earth). These five *bhūta* constitute the physical

universe. Air is said to have been generated from space, fire from space, water from fire, and earth from water. Fire and water, which are said to pervade the entire universe, have a close nexus and are believed to possess procreative powers (Narayanan, 1995). The tripartite nature of *agni* has been connected with the three forms of water – celestial, atmospheric, and terrestrial, called by different synonyms in Sanskrit so that they have characteristics and attributes responsible for different cosmic, atmospheric, or terrestrial actions.

In the social and religious traditions of India since Vedic times, water has enjoyed a unique status. Water is the single most important tool/ mode for performing daily religious rituals or social ceremonies and a primary means for purification of body and soul in Hindu culture.

From birth till death in a Hindu society, water remains an essential ingredient in performing all rituals.

Vedas and Their Chronology

The time periods of various Vedas are as follows:

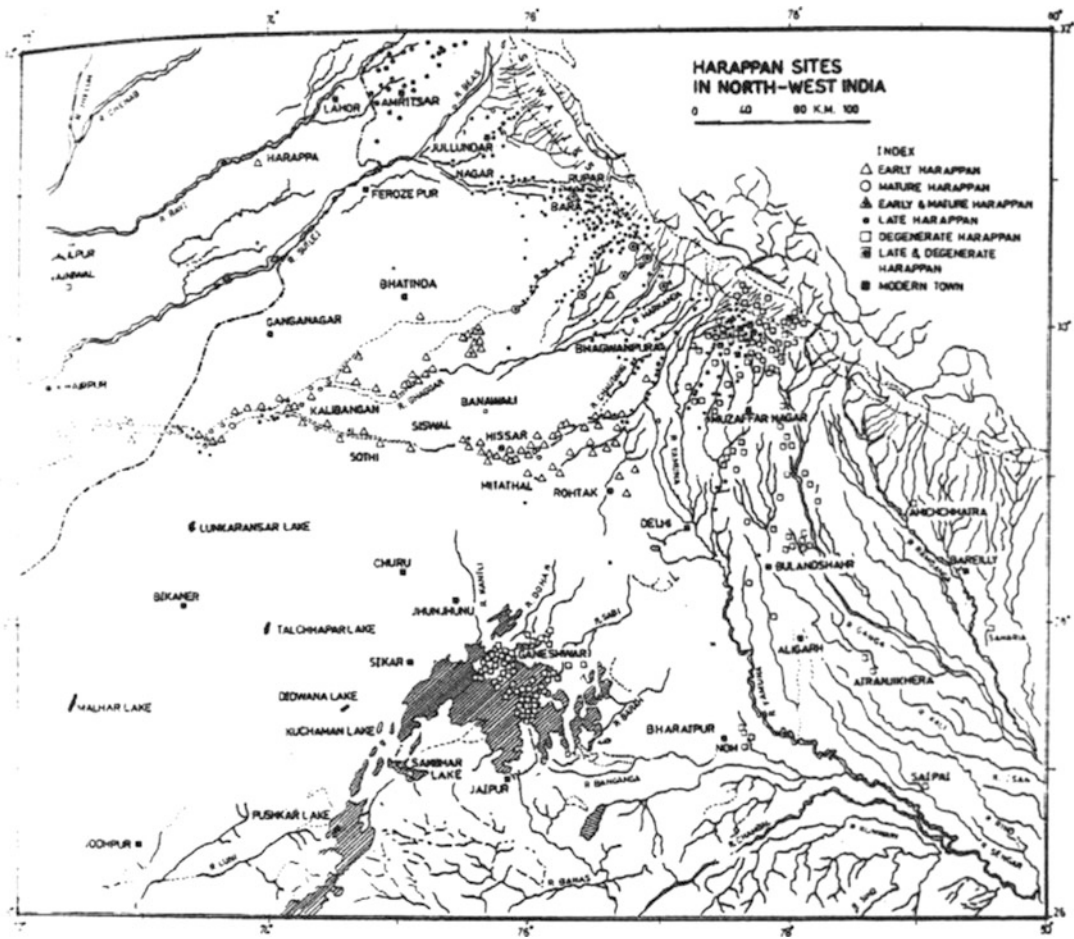
<i>R̥gveda</i>	6500–3100 BCE
<i>Sāma Veda</i>	3100–2500 BCE
<i>Yajur Veda</i>	2500–2000 BCE
<i>Atharva Veda</i>	2000–1500 BCE

An organic chronological development in India from 6500 BCE has been suggested (Frawley, 1994), taking into account both Vedic literature and recent archaeological findings.

6500–3100 BCE	Pre-Harappan (early Rigvedic period)
3100–1900 BCE	Mature Harappan (period of four Vedas)
1900–1000 BCE	Late Harappan (late Vedic and Brahmanic period)

The Myth of Aryan Invasion

For the past hundred years or so, Mortimer Wheeler’s hypothesis of “swashbuckling,



Water in India: Spiritual and Technical Aspects, Fig. 2 Harappan sites in Northwest India (Kalyanaraman, 1998)

of Harappan and Sarasvatī civilization sites. According to archaeologist Bisht, before the mature Harappan stage, many regional cultures such as Amri, Kot Dirji, Kalibangan, Dholavira, and Lothal had coalesced into the cultural umbrella of Harappa. They were bound by common economic compulsions and cultural ethos. The site of Dholavira is an excellent example of a Harappan city that tells the history of early, transition, mature, late, and final phases of the Indus-Sarasvatī (Harappan) civilization in India (ca. 3500–1700 BCE). The site spreads over an area of 100 ha. This compares well with the size of Harappa, Rakhigarhi, or Ganveriwala. All this evidence has proved the invasion theory to be unfounded, showing that the Aryans were the native Indians, having an unbroken chronology of civilization.

Place of Water in Ancient Indian Literature

Water has enjoyed a high status in the social and religious context of ancient Indian culture. It was an essential medium for performing daily religious rituals and social ceremonies and a primary means for the purification of body and soul. Even after thousands of years, the rivers in India, especially Gangā (the Ganges) and Yamunā, are considered divine and capable of purifying a sinful body with a few drops of their water. *Agni* (fire) is said to be born from the waters. Both water and fire are said to possess procreative powers. Water is considered a mother, while fire is seen as a prolific generator (Narayanan, 1995).

The place of water as a life-giving and life-sustaining element was very high. It was considered a cleanser of sins and regarded as a divine protector. It was addressed by various names – nectar, honey, ambrosia – in prayers. Stagnant water was considered unhygienic.

The cosmic energy is the generator of the universe, the embryo of waters the leader of humans, most virile defender of the human race, it remains ever illuminated by its own radiance and it provides sustenance for its beloved progeny. (RV 3.1.12)

Earth was formerly water upon the ocean of space. (*Atharvaveda* AV 13.6)

Water or the water element had many names in the Vedas and other Vedic literature. It has more than 100 synonyms. These are not synonyms in a strict sense, since they have been used to indicate their different forms/states and contexts. Some names for water are *Ambu*, *toyam*, *vāri*, *jalam*, *āpaḥ*, *bheṣajam*, *udakam*, *salila*, *madhu*, *ambha*, *ghṛtam*, and *kṣīram*. For example, *salila* is a technical word in the Vedas which is different from *āpaḥ* as mentioned in a mantra from *śatapatha brāhmaṇa* (11.1.6.1) which says that *āpaḥ* was indeed *salila* earlier. *Salila* is the primordial state of the universe, when there is nothing manifested.

The *Chhandogya Upanishad* (7.10.1) says that “it is the waters that pervade everything, big or small, the earth, the atmosphere, the heaven, the mountains, gods, men, animals, birds, grass, plants, dogs, worms, insects, ants. All these worldly manifestations are waters indeed.”

Payers of Water

In the ancient Indian literature, there are a large number of prayers seeking benevolence of water. For example, in *Rgveda* the seer prays thus – “The waters, with their source, the ocean, proceed from the midst of the firmament, flowing incessantly, purifying (all things): may the divine waters, whom the thunder-bearing *Indra*, the showerer, sent forth, protect me here on earth. May the waters that are in the sky, or those that flow (on the earth), those in the channels that have been dug, or those that have sprung up

spontaneously, and those that seek the ocean. All pure and purifying, may those divine waters protect me here on earth” (RV 7.49.1-2) (Arya & Joshi, 1997).

The seers in all the four Vedas hail water practically as a form of god and worship it as such, since it was considered life giving. Water has been variously described as “incarnation of god,” “nectar,” and “the protector of the earth and the environment.”

The sages in (Yajur Veda) (Arya, 1999) pray: “O Water, thou art the reservoir of welfare and propriety, sustain us to become strong. We look up to thee to be blessed by thy kind nectar on this earth. O water, we approach thee to get rid of our sins. May the water cleanse the earth, the earth cleanse me. May the holy waters make me devoid of sins. May the waters remove my bad deeds. The waters that kept the Agni (fire) inside them, bless us. The waters that generate all prosperity on earth and heaven and those which dwell in different forms in the atmosphere, those who irrigate the earth, may be those waters be kind to us and bless us. O Water, kindly touch me with thy divine self and establish strength, radiance, intellect and wisdom in me.”

Nature's Forces as Deities

In Vedic cosmology, *pṛthivī* (earth) symbolizes the material base and *dyāvā* (heaven) symbolizes an unmanifested immortal source. Together and between them, they form the *paryāvaraṇa* (environment).

The seer praises Heaven and Earth (*dyāvā pṛthivī*) by saying, “You are surrounded, Heaven and Earth, by water; you are the asylum for water; imbued with water; the augmenters of water; vast and manifold; you are the first propitiated in the sacrifice; the pious (people) pray to you for happiness, that the sacrifice may be celebrated. May Heaven and Earth, the effusers of water, the milkers of water, dischargers of the functions of water, divinities, the promoters of sacrifice, the bestowers of wealth, of renown, of food, of male posterity, combine together” (RV 6.70.4-5) (Arya & Joshi, 1997).

Water stands for all the elements, because it is really a combination of water, fire, and earth, according to the tripartite creation of the gross elements. Water is all pervading.

Waters Regarded as Having Medicinal Powers

The Vedas also mention the medicinal qualities of water. *Rgveda* hails water as the reservoir of all curative medicines and of nectar.

The *Atharvaveda* describes various sources of waters and describes them as dispellers of diseases and as more healing than any other healer. The scriptures believed that waters avert pain and that they are restorative and curing. Wherever waters fall on earth, plants grow. The hymns in *Atharvaveda* (6.23, 24, 57) hail water as possessing medicinal qualities. A hymn in *Atharvaveda* prays for waters to cure “incurable” diseases.

The *Rgveda* (1.161.9) states, “There exists no better element other than water which is more beneficent to the living beings. Hence waters are supreme.” Varuna is a cosmic ruler as well as the deity that dwells in waters, presides over them, and is prayed to for granting strength and virility from waters.

Another hymn from the *Rgveda* says

Ambrosia is in the waters, in the waters are medicinal herbs; therefore, divine (priest), be prompt in their praise. Soma has declared to me, ‘all medicaments, as well as Agni, the benefactor of the universe, are in the waters’: the waters contain all healing herbs. Waters, bring to perfection all disease-dispelling medicaments for (the good of) my body, so that I may long behold the Sun. Waters, take away whatever sin has been (found) in me, whether I have (knowingly) done wrong or have pronounced imprecations (against holy men) or (have spoken) untruth. I have this day entered into the waters – we have mingled with essence – Agni, abiding in the waters, approach, and fill me, thus (bathed), with vigour. (RV 1.23.19-23) (Arya & Joshi, 1997).

According to *Taittareyī Āraṇyaka* (7.3.2), Agni is an antecedent form and sun the later. Water is a compound and lightning is the joining element. *Maitreyī Saṃhitā* further divides water into three places – sky, earth, and mid-region.

Vājasaneyī Saṃhitā describes the medicinal use of waters. “O water, which we have drunk, become refreshing in our body. May you be pleasant to us by driving away diseases and pains.” Like Agni and Vāyu, *āpaḥ* (water) also serves as a purifying agent.

Rivers as Goddesses

The rivers and river waters have been treated with great reverence since ancient times. Traditionally, rivers such as Gangā, Yamunā, or Narmadā are worshipped as goddesses. Every morning and evening, on the banks of the Gangā at Haridwār, there is daily Gangā worship with lighted lamps in the presence of thousands of devotees, traditional holy music, and chants of mantras. The Sarasvatī River was one of the largest rivers in ancient India before 3000 BCE and drained the Sutlej and the Yamunā. By the end of Harappan culture, the Sarasvatī went dry, bringing about the end of Harappan civilization around 1900 BCE. The Vedic texts are replete with references to the River Sarasvatī and the seas.

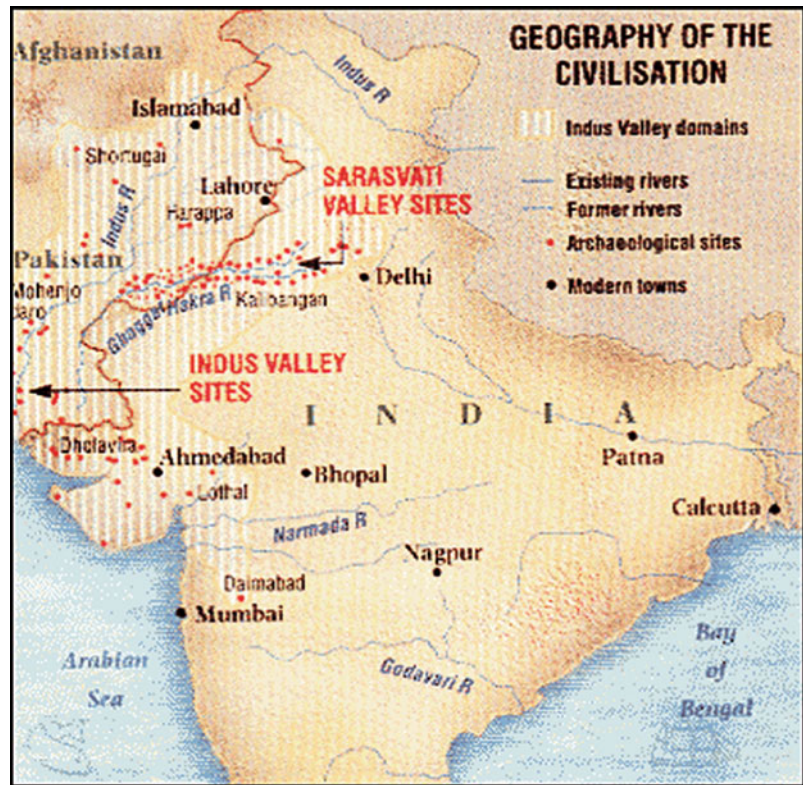
River Sarasvatī: Myth or Reality?

Whereas the famous River Gangā is mentioned only once in the *Rgveda*, the River Sarasvatī is mentioned at least 60 times. Sarasvatī is now a dry river, but it once flowed all the way from the Himalayas to the ocean across the desert of Rajasthan. Research by Dr. Wakankar has verified that the River Sarasvatī changed course at least four times before going completely dry around 1900 BCE. The latest satellite data combined with field archaeological studies have shown that the *Rgvedic* Sarasvatī had stopped being a perennial river long before 3000 BCE (Giri).

Numerous archaeological sites have also been located along the course of this river, thereby confirming Vedic accounts. The Sarasvatī is now dated long before 3000 BCE. This means that the *Rgveda* described the geography of North India long before 3000 BCE. This shows that the *Rgveda* must have been in existence no later than 3500 BCE.

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Fig. 3 Archaeological sites along erstwhile Sarasvatī River



Tritium (hydrogen isotope) analysis of deep water samples taken by Bhabha Atomic Research Centre (BARC), India, has provided a broad spectrum dating for the waters of the Sarasvatī River now revealed as groundwater sanctuaries and aquifers. The waters range from 4,000 to 8,000 years BP (Kalyanaraman 1998).

For over 2,000 years (6000–4000 BCE), the Sarasvatī flowed from Bandarpunch massif (Sarasvatī Rupin glacier confluence at Naitwar in western Garhwal). Figure 3 shows the location of archaeological sites along Sarasvatī River. A remote sensing study of the India desert reveals numerous signatures of palaeochannels. The LANDSAT imagery highlights the course of the River Sarasvatī in Punjab, Haryana, and Rajasthan. The digital enhancement studies of IRS-1C data (1995), combined with radar imagery from European remote sensing satellites ERS I/2, have identified subsurface features and reorganized the palaeochannels beneath the sands of the Thar desert in northwestern India (Paik, 2000).

Ancient Weather Science

In the early Ṛgvedic period, the performance of *Yajnas* (sacrifices) as described in Vedic and Brahmanic literature has some scientific basis. These rituals were performed to ensure timely and adequate rainfall for abundant availability of food, thriving of animal and plant life and for overall human prosperity (Sharma, 2002). The *Yajnas* are very closely related to the evolution of the universe, the solar system, human procreation, occurrence of the seasons, rainfall, and life on earth. Several places in the Vedic literature mention that *Yajnas* produce rain which in turn produces food.

The subject of meteorology was dealt with by several ancient sages, including Nārada, Kashyap, Garg, Parāshar, Vasishṭha, Druhin, Brihaspati, Devala, Vajra, Sahadev, and Rishiputra. *Ashṭādhyāyī* (500 BC) by Pāṇini is perhaps one of the earliest post-Vedic works giving information on rainfall measurement and droughts.

The *Arthashastra* (fourth century BC) of *Kautilya* gives information on rainfall distribution in the country as well as the methods of its measurement. Several of the old treatises in the form of *Purāṇas*, such as *Matsya Purāṇa*, *Vāyu Purāṇa*, or *Vishṇu Purāṇa*, dealt with the role of the sun in rainfall. Water science, which was initially based on observations, kept being refined, and in the post-Vedic period from the third century BC to the sixth century AD, many of the earlier hypotheses came to be perfected. *Kautilya* even gave an estimate of the average rainfall in various parts of India.

In Varāhamihira's time, the units of measurement of rainfall were the *pala*, *adhaka*, and *droṇa*. The rain gage was round with a diameter of one *hasta* (18 in., 46 cm) and had marks of *pala*. When it was full, it indicated one *adhak* of rainfall. One *droṇa* means 2 1/2 in. (6.4 cm) of rain. Accordingly to Parashar, the height and diameter of the rain gage should be 8 *angulas* (6 in., 15 cm) and 20 *angulas* (15 in., 38 cm), respectively, and when it is filled to the brim, it measures one *adhaka*. Parashar also gives a method of measuring rainfall on the ground. If it measures four cubits on the ground, it amounts to one *droṇa*.

Ramanathan (1993) described the significance of rituals and *yagnas* (sacrifices) with their cosmic and scientific interpretations in great details. Observations and measurements of wind, clouds, lightning, thunder, rain, solid precipitation, atmospheric optical phenomena, and agricultural meteorology were presented.

Just as the water vapours are carried higher in the form of clouds and are condensed in the presence of cold air existing in the sky, similarly one can reach the height of spiritual progress and can get strengthened due to restraining the breath through Yogic exercise. (YV 23.26) (Arya, 1999).

The uniform water passes upwards and downwards in the course of days, clouds give joy to the earth; fires rejoice the heavens. (RV 1.164.51) (Arya & Joshi, 1997).

O all learned people, fully realise your conduct towards different objects of the universe, know ye the electricity that maintains all beautiful objects, the sun, the invisible matter brought into creation, the invigorating vital airs, thus ye become the utilisers of all objects. Homage to him who knows the science of clouds, and to him who knows the science of electricity. (Yajur Veda) (Arya, 1999).

These hymns give insight into the cloud-seeding phenomenon and occurrence of rains. Various activities occurring in the firmament were well observed and formulated in scientific terms.

The Present-Day Indian Water Scenario

Present-day India has a geographical area of 329 million hectares (Mha) which is about 2.4 % of the world's lands. The country has a population of over one billion which is over 16 % of the world's population. It has 12 major river basins of catchment area more than 20,000 sq km and 48 medium river basins with catchment area varying from 2,000 to 20,000 km². The presence of the great mountain mass formed by the Himalayas and its spurs on the north and of the ocean on the south are the two major influences operating on the climate of India.

Although the average water availability in the country remains by and large fixed, the per capita water availability has been reducing progressively due to increasing population. As against the per capita water availability of 5,300 m³ in 1955, it was reduced to about 2,200 m³ by 1997 and is presently of the order of about 1,545 m³. With the projected population growth, it is estimated that the average availability might be only of the order of 1,140 m³ by 2050. India needs to build storage capacity to the tune of at least 450 BCM by 2050, against the present capacity of 253 BCM.

Major River Basins of the Country

India is blessed with many rivers. As many as 12 of them are classified as major rivers whose total catchment area is 252.8 million hectares (Mha). See Fig. 4. Of the major rivers, the Ganga – Brahmaputra – Meghna system is the biggest with a catchment area of about 110 Mha, which is more than 43 % of the catchment area of all the major rivers in the country. A total potential of 1,869.35 BCM is available in the country as shown in Table 1.



Water in India: Spiritual and Technical Aspects, Fig. 4 Major river basins of India

National Water Policy

The Government of India has formulated its National Water Policy (revised 2012) which is a broad blueprint of the water resources development, priorities, and use in the country.

Festivals Related to Water

The focal point of Hindu social, cultural, and religious rituals has been water. Indian mythology attaches a lot of importance to the bath (*snāna*) which is mandatory for participation in any important religious occasion. A dip in holy rivers is considered an essential part of Hindu culture, especially on specific occasions such as

the solar and lunar eclipses or occasions specified on the basis of specific planetary configurations, which are considered to have a cosmobiological effect on the human body. In a cycle of 12 years, a great Indian festival takes place which is known as Mahā Kumbha or Great Kumbha, where millions assemble and have a dip in the waters of the sacred rivers. Every third year, a smaller water festival called Ardhā Kumbha (half Kumbha) is also held, where people congregate at specified places at the banks of the holy rivers (Sharma, 1998). In the mythological scriptures, it says that the elixir of life, ambrosia (*amṛt*), which emerged from the churning of the ocean by the gods and demons, splashed out of the pitcher and fell to earth at four places: Haridwār, Prayāg, Ujjain, and Nāsik. These are located on the banks of the

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Table 1 Basinwise surface water potential of India
(km³ or BCM/year)

Sl. no.	Name of the river basin	Average annual potential in river
1.	Indus (up to border)	73.31
2.	(a) Ganga	525.02
	(b) Brahmaputra, Barak and others	585.60
3.	Godavari	110.54
4.	Krishna	78.12
5.	Cauvery	21.36
6.	Pennar	6.32
7.	East flowing rivers between Mahanadi and Pennar	22.52
8.	East flowing rivers between Pennar and Kanyakumari	16.46
9.	Mahanadi	66.88
10.	Brahmani and Baitarni	28.48
11.	Subernarekha	12.37
12.	Sabarmati	3.81
13.	Mahi	11.02
14.	West flowing rivers of Kutch, Sabarmati including Luni	15.10
15.	Narmada	45.64
16.	Tapi	14.88
17.	West flowing rivers from Tapi to Tadri	87.41
18.	West flowing rivers from Tadri to Kanyakumari	113.53
19.	Area of Inland drainage in Rajasthan desert	NEG.
20.	Minor river basins drainage into Bangladesh and Myanmar	31.00
Total		1,869.35

River Gangā, at the confluence of the rivers Gangā, Yamunā, and Sarasvatī; on the banks of Shiprā; and on the banks of Godāvarī. A tussle ensued among the gods and the demons for 12 days. During this period, the moon did not let the *amṛt* fall from the pitcher, the sun did not let the pitcher crack, Jupiter protected it from demons, and Saturn saved it from being whisked away. Thus, these four planets, which were responsible for saving the pitcher of ambrosia (*amṛt kumbha*), have become an integral part of the Kumbha. Various astronomical conjugations

during Kumbha represent various stages of the solar cycle which have a direct influence on human beings and the biosphere. The holding of Kumbha at an interval of 12 years is symbolic of the need for purifying the body by sublimating the inherent vices of the 12 sense organs – five organs of action, five organs of perception, and the mind and the intellect – thereby arousing the six psychic centers or *chakra* separated from each other at distance of 12 *angula* (finger widths) for attaining the *amṛt kumbha* or pitcher of ambrosia (Dixit, 2001).

Water festivals are also celebrated in several other ways in North and South India. It is customary to take a dip in the holy waters of rivers on various auspicious occasions.

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Water Management and Reservoirs in India and Sri Lanka

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Water storage and distribution technologies have played an important role in the histories of southern India and Sri Lanka. Given the variability in rainfall and the relatively dry conditions over much of the region, it would have been difficult for southern Asian agriculture, diet, and cuisine – particularly the heavy emphasis placed on rice – to have taken the forms they did without the historical development of water management techniques. Reservoirs, alternately known as “tanks,” also served important roles as sources of domestic water, stock tanks, and sources of resources such as fish and clay. Moreover, debates about the efficiency, sustainability, and equitability of modern “big dam” projects versus “traditional” methods of providing much-needed domestic and agricultural water continue to dominate Indian politics today. Here, we review historical forms of water management in South India and Sri Lanka, paying particular attention to ancient reservoir systems.

South India and Sri Lanka are dominated by a monsoonal climate, whereby the southwest (or advancing) monsoon generally brings rains between the months of June and October and the northeast (retreating) monsoon in November and December. In addition to monsoon strength, a variety of topographic factors relate to the distribution and concentration of rainfall across the region. Parts of the southwestern and western coasts of India receive between 3,000 and 3,200 mm of rainfall a year due to the orographic (related to, or caused by, physical geography, such as mountains or sloping terrain) effects of the Western Ghats – South India’s most pronounced north–south ranging mountain chain. On the eastern side of the Ghats, however, a rain shadow is created that markedly reduces the amount of precipitation in the central areas

of the southern peninsula. For example, Bengaluru, the capital city of the modern state of Karnataka, receives an average of around 850 mm of rainfall per year, while Hyderabad, the capital of Andhra Pradesh, receives an average of only 700 mm of rainfall. Indeed, much of the area within the orographic rain shadow of the Western Ghats can be considered a semiarid climate, with average rainfall levels falling as low as 400 mm (India Meteorological Department, 1981). Sri Lanka’s topography creates a similar pattern in which the southwestern coastal areas receive the bulk of the advancing monsoon and the northern and eastern coasts – largely in the rain shadow of Sri Lanka’s central highlands – receive precipitation from the shorter, retreating monsoon. However, it is important to note that actual rainfall in all parts of the Indian peninsula and Sri Lanka can show significant intra- and interannual variability as a result of being dependent on the relative strength of the monsoon. All of the rivers of the Indian peninsula and Sri Lanka are ultimately monsoon-dependent, unlike the great northern Indus and Ganges rivers systems which also receive seasonal runoff from Himalayan snowmelt. Thus, rainfall is one of the most important variables influencing agriculture and vegetation across this region.

South Indian and Sri Lankan reservoirs include a range of facilities constructed for the purposes of collecting and storing water, generally for agricultural production. These consist of artificial embankments built across paths of gravity water flow, whether intermittent streams, rivers, or simply slopes that might carry runoff after a monsoon rain. Reservoirs may or may not involve excavation of a basin to contain this water, but they are all storage or storage/distribution devices built on a relatively large scale and meant to contain water behind an embankment or dam rather than within its major construction. In this sense, we make a distinction between cisterns (which collect and store water within a rock-cut or other constructed facility), wells (which tap the water table), reservoirs, and tanks. The term “tank” is widespread in the South Asian literature, indiscriminately used to describe almost any water-holding feature, although the term most

frequently refers either to reservoirs or to temple tanks – large masonry structures that hold water for ritual ablutions and other functions associated with temple worship. Temple tanks often derive their water from the water table. As such, temple tanks and reservoirs are wholly different in construction, morphology, and operation, similar only in their capacities as water-holding devices and in certain parallels of meaning and symbolism (Morrison, 2009, 2012).

Early Forms of Water Management in South India and Sri Lanka

The earliest culturally significant water catchment features in South India were not constructed reservoirs (in the terminology outlined above), but seasonal pooling basins, or cisterns, which developed naturally from the differential weathering of bedrock or, in some instances, were created by quarrying stone basins and pooling sheet flow behind low stone embankments (Fig. 1). In geomorphological terms, these features are known variably as gnammas, rock pools, or weathering pits and are considered to be characteristic features of residual hills and inselbergs – isolated hills composed of resistant rocks (e.g., granite or gneiss) that express pronounced topographic relief from a surrounding plain – throughout the heavily weathered terrain of the tropics and subtropics (Thomas, 1994; see also Porembski & Barthlott, 2000). In South Asia, such basins occur on the granite and gneiss hills that characterize much of the central and southern portions of the Indian peninsula as well as parts of Sri Lanka (e.g., Fernando, 1976). Indeed, because granite and gneiss are particularly impermeable rock types, the bare hills of South India generate large volumes of runoff water during the heavy monsoon months that collects in such depressions.

Water retaining rock pools appear to have taken on cultural significance by at least the Iron Age (1000–500 BCE) in several regions of South India. It is evident from systematic archaeological survey that during this period inhabitants both modified and constructed rock pools to store



Water Management and Reservoirs in India and Sri Lanka, Fig. 1 Sediment filled and abandoned modified rock pool at an Iron Age site in the Koppal district of northern Karnataka (photo by Andrew M. Bauer)

water for human and animal consumption. For example, numerous prehistoric herding sites located on granitic hills in central Karnataka show associations with rock pools, suggesting the landscape features were important to early forms of land use and grazing routines in the region (Bauer, 2011, 2014). It is also important to note that there is a clear cultural association between such rock pools and early mortuary and ritual locations, which were often marked by the construction of megalith monuments. Large concentrations of elaborately constructed megaliths – ranging from dolmen cists, stone circles, rock cairns, platform enclosures, stone spirals, and more – appear to have been deliberately placed adjacent to water basins in many hilltop locations. Perhaps the most striking example of such an association occurs at the site of Hire Benakal in northern Karnataka, where hundreds of megaliths are found near a broad shallow water basin that likely began as a rock pool and was subsequently expanded by quarrying activities for the construction of monuments (Fig. 2).

Additional sites also demonstrate associations between water and culturally significant ritual places. For example, a brick platform structure enclosed by granite boulders at Bandibassappa Camp, also a large megalithic complex in northern Karnataka, appears to have been situated adjacent to a rock pool that was later modified.



Water Management and Reservoirs in India and Sri Lanka, Fig. 2 The site of Hire Benakal, showing dolmen cists on the quarried banks of a basin feature that likely began as a natural rock pool (photo by Andrew M. Bauer)



Water Management and Reservoirs in India and Sri Lanka, Fig. 3 Passage-chamber megalith associated with a modified rock pool at an Iron Age site in the Koppal district of northern Karnataka (photo by Andrew M. Bauer)

Furthermore, systematic documentation by Bauer (2014, 2011) and Bauer and Trivedi (2013) of the area around Hire Benakal suggests that additional megalithic monuments were regularly sited adjacent to ancient water retaining rock pools (Fig. 3). Gordon and Allchin (1955) also reported 80 megaliths at a site near Bilebhavi where they identified two “tanks” (cisterns), one of which was “lined with stone slabs.” They likewise recorded a similar construction on a hilltop megalith site near Koppal (Gordon & Allchin, 1955, p. 99). The association between megaliths and water basins has also been noticed in Tamil Nadu and Sri Lanka (cf. Myrdal-Runebjer, 1996; Seneviratne, 1984), suggesting a ritual importance to water and possibly a sacred dimension to early water management throughout much of the region.

Although rock pools likely served as the earliest water retention features in the region, it is clear that during the Iron Age, humans began deliberately expanding pooling basins and creating them through activities of quarrying, excavation, and the construction of embankments, or bunds. This is evidenced not only at megalithic ritual sites, such as Hire Benakal, but also at settlement sites, where both cobble-lined basins and constructed earthen bunds are present. At the Iron Age habitation site of Kadebakele (northern Karnataka), for example, inhabitants modified

the drainage pattern on top of a granitic hill to form a water catchment basin. Excavations in this reservoir show that it collected and held water for only part of the year, partially a consequence of the reservoir’s relatively small catchment area of 0.027 km². The facility also experienced major drying episodes as well as significant siltation (Bauer, 2014). Nevertheless, it certainly provided much-needed water to local residents at certain times.

It is difficult to say to what extent these early water retention features may have supported cultivation. Most are quite small and lack provisions for water distribution necessary for large-scale agriculture. Moreover, they are often perched atop high hills with little cultivable land. However, some early reservoirs do occur within natural drainage ways, occasionally in association with check dams and at the base of topographic features where seasonal water could potentially be pooled for crop production. In fact, Devaraj, Shaffer, Patil, and Balasubramanya (1995, p. 66) report “interlaced, hydraulically laminated” deposits behind a “rammed” earthen construction near the base of a granite outcrop at Watgal – a Neolithic (3000–1000 BCE) to Iron Age (1000–500 BCE) period settlement site in northern Karnataka. (However, it is important to note that the authors do not identify this feature as a reservoir or attribute it with any water retaining

“function.”) It is difficult to characterize the entire range of variability in form and function of early water management constructions without more systematic work. Indeed, few regions have been systematically studied, and the patterns described above may not hold true across the entire region. Nevertheless, it seems that water retention techniques began to be practiced in a variety of settings during the Iron Age (see also Allchin, 1954). In addition, the development of water management technology during this period generally coincided with the introduction of new cultigens – including rice cultivation – suggesting that water retaining features became increasingly important to agricultural production by the end of the first millennium BCE. At Kadabakele, for example, farmers of the middle Iron Age (ca. 800–550 BCE) grew a suit of dryland crops similar to those used in the preceding Southern Neolithic, but with the addition of water-intensive crops such as bananas and wheat (Morrison, Reddy, & Kashyap, 2014).

In the first millennium CE, there is stronger evidence for the construction of larger reservoirs that were used to meet the hydrological requirements of cultivation. A series of reservoir walls have been reported in the environs surrounding Sanchi – a well-known Buddhist monastic site in west-central Madhya Pradesh spanning the third century BCE to the twelfth century CE. These reservoir features are built of earthen embankments reinforced by stone masonry, with dams reaching nearly 6 m in height and expanding across drainage valleys, in some cases exceeding 1 km in length. Moreover, catchment areas range from 0.74 to 17 km² (Shaw & Sutcliffe, 2001), potentially damming considerably more water than the Iron Age features discussed above. Artifact associations, as well as the proximity of the embankments to the site of Sanchi, have allowed scholars to suggest that several of these features were constructed as early as the second century BCE, while others were built throughout the first millennium CE (Marshall, 1940, p. 13; Shaw & Sutcliffe, 2001).

Although dating features such as reservoir walls remain problematic without direct geochronological assessment (e.g., radiocarbon, optically

stimulated luminescence, etc.) or inscriptional data, textual references from the Early Historic Period (500 BCE–CE 500) suggest that reservoir construction was prevalent in some parts of India, and in South Asia more generally, during this time. For example, Chakravarti’s (1998) analysis of the *Arthaśāstra* – an economic and political treatise composed sometime in the late centuries BCE or early centuries CE – suggests that Mauryan rulers (ca. 324–185 BCE) were concerned with establishing irrigation works. Moreover, numerous inscriptions and textual references indicate that the construction of reservoirs and irrigation facilities underwent remarkable development in Sri Lanka during the Early Historic Period, particularly on the island’s drier north and east sides. Northeast of Sigiriya, the Minneriya reservoir built during the reign of Mahasena (CE 276–303) is particularly noteworthy. This reservoir – fed by a canal as well as surface runoff – consisted of an embankment nearly 2 km in length and at places exceeded over 13 m in height. Inscriptions dated to the reign of Mahasena’s successor speak of “three harvests of [rice] paddy per year,” suggesting a marked impact on agricultural production (Gunawardana, 1971, p. 8).

Middle Period Reservoirs: The “Traditional” System

It should be clear from the above discussion that reservoirs and water storage features have a long history in South India, and South Asia more generally. However, the proliferation of large reservoir construction for the purposes of agricultural intensification is most salient in South India after the Early Historic Period and in Sri Lanka only slightly earlier. Many reservoirs continue to be used, although the expansion of both electricity and deep bore wells has significantly transformed water use across Southern Asia toward greater exploitation of ground as opposed to surface water.

Numerous textual sources clearly indicate that reservoirs played an important role in the Early Middle Period (CE 500–1300). Although small

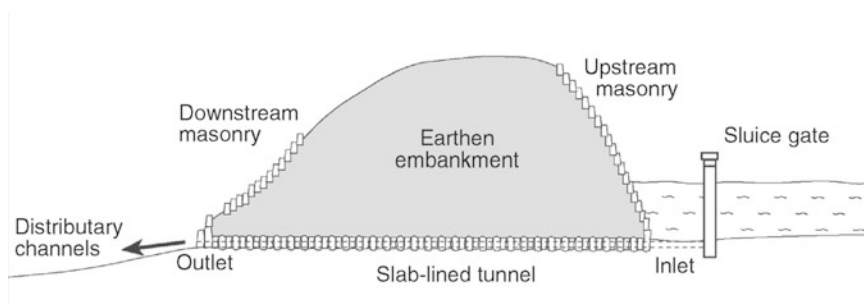


Water Management and Reservoirs in India and Sri Lanka, Fig. 4 A Middle Period reservoir embankment and sluice gate used to dam a valley below the Iron Age site of Hire Benakal (photo by Andrew M. Bauer)

dam-and-basin facilities for water impoundment continued to be built and used, Middle Period reservoirs typically consist of masonry-faced earthen dams thrown up across valleys, at the base of hills, and in other locations where seasonal runoff and small streams could be captured (Fig. 4) (Morrison, 1993a, 2009). Like the Minneriya reservoir in Sri Lanka, some were supplied by canals, which took off via diversion weirs or anicuts, from perennial rivers or intermittent streams. Water was moved downstream from reservoirs to agricultural fields through masonry-lined tunnels under the embankments, which were regulated by sluice gates (Figs. 5 and 6). Some water was also released over specially constructed waste weirs, facilities which range from boulder-filled cuts to elaborately built spillways (Fig. 7). Although the focus was clearly on the storage and downstream distribution of water, reservoir beds were also sometimes used for cultivation and reservoirs served as important sources of fish, silt and clay, and water for livestock. Reservoirs were also used to raise the water table around them, an important function even when the bed failed to fill. In fact, we have documented a consistent (but not universal) pattern of wells downslope from sluice gates (Morrison, 2009).

Reservoirs were particularly important in the far south, in present-day Tamil Nadu, where many of them were supplied by river-fed canals (Ludden, 1999). There it is possible to see perhaps the greatest elaboration of the so-called system reservoirs – long chains of reservoir facilities that flow one into the other, linking large areas into tightly knit watersheds (Sharma & Sharma, 1990; see also Mosse, 2003). Unfortunately, none of these systems has been specifically analyzed on the ground to determine precise construction sequences, so although we know of many specific single-reservoir projects dating as early as the seventh century CE, we cannot say exactly how the overall system functioned at this time or even how much of the landscape was under reservoir irrigation. It should be noted, however, that Early Middle Period reservoirs, “traditional” by any reckoning, ranged widely in size from very small ponds to vast “seas,” the latter falling well within the contemporary definition of a “large dam (Crest length ≥ 500 m, maximum flood discharge $\geq 2,000 \text{ m}^3 \text{ s}^{-1}$, “especially difficult foundation problems” or “unusual design” (ICOLD World Register of Dams, 1998)).”

Similar to the “systems reservoirs” of Tamil Nadu, large Sri Lankan Early Middle Period reservoirs were linked through vast networks of canals. The Minneriya reservoir, for example, was connected to other facilities via the construction of a “great canal” during the reign of Aggabodhi I (ca. CE 571–604), and composite maps of the irrigation facilities around Sigiriya show that it fed at least two large reservoirs – the Kaudulla and Kantalai reservoirs. Moreover, detailed survey has shown that smaller dam-and-basin features were also probably constructed and maintained throughout the period (Myrdal-Runebjer, 1996). Again, it is difficult to know how the overall systems functioned simultaneously. However, it is clear that Middle Period rulers and elite made demonstrative efforts to construct new irrigation facilities and repair older ones. In fact, the Minneriya inflow and outflow canals were repaired at least several times in the early centuries of the second millennium CE (Myrdal-Runebjer, 1996; see also Brohier, 1934; Gunawardana, 1971).



Water Management and Reservoirs in India and Sri Lanka, Fig. 5 Diagrammatic cross section of a reservoir embankment and sluice gate



Water Management and Reservoirs in India and Sri Lanka, Fig. 6 The northern sluice of the Daroji reservoir, south of Vijayanagara. This “double sluice” construction became prominent in the sixteenth century, when the Daroji embankment was constructed. This sluice and reservoir have been maintained and continue to operate (photo by Kathleen D. Morrison)

This pattern of extensive reservoir use in Sri Lanka and the far south of the Indian peninsula contrasts with that of drier regions in the northern interior of the subcontinent (Karnataka and parts of Andhra Pradesh). In these northern regions,

reservoirs were (and are) almost exclusively run-off-fed, and, given lower rainfall, they are generally not as closely spaced as those of the southern Tamil country. Still, many regions saw the use of both system and isolated reservoirs. In the area we have studied in northern Karnataka, reservoirs seem to have been only a minor component of Early Middle Period agricultural strategies. However, by the Late Middle Period (1300–1700), and especially with the expansion of the large but loosely knit empire of Vijayanagara (ca. 1330–1600) across much of the peninsula, reservoir irrigation expanded considerably, especially in the drier zones where it had previously been limited. In and around the eponymous capital city of this empire, urban foundations in the early fourteenth century and the subsequent expansion of settlement and population explosion in the region propelled reservoirs into increasingly important components of larger agrarian and political strategies (Fig. 8). Important from the start of the Vijayanagara period, reservoirs also constituted a key form of agricultural intensification in the sixteenth century, or Late Vijayanagara period, especially in regions where canal irrigation was not feasible (Morrison, 1995, 2001).

Reservoirs played variable roles in the processes of Vijayanagara agricultural intensification and change; this variation was structured as much by political factors and settlement dynamics as by environmental variables such as runoff and soil conditions. What is common to most parts of the urban hinterland, however, is the

Water Management and Reservoirs in India and Sri Lanka,

Fig. 7 Masonry waste weir, or spillway, to regulate high water levels at the edge of a Middle Period reservoir embankment near the village of Kurugodu (photo by Kathleen D. Morrison)



Water Management and Reservoirs in India and Sri Lanka, Fig. 8

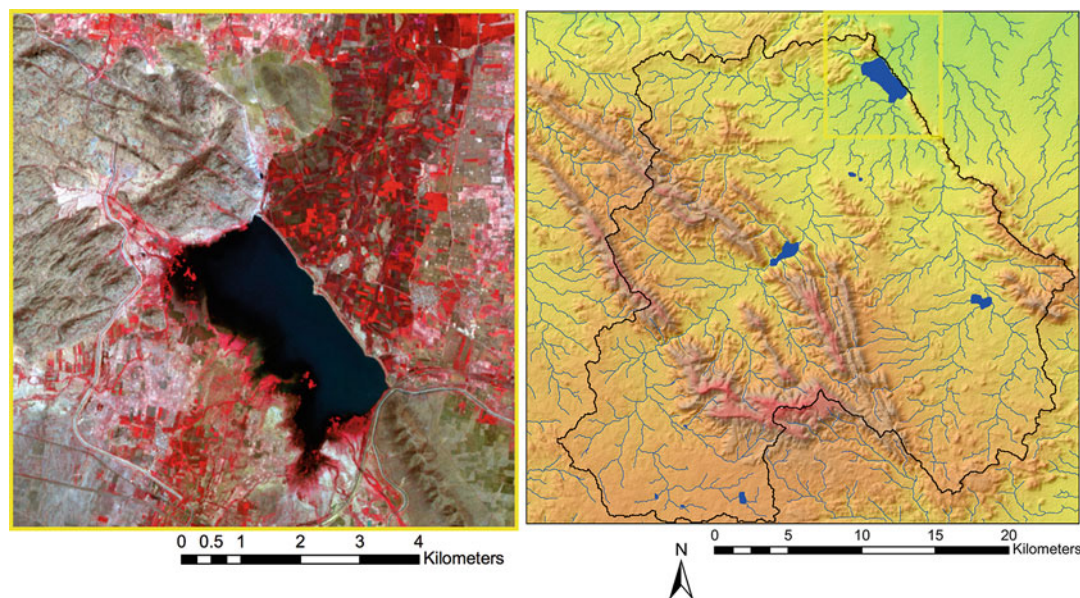
Small Middle Period reservoir and sluice gate in the Daroji Valley, south of Vijayanagara (photo by Kathleen D. Morrison)



way in which the vast majority of reservoirs fell out of use after (in some cases, during) the Vijayanagara period. Very few of the reservoirs from the original system still effectively function, though there are a few notable “living” reservoirs with long histories of maintenance and reconstruction (Morrison, 1993, 1995). For example, the Daroji reservoir, the terminus of one of the largest systems in our study area, continues to collect runoff from a catchment area of 955 km² and provides water for downstream agricultural fields (Fig. 9).

Research on Middle Period reservoirs includes analyses of pollen and charcoal from reservoir

sediments (which allow the reconstruction of fire and vegetation histories), sedimentological studies of reservoir fill and changes to erosional regimes and local hydrology, and stylistic analyses of sluice and embankment construction (e.g., Morrison, 1994, 1995; Myrdal-Runebjerg, 1994, 1996). In addition, we have also considered tens of thousands of textual and inscriptional records describing facility construction and maintenance as well as conflicts over water, land, labor, and rule (Kotraiah, 1995; Morrison, 1995; Morrison & Lycett, 1994, 1997). All of these diverse lines of evidence suggest that Middle Period reservoirs, like their contemporary and



Water Management and Reservoirs in India and Sri Lanka, Fig. 9 *Left:* inset showing ASTER satellite image of the Daroji reservoir, first built in the sixteenth century south of Vijayanagara. Notice the strong growth of agricultural crops indicated by the reflection of near-infrared

wavelengths (shown here in red) downstream from the embankment. *Right:* digital elevation model and modeled watershed catchment area of the Daroji reservoir basin (data originally obtained from NASA)

colonial counterparts (Mosse, 2003, pp. 45–46), were highly unreliable sources of irrigation, especially in more arid regions. Runoff-fed reservoirs, in particular, may fail to fill in dry years; in the drier districts, this meant not only that reservoirs could usually not support wet crops such as rice but also that dry crops such as millets might not be assisted by the facility. The situation was somewhat better in areas of higher rainfall, but everywhere in southern India reservoirs are marked by high evaporation rates, high siltation rates, and ongoing maintenance challenges (Fig. 10). Indeed, early colonial observers noted that in drought years, reservoir-watered fields actually fared worse than solely rainfed ones, although this was clearly an extreme example.

Reservoirs, Politics, and Contemporary Development

Across much of South Asia, contemporary “big dam” projects have been cast as the legacies of

high modernist social and environmental engineering (cf. Gadgil & Guha, 2000; Scott, 1998). In India, well-organized and highly visible social protests have been made against specific projects such as the Sardar Sarovar project and others along the Narmada River. Often, antidam groups suggest that the answer to sustainable and equitable development lies in a return to a “traditional” system of technology and management. It is not our purpose to argue the case for “modern” or “traditional” forms of water distribution. Rather, we wish to suggest that arguments that hinge on the dichotomies of large/small, inequitable/equitable, and political/apolitical that often accompany distinctions between “modern” and “traditional” forms of water management are inappropriate.

The notion that large political dam projects are entirely a product of modernity is decidedly incorrect. This is no clearer than in South India, where some Middle Period reservoirs were created with embankments more than 3.5 km in length and over 15 m in height. As already

Water Management and Reservoirs in India and Sri Lanka, Fig. 10 Photo showing the accumulation of an estimated 2–3 m of silt and clay, to near the top of a sluice gate. This reservoir is adjacent to the village of Avinamodugu, south of Vijayanagara (photo by Kathleen D. Morrison)



noted, the Daroji reservoir in northern Karnataka pooled runoff over a total catchment area of nearly 1,000 km²; however, size alone is not the issue. Both small and large reservoirs were deeply political projects, tied to networks of patronage and power. Middle Period reservoir construction was sponsored by a wide range of political leaders from kings (rarely) to local chiefs (commonly) and was also connected with Hindu temples in a number of ways (Morrison, 1995; Morrison & Lycett, 1994, 1997). Moreover, even during the Iron Age and Early Historic Periods, shifts from a reliance on rain-fed agriculture to reservoir irrigation would have produced a new material order on the landscape that was necessarily related to sociopolitical fields. Indeed, the questions – How was labor mobilized? Who had access to irrigation water? And how was this decided? – are entirely appropriate in examining the entire history of water management. The answers to these questions undoubtedly had sociopolitical ramifications for ancient inhabitants. This may have especially been the case when irrigation accompanied the introduction of new cultigens and cultural values of cuisine shifted. It is not difficult to imagine the profound social consequences of being a dry-farming millet producer/consumer versus a wet-farming rice producer/consumer when rice was a high status cultigen and the preferred donation to Hindu temple gods during the Middle Period, for example.

The above considerations of the (un)reliability and the political nature of historic reservoirs of South India and Sri Lanka are not to suggest that these impressive systems have no contemporary value with regard to (re)developing water management strategies. Quite the opposite is true: work on the 3,000-year history of irrigation in southern India shows both success and failure in equal measure, portents for a reasonably hopeful future. Thus, although there is no simple solution to the water problems of the dry tropics of South Asia, surely an informed perspective on the actual historical experiences of the region must provide a more secure basis for future planning than either a romantic and unrealistic view of “tradition” or a blind faith in “modern” science and technology.

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Water Management at Angkor

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What Was Angkor?

Angkor was the capital city of the Khmer kingdom from the latter half of the first millennium AD. At its peak in the eleventh to twelfth century AD, the Khmer kingdom incorporated Cambodia, southern Vietnam, southern Laos, and parts of Thailand. Angkor was the primate city of this vast kingdom and was connected to a network of smaller, satellite cities by an extensive road system (Hendrickson, 2010). King Jayavarman II founded Angkor, it is commonly said, in 802 AD, proclaiming himself the universal king and unifying a constellation of smaller chiefdoms that were grouped by Chinese visitors under the generic names “*Funan*” and “*Chenla*.” However, this date comes from a stone inscription (K235; Coedès & Dupont, 1943–1946) written hundreds of years after the events it depicts, and its veracity is widely questioned (Vickery, 1998). Indeed, many of the early state temples that characterized Angkor’s urban form may be much older than the epigraphic evidence suggests (Penny et al., 2006; Pottier, 1996). Whatever the date of Angkor’s establishment as a city, it likely emerged from a long period of occupation in the area that dates back to the second millennium BC.

No primary historical documents (stone inscriptions in Khmer and Sanskrit) from Angkor are known after the end of the thirteenth century AD. Monumental construction in the capital also ceased at this time. It is not until the late sixteenth century that European visitors – initially Portuguese missionaries and merchants – began to describe Angkor (Groslier, 1958). At that time, the city was in ruin, almost completely abandoned and overgrown with forest. More detailed accounts emerged in the nineteenth century from explorers such as Henri Mouhot – often incorrectly credited with the “discovery” of Angkor in

1860 – and in the subsequent and ultimately ill-fated “Mekong Expedition” of 1866, led by Doudart de Lagrée (Osborne, 1996). The romantic notion of the ruined city conjured in nineteenth-century Europe by these reports from the Far East was, in part, fanciful. Angkor was never completely abandoned by the Khmer, and in fact the city was reoccupied – if only briefly – by a Khmer king in the 1550s. Angkor Wat was probably continuously occupied by Theravāda Buddhist monks, and significant construction occurred in the sixteenth century at Angkor Wat and extensively within the enclosure of Angkor Thom (Jacques, 2007).

Discovery of the Water Management Network

The dense jungle that covered most of the abandoned city hampered the initial European attempts to explore and map Angkor. Even in the earliest maps, however, the significance of hydraulic infrastructure in defining the urban form is clear. By the late 1930s, scholars from the École Française d’Extrême Orient (EFEO), particularly Georges Trouvé and Henri Marchal, were producing maps of central Angkor that revealed an astonishing array of infrastructural elements – canals, embankments, dykes, moats, reservoirs, and ponds – used for trapping, holding, and moving surface waters around the city (Goloubew, 1941; Trouvé, 1933). Moreover, these features are shown to be part of a complex, interconnected network of water management infrastructure, covering a large area. The publication, in 1979, of Bernard-Philippe Groslier’s *La Cité Hydraulique Angkorienne* represents an important point of inflection in the analysis of Angkor’s water management infrastructure, capitalizing as it does on half a century of archaeological excavation and aerial survey undertaken by Groslier and his colleagues from the EFEO. *La Cité Hydraulique* is Groslier’s best known work and the first attempt to consider Angkor’s entire water management system from a functional, mechanistic point of view, even though he had presaged this approach some decades earlier on a

smaller scale (Groslier, 1958). It was also his most unequivocal statement on the role of the water management system in the demise and eventual collapse of the city.

Research on Angkor's water management system ground to a halt during the early 1970s as the Cambodian Civil War gained momentum, forcing the EFEO to flee Cambodia. It was not until the United Nations intervention in Cambodia in 1992 that the EFEO was able to reestablish its research base in Siem Reap and recommence its work. The publication of a comprehensive map of Angkor's central and southern districts by Christophe Pottier (1999) fundamentally changed the known scale and, particularly, the complexity of the settlement matrix, including its water management network. Advances in remote sensing techniques produced increasingly detailed maps of the city, notably the 2007 publication by Damian Evans, Christophe Pottier, and colleagues of the first comprehensive map of the entire city (Evans et al., 2007) and, again in 2013, using laser-based mapping of the landscape below the forest canopy (Evans et al., 2013). These findings represent the culmination of an aerial archaeology program that began in the 1930s. We now know that the water management network incorporates an area of between 900 and 1,000 km², making Angkor the largest preindustrial settlement on Earth. It is the water management network, in fact, which gives coherence to the low-density occupation scattered among it and to the state-level religious and administrative centers. It defines and delineates the city.

Demise, Collapse, and Reuse

Groslier (1979) observed a tendency to create new rather than renovate old water management infrastructure, creating an unwieldy degree of complexity. By the end of the eleventh century AD, he says, all of the natural rivers had been captured and diverted to feed the water management network, and Angkor had reached its carrying capacity in terms of hydraulic infrastructure. Angkor's development from that point would be characterized by the city choking on its own infrastructure.

The scale and complexity of the water management system had two primary implications in Groslier's hypothesis: First, the operation of any one part of the system was directly dependent on many other parts, meaning that even relatively small changes (such as a particularly wet year or the infilling of one important canal) can trigger a catastrophic failure across the entire system. Second, the trapping of surface water within the water management system encouraged the sedimentation of suspended silt and clay, along with the nutrients that adsorb to them. While initially beneficial to rice agriculture, long periods of stagnation in a large network effectively stripped the nutrients from the irrigation water. The consequence was to accentuate problems of siltation "upstream" while starving nutrients from receiving fields "downstream." He also argued that drying of rice fields, presumably a result of failures in the irrigation system, resulted in the oxidization of mobile iron in the soil, creating a hard and sterile base that further compromised the productivity of rice fields.

The comprehensive maps of Angkor's water management system identify numerous instances of apparent failures in the network – canals breaching their banks or cutting through or around embankments and bridges (Evans et al., 2007; Pottier, 1999). The well-known example of "Spean Thma" (stone bridge), which crosses over an N-S canal to the east of Angkor Thom, has become emblematic of the degeneration of the water management network. In that case, the post-thirteenth-century bridge was partially destroyed as the canal – now the Siem Reap River – eroded several meters into its bed (Kummu, 2009). Further downstream the soil from this erosion filled major canals linking Angkor with the Tonle Sap Lake (Buckley et al., 2010). It is clear that, by the fourteenth century, Angkor's water management network was suffering from numerous problems that were not or could not be rectified. Some have argued that the water management system created a kind of "inertial force" for the people of Angkor (Fletcher et al., 2008). It was too large and too complex to remove or reconfigure, forcing communities and the administration to deal with the strangulating legacy of redundant or inefficient

infrastructure – the product of hundreds of years of intensive water management. As Groslier (1979) put it, “they had hardly any choice: once they had adopted their course of action, they found themselves as if dragged down the slope without any power to stop themselves” (p. 191).

The degeneration and eventual failure of Angkor’s water management system in the fourteenth and fifteenth centuries is coincident with severe drought (Buckley et al., 2010), which caused significant social upheaval throughout Asia (Lieberman & Buckley, 2012; Sinha et al., 2011). The most severe droughts during this period occurred between approximately 1350–1370 and 1400–1420 AD, punctuated by an unusually wet period in the last decades of the fourteenth century. Much of the physical evidence for problems in the water management system dates to this period of dramatic instability, suggesting that climate may have been the specific trigger for the collapse of the water management network and the abandonment of the city by the elite. It is clear, however, that Angkor’s remarkable vulnerability to climatic variability was created by the size, complexity, and rigidity of its urban fabric and, particularly, its water management system.

Parts of the Angkor’s water management system still operate today. Alterations to the system during the 1940s allowed water to flow once more into the West Baray reservoir, which now supplements the water supply to the modern city of Siem Reap. Similarly, the Jayatataka (North Baray) – the last of the great reservoirs to be constructed in the twelfth century – was re-flooded recently by the Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA National Authority), providing five million cubic meters of water for local communities and to recharge the severely depleted groundwater aquifer. In total, the rehabilitated water management network can store 65 million cubic meters of water, with plans to increase the storage to more than 100 million cubic meters (Peou, 2013). Once again, Angkor’s water management network is being used to secure livelihoods and support development as it did more than 600 years ago for one of the most extraordinary cities on Earth.

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- field system (Dillehay et al. 1997). Upon excavation, two additional, earlier canal profiles lay bedded below the topmost canal profile. Apparently the earliest, bottommost canal was covered by a soil deposition episode requiring construction of a higher level canal; this canal was covered by a later deposition event and the uppermost canal built. Starting from the deepest canal, each successive higher canal had a shallower slope built over the depositional layer covering the previous canal. The cross-sectional area of successive canal profiles increased from the bottommost to the highest level canal. In essence, the ancients discovered a basic tenet of fluid mechanics: to maintain the same flow rate for all canal phases, the canal cross-sectional area must increase as the slope decreases. From these early origins, the archaeological record demonstrates continued progress in water management and hydraulic technology over millennia to meet the demands of large populations requiring predictable food supplies.
- Ancient Peruvian civilizations exhibited a wide variety of agricultural systems compatible with different ecological conditions found in coastal and highland settings. Peruvian north coast societies farmed alluvial river valleys using coastal rivers to supply water to canal networks supplying field systems. In south coast areas where rivers were deeply downcut from tectonic uplift and unable to support canal irrigation, underground galleries cut deep into the groundwater aquifer conducted water to distal surface field systems. In contrast to coastal irrigation practices, Andean highland agriculture depended on mountainside terraces supplied by rainfall and valley bottomland areas supplied by rainfall runoff streams originating from mountainous watershed regions.

Water Management in Ancient Peru

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Water management in ancient Peru began in the north coast Zaña Valley (Fig. 1). Here a 2.5 km-long canal dating to 4705 BCE was sourced by the Rio Nancho and supplied water to a small

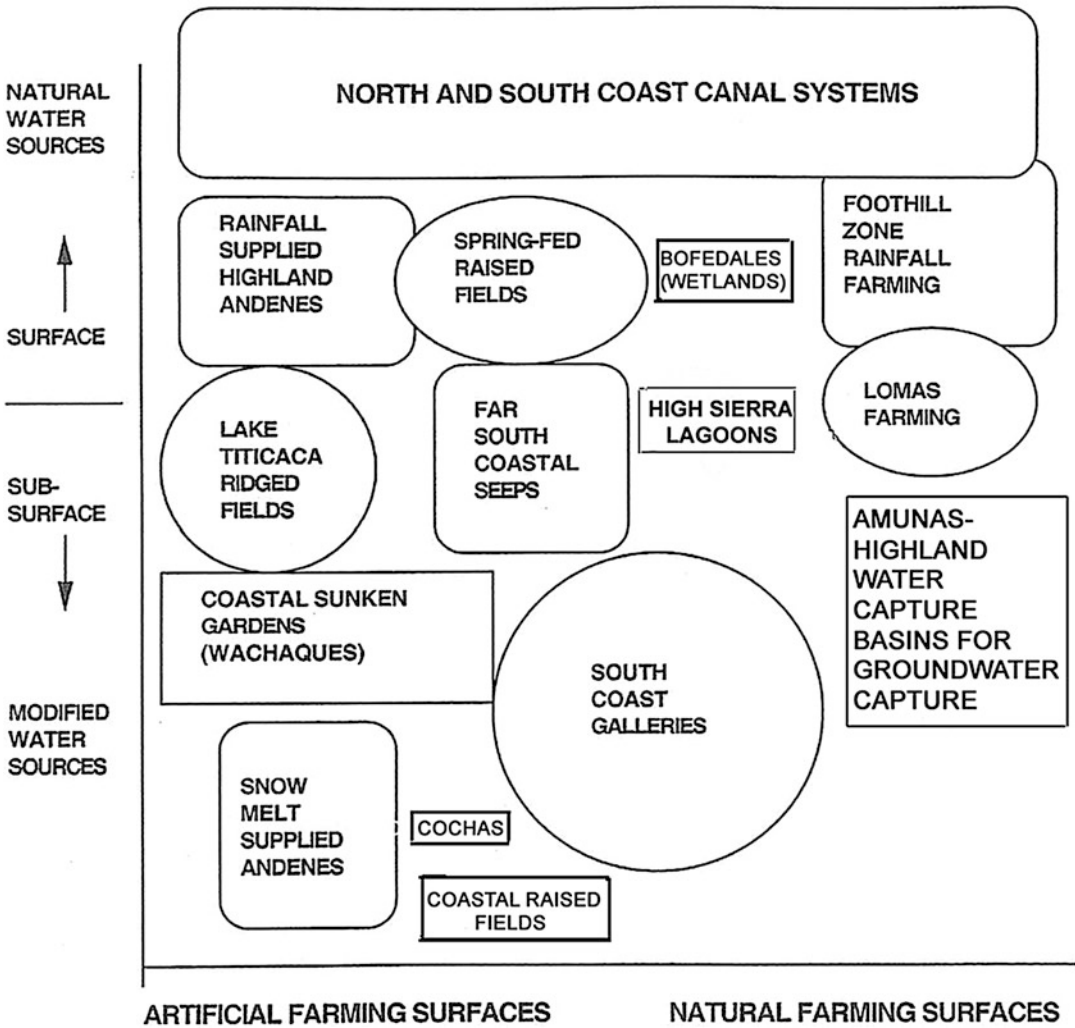
A characteristic of Andean coastal societies revealed from the archaeological record was their vulnerability to periodic El Niño flooding and drought (Moseley, 1987, 1997, 2008; Ortloff, 2009). Climate research (Abbott, et al. 1997; Binford, Kolata, & Brenner, 1997; Shimada, Schaff, Thompson, & Moseley-Thompson, 1991; Thompson et al., 1982, Thompson, Hastenrath, & Arnao, 1989; Weng et al., 2000) reveals sixth- and



Water Management in Ancient Peru, Fig. 1 Site map of Peru

tenth-century CE drought periods affecting survivability of major Andean societies (Ortloff & Moseley, 2008; Fig. 2). In other cases, flooding caused severe damage to canals and field systems through deposition/erosion events and geophysical landscape change that degraded agricultural and marine resource areas (Contreras, 2010; Moseley & Deeds, 1982; Ortloff, 2012). For extensive drought periods, the archaeological record indicates migration from homeland areas to areas with greater water/land resources (Dillehay, 2001). In other cases, intervalley canal construction projects were initiated to transfer water from adjacent, water-rich river valleys to resupply desiccated intravalley canal-supplied field systems (Ortloff, Moseley, & Feldman, 1983). Where reconstruction/repair solutions were not feasible for societies

whose water supply systems did not permit modification or innovative water management/transfer solutions, these societies disappear from the archaeological record (Fig. 2). In contrast to coastal societies, highland societies using terrace agriculture were able to transfer agriculture to higher terrace elevations where higher rainfall levels prevailed as drought initiated. For the Bolivian Tiwanaku society located on the Bolivian altiplano, raised-field agricultural systems dependent upon groundwater provided short-term drought defense (Ortloff & Kolata, 1993). In contrast, coastal irrigation relying on water from highland watershed areas sourcing coastal rivers was diminished by evaporation and ground absorption with only a small percentage available for irrigation agriculture. In northernmost Peruvian coastal valleys,



Water Management in Ancient Peru, Fig. 2 Agricultural strategies practiced by Andean societies subject to different ecological conditions: the variety

of categories shown are for natural and modified (artificial) landscapes for surface and subsurface (groundwater) water sources

societies constructed extensive intervalley canal networks to direct river water from adjacent valleys to intravalley farming areas (Kosok, 1985) to enhance agricultural production. As agricultural productivity for different societies was subject to frequent unstable weather/climate anomalies affecting water supplies, water management needed to be adaptable to changing environmental challenges to maintain production.

To quantify the development of water management and its relation to sustainability of different Andean societies, an equation governing

agricultural sustainability is presented consisting of terms relevant to agricultural productivity (water supply/management, agricultural system type, and vulnerability to flood/drought conditions, land area, fertility, population in balance with food supply), response to agricultural crises (technology innovation, food storage, labor supply), and intensity/duration of a climate change event. The equation sums contributions from these terms to yield a sustainability “score” characterizing different societies’ success or failure responding to climate crises given their

agrosystem's characteristics. While explanations involving environmental, sociopolitical, ideological, and cultural factors influence societal continuity and sustainability (Renfrew & Cooke, 1979; Bawden & Reycraft, 2000, 2009), the sustainability equation focuses on vulnerabilities of different agricultural systems used by different societies in different ecological zones to reveal causes for agricultural system failure (or success) under climate duress. In subsequent sections, all contributing sustainability (Q) equation components are discussed in detail as to their relevance to agricultural system sustainability/water management under climate change events and integrated into the subsequent Q equation section (**The Q Sustainability Equation**) to produce Fig. 4 results.

Runoff Ratio (R)

During drought, coastal farmland that normally supports an abundance of crop types supports a reduced number of types with low water demands and yields are reduced in response to lower water supplies. Sierra rangeland, in contrast, supports pastoralism and crops adapted to cold extremes based upon elevated rainfall amounts at higher altitudes. One reason for differences between coastal and highland agriculture under drought is related to soil properties that influence rainfall infiltration, runoff, and transport rates from highland rainfall sources. Highland soils retain water within their porous structure until saturation is reached; past this level, runoff occurs to supply coastal rivers sourcing valley irrigation systems. Channeled runoff is subject to evaporation and subsurface absorbance effects resulting in imbalances in the rainfall/runoff delivery rate from sierra to coastal areas. To illustrate effects of drought and the hydrological relationship between rainfall, soil properties, runoff and flow losses, a Moquegua Basin example is given.

The Moquegua Valley lies on the Pacific watershed west of Lake Titicaca. The valley river system is 139 km in length with headwaters reaching above 5,100 masl. Along the Moquegua

coast precipitation is negligible but increases gradually in the interior with altitude. However, the quantity of rainwater only exceeds saturated retention values in 19 % of the basin above 3,900 masl. Between 3,900 and 4,500 m, average rainfall is ~360 mm/year and about 260 mm of this amount is retained in saturated soil so that only 100 mm is available as runoff (ONERN, 1976). In this zone, a 10 %, or 36 mm, decline in rainfall to 324 mm decreases runoff by 36 % from 100 to 64 mm. For soil retention capabilities typical of this area, a 15 % decrease in rainfall results in a 54 % decrease in runoff. In the elevation zone between 4,500 and 4,900 masl, rainfall averages 480 mm/year and a 10 % or 15 % rainfall reduction results in runoff reductions of 21.8 % and 32.7 %, respectively. Comprising less than 3 % of the Moquegua Basin, precipitation above 4,900 masl is principally snow and ice, and the runoff contribution is unknown as the amount of moisture retained in glaciers and snowfields is unknown. For the upper river basin, rainfall declines of 10–15 % result in runoff reductions of 25–40 % or more. The asymmetric relationship between rainfall and runoff works in reverse: increased precipitation rapidly saturates soil and amplifies runoff. Other than during spring floods, the valley river does not normally carry surface flow at elevations below 1,200 masl and farming in the coastal section of the drainage depends on groundwater springs originating high in the river basin. The relationship between highland rainfall and coastal spring flow is asymmetric because subsurface water flows through aquifers of different porosity, permeability, and saturation values. Although these values are poorly known, coastal spring flow may have dropped by 80 % during the tenth- to eleventh-century CE drought (Ortloff, 1989, 2009). Coastal river hydrographs track availability of coastal irrigation water over time and variations exist between coastal valleys depending on soil geomorphology, topography, agricultural activity, and temperature/humidity history. Nonetheless, drought has a greater effect on coastal irrigation farming than on sierra rainfall farming. Even after the arrival of irrigation water to coastal field systems, approximately 85 % is

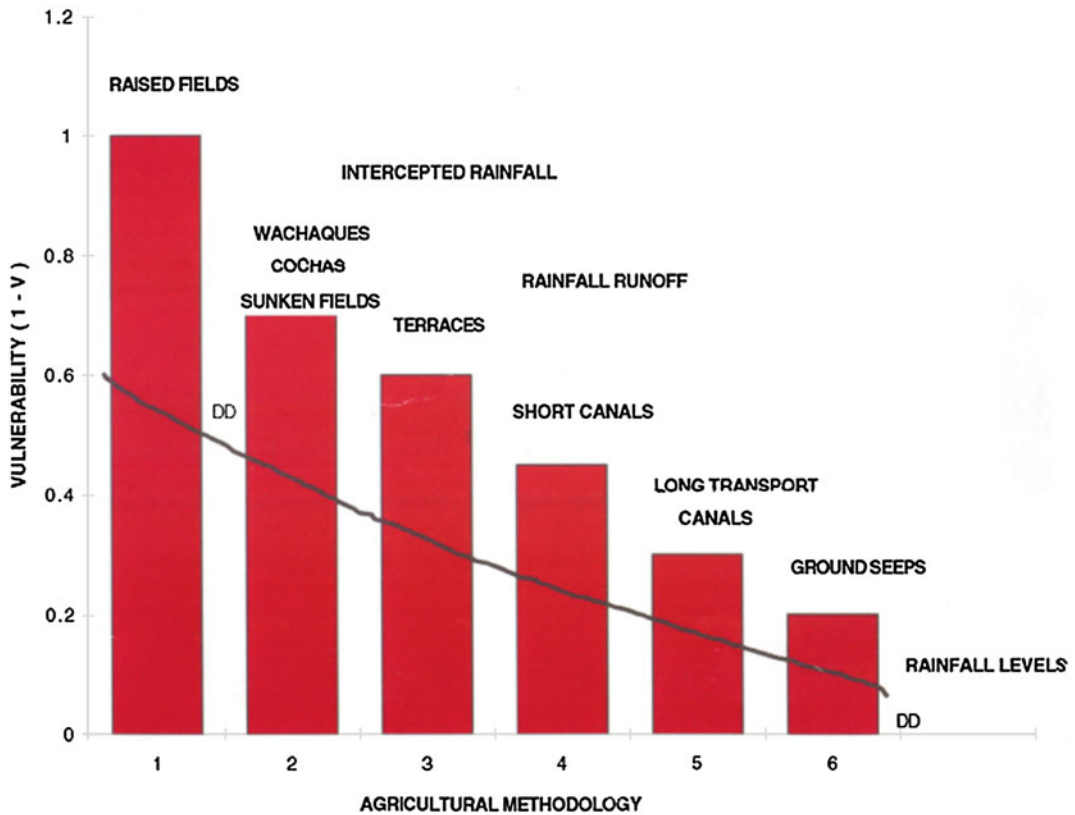
lost to evaporation from soils leaving only 15 % absorbed by plant roots. In dry periods, rain at high altitudes may sustain limited highland agriculture but coastal agriculture derived from runoff into rivers from the same watershed will experience a severe irrigation water deficit.

To quantify these effects, a Runoff Ratio (R) is defined as the average rainfall runoff rate from a watershed area divided by the average rainfall delivery rate to the same area. Coastal societies dependent upon irrigation from highland runoff sources are characterized by $R < 1$ in normal rainfall periods and $R \ll 1$ under drought conditions. Societies dependent upon groundwater-based agriculture experience $R < 1$ in normal rainfall periods due to limited rainfall infiltration to groundwater and $R \approx 0$ under extended drought conditions. Highland terrace systems dependent upon rainfall have $R \approx 1$ in normal rainfall periods and $R \ll 1$ under drought conditions. Here drought is not necessarily total absence of rainfall but rather a decrease in average seasonal levels over an extended time period.

Vulnerability Index (V)

Another component influencing agricultural sustainability/water management is the design and function of field systems given their water supply systems. Different sites throughout Peru employed different agricultural systems (Fig. 2) tailored to local ecological conditions. Each system type is assigned an integer V value (Fig. 3) related to its ability to maintain productivity at different water supply levels. The relative integer values rank the survivability of different systems relative to each other under water deficit conditions. Highly vulnerable agrosystems rely on a continuous supply of water from seasonal rainfall runoff; when long-term drought occurs, these systems fail as $R \ll 1$. Raised-field agriculture (Fig. 3, Index 1), widely practiced by the 300 BCE–CE 1100 Tiwanaku society (Kolata, 1993; Kolata & Ortloff, 1989; Moseley, 1992) on altiplano areas bounding the southern periphery of Lake Titicaca, consisted of agricultural soil mounds constructed from excavated troughs.

Troughs were dug below groundwater level and were relatively invulnerable to short-term drought as groundwater recharge flow from infiltrated rain deposited into distant watershed areas continually sustains the groundwater level in troughs. Raised fields were relatively invulnerable to excessive rainfall because elaborate field drainage canals shunted excess water directly into Lake Titicaca limiting groundwater infiltration. Because rainfall infiltration and Lake Titicaca height vary with seasonal and longer-term rainfall/runoff fluctuations, the groundwater profile necessary to maintain the swale water height and the phreatic zone within raised-field mounds to support different crop types is altered. Thus, shifting of agricultural zones toward available high groundwater areas distant from Lake Titicaca margins sustained limited agriculture during drought and provided limited agricultural sustainability. The next least-vulnerable agricultural systems to drought are sunken gardens dug to the phreatic groundwater boundary to support agriculture (Index 2). Here the slow decline of groundwater level yields relative invulnerability to short-term drought. The next level of vulnerability (Index 3) is represented by agricultural terraces widely used by highland societies. Terraces supplied by normal rainfall levels provide a highly productive agricultural system, but when rainfall diminishes, these systems become marginal for production unless supplied by snow melt and/or spring-channeled water. Next in increased vulnerability (Index 4) is canal irrigation practiced by Peruvian north and south coast societies. These systems are productive when highland rainfall exceeds saturation conditions ($R \approx 1$) but vulnerable due to the asymmetry between highland rainfall and runoff to coastal valleys. Generally, long canals are more vulnerable (Index 5) than short canals due to greater seepage/evaporation losses. Yet more vulnerable systems (Index 6) are coastal seeps that supply agriculture in the Ilo area of the Moquegua Valley (Fig. 1) and rely on groundwater seepage to coastal areas over long underground distances. A variant of these systems found in the Casma Valley (Moore, 1988, 2000, Figs. 1 and 2) represent temporary, high productivity agriculture



Water Management in Ancient Peru, Fig. 3 Vulnerability Index classification values; different agricultural systems exhibit different vulnerabilities to

drought/flood conditions depending on defensive designs that incorporate memory of prior climate/weather events

derived from infiltrated El Niño rains amplifying the valley water table profile. Survival of the more vulnerable agrosystems is questionable below a critical water supply level (DD, Fig. 3) with system extinction inevitable whenever reconfiguration to a lower vulnerability system is impossible. A Vulnerability Index ($1-V$) defined in Fig. 3 is such that the largest values of the index denote the least-vulnerable agrosystems.

Technology

Agrosystem sustainability subject to weather/climate variations depends on the ability to modify/incorporate a defensive water management technology T in time t , denoted as (dT/dt) , faster than the creation/evolution rate of a climate-related

disaster (dD/dt) in the form of floods and/or extended duration drought. For $0 \leq dT/dt \leq 1$, $dT/dt = 0$ means no timely water management/engineering modifications available/possible to defend against severe climate challenges; $dT/dt = 1$ denotes engineering/labor/management solutions available to maintain/sustain productivity during climate challenges. To quantify the definition of climate-related disaster between limits $0.5 \leq dD/dt \leq 5$, reference is made to the duration and severity of drought/flood periods indicated by ice core, limnological and paleobiotic data (Abbott et al. 1997; Contreras, 2010; Tapia et al., 2000; Thompson et al. 1982, 1989). Societies utilizing a low-vulnerability agricultural system dependent upon groundwater exhibit a slow response to drought for which dD/dt is low (~ 0.5); societies dependent upon high- vulnerability canal

irrigation experience rapid decline in water supplies from low runoff during drought for which dD/dt is high (~ 5). For flood events, dT/dD is low due to the rapid destructive onset of flood-water on canal irrigation systems that lack flood defenses. While some flood defense systems have been noted in the Intervalley Canal and Jequetepeque Valley canal systems (Ortloff, 2009), research in this field is in a preliminary stage.

The Q Sustainability Equation

In literature related to the collapse of civilizations (Diamond, 2004; Renfrew & Cooke, 1979; Scarborough, 2006), causative criteria link damage from climate change effects on agriculture as one of several factors influencing societal transformation. The basic premise is that if agriculture fails, then societal transformation is inevitable. Factors affecting agricultural sustainability for systems of different vulnerability classes include use of food storage structures (S), water engineering to counter an agricultural production decline (dT/dt), and a labor force as a fraction of the total population P' to implement defensive strategies. Other factors include field system yield per unit area (Y), field area under production (A), and the available water supply (R). The time-dependent magnitude of a developing climate threat (dD/dt) in relation to the rate of water engineering defense against developing threats (dT/dt) is a further element in the trend equation that influences agricultural sustainability. The influence of individual terms is given by numerical values to denote their presence, use intensity, and application. The sum (Q) of numerical values from individual components permits a “score” useful to compare different societies’ success or failure dealing with climate-related stress. Quantities (Q , R , S , V , A , Y , P' , dT/dt , dD/dt) are number values normalized to the maximum reference state for each variable. A large value of Q over time connotes agricultural sustainability, while a small value denotes the opposite. In the trend equation, values specified for the Vulnerability Index are shown in Fig. 3; S is given a numerical

value depending upon its presence or absence; P' reflects the degree to which population is balanced with the available food supply and the derivative terms indicate the duration and magnitude of drought events and defensive engineering technologies available to maintain agricultural sustainability. The Q equation applies for a closed system (food supply from near vicinity areas of a capital city/satellite center with no imports from remote areas) and is given as

$$Q = S + YAR + (1 - V) + P'(2 - P')(dT/dt)/(dD/dt)$$

Here R is the Runoff Ratio ($0 \leq R \leq 1$), S the agricultural storage capacity ($0 \leq S \leq 1$) normalized to S_{mx} where $S = 0$ represents no crop storage, and $S = 1$ represents storage of all non-consumed crops. Intermediate S values indicate limited food storage facilities for defense against short-term crop failures. $(1 - V)$ is the agricultural Vulnerability Index ($0 \leq V \leq 1$). YAR represents crop yield per unit area (Y) times the total field area (A) in production times the available area water supply; parameters are normalized to their maximum values so that $0 \leq YAR \leq 1$. The lower limit indicates poor crop yield over a small land area with limited water supplies, while the unity limit indicates high crop productivity over the largest available agricultural area sustained by irrigation. $P' = P/P_{mx}$ is the population where P_{mx} is the maximum possible population sustainable by the agrosystem. When $P' = 1$, then $P'(2 - P') = 1$ at the maximum population level sustained by the food supply (or, equivalently, $\partial Q/\partial P' = 0$ at $P' = 1$). If $P' \rightarrow 0$, then $P'(2 - P') \rightarrow 0$, resulting in a small population as may occur after a natural or man-made disaster. Thus, $0 \leq P'(2 - P') \leq 1$ is the range of population variation from balance with the food supply ($P' \approx 1$) to out-of-balance extremes that limit the labor force as a fraction of P' necessary to implement labor-intensive farming or construction tasks. The lower limit may result from out-migration, famine, warfare, or other population decline/dispersal situations resulting from climate/political/economic instabilities, while the upper limit represents a stable

food supply/population balance. Intermediate values result from population size adjustments to declining food supply from a variety of destructive weather/climate effects and signal-insufficient labor to implement defensive measures for a sufficient $dT/dt \rightarrow 1$ response. The engineering/technology term $0 \leq dT/dt \leq 1$ represents the time rate of technology (T) change to counter destructive weather/climate change effects on agricultural production (excessive rainfall, drought, climate-induced geophysical landscape changes); $dT/dt = 1$ represents engineering technology sufficient to successfully respond to agricultural duress with remediation repair/modification efforts. The dD/dt term represents the rate of disaster-producing effects; for $0.5 \leq dD/dt \leq 5$, large values occur for rapidly evolving disasters (e.g., El Niño flood events) and small for slowly evolving weather/climate variations that pose gradually increasing threats to agricultural production. When $(dT/dt)/(dD/dt) = dT/dD \rightarrow 2$, engineering technology to defend against slow decreases in water supply exceeds the rate of disaster evolution leading to positive contribution to agricultural sustainability. If a flood event occurs beyond any defense counter to provide field system protection, then $dT/dD \rightarrow 0$ indicating little or no contribution to agricultural sustainability. If a weather-/climate-related disaster evolves at the same rate as defensive response technology, then dT/dD is a positive number with a contribution to sustainability. If $P' < 1$, the labor to make rapid dT/dt corrections is not available and Q decreases. If $P' \rightarrow 1$ in the presence of a declining water supply, then agricultural resources are inadequate to feed a large workforce over time to ensure rapid dT/dt changes. Thus, only population balanced with agricultural supply promotes large Q values. From the Q equation, sustainability is enhanced when the runoff ratio/water supply (R), land area (A) in cultivation, and crop storage (S) are high, a stable population is balanced with agricultural output ($P' = 1$), system $(1-V)$ vulnerability is low, the engineering innovation rate dT/dt exceeds the weather/climate-induced disaster evolution rate dD/dt , and soil productivity (Y)/unit water input is high. High Q values over time indicate a society with foresight to maintain sustainable agriculture

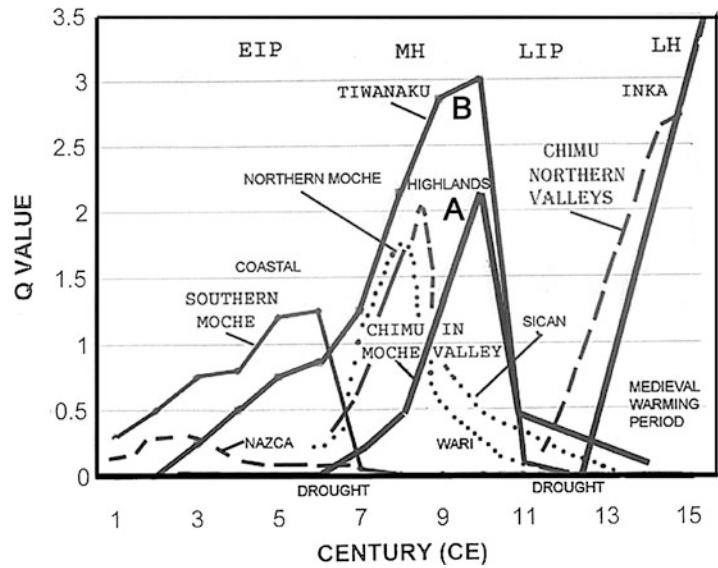
despite weather/climate variations; low Q indicates gaps in the perception of climate threats and inadequate disaster defenses resulting in marginal agricultural system performance. For extreme, long-lasting drought, Q ultimately drifts to smaller values in time indicating that sustainability is no longer possible.

Numerical Values for the Q Equation

To illustrate Fig. 4 Q values for drought originating in the tenth to eleventh centuries for the Chimu Moche Valley presence, $S = 0.5$ indicating comestibles storage within Chan Chan but few other compounds devoted to food storage. $(1-V)$ is ~ 0.5 indicating dependence upon runoff-based, short intravalley canal systems. YAR is composed by $Y = 1$ from fertile alluvial valley soils for large agricultural areas ($A = 1$), but $R = 0.5$ indicating decreasing tenth-century highland runoff to Chimu field systems. $P' = 1$ indicating a population previously balanced with food resources before drought onset. dT/dt is close to unity to improvise technological changes to combat drought but $dD/dt \approx 2$ with higher values immanent as drought intensified over time. Summing up the contributions from individual components, $Q \approx 0.5 + 1 \cdot 1 \cdot 0.5 + 0.5 + 1 \cdot (1/2) = 2$; this value is represented by point A in Fig. 4 and presages late LIP abandonment of Moche Valley agrosystems as drought intensified. As a further example, Tiwanaku society experienced tenth- to eleventh-century drought; here $S = 0.4$ from urban circular structures used as food storage facilities with $YAR = 0.8 \cdot 0.8 \cdot 0.4 = 0.24$ representative of declining yields from declining areas as drought progressed. As raised fields are dependent upon groundwater/spring water, $(1-V) \approx 0.5$ indicating increased vulnerability as drought progressed. $P' = 0.95$ reflecting a trend away from population levels balanced with food supplies as tenth- to eleventh-century drought continues. As immediate consequences of drought on groundwater-dependent raised-field systems was gradual, $dD/dt = 0.5$; this value increases steadily as drought intensified over time. Labor to alter

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Fig. 4 Sustainability Q values versus time for different Andean societies



vast raised-field areas to follow down the declining water table was not available implying $dT/dt = 0.6$. Summing up individual contribution components,

$Q \approx 0.4 + 0.24 + 1 + 0.95 \cdot (0.6/0.5) = 2.8$ and is represented by point **B** in Fig. 4 at tenth-century drought initiation. Later times experience severe Y, R, and urban P' decreases leading to abandonment of Tiwanaku city. Data from early phases of other major societies in periods of adequate rainfall and terminal phase drought are used in Fig. 4.

Historical Climate Variation and Agricultural Sustainability of Andean Societies

Intermediate and Horizon periods characterize Andean historical patterns. The Early Intermediate Period (EIP, 100 BCE–700 CE) is characterized by north coast Moche architectural/agricultural complexes, central coast Lima societies, and south coast Paracas and early Nazca societies. EIP Moche settlements south of the Jequetepeque Valley and south coast Nazca settlements had minimum Q values in the sixth- to seventh-century CE coincident with a drought episode (Shimada, 1994a, 1994b; Shimada et al., 1991; Thompson et al., 1982, 1989) and

relied on runoff water channeled into coastal river valley irrigation systems; the Nazca relied on groundwater-based, subterranean gallery water supplies. Drought reduced agricultural sustainability for Index 4 and 5 systems characteristic of north and south coasts where low R prevailed. Late EIP transfer of Moche traditions to northern coastal valleys and integration with local Gallinazo societies led to new city centers (Bawden, 1999, 2010; Bawden & Reycraft, 2009; Shimada, 1994b) with amplified land and water resources for agriculture. Seventh-century CE drought influenced collapse of Lambayeque Valley Sicán society with abandonment of Batán Grande. Later construction of Tucumé resurrected Sicán society only to fall to Chimu expansion in the fourteenth century CE. During the Middle Horizon (MH, 700–1000 CE), Tiwanaku and Wari societies dominated the southern/central Andean highlands through political, economic, military, and religious influences. Wari settlements in the Ayacucho area were supplemented by dispersed administrative centers at Pikillaqta, Cajamarquilla, Viracochapampa, Cerro Baúl, Huanuco Pampa, Jincamocco, Chuquibamba, and Wari-Wilka. The Late Intermediate Period (LIP, 1000–1490 CE) was characterized by Chimu north coast occupation from the Chancay to Lambayeque coastal valleys (Mackey, 2009) with administrative centers (Farfán,

Manchan, Purgatorio, Túcume) and ceremonial centers (Pacatnamú, Chotuna) administered from the capital city of Chan Chan. Centrally administered, multi-valley agricultural complexes directed from satellite administrative centers sharing common political/social/religious practices characterized LIP times. Inka military conquest and dominance of highland and coastal societies characterized the Late Horizon (LH, 1490–1532 CE). The climate change history reflected in the Quelccaya/Huascarán ice cores (Thompson et al., 1982, 1989), Lake Titicaca, and Cuzco area sediment cores (Abbott et al., 1997; Binford et al., 1997) indicate drought episodes (570–610 and 650–730 CE) in the late EIP influencing decline of coastal Moche and Nazca polities. Drought-induced low Runoff Ratio R combined with high-vulnerability irrigation systems resulted in low dT/dD as water management strategies/engineering innovation could not overcome long-term drought effects.

In early LIP times the Chimú brought water management to a high level through advanced hydraulic technologies (Ortloff, 2009) that permitted the development of intravalley canal networks (Fig. 2). As drought progressed in late LIP centuries, a limited degree of Moche Valley irrigation restoration occurred through combined use of the Chicama-Moche Intervalley Canal and Chimú strategy involving transfer of agriculture to northern valleys away from their Moche Valley heartland through conquest of the Lambayeque Valley Sicán ~1375 CE that provided large land areas and high flow rate rivers.

The Tiwanaku achieved high sustainability until the long-term tenth- to eleventh-century drought lowered the water table beyond levels to support agriculture. Sustained drought reduced annual rainfall levels by 5–10 % from previous norms depressing water table height and agricultural yield. Relocation of agricultural zones to distant high water table areas and employment of *cochas* marginally extended sustainability as drought progressed resulting in population resettlement in small groups away from city precincts (Janusek, 2004). Wari penetration into the Moquegua Valley was enhanced by a short period of above-average precipitation in early MH

times, but toward late MH, diminishing rainfall levels undermined agrosystem productivity as multi-century drought set in after ~1100 CE (Abbott et al., 1997; Baker et al., 2001; Thompson et al., 1982). Wari sites in northern sierra locations were abandoned in this time period. While Tiwanaku raised fields had capability for agricultural area shifts, the option to lower all 80,000 km² of raised-field troughs to follow down the retreating water table would require vast labor input, while food supplies continually declined. Thus, no long-term drought recovery was possible for the Tiwanaku society past 1100 CE. In contrast, multi-valley Chimú canal networks monitored through dispersed, state-controlled administrative centers utilized advanced water management technologies and large labor resources permitting installation/expansion of irrigation systems supplied by larger flow rate rivers in conquered and settled far north coast areas. Although highland terrace agriculture countered drought by elevating farming zones to take advantage of higher rainfall levels, yields (Y) decreased due to poor soils, cold, and decreased farming area (A). The MH Wari expansion into northern coastal/sierra territories provided new territories and colonies with less vulnerable agrosystems than their heartland terrace systems. While details of Wari expansion are fragmentary, little is seen of Wari sites past twelfth century CE indicating decline of coastal and highland administrative centers (Fig. 4).

Expansion of Moche, Tiwanaku, Wari, and Chimú societies away from their heartland capitals was their strategy to gain additional resources in territories with less vulnerable agrosystems (Murra, 1985). The water supply advantage to highland systems was manifest in the LH to the advantage of the Inka as rainfall levels restored to earlier norms. The Inka policy of population relocation to revitalize lowland agricultural centers in different ecological zones (D'Altroy, 2003) initiated the end of conquered LIP societies. The Inka were beneficiaries of increased LH rainfall as successive rulers expanded conquered territories and resettlement of conquered peoples to industrialize agriculture to high productivity levels. With Inka conquest and incorporation of Chimú

territories in the late fourteenth century CE, the Chimu disappear from the archaeological record as their cultural symbols, practices, cities, and settlements were subsumed by Inka overlords.

Figure 4 shows Q histories for major Andean societies and illustrates that climate change appears to be a significant factor influencing Andean historical patterns. While societal socio-political events influence transition scenarios, once the agricultural base collapses, the foundational underpinnings underwriting societal continuity are altered.

Conclusions

Without sustainable agriculture and water management practices that can survive weather/climate excursions beyond norms on which agricultural system designs were originally made, destabilizing conditions challenge societal continuity. As an example, LIP Chimu water management proceeds through intravalley canal rebuilding/modification/extension programs and flood/drought defensive measures (Ortloff, 2009, pp.199–204) that increase cultivated land areas and productivity commensurate with increasing population demands. They show, under tenth- to eleventh-century climate change duress, intervalley mega-canal building projects and conquest of northern valleys as the solution to sustain and grow agriculture. For the MH Tiwanaku, no major modifications were available to continue raised-field agriculture as groundwater levels declined and limited raised-field agriculture leading to abandonment of the capital city in the tenth to eleventh century. MH Wari society likewise declined due to drought in the same time period as their terrace agricultural systems failed under decreased rainfall amounts. Figure 4 indicates results for other major Andean societies in response to sixth- and tenth-century droughts leading to their continuance or disappearance from the archaeological record depending upon the flexibility and adaptability of their agrosystem designs to allow water management/engineering response technologies under decreasing water supply. Thus, water

management survival strategies continually developed to match climate challenges over time for Andean societies, and the success of these strategies decided either their survival or collapse as the archaeological record indicates.

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Water Procurement in the Prehistoric Caribbean

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When Ceramic Age peoples arrived in the Caribbean, water was readily available on some volcanic islands like Dominica but virtually absent on most of the coral islands like Barbados. Initially this would have been a major constraint to settlement and survival. In years of regular rainfall, rainwater could be collected from rock pools, caught in foliage of plants and collected in pottery vessels or even upturned conch shells. When the rains failed, however, drought would have led to serious problems on islands without the ability to maintain surface water supplies in the form of rivers

and streams. On at least three islands in the southern Caribbean, Barbados, Mustique and Carriacou, Amerindians developed a specific alternative way of guaranteeing a water supply. It may be assumed that the technique was used on other islands although archaeological evidence has not yet been located.

On coral rock islands (Machel, 1999), where the bedrock is highly permeable, salt seawater may infiltrate under all of the island or at least around the coastal fringe. Rainwater falling onto the island will seep down until it reaches denser salt water. It will then flow towards the sea on this denser water. At the head of beaches it will be quite shallow before it mixes with seawater (Schultz, 1995). Somehow Amerindians recognised this source of sub-surface fresh water and tapped into it. Although similar to sinking wells elsewhere in the world, the process of tapping into this water required great skill; otherwise salt and fresh water would be mixed and the water source spoiled.

Excavations at the Amerindian settlement at Heywoods (Port St Charles) on the west coast of Barbados revealed two methods used to tap into this shallow supply of fresh water (Drewett, 2000). The main Ceramic Age settlement at Heywoods was occupied from about AD 600 to AD 1200 (Late Saladoid – Troumassoid). Several round houses and burial areas have been excavated together with wood- and pot-lined water holes (Drewett, 2000).

Two wood-lined water holes were excavated. These consisted of wood planking some 1 m in length sunk into the soft sand and held in place by large coral rocks. Both were roughly square in shape (Fig. 1).

The wood used was false mastic (*Mastichodendron* sp.) and *lignum vitae* (*Guaiaecum* sp.). One was dated to ca. AD 780–1020 (B-147314) and the other to ca. AD 790–1030 (B-147313). In both wells calabash (*Crescentia cujete*) remains were recovered suggesting these were used to scoop up the fresh water (Fig. 2).

More common, and possibly more successful, were the pot-lined water holes. A shallow hole was dug into the underlying wet sand and a large



Water Procurement in the Prehistoric Caribbean, Fig. 1 Wood-lined water hole at Heywoods, Barbados. ca. AD 800–1000 (Source by author, photo by Abel Drewett)



Water Procurement in the Prehistoric Caribbean, Fig. 2 Calabash water scoops from wood-lined water hole at Heywoods, Barbados. Fragments on left ca. AD 800–1000. Modern example on right (Source and photo by author)

cooking/storage pot was sunk into the wet sand. These pots had been pre-prepared with their bases carefully removed (Fig. 3).

The pot was carefully pressed into the wet sand while more sand was scooped out of the interior. Additional pots were then stacked on top, acting as a cofferdam to stop wet sand slumping back in. The pots were held in place with coral rock boulders and/or wooded wedges. After a couple of hours any sediment in the water



Water Procurement in the Prehistoric Caribbean, Fig. 3 Large cooking/storage pot with base removed found in pot-lined water hole at Heywoods, Barbados. ca. AD 1000–1200 (Source by author, photo by Abel Drewett)



Water Procurement in the Prehistoric Caribbean, Fig. 4 Pot-lined water hole at Heywoods, Barbados. ca. AD 1000–1200. Plan view (Source by author, photo by Abel Drewett)

would settle with the pressure of the underlying water pushing the fresh water up into the pot-lined hole (Figs. 4 and 5).

It is uncertain whether these pot-lined water holes were left open or had a removable cover. None were found covered although several had large sherds of pottery in the water holes, which could have been used as lids. Flat cassava griddles found elsewhere on the site would have also made suitable lids, as would organic materials like large leaves or planks of wood. A major problem was probably local soiling of the water by domestic rubbish or even human burials, which were also within the domestic area. This might explain why holes had to be regularly



Water Procurement in the Prehistoric Caribbean, Fig. 5 Pot-lined water hole at Heywoods, Barbados, ca. AD 1000–1200. Section view (Source by author, photo by Abel Drewett)

replaced. Twenty three were systematically excavated during the main phase of salvage excavations at Heywoods during 1998/1999, but many more were noted during building work for the Port St Charles marina constructed on the site.

Some of the pot-lined water holes had a highly decorated pot rest resting on the top of the stack. These are like ceramic collars in which large unstable pots were set to make them stable on uneven ground. One found was 32 cm in diameter and 17 cm high. It was red-slipped with white on red paint and grooved decoration in a concave-ended rectangle and vertical line pattern. This was among the finest pottery found on the site, so it would suggest great importance of the mouth of the hole. Tapping into this underlying source of water may have involved great perceived risk involving careful ritual, for Amerindians believed that a river of the dead ran under their houses and settlements. Ritual specialists were no doubt involved in the placing and digging of these pot-lined water holes and perhaps hallucinogenic drugs, like cohoba, were taken prior to digging rituals (Drewett, 2002).

How widespread the use of pot-lined wells was in the prehistoric Caribbean remains uncertain particularly because of limited archaeological excavation in the southern Caribbean. To date they have certainly been recorded on three

sites on Barbados: Heywoods, Spring Garden and Maxwell. They have also been recorded on Mustique and Carriacou. Many further examples may have been lost by coastal erosion or await discovery.

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Water Systems in Bronze and Iron Age Israel

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The Near East is located on the edge of the desert. Part of the region is arid/semiarid, and as droughts are a frequent phenomenon, water is a scarce resource even in the Mediterranean climate zone. Water was therefore an important factor determining the situation of settlements in antiquity. Initially, many settlements were located near water sources, mainly springs (rivers are a rare phenomenon in Israel). However, since security was also a major consideration, larger settlements gradually tended to be situated on top of hills. In this conflict of interests, security had, in most cases, the upper hand, and alternative means of obtaining drinking water had to be secured.

Wells

A well is an artificial shaft sunk into the ground all the way to the water table. One of the earliest known wells was uncovered at the submerged Neolithic village of “Atlit Yam.” Later wells are known from Beersheba, Lachish, and Tel Zeror, and it seems as if the practice became widespread from the Iron Age onward (and mainly from the Classical periods). Notably, however, wells are typical of lower regions and plains. It is more difficult to dig wells in mountainous areas because of both the depth of the water table and the hardness of the rocks. Wells were, therefore, only a partial solution, and in most cases, people used different methods (see below).

Cisterns

Cisterns were cut out of rock in order to collect and store rainwater. The first known cisterns were apparently dug into the soft limestone of the coastal plain in the late Chalcolithic or Early Bronze Age at Mesar. The earliest cisterns were not plastered, but due to the softness of the stone could still hold the water. The first plastered cisterns were discovered in several Middle Bronze Age sites (e.g., Hazor and Gezer) (see section “[Extra 1: The Open Cisterns of the Negev in the Tenth Century BCE](#)”). Their use, however, was still sporadic. Plastered cisterns became widespread only during Iron Age I and mainly in Iron Age II. The use of cisterns became even more widespread in later periods. While cisterns became common and at times dozens of cisterns were unearthed in a single site, it appears that they were still dug at the family level. Communities, let alone cities/states, had to develop a better solution to the danger posed by the scarcity of water.

Large-Scale Waterworks

Large settlements, if not located on a large spring or a river, needed a guaranteed water source for the summer, and all the more so for periods of

siege. After all, the fate of a conquered city in the ancient Near East was horrific, and any effort was done to secure the city and to enable it to withstand siege.

The earliest large-scale waterworks, evidently beyond the scope of the household, are dated to the Early Bronze Age – the time period when the first cities emerged in the southern Levant. These early water systems are basically large pools, usually located in the lowest part of the settlements, into which rainwater was collected. Such systems were found at “Arad,” Ai, and probably also at Tel Qashish. “Arad, located on the edge of the desert, is a unique example. The city was built not on top of a hill, but rather on a basin, probably in order to ease the collection of water. A slightly different type of water system was located outside the city of Jawa, in Transjordan. Here, dams were built on a dry wadi, absorbing floods, and securing water for the dry season. Such large-scale works were able to support a large population.

Still, in the climatic conditions of the land of Israel, in which droughts are frequent and evaporation is high, rains and pools cannot be regarded as a secure source of water. In cases of failing rain, people would have to go to the nearest spring (usually just below the city). In times of siege, however, which began to become a major consideration as time progressed, such an enterprise was not feasible. Cities had to rely on a more permanent and secure source of water. They developed more sophisticated methods to guarantee access to permanent sources of water, i.e., to springs (which were usually located in the valleys below the cities).

Waterworks technology seems to have advanced substantially in the first half of the second millennium BCE. The notable water system of this period (Middle Bronze Age) is that of Jerusalem (see section “[Extra 2: Jerusalem’s Water Systems During the Iron Age](#)”). Here, an attempt was made not only to collect rainwater but also to secure access to the water of the nearest spring – the Gihon – which was located below the city at the Kidron Valley. From within the city, a large tunnel was dug in the hard limestone. The tunnel went outside the city wall until

it reached a fortified pool that was built on the spring and stored its water. An additional water system which is probably dated to this period was exposed at Gezer. Here, a tunnel was dug within the city's confines, reaching the water table (similar to type 3, below, but much earlier).

The real "breakthrough" in water systems, however, was accomplished during the Iron Age and mainly during Iron Age II. A relatively large number of Iron Age water systems were unearthed over the years, and these can be divided into the following types:

1. Covered stairways (galleries). This is the simplest form of Iron Age waterwork. A shallow tunnel was dug on the tell's slope, from beneath the city wall, all the way down to the spring. (A tell is an artificial mound formed by the accumulated remains of ancient settlements.) The tunnel was then covered. Thus, in times of siege, city inhabitants could sneak from the city to the spring through the covered stairway without being seen by the enemy. Such systems were discovered in Megiddo and Tell es-Saiyidyeh. Obviously, these systems had their limitations. The spring was known to the enemy, and the gallery could easily be discovered. Once discovered, it could not have been used anymore.
- 2a. Tunnels. Many Iron Age water systems were dug under the ground, from within the city to the spring. Initially, a large shaft was dug through the earlier layers of the tell. Since these were pretty loose, the shaft was supported by massive retainer walls that prevented their collapse. After reaching bedrock, a smaller tunnel was dug in the rock, at an angle that lowered it toward the spring. Such systems were discovered, for example, in Gibeon and Megiddo (early phase of the tunnel).
- 2b. A modification of this type of water system is also known. In some cases, a tunnel brought the water from the spring toward the bottom of the shaft (i.e., toward the city). Such systems are known, for example, at Megiddo (a later phase), the Warren Shaft system in Jerusalem (see note: Jerusalem water system during the Iron Age) is a variation of this type.
3. "Tunnels" dug to the water table. This type is very similar in its form to the previous one. A wide vertical shaft was dug through the tell's layers to bedrock, and this was followed by a narrow diagonal tunnel that was dug in the rock. This diagonal tunnel, however, did not reach the spring; it descended until it reached the water table (in a sense, this waterwork was like a complex well). While very similar in form to type b, this is simply a large and complex well. Such systems were not only concealed from the enemy, but were also completely secured. Some were discovered, for example, at Hazor and Gibeon (the pool).
4. The last type of large-scale Iron Age waterworks is that of large underground reservoirs, dug into bedrock (inside the cities). Rainwater was collected through an extensive system of plastered tunnels (e.g., at Beth Shemesh) or from floodwaters in nearby wadies (Beersheba). (A wadi is a valley, ravine, or channel that is dry except in the rainy season.) Smaller reservoirs are also known in this period, e.g., in the fort at "Arad." While not as reliable as permanent water sources, it appears as if such large reservoirs could absorb enough water underground to overcome the limitations discussed above (regarding the dependence on rainwater).

The galleries (type 1) were the simplest type, and indeed, they were used earlier in the Iron Age. It appears as if type 2 was developed to overcome the limitation of the galleries. Type 3 was seemingly the most advanced system.

We do not know if these systems were developed on the basis of the knowledge that there was a water table “down there” (the people of the time had to have had this knowledge, as they were familiar with wells) or whether hewers of a type 2 system accidentally reached the water table, and this discovery gave rise to the development of this type (structurally, type 3 is very similar to type 2). This reconstruction is of course speculative, and we need more detailed chronological information in order to confirm or refute it. We also need to remember that some complex water systems were already constructed in the Bronze Age, as mentioned above.

Various water systems are also mentioned briefly in the period’s written sources, e.g., the Bible (e.g., II Kings 20: 20; Isaiah 22: 9–11; II Chr. 32: 30), and ancient inscriptions (e.g., the Mesha inscription).

The most sophisticated Iron Age water system is Hezekiah’s tunnel, which was dug in Jerusalem during the late eighth century BCE. A 533 m long underground tunnel brought the water from the Gihon spring to a lower point that was located in the other side of the city, in order to collect the water in a pool in a secure place.

In later periods, and especially from the Hasmonean and Roman period onward, larger water systems, e.g., 10 km of aqueducts, were built, but this is beyond the scope of this entry.

Extra 1: The Open Cisterns of the Negev in the Tenth Century BCE

During the tenth century BCE, the period of the biblical United Monarchy, dozens of settlements were built in the Negev desert of southern Israel. The exact nature of these sites is debated: some view them as royal forts and others believe that only the initiative was royal, while some consider that the entire phenomenon resulted from the settlement of the desert’s nomads. Notably, these sites were located away from the few springs that exist in the Negev, and their main source of water was large open cisterns that were discovered at practically every site. These large cisterns were probably covered with skins in

order to minimize evaporation. It is also likely that when the rains failed, the inhabitants of many of the sites could go back to the springs, located several kilometers away, and bring drinking water from them.

Extra 2: Jerusalem’s Water Systems During the Iron Age

The Gihon spring of Jerusalem is one of the major springs in the central hill country. It is likely that it was one of the causes for the establishment of the city on the low hill, later known as the City of David. The inhabitants of the city used the spring from earliest times. The most ancient water systems are two tunnels, probably dated to the Early or Middle Bronze Age. During the Middle Bronze Age, an impressive water system was dug in Jerusalem (above in the text). It is during the Iron Age, however, that the most famous waterworks were constructed. As many issues are still debated, the following is only a brief summary that is intended to give a succinct overview, and it cannot deal with all the debated details. The earlier Iron Age system, known as the Warren Shaft (after Captain C. Warren who rediscovered it in the nineteenth century), enabled free access to water through a system of underground tunnels and a shaft. In the past, many scholars believed that it is through this shaft that David conquered Jerusalem (II Samuel 5: 6–9). It appears, however, that this system was constructed only in the eighth century BCE. At this time, improvements were made in the existing system of tunnels (that were cut in the Middle Bronze Age). The works included lowering the bottom of an existing tunnel that led from within the city wall, outward (henceforth, the upper tunnel), thus, exposing a natural karstic shaft that was probably not known before (although some dispute this). Once the shaft was discovered, and its significance was apparently observed, previous works ceased, and it became the central part of a new system. A lower tunnel, connecting the spring and the bottom of the shaft, was dug, enabling the water to flow from the former to the latter. Thus, people could walk in

the upper tunnel, from within the city walls to the top of the shaft, and draw water. The level of the water at the bottom of the shaft was increased through the use of dams, making water drawing easier. Notably, this system was not very convenient and was probably intended to be used only at times of siege. The Warren Shaft system, however, was not in use for long, and it went out of use in the late eighth century BCE, when Hezekiah's tunnel was constructed. Hezekiah's tunnel involved the digging of an underground tunnel that led from the spring to a pool at the other side of the City of David ridge, within the city walls. Hence, all the water from the spring was secured. The last stage of the enterprise involved the meeting of two groups of hewers who worked from both sides of the tunnel simultaneously; this is commemorated in the famous Siloam inscription. (The inscription was discovered in 1880 by a boy who was bathing in the waters of the Gihon Spring and was studied by Conrad Schick, one of the first explorers of Jerusalem. Engraved in the rock, the inscription describes the meeting of the two groups of hewers who had begun digging from opposite ends of the tunnel. "The tunneling was completed. . . While the hewers wielded the ax, each man toward his fellow. . . there was heard a man's voice calling to his fellow. . . the hewers hacked each toward the other, ax against ax, and the water flowed from the spring to the pool, a distance of 1,200 cubits. . . ." The inscription is now in the Istanbul Museum.) Hezekiah's tunnel is an impressive engineering enterprise. Even today, some of the accomplishments still raise questions as to how they were achieved. Among the intriguing questions are, for example, how the workers had enough air during the work, how the two groups were able to meet, and how they were able to maintain such a shallow sloping angle.

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Water Technology in the Andes

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In this entry I describe ancient water technology in the Andes, South America, insofar as it pertains to economic activity. What I do not do here is describe the exclusively ceremonial or ritual uses of water (Glowacki & Malpass, 2003; Lumbreras, González, Lietaer, & Solís, 1976), although water, technology, and ritual do often go together in the Andes (Salomon, 1998; see also, de Avila, 1999 [1598?], p. 419, for an ethnohistoric example). Furthermore, given the geographical extent of the Andes, I focus mainly, though not exclusively, on water management infrastructure in the Central Andes, rather than that found beyond this area, such as the *bordos* – humped earth field boundaries that facilitated irrigated water conduit and retention – of the Catamarca region of Northwestern Argentina (Salminci, Tchilinguirian, & Lane, 2014) and complex causeway and canal network systems of the Amazon such as the Llanos de Moxos (Erickson, 1980, 2008). I should also mention that pre-Hispanic water technology, as applied to farming and herding in the Andes, was generally more varied and productive in the past than at present.

Water technology in the Central Andes can be roughly divided geographically into coast and

highland. Although there were some commonalities in the technology used in both areas, for instance, irrigation canals, there were substantial differences that derive from fundamental dissimilarities in the landscape, peculiarities of water discharge, and its overall availability. The coast desert strip is mainly characterized by water flow, rather than water storage, as seen in features such as irrigation canals, filtration galleries, and diversion embankments, which feed into a system dependent on floodwater and irrigation farming.

The highlands, with its vertical gradients, narrow valleys, and highland alpine *pampas*, favor technologies that emphasize water storage. Coastal water technology is also primarily targeted towards agricultural production, with the possible exception of *lomas* agropastoralism on fields and pastures located on the westernmost outlying hills of the Andes (c. 200–800 m). Agropastoralism along the *lomas* of the central and southern coast is sustained by the endemic winter fogs, known as *garúa*, that prevail in this area (Denevan, 2001; Engel, 1973). Meanwhile, the highlands display a more varied retinue of technological features that have so far eluded simple categorization into solely agricultural production. Indeed, in many cases highland water technology can serve the interests of both farmers and herders as part of a longstanding agropastoralist tradition (Lane, 2006b). Examples of this are the *q'ochas* (Flores Ochoa & Paz Flores, 1986; Flores Ochoa, Paz Flores, & Rozas, 1996) and the artificial *bofedales* (Lane, 2009; Palacios Rios, 1996) described in greater detail below.

Water technology on the coast has been studied intensely (e.g., Billman, 2002; Farrington, 1980; Kosok, 1965; Ortloff, 1993, 1995; Park, 1983; Rostworowski, 1998), while the highlands have merited much less attention. This was a concern already mentioned by Sherbondy (1969, p. 188) in the late 1960s. The reasons for the general paucity of studies into highland water technology are various, ranging from difficulty of access through to the low visibility of these features in the rugged terrain. This bias, which has existed since the time of the first Spanish chroniclers, has only started to be addressed from the

Water Technology in the Andes, Table 1 Main water technologies addressed herein

	Category	Type	Description
Water technology		Terraces	Artificial steps or benches on sloped terrain
		Irrigation canals	Canals distributing water to fields and land features
		<i>Puquios</i>	Underground filtration canals
	Dry	Pond fields (<i>Q'ochas</i>)	Sunken pond fields (highlands)
		Sunken gardens	Artificially depressed land plots
		<i>Camellones</i>	Raised field cultivation fields
		Water dams	Artificial lake
		Water reservoirs	Artificial pond
	Wet	Artificial <i>bofedales</i>	Irrigated moorland
		Silt dam	Large artificial silt trap
		Silt reservoir	Small artificial silt trap or silt terrace

latter half of the twentieth century onwards in the form of pioneering work into highland terracing, or *andenes* (Bonavia, 1967–1968; Donkin, 1979; Treacy, 1994a); raised field systems, also known as *waru-waru* or *camellones* (Erickson, 1986; Erickson & Chandler, 1989); pond fields, also known as *q'ochas* or *cochas* (Flores Ochoa & Paz Flores, 1986; Flores Ochoa et al., 1996; Rozas, 1986; Valdivia, Reinoso, & Mujica, 1999); and artificially irrigated moors, commonly referred to as *bofedales* (Lane, 2009; Palacios Rios, 1977, 1981, 1996). Nevertheless, there is still a substantial amount of work to do.

For the purposes of this entry, I divide water technology into two main types, *dry* and *wet*, in which *dry* designates technology in which water is a periodic component - such as in terraces and irrigation canals – whereas *wet* technology is reserved for those features for which water is an integral part of the technology, as in dams and reservoirs (see Table 1). A further, general consideration to reflect on is the importance of geological storage inherent in many of these technologies. For instance, water storage in artificial dams and reservoirs can also aid in the replenishment of natural aquifers thereby contributing to the water levels within the overall system.

Dry Water Technology

The main dry water technology systems found in the Andes are terraces; irrigation canals; sunken

gardens, otherwise known as pond fields, *q'ochas*, or *qochawiñas*; *puquios*; and sunken gardens. These are treated in turn below.

Terraces

Cultivation terraces, or *andenes*, are a water-using technology based around the creation of a series of level “steps” on otherwise sloped gradients of hills, ridges, and mountains. In the New World, terracing has a long tradition that covers North, Central, and South America (see Donkin, 1979, pp. 23, Map 22.21). In South America their distribution is mainly concentrated along the central Andean area, the dry Pacific coast, upwards into the semiarid western Andes and through to the cloud forest clad flanks of the eastern cordillera towards the Amazon.

Originally the earliest terracing in the Central Andes had been dated to around 500 BC (Donkin, 1979, p. 17), but more recent data has pushed the earliest known terraces to the Preceramic period c. 2480–2320 BC (Brooks, 1998). Whatever their antiquity the use of terracing was already widely established by the Middle Horizon (AD 700–1100), having by then spread substantially throughout the Andean region (Finucane, 2009). It is also widely recognized that terracing reached its apogee under the Inca Empire during the Late Horizon (AD 1438–1532) (Bonavia, 1967–1968, p. 270).

Donkin (1979, p. 22), in his seminal work on terracing in the New World, claims that 95 % of known terraces are found in either semiarid or arid

environments, which in turn means that the vast majority of these have to be irrigated. In the Andes the terraces on the western slopes are generally noted for being almost exclusively irrigated (Denevan, 2001, p. 183), hemmed as they are by the lower, drier western cordillera and the coastal desert. The terraces closer to the Amazon Basin are more likely to be rain fed given the higher degree of precipitation. Treacy (1994a, pp. 42–45) has identified four main functions fulfilled by terraces:

1. Platform for deep soil matrix which facilitates cultivation
2. Control of erosion
3. Creation of a sustainable microclimate
4. Control of humidity

It is worth describing these four aspects in some more detail as they are factors that are often highlighted by other water technology types, for instance, silt reservoirs (1–4), sunken fields (3, 4), and *camellones* (1, 3, 4). The main disadvantage of terracing is that the overall area of cultivation is somewhat reduced through their construction (Denevan, 2001, p. 183). Nevertheless, the advantages accrued means that the density of cultivation on terraces more than compensates for this partial loss of land surface.

The deepening of the soil matrix (1) allows for an extension of cultivation into areas that are either too steep or too rocky for normal agriculture. In turn terracing allows for the control of erosion along the otherwise heavily soil-depleted slope areas. This second function, control of erosion (2), is normally recognized as the most important function of terraces in the highlands, as it provides nutrient-rich soils while also helping alleviate the impact of the floods and mud avalanches (*huaicos*) endemic to these tree-denuded uplands.

The creation of a distinct microclimate (3) in which the relative temperature is ameliorated in respect to frost is especially important in the highlands, as it allows for the possibility of successful cultivation of certain crops at heights from which they would normally be precluded. Maize has usually been the favored crop in any consideration of cultivation arising from

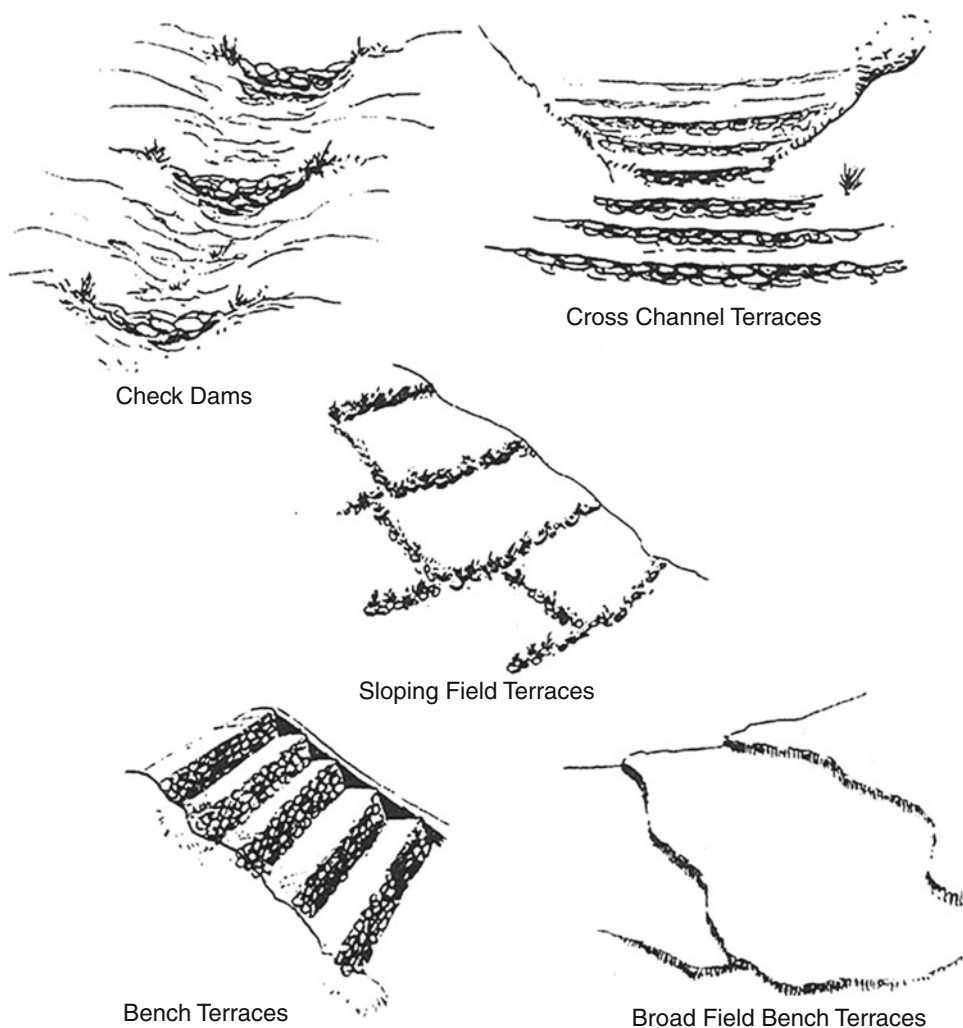
temperature control (Earls, 1986). There are suggestions that animals might have been fed on the leftovers found in the fields after the gathering of the maize harvest for the Late Intermediate period (AD 1000–1480) along the north-central coast (Jones & Bonavia, 1992) and for Chavin de Huantar (900–200 BC) in the highlands (Burger & van der Merwe, 1990).

The last major function of terraces was the control of humidity (4). The availability of a flat surface, with deep soil and retaining stone wall, facilitates the accumulation and storage of water. This is achieved primarily through blocking the natural flow of water downhill occasioned by the construction of terraces. The existence of a deep soil matrix allows for the roots of plants to take deep root raising water levels that can be advantageous during periods of water shortage. Level surfaces also allows for a more symmetrical distribution of irrigated water. Many terraces are constructed of fieldstone and have an inner layer of permeable gravel or rock; this allows for the adequate drainage of excess water, which means that terraces are not water saturated, thus limiting the possibilities of drowning seeds and seedlings (Bonavia, 1967–1968, p. 231).

Denevan (2001, pp. 175–180; see Fig. 1) has identified five main types of terracing for the Andes: check dams, cross-channel terraces, sloping field terraces, bench terraces, and broad-field bench terraces. The first two involve direct water flow from streams, while the other three, especially the last two, are normally irrigated by canals. Check dams and cross-channel terraces will be discussed later in the context of *wet* water technology.

Sloping Field Terraces

Denevan (2001, p. 176) categorizes sloping field terraces as the most common form of terracing to be found across the Andes, usually in side valleys away from rivers or intermittent streams. Donkin (1979) has recorded them across the Andes from Argentina and Chile through to Ecuador. Sloping field terraces are built along the natural slope with soil accumulation occurring behind a retainer wall. Although the cultivation zone itself is sloped, the terrace wall acts to level the slope



Water Technology in the Andes, Fig. 1 Five types of terracing (From Denevan (2001))

through soil accumulation, allowing for control of erosion, water runoff, and moisture retention.

Sloping field terraces are usually partitioned into discrete parcels incorporating sidewalls; these can act as conveyors or deflectors of water flow. Sloping field terraces can contour the hill-sides, breaking them up into small field units (Lane, 2006a) perhaps suggesting slow construction over time. In other cases such as in Tarma, the terraces are regularly patterned suggesting a coeval, perhaps centralized construction (Denevan, 2001). Overhead feeder canals sometimes irrigate these terraces, although the vast majority sustain themselves on the yearly rains,

localized springs, or slope seepage. These features are therefore not regimented into equidistant parallel strips but can occur haphazardly along a mountain flank. The vast majority of these terraces have been documented for the areas above 3,500 m. At this height there is usually enough rainfall for at least one crop a year (Denevan, 2001, p. 177).

Bench Terraces

The classic image of Andean terracing is that of bench terraces, variously known as *andenes*, *patasi*, *bancales*, and *takhanes* (Fig. 2). The most characteristic of these terraces are built of



Water Technology in the Andes, Fig. 2 Bench terraces, Santiago River, Upper Ica Basin, Peru (Photo by author)

close-fitting stone retaining walls usually between 1 and 5 m in height. They tend to occur along valley sides and are usually arranged in parallel vertical rows. The walls slope inwards thereby presenting a leveled surface apt for cultivation that is usually fed by some form of integrated irrigation system.

Treacy (1994a, p. 129) describes a well-documented integrated irrigation system at Coporaque, but they are ubiquitous across much of the Central Andes. Some bench terraces are banked with earth rather than the more sturdy stone walling (Denevan, 2001, p. 179). A number of these terrace types have been excavated (e.g., Bonavia, 1967–1968; Donkin, 1979; Schjellerup, 1986; Treacy, 1994a) showing what Denevan (2001, p. 179) describes as a series of drainage horizons. These are constructed in the Upper Mantaro Valley of an initial cobble layer lain over a buried topsoil; this cobble layer is in turn overlain by a “modern” humic topsoil which retains moisture. Excess water is quickly drained through the cobble layer outwards from the terrace (Bonavia, 1967–1968, pp. 230–233). Schjellerup (1986) has identified a similar

internal construction for the terraces at Atuén in the Chachapoyas Region and Keeley (1985) for the Cusichaca Valley. These two examples, among others, seem to indicate that bench terrace architecture shares broad similarities across a vast geographical region.

Broad-Field Terraces

Broad-field terraces are similar in composition to bench terraces, with the added difference that the cultivation surface is significantly wider, sometimes exceeding 100 m; while retention walls tend to be lower (Denevan, 2001, p. 180). Geologically, therefore, they are found in different environments to the traditional bench terrace described above favoring more undulating and gentler sloped valleys such as those in Northwestern Argentina or the riverine banks such as along the Vilcanota River valley near Cuzco.

Irrigation Canals and Puquios

Irrigation canals are among the most basic water feature; their function is simply to move water from where it is abundant to where it is needed (Fig. 3). This though belies the potential



Water Technology in the Andes, Fig. 3 Stone-lined canal, Cachi Valley, NW Argentina (Photo by author)

complexity of irrigation networks, especially in hyperarid places such as Puna de Atacama on the borders of Argentina, Bolivia, and Chile (Quesada, 2006), although canal networks in the Central Andes can be equally extensive, complex, and ancient (e.g., Dillehay, Eling, & Rossen, 2005; Farrington, 1980; Guillet et al., 1987; Mitchell & Guillet, 1994; Sherbondy, 1994; Treacy, 1994b).

Irrigation canals have a long history within the Andean region, especially along the dry coastal valley. Claims have been made for irrigation canals by around 3400 BC and perhaps as far back as 4700 BC in the Zaña Valley along the north coast (Dillehay et al., 2005; Dillehay, Rossen, & Netherley, 1997). Indeed, the whole of the coast presents a series of small to large canals crisscrossing the valleys and sometimes across valleys. It was partially the monumental scale of this endeavor in the Andes that first suggested to

Wittfogel (1957) and Steward (1955) the possibility of centralized states based around the organization of labor for the maintenance of complex irrigation canal systems. For instance, the Moche (AD 1–650) and the Chimú (AD 1100–1470) are characterized by their hydraulic expertise and extensive canal building (see Ortloff, 1995; Park, 1983; Pozorski & Pozorski, 1982).

Away from the coast, the highlands also demonstrate substantial evidence for widespread use of irrigation canals. The scale of irrigation canal use in the highlands is lower as a consequence of the more generalized availability of rainfall than on the coast. Also, the lack of flat, irrigable land surfaces means that irrigation is limited to bringing water from aquifers to fields and terraces. Even so, the magnitude of these networks can be impressive even at the local scale. In the modern Chaclacayo *microcuenca* (c. 140 km²) located in the Ancash highlands, 15 modern canals have been identified covering a distance of 58.3 km across the whole area (Junta de Desarrollo Distrital de Pamparomás, 2000). This pattern is replicated across the Central Andes with the caveat that in the past these networks were both more extensive and better organized (Denevan, 2001; Gelles, 2000).

The important role that irrigation canals hold within the social fabric of Andean highland communities should not be underestimated; Gelles (2000) and Trawick (2003) have attested to the enduring centrality and the social obligations that go hand in hand with canal maintenance and equitable distribution of water. Archaeologically, irrigation canals have been relatively understudied in the highlands, other than around the Titicaca Basin and the Inca heartland of Cuzco (see Erickson, 1993; Kolata & Ortloff, 1996). One reason for this is that their visibility is low when compared to that of terraces and other water technology and the fact that subsequent reuse can obliterate earlier, older use. Still, both in the highlands and coast they represent the most important linking component between the different types of water technologies.

Farrington (1980, p. 289) has identified two main types of canals: stone lined and unlined canals. The main distinction between these two

types of canals is that the stone-lined canals are usually the *acequia madres*, or main feeder canals, the core of the irrigation system, from which more localized outtakes, or *acequia secundarias*, then disperse the water to individual plots and terraces. The latter category are usually made up of earthen or sod-banked canals, being much more transient constructions their course can change with relative frequency depending on fallow seasons and shifting cultivation patterns. Cobble or slab-lined canals are usually more static and permanent features and thus easier to observe and record archaeologically. The volume of water from streams is controlled and then distributed by means of sluice gates (*boca tomas*); *boca tomas* are also sometimes cut into *acequia madres* so as to facilitate subsequent water distribution throughout the irrigation network.

Denevan (2001, p. 146) has recognized the basic engineering functions of canals as being:

1. The deliverance of water at the point of need
2. To do so in the most efficient manner with a minimum of canal scouring, sedimentation, or atmospheric transvaporization

Transvaporization is a serious problem in the coastal valleys. Kus (1984) in particular, recognized this in the large and wide Moche- and Chimú-period canal systems. A way around this problem is the use of subterranean canals to transport water; their underground nature makes them hard to detect archaeologically. Nevertheless, their presence has been uncovered, for instance, in Northwestern Argentina (Páez & Giovannetti, 2014) where they crisscross the cultivation fields. Although coastal canals demonstrate an exceptionally high degree of hydraulic complexity, expressed explicitly in their scale and monumentality (Oré, 2005; Ortloff, 1995), this should not blind us to the fact that the indigenous people of the highlands demonstrated a similar awareness of hydraulic expertise in their constructions, albeit usually at a different scale of monumentality to that found on the coast.

Furthermore, there is evidence to suggest the construction of large canals in the highlands,

bringing water from the summit of the cordillera (*puna*) down to the mainly agricultural lower-valley (*yunga*) areas and even all the way down to the coast. This is the case with the Huiru Catac, or Tokanka, Canal of the North-central Jimbe Valley (Gambini, 1983–1984; Villafana Avila, 1986), and the South-central Achirana Canal (Oré, 2005). Still, the importance of these large canal systems in these areas should not be overestimated, given that the highlands usually present extensive interconnected irrigation networks of smaller canals rather than these monumental endeavors, more common to the coast.

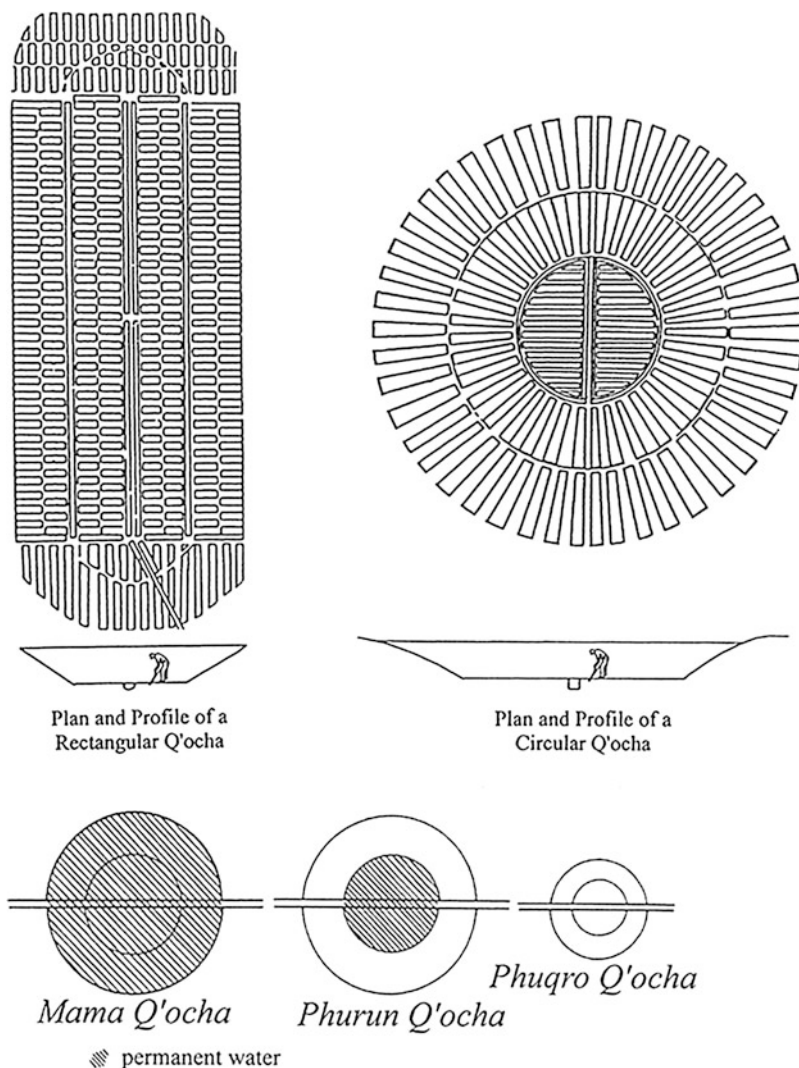
One final technology that in some way incorporates the concept of canals, referred to aqueducts and filtration galleries, is those described in detail for the Nazca region of the South-central Andes (Schreiber & Lancho Rojas, 1995, 2003) although their presence has been observed south in Chile and as far north as the Santa Valley in the North-central Andes, as well as in the highlands (Barnes & Fleming, 1991, p. 51). In the South-central Andes these aqueducts and *puquios*, literally canals and wells, are probably Nazca period (100 BC – AD 650) features, with possible expansion of the system under Spanish colonial rule (post-AD 1532) (Barnes & Fleming, 1991; Schreiber & Lancho Rojas, 2003).

This technology comprises a series of vertical and horizontal trenches (aqueducts) and tunnels (*puquios*) that tap into phreatic aquifers, especially in sections of coastal valleys – such as in the Nazca area – where surface river water periodically disappears underground. This water is then brought to the surface to irrigate agricultural land. Water availability in these features fluctuates according to the annual discharge in the rivers (Schreiber & Lancho Rojas, 2003).

Pond Fields and Sunken Gardens

Pond fields, *q'ochas* or *qochawñas* (Fig. 4), referred to generically from hereon in as *q'ochas*, are a relatively recent discovery (Flores Ochoa & Paz Flores, 1986; Flores Ochoa et al., 1996; Rosas, 1986; Valdivia et al., 1999). These comprise differentially sized, shallow sunken fields linked by canals that feed water to these depressions. They are farmed by rotation

Water Technology in the Andes, Fig. 4 *Q'ochas*
from Erickson (2000)



allowing the pond fields to lie fallow for between 3 and 5 years after a harvest. During the fallow years the *q'ochas* are used either as drinking ponds, or as reservoirs for animals and people, or to grow fodder for animals. This last point is important as it serves to emphasize the dual nature –farming and herding – of many of the water features in the highlands.

In a similar fashion to the raised fields discussed below, *q'ochas* are important for controlling water and seasonal runoff, for nutrient capture, and for aquaculture, as well as providing an improved microclimate in which to practice agriculture. Additionally, *q'ochas* provide an

important source of sod for construction purposes and are sometimes used for the preparation of freeze-dried tubers, known locally as *chuño*. Generically, both raised fields and pond fields address the aforementioned problems of nutrient retention and soil conservation, concerns that are also present in the construction and maintenance of terraces.

Along the northern coast similar structures known as sunken gardens, *hoyas*, *wachaques*, or *mahamaes* (Fig. 5) have been identified (Parsons, 1968; Rowe, 1969; Smith, 1979). Inland on these coastal valleys, these 2000-year-old, agglutinated sunken gardens tapped phreatic water sources to

Water Technology in the Andes, Fig. 5 Sunken gardens from the Casma Valley, Peru (Kosok, 1965)



provide rich and shaded agricultural land while also benefitting from periodic flooding such as the pond fields above (Knapp, 1987, *contra* Parsons & Psuty, 1975) which in effect also controlled the flooding episodes from the nearby river. It is now widely acknowledged that this technology was both productive and widespread (Shimada, 1994, p. 53).

Wet Water Technology

In this section we consider those features in which water is either an integral part – as in the case of reservoirs and dams – or through which water flows constantly or almost constantly. Within this last category we include two important features of water and field technology: raised fields, *camellones* or *waru-waru*, and artificially irrigated high-altitude moorlands or *bofedales* (known as *vegas* in Argentina and Chile). Both types of water technology exist within the same area, the Titicaca Basin region, with *camellones* and artificial *bofedales* present across a large area of the Andes. *Camellones* occur from French Guyana across to Colombia down to Bolivia (e.g., de la Torre & Burga, 1986; Plazas, Falchetti, Sáenz Samper, & Archila, 1993),

wherever the predominant ecozones are *páramo* and humid *puna* (Custred, 1977), while artificial *bofedales* are found throughout areas in which camelids were herded in the past (e.g., Lane, 2009; Palacios Rios, 1996; Quesada, 2010). Artificial irrigation of pastureland is still practiced nowadays, albeit to a lesser scale than formerly and mainly through the diverting of water onto silt-clogged areas using temporary sod canals (Fig. 6).

In the past large-scale construction of dams and reservoirs, for water storage but also for trapping silt, allowed the creation of large areas of artificial *bofedal*. While water reservoirs and dams are pretty self-explanatory, silt reservoirs and dams require further explanation. In essence, they constitute differentially sized silt catchments, otherwise known as check dams or cross-channel terraces in the literature (Denevan, 2001, pp. 175–180; see Fig. 1). Their presence in the Andes has only recently been documented (Lane, 2009) and they represent a variation on the artificial *bofedales* mentioned above. Denevan (2001, p. 157) and Scarborough (2003, p. 59) have previously argued that there is little evidence for dams and reservoirs – also known as *represas*, *reservorios*, and *estanques* – in the Andes, yet recent studies confirm that their presence was



Water Technology in the Andes, Fig. 6 Modern sod-canal feeding artificial *bofedal* or *vega*, Cachi Valley, NW Argentina (Photo by author)

much more ubiquitous across the Andes than has been commonly acknowledged (e.g., Herrera, 2011; Lane, 2009; Lanzelotti, 2011; Salomon, 1998).

Raised Fields

Although raised field – *camellones* or *waru-warú* – systems are found across a large area of the Andes (Herrera, 2011, Fig. 1), the most detailed studies have been conducted on those from the Titicaca Basin (see de la Torre & Burga, 1986; Erickson & Chandler, 1989; Kolata & Ortloff, 1996; Smith, Denevan, & Hamilton, 1968). These raised fields (Fig. 7) are a series of large, elevated cultivation platforms constructed in areas of waterlogged soils or areas prone to annual flooding. In between these platforms there are a series of shallow ditches, forming a ridge and furrow pattern. The furrows are permanently inundated with water from adjacent canals. In a similar fashion to the terraces above, raised

field systems have certain advantages over normal fields, summarized below:

1. Soil improvement
2. Greater control of annual flood and rainfall waters
3. Capture and reutilization of sediments and soil nutrients
4. Ameliorated microclimate promoting better plant growth conditions
5. Creation of wetlands, enriching of local flora and fauna

Together these five factors make agriculture in this *puna* environment viable. Indeed, in the treeless and sloped expanse of the Andean *puna*, soil leeching on normal fields is a constant problem that adversely affects animal, plant, and human communities. In turn this leads to environmental deterioration and eventual abandonment if measures are not taken to artificially replenish and maintain the soils (Young, Leon, Cano, & Herrera-MacBryde, 2005; Young, León, & Herrera-MacBryde, 1997). In a similar fashion to terraces, raised fields can proportionally increase productivity compensating for the land lost to flooding (Erickson, 1993).

Water Dams

As previously mentioned, water dams have received little attention. Yet their presence has been increasingly recorded across huge areas of the Andes. Perhaps a reason for their absence from the literature is twofold. First there is the fact that the majority of these dams are located in the generally more inaccessible upper reaches of the highlands; and second, many of these pre-Hispanic features are increasingly being destroyed by modern micro-dams (Lane, 2013). Invariably the majority of these high-altitude dams are located in the westernmost mountain range of the Andes (although see, Herrera, 2011, pp. 64–65, for a notable exception to this rule), given that this is a non-glaciated range and thus lacks a permanent source of water.

Aside from scattered evidence of highland dams reported by Donkin (1979, p. 105) near Arequipa in the South-central Andes; Salomon



Water Technology in the Andes, Fig. 7 Raised fields, Tiahuanaco, Bolivia (Photo by author)

(1998) in the Huarochiri Province of the Central Andes; and Gambini (1983–1984, p. 111) in the Jimbe Valley of the North-central Andes and increasing evidence for these structures from as far afield as Argentina (Cornejo, 2001; Lancelotti, 2011), the first major study into water dams appeared only during the last decade (Lane, 2006a). Here, in a survey of *c.* 80 km² of the Cordillera Negra of the Ancash Province, 18 pre-Hispanic water dams were identified at areas between 4,100 and 4,800 m. At this height there is little sedimentation of lake basins given that the maximum height of the western mountain range is *c.* 5,200 m. In the dams built at this altitude, water is gathered during annual rains and from springs. Interestingly, these features are located in areas where the underlying geology is mostly basaltic andesite which is a relatively hard, though brittle rock with limited porosity. Fissures in the rock though facilitate permeability leading to the enhancement of underground aquifers.

These structures are gravity dams given that their weight and mass is what holds back the water (Fig. 8). The dam walls are constructed of large stone blocks, with the inside of the structure infilled by compacted earth and stone. They are roughly triangular with a wide base tapering towards a narrower crest. By these means it counteracts the water pressure that is exponentially greater at the base of the dam. These structures

are usually anchored to natural rock outcrops, adding greater solidity to the construction. A series of sluices cut into the dam wall regulate water flow. These dams come in very different sizes, from 5 m to over 100 m across and capacities, ranging from *c.* 6,000 m³ to *c.* 700,000 m³ (Lane, 2009, pp. 175–176).

Water Reservoirs

Water reservoirs (Fig. 9) are mentioned and pictured in ethnohistoric sources (see Guaman Poma de Ayala, 1993 [1615], p. 937) and have been extensively recorded for the coastal areas in association with irrigation agriculture (e.g., Farrington, 1980; Kosok, 1965; Netherly, 1984) they are also known as “holding ponds” (Vreeland, 1986). Similarly, in the highlands they have been reported by Donkin (1979) and Gambini (1983–1984) among others. Water reservoirs are increasingly targeted by nongovernmental organizations as a cheap and efficient means towards localized water storage (see Venturi & Villanueva, 2002).

This close association between cultivated fields and reservoirs means that these features are usually located within agricultural zones. Reservoirs are generally round, ovular, or roughly rectangular and vary between 10 and 15 m in relative diameter or length, holding roughly between 100 and 300 m³ of water. Construction is of a rough coursed-stone internal wall



Water Technology in the Andes, Fig. 8 Water dam, Cordillera Negra, Ancash Highlands, Peru (Photo by author)

and either a similar external wall or an earthen embankment. Reservoirs are enclosed constructions in that they enclose a specifically bounded area on all sides. A canal, either earthen or stonewalled, acts as a feeder, diverting water towards the reservoir (Fig. 10). These canals have to be periodically cleaned or recut as sedimentation is a serious problem for these features.

Artificial Bofedales

An Andean *bofedal* is a poorly drained area of moorland on which plant communities favorable for the rearing of camelids grow, especially for alpacas (*Lama pacos*), the less hardy of the two camelid domesticates. They are also known as *distichia* moors, wet pastures, and high-altitude moorlands (Aldenderfer, 1998; Dransart, 2002; Kuznar, 1995). These natural habitats represent an extremely rich pastoral resource and are thus highly coveted by local communities (Browman, 1990). For these reasons some communities have constructed artificial *bofedales* fed by irrigation canals to supplement the naturally occurring

areas of moorland (Palacios Rios, 1977, 1981, 1996). Irrigated *bofedales* appear across a large geographical area (e.g., Carhuallanqui, 1998; Kuznar, 1995); furthermore they are mentioned ethnohistorically (Guaman Poma de Ayala, 1993 [1615], p. 780) and attested archaeologically (Erickson, 2000, p. 343; Quesada, 2010, p. 88) underlining their antiquity and present importance across the Andes.

The majority of the ethnographically recorded artificial *bofedales* are small- to medium-scale affairs reflecting a household-type economy, although in some cases the area turned over to artificial *bofedal* via irrigation can be truly massive. For instance, among the Chichillapi communities of Puna, an area of 2,200 ha. was turned into an artificial *bofedal* (Palacios Rios, 1977, 1981, 1996). Here at Chichillapi the main area of artificial *bofedales* lies at and above 4,000 m, along the Chila River, and belonged to the Laka community of agropastoralists. Riverine water was diverted and dispersed towards the sides of the valley by two large outtake canals called



Water Technology in the Andes, Fig. 9 Water reservoir, Cordillera Blanca, Ancash Highlands, Peru (Photo by author)

hach'a irpas which directed the water towards the margins of the *bofedal* area. These canals run along the left and right edge of the *bofedal*; the canals were between 1.7 and 2.2 m wide, 0.6 and 0.8 m deep and run some 9–17 km. The canal walls were banked with reinforced sods that created a living embankment along the canal's length. A series of shorter feeder canals called *hisk'a irpas* then distributed the water more locally creating the *bofedal* proper. This system of irrigation is similar in essence to that employed by farmers to irrigate their own plots of land using canals.

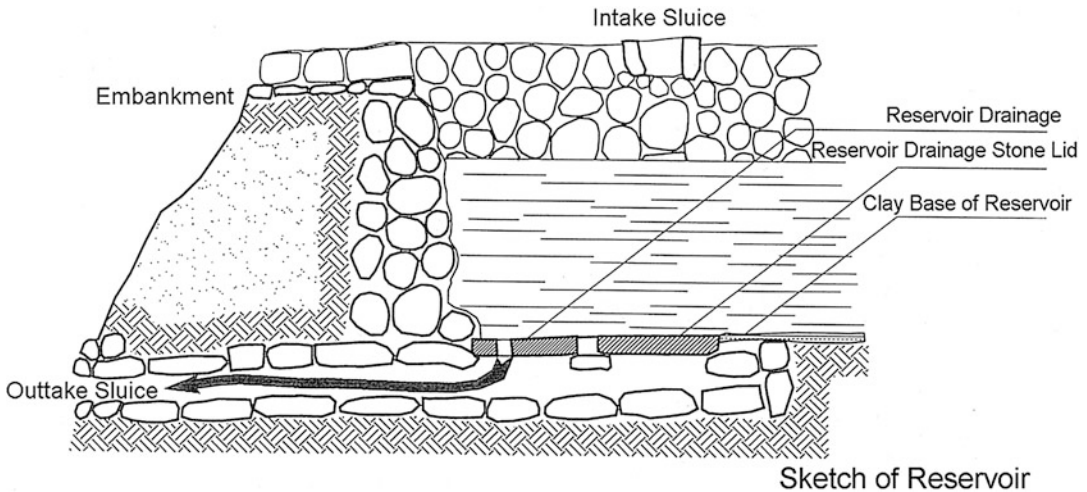
Bofedales are fragile environments that require constant maintenance by households and communities who clean them once a year after the rainy season. Given the large areas of dried-up *bofedales*, it is likely that there were many more *bofedales* in use during the pre-Hispanic period when powerful agropastoralist communities and polities controlled the highlands (Erickson, 2000, p. 343). Apart from the obvious

grazing advantage accrued for animals, *bofedales* are also important areas for the retention of organic silts and for geologic water storage (Fairley, 2003). Given the different geological and geographical environments in the Andes, it is evident that regional differences existed in artificial *bofedal* construction. This can be seen in the evidence for silt dams and reservoirs from the north-central highlands (Lane, 2006a, 2009).

Silt Dams

Recent studies (Lane, 2006a, 2006b, 2007, 2009) into hydraulic technology in the Ancash highlands have uncovered evidence for a distinct form of wetland or *bofedal* creation and capture. Rather than the household scale of *bofedal* construction described above, the scale of *bofedal* construction here is beyond that even of the Chichillapi herders of Puna (Palacios Rios, 1977, 1981, 1996) to encompass truly monumental scales.

In the case study from the Ancash highlands, five silt dams created over 372,027 m² of artificial



Water Technology in the Andes, Fig. 10 Schematic of pre-Hispanic water reservoir

bofedal, although this does not include the areas with preexisting natural *bofedal* and those created via the use of silt reservoirs described below. Outwardly, these dam-like structures bear striking similarities, including size, to the normal water dams described above, in that they were constructed of double-faced walls, infilled with compacted earth, stone, and clay, making an impermeable barrier behind which sediment and water are stored (Fig. 11). The central part of many of the dams was reinforced by step-like walling, probably reflecting the added pressure present in this area of the structure. Unlike the water dams, though, the silt dams were located much lower down the altitudinal ladder of the Andes, occurring normally between 3,800 and 4,450 m.

Freisem (1998) has interpreted them as secondary erosion dams used in the prevention of periodic silt and loam floods that afflict fields and settlements throughout the Andes. Similar structures have also been identified along the coast, such as in the Chao Valley (Brooks, Willett, Kent, Vasquez, & Rosales, 2005). While this interpretation is very plausible, it is likely that these structures had a dual purpose. So that alongside checking erosion discharges, these structures provided silt platforms that facilitated the creation of a *bofedal* for use in grazing. Furthermore, accumulation of silt-rich sediment behind these

structures provided a bank of material for use in nutrient-depleted terraces.

Unlike water dams, silt dams are not necessarily anchored onto rock and they usually have only one discernible outtake sluice located along the base of the structure, usually at its center. The basic principle governing the silt dam is that of geologic water storage (Fairley, 2003); in this case the accumulated soil basin acts as an aquifer in which water is both stored and purified through the soil. The soil also acts a water barrier to water seepage therefore, the sluice should be viewed rather as a sieve that siphons excess water out of the basin while the soil retains enough saturated moisture for the growth of *bofedal*-type vegetation.

Silt dams would have been the result of a process of construction, accretion, and maintenance. In the main, the initial silt basin would probably have been small and would have grown slowly through silt accumulation during the annual rains, a system of accretion known as varve formation (Leet, 1982).

Silt Reservoirs

Another technology facilitating the creation of *bofedales* is that of silt reservoirs, otherwise known as check dams or cross-channel terraces (Denevan, 2001). A detailed case study describes their presence in Ancash highlands of the



Water Technology in the Andes, Fig. 11 Silt dam, Cordillera Negra, Ancash Highlands, Peru (Photo by author)

North-central Andes (Lane, 2006a, 2009) but there is increasingly evidence to suggest they existed across a large area of the Andes including the North-central coastal Jequetepeque Valley (Dillehay & Kolata, 2004) and the South-central highland Colca Valley (Treacy & Denevan, 1994). In these two cases though, check dams and cross-channel terraces are used primarily for agriculture in a similar fashion to the terraces discussed above. Further cases of cross-channel terraces have been documented by Denevan (2001) quoting Regal's work in the Chiva River Basin and by Donkin (1979) reporting on Ecuador, Chile, and Northwestern Argentina.

In the case of silt reservoirs of the Ancash highlands, their location at the *suní-puna* transition above 3,900 m – and up to 4,400 m – precludes a substantial agricultural *raison d'être* given the enduring cold and harshness of the environment at this altitude, suggesting rather their use as stepped *bofedal* terracing. This is similar to the cross-channel terraces recorded in the area of Socaire along the edge of the Chilean Altiplano

at around 3,700–3,900 m (Donkin, 1979, p. 126). The Ancash silt reservoirs are open features usually semicircular or horseshoe shape ranging between 7 and 20 m in length, with an average height that ranges between 60 and 200 cm. These features tend to be wider at the center of the reservoir, varying between 60 and 120 cm, although some of the larger constructions reach widths of up to 160 cm across the center (Fig. 12).

These features are of double-faced stonewalling, infilled with compacted rock and clay. They are set perpendicular to the water, impeding its uninterrupted flow thus acting as a silt trap and as an erosion barrier to the annual hill-wash episodes and high-energy highland discharges that occur periodically in these landscape. In turn the entrapment of silt permits the creation of small *bofedal* microenvironments behind the walls. As with the silt and water dams, silt reservoirs utilize, where possible, natural rock outcrops lending further stability to the structures. The primary functions of these structures are erosion control, silt entrapment, water

Water Technology in the Andes, Fig. 12 Silt reservoirs, Cordillera Negra, Ancash Highlands, Peru (Photo by author)



catchment, and subsequent distribution with the added result of creating a small area of *bofedal*.

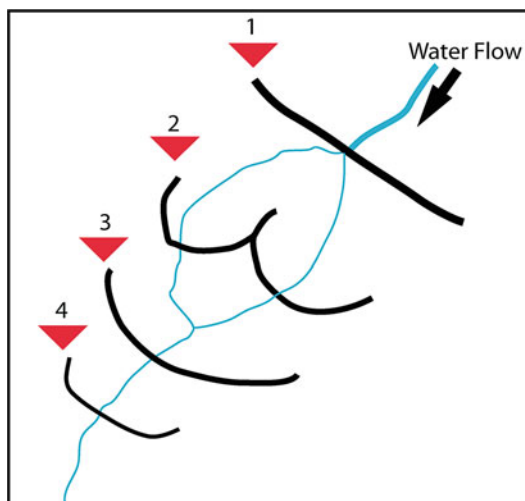
Similar to check dams these reservoirs are positioned across the breadth of small highland pampas that form in ravines. In these broad sloping areas, the silt reservoirs are positioned so as to distribute water across the widest extent possible thus providing the maximum possible platform on which to develop the microenvironment necessary for a *bofedal* (Fig. 13). As with the silt dams described above, these features have a drainage sluice, usually along the bottom and center of the structure; this helps drain excess water from the structure.

Conclusion

Water is a perennial subject matter whose relevance and importance is constantly growing in a world where pollution and scarcity increasingly undermine its availability and characteristics (Gleick et al., 2014). Water technology is seen as a means of harnessing this scarce resource. Here we have addressed a number of technologies employed by pre-Hispanic societies towards controlling and managing water and in many instances, soil, for the general improvement of local environmental and economic conditions.

And this is the crux of the matter; millennia of development in water technology in the Andes rendered this area into a veritable series of managed landscapes (Denevan, 2001). Nevertheless, this should not blind us to the fact of collapse or maladjustment of some of these technologies in the past (see Lentz, 2000; also Graffam, 1992, describing the decline in the use of raised field systems during the pre-Hispanic period); it is also a truism that, in the main, these technologies adjusted themselves exceptionally well to the exigencies of this land. This situation changed under Spanish colonial and subsequently republican rule so that many of these technologies – sunken gardens, *q'ochas*, and silt reservoirs – were only partially maintained or not maintained at all leading invariably to degradation, erosion, and abandonment of vast tracts of the Andes.

Although this can be visibly seen, for instance, in the number of abandoned terraces that litter the highlands, its effects on the coast are if anything even more obvious. Here modern agro-industry often emphasizes high water intake monoculture, such as asparagus (Lawrence, 2010) and artichokes, that drains local aquifers and demands labor resources not available locally. In turn this leads to a human exodus from the highlands to the coast and even to the creation of modern megacanal that siphon water from the highlands to the



Water Technology in the Andes, Fig. 13 Schematic part of a silt reservoir system (approximate scale 1:500). Silt reservoirs store and filter water through the accumulation of humid silty soils. As the water flows to these structures, sediments are dragged with it, which is then trapped by silt reservoir walls. At the same time water is diverted towards the sides of the valley that would not usually benefit from this water flow. This in turn slows the velocity of this water reducing erosion, lessening loss of silt. (1) Water flow is halted by a robust, almost lineal, wall behind in which silt accumulates. Excess water is diverted through a sluice at the base of the reservoir wall and through earthen canals towards two further interconnected silt reservoirs downslope; (2) behind the walls of these two interconnected silt reservoirs a medium-sized area of artificial *bofedal* is created; (3) excess water and silt flow from (2) are captured by a further lower-lying silt reservoir, associated with (4) with similar results to (2); (4) excess water from (3) finally reaches a small silt reservoir which acts as a filtration terrace or check dam to the whole system. A further small *bofedal* is created behind this structure

coast (as in the case of the Majes Canal in South-central Peru, see Boelens & Gelles, 2005; Gelles, 2000), culminating in the almost wholesale destruction of traditional methods and farming along the coast and its gradual decay in the highlands.

Efforts at preserving these traditions exist (e.g., Branch et al., 2007; Erickson, 1998; Kendall, 1994; PIWA, 1994), as do blueprints arguing for the continuation of traditional technology and its advantages for rural development (Herrera, 2011, 2013). Nevertheless, they have yet to make significant headway against the

predominant political ecology (Lane, 2013). A paradigm that de-incentivizes small-holder, local production (Mayer, 2002), through an increasing emphasis on large-scale (Meade, Baldwin, & Calvin, 2010), export market production especially along the coast. Given these circumstances it is imperative that every effort is expended in identifying and describing these ancient water technologies. On the coast many of the remaining vestiges of these have already disappeared; soon abandonment, dislocation, and disuse will do the same to those in the highlands. It is our duty to document these and the traditions that underpin them before they too cease to exist.

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Weaving Cotton in Ethiopia and Nubia

Michael Gervers

Archaeological material finds provide invaluable information about the nature and source of textiles and textile fibres in Nubia in the early Christian era. In the half century since Griffith and Crowfoot first identified cotton among the textile fragments excavated at Karanog and Meroe, much more cotton fabric has been retrieved from the rescue excavations of early habitation sites along the Nile subsequently inundated by Lake Nasser; i.e., between Aswan in Upper Egypt and Wadi Halfa in northern Sudan. The oldest fragments identified as cotton have been dated to the Roman period and may be as early as the first century AD. The great majority are attributable to the late Meroitic period, ca. 200-ca. 330 AD, at which time cotton appears to have been the most commonly available fabric. The following period, from ca. 330 to ca. 550 AD, sees a swift

and remarkable change in the predominant textile fibre in the region. The use of cotton plummets and is replaced by animal fibre, largely camel's wool.

The quantity of cotton found in excavations of the Roman and late Meroitic periods has led many to conclude that the fibre reached Lower Nubia from the south, where it is thought to have been grown, since this area lies in the rain belt and could have provided the environment necessary for growth. However, no specific sites for cotton cultivation in Nubia and the Sudan at this period have been identified and in view of the chronology of the archaeological evidence, and of what is known of the political and economic situation and agricultural production of the period, there is good reason to suppose that vegetable fibres for textiles were not then grown in Nubia or even in the Sudan. Rather, the Nubians, lacking any such indigenous source of raw material, were obliged to import whatever they required either as cloth or raw fibre. These goods included linen, which, throughout much of the Middle Ages under the provisions of the *baqt* agreement, was one of the principal items received by the Nubians in exchange for slaves. The *baqt* was first formulated in the seventh century, by which time, in the absence of adequate supplies of cotton, the Nubians seem to have sought imported linen as an alternative. The cotton would have been *gossypium arboreum*, and its ultimate source would have been the west coast of India. How it reached Nubia is uncertain. It could have come via the eastern desert trade routes from such ports as Suakin on the Red Sea, or via the kingdom of Axum, which by 300 AD. enjoyed a thriving trade with India. The costs and difficulties of overland transport, however, make it more likely that cotton reached Nubia through the Roman world to the north via the Nile. Since the archaeological cotton remains from Nubia were not made from locally grown fibres, there can be little question of cotton reaching Ethiopia from the Sudan. One early reference which is universally accepted speaks of the direct importation to the Red Sea Axumite port of Adulis of cotton from India in the first century AD. The first

indication we have of the production of fine cotton cloth in Abyssinia occurs at the end of the thirteenth century in the commentary of Polo: "Good cotton and buckram cloths are woven here". If his source for the supply is accurate, one can reasonably conclude that by that time cotton cultivation and weaving was well established in the highlands.

Textiles, especially imported, have always been an expensive commodity. Their distribution through the ranks of a society depends directly on the geographical diffusion of the raw material, the quantities produced and the availability of mechanisms to spin and weave it into cloth. An Egyptian source for cotton grown in India would explain why a blue and white cotton tapestry decorated with Egyptian symbols was among the Meroitic finds from Qasr Ibrim. It would also explain why the cotton, if imported raw from India and locally spun, would appear different in texture from contemporaneous cotton cloth of Indian origin discovered at Palmyra. Cotton cloth woven in the humid atmosphere of India could be much finer than that produced in the arid climate of Egypt or Upper Nubia. The latter, if woven on the warp-weighted loom, as is supposed, would have to be much thicker and coarser to prevent it from breaking under the stress of the weights. Consequently, it would have appeared softer than the material from Palmyra and more like wool. When cotton became less available from the fourth century and was replaced by wool, the warp-weighted loom would have been all the more appropriate for weaving it. Weaving in Ethiopia today is carried out almost entirely on a pit-treadle loom, whose treadles are suspended in a hole in the ground. The weaver sits at the edge of the pit with his legs inside so that his feet can operate the treadles. The origin of this loom in Ethiopia is uncertain, although numerous writers have noted how closely it parallels the Hindu loom, and some suggest that the technology is the result of direct importation from the Indian subcontinent. Endrei believes this loom originated in India for the purpose of cotton weaving. The specific characteristics of the Abyssinian loom, according to Boser, are its

sturdy frame, the width of the comb and consequently of the cloth produced, and the depth of the pit. Boser goes on to say that regardless of how this loom got to Abyssinia, it did not spread thence to other parts of Africa. It did not spread, until recent times at least, even to southern and western Ethiopia. A close relative is the warp-weighted pit loom which is found frequently in Persia, Syria and Egypt where it was, and is, used particularly for weaving woollen, and in Egypt at any rate for weaving linen thread. It does not seem to be appropriate for weaving with a cotton warp as the strain placed by the weights on the thread would cause it to break. This restriction would explain the absence of the warp-weighted loom in Ethiopia, where cotton is by far the principal fibre used for weaving today. The technical association of the Ethiopian loom with cotton would also argue in favour of a common development, if not introduction, of cotton growing and weaving to the Abyssinian highlands.

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Wei Boyang

Fabrizio Pregadio

Although many Chinese works relate the name of Wei Boyang to the origins of alchemy, nothing is known about him from a historical point of view, and his figure may be entirely legendary. Some sources, which place him in the second century, relate that he came from Shangyu (in modern Zhejiang) and transmitted his teaching to Xu Congshi, who in turn handed it down to Chunyu (alternative spelling: Shunyu) Shutong. The text deemed to embody the gist of this transmission is the *Zhouyi cantong qi* (Agreement of the Three According to the Book of Changes), a scripture in verses that is attributed to Wei Boyang. The commentaries usually interpret the “Three” as Heaven, Earth, and Man, or as Daoism, cosmology, and alchemy. The *Book of Changes* is the *Zhouyi* (or I Ching, also spelled *Yijing*), the renowned divination manual, which also includes a classical exposition of cosmology in its section commonly known in the West as “Great Treatise.”

The genesis of the *Cantong qi* is as obscure as its putative author. Current research tends to consider that an originally Han text on cosmology may have been elaborated into an exposition of alchemical doctrines, perhaps at different dates until the seventh century. The very few references to a *Cantong qi* before that time seem to refer to the original cosmological treatise, whose circulation may conceivably have

been restricted due to its association with an unofficial and proscribed body of writings propounding esoteric interpretations of the Confucian classics.

Since the late Tang, however, the *Cantong qi* began almost abruptly to exert a far greater influence in the history of Chinese alchemy than that of any other text. Hidden in the highly allusive language, and the thick layers of symbols and images that characterize this scripture, is an exposition of the doctrine that inspired a variety of commentaries (about 30 of which are extant) and other texts, written between the eighth and the nineteenth centuries, in both Daoist and Neo-Confucian traditions. One of the most well-known exegeses was written by the Neo-Confucian philosopher Zhu Xi, who commended the high literary quality of the text.

The *Cantong qi* would hardly be intelligible without recourse to the related literature. Although it was occasionally read as a treatise on cosmology, most commentaries agree that it articulates the theories found in the tradition of the *Book of Changes*, applying them to the alchemical work. The *gua* (trigrams and hexagrams) of the *Book of Changes* are used both to construct a cosmological model and, at the same time, to represent phases of the process performed by the alchemist. The various possible levels of reading of the text possibly mean that it was used within both the main traditions of ► [alchemy in China](#), i.e., *waidan* or “external alchemy” and *neidan* or “internal alchemy.”

See Also

- [Alchemy in China](#)
- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)

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- *Dja-yôbwê* (dja stone). Here the term refers to the contents; it designates what is contained in the package or *dja*. These original elements would be in stone and would be concerned with different realms of human knowledge deemed worthy of interest.
 - *Sika-yôbwê* (stone of gold) money. In this second case, the term describes a price or a monetary total. These elements would deal with economics, calculation, and mathematics.
 - *Nsangan-yôbwê* (stone of a fine). This term describes the price of a fine, a tax, or a tribute, and is concerned with elements of economics and finance.
 - *Ahindr-yôbwê* (proverb stone). This term evokes the notion of speech, thought, and discourse, the fields of literature and philosophy.
 - *Ngwa-yôbwê* (game stone). This term refers to the figures comprised of graphic signs. The exercise of reading or deciphering the signs was considered a kind of game, involving elements of imitation and intellectual training.

Weights and Measures in Africa: Akan Gold Weights

Georges Niangoran-Bouah

The subject of gold weights is complex and multidimensional. It can be understood only when placed in the context of its original cultural environment, which was linked intimately to gold for its physical substance and to the package (*dja*) in which it came for its sociocultural identity.

The Akan country, on the Gulf of Guinea in West Africa, was and is an area of gold deposits. This metal is both feared and worshipped. Well before the first contacts with Europeans in the fifteenth century, the Akan people used gold dust as a medium of exchange. However, the concept of “gold weights” came from Western traders (Dutch, Portuguese, English, and French).

The first question to ask is: are the figures really weights? In describing these figures, the Baolé use several different terms: *Dja-yôbwê*, *sika-yôbwê*, *shin-dra-yôbwê*, *nsangan-yôbwê*, *ngwa-yôbwê*. Let us look at the meaning of each of them.

As we see, the term “weights” appears nowhere in these descriptions.

The *dja* or *sanaa* was originally a package made of animal skin or thick cloth in which the Akan placed their figurines and certain accessories. It seems to have been a kind of encyclopedia written in miniature figures. The package and its contents symbolized the economic power of the living king and the spirits of the dead sovereigns. The act of taking possession of the *dja* signified for a new ruler that he was assuming the power to raise taxes, impose fines, and take measures to increase the state treasury. For his subjects, knowing that the ruler was in possession of the *dja* of the state meant that they judged him capable of administering the financial and economic heritage of the country.

Many different objects can be found in a *dja*, but we will mention here only the essential, original ones.

The equipment is a group of accessories used to manipulate the gold power. They consist of (1) balance scales, used to determine the weight value of different quantities of gold dust used as a medium of exchange; (2) spoons to put the gold

**Weights and Measures in
Africa: Akan Gold
Weights, Fig. 1** Weights
with figurative elements



dust on the plates of the scales; (3) boxes of many different kinds, their covers often decorated with graphic designs. They are used to hold gold dust already weighed or about to be weighed; (4) winnowing baskets used to separate and rid the gold powder of any impurities; and (5) sieves to separate the different grains of gold dust.

The weights provide knowledge of the weight and monetary value of the quantity of gold powder placed in the plate of the scale. There are three kinds of weights – figurative weights, weights with graphic designs, and geometric weights (Figs. 1, 2, and 3). Gold weights were (usually) made of an original alloy whose composition was similar to that of bronze and brass. However, there are also weights made of silver, copper, and solid gold.

The weights were made by the Tounfouê, an artisans' group, different from blacksmiths and jewelers. These artisans used the lost wax method to produce the weights.

The Akan used a system of computing weight consisting of 11 units. It began at *dama* and ended with *bèna*. It was possible to multiply *bèna* by infinity and the values went from single to double or were multiplied by two. There were three series of weights – small, medium, and large. They could be added and multiplied.

The small weights series consisted of ten monetary units and was used for all sorts of small transactions:

- ba = unit = 0.148 g
- ba (*gnon*) = ba × 2
- ba (*nsan*) = ba × 3
- ba (*nan*) = ba × 4
- ba (*nou*) = ba × 5
- ba (*nzien*) = ba × 6
- ba (*nzo*) = ba × 7
- ba (*motchué*) = ba × 8
- ba (*brou*) = ba × 10

**Weights and Measures in
Africa: Akan Gold**

Weights, Fig. 2 Weights
with graphic designs
(Photographs by the author.
Used with his permission)



**Weights and Measures in
Africa: Akan Gold**

Weights, Fig. 3 Weights
with geometric elements



The medium weights series consisted of seven units. The computation is done from simple to double, and each unit has multiples and submultiples.

Assan = 4 m.v.

Gbangbandia = 4 m.v.

Tya = 5 m.v.

Anui = 5 m.v.

Gua = 5 m.v.

Anan = 5 m.v.

Tyasue = 5 m.v.

Total = 33 m.v.

These 7 units comprise 33 monetary values. The smallest value is *météba* which equals 12 *ba* or 1.77 g. The largest value is the *ta*, which equals 348 *ba* or 51 g of gold.

In practice, the system worked as follows. For example, the *gua*, the fifth unit, comprised the following five monetary values:

Météba = 12 *ba* = 1.77 g of gold

Adjratchui = 24 *ba* = 3.55 g of gold

Tra = 48 *ba* = 7.54 g of gold

These are all sub-multiples of *gua*.

Gua = 96 *ba* = 14.20 g of gold (Unit of this series)

Guagnan = 192 *ba* = 28.40 g of gold (Multiple of *gua*)

The large weight and monetary values series had only three units. They were:

Banda = 384 *ba* = 56.80 g of gold

Banna = 432 *ba* = 67.44 g of gold

Pereguan = 478 *ba* = 71.92 g of gold.

In considering the weights and numeric representation, we will consider here only those weights with graphic signs which correspond with calculation and mathematics.

Concerning the signs and marks, the anthropologist François H. Abel has written: "A. Amélékia, a well known man named Diénélou confirmed for me that the Ancients

knew how to read from the weights. . . In the village of Lomo-north, in the region of Toumodi, the village chief knew that the signs on the weights had meaning."

Savary, the Director of the Department of Black Africa in the Museum of Ethnography in Geneva has written: "Each weight is the product of two signs written on it. . . Reading it is sometimes simple, but often difficult. This is because some Black Africans had a different concept for numeric figuration and for the representation of the product of two numbers. [Also] zero did not exist. . .". In the system, figures and numbers are represented by vertical and horizontal lines, such as marks and arrows similar to those still seen in charcoal in the houses of African villages.

Commenting in 1605 on the Akan system of accounting and calculating, the Dutch explorer and historian Pieter de Marées made this remark: "The Negroes have weights of copper and tin which they have cast themselves, and, although they do not divide in the same way we do, it comes out the same, and the accounting is always correct."

For the people of the Akan civilization, the gold weights contained in the *dja* constitute a fundamental cultural text, comparable to the Christian *Bible*, the Islamic *Qu'rān*, or the Hindu *Veda*. It is within this sacred package that they had consigned, in idiogrammatic letters and signs, their knowledge and values to be passed on to posterity. In this way, their descendants would not have to reinvent that which had been known by their ancestors and which constituted the foundation of their civilization.

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Weights and Measures in China

Hans Ulrich Vogel

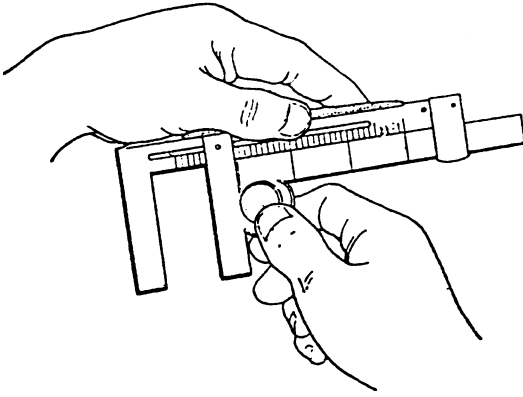
Metrology means the “science of weights and measures.” But when referring to premodern periods the term “knowledge of weights and measures” is more appropriate. In a more concrete sense, metrology is the art of calculation with number, weight, and measure units in the economic and fiscal domains as well as in science. “Metrosophy” may be defined as “number speculation within cosmological philosophemes,” but from a more inclusive perspective the relationships between magical, religious, and political thought on the one hand and metrology on the other also have to be taken into account. In both metrology and metrosophy, numbers are of great importance. In metrology, they are used for defining and counting measure and weight units, while in metrosophy they serve as basic stuff for the creation of systems of number symbolisms, magical numbers, and correlative numerologies.

For the study of metrosophy and metrology, two different types of sources are basically available. First, we may mention sources of the tradition type, like the metrosophical and metrological sections in chapters of the dynastic histories. Although these sections also contain information of a metrological nature, it is clear that they are principally metrosophical in character. The second important types of sources are concrete remains, especially the relatively great number of real ancient weights and measures which either have been excavated at archaeological sites or

which survived by having been handed down from generation to generation. While the sources of the tradition type are closely related with metrosophical thought and number systems, concrete remains inform us almost exclusively of metrological aspects and realities. The tension between these two clusters of information and data is of particular importance and is rewarding to be investigated.

Chapter 21A in the *Hanshu*, written in the first century AD, contains one of the first surviving texts that gives evidence of a system integrating metrology with such diverse fields as numerology, musical pitch, astronomical phenomena, astronomy, cosmology, historiography, and political, ethical, and moral thought. The textual arrangement of this chapter makes clear that metrology belonged to the traditional Chinese science of mathematical harmonics (*lü* or *lülü*).

Chapter 21A of the *Hanshu* states that harmonics consist of five categories: number, musical pitch, length measures, capacity measures, and weights and balances. All five had their origin in the *huangzhong* pitch-pipe, which had been created and standardized by the legendary Yellow Emperor. Obviously, the antiquity of these conceptual and technical devices was an important criterion for their purported eternal validity. Within the five categories a certain hierarchy is expressed, ranking numbers above, followed, in descending order, by pitch, length, capacity, and weight measures. Numbers are obviously of primary importance, because they provided the basic counting units for the other four categories. Metrology was grounded on a numerological system combining the numbers of the ► [Five Phases \(Wuxing\)](#) and other numerological concepts with the numbers derived from the changes of yin and yang as they are described in the *Yijing* (I Ching Book of Changes) and its commentaries. Moreover, weights and measures were conceived as an integrated system. With grains of medium-sized black millet, the length and capacity of the *huangzhong* pitch-pipe were measured and thus the basic length and capacity measure units derived. The weight of the grain filling of the pitch-pipe also served as the basis for fixing the weight units (Fig. 1).



Weights and Measures in China, Fig. 1 Handling the Wang Mang proto sliding callipers (From Dong-rui (1979) (in Chinese))

Concrete remains of ancient Chinese weights and measures are of great importance for supplementing the information contained in the largely normative written sources. A spectacular example are the proto sliding callipers of the Wang Mang period (AD 9–23), of which apparently three pairs survived.

The intaglio inscription on the movable part says: “Manufactured at the first day of the first month of the first year of the Shijian guo reign-period.” This corresponds to March 15, AD 9, the first day of Wang Mang’s interregnum. The front side of the fixed part of the sliding callipers is divided into 5 in. (*cun*), that of the movable part into 5 in. In addition, the 4 in. of the fixed part are further subdivided into ten parts (*fen*) each. With the Wang Mang proto sliding callipers outer diameters of less than 4 in. could be measured. The most conspicuous difference between modern sliding callipers and the Wang Mang piece is that the latter does not have the differential scale of the vernier.

No less spectacular is the great number of other Chinese metrological remains. For instance, more than 240 ancient length measures are known, which can serve as a basis for ascertaining the “true” length of a length measure unit of a given period. This is no easy task as may be shown in the case of the length measure unit *chi* of the Eastern Han period. Modern measuring has shown that the actual lengths of 85 concrete

chi measures of this period vary from 20.49 to 24.73 cm. Obviously, state efforts at unification and standardization of weights and measures were of limited success and collided with diverging interests having their origin in different regional, local, political, economic, fiscal, and social conditions. Small wonder that in the *Suishu*, the dynastic history of the Sui dynasty written in the early seventh century, 15 different *chi* measures are listed.

The development of the types of weighing apparatuses can be divided into three stages. From the fifth century BCE to the second century AD balances with equal arms prevailed. In the period from the third to the ninth centuries the steelyard with unequal arms appeared and was used together with the ancient balances. Finally, the third stage from the tenth to the early twentieth centuries was characterized by the emergence of the highly accurate *deng* steelyard and the introduction of a decimal system of weighing units. An important promoter in the introduction and improvement of the *deng* steelyard was the eunuch Liu Chenggui (950–1013). Liu was in charge of the court treasury and fiscal affairs. The purpose of the introduction of the *deng* steelyard was to reduce disputes in the weighing of precious metals, which arose between different officials involved in fiscal affairs.

See Also

- [Acoustics in Chinese Culture](#)
- [Five Phases \(Wuxing\)](#)
- [Yinyang](#)

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Weights and Measures in Egypt

Ruth Hendricks Willard

The gradual change from a nomadic to a settled existence, which began about 8000 BCE, marked humankind's determination to shape the environment to their requirements. Needing units of measure for both building and agriculture, people

chose the most readily available and useable references – simple parts of the human body in various positions. The need for uniform measurements was recognized, and as early as 3000 BCE official reference standards of length, volume, and weight were being maintained in temples and royal palaces in Egypt, Mesopotamia, and around the eastern seaboard of the Mediterranean.

The standards developed in these ancient cultures moved westward, mostly as a result of trade, to the Greek and Roman empires, thence to Gaul and Britain via the Roman conquest. Egypt, by virtue of its geography a great trading nation and of its climate a preserver of archaeological treasures, has provided an incomparable record of this metrological heritage.

Measures of Length

Throughout the ancient Middle East, the basic unit of linear measure was the cubit, which was defined as the length of the forearm from the point of the elbow to extended fingertips. In Mesopotamia, the cubit was generally subdivided into 2 ft each of three or four palms, a palm having four digits. In Egypt, however, the most ubiquitous standard was the royal cubit. It was subdivided into seven palms (28 digits), these divisions having significant mystical relationship to the four 7-day phases of the 28-day lunar month by which time was reckoned. The basic sub-unit was the digit (finger width): 4 digits = a palm; 5 digits = a hand; 12 digits (outstretched forefinger tip to little finger tip) = a small span (1/3 cubit); 14 digits (outstretched thumb tip to little finger tip) = 1 large span (1/2 cubit). Measurements smaller than a cubit were expressed in digits (up to ten), in palms and digits, or rarely, as 1/2 or 1/3 cubit.

Surveys of the Great Pyramid confirm its construction according to the royal cubit of 20.62 in. (52.4 cm). The skill of the Egyptian workmen is shown by the fact that the sides of its base vary no more than 0.05 % from the mean length of 440 cubits (9,069.45 in. or 230,364 m). The Egyptians also employed a short cubit of

6 palms (24 digits) = 17.68 in. (44.9 cm) for general purposes including calibration of the Nilometers (masonry stairwells leading down to the river at points where the priests recorded the rise of the annual floods).

Egyptian measuring scales are square rods with one face half-beveled to form a reading surface. The fractions of the digit are shown by dividing the first into halves, the second into thirds, and so on down to sixteenths. The oldest extant cubit rods date from the Eighteenth Dynasty, 1550–1307 BCE; none are longer than the double cubit, 41.2 in. Most of those used by the workmen are made of wood with deeply cut notches of division. The stone cubit rods are generally ceremonial, belonging to the temples and crowded with inscriptions referring to the religious aspects of the digits as connected with the gods and with the signs of the nomes. On these, the calibrations are often carelessly marked.

Land was measured by a linear unit called *khet* or *khet u nu* (reel of cord) 100 royal cubits in length. Measuring cords were made of palm-fibre or flax-fibre and knotted at 5-cubit intervals. For long distances the foot (12 digits) and the pace (double step) were used; 2 paces measured heel to toe = the extended arms (4 cubits), and 100 paces = a stade. This distance later used by the Greeks in the Olympic foot races known as a stadium.

Measures of Area

The basic unit for reckoning areas of fields and nomes [a name given to regional divisions in Egypt] was the *setat*, the square of the *khet*, containing, therefore, 10,000 square cubits. Such an area was called a cubit of land, but was visualized as 100 parallel strips of land each 1×100 cubits. Ten *setats* were called a thousand of land. In devising ways to re-establish field boundaries after the annual flooding of the Nile, the Egyptians discovered the rudiments of geometry. A new unit formed from the diagonal of a square with sides equal to the royal cubit was found to be divisible by 40 digits of 0.73 in., twice the length

of the *remen* (forearm from elbow to clenched knuckles) and consequently named the double *remen*. Half of the area of 100×100 cubits was also called *remen* in land measure. By having two standards, one the diagonal on the square of the other, it was possible to denote areas in squares equal to one-half or double the area of others.

Measures of Time

Through studies based primarily on the movements of the heavenly bodies in relation to the regular flooding of the Nile the Egyptians established two calendars. The priests followed an exact year of $365 \frac{1}{4}$ days, while the civil year was subdivided into three seasons of 4 months each having 30 days – inundation, cultivation, and harvest – plus 5 days-upon-the-year.

Measures of Volume

In establishing standard units of capacity for barter, taxation, and medication convenient reference was made to human factors such as a mouthful (tablespoonful), handful, cupful (two handfuls) and sack- (hide-) ful for easy carriage. The principal Egyptian standards from small to large were the *ro*, *hin*, *hekat*, and *khar*.

Medications were prescribed in terms of the *ro* (mouthful, tablespoonful) = $\frac{1}{2}$ fl oz (14.5 cc). By the usual Egyptian method of doubling this standard produces 2 *ro* = 1 handful (fl oz, jigger); 4 *ro* = 2 handfuls (jack, jackpot); 8 *ro* = 4 handfuls (gill); 16 *ro* = 2 hands cuppedful (cup); 32 *ro* = jugful (pint, *hin*); 64 *ro* = pitcherful (quart) and, by extension, the old English measures including the gallon, peck, bushel, barrel, hogshead, and tun.

The *hin* for liquids was subdivided dimidially down to $\frac{1}{32}$ = 1 *ro*. There was also $\frac{1}{3}$ *hin* known as the *khay*, thirds being a peculiarity of Egyptian metrology occurring also in the subdivision of the cubit and *qedet* standards. There were two principal standards for larger volumes. Multiples of the *hin* were decimal: 10 *hin* = 1 *hekat* (4.7 L). The *hekat* was the official corn measure:

hekat = 10 hin; 30 hekats = 1 cu cubit. The khar, originally a hide or sackful, was a special standard = 20 hekats (94 L). Subdivisions of the hekat in the dimidial series $1/2$ – $1/64$ (=5 ro), an amount frequently prescribed for internal medications) were always written in symbols now known as the Horus-eye notation. The Rhind Mathematical Papyrus, attributed to the Twelfth Dynasty (1991–1783 BCE), provides the following conversion table: $9,600 \text{ ro} = 300 \text{ hin} = 30 \text{ hekat} = 3/2 \text{ khar} = 1 \text{ cubic cubit}$ (37 U.S. gallons).

The early use of additional capacity standards is documented by wall paintings in a Mastaba tomb of the Third Dynasty, ca. 2630 BCE. Two series of cylindrical capacity measures, one of copper, for measuring wine and oil, and one of hooped wood staves for grain, have been shown to conform to a mixed series in binary progression based on the standards of both the Egyptian hin and the Syro-Phoenician *kotyle* (21.4 cu in. or 350 cc). Other standards of volume used in Egypt include the Syro-Babylonian *log* (33.1 cu in. or 542 cc), the Attic *kotyle* (17.2 cu in. or 282 cc), and the Persian *kapetis* (74.9 cu in. or 1,227 cc).

Measures of Weight

A search for the origins of weighing reveals that this intuitive use of the lever evolved independently in at least three ancient civilizations – Mesopotamia, the Indus Valley, and Egypt – and that all three were routinely employing balance and weights by the middle of the third millennium BCE. The weights, made in durable stone, have survived in sufficient numbers to permit study of the ancient weight standards. However, very few balances, which were usually constructed of wood in the earliest periods, exist today.

It is possible, nonetheless, to trace not only the evolution of weighing instruments but also the uses to which they were put in dynastic Egypt during the period 2700–650 BCE. As a means of enhancing the quality of the afterlife of their leaders, Egyptian artisans carved or painted

scenes from their earthly life in tombs and temples. Because of a mild, dry climate, many of those monuments survived into modern times. While it is still possible for visitors to experience the excitement of discovering the weighing scenes in situ, not all of the tombs and temples have survived the two centuries of study and tourism to which they have been subjected. Colors have faded; walls and in fact entire structures have disintegrated or been destroyed or closed. We turn, therefore to the remarkable work of the Egyptologists of the nineteenth and early twentieth centuries, a period of intensive recording and copying of Egyptian inscriptions, reliefs, and paintings. Hence, it becomes necessary to consider not only possible errors in the original, but also the errors resulting from the deterioration of the works being copied.

For information regarding the practice of weighing, we are indebted primarily to Sir W. M. Flinders Petrie. He was the first Egyptologist to identify, collect, and study the ancient weights for the insights they could provide into the cultural and trade relations among the various nations of the Near East. His numerous publications include chapters on the metrological findings of each site excavated. Most large museums have specimens of ancient Egyptian weights.

The practice of weighing began with the discovery of metalworking. The earliest weights are of a small order, suggesting that at first only small quantities needed to be weighed. Egyptians developed two indigenous weight standards and as an international trading center employed at least six more. The Egyptian national standard was based on the qedet, which varied over time from 138 to 152 gr giving a median value of 144 gr (9.33 g). It was multiplied decimally: $10 \text{ qedet} = 1 \text{ deben}$; $10 \text{ deben} = 1 \text{ sep}$, as first recorded in a Third Dynasty tomb painting. The unit was sometimes divided into thirds as evidenced by a series of graves from the First Dynasty (2920–2770 BCE). The qedet is the basis of nearly all statements of weight from the Eighteenth Dynasty onward. The qedet and deben were also known as the kite and *uten* when applied to pieces of copper used as a medium of exchange.

Less well known but more influential in world affairs was the *beqa*, which was associated with the weighing of gold and silver from pre-Dynastic times and used in Egypt for nearly 4,000 years. Although the standard is seldom mentioned in Egyptian inscriptions, numerous beqa weights have survived. These are sometimes marked with the hieroglyph for gold (*nub*) perhaps recalling its origin in the Nubian gold fields. As in most Middle Eastern standards, the basic unit was called a *shekel*; 50 beqa shekels = 1 *mina*. The beqa shekel was multiplied decimally to 7,000 shekels and subdivided dimidially down to 1/16. Over time, the several distinct values merged into a single standard of 192 gr (12.4 g), which was adopted by the Greeks around 700 BCE as the standard of Aegina. From it evolved two of the Roman pounds, the silver denarius and the gold aureous coinage. In the seventh century AD it was adopted by the Arabic Empire for bulk gold and it ultimately became the basis for the English troy weight standard.

Other standards in use in Egypt included the Palestinian *peyem*, 120 gr (7.78 g); Mesopotamian *daric*, 129 gr (8.36 g); Attic *stater*, 135 gr (3.75 g); Persian *khairine*, 178 gr (11.53 g), and Phoenician *sela*, 218 gr (14.13 g).

The Evolution of the Equal Arm Balance

All of the balances used in Egypt before the Roman occupation in 30 BCE were equilateral, doubtless inspired by the yokes with which men balanced heavy loads on their shoulders. During the Old Kingdom (2686–2181 BCE) most balance beams were flat and rectangular, pierced vertically for support at the fulcrum and for the hangers, which were single cords hooked at the end to hold baskets or bags of gold dust. With but one exception, shown in (Fig. 1), they were made of perishable wood until about 1550 BCE. Hence, the only records of their design and use come from reliefs, paintings, and inscriptions.

Significant innovations during the Old Kingdom include specialized tongs to hold metal vessels, counterweights of a predetermined mass,



Weights and Measures in Egypt, Fig. 1 This is the earliest known Egyptian balance. It was skillfully cut from pinkish brown limestone, a material commonly used for making vessels in prehistoric times, but seldom later. The three suspension holes were drilled with a primitive bow drill and flint point. The beam is 3.35 in. long. Its width varies from 1.6 to 2.0 in. and its depth from 1.7 to 2.0 in. The diameter of the central hole is 0.03 in. and that of both end holes is 0.07 in. As to sensitivity, a change of 1 in 500 can be seen by the change of level. A plaster model of this balance was tested at the Science Museum in London (Photo at the Petrie Museum, University College, London by O. W. Willard in 1993)

tongues, and plummets to help in sighting the vertical. Nearly all of the Fifth and Sixth Dynasties weighing scenes come from the tombs of royal officials, and depict the weighing of metal in the course of manufacturing. There is no evidence of buying selling, or exchanging goods by weight in this early period.

The decline of the Old Kingdom was followed by the First Intermediate Period, an epoch of chaos, civil war, hunger, violence, and invasion. No evidence of weighing has been found from this period, which encompassed the 7th to 10th Dynasties and lasted from 2134 to 2040 BCE. Eventually Theban warlords gained supremacy

and established the Middle Kingdom with its capital first at Thebes and later at Itjtawy, a newly built city near Memphis.

The Middle Kingdom

Weighing scenes are found at Beni Hasan, the most noteworthy necropolis of the Middle Kingdom, where 39 tombs are cut out of the rock cliffs at Beni Hasan, on the east bank of the Nile. The tomb paintings here depict balances with an improved suspension system. The beam is suspended from a bracket near the top of the upright and can swing more freely because of a ring added to the top of the tongue. As in the fifth and sixth Dynasties, the plummet appears to hang from a point near the bottom of the tongue suggesting that the tongue and beam are rigidly attached and move together. The baskets are now suspended by multiple cords, depicted as two but presumed to be four, since that is also the case in the New Kingdom, from which we have extant pans with four holes. One representation shows workers weighing two sets of objects against one another. Another representation shows the introduction of shallow, concave pans made possible by the multiple suspension cords. Weight boxes are shown below each standing balance.

A totally new aspect of weighing appears in one Twelfth Dynasty relief. Here we see a jeweler who has left the workplace to show his finished product to the nomarch (local ruler). Reading between the lines, we note that he has suspended the balance from a full-length stand, but by using an extension cord, he has brought the scale and its contents down to a level he can reach while kneeling before his ruler.

During the Second Intermediate Period, from 1640 to 1532 BCE, the political situation was unstable, with several dynasties ruling in various areas simultaneously. While there was undoubtedly turmoil during the takeover, Egyptian life was enriched by the introduction of horses, wheeled chariots, hump backed cattle, and new tools, weapons and musical instruments. Innovations relevant to metrology included the working of bronze and weights cast in the shapes of animals.

The New Kingdom 1550–1070

Both the equipment and the philosophy of weighing underwent major changes during the New Kingdom (1550–1070 BCE). While the equal arm balance of the Old and Middle Kingdoms had been modified in ways that made using it more convenient, there was still the problem of accuracy. The end suspension cords could wander in holes drilled vertically through the beam and those holes, even if exactly equidistant from the fulcrum initially, might not remain so after the wearing away inherent in use. Either early in the New Kingdom (or possibly late in the Second Intermediate) a radically different scale beam made its appearance. Constructed of either wood or bronze, it was round in section. Suspension cords entered at the beam end through longitudinal bores and emerged through intersecting radially drilled holes, being knotted on top of the beam. Any inequality in the distance of the beam ends from the fulcrum could be adjusted by simply filing the longer end, restoring the balance to accuracy. This principle was later improved upon in the large standing balances with flared beam ends that allowed the four strings to diverge from the lowest point on the flange, making for even greater accuracy.

While the great majority of representations from this period depict large, stately standing balances, the extant specimens are all small and portable. The beams, which may be of bronze or wood, are invariably round in section. The Cairo Museum displays several. A hand-held balance at the Science Museum in London was excavated at Amarna and dates from the reign of Akhenaten, Eighteenth Dynasty, c. 1331 BCE. The length of the round, tapering wooden beam is 30 cm and the diameter of the copper pans is 7.4 cm; the sensitivity is plus or minus 2 gr per hundred in each pan. Bronze animal weights characteristic of the Eighteenth Dynasty are shown with this balance. Two previously unpublished specimens were found at the University of California's Phoebe Apperson Hearst Museum of Anthropology. Both were excavated at Naga ed-Deir during the 1899–1904 Hearst Expedition led by G.A. Reisner. While it is impossible to date either



Weights and Measures in Egypt, Fig. 2 Two New Kingdom-type balance beams (Photo by O. W. Willard by permission of the Phoebe Apperson Hearst Museum of Anthropology, University of California)

one with certainty, both have the general characteristics of New Kingdom balances (see Fig. 2).

Specimen 6-13624, from a cemetery dating from the late Old Kingdom through the Middle Kingdom, was found near the entrance of tomb 434 with the excavator's notation *ghadim* (fill). The wood is acacia, sub-species not identified. The round, tapering beam is 50.3 cm long with a diameter of 2.7 cm at the center, drilled in the New Kingdom manner for central and end suspensions. Unlike the Amarna balance above, the beam has a definite arch in the middle. There is the imprint of a narrow saddle or support of some kind at the fulcrum. The ends are knobbed, with a decorative channel around each. On each side of the suspension holes, there is a decorative double annulet with a channel between. No pans were found.

Specimen 6-2702 is believed to have come from a cemetery dating from early dynastic to Roman times. The wood is acacia, sub-species not identified; the round beam is 31.2 cm long and 2.0 cm in diameter at the center. There is a bulge in the center of the beam and the ends are slightly flared, foretelling the more pronounced flanges of the large ceremonial balance. There is also an unexplained diametric hole about 1.0 cm from the fulcrum hole. No pans were found.

The most magnificent weighing scenes are those representing the brilliant Eighteenth Dynasty, which ruled Egypt from 1550 to 1307 BCE. The ceremonial balances, sometimes 10 ft tall, are often adorned with the head of a god as a finial. The beam hangs from a bracket that may be in the shape of the feather representing Maat, the goddess of truth. The bronze tongue, which has evolved into a pointer, moves with the beam. In many examples, the operator holds the plummet

in his hand as if to inspect it for flaws before beginning the weighing procedure. Shallow concave pans, usually of metal, are suspended by multiple cords thought to be four in number although sometimes depicted as two or three. The conventional stone weights, geometric in form, have been replaced with handsome animal shapes in cast bronze.

Ambiguities in the drawings coupled with the lack of physical specimens have fostered intense interest in the central suspension and indicator system. The explanation most generally accepted was offered by Petrie in 1888:

The beam was suspended by a loop or ring from a bracket projecting from the stand; this bracket is shown in side view though at right angles to the beam just as the Egyptians drew a full eye in a side face. Then below the beam, a long tongue was attached, not above the beam, as with us. To test the level of the beam, a plummet hung down from the tongue, and it was this plummet which was observed to see if the tongue was vertical and the beam horizontal. The weigher is often shown steadying this plummet with his hand, as it would be set swinging by the motions of the beam. Such is the whole system, which is so simple that it seems strange that any mistake could be made about it to say nothing about the mechanical absurdity of the explanation which has been current for so long.

The "mechanical absurdity" theory to which Petrie referred had been offered by Wilkinson in 1837. Referring specifically to an illustration showing the balance being used by the *Qabbaneh*, or Public Weighers, he wrote,

The beam passed through a ring suspended from a horizontal rod immediately above and parallel to it, and when equally balanced, the ring, which was large enough to allow the beam to play freely, showed when the scales were equally poised. It had the additional effect of preventing the beam

tilting when the goods were taken out of one, and the weights allowed to remain in the other. To the lower part of the ring a small plummet was fixed and this being touched by hand and found to hang freely indicated, without the necessity of looking at the beam, that the weight as just.

Though acclaimed for his understanding of the Egyptian artistic canon and for the accuracy of his copies, Wilkinson overlooked the obvious fact that the vertical plane of the bracket, shown in profile, would have been perpendicular to that of the beam. The single-ring hanging mechanism as shown could not possibly have worked. It would appear that either the original drawing was erroneous, or deterioration in the ancient surface caused Wilkinson to miscopy it.

Recent research has centered in the nature and function of the triangular shape bisected by the plumb line that project below the beam. Spiegler postulates an arrangement of three strings fastened at the beam and equipped at the tip with a plummet. As the beam is tipped, a slack string allows the plummet to swing. Jenemann and Robens note that such a mechanism would work only with large deflections that could be seen more easily by visual observation. Furthermore, in colored drawings the triangle is clearly opaque, indicting a solid object. They then suggest that the flat side of the triangular plane, while shown frontally in the drawings, is actually perpendicular to the beam, while the plummet hangs independently in front of the tongue, an arrangement considered to be more sensitive than one in which the tongue pierces the beam longitudinally.

Skinner states, "For larger wooden or bronze beams a bronze tongue was driven vertically through the center of the beam with a ring on top for suspension from a bracket. The tongue protruding below the beam acted as a swinging index, which was sighted against a freely-suspended plum-bob to denote when the beam was horizontal and in balance." In the absence of New Kingdom specimens, perhaps conclusions can be drawn from a small bronze goldsmith's balance dating to the Greco-Egyptian period, 304–30 BCE. The beam is suspended from a ring in the bracket intersecting a ring in the top of the tongue or pointer, which pierces the

beam and extends below it. The plummet hangs from the bracket, behind the tongue. The original is in the Cairo Museum and its replica, a plaster cast, is in the Science Museum, London.

Expanding Roles for the Balance: Trade, Tribute, Offerings

With Egypt's transformation to an international power, new roles evolved for the balance. Along with the customary depictions of jewelers and other metal workers there are scenes of the balance used in weighing tribute to the pharaoh and offerings to the national god Amun and, for the first time, in domestic and foreign trade. Short gold or silver cylinders about 5 in. in diameter served as a sort of currency. Variable in mass, these must have been weighed in each transaction. Medicine however, continued to be measured rather than weighed.

The earliest known depiction of the balance in commerce is found in a remarkable painting from the tomb of Kenamun, Mayor of Thebes and Superintendent of the Granaries of Amun under Amenophis III, 1391–1353 BCE. Syrian ships were anchored on the Nile off Thebes, while on shore two male shopkeepers engage in private trading with the sailors. Since the commodities – sandals, apparel, and various objects – are too large to weigh on the hand balances shown, the sellers are obviously weighing out the amount of gold needed to make the purchases.

Among the various public officials were the Qabbaneh, or public weighers, who erected their balances in the market place while a notary stood by to record the details. They were required by law to adjust the sale of each commodity with the strictest regard to justice, without favoring either the buyer or the seller. The penalty for falsification of weights or records was the loss of both hands, inflicted upon the seller, the weigher, and the notary alike. The Qabbaneh were still functioning in early twentieth century Thebes.

Hatshepsut, who ruled as Egypt's only female Pharaoh (1473–1458 BCE) built at Deir el Bahari a magnificent temple with extensive terraced

gardens facing the Nile. She dispatched an expedition to the fabled land of Punt in search of treasures to be offered to the sun god Amun, to whom the temple was dedicated, and recorded the presentation in a monumental relief on the south face of the second terrace. In the weighing scene, a massive balance is piled high with cylindrical gold ingots being weighed against some loaf-shaped weights of the Middle Kingdom and some bronze animal-shaped weights characteristic of the Eighteenth Dynasty. In the background are trays holding additional loaf shaped weights and quantities of electrum (a naturally-occurring alloy of gold and silver) in bars and rings. The inscriptions read,

The balances accurate and true of Thoth, which the King of Upper and Lower Egypt (Hatshepsut) made for her father Amun, lord of Thebes, in order to weigh the silver, gold, lapis lazuli, malachite, and every splendid costly stone, for the sake of the life, prosperity, and health of her majesty. Weighing the gold and electrum, the impost of the southern countries, for Amun-Re, lord of Thebes. Recording in writing, reckoning the numbers, summing up in millions, hundred of thousands, tens of thousands, thousands, and hundreds.

Thutmose III, successor to Hatshepsut, so extended the Egyptian holdings in Asia and northern Ethiopia that he has been referred to as the Napoleon of Egypt. During this period, the coffers of the state were greatly enriched by both tribute from and trade with the nations they had subdued. A weighing scene in the tomb of his Vizier, Rekhmire, is inscribed in part, "This great heap of electrum, which is measured by the heket, making 36,692 deben.

The Papyrus Harris, now in the British Museum, represents the testimony of Rameses III, Pharaoh (1194–1163 BCE) as he nears the end of his life and affords an understanding of both the physical nature and the significant role of the ceremonial balance in the New Kingdom. Describing his stewardship as the god's representative, he states as part of the prayer and recital of the king's benefactions,

I made for thee splendid balances of electrum, the like which had not been made since the time of the god. Thoth sat upon it as guardian of the balances, being a great and august ape of gold in beaten work.

Thou weighest before thee, O my father Re, when thou measurest of gold and silver by the hundred thousands, brought as tribute before thee from their coffers, and given to thy august treasury in the house of Atum. I founded for it (namely the balance; evidently offerings were made to it) daily divine offerings in order to supply its altar at early morning.

In another section, Rameses describes the king's gifts to Re including (in part), "Fine mountain gold and gold for the balances 1,278 deben, 9 $\frac{2}{3}$ kedet. (The gold amounts to some 311 $\frac{3}{4}$ pounds troy, and the silver to nearly 461 pounds troy.) Crude silver for the balances and silver in vessels 1,891 deben, $\frac{1}{2}$ kedet. Black copper for the balances 67 deben, 3 kedet.

Weighing the Soul

Souls too were weighed. The Egyptian concept of right conduct as a prerequisite for admission to paradise grew out of the cult of the god Osiris, which with its promise of immortality began to flourish during the First Intermediate Period. But it was first represented pictorially in the New Kingdom, when an elaborately illustrated roll of papyrus known as the Book of the Dead (or, more properly, The Book of Coming Out by Day) was placed in the tomb. Along with spells and instructions for entering into the kingdom of the gods, each Book of the Dead included a weighing scene in which the heart of the deceased, often represented by the hieroglyph for heart, was weighed against the feather of truth, symbol of the goddess Maat. The deceased was required to make a "negative confession" denying the commission of 42 specific sins such as giving short measure or falsifying the scales of the balance. The jackal-headed god Anubis tested the plummet of the scales, while the ibis-headed god Thoth prepared to record the results and a beast called the Devourer of Souls stood by to perform his duty, should the applicant's heart be found wanting (see Fig. 3).

This allegorical concept, first presented graphically by the Egyptians, persisted in the Christian world through the Middle Ages as demonstrated by surviving legends, stained glass windows, and



Weights and Measures in Egypt, Fig. 3 The Judgment Scene: Ani's heart being weighed in the balance (the first three of six panels). *Left to right, top:* The company of the gods, who hear Ani's testimony. Lower register, *left to right:* Ani and his wife Thuthu entering the Hall of Judgment; Rehenet and Meskhnet, the Goddesses of birth; (small figures. L 2 r) Ani's soul, Ani's Embryo, Ani's luck or destiny; Anubis testing the tongue of the balance;

Thoth recording the result of the weighing, The Devourer of the Unjustified; Not shown here: Horus, the falcon-headed god, introducing Ani into the presence of Osiris; Ani kneeling before Osiris, Osiris enthroned within a shrine. Behind him are Isis and Nephthys, and before him upon a lotus stand, the children of Horus (Wallis, 1969). The original Papyrus of Ani is in (The British Museum, No. 10470 Sheet 3 and 4)

paintings in which Anubis is replaced by St. Michael and the feather replaced by a toad. In 1901, Dr. Duncan McDougal of Haverhill, Massachusetts conducted the first of several experiments to determine whether the soul has weight. He found that in addition to the gradual weight loss related to the loss of body fluids as death approached, at the exact moment of death there were sudden weight losses of $\frac{3}{8}$ oz, $\frac{1}{2}$ oz, and $\frac{3}{4}$ oz. He attributed this weight loss to the departure of the soul. In his book, *Weighing the Soul*, Fisher relates other scientific research dating from Leonardo da Vinci in 1515 to American and European physicists in modern times. As recently as 1972, according to Agence France Press, a Swedish doctor set out to determine the mass of the human soul by placing the deathbeds of seriously ill patients on extremely sensitive scales. As each died and the soul left the body, the needle dropped 21 g, he reported.

The reliefs and paintings with which the Egyptians adorned tombs and temples celebrate the enduring values of their culture over a period of more than 3,000 years. The Eighteenth Dynasty

weighing scenes with their monumental balances and graceful animal-shaped weights are generally considered the apex of the genre. After this period of artistic and religious ferment Egypt returned to the old familiar ways, recasting their weights in geometric shapes. And as time went on, the illustrations grew more and more fanciful, as if the artists preparing them were not familiar with the actual instruments. While these enigmatic drawings, at once lively and serene, do not reveal all the technicalities of the Egyptian balance, they do provide a window into an ancient culture whose achievements in many fields are still reflected in modern life.

Whether constructed of wood or of bronze, the improved Egyptian balance became the standard weighing instrument of the Near East until Roman times. Glassmaking, another technical innovation of the Eighteenth Dynasty, was applied to metrology with the production of a few weights during the Roman and Byzantine periods. The Arabs, after their conquest of the country in AD 640, continued the tradition, issuing a fine series of reference weights for their

coinage. These are circular discs of transparent glass in various colors molded with a thick rim surrounding a central depression and civil inscriptions in Arabic. The Arabic standard of metrology continued to be dominant through the nineteenth century with standards varying city by city and by commodity. The metric system was made permissible in Egypt in 1873.

See Also

- [Calendars in Egypt](#)
- [Pyramids in Egypt](#)

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Weights and Measures in Islam

Ulrich Rebstock

In the sphere of Islamic influence the Quranic injunction “to give full measure and to weigh with the right scales” (*Qur’ān* 17:35), led – in the long run – to systems of measuring that were subjected to the authority and control of politics and law. But only a few measuring standards were substituted by new Islamic prescriptions. The most lasting novelty set off through the Quranic revelation affected the measure of time. It assumed a dual character. The natural solar year gave way to the ritual lunar year (29–30 days of the month), except in some fields of public administration and astronomical science. Within the sphere of the metrological systems of measures and weights, however, the *Qur’ān* remains vague. Among the terms most often mentioned, *kayl* or *mikyāl* (Sura 12:12 and

passim, ‘measure of capacity’), *mīzān* and *mithqāl* (Sura 6:152, 21:47 and *passim*, ‘weight’), range first. Others, like *qinṭār* (3:75, ‘hundred-weight’), *darāhim* (3:75, pl. of *dirham*), *dīnār* (3:75) and *ḥabba min ḥardal* (21:47, ‘grain of mustard’), are used in a metaphorical sense. A more systematic elaboration of metrical definitions and ratios, mainly for juridical purposes, was effectuated in the ‘traditions of the Prophet’ (*ḥadīth*, pl. *aḥādīth*). The characteristic aspects of the genesis of Islamic law – a cumulative development until the fourth and tenth century, geographically restricted proliferation of the various law schools (*madhāhib*), lack of normative authority – did, however, not allow for the introduction of uniform and ubiquitously accepted Islamic metric systems. Thus, the weights and measures which were used in Arabia and outside it, in the lands conquered by the Muslims, co-existed side by side, replaced each other, sometimes only by function, or by name, or intermingled. The striking feature of the metric systems that were in use in the early, medieval and pre-modern Islamic countries was their diversity. Neither in time, nor in space, could standard values develop that were accepted beyond their regional borders and their rulers’ period. Although some names of units of measure, e.g. *dhirāʾ*, *dirham* or *raṭl*, were widely diffused throughout the Islamic world, their absolute values and use in practice differed considerably. Notwithstanding this bewildering array of measures, a few basic terms that have survived until modern times stand for the cultural continuity between the Ancient Orient and the Islamic world: *raṭl* (Greek litron, ‘litre’), *irdabb* (Greek artabe, Persian ‘measure of capacity’), *maṭar* (Greek metretes, ‘measure of 40 L’), *ḳisṭ* (Greek xestes, Latin sextarius, ‘jug’), *qinṭār* (Latin centenarius, ‘hundredweight’), *ḳaf īz* (Persian ‘measuring cup’), *ḳīrāṭ* (Greek keratios, ‘carat’), *istār* (Greek stater, ‘weight of gold coin’), *dirham* (Greek drachme), *dīnār* (Latin denarius), *kayl* (Aramaic measure of capacity), *mann/mannā* (Babylonian unit of weight), *kurr* (Babylonian measure of capacity).

The development of systems of measure was influenced by the interplay between cultural

tradition and the order of authorities. Until the tenth century, the spread of Islam brought about an intercontinental economic and cultural sphere which amalgamated measuring standards of Egyptian, Arabic, Greek, Roman-Byzantine, Mesopotamian and Persian origin. This resulted in a multiplicity of regional and functional systems of measurement, which were constantly modified by power politics, institutional reforms or, simply, by the rulers’ autocratic order. Quite often, the advent of new dynasties brought about the introduction of new metrological standards, mainly in the field of the basic weight units of currency of gold (*mithqāl*) and silver (*dirham*), and the exchange rate of gold *dīnār* and silver *dirham*, which were fixed at a very early state by the canonical texts of the *Qurʾān* and the prophetic tradition (*ḥadīth*). Contrary to the more or less stable weight rate (10 weight *dirhams* equal 7 weight *mithqāl*), which everyday use polished into the handier ratio of 3:2, the prescribed rate of value (10 silver *dirhams* equal 1 gold *dīnār*) incessantly deteriorated over the course of time. Ratios of 12:1, 16 4/5:1, 20:1, 30:1 and even 50:1 are recorded. Nevertheless, modern Islamic jurists insist on referring to the canonical rates (10:7; 10:1) when, for example, fixing the minimum income (*niṣāb*) for the obligatory alms payment (*zakāt*) by Muslims of a determinate portion of their lawful property. The canonical ratio of the value of gold and silver (10:1) reflected the historical situation in the Mediterranean region and the Middle East after the Roman period (12:1). During the Il-Khānid period (thirteenth to fourteenth century), silver from Central Asia was massively imported to the West, the price of silver sank again, for a short period, to the Roman value. Gold, in contrast, remained remarkably stable over the millennium. Under the Persian king Darius the Great (522–486), mutton cost the same as in Anatolia in 1340: the equivalent of 1.9355 g pure gold.

Alphabetic list of abbreviations used

<i>ar</i>	<i>aruzza</i> , pl. <i>aruzzāt</i>	Grain of rice
<i>ash</i>	<i>ashl</i> , pl. <i>ashwāl</i> , <i>ushūl</i>	Part of a ‘rope’
<i>az</i>	<i>azla/azāla</i> , pl. <i>azāla</i> , <i>azālāt</i>	Unit of capacity measure

(continued)

<i>as</i>	‘ashīr, pl. ‘ashīrāt, ‘ushrān, a‘shur	Tenth
<i>ba</i>	baṭṭa	Leather bottle
<i>bā</i>	bāb, pl. abwāb	Portion
<i>bā‘</i>	bā‘, pl. abwā‘	Arms’ span
<i>da</i>	dāniḳ, pl. dawāniḳ, dawānīḳ	1/6 of a dirham/dīnār
<i>dh</i>	dhirā‘, pl. dhirā‘āt, adhru‘	Ell
<i>dī</i>	dīnār, pl. danānīr	Gold dīnār
<i>dir</i>	dirham, pl. darāhim	Silver-dirham
<i>dj</i>	djarīb, pl. djirbān, adjriba	Unit of square measure
<i>djo</i>	djou	Barleycorn (Persian)
<i>fa</i>	fals, pl. fulūs, afluṣ	Small coin
<i>fad</i>	faddān, pl. fadādīn	Yoke of oxen
<i>far</i>	farq	Unit of capacity measure
<i>fā</i>	fātil	Small unit of weight
<i>ghi</i>	ghirāra, pl. gharā’ir	Sack
<i>ha</i>	habba, pl. hubūb, habbāt	Seed
<i>hab</i>	habl, pl. hibāl, hubūl	Rope, thread
<i>hi</i>	himl, pl. aḥmāl	Camel-load
<i>ir</i>	irdabb, pl. arādibb	Unit of capacity measure
<i>is</i>	istār, pl. asātir	Unit of weight measure (Greek)
<i>iṣ</i>	iṣba‘, pl. aṣābi‘	Width of middle finger
<i>ka</i>	kaff, pl. kaffāt	Hand
<i>kā</i>	kāra	Load carried on the back
<i>kay</i>	kayl/kayla, pl. akyāl, akāyil	Unit of weight measure
<i>kayl</i>	kayladja, pl. kayladjāt, kayālidj	Unit of capacity measure
<i>ku</i>	kurr, pl. akrār	Unit of capacity measure
<i>ka</i>	kaḟīz, pl. aḳfīza, kifzān	Unit of capacity weight
<i>kab</i>	kab(a)ḍa, pl. kabaḍāt	Width of fist
<i>kad</i>	kadaḥ, pl. aḳdāḥ	Unit of capacity measure
<i>kal</i>	kalam, pl. aḳlām	‘Strip’
<i>kām</i>	kāma	Build, fathom
<i>kaṣ</i>	kaṣaba, pl. kaṣabāt	Pole, rod
<i>kin</i>	kinṭār, pl. kanāḟīr	‘Hundredweight’
<i>kis</i>	kisṭ, pl. aḳsāt	‘Portion’
<i>kī</i>	kīrāt, pl. qarārīt	Carat
<i>ku</i>	kulla, pl. ḳulal, ḳilāl	Jug

(continued)

<i>ma</i>	mann/mannā, pl. amnān, amunnā’	Unit of weight measure
<i>mak</i>	makkūk, pl. makākīk	Unit of capacity measure
<i>mar</i>	marzbān	Unit of capacity measure (Persian)
<i>maṭ</i>	maṭar, pl. amṭār	Unit of liquid
<i>mi</i>	mithkāl, pl. mathāḳīl	Unit of weight measure
<i>mish</i>	mishkā‘	Drinking-vessel
<i>mu</i>	mudd, pl. amdād	Unit of capacity measure
<i>mud</i>	mudy, pl. amdā’	Unit of capacity measure
<i>na</i>	naḳīr	‘Small spot’ (Arabic)
<i>nu</i>	nügi, pl. nügiler	Unit of weight measure (Turkish)
<i>oḳ</i>	oḳka, pl. oḳkalar	Unit of weight measure (Turkish)
<i>pe</i>	peymāne	Bowl
<i>r</i>	raṭl, pl. arṭāl	‘Litre’
<i>ru</i>	rub‘, pl. arbā‘	Fourth
<i>sha</i>	sha‘īr, pl. sha‘īrāt	Grain of barley
<i>shi</i>	shibr, pl. ashbār	Span of hand
<i>si</i>	silsila, pl. salāsīl	Chain
<i>su</i>	sunbul, pl. sanābil	Ear of grain
<i>ša</i>	šā‘, pl. aṣwu‘, aṣwā‘	Unit of capacity of weight
<i>th</i>	thumn, pl. athmān	Eighth
<i>ti</i>	tillīs	Unit of capacity measure
<i>ṭa</i>	ṭassūdī, pl. ṭasāsīdj	Unit of weight measure
<i>‘ush</i>	‘ushr, pl. a‘shār	Tenth
<i>ūk</i>	ūkīya, pl. awḳiyā, ūkīyāt	Unit of weight measure
<i>wa</i>	waiba	Unit of (dry) capacity measure
<i>was</i>	wasḳ, pl. awsāḳ	(Camel’s) load
<i>za</i>	zabīl	Basket made of palm- leaves

The overall cultural diversity of the Islamic world corresponds to the diversity of the metric systems, which came into use between the Atlantic and the Indian sub-continent. Three geographical units can be differentiated: The Islamic Arab West, from Andalusia to Iraq, Persia and the adjacent areas under Persian influence, and India. The following comments omit the metric systems of India (see *EI* ² VI, pp. 121a–122a, s.v. *makāyīl*,

and VII, pp. 138a–140b, s.v. *misāḥa*) and concentrate on the development in the Arab West, in consideration of the situation in Persia. Emphasis is laid on the early Islamic and medieval period. The absolute equivalents in modern metric values stem back to archaeological evidence or observations of European travellers.

Measures of Length

Along with the basic unit of length, the *dhirāʿ*, several other units were used, some of them only for particular purposes (construction, geometry, etc.). In theory, i.e. without considering their actual common occurrence or precise values, these units could be arranged to the following equation:

$$1 \text{ ash} = 1 \text{ si} = 10 \text{ bā} = 10 \text{ kaṣ} = 15 \text{ bā} \cdot (\text{or } \text{kām}) = 60 \text{ dh} (= \text{Persian } \text{gaz}) = 360 \text{ kab} = 1,440 \text{ iṣ} = 3,600 \text{ fa} = 8,640 \text{ sha}.$$

The ‘black ell’ (*al-dhirāʿ al-sawdāʿ*), being ca. 54.04 cm, is said to refer to the length of the ell (from the elbow to the tip of the middle finger) of a slave of the Caliph al-Manṣūr (r. 754–775) or the Caliph al-Maʾmūn (r. 813–833). Another etymology links the measure to the unit by which the ‘Nilometer’ of the island of al-Rawḍa was operated. There are almost 30 variants of the ell, some varying 30-fold from the original. By the eleventh century, at least 11 different types of *dhirāʿ* can be differentiated:

- 1 *dhirāʿ sawdāʿ* = $1 + 1/7 + 2/3 \cdot 1/7 \text{ dh al-yad}$ (of the hand) = $1 + 1/8 + 1/9 \text{ dh al-ḥadīd}$ (iron ell)
- 1 *dh fiḍḍīya* (silver) = $1 - 1/7 \text{ dh al-sawdāʿ}$
- 1 *dh yūsuf īya* (of Abū Yūsuf, d. 798) = $1 - 2/3 \cdot 1/7 \text{ dh al-sawdāʿ}$
- 1 *dh hāshimīya* (of the Banū Hāshim) = $1 + 1/8 + 1/10 \text{ dh al-sawdāʿ}$
- 1 *dh bilālīya* (of Bilāl b. Abī Burda, d. 739) = $1 \text{ dh al-sawdāʿ} + 2 + 2/3 \cdot 1/7 \text{ iṣ}$
- 1 *dh fiḍḍīya* (al-misāḥa) = 7 or 8 *dh al-yad*
- 1 *dh ʿumarīya* (of ʿUmar b. ʿAbd al-ʿazīz, d. 720) = $1 + 1/2 \text{ dh al-yad}$

- 1 *dh mīzānīya* (surveyor’s ell) = 3 *dh al-yad*
- 1 *dh mābahrāmī* = $1 + 1/2 \text{ dh al-ḥadīd}$

In addition to these different norms of the *dhirāʿ*, a multitude of ells was used depending on the profession involved: carpenters, cloth-makers, constructors etc. Moreover, the ells used in different cities under the same name differed: the medieval cloth-ell of Damascus (ca. 63.035 cm), for example, was 1/12 longer than the cloth-ell of Cairo (58.187 cm).

Measures of Area

The calculation of the surface of (straight) areas operated with the conventional measures of length. The basic units, however, were the *kaf īz* and the *djarīb*, two specific measures of surface area. Originally and throughout the Islamic period, both units also served as measures of capacity. One *djarīb* was conceived of as representing the surface area of agricultural land which could be sown with the amount of seed one *djarīb* contained.

Based on the ratio of the length units ($1 \text{ ash} = 10 \text{ bā} = 60 \text{ dh} = 360 \text{ kab} = 1440 \text{ iṣ}$), the following ratio of units of surface area measurement can be generated:

$$1 \text{ ash} = 60 \text{ dh} \cdot 60 \text{ dh} = 3,600 \text{ dh}^2 = 1 \text{ dj}$$

and:

$$1 \text{ dj} = 10 \text{ ka} = 10 \cdot 360 \text{ dh}^2 \\ = [\text{in Persia}] 60 \text{ ka} = 600 \text{ ʿas} = 600 \cdot 6 \text{ dh}^2 \\ = 100 \text{ ʿas} = 100 \cdot 36 \text{ dh}^2$$

This *djarīb* was called the ‘small’ *djarīb*, being 100 square *kabaḍa* (or *kaṣaba*; the units being often exchangeable) which renders: $100 \cdot (399 \cdot 399 \text{ cm})^2 = 1,592 \text{ m}^2$. The ‘big’ *djarīb* had $5,837 \frac{1}{3} \text{ m}^2$, i.e. $3 \frac{2}{3}$ ‘small’ *djarīb*, and corresponded roughly to the predominantly Egyptian *faddān* which was calculated as 400 square *kaṣaba*, i.e. $6,368 \text{ m}^2$. During the nineteenth century, the *faddān* was reduced to $4,200.833 \text{ m}^2$.

Weights and Measures in Islam, Table 1

	<i>ashl</i>	<i>bāb</i>	<i>dhirāʿ</i>	<i>ḳabaḍa</i>	<i>iṣbaʿ</i>
<i>ashl</i>	1 <i>dj</i>	1 <i>ḳab</i>	5/3 <i>ash</i>	1/6 + 1/9 <i>ash</i>	1/24 + 1/36 <i>ash</i> = 2 1/2 <i>dh</i> ²
<i>bāb</i>		1 <i>ash</i>	1 <i>ash</i> = 6 <i>dh</i> ²	1/36 <i>ash</i> = 1 <i>dh</i> ²	1/144 <i>iṣ</i> = ¼ <i>dh</i> ²
<i>dhirāʿ</i>			1/36 <i>ash</i> = 1 <i>dh</i> ²	1/216 <i>ash</i> = 1/6 <i>dh</i> ²	1/864 <i>ash</i> = 1/24 <i>dh</i> ²
<i>ḳabaḍa</i>				1/1,296 <i>ash</i> = 1/144 <i>dh</i> ²	1/5,841 <i>ash</i> = 1/576 <i>dh</i> ²
<i>iṣbaʿ</i>					1/20,736 <i>ash</i> = 1/2,304 <i>dh</i> ²

Weights and Measures in Islam, Table 2

	<i>azla</i> ³	<i>dhirāʿ</i> ³	<i>ḳafīz</i> ³	<i>ḳabaḍa</i> ³	<i>iṣbaʿ</i> ³
<i>azla</i> ³	1	100	6,000	172,800 = 10 ² · (12 <i>ḳab</i>) ³	11,059,200 = 10 ² · (48 <i>iṣ</i>) ³
<i>dhirāʿ</i> ³				1,728	110,592
<i>ḳabaḍa</i> ³					64

Weights and Measures in Islam, Table 3

	<i>dāniḳ</i>	<i>ḳīrāt</i>	<i>ṭassūdj</i>	<i>ḥabba</i>	<i>ʿashīr</i>	<i>fals</i>	<i>aruzza</i>
I. Dīnār	12 1/2	20	24	60			
Dirham		12	24	48	60		
II. Dīnār	6	20 <i>baghdādī</i> 24 <i>baṣrī</i>		60 <i>baghdādī</i> 72 <i>ḥurās./shāmī</i>	60		
Dirham	6			48 <i>baghdādī/baṣrī</i> 36 <i>ḥurās./shāmī</i>	60	96	
III. Dīnār	[12]	[20]	24	60			240
IV. Dīnār		24/20	576	[72] 600/7		600	
V. Dīnār	6			75	60		

If multiplied with one another these units render the matrix (see above).

There is substantial evidence that the professional surveyors during the Abbasid period used a specific system of calculation. They divided the biggest unit, the *azla*, into 100 *dh mīzānīya* which corresponded to 48 *iṣ ʿumarīya* (see above), hence:

$$1 \text{ az} = 100 \text{ dh}^2 = 100 \cdot 12^2 \text{ ḳab}^2 = 100 \cdot 12^2 \cdot 4^2 \text{ iṣ}^2$$

In the Turkish lands of the Ottoman Empire (Minor Asia, Iraq, Syria and Palestine) the *dönüm* (turn), Arabic *dūnam*, was – until recent times – the standard measure of area. Originally measuring 939 m², it has been adjusted in colonial times to 1,000 m² (in Iraq to 2,500 m²) (Tables 1, 2, and 3).

Measures of Capacity

Most of the confusion about the system of the Islamic measures of capacity, both in primary medieval and in modern secondary texts, dates back to the Oriental practice to measure grain, pulse, and some liquids in capacity, but not in weight. The Arabic term *mīzān* does not clearly differentiate between the two. The transition from volume to weight needs the related quantity of the litre of water: the volume of approx. 75–77 kg of wheat and 60–72 kg of barley correspond to the volume of 100 kg/L of water.

From this economic and agricultural use of measures of capacity the proper mathematical and technical calculation of volumes must be set apart. This calculation is built on the calculation

of the surface area multiplied by the third dimension. The names used for the cubic units of measure do not change. Related to the *dhirā·mīzānīya* and based on the ratio $1\ az = 100\ dh^3 = 100\ ku$, the following values are produced: (see matrix below).

Most of the units of measures of capacity are regarded as units of weights too. It is therefore impossible to separate the two systems properly. Depending on the material measured, additionally different types of the same unit, e.g., a 'honey-*farḳ*' or a 'barley-*irdabb*', were used. The absolute values of these types differed considerably in different regions and periods. In order to allow a comparative overview, units that are related to each other by practical use are grouped together. Minor local variations and temporal changes are ignored.

Few of these units have a canonical background: $1\ was = 60\ šā· = 240\ mu = \text{ca. } 252\ \text{L}$. Far bigger than this *mudd* (ca. 1.05 L) of Medina were the *mudd* of Egypt and Iraq (2.5 L), of Syria (3.67 L), of the Maghreb (4.32 L), and that of Jerusalem (100 L). The prophetic *šā·* was exactly 4.2125 L. Being the quantitative lower limit (*nišāb*) for the liability for the *zakāt* (alms) taxes, the measure of five *wasḳ* of dates, for example, was equated in value with five *ūḳīya* (= 200 *dir* = 529.9 g), 20 *dī* (or *mithḳāl*, = 84.7 g, see later), five *dhawd* (camels), the *nišāb* of cotton (5 *was* = 1, 600 *dir* · *irāḳī* à 130 g), or 50 *kay*. Therefore, the values given for one *wasḳ* greatly differ. In the time of Hārūn al-Rashīd (around 800), a short-lived *wasḳ* (1 *was* = 2 1/2 prophetic *was*) was introduced.

Towards the end of the seventh century, the *ḳaf īz* (usually corresponding to $1/10\ dj = 1/60\ kurr$) was used instead of this prophetic *šā·* in Iraq. Another specific *ḳaf īz* of capacity is recorded from Iraq around 990: $1\ ḳa = 1\ ḳaffa$ (basket) = $1/2\ zabīl$ (basket made of palm leaves).

In Egypt grain, but in particular wheat, was measured by *irdabb*: $1\ ir = 6\ wa = 24\ ru = 48\ ḳad = 90\ ma = 96\ ḳad$ (small) = ca. 90 L. Different values extant for the *irdabb* (between

72.3 kg, modern 182 L) may be explained also by the difference of volume between, for example, wheat, barley and lentils (100:80:104).

Egyptian flour was measured in *tillīs*: $1\ ti = 3/2\ wa = 3\ ba = 15\ ma = 24\ ḳad = 22.5\ \text{L}$. There, the *waiba* of rice (1 *wa* = 8 *ḳad* = 24 *r kabīr*), as observed around 1665, contained only 12.5 l. Three centuries before in Tunis, it was equal to 12 prophetic *mudd* (ca. 12.6 l).

In Medina and Iraq, honey but also wheat was measured in *farḳ*: $1\ fa = 3\ ša = 36\ r\ bagdādī = 19\ \text{L}$. In Egypt and Syria, the *mudy* – not to be confused with the *mudd* – replaced the *ḳisṭ* when not oil but food was measured. It is sometimes called 'the Syrian *djarīb*', sometimes equated with the *ḳaf īz*. The practice in Syria, however: $1\ ḳa = 8\ mak = 12\ ša$, the indication: $1\ mud = 15\ mak = 22\ 1/2\ ša$ does not confirm this. In Palestine, a square *mudy* was known ($1\ mud^2 = 1\ ḥab \cdot 1\ ḥab$).

Olive oil was merchandised in *maṭar* (1 *maṭ* = 2 *ḳu* = ca. 17 kg) in the Maghreb, in *ḳulla* (1 *ḳu* = 12 *th* = 27 *r* = 13.6 kg) in Andalusia. In Egypt, the *thumn* corresponded to $1/8\ ḳad$ (today 0.29 L), in Qayrawān to 6 prophetic *mu* = 6.32 L. Oil and other liquids were also measured in *ḳisṭ*: In Iraq, the 'small' *ḳisṭ* (1 *ḳi* = 3 *r* = 1.22 L) was half of the 'great' *ḳisṭ*, in Egypt it was half of a *šā·*: 211 L; elsewhere the *ḳisṭ* is given as: $1\ maṭ = 4\ ḳi = 21\ 1/3\ r\ djarwī$ (see below) = 192 *ūḳ* (capacity) = 256 *ūḳ* (weight). In Andalusia, wine and vinegar were sold in *rub·* (1 *ru* = $1/4\ ḳad = 18\ r = 216\ ūḳ = 1,728\ mi = 8.16\ \text{L}$, in Persia the *peymāne* (bowl, 8.3 L) was in use for this purpose. In Iraq, wine, but also oil and honey, were measured by *makkūk* or *mishḳā·* (drinking-vessel): $1\ mak = 48\ th \text{ à } 50\ dir = 64\ mish \text{ à } 37\ 1/2\ dir = 7.5\ \text{L}$.

Another widespread unit of capacity was the *ghirāra*, mainly used for grain: $1\ ghi = 3\ ir\ miṣrī = 12\ kay = 14\ mak = 72\ mu\ dimashḳī = 73\ 1/2\ mu\ miṣrī = 265\ \text{L}$. In Egypt, the *kayla* = 8 *ḳad* was 7.5 L (modern 16.5 L).

This *kayla* is not identical with the *kayladja*, presumably an originally Persian unit of capacity measure: $1\ kayl = 1/2\ ša = 1/3\ mak = 3/14$

$ghi = 1/6 \text{ } \bar{ka}$ wheat = $1/5 \text{ } \bar{ka}$ barley = ca. $1 \text{ } 7/8 \text{ } ma = 2.5 \text{ L}$ (or 2 L in East Iran).

The most basic of all grain measures, especially in the Islamic East, was the old Babylonian *kurr*.

$1 \text{ } ku = 30 \text{ } \bar{ka} = 60 \text{ } \bar{ka} = 480 \text{ } mak = 600$
 $'ushr'as = 1,440 \text{ } kayl = 5,769 \text{ } ru = 7,200$
 $r = 11,520 \text{ } th = 2,925 \text{ kg}$ (wheat).

Smaller than this 'big' *kurr* of Baghdad was the *kurr* of Wāsiṭ and Baṣra ($1 \text{ } ku = 60 \text{ } \bar{ka} = 480 \text{ } mak = 1,440 \text{ } kayl \text{ } \bar{a} \text{ } 600 \text{ } dir$ of wheat = $2,700 \text{ kg}$); a 'reformed' *kurr* even amounted only to: $1 \text{ } ku = 60 \text{ } \bar{ka} \text{ } \bar{a} \text{ } 25 \text{ } r \text{ } baghdādī = 609.375 \text{ kg}$ (wheat). Moreover, depending on the kind of grain measured, different *akrār* were used: In fourteenth century Baghdad, the *kurr* of wheat weighed $2,925 \text{ kg}$, that of barley $2,437.5 \text{ kg}$, and that of rice $3.656,25 \text{ kg}$. The common sub-units of the *kurr*, the *ḳaf īz*, *makkūk*, *kayladja*, and *thumn* differed respectively, sometimes not only proportionally. Thus, in twelfth century Aleppo, a quite different *makkūk* existed: $1 \text{ } mak = 19 \text{ } sun = 28.5 \text{ } r \text{ } \bar{a} \text{ } 684 \text{ } dir \text{ } \bar{a} \text{ } 3.125 \text{ g} = 60.92 \text{ kg}$. About the same time, the *ḳaf īz* of ḥamāh was $7/8 \text{ } \bar{ka}$ of that of Shayzar. In Aleppo, $4 \text{ } mak$ made one *marzbān* ($1 \text{ } mar = 1/4 \text{ } mak = 19/4 \text{ } sun = 57/8 \text{ } r = 4,873 \text{ } 1/2 \text{ } dir = 15.23 \text{ kg}$).

Towards the end of the tenth century, the mathematician al-Būzjdjānī compared the new 'reformed' (Arabic *mu·addal*) *djarīb* – this *djarīb* was not measured with 10 but with $2 \text{ } 1/2 \text{ } \bar{ka}$ only – which was introduced after 978 by his Lord, the Būyid ‘Aḏud al-Dawla, with four different common types of the *kurr*. His systematic treatment of the issue will throw some light on the complex variety of the units used and their specific relation when being transformed from one into another (see matrix below).

Besides *simsim* (sesame), *ḥinṭa* (wheat), *djahkandam* (mixture of $1/2 \text{ } ḥinṭa + 1/2 \text{ } sha·īr$), and *sha·īr* (barley), a fifth category is formed to include all kinds of grain and dry goods that do not belong to one of the aforementioned categories: nuts, like almonds, pistachios and hazelnuts,

dried pears, plums etc. From the matrixes 1–4, exactly 280 possible combinations result by which the transfer of one given quantity (and value) of one commodity into another can be calculated.

1. Ratio of *kurr*-Variants
2. *Djarīb* per *kurr*
3. Ratios Between sub-units (as indicated by Al-Būzjdjānī)
4. Ratio of Capacity Between Different Kinds of Grain

Types of <i>kurr</i>	<i>mu·addal</i>	<i>kāmīl</i>	<i>fālidj</i>	<i>hāshimī</i>	<i>sulaymānī</i>
<i>mu·addal</i>	1	2	$2 \text{ } 1/2$	3	$3 \text{ } 1/2 + 1/4$
<i>kāmīl</i>	$1/4$	1	$1 \text{ } 1/4$	$1 \text{ } 1/2$	$1 \text{ } 1/2 + 1/4 + 1 \text{ } 1/8$
<i>fālidj</i>	$2/5$	$4/5$	1	$1 \text{ } 1/5$	$1 \text{ } 1/2$
<i>hāshimī</i>	$1/3$	$2/3$	$5/6$	1	$1 \text{ } 1/4$
<i>sulaymānī</i>	$1/6 + 1/10$	$1/3 + 1/5$	$2/3$	$4/5$	1
[ratio]	60	30	24	20	16

Types of <i>kurr</i>	<i>mu·addal</i>	<i>kāmīl</i>	<i>fālidj</i>	<i>hāshimī</i>	<i>sulaymānī</i>
<i>djarīb/ kurr</i>	24	12	$9 \text{ } 3/5$	8	$6 \text{ } 2/5$
<i>fraction</i>	$1/3 \cdot 1/8$	$1/2 \cdot 1/6$	$1/2 \cdot 1/6 + 1/6 \cdot 1/8$	$1/8$	$1/8 + 1/4 \cdot 1/8$

	<i>makkūk</i>	<i>ushr</i>	<i>kayladja</i>	<i>rub·</i>	<i>raṭl</i>	<i>thumn</i>
<i>kurr</i>	480	600	1,440	5,760	7,200	11,520
<i>makkūk</i>		$1 \text{ } 1/4$		12	15	24
<i>ushr</i>			$1/4 + 1/6$			
<i>kayladja</i>					5	8
<i>ḥubūb</i>	4	5			60	
<i>rub·</i>		$1/12 + 1/48$			$1 \text{ } 1/4$	
<i>thumn</i>		$1/20 + 1/60$			$1/2 + 1/8$	

	<i>simsim</i>	<i>ḥinṭa</i>	<i>djahkandam</i>	<i>sha·īr</i>
<i>simsim</i>	1	2	$2 \text{ } 2/3$	4
<i>ḥinṭa</i>	$1/2$	1	$1 \text{ } 1/3$	2
<i>djahkandam</i>	$1/4 + 1/8$	$1/2 + 1/4$	1	$1 \text{ } 1/2$
<i>sha·īr</i>	$1/4$	$1/2$	$2/3$	1
[ratio]	8	4	3	2

	gold <i>ķīrāṭ</i>	gold <i>ḥabba</i>	silver <i>ķīrāṭ</i>	silver <i>ḥabba</i>
Iraq	0.212 g	0.0706 g	0.247 g	0.062 g
Egypt etc.	0.176 g	0.0706 g	0.186 g	0.0495 g
Maghreb	0.197 g	0.787 g		

Example

If 24 *ku* of oats (*ḥurṭumān* = category of *shaṭīr*) should be transferred into *kurr sulaymānī* of pepper grass (*ḥabb al-rishād* = category of *ḥinṭa*), then the rule of seven is required, in short:

$$24 \text{ ku } kāmīl \text{ shaṭīr} - 1/6 \cdot 24 = 22 \\ \text{ku } sulaymānī \text{ ḥinṭa} + 30 \text{ ḳa}.$$

Measures of Weight

The entire Islamic system of weights is based on the *dirham* and the *raṭl*. The *raṭl* is the most common smallest unit, or reference, of weight. The weight of the *dirham* is used for two different purposes. The two values differ correspondingly:

Dirham al-fiḍḍa (Silver Dirham)

Calibration of the silver (*dirham*) and gold (*dīnār*) coins was done with the help of glass weights. The earliest preserved exemplars date back to the second half of the eighth century. The *dirham* weight defined the weight of the *dirham* coin, the *mithkāl* weight the weight of the *dīnār*. The most precise glass weights of the *mithkāl* have an average weight of 4.233 g (max. tolerance 1/3 mg). Archaeological finds affirm both the weight of the *dirham* in accordance to the canonical ratio of *dirham*: *mithkāl* (= 10:7): 2.97 g, as to the 'rounded' ratio (= 3:2): 2.82 g. An exceptional *mithkāl* weight was in use in Egypt under the Ayyubid dynasty and in the Maghreb under the Almohad dynasty (4.722 g).

The *mithkāl* gold and the *dirham* silver were divided into *ķīrāṭ* and *ḥabba*.

$$1 \text{ mi gold} = 20 \text{ ķī} = 60 \text{ ḥa}; \\ 1 \text{ dir silver} = 12 \text{ ķī} = 48 \text{ ḥa (Iraq)}$$

$$1 \text{ mi gold} = 24 \text{ ķī} = 60 \text{ ḥa};$$

$$1 \text{ dir silver} = 16 \text{ ķī} = 60 \text{ ḥ (Arabia, Egypt, Syria)}$$

Hence, the values (see matrix below).

In addition to these general systematic differences a variety of deviating systems from different regions, authors and periods are recorded (tenth to thirteenth century; indicated as I–V), that integrate sub-units like the *dāniḳ*, *ṭassūdj*, *ashīr*, *fals*, and *aruzza* (which elsewhere corresponds to 25 *ḥa ḥardal*, grains of mustard, i.e. ca. 0.0186 g); one author defines the *ḥa ḥardal* as 1/70 of a *ḥabba* (which is sometimes replaced by '*ḳamḥa*', grain of wheat), 60 of which make one silver *dirham*, i.e. 1 *ḥa ḥardal* = 0.0007 g. From the vague comments of sources, it must be assumed that most of these different systems were in use as weight measures too (see matrix below).

According to the actual ratio of value between gold and silver currency, the moneychangers had to take several factors into consideration when transferring amounts of money from one currency into the other. This could result in thirteenth century Egypt, for example, when 16 4/5 *dir* were equivalent to 1 *dī*, in the following calculations:

$$1 \text{ dī} = 1,440 \text{ ḥa fiḍḍa} [10 \cdot 60/7 \cdot 16 \text{ 4/5} = 1,440]; \\ \text{and} \\ 1 \text{ ḥa gold} = 1/5 + 2/25 \text{ ķī} = 16 \text{ 4/5 ḥa silver}; \text{ or} \\ 1 \text{ fa} = 2 \text{ 2/5 ḥa silver} = 1/7 \text{ ḥa gold} [2 \text{ 2/5} : \\ 1/7 = 16 \text{ 4/5}].$$

Dirham al-kayl (Weight Dirham)

In contrast to the homogeneous evidence of the weight of the 'silver *dirham*' the extant values of the weight of the 'weight *dirham*' deviate considerably from one another. They range from 3.086 to 3.148 g. When not indicated otherwise, the following comments will be based on the established average standard value of 1 *dir* = 3,125 g with which the 'canonical' (ratio 10: 7) *mithkāl* of 4.464 g is corresponding. From textual evidence some of which are included in the matrix above, different regional values of the *dirham*/*mithkāl* weight can be deduced:

Egypt 3.125/4.68 g; Syria (Aleppo twelfth century) 3.14/4.427 g, (Aleppo nineteenth century) 1 *dir* = 3.167 g, Damascus 3.086/4.62 g; Anatolia (Ottoman period) 3.086/4.81 g; Iraq 3.125/4.46 g; Iran (fourteenth century) 1 *mī* = 4.3 g, (sixteenth century) [3.26]/4.639 g; Maghreb 3.3/4.722 g; East Africa (sixteenth century) 1 *mī* = 4.41 g.

With the exception of Persia, where the *mann* dominated the system of weight measures, the *raṭl* became the most common and widespread unit of weight measure in the Islamic world, comparable in size and function to the European ‘pound’ (Pfund, livre, libra, Italian loan word ‘rotolo’). The *raṭl* was measured in *dirham*. Depending on what was measured, and where and when, the *raṭl* could take different numbers of *dirham* (values between 96 and 1.040 are recorded) of different *dirham* weights (standard value: 1 *dir* = 3.125 g).

If integrated into the early Meccan system:

1 *r* = 2 *ma* [à 130 *dir*] = 12 *ūḳ* = 480 *dir* = 1/100 *ḳin*,

the *mithḳāl* weights produce the following (fictitious) relation:

1 *mi* = 20 *ḳī* = 60 [or 100] *ḥa* = 10/7 *dir* = 1/336 *r* (for Iraq; 1 *ḳī* = 0.223 g)
 1 *mi* = 24 *ḳī* = 96 *ḥa* = 3/2 *dir* = 1/320 *r* (for Mecca, Egypt etc.; 1 *ḳī* = 0.195 g).

From archaeological (glass weights) and textual evidence, several hundred *raṭl* weights are known. The following list enumerates (in order of size, with ‘[...]’ values developed) some of the standard *raṭl* weights repeatedly recorded (see matrix below).

Besides the *raṭl*, the *mann* was an important unit of weight everywhere in the Islamic world, in particular in the Persian East, where it weighed between 260 *dir* (= 816.5 g) and 2,080 *dir* (= 6,656 g). A similar variety of *mann* weights was used in Asia Minor (twelfth century onwards). Until the fifteenth century it was used instead of one half of a *raṭl* à 130 *dirham*. Then a ‘big’ *mann* (ca. 3–3.25 kg), and a ‘middle’ *mann* of 1.920 g

came into use. During the Safawid period (sixteenth century), a ‘super’ *mann*, later called the ‘royal’ *mann* (between 5.7 and 6 kg), was introduced. The Ottomans used the *okḳa* (1 *ok* = 2 *nu* = 400 *dir* à 3.207 g = 1.2828 kg) instead of the *raṭl*. Its stability was proverbial: *Okka her yerde dört yüz dirhem gelir* (... to be no different from anybody else).

The biggest unit – besides the rather colloquial *ḥiml*, camel-load (1 *ḥi* = ca. 250 kg) – was the *ḳinṭār*, the hundredweight (= 100 *r*). Depending on the type of *raṭl* it was based on, the *ḳinṭār* weights differed. In medieval Egypt, different *ḳinṭār* weights were common: *fulfulī* (pepper) = 100 *r* à 144 *dir* = 45 kg; *laithī* = 100 *r* à 200 *dir* = 62 kg; *djarwī* = 100 *r* à 312 *dir* = 96.7 kg; *mannī* = 100 *r* à 260 *dir* = 81.25 kg; ‘big’ = 24 *ru* = 240 *r* à 160 *dir* = 38,600 *dir* = 120 kg. In a treatise composed by a customs officer in the thirteenth century, additional *ḳinṭār* names, but no values, for specific goods are mentioned. While the *ḳinṭār* of Syria (Aleppo, ḥimṣ, ḥamāh) was always equivalent to 100 local *raṭl*, it was taken for 100 *mann* in late medieval Iraq. In Iran (fifteenth century) and Asia Minor (Ottoman period) 1 *ḳinṭār* weighed ca. 57 kg.

The smaller weight unit of *istār* (1 *is* = 4 1/2 *mi* = 6 3/7 *dir* = 20.07 g), only known from Egypt, was used there to weigh silk: 1 *s-ḳ-ṭ* [?] = 3 *ru* = 90 *man* = 180 *is*.

The Quranic ‘*ḥabba min ḥardal*’ (the ‘grain of mustard’, see above), being 1/70 *ḥa* of 1/60 *dir* each (= ca. 0.0007 g), seems to have remained the smallest unit of weight in use in the Islamic world. If calculated properly, the fictitious *naḳīr* (1 *djo* = 6 [ḥa] *ḥardal* = 72 *fa* = 432 *fāl* = 2,592 *na* = 1/96 *mi* = 0.045 g) would correspond to ca. 5 ng.

al-Ḳurashī

The research of the history of weights and measures and their use in the Islamic world is based on a variety of sources. Unfortunately, no particular literary type of text developed that could

claim to be called ‘professional’. The information available is scattered over texts on law, social and economic history, administration and geography. They generally lack a systematic character, i.e. ignore comparative and proportionate references. The most recent endeavor to collect all information available in the historical sources was undertaken by Maḥmūd Fākhūrī and ṣalāḥ al-Dīn knawwām in: *Madjmūʿ at waḥdāt al-qiyās al-ʿarabīya al-islāmīya*, Beirut: Maktabat Lubnān Nāshirūn, 2002. Only occasionally, external sources, records of both European and Oriental travellers, allow the fixation of absolute values. With regard to their geographical and chronological diversity, the reconstruction of entire systems of measurement and of their relation to each other has just begun.

Aleppo: weights	
1 <i>dir</i> = 60 <i>ḥa</i>	1 <i>dī</i> = (22 + 1/2) <i>kī</i> = 90 <i>ḥa</i>
1 <i>kī</i> = 4 <i>ḥa</i> = 2/45 <i>dī</i>	1 <i>dī</i> = 3/2 <i>dī</i> (Iraq)
1 <i>ḥa/dī</i> = (6/7 + 2/21) <i>ḥa/dī</i> (Egypt)	1 <i>ḥa</i> = [(1 + 3/25) <i>ḥa</i> (Syria)]
1 <i>kī</i> = (1 + 1/4) <i>kī</i> (Iraq)	1 <i>kī</i> = (1 + 1/8) <i>kī</i> (Iraq)
1 <i>r</i> = 7,560 <i>kī</i>	

Anṭākiya: weights

1 <i>r</i> = [16/17 <i>r sulaymānī</i>]
1 <i>r</i> = [4/5 <i>r Ṣāhirī</i>]
1 <i>r</i> = 384 <i>dir</i> = [12 <i>ūḳ</i>] = [17 1/7 <i>mī</i>] = (268 4/5) <i>mī</i>
1 <i>ūḳ</i> = 32 <i>dir</i> (22 2/5) <i>mī</i>
1 <i>r</i> = (3/5 + 1/25) <i>r</i> (Syria) = (2 + 1/2 + 1/20 + 1/100) <i>r fulfulī</i> = 4/5 <i>r Ṣāhirī</i> = (2/3 + 1/4 + 1/100) <i>r ḥaythamī</i>

Ardabīl: weights

1 <i>r</i> = [9/5 <i>r sulaymānī</i>]	1 <i>r</i> = 1.080 <i>r</i> = [12 <i>ūḳ</i>] = 756 <i>mī</i>
1 <i>ūḳ</i> = 90 <i>dir</i>	1 <i>mī</i> = 63 <i>dir</i>
1 <i>r</i> = 1 4/5 <i>r sulaymānī</i> = 8 2/5 <i>r</i> (Iraq)	

Asyūt (Egypt): weights

1 <i>r</i> = [5/3 <i>r sulaymānī</i>] = <i>r</i> (ṭaḥāwī, ʿAkkā)	1 <i>r</i> = 720 <i>dir</i> = 1/5 <i>kīs</i>
1 <i>r</i> = 1,000 <i>dir</i> = 700 <i>mī</i> = [12 <i>ūḳ</i>]	1 <i>ūḳ</i> = 83 1/3 <i>dir</i> = 58 1/3 <i>mī</i>
1 <i>r</i> = 1 2/3 <i>r</i> (Syria) = 31/3 <i>r djarwī</i> = 6 2/3 <i>r fulfulī</i> = (7 + 2/3 + 1/9) <i>r</i> (Iraq)	

Baghdad: measures of capacity

1 <i>r</i> = [3/16 <i>ṣa</i> (ḥidjāz)] = [2 <i>ma</i>] = [1/4 <i>mu</i> (Damascus)] = 3/14 <i>r</i> (Syria)
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Bardhaʿa (Azarbaydjan): weights

1 <i>r</i> = [7/5 <i>r sulaymānī</i>]	1 <i>r</i> = 840 <i>dir</i> = [14 <i>ūḳ</i>]
1 <i>ūḳ</i> = 588 <i>mī</i>	1 <i>ūḳ/mī</i> = 49 <i>dir</i>
1 <i>r</i> = 1 2/3 <i>r sulaymānī</i>	
= (6 + 1/3 + 1/5) <i>r sulaymānī</i>	

Damascus: measures of capacity

1 <i>mu</i> = 1 4/7 <i>mu</i> (ḥidjāz) = 4 <i>r</i> (Baghdad)

Weights

1 <i>r</i> = 12 <i>ūḳ</i> = 600 <i>dir</i> = 1 <i>r sulaymānī</i>	1 <i>ūḳ</i> = 50 <i>dir</i>
1 <i>r</i> = 420 <i>mī</i> = 3,600 <i>da</i> = 14,400 <i>kī</i> = 36,000 <i>ḥa</i>	1 <i>kī</i> = 1 3/8 <i>da</i> (Iraq)
1 <i>ūḳ</i> = 35 <i>mī</i> = 300 <i>da</i> 1,200 <i>kī</i> = 3,000 <i>ḥa</i>	1 <i>kī</i> = [15/16 <i>kī</i> (Aleppo)]
1 <i>ḥa</i> = (6/7 + 1/28) <i>ḥa</i> (Aleppo)	
1 <i>ūḳ</i> (small, silk) = 10 <i>dir</i> = 1/50 <i>r</i> = 1/20 <i>is</i>	

Diyār Bakr (N-Syria)

1 <i>dir</i> = 60 <i>ḥa</i>	1 <i>dī</i> = 22 1/2 <i>kī</i> = 90 <i>ḥa</i>
1 <i>kī</i> = 4 <i>ḥa</i> = 2/45 <i>dī</i>	1 <i>ḥa</i> = 1/4 <i>kī</i> = 1/90 <i>dī</i>

Diyār Muḍar (N-Syria)

1 <i>dir</i> = 60 <i>ḥa</i>	1 <i>dī</i> = 22 1/2 <i>kī</i> = 90 <i>ḥa</i>
1 <i>kī</i> = 4 <i>ḥa</i> = 2/45 <i>dī</i>	1 <i>ḥa</i> = 1/4 <i>kī</i> = 1/90 <i>dī</i>

Djarwī: weights

1 <i>r</i> = [6/7 <i>ma</i> (Syria, general)]
1 <i>r</i> = [1/2 <i>r sulaymānī</i>]
1 <i>r</i> = 300 <i>dir</i> = 1/2 <i>r</i> (Syria) = (1/5 + 1/10) <i>r</i> (ṭaḥāwī) = 1 1/6 <i>ma</i> = 210 <i>mī</i> = 2 1/3 <i>r</i> (Iraq) = [3/10 <i>r</i> (Asyūṭī)]

Djazīra: weights

1 <i>dir</i> = 60 <i>ḥa</i>	1 <i>dī</i> = 22 1/2 <i>kī</i> = 2/45 <i>dī</i>
1 <i>kī</i> = 4 <i>ḥa</i> = 2/45 <i>dī</i>	1 <i>ḥa</i> = 1/4 <i>kī</i> = 1/90 <i>dī</i>

Egypt: measures of area

1 <i>fad</i> = 100 <i>dh</i> · 100 <i>dh</i> = 20 <i>ḳab</i>
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Measures of capacity

1 <i>ku</i> = 1 <i>ḳin fulfulī</i> = 1/4 <i>ḳin</i> (Syria)

Weights	
1 <i>dir</i> = 60 <i>ḥa</i>	1 <i>da</i> = 6 <i>ḥa</i>
1 <i>dir</i> = (1/2 + 1/5) <i>dī</i> = 16 4/5 <i>kī</i>	1 <i>kī</i> = 3 4/7 <i>ḥa</i>
1 <i>dī</i> = 10/7 <i>dir</i> = 24 <i>kī</i> = 85 5/7 <i>ḥa/dir</i>	1 <i>da/dī</i> = 8 4/7 <i>ḥa/dir</i>
1 <i>kī</i> = (1/7 + 1/14) <i>da</i> [sic]	1 <i>da</i> = 2 2/5 <i>kī</i>
1 <i>dī</i> = 600/7 <i>ḥa</i>	1 <i>kī</i> = 25/7 <i>ḥa</i> = (1/24 + 1/42) <i>dir</i>
1 <i>ḥa</i> = (1/5 + 2/25) <i>kī</i>	1 <i>ḥa/dī</i> = (1/100 + 1/600) <i>dī</i>
1 <i>ḥa/dī</i> = [(1 + 1/21) <i>ḥa/dī</i> (Aleppo)]	1 <i>kī</i> = [15/16 <i>kī</i> (Aleppo)]
1 <i>kī</i> = [21/25 <i>kī</i> (Iraq)]	1 <i>kī/dir</i> = [3/8 <i>da</i> (Iraq)]
1 <i>r</i> = 1 <i>ḳin fulfulī</i> = 1/4 <i>ḳin</i> (Syria)	

Filasṭīn (Palestine, incl. Tiberias): measures of length and area	
1 <i>ḥab</i> = 40 <i>dh</i>	1 <i>mudy</i> = 1 <i>ḥab</i> · 1 <i>ḥab</i>

Weights
1 <i>ra</i> = 420 <i>mi</i> = 3,600 <i>da</i> = 14,400 <i>kī</i> = 36,000 <i>ḥa</i>
1 <i>ūḳ</i> = 35 <i>mi</i> = 300 <i>da</i> = 1,200 <i>kī</i> = 3,000 <i>ḥa</i>

Fulfulī: measures of capacity
1 <i>ra</i> = [7/32 <i>ṣa</i> (ḥidjāz)] = [7/8 prophetic <i>mu</i>]

Weights
1 <i>r</i> = [7/12 <i>r</i> (Syria, general)]
1 <i>r</i> = 2 <i>r djarwī</i>
1 <i>r</i> = [1/4 <i>r sulaymānī</i>]
1 <i>ḳin</i> = 1 <i>r</i> (Egypt) = 1/4 <i>ḳin</i> (Syria)
1 <i>r/ūḳ</i> = 12 1/2 <i>dir</i> = (8 1/2 + 1/4) <i>mi</i> = 1/4 <i>r</i> (Syria) = (1/3 + 1/4) <i>ma</i>
1 <i>r</i> = [6/7 <i>r</i> (Iraq)] = [3/8 <i>r ḥaythamī</i>] = [5/16 <i>r Ṣāḥirī</i>] = [3/2 <i>r</i> (Asyūṭī)] = [3/2 <i>r</i> (ṭaḥāwī)] = [25/64 <i>r</i> (Anṭākiya)]
1 <i>r</i> = 150 <i>dir</i> = 105 <i>mi</i>

Ghaylānī, see Yemen

ḥaithamī: weights
1 <i>r</i> = 400 <i>dir</i> = [12 <i>ūḳ</i>] 1 <i>ūḳ</i> = 33 1/3 <i>dir</i>
1 <i>r</i> = 2/3 <i>r</i> (Syria) = 2 <i>r laythī</i> = 2 2/3 <i>r fulfulī</i> = 3 1/9 <i>r</i> (Iraq) = 1 5/9 <i>ma</i> (Iraq) = 1 5/6 <i>r Ṣāḥirī</i> = 1 11/150 <i>ra</i> (Anṭākiya)

ḥidjāz: measures of capacity
1 <i>was</i> = 60 <i>ṣa</i> = 240 <i>mu</i> 1 <i>mu</i> = 1 3/4 <i>mu</i> (Damascus)
1 <i>ṣa</i> = 5 1/3 <i>r</i> (Baghdad) = 1 1/7 <i>r</i> (Syria) = 4 4/7 <i>r fulfulī</i> = 2 2/3 <i>ma</i> = 8 <i>r</i> (Abū ḥanīfa: Baghdad)

Weights	
1 <i>dī</i> = 24 <i>kī</i>	1 <i>r</i> = 3/601 <i>r sulaymānī</i>

Iraq: measures of length and area	
1 <i>dj</i> = 60 <i>dh</i> · 60 <i>dh</i> = [3,600 <i>dh</i> ²] = 10 <i>ḳa</i> = 100 <i>as</i>	
1 <i>ḳas</i> = 6 <i>dh</i> = 1 <i>bā</i> = 1/10 <i>ash</i>	1 <i>dj</i> = 1 <i>ash</i> · 1 <i>ash</i>
1 <i>as</i> = 1 <i>bā</i> · 1 <i>bā</i>	1 <i>mud</i> = 30 <i>ḳal</i> ² = 1687 1/2 <i>dh</i> ²
1 <i>ḳa</i> = 7 1/2 <i>dh</i> = 1/4 (or 1/3) <i>si</i>	

Measures of capacity	
1 <i>ku</i> = 60 <i>ḳa</i>	1 <i>mu</i> = 3/4 prophetic <i>mu</i>

Weights	
1 <i>dī</i> = 6 <i>da</i> = 60 <i>ḥa</i> = 20 <i>kī</i>	1 <i>kī</i> = 3 <i>ḥa</i>
1 <i>dir</i> = 48 <i>ṭa</i> = 48 <i>ḥa</i> = 6 <i>da</i>	1 <i>da/dir</i> = 8 <i>ḥa/dir</i>
1 <i>dir</i> = (1/2 + 1/5) <i>dī</i>	1 <i>ḥa/dir</i> = 1/48 <i>dir</i>
1 <i>ṭa</i> = 4/5 <i>ḥa</i> (Syria)	1 <i>dī</i> = 2/3 <i>dī</i> (Aleppo)
1 <i>kī</i> = [4/5 <i>kī</i> (Aleppo)]	1 <i>kī</i> = 1 1/7 + 1/21 <i>kī</i> (Damascus, Egypt)
1 <i>da</i> = 2 2/3 <i>kī/dir</i> (Dam., Egypt)	1 <i>da</i> = 2 1/3 <i>kī</i>
1 <i>kī</i> = 8/9 <i>kī</i> (Aleppo, weight)	1 <i>r</i> = [3/14 <i>r sulaymānī</i>]
1 <i>ūḳ</i> = [1/1,200 <i>ḳin</i> (Syria)]	1 <i>r</i> = 1/2 <i>r</i> (Syria, general)
1 <i>r</i> = 128 4/7 <i>dir</i> = 90 <i>mi</i>	1 <i>r</i> = [12 <i>ūḳ</i>]
1 <i>ūḳ</i> = 10 5/7 <i>dir</i> = 7 1/2 <i>mi</i>	

$1 r = 1,800 k\bar{i} = 6,171 \frac{3}{7} ha/d\bar{i} = 5,400 ha/dir = 3/14 r$ (Syria) = $6/7 r$ $fulful\bar{i} = 1/2 ma = [9/14 r layth\bar{i}]$	
$1 r = [9/28 r haytham\bar{i}] = [9/35 r (Asy\bar{u}t\bar{i})] = [5/42 r (Ardab\bar{i}l)]$	

Laythi: weights	
$1 r = [1/3 r sulaym\bar{a}n\bar{i}]$	$1 r = [7/9 ma (Syria, general)]$
$1 r = 100 dir = [6 \frac{3}{33} \bar{u}k]$	$1 r = [1/2 r haytham\bar{i}]$
$1 \bar{u}k = 16 \frac{1}{2} dir = 140 mi = 11 \frac{2}{3} mi sulaym\bar{a}n\bar{i}$	
$1 r = 1 \frac{1}{4} r fulful\bar{i} = 6/7 ma = 1 \frac{5}{9} r (Iraq)$	

Mak\bar{a}y\bar{i}l al-nab\bar{i}y (prophetic measures)
$1 mu = 1 \frac{1}{3} r (Iraq) = 171 \frac{3}{7} dir = 3 \frac{3}{7} \bar{u}k (Syria) = 1 \frac{1}{7} r fulful\bar{i} = 120 mi$

Sulaym\bar{a}n\bar{i}: weights
$1 r = 1 r (Damascus) = 200 \frac{1}{3} r (\text{ḥidj\bar{a}z}) = 4 r fulful\bar{i} = 4 \frac{1}{3} r (Iraq) = 3 r layth\bar{i} = 2 r djarw\bar{i} = 2 \frac{4}{19} r (Ghayl\bar{a}n\bar{i}) = 1 \frac{1}{2} r haytham\bar{i} = 1 \frac{1}{4} r Z\bar{a}hir\bar{i} = 5/4 r (Bardha\bar{i}) = 5/9 r (Ardab\bar{i}l) = 3/5 r (Asy\bar{u}t\bar{i}) = 1 \frac{1}{16} r (An\bar{t}\bar{a}kiya)$
$1 r = [2 \frac{2}{15} ma (Syria, general)] = [7/3 ma (Syria, general)] = [5/7 r (Bardha\bar{i})] = [5/9 r (Ardab\bar{i}l)]$

Syria: measures of capacity	
$1 ghi = 3 ka (Iraq) = 12 ru = 72 mu$	$1 \bar{u}k = [7/24 prophetic mu]$
$1 r = [7/8 \text{ḥidj\bar{a}z}] = [4 \frac{2}{3} r (Baghdad)]$	

Weights	
$1 dir = 60 ha$	$1 ha = 6 da$
$1 da = 10 ha$	$1 dir = (1/2 + 1/5) d\bar{i} = 16 \frac{4}{5} k\bar{i}/d\bar{i}$

$1 k\bar{i} = 3 \frac{4}{7} ha$	$1 d\bar{i} = 1 \frac{3}{7} dir = 24 k\bar{i} = 85 \frac{5}{7} ha$
$1 da/d\bar{i} = 8 \frac{4}{7} ha/d\bar{i}$	$1 k\bar{i} = (1/7 + 1/14) ha$
$1 da = 1 \frac{4}{5} k\bar{i}$	$1 d\bar{i} = 600/7 ha$
$1 ha = (1/5 + 2/25) k\bar{i}$	$1 ha = 4/5 ta (Iraq)$
$1 ha/d\bar{i} = (1/100 + 1/600) d\bar{i}$	$1 ha = (6/7 + 1/28) ha (Aleppo)$
$1 k\bar{i} = 25/7 ha = (1/28 + 1/42) dir = 1/24 d\bar{i}$	

Weights (Syria, specific)
$1 r = 420 mi = 3,600 da = 14,400 k\bar{i} = 36,000 ha$
$1 \bar{u}k = 35 mi = 300 da = 1,200 k\bar{i} = 3,000 ha$
$1 kin = [4 kin fulful\bar{i}] = [4 r (Egypt)] = 42,000 mi = 60,000 dir$
$1 r = [4 r/\bar{u}k fulful\bar{i}] = [2 r djarw\bar{i}] = [14/3 r (Iraq)]$
$1 r = [3/2 r haytham\bar{i}] = [3/5 r (Asy\bar{u}t\bar{i})] = [16/25 r (An\bar{t}\bar{a}kiya)]$

Weights (Syria, unspecified)
$1 kin = 100 r = 233 \frac{1}{3} ma = 466 \frac{2}{3} r [sic] = 1,200 \bar{u}k (Iraq)$
$1 ma = 260 dir \approx 257 \frac{1}{7} dir = 180 mi = 2 r (Iraq) = 1 \frac{5}{7} r fulful\bar{i} = 13/30 r sulaym\bar{a}n\bar{i}$
$1 ma = 1 \frac{2}{7} r layth\bar{i} = 6/7 r djarw\bar{i} = 3/7 r sulaym\bar{a}n\bar{i}$
$1 r/\bar{u}k = 5 \frac{1}{7} \bar{u}k = 1/4 ma = 3 \frac{3}{4} mi$

ṭah\bar{a}w\bar{i}: weights	
$1 r = [3/10 r djarw\bar{i}]$	$1 r = 1 r (Asy\bar{u}t\bar{i})$

Yemen (Ghayl\bar{a}n\bar{i}): weights	
$1 r = [19/42 r sulaym\bar{a}n\bar{i}]$	$1 \bar{u}k = (15 \frac{1}{2} + 1/3) mi sulaym\bar{a}n\bar{i}$
$1 r = [271 \frac{2}{3} + 2/7] dir sulaym\bar{a}n\bar{i} = 190 mi sulaym\bar{a}n\bar{i}$	

Z\bar{a}hir\bar{i} (Fa\bar{t}imid): weights	
$1 r = 480 dir = [12 \bar{u}k] = 336 mi$	$1 \bar{u}k = 40 dir = 28 mi$

$1 r = 4/5 r \text{ (Syria)} = 1 \frac{1}{5} r$ $haythamī = 3 \frac{1}{5} r$ $fulfulī = 1 \frac{1}{4} r$ $(Anṭākiya) = (3 \frac{2}{3} + 2/30)$ $r \text{ (Iraq)}$	
Ells (<i>adhru</i> *, unspecified): <i>dhirā</i> * <i>al-yad</i> $1 dh = 2 shi \text{ (cloth)} = 18 iṣ \text{ (medium)} = 24 iṣ$ $\text{(without thumb)} = [3/4 dh \text{ (} kāsīmī \text{)}]$	
<i>dhirā</i> * <i>kāsīmī</i> (= <i>hāshimī</i>) $1 dh = 1 \frac{1}{3} dh$ $(yad) = 24 iṣ = 6 kab$ $1 Iṣ = 1/4 kab = 1/24 dh$	$1 kab = 1/6 dh$
<i>dhirā</i> * <i>hāshimī</i> (<i>mālikī</i>) $1 dh = 8 kab = [3/4 dh \text{ (} mābahrāmī \text{)}]$	
<i>dhirā</i> * <i>mābahrāmī</i> (<i>sūd</i>) $1 dh = 1 \frac{2}{3} dh \text{ (} hāshimī \text{)} = 60 fa = 1/3 \text{ (or } 1/6)$ <i>kab</i> $1 dj = 36 dh \cdot 36 dh$	

During the tenth century, mathematicians became aware of the complexity of the metric systems in use. Their particular perspective on the issue differed from what their legal and other colleagues had been noting down hitherto. They not only tried to present a systemized enumeration of all units related, but also endeavoured, for pedagogical reasons, to systematize the usage of measuring units in popular treatises. They sometimes even expressed efforts to standardise and facilitate the conversions customs, market and tax officers had to enact. Thus, stimulated by theoretical manuals, mathematically standardised methods of measuring and of converting quantities from one system into another became popularised. To some extent, these devices even had retroactive effects on the practice of Islamic laws.

Among these manuals, the “Book on the Basis of Arithmetic and the Division of Inheritances” (*Kitāb al-Tadhkira bi-uṣūl al-ḥisab wa l-farāʿid*), written by the Damascene mathematician ‘Alī

b. al-Khiḍr al-ʿUthmānī al-ḡurashī (1030–1067 AD) contains the most coherent information on the metric systems that were in use in the Islamic Middle East up to the lifetime of the author. The following list of units of weight, currency, capacity and length, together with the localities they refer to arranged in alphabetical order, is extracted and, if indicated by ‘[...]’, concluded from different chapters of this *Kitāb al-Tadhkira*.

Egypt (Abbasid period)	96 dir	300 g
Rūmī (Asia Minor) I	102 6/7 dir	321.43 g
Umayyad period	[110 dir]	340 g
Rūmī (Asia Minor) II	120 dir	375 g
Iraq (medieval)	128 4/7 dir	401.79 g
Abbasid period (Egypt, Baghdad)	130 dir	406.25 g
Maghreb	130 dir	406.25 g
Maghreb	137 1/7 dir	428.57 g
Umayyad period (Egypt)	[140 dir]	437.5 g
Maghreb (Fāṭimid period)	140 dir	437.5 g
Egypt (later Abbasid period)	144 dir	450 g
Fulfulī	150 dir	468.75 g
Maghreb (Ibn Baṭṭūṭa)	150 dir	468.75 g
‘big’ Egypt (Abbasid period)	160 dir	500 g
Maghreb (Ibn Baṭṭūṭa)	180 dir	562.5 g
Laithī	200 dir	625 g
Djarwī	312 dir	975 g
Turkestan (fourteenth century)	330 dir	1,031.25 g
Fes/Marrakesh (fourteenth century; = 16 ūḡ)	336 dir	1,050 g

(continued)

Aleppo (twelfth and thirteenth century)	480 <i>dir</i>	1,500 g
Syria/Palestine (fourteenth century)	592 1/2 <i>dir</i>	1,851.56 g
ḥimṣ (twelfth century)	684 <i>dir</i> [sic]	2,137.5 g
Aleppo (after thirteenth century)	[724 <i>dir</i>]	2,273 g
Jerusalem (medieval)	800 <i>dir</i>	2,500 g
ḥimṣ (Syria, medieval)	864 <i>dir</i>	2,700 g
Constantinople (eighteenth century)	876 <i>dir</i>	2,800 kg
Jerusalem (nineteenth century)	900 <i>dir</i>	2,812.5 g
Iran (Shīrāz, Fārs; in <i>mann</i>)	1,040 <i>dir</i>	3,250 g
Sivas	1,440 <i>dir</i>	4,618 g

See Also

► Nilometer

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Weights and Measures in Japan

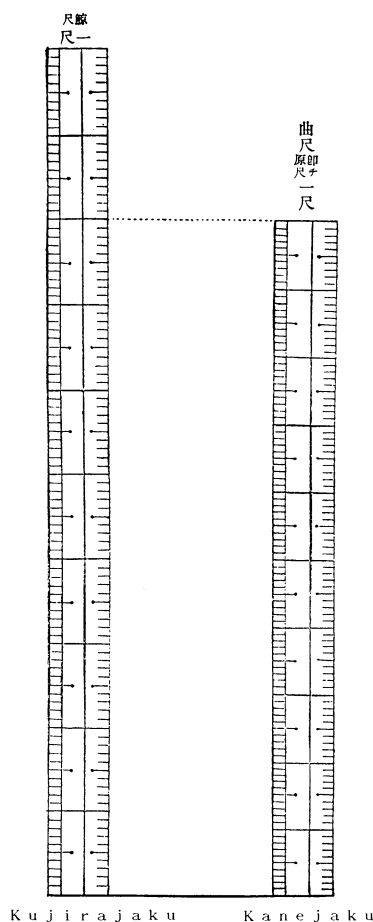
Shigeo Iwata

Japan used the 17.3 cm-long linear measure unit that was common to all the regions in East Asia for a period of 25,000 years. Under the influence of China, the Japanese measuring unit gradually lengthened during the period from the end of the eleventh century BCE to the middle of the third century BCE. Then, the length of the Japanese measure *shaku* was stabilized at 23 cm and remained unchanged until the end of the second century AD. Various civil disturbances in China had the effect of lengthening the linear measure substantially to 29 cm until the middle of the seventh century, and no more significant variation has since been observed (Fig. 1).

Length

Under the Chinese Tang dynasty, a law was enacted mandating the use of two methods based on large and small linear measures. The large scale was 1.2 times as long as the small scale, which we refer to as the ancient linear measure. The small scale was used for music, astronomy, and ceremonial items.

Japan introduced this Chinese measuring system in 701. The large scale later became known as *kanejaku*, which refers to an L-shaped ruler used by architects. The small scale gradually dropped out of use. Linear measurement tools were mainly made of wood, though ivory was also used in ancient times. The largest unit of length in ancient times was the *ri*, which was 5–70 *cho* (a *cho* was 109.1 m). The *ri* was set to



Weights and Measures in Japan, Fig. 1 Linear measure (Drawing by The Ministry of Finance. *Doryoko Shurui Hyo* (The Classification Table of Weights and Measures) Genbei Kinokuniya, 1875. Chos 1, 4–6, 9–11)

36 *cho* in the seventeenth century. One *shaku* was one-tenth of a *jo*. Metal linear measurement tools began appearing in the medieval era.

The average value of one *shaku* was 29.6 cm in the seventh century, 29.7 cm in the eighth century, 29.8 cm in the ninth century, 29.9 cm in the tenth century, 30.1 cm in the twelfth century, 30.2 cm in the fourteenth century, and 30.3 cm in the eighteenth century. The rate of elongation was slower than in China.

Several linear measures for sewing appeared in the medieval era. The length of one *shaku* ranged from 1.15 to 1.27 times that of a *kanejaku*. These linear measures for sewing were neatly arranged into two kinds of scales. One scale,

1.20 times as long as a *kanejaku*, was called *gofukujaku*, while the other was 1.25 times as long as the *kanejaku* and called a *kujirajaku*. The *gofukujaku* gradually dropped out of use in the first half of the eighteenth century and was finally abolished in 1875.

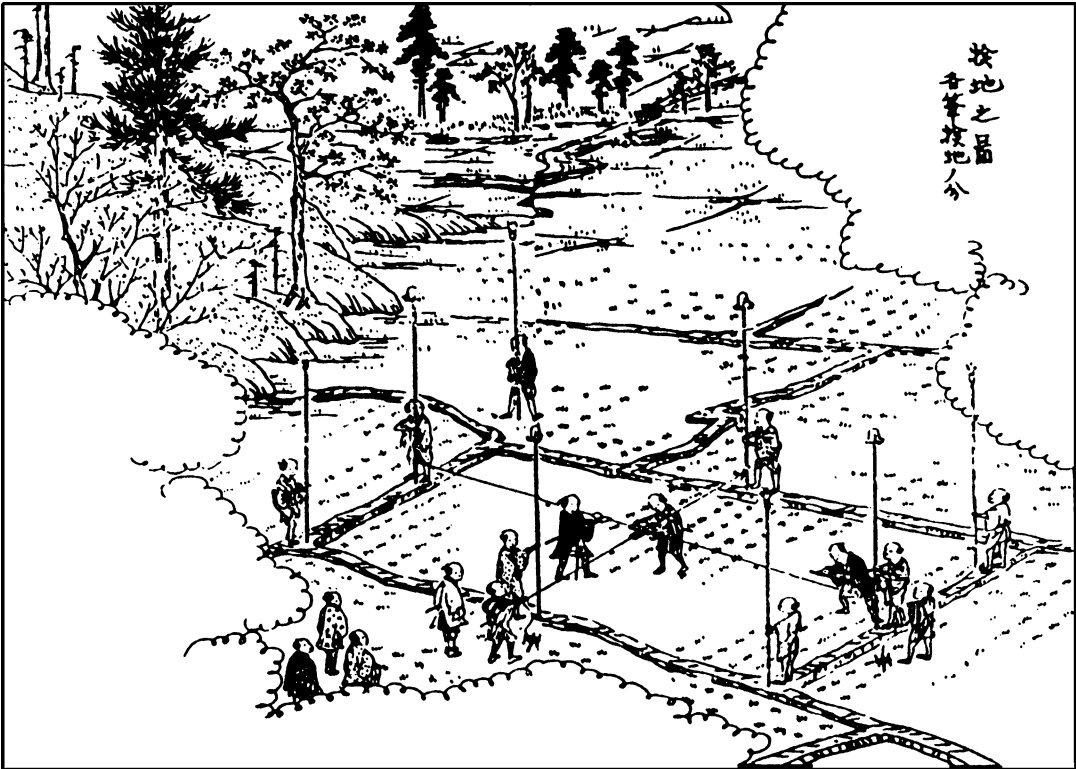
Area

The earliest area unit we know of was the *shiro*, which was in use before the sixth century. One *shiro* was 30 *shaku* square. In 646, new units were defined: the *bu*, which was six *shaku* square; the *tan*, equal to 360 *bu*; and the *cho*, equal to ten *tan*. One *tan* has been equal to 300 *bu* since the end of the sixteenth century. For land surveying purposes, one *bu* was defined as six *shaku* five *sun* square, rather than six *shaku* square. At the end of the sixteenth century, a *bu* was defined as six *shaku* three *sun* square. Despite this, the *bu* was commonly considered to be six *shaku* square, and was finally defined as such in 1891. A *se* was ten times as large as a *bu*, which was also referred to as a *tsubo*. These names appeared in the medieval era. Land surveyors made their measurements using flax string measures and wood measuring poles (Figs. 2 and 3).

Volume

The names for most units of volume also came from China. The basic unit was the *sho*. One *sho* averaged 750 cm³ in the eighth century, 800 cm³ in the ninth century, 970 cm³ in the eleventh century, 1,400 cm³ in the fifteenth century, and 1,650 cm³ in the sixteenth century. Since the seventeenth century, the average value has remained constant at 1,804 cm³. During the medieval era, different measures of volume were used for goods, taxes, and financial transactions (Fig. 4).

The Tokugawa-Shogunate (1603–1867) established the ► [East and West Measure Guilds](#) in 1655, and exerted strong control over the new standard. Use of *sho* continued until 1958, when the *shaku-kan* system was abolished.



Weights and Measures in Japan, Fig. 2 Land surveying (From *Tokugawa Bakufu Kenchi Yoryaku* (Essential summary of the Government of prefectures, Tokugawa Shogunate). Tokyo: Kashiwa Shobo, 1915)

Rectangular measures were made of wood. The brims of many dry measures were protected by ► [bamboo](#) or iron laminae. Most of the large dry measures also featured a narrow iron bar positioned diagonally across the top. Round wooden sticks were used to level off the tops of measures. Liquid measures had lacquered surfaces to prevent the contents from leaking.

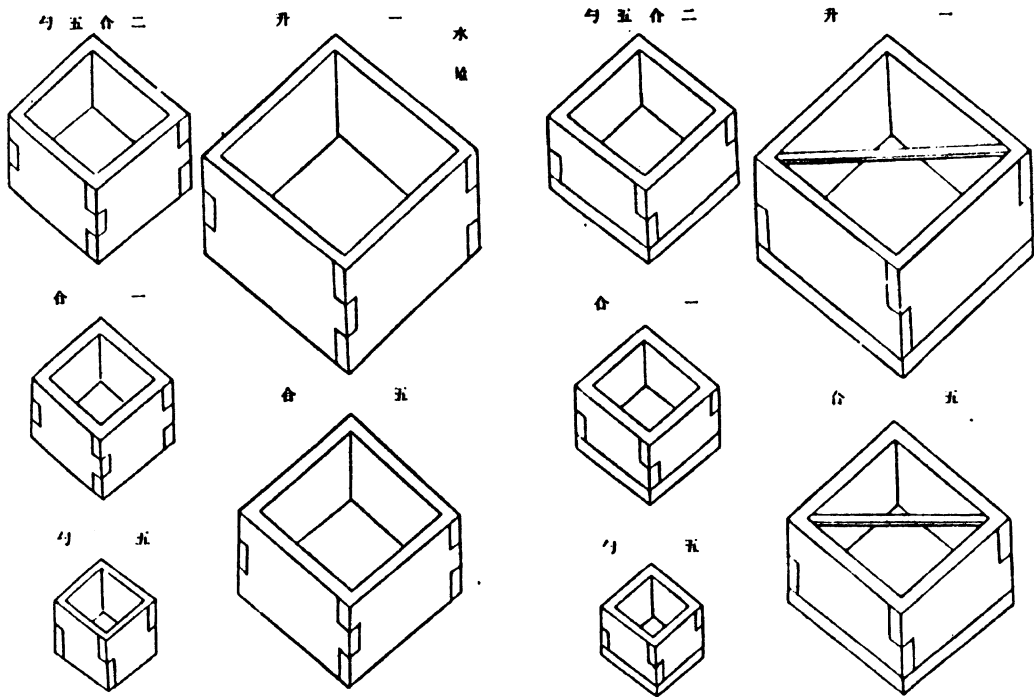
Standard sizes for measures have been one *to*, seven *sho*, five *sho*, one *sho*, five *go*, two *go* five *shaku*, and one *go* since 1655, and one *to*, five *sho*, one *sho*, five *go*, two *go* five *shaku*, one *go*, and five *shaku* since 1875.

Mass

Between the eighth century BCE and the fifth century AD, the Chinese expressed mass in terms of the *liang*, which was equal to 14 g. In this measuring system, one *jin* was equal to

16 *liang*, and one *liang* to 24 *zhu*. The civil disturbances of the third and seventh centuries also had their effect on the *liang*, which tripled in mass. Under the Chinese Tang dynasty, a law stipulating two measuring scales was enacted, which fixed the mass of the new large *liang* at three times that of the mass of the older *liang*, which became used only for medicine.

Japan adopted this Chinese measuring system as well, changing the names of *jin*, *liang*, and *zhu* to the *kin*, *ryo*, and *shu*, but retaining the same characters. The absolute mass of the *ryo* in the large scale decreased year by year, while that in the small scale became rather unclear. The average mass of one *ryo* was 42 g in the eighth century, 40 g in the tenth century, 39 g in the twelfth century, and 37.47 g at the end of the sixteenth century. Under the strong control of the Tokugawa-Shogunate, the average mass of the *ryo* remained almost unchanged until the end of the nineteenth century. The *kan* and



Liquid measure

Dry measure

Weights and Measures in Japan, Fig. 3 Measures (Drawing by The Ministry of Finance. *Doryoko Shurui Hyo* (The Classification Table of Weights and Measures) Genbei Kinokuniya, 1875. Chos 1, 4–6, 9–11)

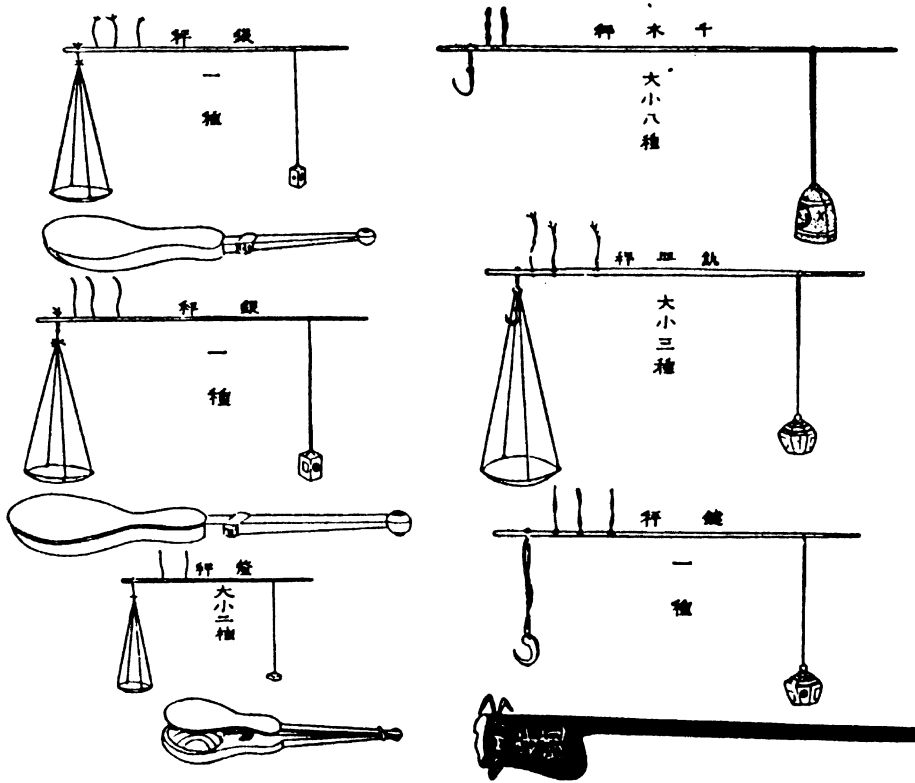
monme appeared in the medieval era. One *kan* was equal to 100 *ryo*, and one *monme* equal to one-tenth of a *ryo*. These units gradually became standard.

Chinese use of the steelyard dates back to at least several centuries BCE. The steelyard was also used in Japan, where the Tokugawa-Shogunate established the East and West Steelyard Guilds in 1653. Steelyard beams were made of white oak, persimmon wood, ivory, horn, and bone. The beam had from one fulcrum to eight fulcra, which were made using string, cord, or rope. A copper pan or bronze hook was installed on the end of the beam, and the bob-weight was made of bronze or iron. Steelyards were used for most commercial transactions (Fig. 5).

Balance makers did not belong to a guild, so standards for making balances were never formulated. The most famous balance makers were

members of the Nakabori family, who lived mainly in the western counties of Japan. The balance beam was suspended by its pointer from the center of a box-mounted rectangular wooden stand. A central pin was used for the main fulcrum, and during the final stages of weighing, bearing friction was overcome by tapping on the pin with a small wooden hammer. Balances were mainly used in the manufacture of gold, silver, and copper coins, and in money-changing transactions.

Beginning in the seventeenth century, users of the balance had to be supplied with weights made by the Goto family. Two sets of weights were available: one consisted of weights of 20, 10, 5, 4, 3, 2, 1 *ryo*, 5, 4, 3, 2, 1 *monme*, and 5, 4, 3, 2, 1 *fun*, and the other was identical to the first but for the addition of 50 and 30 *ryo* weights. Weights were made of bronze, and engraved on the surface with the inspector's mark and maker's crest, leaves

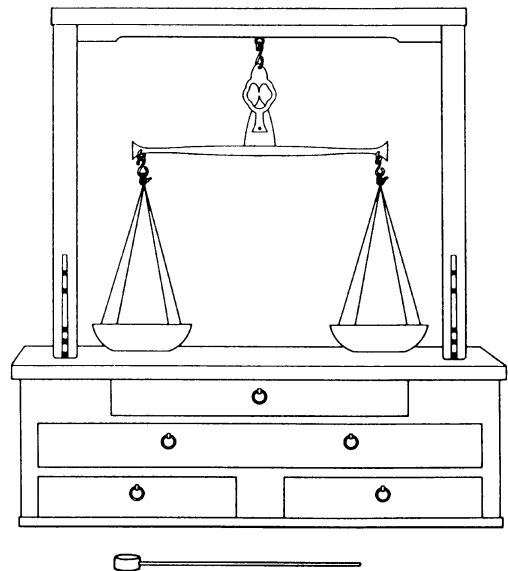


Weights and Measures in Japan, Fig. 4 Steelyard (Drawing by The Ministry of Finance. *Doryoko Shurui Hyo* (The classification table of weights and measures) Genbei Kinokuniya, 1875. Chos 1, 4–6, 9–11)

and flowers of the Japanese paulownia. The Goto family belonged to the Guild of Goldsmiths, and were inspectors authorized by the feudal government. They examined user's weights periodically by comparing them with standard weights.

Transition to the Metric System

In 1886, Japan signed the Treaty of the Meter, and promulgated the Law of Weights and Measures. As a result, the *shaku-kan* system and metric system began to be used jointly in 1891. The conversion coefficients between these two measuring systems were also fixed at the same time (Table 1). The law went into formal effect in 1893. In 1903, the Central Inspection Institute of Weights and Measures was established in Tokyo. Japan also adopted the units of the foot-pound system as legal in 1909.



Weights and Measures in Japan, Fig. 5 Balance (Drawing by Shigeo Iwata (1981))

Weights and Measures in Japan, Table 1 Conversion tables of Japanese weights and measures (1891–1958)

Length								
ri	cho	ken	shaku	sun	bu	rin	mo	Metric system
1	36	2,160	12,960	129,600	1,296,000	12,960,000	129,600,000	3.927 km
	1	60	360	3,600	36,000	360,000	3,600,000	109.1 m
		1	6	60	600	6,000	60,000	1.818 m
			1	10	100	1,000	10,000	30.30 cm
				1	10	100	1,000	3.030 cm
					1	10	100	0.303 cm
						1	10	0.0303 cm
							1	0.00303 cm
Area								
cho		tan	se	bu (tsubo)		go	shaku	Metric system
1		10	100	3,000		30,000	300,000	9,917 m ²
		1	10	300		3,000	30,000	991.7 m ²
			1	30		300	3,000	99.17 m ²
				1		10	100	3.306 m ²
						1	10	0.331 m ²
							1	0.0331 m ²
Volume								
koku		to		sho		go	shaku	Metric system
1		10		100		1,000	10,000	180,400 cm ³
		1		10		100	1,000	18,040 cm ³
				1		10	100	1,804 cm ³
						1	10	180.4 cm ³
							1	18.04 cm ³
Mass								
kan	ryo	monme		fun	rin		mo	Metric system
1	100	1,000		10,000	100,000		1,000,000	3.750 kg
	1	10		100	1,000		10,000	37.50 g
		1		10	100		1,000	3.750 g
				1	10		100	0.375 g
					1		10	0.0375 g
							1	0.00375 g

A Measurement Law was passed by the Diet in 1951, and went into effect on March 1, 1952. It mandated that measuring units be based on the metric system. The *shaku-kan* system and foot-pound system were abolished in 1958.

A new Measurement Law was promulgated on May 20, 1993, and went into effect on November 1, 1993. The law made a sweeping revision of the regulations by adopting the *Système Internationale d'Unités*. The units of the other measuring systems on commercial transactions and certifications were abolished by the end of the twentieth century.

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Weights and Measures in Mesoamerica

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Indian Measures

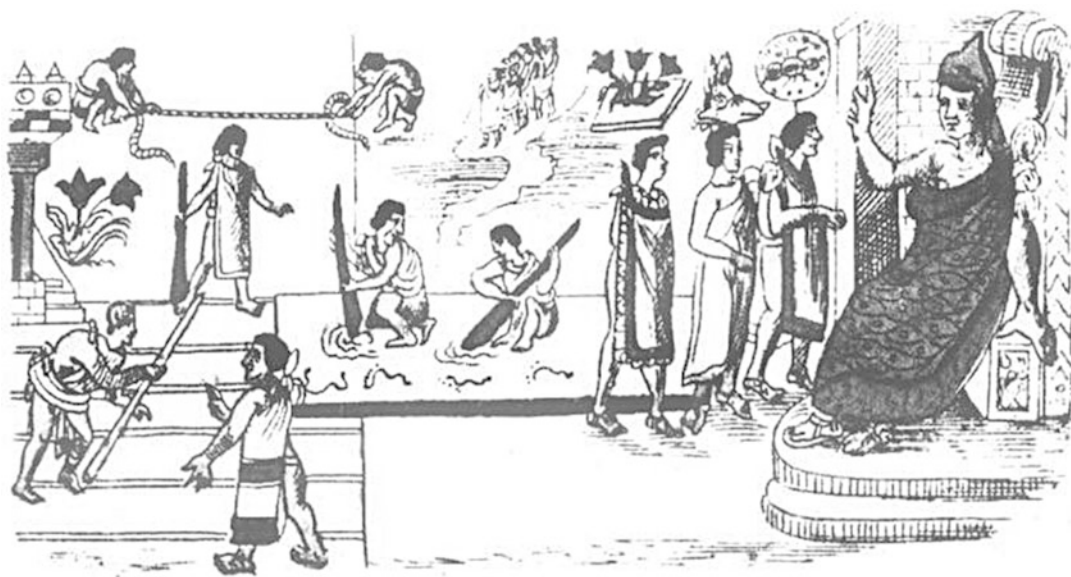
In Latin America, the Indian populations measured and counted the goods, lands, merchandise, and the days and months according to scientist systems that historiography began to decrypt. After the Spanish conquest, the conquerors imported the weights and measures of their country, the Castille, which, itself, had borrowed a good part from the Arab-Berber occupants (Villena). In Mesoamerica, in Mexico in particular, the result was a new syncretism which merged the different systems. The Indians adopted the measures of the conquerors who did not hesitate to attribute Indian names to the new measures.

“Los aztecas tenían una fuerte tendencia a medir y contar” [The Aztecs had a strong tendency to measure and count] (Harvey and Williams). The arithmetic system was based on three major numbers: 20, 400, and 8,000. The number 20 is called “a count” (*cempoalli* in Náhuatl language), $20^2 = 400$ or “a head of hair” (*centzontli*), and $20^3 = 8,000$ “a bag” (*cen-xiquipilli*). The system was vigesimal. The pictograms representing these three numbers used the glyphs “banner” (*pantli*, 20), pen or stylized “hair” (*tzontli* 400), and “bag of copal or incense” (*xiquipilli* 8 000). For quantities of less than

20, the populations of the highlands used a small white circle for the number 1, and five of these circles united by a lower stroke for the number 5. The integers between these positions (20, 400, 8,000) were of the quantities which could be added or multiplied. Thus, 49 is represented as “2 count and 9” and 500 as “a head of hair and 5 counts.” (Royas Rabiela). The numbering system was “from a position of line and point and employed only four symbols: the vertical line, five circles linked by a line, the point, and the glyph of maize, with position indicative of the value of the symbol to represent the function of zero.” The Mayas and the Zapotecs employed the point for 1, one bar for 5, and four bars for 20, and they created a sign for zero. With these three signs they represented any quantity.

The calendars were a measure of the time and recorded the days, weeks, months, years, and centuries (in fact the generations) from the astronomical observation of solar, lunar, and Venusian phenomena. The higher cycle (century) or Venus cycle lasted 52 years and combined two calendars, one of 260 days and one of 365 days. The first was the ritual calendar of 13 periods of 20 days each; the other was a solar calendar of 18 periods of 20 days, more than a short period of 5 days. The period of 20 days was a month. The combination of the two calendars was allowed to repeat the same date to 52 years or a “century.” This Maya system recorded the time with great accuracy.

The measures of length were modeled on the human body, the more common unit of length was the “fathom” or “toise” (*cenmaitl*, literally a “hand”), the distance between the fingers of two arms apart in the horizontal position. It was used to measure fields, houses, streets, and canals and on maps drawn up for economic or tax purposes. The other measures were submultiples. There also existed a vertical “toise,” measured from the foot to the high arm vertically and a cubit which meant the distance between the elbow and the fingers outstretched to the other arm. The fields were also measured “on the rope,” and the measurement of standard area was a *mecatl* of 400 (20×20) mecate squared (Matías Alonso).



Weights and Measures in Mesoamerica, Fig. 1 Workers prepare the land (perhaps a swamp to dry up) and level it; the surveyors measure with the rope, and the king handles the distribution of the fields (Source: Teresa Rojas Rabiela, p. 43, after the Códice Durán,

Historia de las Indias de Nueva España e Islas de Tierra Firme written in the second half of the sixteenth century by the Dominican Diego Durán and conserved in the Biblioteca Nacional de España)

The various peoples of Mesoamerica did not seem to weigh the goods (products) and did not have scales, and Hernán Cortés, the conquistador, had the opportunity in 1529 to see the market of Tlatelolco, and the transactions which went on there. He wrote, “everything is sold by count and measure, and up till now I haven’t seen anything sold by weight.” Yet the concept of “load” (*tameme*) was in common usage; it meant the mass a porter (*tlamamalli*) could carry in a day. It therefore combines a time measurement and a unit of mass evaluated by the carriers who raised it and an empirical adjustment, by taking into account the distance to browse. In sum the load was a measure adapted to the labor force of the bearer.

For volume, each product had its specific measure. Maize or beans were measured in “loft (granary),” honey in *cantars* of 100 lb (from Latin *centenarium*), cotton in bales, cocoa in loads, and salt in “bread.” So the level of development attained by the Mesoamerican people before the Conquest makes it very likely that they had an ensemble of measures and standards

used in the apportionment of land, commercial transactions, levying of taxes, construction, pharmacy, etc., and that these measures constituted unified and coherent systems.

Teresa Rojas Rabiela, from whom we borrow this information, states that she has only attempted an outline on a field still overlooked. The modesty of her judgment must not hide the fact that the measures of surface and capacity (volume) remained in wide use and the majority of the Indian population has remained faithful to the measures and ancestral practices (Fig. 1).

Weights and Measures of New Spain

In the sources of the eighteenth century, the range of different names involved – *carga*, *fanega*, and *arroba* or *brazas*, *codos*, and *varas* – hides the numerical relations which link multiples and sub-multiples. The *carga* is made up of two *fanegas*, composed in turn of six to eight *arrobas* (García Acosta, Hocquet). In general, the

historian goes from the largest to the smallest, whereas in practice, the peasant, the muleteer, or the trader proceeds in the reverse order. In the same way that the metric *quintal* is made up of grams and kilograms between which the factor ten governs all relations, in the eighteenth century, two and six (equals two multiplied by three) governed the relations of the *carga* with its sub-multiples. The decimal metric system is a scientific system, mathematic in character, invariant, exterior to humans (Hocquet 1995). In contrast, previous systems were based on people or on observations concerning them or on their work and capacity to complete certain tasks with the aid of animals. That is, if a mule must climb steep paths with its load, the muleteer compensates for this by lowering the weight of the load by one or two *arrobas*. At times, the sources mention *cargas pequeñas* in contrast to *cargas regulares de mula*. "As long as freighting relied chiefly on pack trains and carts, the weight of the loads was determined by distances to the customer, the availability of pasture *en route*, as well as by the nature of roads and tracks. In the case of steep mountain paths, broken country or long distances, the *carga*, the traditional load of a mule, could be lowered in weight. So a mule load could comprise one and a half or two *fanegas*. In 1832 the Governor of Oaxaca stated that because of the poor roads the *carga* could never consist of more than eight *arrobas*" (Ewald). Generally the custom of mentioning the number of *arrobas* making up a *fanega* or a *carga* does not eliminate the uncertainties which surround all quantitative data. In 1751, the *carga* of salt in Tehuantepec consisted of 14 *arrobas*. Another eighteenth-century source stated that moist Tehuantepec salt was 16 *arrobas*, while drier salt was computed at 12–14 *arrobas*. The dampness or dryness of goods being transported markedly affects their weight. The presence of water increases the weight of light goods such as grains, but it lessens the weight of heavier ones, in particular salt. In Tehuantepec, the variation in weight often reached a quarter.

But there is another trap: Ralph Roys, for example, noted that a *fanega* "is variously

defined as 1.6 bushels, and a load of 100 lb of grain," which is an example of recent efforts to align traditional measurements with those of the national market governed by the decimal metric system, while at the same time conserving the ancient names. But this statement has led a number of scholars to assume that a *fanega* weighs 100 lb, which is seldom the case. The *fanega*, like the bushel, is a measure of capacity, not weight. It is important not to confuse measures of capacity, which are volumes, and units of weight which measure mass: weighing the contents of a volumetric measure can only lead to considerable distortions, since each body (or matter) has a specific weight by which it distinguishes itself from all others. The foreigners who traveled or worked in nineteenth-century Mexico reported that a *fanega* of salt weighed approximately 70 kg and a *carga* 140 kg. The nineteenth-century sources gave 300 lb as the equivalent of a *carga*. The historian will recognize the mule load of 300 lb and the 16-ounce pound, such familiar territory that he would think he was in Castile in the time of the Catholic Kings (Gual Camarena).

A New Synthesis

The Spanish imposed Andalusian and Castilian measures that the Indians adopted easily, because, like their own, they were anthropometric. The result of this adoption was that Mesoamerican symbols of measure were transcribed in European terms on the pictograms of indigenous manuscripts written in the Náhuatl language (Alonso, Castillo Ferreras). Bars represented digits, little black circles were for 20s, and other signs represented hands or feet. Thus, to go back to the example of the "*carga*" already cited, the Indians gave the name *tlamamalli* to the load (*carga*) that a *tameme* (porter) could carry on his shoulders during a day's work. In the *novohispano* system, this load had the name *tameme*, by a simple movement of language and meaning. It was equivalent to a Spanish *half-fanega* or to two *arrobas*.

This indigenous load varied in weight, in the function of the weighed merchandise, and with the strength of the carrier: for cocoa it was equivalent to three *xiquipilli* of 8,000 grains each, and it is clear that there is a mixture between Indian and Hispanic measures.

Among the measures of capacity, of great diversity, the smallest were the *centlachipiniltontli* (*una gotilla de algo*) and, its multiple, the *centlachipinilli*, which literally means “a small something” (*una gota de algo*). There were also small measures used in pharmacy, such as spoonfuls (*cemixcolli*, *cenxumatli*, etc.). *Testal* designated the quantity of cornmeal necessary to make a tortilla for one person. The concept of mass had more to do with daily people’s usages than with practical knowledge of balance and weights.

To measure dry materials, in particular for grains, they were often able to use measures equivalent to those imported from Spain: the *acalli*, for example, of which we do not know the weight, was part of an arithmetic system with the *cencaauhacalli* equal to a *half-fanega* and with the *cuauhacaltontili* equal to a *celemin*. Such equivalent approaches make it possible to conclude that the conquerors tried to impose their own system while at the same time adopted the native terms.

Measures of length were used for the fabrication of clothing, especially for ponchos, made of bands of different widths. Most measures of length were based on proportions of the human body: *cemiztehtl*, *cemmapilli*, and *cemmatl*, literally a finger, a palm, and a span. This “span” designated the height of a man, from foot to raised hand, but it also measured the diagonal, from the left foot to the raised right hand, and it stood for three Spanish *varas* (yards or cubits). Such a dimension proves that the “span” was a geometric measure and not an anthropometric one; it was obtained by attaching an anthropometric measure such as a digit, measured by its width, to a coefficient. However, for land measures, certain spans were smaller, and the *vara* was therefore equal to two spans: in Tula, there was a division of land in order to reform the tax law, and “each Indian was given 100 *varas* in

length and 20 in width. Each one of these *varas* made two spans; this is the measure which the Indians use.” Standards of measure and length existed, and, to measure land, poles or cords were used, just as European surveyors did. Road measures also existed, which were used by travelers, soldiers, and merchants. These were the *cennecehuilli* and the *cennetlalolli*, which Spanish authors tended to translate as “leagues.”

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Weights and Measures in Peru

Shigeo Iwata

Ancient Peru covered most of the Andes, where the Peruvian culture lasted for more than 10,000 years. Because most of the region was in the highlands, more than 3,000 m high, their metrology was slightly different from other civilizations. Also, they had no form of writing until 1532. For calculation and for recording metrological units decimally, they used *quipus*, spatial arrays of multicolored knotted cords. The names of the units and the values differed significantly depending on the period, the people, and the region.

Length

Peruvians used linear measurements that were related to human measurement patterns. Examples are listed in Table 1.

Peruvians chewed lime and *lipta* with coca leaves as a stimulant. They invented a measure called *cocada*, which measures how far one can walk while under the drug’s influence. This distance is 3 km on level ground or 2 km on an uphill slope when carrying a 45 kg load for 35–40 min in Pataz county.

A twelfth-century pre-Inca site in Puruchuco, located about 6 km from Lima, was recently restored. The linear measurements of each part of the structure showed that the average stature of men from head to toe was 1.701 m, while the height from the middle fingertip to one’s toe was 2.106 m. They used a geometrical design of proportions based on the golden section (1:1.618) between the sides of the rectangles.

Area

The Aymara called the area where they could raise one or two heads of cattle the *callapa*. *Tupu* was the Incan name for an area of cultivated

Weights and Measures in Peru, Table 1 Examples of Peruvian linear measurements

	Quechua	Aymara	Inca	Ratio	Metric system
Handbreadth		<i>ttkhlli</i>		0.051	8.5 cm
Link	<i>yaku</i>	<i>vicu</i>		0.107	18 cm
Span	<i>capa</i>	<i>chia</i>		0.125	21 cm
Cubit	<i>cuchuch tupu</i>			0.25	42 cm
Yard	<i>sikya</i>			0.50	84 cm
Pace		<i>chillque</i>		0.89	150 cm
Fathom	<i>rikra</i>			1.00	168 cm
		<i>loca</i>		10^2	168 m
		<i>ecca</i>		10^3	1.68 km
	<i>cocoda</i>			$1.19\text{--}1.79 \times 10^3$	2–3 km
League	<i>tupu</i>		<i>tupu</i>	3.33×10^3	5.6 km
		<i>yapu</i>		5.00×10^3	8.4 km
		<i>chuta (sayhua)</i>		10^4	16.8 km
			<i>guamanin</i>	10^5	168 km

land or pasture where a married couple could live. The Inca called the area, which was equal to 625 m² *hui*ri. This was the area a man could cultivate in 1 day. The Cuzco called the area equal to 282 m² of sweet potatoes or corn *papacancha*.

Volume

The Peruvians used a single hand-cupped *gowpen* to measure small portions of grain. They also used gourds, dried pumpkins, pots, and jars to measure things. The names of the units and the values are shown in Table 2.

The Quechua called a broad crate filled with coca or red pepper a *runcu*. One-half of

a *runcu* was called *checta runcu*, one-fourth was called *cutmu*, and one-eighth was called *sillcu*.

Mass

Because fewer weights have been discovered in the Peruvian region than in other civilizations, it has been difficult to estimate the mass standard accurately. We assume that the average mass of unit was 23.1 g. The notation was based on the decimal system. The maximum unit was assumed to be 23.1 kg, which is about 80 % of the maximum units from other civilizations, 27–30 kg in Egypt, Mesopotamia, Indus, and China. This is probably because of the low concentration of oxygen in the atmosphere in the Andean highlands.

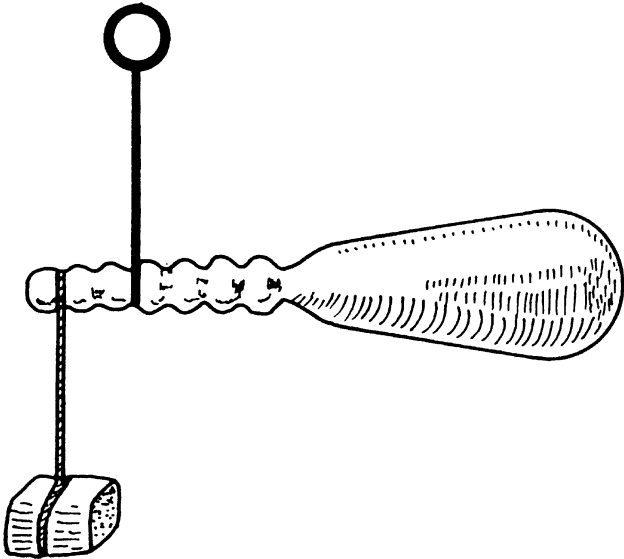
Thirty-nine percent of the weights were made of stone, 32 % of iron, 24 % of lead, and 5 % were made of other nonferrous metals. One-third of the weights were globe-shaped; the others were conical, cylindrical, or in spindle and other irregular forms.

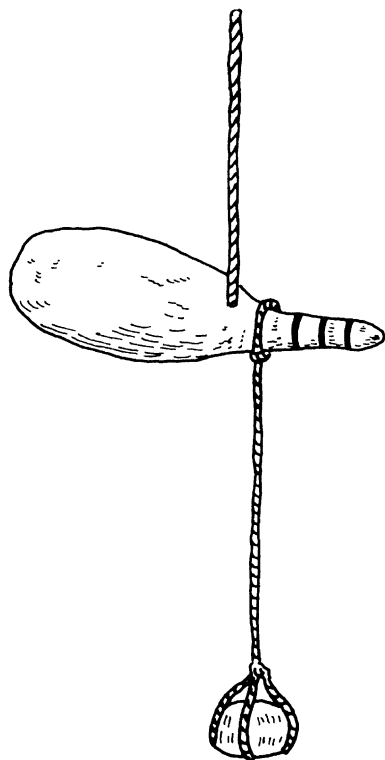
All types of scales, namely balance, steel-yard, bismar, and movable load, were

Weights and Measures in Peru, Table 2 Hand-cupped “gowpen” measure of the Peruvians

	Quechua	Aymara	Ratio	Metric system (cm ³)
Gowpen (double hand-cupped)	<i>poktoy</i>	<i>iuu</i>	0.043	300
		<i>laqui</i>	1.00	7,000
	<i>pokcha</i>	<i>hullu</i>	2.00	14,000

Weights and Measures in Peru, Fig. 1 Bismar (Adapted by the author from Uhle (1925), p. 335)

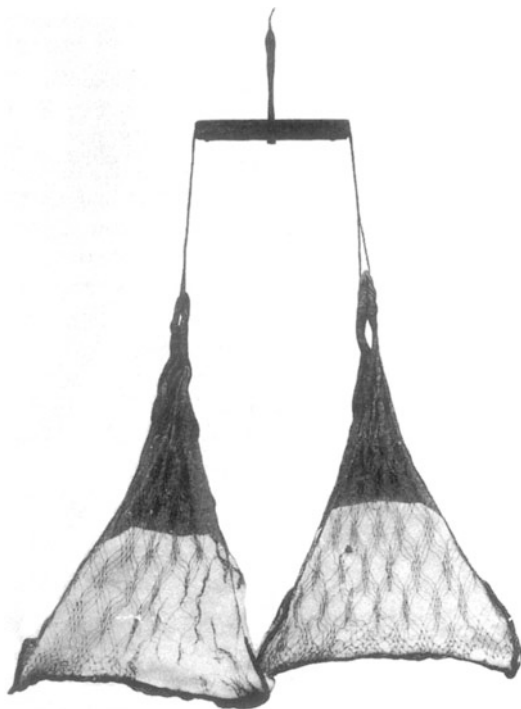




Weights and Measures in Peru, Fig. 2 Movable load scale (Adapted by the author from Rivet (1923), p. 535)

discovered in the northwest region of South America. The fulcrum was the cord-pivot type. Balance beams were made of wood, horn, and bone with humans, monkeys, birds, and geometrical patterns engraved on them. The two items supporting the load and weights were mostly nets, and partly pans of metals. The balance might have been invented by the ninth century (Figs. 1 and 2).

Miquel de Estete, who attended Francisco Pizarro, found a steelyard on the coast of Ecuador in 1531. The steelyard was graduated from the middle of the beam to the end, and had a bob-weight suspended from the arm. The steelyard was used to weigh gold and silver. The bismar was discovered at the market in Tarma, 170 km northeast of Lima. The total length was 27.8 cm, and the capacity was assumed to be 924 g. The movable load scale, called *wipe* in the actual place, was discovered in Huarochiri,



Weights and Measures in Peru, Fig. 3 Balance (From the Museo Amano)

90 km to the east of Lima. The scale was made of wood, and was used to weigh coca leaves (Fig. 3).

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Weights and Measures in the Indus Valley

Shigeo Iwata

The golden era of the Indus civilization in ancient India extended from 2300 to 1750 BCE. This vast civilization had significant uniformity and standardization in its material culture, as reflected in its town planning, building construction, pottery, metallurgy, and system of weights and measures.

The prosperity of the Indus cities depended to a large extent on trade. Many raw materials were brought by land and sea routes from within and outside the Indus valley. Inland trade must have extended beyond the Baluchistan to Afghanistan route and the Iranian highlands on the one hand, and to the Punjab and Aravalli hills on the other. Overseas trade covered the Makran and Persian Gulf ports on the west and the Gujarat and Konkan ports, if not those of the Malabar coast in the south. The writing system has not yet been deciphered, and the names of their measuring units are still unknown.

Length

A unit of length, which corresponds to a fathom, was revealed in the process of analyzing the city plans of Lothal, Surkotada, Kalibangan, Dolavira, Harappa, and Mohenjo-daro. The mean value with standard deviation of the units used in these cities was 168 ± 1.1 cm.

The minimum division of graduation found in the segment of an ivory-made linear measure excavated in Lothal was 1.79 mm (that corresponds to 1/940 of a fathom), while that of the fragment of a shell-made one from Mohenjo-daro was 6.72 mm (1/250 of a fathom), and that of bronze-made one from Harapa was 9.33 mm (1/180 of a fathom).

Area and Volume

The use of area measures should have been quite common. There is, however, no piece of evidence that could be connected with an area measure. In the excavations carried out at various sites of the Indus civilization a variety of pots made of clay, and sometimes of metal, have been discovered. No systematic determinations of the volumes of pottery seem, however, to have been made.

Mass

The oldest known weight in the Indus measuring system was excavated from Dashli Tepe, south Turkmenia in Russia. This era dates back to the fifth millennium BCE. The other three weights belong to the fourth millennium BCE and were discovered in northern Iran. These weights belong to pre-Indus civilization. In the third millennium BCE the Indus measuring system was further developed in the ancient regions of Iran and Afghanistan.

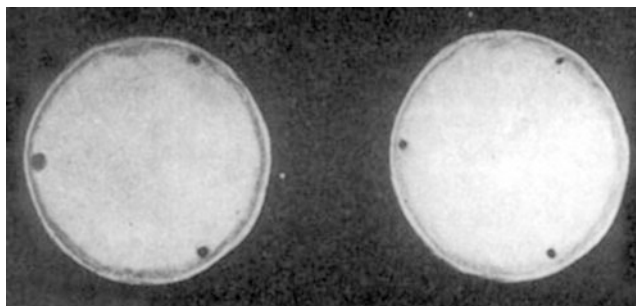
A total of 558 weights were excavated from Mohenjo-daro, Harappa, and Chanhu-daro, not including defective weights. They did not find statistically significant differences between weights that were excavated from five different layers, each measuring about 1.5 m in depth. This was evidence that strong control existed for at least a 500-year period. The 13.7-g weight seems to be one of the units used in the Indus valley. The notation was based on the binary and decimal systems. Eighty-three percent of the weights which were excavated from the above three cities were cubic, and 68 % were made of chert.

Balance pans were made of copper, bronze, and ceramics. A bronze beam was found with the two pans in Mohenjo-daro. The fulcrum was the cord-pivot type (Fig. 1).

The measuring system used in the Indus valley was different from the Mesopotamian and Egyptian measuring systems, but the sensitivity of precision balances used in these regions is assumed to have been comparable. The weights

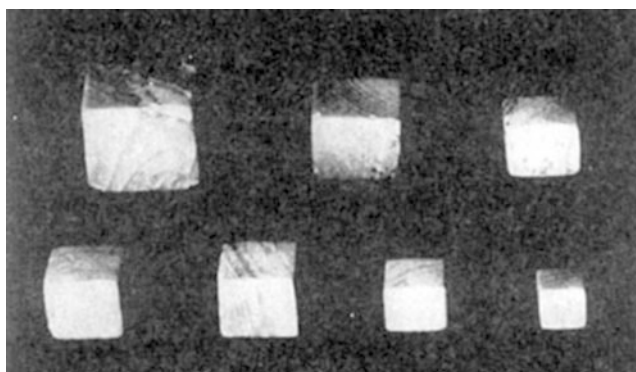
Weights and Measures in the Indus Valley,

Fig. 1 Balance pans
(Photograph by the
Mainichi Newspapers,
1961; used with
permission)



Weights and Measures in the Indus Valley,

Fig. 2 Weights
(Photograph by the
Mainichi Newspapers,
1961; used with
permission)



excavated from Taxila (sixth century BCE to seventh century AD) descend from the system of weights used in the Indus civilization (Fig. 2).

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Weights and Measures of the Hebrews

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Weights

The earliest Biblical reference to a unit of weight is in Genesis 23:16: “Abraham came to an agreement with him and weighed out. . . four hundred shekels (of silver) of the standard recognized by merchants.” Abraham was a new immigrant in Canaan. The *shekel* units which he used to weigh out the silver for Ephron the Hittite may have been those of his native Mesopotamia, with which he would have been most familiar.

The Mesopotamian shekel weighed about 8.3–8.5 g. Sixty shekels = 1 *maneh* (Greek: mna, mana. English translations of the Bible often render *maneh* as “pound”) of 497–508 g. Sixty *maneh* = 1 *kikar* (Greek, Talanton; English,

talent) of 29.8–30.5 kg. This system, which was originally Sumerian, in the fourth or third millennium BCE, was used with little change for thousands of years by the peoples of Mesopotamia; the terms SH-Q-L, M-N-H, and K-K-R are Semitic in origin and were first used by the Akkadians. Systems similar in structure, though varying in detail and in the absolute mass of the units, were used by most of the peoples of the Eastern Mediterranean, well into Roman Imperial times.

The term shekel is, in short, a generic one, and in this context could apply to any one of a number of units (including the Mesopotamian) in use in Canaan in the Bronze Age. Since the price of 400 shekels for the Cave of Machpelah was quoted by Ephron himself (Genesis 23:14), these may very well have been shekels of the Syrian standard (also called Ugaritic), weighing about 9.4 g. Weights on this standard were used throughout Canaan and northern Syria and are found at Bronze Age sites in the Aegean Sea, as far north as Troy. The standard also reached Egypt, where its unit became the *qedet*. Three thousand Syrian shekels made one *talent*.

Genesis 24:22 says: "...the man took a gold nose-ring weighing half a shekel, and two bracelets for her wrists weighing ten shekels ..." The Hebrew word rendered in English as "half a shekel" is *beka'*. The word means "half" and appears on certain Iron Age weights described below.

The next mention of units of weight in the Bible is in the Book of Exodus. Several hundred years have passed; the Children of Israel, now a numerous people, have received the Law at Mt. Sinai. This includes instructions for the payment of taxes and the performance of religious ritual, which call for clearly defined units of measurement. The first specifically Hebrew unit of weight is *shekel ha-kodesh*, which the King James version translates as "shekel of the sanctuary" and the New English Bible as "shekel by the sacred standard," "twenty *gerahs* to the shekel" (Exodus 30:13). This unit is referred to repeatedly (Exodus 30:24, 38:24–26; Leviticus 5:15, 27:25; etc.). Reference is now also made to *talents* of silver and gold: the *talent* weighed 3,000

shekels (Exodus 38:25, 26). There are no surviving artifacts of this period from which the absolute mass of these units might be inferred.

It should be stressed that the *shekel ha-kodesh* and its fractions were used by the Hebrews for religious purposes, but not necessarily in commerce. In the ancient world, as in medieval Europe, there were many weight systems in simultaneous use in international trade. Weights representing all the major systems of the ancient Near East are found at all important archeological sites in Israel and were obviously in use there. These systems are often linked by networks of interrelationships, with multiples of different units having a common mass and being used interchangeably.

The oldest extant weights bearing Hebrew inscriptions date from the period of the Kingdom of Judah (tenth to sixth centuries BCE). They are normally of limestone, dome-shaped with a flat bottom; a few bronze specimens exist. There are several types, all rare. The total number of known specimens of all groups is a few dozen. They are:

- *Necef*. Average mass about 9.8 g. The *necef* is not mentioned in the Bible. The name means "half": it may have originally been half of some more ancient unit. Scholars today identify the *necef* with the Canaanite/Syrian/Aegean unit already described. It is also equivalent to 1 Egyptian *qedet* and to four-fifths of the royal *shekel* of Judah (see below).
- *Beka'*. This word also means "half" (Genesis 24:22, see above). The mean mass of this group is about 6 g. The *beka'* is one-half of the "shekel of the king" first mentioned in II Samuel 14:26.
- *Pym* (Petrie: *peyem*). Mean mass about 7.8 g. The word appears once in the Bible (I Samuel 13:21): "The charge was two-thirds of a shekel (Hebrew: *pym*) for (sharpening) ploughshares and mattocks, and one-third (of a shekel) for sharpening the axes and setting the goads." The *pym* is two-thirds of the royal shekel.
- *Shekel*. Weights of this group are inscribed, not with a word, but a sign γ . Its meaning has been variously interpreted as being an official adjuster's mark, a symbol of the bag (*tsror*) in

which lump silver was often carried, and a stylized representation of the royal scarab emblem of the kings of Judah. Sir Flinders Petrie read it as a monogram composed of the Greek letters *chi* λ and *omicron* o and, on this basis, erroneously attributed these weights to a (supposed) system which he called Khoirine. The mean mass of the shekel, calculated from all known marked specimens, is about 11.4 g.

The shekel sign is accompanied by a mark indicating the denomination: 1, 2, 4, 8, 16, and 24. Since numbers of shekels are given in the Bible in multiples of 50, this binary multiplication seems illogical; it is explained by the fact that this shekel is equal in mass to one and a quarter Egyptian qedets. Hence, 4 shekels = 5 qedet, 8 shekels = 10 qedet, etc. The denomination marks on the shekel weights are, in fact (apart from simple strokes to indicate 1 and 2), Egyptian hieratic decimal numerals, the sign for 4 shekels meaning in Egyptian 5, that for 8 meaning 10, and so on. These weights thus could be conveniently used interchangeably to weigh either in shekels or qedets. In fact, it can be seen that all the units here described are closely related. The Canaanite/Syrian/Aegean maneh of about 940 g can be divided into either 80 royal shekels, 100 necef (or qedet), 120 pym, or 160 beka', providing simple arithmetical relationships between the systems prevalent in different regions.

The name "royal shekel" is confirmed by the existence of a two-shekel weight inscribed in Hebrew "L-M-L-KH" (of the king). A series of fractional weights also exists, both for the shekel and for the necef, showing that both were divided into 20 units (*gerah*). The denominations of these are also indicated by Egyptian hieratic numerals.

Scholars attribute most of these weights to some time near the end of the seventh century BCE, leading some of them to suggest that the religious reforms of Josiah (II Kings 22, 23; II Chronicles 34, 35) were accompanied by a reform of weights and measures. There is no

direct documentary evidence of this. In fact, biblical references are less than enlightening. Ezekiel, foreseeing the rebuilding of the Temple, orders that the maneh shall consist of "twenty, and twenty-five, and fifteen (i.e., 60) shekels." This is so inconsistent with other data that the translators of the New English Bible assume a misspelling in the Hebrew text and render *essrim* as "ten" (Ezekiel 45:10), giving 50 shekels to the maneh as before. After the Temple was rebuilt, the people of Israel pledged to pay an annual tax of one-third shekel, not one-half as in Moses' time (Nehemiah 10:32).

Nothing more is heard of the *shekel ha-kodesh*; it is last mentioned in Numbers 18:16. Yet the correct weight of the Temple tax was a subject of deep concern to the Jewish religious authorities; it is discussed at length in the Mishnah, the textbook of Jewish laws. By the first century BCE, it had been decided that all religious taxes should be paid in "shekels of the sacred standard, of the maneh of Tyre." The Tyrian shekel at that time weighed a little over 14 g and was famous for its purity of metal and uniformity of weight. No other coin would do. This is the reason why Jesus found so many money-changers in the Temple precinct (Matthew 21:12): Jewish pilgrims arriving from foreign parts and wishing to pay their dues needed Tyrian shekels in order to do so.

From AD 66 to 70, when Jerusalem was besieged by the Romans and Tyrian coin was no longer obtainable, the shekels struck throughout the siege by the embattled Jews (probably for religious use) were of the Tyrian standard.

The use of Hebrew weights and measures for secular commerce almost certainly ended with the fall of the Kingdom of Judah and the destruction of the Temple by Nebuchadnezzar in 586 BCE. There is no evidence from the successive periods of Persian, Hellenistic, and Roman domination of the Land of Israel (or from times of relative independence, under the Hasmonean and Herodian dynasties) of the use of any specially Jewish units. Rabbinical discussions of weights and measures usually center on attempts to define

Biblical units in terms of contemporary non-Jewish systems, in order to ensure the proper performance of the mitzvot (commandments).

Measures of Length and Area

The Hebrew unit of linear measure was the *ammah* or cubit – the length of a man’s forearm, from the elbow to the tip of the middle finger. Deuteronomy 3:11 actually uses the expression *le-ammat ish* – “by the forearm of an adult male.” The measurement of length by units based on parts of the human body is universal among ancient cultures.

The Bible mentions no unit greater than a cubit. *Kaneh ha-midah*, the surveyor’s measuring rod (or reed), was six cubits in length (Ezekiel 40:5). The measurements of the inner temple are given by Ezekiel as 500×500 *kaneh* (Ezekiel 42:16–20); the Authorized Version translates these as “reeds,” the New English Bible as “cubits.” Surveyor’s measurements of up to 25,000 cubits are on record (Ezekiel 45:1). Long distances are expressed in terms of a day’s journey, *derekh yom* (Genesis 30:35; Numbers 11:31; II Kings 3:9).

The Hebrews used two cubits, one a hand’s breadth (*tefah* or *tofah*) longer than the other (Ezekiel 40:5, 43:13). The longer cubit was used in the rebuilding of the Second Temple (Ezekiel 40–48) and also, presumably, in building the Temple of Solomon, since the dimensions quoted for the Holy of Holies and the Sanctuary are the same in both cases (20×20 cubits and 20×40 cubits, respectively: I Kings 6:14–28, Ezekiel 41:1–4).

The use of two cubits suggests an association with Egyptian linear measure. The greater (“Royal”) Egyptian cubit was of seven hands, each hand of four fingers (also four spans of seven fingers each). Its length of about 52.5 cm is attested by many surviving measuring rods and by records of the dimensions of surviving monuments. The lesser Egyptian cubit was of six hands.

The Biblical fractional units of length are the span (*zeret*, Exodus 28:16, 39:9; I Samuel 17:4), the hand (*tefah* or *tofah*, Exodus 25:25, 37:12; I Kings 7:26; II Chronicles 4:5), and the finger (*etzba*, Jeremiah 52:21). The only direct clue to the absolute value of the Hebrew cubit is the Siloam inscription (ca. 700 BCE) from which Conder estimates a value of 17.1 in. (43.4 cm); he warns, however, that this estimate may be in error by 10 % or more.

The Mishnah (second to third century AD) states that the greater cubit was of six hands, the lesser of five; the hand is of four fingers. Six hands of Egyptian dimensions would measure 45 cm. Most rabbinical estimates, however, are in the range 58–66 cm.

There are no specially named units of area in the Bible. Ezekiel, discussing the layout of rebuilt Jerusalem, speaks of “twenty-five thousand cubits square (*revi’it*)” (Ezekiel 48:20).

Measures of Cubic Capacity

...your bushel (Heb. *ephah*) and your gallon (Heb. *bath*) shall be honest. There shall be one standard for each, taking each as the tenth of a *homer*, and the *homer* shall have its fixed standard (Ezekiel 45:11).

Solid and liquid measures are thus given a common basis. The volumetric measures mentioned in the Bible are *ephah* (Leviticus 19:36; Deuteronomy 25:14 (“measure”); Judges 6:19; Ezekiel 45:24); *s’ah*, *seah* (Genesis 18:6; I Samuel 25:18; I Kings 18:32 (always “measure”)); *kab*, *cab* (II Kings 6:25); and *omer* (Exodus 17:36 – “An *omer* is one-tenth of an *ephah*”); these are always associated with solid measure. *Letekh* (Hosea 3:2 – AV, “a half *homer* of barley”; NEB, “a measure of wine”) is mentioned only once. *Homer* (Ezekiel 45:11, see above) and *kor*, *cor* (I Kings 4:22, 5:11) are associated with both solid and liquid measures. *Bath* (I Kings 7:26, 38; I Chronicles 2:10) and *log* (Leviticus 14:10, 12, 15, 21, 24) are associated with liquid measure. The relations between any

of these measures are only mentioned once or twice. The Mishnah gives a table relating some of them: 1 *ephah* = 3 *se'ah*; 1 *se'ah* = 6 *kab*; 1 *kab* = 4 *log*; 1 *log* = 6 eggs. The water displaced by 1 egg is about 55 ml (there are differing rabbinical views on the precise quantity), which would give the *log* a volume of 330 ml and the *ephah* and *bath* each about 24 l.

Attempts to establish mathematical relationships between ancient units of length, mass, and volume were popular a century ago, but today are not taken seriously. Reliance on post-Biblical authors such as Josephus Flavius is also risky: Josephus lived more than a thousand years after King Solomon and is more likely to have been concerned with giving his (mainly non-Jewish) reading public a notion of orders of magnitude than with achieving a maximum of mensural precision. Hebrew weights and measures will always remain a subject fraught with uncertainty, which will be dispelled only when archeologists are able to recover the actual instruments of measurement.

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Weights and Measures: Animal-Shaped Weights of Burma

Donald Gear and Joan Gear

The royal animal-shaped weights of the Burmese Empires appear to be unique not only as a weight system, but also as one of the most important artifact series, especially in a country with but few durable artifacts. Their shape motifs are mythically leonine (lion-like), elephantine, anserine (goose-like), and gallinaceous (poultry-like). They symbolize Buddhist and pre-Buddhist beliefs, and the Burmese institution of monarchy and its continuity, dynastic, and imperial changes.

For the purpose of this account the Burmese empires comprise those regions of the Southeast Asian peninsula now known as Myanmar (Burma) and northern Thailand (Siam).

Buddhist art in India gave rise to the Burmese choices of animal motifs to use on the weights. The anserine weight, in a tenth century Indian style, apparently was chosen first during a period of Theravāda revival. However, the motifs were ancient even then, originating before the Burmese entered Burma. Shamanistic and animistic influences, both of the post-1000 BCE steppes and China, are also evident. Even more obvious is the use of Chinese models and execution for most of the style groups. Moreover, the decision to use Buddhist symbolic animals may also have been influenced by the enduring association of Indian and Chinese Mahāyāna Buddhists with commerce.

The mass units and scales reached Burma from India before the twelfth century AD, but India itself obtained them from Achaemenid Persia, which in turn, obtained them from Assyria and Babylonia. However, with the growth of Chinese trade in Southeast Asia from the thirteenth century onward and the adoption in Burma of Chinese mass standards, the Indian mass system was displaced. (A mass unit is defined here as that which was used in multiples to form weights



Weights and Measures: Animal-Shaped Weights of Burma, Fig. 1 Weights of different shapes (Photograph by the author)

mainly used for heavy trade goods and in fractions mainly for bullion or small amounts of other valuable items, the multiples and fractions together forming the mass scale).

A Burmese term often given to the animal-shaped weights is *shway arlay* (gold weights) which may have been derived from the expression *sri arlay* (king's weights). However, in the East the word gold has customarily been associated with royalty. Also, until the late eighteenth century the weights of Burma were mainly used on behalf of the king, who enjoyed monopolies in trade and was the chief import/export broker.

Of the three main weight shapes, the leonine and anserine were used throughout the empires, while those of elephant shapes were used only in north Siam. The first two shapes were still in use in 1970 along the more remote routes that pass from northeast Burma into Yunnan, north Siam, north Laos, and the Thai cantons of Vietnam.

Most commonly, the diameters and heights of the weights do not exceed about 70×120 mm. In shape they occur in three leonine- and seven bird-weight style groups which can be placed in stylistic sequence. A sequence in the elephant-shaped weight styles has not been identified with certainty (Fig. 1).

The leonine shape, called *to* (taw = "royal" in Burmese) is a stylized combination of the parts of

four animals. The lion of west and south Asia supplied the model for the open-mouth, bearded head and probably for the crouching torso. The horns were either bull-like or were adapted from the antlered muntjac deer of eastern and southern Asia. The tail of two of the styled groups is usually lion-like, but it is occasionally horse-like. With one exception, all the tails are characterized by the artificially raised tail base of the ancient Yunnanese horse. The legs and feet were modeled upon those of the elephant. All these animal representations are present on the abacus of the Asokan pillar at Sarnath.

The standing bird shapes of six of the bird style groups are in the form of a stylized Chinese mandarin drake (*aix galericulata*) having a knobbed crest and known as a *hintha* (Pali). The model for the squatting/brooding, gallinaceous style group has not been identified.

The elephant shapes are naturalistic. In Siam, the weights of elephant shape, known as *chang* in Thai, are difficult to separate from those figurines of similar shape intended for other purposes. The animal representations stand on usually pyramid-shaped bases which may be rectangular, octagonal, circular, or hexagonal.

Frequently, impressed signs 4–19 mm in size are found, usually on the front or right side of the base. In shape they may be script-like circular, square, bird- or feline-like or in patterns normally



Weights and Measures: Animal-Shaped Weights of Burma, Fig. 2 Weights of different sizes (Photograph by the author)

of 4, 5, 6, 8, and 9 rays, diverging from a central point. These also can be placed in sequence.

The weights are made of a metal alloy, the essential components being copper (50–80 %), lead (3–30 %) and tin (0–20 %). In some of the nineteenth century weights zinc may amount to as much as 35 %. The alloy, formally known as *ganza* (Tamil *kamsa*), was imported either in the form of broken vessels from Canton or as the coins known as *cash* (Sanskrit, *karsha*) from Yunnan.

The *kyat* was the mass unit of the *to* and *hintha* weights and varied with time from about 14 g in the fifteenth century to over 16 g in the eighteenth century. The 20 *kyat* (320 g) weights constitute about 50 % of all weights, while weights with a mass of about 250 *kyats* (3,750 g) amount to about 2 %. About one-half of the elephant weights weigh less than 45 g and 2 % have a mass greater than 130 g. The average mass unit of the upper part of the gallinaceous mass scale is about 11.2 g and that of the lower part is about 13.9 g. The average mass unit of the elephant-shaped weights is about 12.7 g (Fig. 2).

The essentially decimal mass scale of the *to* and *hintha* weights, based on the mass unit of one *kyat* is 1/8 (or 1/10); 1/4 (or 1/5); 1/2; 1; 2; 5; 10; 20; 50; 100; 250. The elephant-shaped weights occur on the following scale: 1/8; 1/4; 1/2; 1; 2; 5;

10; 20; 40; ?; 60. The gallinaceous scale, at about 37 g, separates into an upper binary scale (1; 2; 4; 8; (?); 32 and what may be a lower trinary scale, 1/9; 1/3; 1. Bengalese and Chinese mass scales of the period are similar in part.

Ninety-nine percent of the *to* and *hintha* weights fall within ± 12 % of the mean mass of a particular style group while about 51 % of them fall within ± 2 %. These variations lie in the making of the weights not in additions, subtractions, oxidation, nor wear. The accuracy of the elephant weights (and figurines) is less.

During the nineteenth century the weights were made at a village near the capital under the supervision of the Chief Minister. These standard weights were stored in the treasury and issued to officials in other towns. It was a criminal offense to use weights other than those made “at the palace”. Special sets of weights were kept for the purposes of comparison and the settling of disputes. Though only two nation-wide “standardizations” have been recorded, the earliest in the eleventh century, nevertheless it was the required duty of each new monarch, upon ascending the throne, to verify the weights.

Copies of animal-shaped weights, usually somewhat crude, are still made today in eastern Burma (Shan States) using techniques similar to those of thirteenth century AD and second

century BCE Burma and Yunnan. The weights were made by the lost-wax technique, using clay to surround the wax model and metal molds to shape the wax model. The high-melting point wax used was produced in Yunnan by an insect.

Among the goods imported from India which may have required weighing were opium, indigo, and mercury. From Yunnan came gold leaf, silver ingots, copper-alloy, cash, salt, white insect wax, cinnabar, and tea. Burma exported gems, including pearls and coral, costly medicines, musk camphor, gums, resins, waxes, ivory, rhinoceros horn, and rare woods. Considerable trade would have been done with other Southeast Asian states, e.g., tin from Malaya and Laos, arsenic, lead, and silver from the Shan States, zinc from Laos.

Seeds and a Chinese type of equal-arm balance were used for the weighing of small highly valuable articles and the steelyard or datchin for large masses. For moderately valuable articles, e.g., foreign silver coins and ingots, the animal-shaped weights would have been used.

Until after the middle of the eighteenth century ordinary village commerce was conducted by barter, counting, purchase with cowries, and by measurement of volume or length. Weights were rarely necessary. However, from the last quarter of the eighteenth century onward, it was the ordinary Burman, rather than the king's officers, who made use of the weights, mainly to weigh currency ingots. This change was caused by the Burmese wars of the time. These resulted in the cessation of the supplies of copper alloy and cowries, led to the Burmese capture of the large lead and silver mines of the Shan States and so to the copying of the Chinese practice of using chopped lead as a low value currency. As a result of the increased need for weights to weigh the abundance of lead and silver ingots, there was a flood of copies from the formerly Burmese north Siam region, now occupied by south Siam (Ayuthya). This new domination also led to the replacement or adjustment of the animal-shaped weights to agree with those of south Siam.

Each of the weight shapes together with its base, and each of the parts of the weights, was intended to convey a particular meaning. The meanings had to be understood by illiterate

speakers of many different languages. Though they were intended to be understood primarily by animists and Buddhists, they would also have been understood by Confucianists, Daoists, and others. Characteristic of animist/Buddhist Southeast Asia (though originating much further away in space and time) was the belief in the earthly, semidivine king. This is what the *to* weight was intended to symbolize. It combined the physical characteristics of a potential Buddha (*bodhisattva*) and a universal monarch (*cakravartin*). These, in turn conveyed the idea of secular power both to animist and Buddhist, being associated with earth, fertility, and healing, with legitimacy of rule and righteousness of conquest (a prerogative of a universal monarch). New styles of *to* weights were issued only at the times of the "righteous conquests" of a Burmese king, usually at the beginning of a dynasty with the accompanying empire-building.

The *hintha* weight symbolizes, among other things, the heavenly perfection and purity of the Buddhist faith, especially that of the Theravāda belief characteristic of Burma and Siam.

The association of feline and anserine representations for symbolic purposes has an origin more remote than Buddhism. The lion-duck association is present on some Asokan pillars. Lion-shaped weights were in use in Assyria about 1500 BCE and duck-shaped weights in Sumeria and Babylonia.

Concerning the elephant weights the kings of Burma and Siam (Ayuthya) were the incarnations of Indra, the chief of the gods, who was ancient before Hinduism, and who rode on an elephant. Thus, one reason (among several) for the choice of the elephant was to symbolize these kings.

The most generally useful of the techniques for establishing the chronological sequence of the weights were the style and sign sequences; the relation of the *to* weight styles, through their symbolism, to the dates of the dynastic changes and territorial expansions; the sequence of increase in the average unit mass of each style group; the dates of the unit masses obtained from the weighings recorded by many European traders from AD 1515, and their relation to the average unit masses of the style groups.

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Wells in China

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Wells played an important role in early human settlements and are an important indicator of civilization. After the invention of wells, primitive societies could use groundwater to serve human purposes and were no longer confined to areas with convenient surface water (Jiao, 2007). A well was usually a gathering place of a village or town. In fact, the word marketplace or *Shi jing* in ancient Chinese literature literally means *market* and *well*. The market originated from a well site because people got together at wells to draw water while selling their goods (Du & Koenig, 2012).

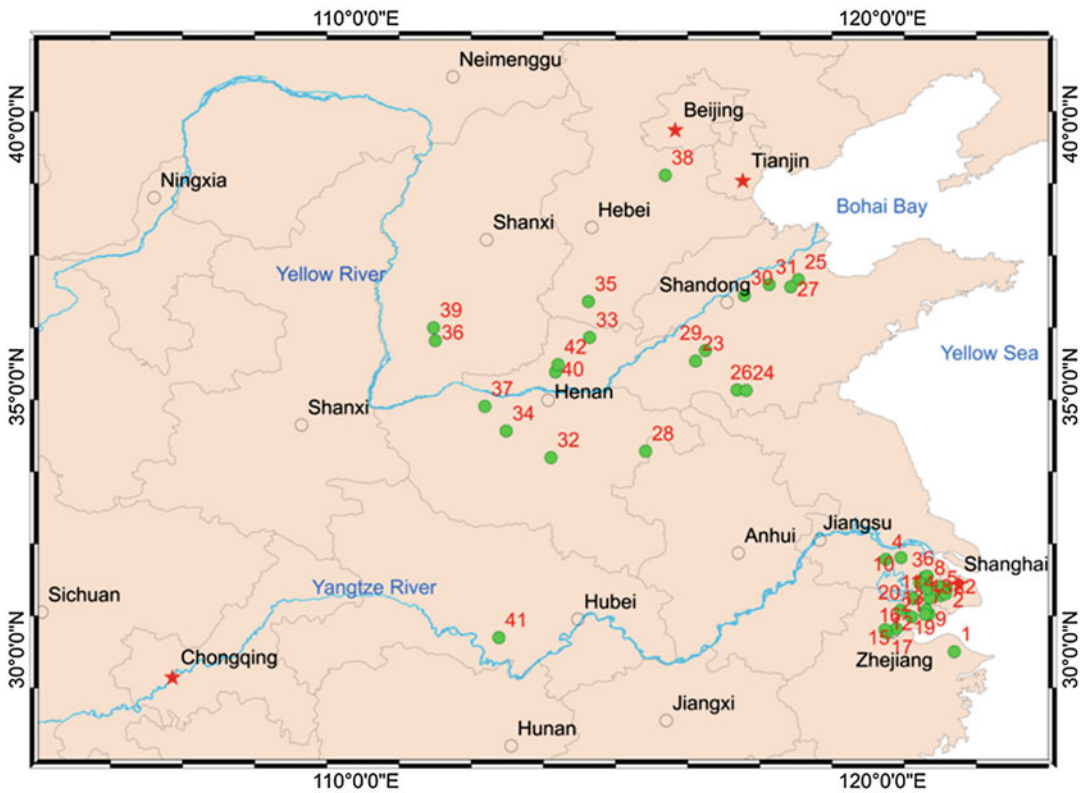
Digging a hole underground to obtain drinking water is a basic instinct even for some animals such as elephants, but only humans can construct a well with a permanent structure. The first Chinese character of the well was found in the inscriptions on oracle bones in the Shang dynasty (1555–1059 BC). There are legends in ancient

Chinese history records which gave credit to two men, Bo Yi (about 2200 BC) and the Yellow Emperor (2698–2650 BC), for inventing wells, while the credit for other inventions such as paper and Chinese characters was given to only one individual. This suggests that well construction might have been practiced in different tribes independently in prehistorical China. *I Ching*, or *Book of Changes*, probably published around or even before 1000 BC, stated that “well water is clean and cool, and can be drunk.” In *Yingzao Fashi*, or *Treatise on Architectural Methods*, published in 1103 AD, the author Li Jie described how to build various wellheads.

A typical modern well may have three components: well body or shaft below the ground surface, wellhead above the ground surface, and the superstructure above the wellhead. The construction of the well body is the most complicated part. It involves excavation, a structure to support the wall, and construction of a well screen and filter below or/and around the well screen. A primitive well may be only a hole in the bare soil but a sophisticated one may have all the components, including a well-constructed shaft.

Prehistorical Wells in China (Before 2100 BC)

A well is a common structure in residential areas after early humans transferred from nomadic lives to lives of settlement, because wells have been frequently unearthed by archeological excavation at many Neolithic culture sites in China. Various human-made depressions such as ash pits, storage pits, kilns, and house foundations may exist in an archeological site. A hole is identified to be a well usually on the basis of some of the following features: a bottom deep enough to reach the then water table (which may be marked by a brown-like horizontal strip), straight or nearly straight walls, footsteps cut into the wall for easy access, relic water vessels, mud or sandy sediments formed underwater exist at the bottom, and well frames.



Wells in China, Fig. 1 Distribution of prehistorical wells in China unearthed before about 2011. The well sites are indicated by green circles. The background shows the

provinces (black circles) and direct-controlled municipalities (stars). The reference of each numbered well site can be found in Cui (2011)

When a well is found in an archeological excavation site in China, the well is studied as one of the many archeological items. So far there is no study focusing on the well itself to understand its paleo-hydrogeological implication. The age of a well and its operation period are usually estimated indirectly from other archeological items or the pottery fragments deposited inside the well.

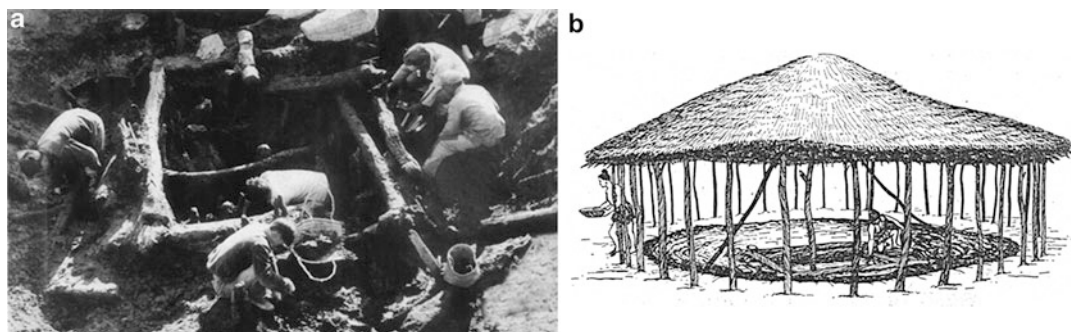
In China, the wells in prehistory unearthed so far are mainly located in two regions: the coastal and central plains of the Yellow River and the coastal plain of the Yangtze River (Cui, 2011; Fig. 1).

Wells in the Yangtze River Plain

The prehistorical sites with wells in the coastal plain of the Yangtze River cover periods ranging

from the Majiabang culture (5000–3000 BC) to the Liangzhu culture (3400–2250 BC). In addition to primitive wells in bare soil, wells supported by hewn logs, wood planks, and weaves of reeds and bamboos or willows are also found. Most of the wells in the coastal plain of the Yangtze River are shallow and less than 3-m deep, probably suggesting a low water table.

Among all the wells, the one found in the Hemudu Neolithic Ruins (5000–4500 BC) is probably the most extensively documented (site 1 in Fig. 1). The well was built approximately 5,600 years ago (Jiao, 2007; Yang, 1987; Fig. 2). The well site contains over 200 wooden components and can be divided into inner and outer parts. The outer part consists of 28 piles around a pond. The inner part, the wooden well itself, lies in the middle of the pond. The walls of the well



Wells in China, Fig. 2 (a) The wooden well at the Hemudu site under excavation, (b) artistic impression of the well with a shelter (Jiao, 2007; Yang, 1987)

were lined with close-set timber piles reinforced by a square wooden frame. The 28 piles in the outer part of the site may have been part of a shelter for the well. The well is believed to have been developed from a natural pond. On the basis of the relic wooden piles around the pond, the orientation of three relic piles inside the well and the pond, and radially distributed small logs and the reed mat shreds, the Hemudu well is speculated to have a shelter (Fig. 2b). If this is true, this may indicate that the people of the Hemudu culture were concerned with water quality and the protection of their water source.

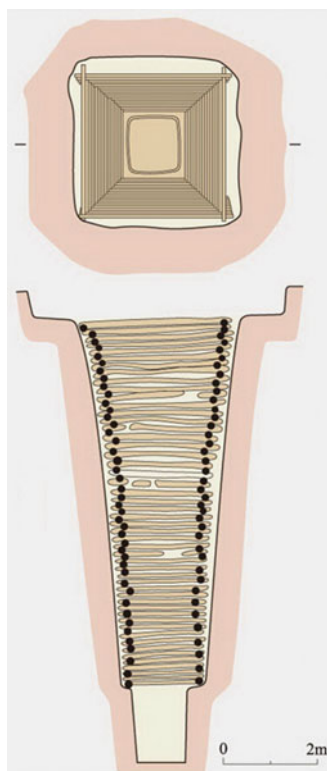
Wells of other construction types are also found. For example, a wooden well found at a culture ruin at Xingang Village, Jiashan County (site 21), belongs to the late Liangzhu culture (3400–2250 BC) (Cui, 2011). The wall of the well consists of two wood planks with a thickness of 5 cm and a length of 1.63 m. The inner diameter of the well is 45 to 63 cm. The planks are from a single tree, which was cut into two halves, with the wood inside being removed. The two pieces are connected by four wood bars which are fixed with the planks by mortise and tenon structure. Below the bottom of the wood is a 10-cm-thick layer of the shells of *Corbicula fluminea*, serving as a filter for the well. At another well site at Guangfulin ruins (site 22), which belongs to the late Liangzhu culture, the well has a diameter of 2.4–2.5 m near the ground surface but it narrows down to 0.3–0.5 at the

bottom. It has a depth of 3.1 m. At the bottom of the well is a box of bamboo plait with a height of 1.1 m. This structure of bamboo plait functions like a well screen which can support the wall of the well and also behaves as a filter to the groundwater. Some culture sites (e.g., site 5) have wells with reed mats near the bottom of the well which are supported by wooden piles.

Wells in Yellow River Plain

Compared to the Yangtze River plain, the culture ruins with wells in the Yellow River catchment are scattered widely in both the central and coastal river plains. Most of the wells are less sophisticated in construction but deeper, suggesting that the water table was typically lower. The prehistorical wells in the Yellow River plain so far unearthed dated as early as the Beixin culture (5300–4100 BC). The number of wells started to increase in the Dawenkou culture (4100–2600 BC) and became quite popular in the Longshan culture (3000–2000 BC). Most wells are simply vertical holes underground without well frames. The depth of the wells varies but usually is greater than 2 m in the early culture periods. It increases toward the late Neolithic cultures and can be over 4 m in the late Longshan culture. The shapes of the wells can be square, rectangular, round, or oval, but are dominated by square and circular at the late stage.

The wells in the central plain of the Yellow River largely belong to the Longshan culture.



Wells in China, Fig. 3 Wooden well in Baiyin ruin in late Longshan culture (Cui 2011)

There are wells in bare soil but also many wells enforced by wooden frames. Most of the wells are located in the residential areas, suggesting that they were for domestic use, but there are also two wells located near kilns, suggesting that they were for making ceramic products. The most impressive well is the one unearthed in the Baiyin culture site (2590–2100) (site 33) which belongs to the late Longshan culture. The well is square shaped, but with rounded corners (Fig. 3). The well dimension is 5.8 by 3.6 m near the surface but progressively smaller toward the bottom with a dimension of 1.2 by 1.1 m. The depth is 11 m. The wall is supported by 46 layers of hewn logs which are connected by mortise and tenon joints. At the bottom of the well, there is a layer of ceramic fragments overlying the original silty yellowish soil (Cui, 2011; Fig. 1).

Wells After Prehistory

The use of wells in ancient China (2852–1600 BC), including the dynasties of Xia (2100–1600 BC), Shang (1600–1046 BC), and Zhou (1045–256 BC), was very common (Du & Koenig, 2012). In the late Zhou dynasty, wells were very popular and the drilling technology was also significantly improved. Various materials such as ceramic rings, pottery clay, bricks, rocks, and hollowed trunks were commonly used to construct the underground part of wells, as observed at many archeological sites. However, the superstructure of a well was usually destroyed.

In the early stage of imperial China (221 BC to 1911 AD), a well became a household item of almost every family, especially in the north part of China. This is indicated by the well models widely unearthed in tombs in Han dynasty (206 BC to 220 AD) (Jiao, 2008). During this period, it was a common practice for the family to bury a dead person, together with some *mingqi*, or spirit wares, to honor their ancestor and make his spirit happy on the journey to paradise. A very popular *mingqi* in the Han dynasty is a miniature of well models, symbolic for water for the ancestor to drink. Such a well model gives us a vivid picture about the wellhead and the superstructure constructed in old China.

Description of various well *mingqi* can be found in Jiao (2008). While most of the *mingqi* are clay models, Fig. 4 shows a bronze model of a wellhead. The model has an elaborate base. The square wellhead sits on a pyramid-shaped platform with a trough between the sloping sides and the outer rim of the square base. Spilled water from the bucket could be easily drained to the trough. The appearance of the wellhead indicates that the original well was made of wood. The superstructure supports a winch or pulley that would hoist the bucket. Such a robust pulley system suggests that the water level may have been fairly deep. This model indicates that the construction of a well was very mature at least in the Han dynasty.

Most of the well models unearthed are mixed with other domestic items such as models of



Wells in China, Fig. 4 A model of bronze wellhead with pulley and bucket unearthed from a tomb of Eastern Han dynasty (AD 25–220 AD) in Shandong Province. The model is 49.5 cm high and 48 cm wide (*square base*) and is a collection of Shandong Provincial Museum (<http://www.asianart.com/exhibitions/shandong/14.html>)

kitchens and toilets, suggesting that these wells were for domestic purposes. There are also some ceramic models of wells which suggest that wells may have been used for irrigation or to extinguish fire (Jiao, 2008).

While large-diameter shallow water wells have been used since ancient China, driven by the salt industry, salt wells started to be built in the Western Jin dynasty (AD 265–316 AD) (Zhou, Zwahlen, & Wang, 2011). Almost 1,000 years ago, people in Zigong, Sichuan Province, were able to drill small-diameter boreholes 100-m deep using cable drilling techniques to pump water from deep brine aquifers to produce salt (Vogel, 1993). This technique was invented between 1041 AD and 1048 AD in the Song dynasty. To lift brine from the well, workers used a bamboo tube suspended from a rope. Today deep drilling is regarded as one of ancient China's greatest innovations, comparable to their invention of paper, printing, gunpowder, and compasses. Xinhai Well in Zigong, which reaches a depth of 1 km, was the deepest in the world when it was drilled in 1835. This well is



Wells in China, Fig. 5 A worker is demonstrating how to pump brine water from a deep well in Daying Country, Sichuan Province. The well is located at the *left-bottom corner* (http://www.sc.xinhuanet.com/content/2007-11/22/content_11744433.htm).

still operational and is a tourist attraction in Zigong. Figure 5 shows such a well in Daying Country, Sichuan Province. It is also called a bamboo well because all the major materials associated with the well, including the well bore, the rope, and the water containers, are made of bamboo, a widely available local plant.

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Western Dominance

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Scientific curiosity was a major motive behind Western overseas expansion from the fifteenth century onward and technological innovations, particularly in shipbuilding, navigational instruments, and firearms, made that expansion possible. But early European explorers and conquistadors did not rely heavily on evidence of scientific or technological achievements as gauges of the worth of the peoples they encountered or as explanations for their growing dominance in the Americas and maritime Africa and Asia. In encounters with the great centers of civilization in Africa and Asia, European superiority in these endeavors was highly selective, marginal, or in many areas nonexistent. In fact, travelers to China and the Indian subcontinent in the early centuries of expansion were as likely to dwell on the technological deficiencies of the West, when compared to these great civilizations, as to boast of European advantages. As in India, China, and Japan, the Europeans were able to make little headway into the heartlands of the Islamic world in this era. That standoff and the fact that they had borrowed so heavily from the scientific learning and technology of Muslim cultures in the centuries of Europe's emergence as a global force, rendered it unlikely that material standards would supplant the long contested religious differences that the Europeans had employed to set themselves off from and above the followers of Islam.

In Africa, disease and geographical barriers and the power of coastal kingdoms prevented the Europeans from translating their technological edge into significant conquests. Failure to move into the African interior also meant that the Europeans had only the vaguest notions about African epistemologies or understandings of the natural world, which were usually dismissed as superstition or fetishism. In sharp contrast to their experience in Africa, European invaders encountered few disease barriers in the Americas. In fact, diseases from smallpox to the measles became powerful allies of the Spanish conquistadors in their assaults on the heavily populated and highly advanced civilizations of Mesoamerica and the Andean highlands. The long isolation of the Amerindian peoples from the Afroeurasian people and cultures left them highly vulnerable to both the microbes borne and the Iron-Age technology wielded by the European invaders. Nonetheless, the Spanish tended to attribute their startling successes in battle against seemingly overwhelming numbers of Aztec or Inca adversaries and the rapid conquests that followed to supernatural forces and to the superiority of their militant brand of Christianity over the "heathen" faiths of the indigenous inhabitants of the "New" World.

Lacking in-depth knowledge of the epistemologies and scientific learning of most of the peoples they encountered in the early centuries of overseas expansion and often enjoying only very selective (but at times critical) technological advantages over them, European explorers, missionaries, and Crown or Company officials were unlikely to rely on material standards to judge the level of development attained by other cultures or to compare overseas civilizations to Europe itself. Until at least the end of the seventeenth century, religious beliefs, or the Europeans' certitude that they possessed vastly superior understandings of the transcendent world, predominated as the gauge by which other cultures and peoples were assessed and ranked. Additional cultural variables, such as the position and treatment of women, were frequently cited as evidence of advancement or savagery; and physical features, especially skin color, were

sometimes emphasized in attempts to distinguish and rank the peoples encountered overseas.

Scientific and technological gauges of past attainments and present abilities remained peripheral to most evaluations of the peoples and cultures that the Europeans encountered as they expanded across the globe. None the less, signs of material advancement – the existence of large cities, sophisticated techniques of fortress construction, or evidence of complex scientific instruments – were often noted and even cited to support arguments regarding the level of development achieved by different peoples. In two areas in particular, in the perception and measurement of time and in perspectives on space associated with artistic and mathematical advances of the Italian Renaissance, European overseas observers began to see a clear divide between the West and all other civilizations and cultures. In addition, as early as the sixteenth century, European commentators began to rank African cultures beneath those of Asia and the Americas, not so much because of skin color or other physical features, as has often been argued, but due to what was perceived as a markedly lower level of material culture in Africa than that found by European travelers and traders in India, China, or central Mexico.

Although ideologies justifying overseas expansion and the domination of non-European peoples from the fourteenth to the early eighteenth century were rooted in religious belief and were generally culture – rather than racially – oriented, material accomplishment, including the assumed capacity for invention and scientific thinking, was increasingly associated with racist defenses of the enslavement of Africans. Defenders of the slave trade sought to counter the abolitionists' objections with often lurid descriptions of the alleged savagery of African life and the debased level of African material culture. Along with skin color and other physical differences, racist writers, such as Samuel Estwick and Dominique Lamiral, emphasized material backwardness and ignorance of the workings of the natural world as proof of the subhuman nature of Africans that justified their subjugation as slaves.

By the last decades of the eighteenth century, this rather broad association between racial ideology, material culture, and the defense of slavery was refined and enhanced by the rise of racist theories allegedly grounded in scientific experimentation and reasoning. Physicians and ethnologists devised a variety of measurements – from skull size and shape to genital configurations – in efforts to prove that there were innate physical, mental, and moral differences between human racial groups. The fact that the measurements reflected a priori assumptions and were based on small and suspect samples, and that even the racial categories themselves were hotly contested, did not prevent “scientific” racism from winning widespread support from European scientists, social commentators, and politicians throughout the nineteenth century. The tenets of scientific racism were popularized among the middle and working classes by practitioners of phrenology, whose booths could be found at county fairs and on the promenades of seaside resort towns, and by the pulp press, where allegedly scientific proofs of European racial superiority were linked to social evolutionist arguments for imperialist expansion.

By the first decades of the nineteenth century, scientific and technological gauges of human achievement and worth were clearly in the ascendant. Earlier measures of the level of development achieved by different cultures continued to be cited. Religious belief, for example, remained of paramount importance to missionaries active in overseas lands. But even missionaries increasingly linked Europe's advances in the sciences and invention to the rhetoric of Christian proselytization. Ignoring past and contemporary tensions between science and religion in Europe itself, prominent missionaries, such as the Abbé Boilat and David Livingstone, argued that Christian culture had been particularly receptive to scientific investigation and technological innovation, and that conversion to Christianity would promote the scientific and material development of colonized peoples. The growing numbers of ethnologists and professionally trained anthropologists, who found in the colonies relatively safe and fertile environments for their

research, also privileged nonscientific or non-technological standards, such as modes of political organization or gender relations, in assessing the level of development attained by African, Asian, Amerindian, and Pacific Island peoples. But evidence of material culture was increasingly linked to societal advance, and indigenous “superstitions,” or at best magical beliefs, contrasted with the scientific mindset that was seen as typical of the educated West.

A number of factors account for the dominance of material standards, particularly those linked to science and technological innovation, in nineteenth-century ideologies of European global hegemony. Most critically, the transformations wrought by industrialization from the middle of the eighteenth century in England and somewhat later in Belgium, Germany, France, and Italy made the gap in scientific and technological capacity and material development between western Europe and non-Western societies increasingly apparent to European and non-European observers alike. Maxim guns, steamboats, and railway lines carried elements of Europe’s industrialization to colonized areas, and champions of imperialist expansion reasoned that these wonders could not help but impress subjugated peoples with the unprecedented degree to which European societies had advanced over their own. Not only did European superiority in science and technology seem obvious, but also it could be empirically tested in ways that claims of higher religious understanding or moral probity could not. Europeans had vastly more firepower, could produce incomparably greater quantities of goods much more rapidly, and could move both these products and themselves about the globe with much greater speed and comfort than any other people, including the once highly touted Chinese. In an age when what were held to be scientific proofs were authoritative, attainments that could be measured statistically were viewed as the most reliable gauges of human ability and social development. Mechanical principles and mathematical propositions could be tested; cast iron or steel bridge spans could be compared for size and strength with the stone or wooden structures of

non-Western societies; and human skulls could be quantified in seemingly infinite ways to assess the highly variable mental capacity of the “races of man.”

The preeminence gained in the nineteenth century by scientific and technological standards of human worth and ability not only bolstered proponents of theories of European racial supremacy, but it also proved vital to various formulations of the civilizing mission ideology that both inspired and rationalized European imperialist expansion from the early 1800s to 1914. Chauvinistic politicians in the metropolises and imperial proconsuls in the colonies increasingly stressed the importance of the diffusion of Western science and technology to what they viewed as the benighted peoples and backward lands that had come under European control. Proponents of the civilizing mission confidently predicted that the world would be remade in the image of industrializing Europe. Given Europe’s material advancement, it was seen as appropriate that Europe and North America serve as the sources of capital, both machine and financial; of entrepreneurial, scientific, and managerial expertise; and of manufactured goods for the rest of the globe. In this view, the non-Western world, including both areas that had been formally colonized and those that had come under the informal sway of the Great Powers, were best suited to provide abundant and cheap land, labor, and raw materials that were required to fuel the industrial economies of Europe and North America.

According to the “improvers” or nonracist advocates of the civilizing mission, the spread of Western education among colonized peoples – emphasizing the inculcation of at least rudimentary Western scientific learning and technological skills – would provide the critical means by which the material level of non-Western societies would gradually be raised. Though they approved of the diffusion of essential Western technology to overseas areas under the paternalist supervision of European colonizers, racist apologists for imperialism had little faith in the ability of subjugated peoples to master the sciences or engineering of the West.

Thus, they envisioned the period of European "tutelage" extending for centuries, if not indefinitely, into the future.

The non-Western peoples who were the targets of the European colonial enterprise were very often awed and overwhelmed by their initial encounters with the science and technology of the industrializing West. Whether they were indigenous leaders resisting the growing encroachments of European forces or scribes and merchants who allied themselves with the invaders, the colonized could not help but be impressed with the clear and increasing advantages in power that the Europeans gained through their superior capacity to tap the resources of the natural world, to produce material goods, and to devise more deadly weapons. As surveys taken as late as the post-World War II era, such as those which form the basis for G. Jahoda's *White Man*, the science and technology of the colonizers gave them an aura of magical power among the colonized masses in many areas. Though Western-educated Africans, Asians, or Polynesians were likely to scoff at such expressions of popular admiration, most came to accept that Western science and technology were not only on the whole superior to their own but essential for the future "development" of societies they hoped someday to rule. Therefore, nationalist critiques of imperial domination often deplored the fact that colonialism had severely constricted the flow of science and technology from the West to dominated areas, and demanded that technical education and scientific facilities for indigenous peoples be expanded and improved.

By the last decades of the nineteenth century, however, a number of influential African, Asian, and Caribbean thinkers were mounting cogent challenges both to notions of European racial superiority based on evidence of scientific and technological achievement and to the advisability of the wholesale transformation of non-Western cultures and societies along Western, industrial lines. Much of this resistance to the hegemonic ideologies of the Western colonizers focused on efforts to reassert and revitalize indigenous epistemologies, modes of social organization, and approaches to the natural world. Thinkers such

as Vivekananda and Aurobindo Ghosh contrasted an Indian spiritualism with the deadening abstractions of Western materialism. African writers, such as the Caribbean-born Edward Blyden, deplored the devastating impact of the Atlantic slave trade on African cultures and celebrated the Africans' strong sense of community, reverence for and care of the elderly, and sophisticated artistic creations.

Ironically, these defenses of colonized cultures were buttressed by contemporary European anthropological studies, usually carried out under the auspices of colonial administrations; by the intense interest in "Oriental" religions fashionable among European intellectuals in the decades before World War I; and by the "discovery" of the abstract power of African masks and other forms of "primitive" artistic expression by Picasso, Derain, Matisse, and other avant-garde artists in the early 1900s. Inadvertently, however, the works of these first generations of Indian and African critics of European hegemonic ideologies often validated the very materialistic standards they sought to contest. For example, Indian thinkers, particularly Vivekananda, repeatedly stressed the scientific accomplishments of India's ancient civilizations, while African and West Indian writers, most notably Anetor Firmin, claimed Egypt, with its impressive engineering and architectural feats, as a civilization that black Africans had done much to build.

With the coming of the First World War, non-Western critics of what had been characterized as the excessively rationalistic, impersonal, and materialistic West found numerous, and highly vocal, European intellectual allies. The horrific trench slaughter on the Western Front and the multitude of ways that Western scientific knowledge and experimentation were harnessed to the war effort as a whole raised profound doubts for noted thinkers, such as Paul Valéry, Sigmund Freud, and Georges Duhamel, about the long-assumed progressive nature of Western science and technology.

After such a savage and suicidal war, the tenets of the civilizing mission rang hollow, and "scientific" racist thought came under increasing assault in both western Europe and the United

States. Collaboration with indigenous elites was increasingly stressed in the governance of the colonies, and a rhetoric of science and technology as agents of development through cooperation with indigenous peoples permeated colonial policy making.

European doubts about the directions taken by the industrial West and its global hegemony gave new impetus to African, Asian, and Caribbean critiques of European global hegemony. René Maran's *Prix Goncourt*-winning novel, *Batouala*, mocked the pretensions of racial superiority held by European colonizers, and idealized village life in French West Africa. The poets of the *négritude* movement, most powerfully L. S. Senghor and Aimé Césaire, mourned the suffering and destruction wrought by European science and technology in Africa and the lands of the slave diaspora, and inverted racist epithets by exulting blackness, intuition, affinity for the natural world, and indifference to inventiveness. Aurobindo Ghosh and Rabindranath Tagore viewed the war as the fulfillment of earlier Indian prophecies of a coming cataclysm in the aggressive and materialist West, and proof of importance of India's spiritual mission in the modern age. Mohandas Gandhi also cited the senseless violence and colossal destructiveness of the war in support of his sweeping assaults on industrial society. In the decades after the war, he sought to formulate for India (and implicitly for other colonized areas) a community-centered, low tech, and conservationist alternative to industrialized society as it had developed in the West. In this same period, Gandhi also worked out a strategy for confrontational but nonviolent protest that repeatedly proved an effective antidote to the advanced technologies of repression employed by Western overlords in the decades of decolonization from the 1920s onward.

Though battered and under assault, the scientific and technological underpinnings of ideologies of Western dominance survived the crisis of two global wars and the powerful critiques of Gandhi and the *négritude* writers largely due to the emergence of the United States as the global power from the 1920s onward. Entering the First World War late and just when new technologies

had restored a war of motion and decision, Americans continued their long-standing infatuation with science and technology after the conflict. Faith in the essentially progressive nature and beneficence of science and technology informed the development (later called modernization) theory that came to dominate both American thinking on colonial issues and that of the European and Japanese imperialist rivals of the United States. After World War II, America's chief rival, the Soviet Union, also championed a rhetoric of development that privileged science and large-scale industrialization. With modernization theory (in a number of capitalist and socialist versions) in the ascendant, non-Western alternatives to social development and economic well-being, such as that formulated by Mohandas Gandhi, were marginalized or openly spurned by the Western-educated elites that governed the new states that emerged from the collapsing colonial empires. Though alternative approaches have gained significant support in some of these new nations, most notably India and Tanzania, international agencies and Western and non-Western planners continue to rely upon modernization schemes, based overwhelmingly on Western precedents, to solve the problems of poverty and growing wealth differentials and the demographic and environmental dilemmas that have been building on a global basis for centuries.

See Also

- [Colonialism and Science](#)
- [East and West](#)
- [Magic and Science](#)
- [Science as a Western Phenomenon](#)
- [Technology and Culture](#)

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Windpower

Richard L. Hills

There is little doubt that the first practical use of the wind as an energy source other than as the motive power for sailing ships occurred in the East. Those of Persia were probably the first but precisely when is uncertain. According to a story of al-ṭabarī, writing around AD 850, and later writers, the second orthodox Caliph, Umar ibn al-Khaṭṭāb, was murdered in AD 644 by a captured Persian technician, Abū Lu'lu'a, who claimed to be able to construct mills driven by the power of the wind and was bitter about the taxes he had to pay. This early date cannot be confirmed but Arabic geographers of the tenth century all confirm the existence of windmills in the region of Seistan in north eastern Iran. For example, al-Mas'ūdī around AD 950 wrote of the wind driving mills and raising water from streams.

Nothing has survived to show how such mills pumped water but later drawings of one type of windmill suggest that it could have been derived

from horizontal corn-grinding watermills. In the lower part of such watermills, the water fell down a chute and struck blades placed radially around a vertical shaft. The top of the shaft passed into a higher room and carried the upper millstone and so rotated it above the bedstone which was set on a floor in the middle of the mill. When developed into a windmill, the wind rotor was situated in the bottom of the mill. The building was constructed with four “loop holes” to direct the wind on to the blades from whichever quarter the wind might be coming. There might be eight or ten blades, and the wind was directed by the loop holes onto one side of the rotor. In this way the sails were pushed round on that side away from the direction of the wind while those advancing into the wind on the other side were shielded by the walls around the loop holes. The grinding stones were placed in an upper room with the upper stone turned by an extension of the rotor shaft in the “underdrift” manner. None of these mills has survived.

The type which may still be in use today had the grinding stones situated in a room below the rotor with the sails above. This necessitated a change to the “overdrift” method of driving the stones where the spindle passed down through the bedstone to a bearing underneath, which had to support the weight of both the upper stone and the sails. It was possible to disconnect the driving shaft at the place where it was connected to the upper stone at the “rynd” to allow for the stones being separated for dressing. The layout for grinding was similar to other corn mills with a hopper mounted on the wall from which the grain was fed into the central hole of the upper stone through a chute or shoe while the flour was passed out around the circumference of the stones.

The advantage of this second layout was that the rotors with the sails could be greatly enlarged. Mills near Seistan and on the borders of Iran and Afghanistan might have rotors approximately 5 m (16.4 ft) high by 3 m (9.8 ft) in diameter. There could be six or eight sails which had wooden framing that was interlaced with straw or covered with wooden boards. The upper parts of these mills were built with one wall that directed the wind on to one side of the rotor

while another wall shielded the other half. Sometimes matting screens were erected to help channel the winds to the sails. There were no brakes, but more screens might be placed across the slots between the walls to regulate the wind reaching the sails; to secure the mill when out of use, the rotor and upper millstone were lowered to rest on the bedstone. A wind speed of 22.40 m s^{-1} (50 mph) was needed to drive these mills at only 30 rpm. Such a mill, working with intermittent wind for about 4 months of the year, would grind enough flour for about 15 families. Seistan was known as the land of the winds and between mid-June to mid-October the wind regularly blew from the north for a period of 120 days. The mills were built in line to face these winds and the famous example at Neh had a long row of 75 mills.

Because these horizontal mills needed such strong and regular winds to power them, they did not spread in this form much beyond the borders of Iran and Afghanistan. They were invented earlier than the Western vertical type but it is doubtful whether there is any connection between the two. Those in the West, which have been described as the “full admission, axial flow type,” first appeared around AD 1150 possibly either in the southeast of England, the northwest of France, or Flanders. However these Persian mills were probably the source of the later Chinese mills and possibly the Tibetan wind-powered prayer wheels.

The wind-powered Tibetan prayer wheels were not surrounded by elaborate buildings to guide the wind onto the rotors. The most common form had a vertical axle with horizontal spokes at its top, on the ends of which were fixed sails shaped like cups so that they caught the wind on one side of the rotor, but were smoothed or curved to present less resistance on the other. The wind would be caught in the concave part of the cup, or a curved sheet, during half the circle to turn the rotor, while in the other half, the convex or streamlined side would be advancing into the wind and so present less resistance. Power output was minimal but was sufficient to turn the prayer wheels which was the only use to which they were applied.

Prayer cylinders designed for automatic repetition of the Buddhist mantra are unlikely to have been produced before the reign of K’ri-srong-Ide-brtsan in AD 755–797 when Buddhism conquered Tibet. It is unlikely that such cylinders were turned by the wind at this period, although no doubt there were prayer flags fluttering in the wind from around this time. Early in the twelfth century, a new fashion for mechanical piety swept China, but again it seems doubtful whether this included wind-powered prayer wheels, which must therefore be placed later, and certainly therefore after the Persian mills.

More is known about the adoption of the windmill in China. Once again early dates for this have been suggested, but these are doubtful. In about AD 1230, Yelu Chu Zai was captured by Jinghi Khan and became his minister. He was an extremely good scholar, administrator and mathematician. An accurate description of the Persian windmill has been discovered in his memoirs, with a comment on how good it would be if the Chinese used it. A Chinese book of the seventeenth century, the *Zhu Qi Tu Shu*, describes the windmill as if it were a European invention, which could be a mistake for Persia. In China, these mills were used for raising water and evolved into an entirely different form from the ones in Persia or Tibet.

Chinese horizontal windmills are still used today along the eastern sea coast north of the Yangtze and in the region of Thangku and Taku near Tientsin to operate chain pumps through gearing for raising salt water for salt pans or fresh water for irrigation. Once again they have no elaborate structures for directing the wind onto the rotors but are closely linked to the way the sails of junks operate. Canvas-covered sails are mounted at the ends of radial arms, each with its own mast, in such a way that they can be spread to catch the wind on the side of the rotor turning away from the wind and be feathered to present the least resistance on the side turning against the wind. The sails can pivot on these masts, and, as on a junk, the sail extends to the front of the mast. The longer, or driving, side of the sail is tied to the rotor framework by a piece of rope of such a length that, when the sail is turning with the

wind, it is held into the wind, but can rotate out of the wind when advancing against the wind. The angle of the sail can be set by the length of rope to a position in which the wind can do useful work on it for more than 180°.

These mills must have been the most efficient of the horizontal types developed before the twentieth century, but all horizontal windmills suffer from the same problem, that only a small part of the wind rotor can be used to its maximum efficiency at any time. The theoretical maximum power coefficient for a simple horizontal windmill is only one third, but in practice it will be much less. These are the reasons why the horizontal windmill has not been developed further and few examples remain at work today.

In the eastern Mediterranean, at some period during the Middle Ages, vertical windmills appeared with a different type of sails from those normally used in the West. The horizontal wind shaft was extended in front of the mill like a ship's bowsprit so that ropes from it could help to stay six or eight radiating spars. The sails were triangular pieces of canvas like the sails of a modern yacht and worked in the same way. The leading edge of each sail was attached to the spar, round which it could be wrapped to reef it in strong winds. The free corner was secured by a rope in much the same way as a ship's boom. These sails were much lighter than those of a conventional western windmill and have found a new application in water pumping mills in some developing countries today.

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Wine in Anatolia

Alexia Smith

The quest for the earliest evidence of viniculture has led many scholars to Transcaucasia and Anatolia, the latter of which spans the Asian portion of modern-day Turkey and derives its name from the Greek for "Land of the Rising Sun". It is not known precisely when viniculture (the cultivation of grapes for wine) or viticulture (cultivation of the vine) as were first practiced, but both were well established in Southwest Asia by the beginning of the third millennium BCE. Several lines of evidence have provided insight into early wine production, including textual accounts, archaeological data such as drinking vessels, chemical analyses of residues within vessels, and ancient plant (archaeobotanical) data, as well as modern biogeographical observations.

The modern distribution of wild grapes is useful for demarcating the area within which grape domestication could have occurred in the past. Today, wild grape (*Vitis vinifera* L. subsp. *sylvestris* [C.C. Gmelin] Berger), is found as a forest climber along the coastal regions of central and southern Europe, areas surrounding the Black Sea, and the southern reaches of the Caspian Sea, with isolated patches growing in Turkmenistan and Tadjikistan. Anatolia clearly falls within this natural range.

Archaeobotanical remains provide more detailed information. (See ► [Agriculture: Ancient Methods](#) of Agriculture by Alexia Smith in this volume for a more detailed description of archaeobotanical remains and their recovery.) In general, wild berries are smaller and more acidic than their domesticated counterparts. While entire grape berries can be found, archaeobotanists most typically encounter charred pips which tend to become shorter and rounder following domestication. In practice, however, distinguishing between wild and domesticated grape pips is challenging, since

considerable overlap in their shape and size exists. Consequently, determining the precise point in time when grapes became domesticated is difficult. What is clear from the archaeobotanical record is that wild grapes have been collected for millennia to be eaten fresh or dried. Fermentation of grapes into wine requires fruit with a minimum sugar content of 10 % and the presence of the principal wine yeast, *Saccharomyces cerevisiae*, which naturally occurs on grape skins. Experiments with wine making may have taken place as early as the Neolithic period (ca. 10,500–5500 BCE), well before viticulture developed as a specialized venture. Some of the earliest grape finds come from Öküzini Cave in southwest Anatolia, and date to the Late Palaeolithic (16,000–10,500 BCE). Grapes also appear consistently during the Neolithic and Chalcolithic (5500–3000 BCE) periods at sites such as Can Hasan III, Çayönü, and Korucutepe. From the Chalcolithic to the Early Bronze Age (ca. 3000–2000 BCE), a rapid increase in the presence of grapes at sites such as Kurban Höyük in southern Anatolia reflects the growth of viniculture.

Changes in the range of Early Bronze Age pottery vessels are also linked with an intensification or expansion of viniculture. At this time chalices and other forms associated with drinking such as the *depas amphikypellon* (a tall, narrow, two-handled tankard) began to increase in number. Other drinking vessels associated with wine include *rhyta* (sing. *rhyton*), which were fashioned out of metal or ceramics in the form of an animal's head. Storage vessels include amphorae (An amphora is a jar, usually made of clay, with a narrow neck and two handles, used by ancient Greeks and Romans for holding oil or wine) and large pithoi (Pithoi were large ceramic storage jars, mainly used for storing agricultural produce such as olive oil, wine, olives, raisins or grain. Such large jars must have been made in several sections and joined together before firing). At sites such as Boğazköy and Alişar Höyük, containers fashioned after a cluster of grapes have been found. The association of vessels with wine

can be affirmed using infrared spectroscopy through the detection of tartaric acid, a compound that occurs naturally in grapes and forms the primary acid within wine. Tartaric acid was detected in a large ceramic tub found in Early Bronze Age levels at Titriş Höyük in southeastern Anatolia, linking it with activities such as grape pressing.

Early texts written in Assyrian dating to the Old Assyrian Colony Age (ca. 2000–1750 BCE, corresponding with the Middle Bronze Age) and the Hittite period (ca. 1600–1200 BCE, Late Bronze Age) have been synthesized by Ronald Gorny and provide additional insights into early wine production. Texts from Cappadocian trading colonies refer to the months of September and October as *qitip karānim*, the “harvesting of grapes” season. Grape harvesting festivals are also mentioned in Hittite texts (EZEN ^{GIŠ}GEŠTIN *túh-šu-u-wa-aš*). In Hittite, grapes or grapevines were called *wiyana* (which features in the etymology of the word “wine”) and are represented in texts with the Sumerogram ^{GIŠ}GEŠTIN. The official position of “GAL.GEŠTIN” is mentioned in the *Palace Chronicle*, an Old Hittite text that documents the court during the reigns of Hattušili I and Muršili I. The early responsibilities of GAL.GEŠTIN included supervision of vineyards and their products, which underscores the importance of vineyards as an elite enterprise. Since the majority of the texts document political, economic, and religious matters, bias in the records exists, and little is known about grape production or wine consumption among the general populace. It seems fair to link early viniculture with the elite, however. Since grape vines require a number of years to become established and yield fruits, only people of means could make such a commitment outside of a garden setting. Alexander Joffe even argues that production of alcoholic beverages may be linked to the rise of the state by allowing emerging elites to increase their level of power through surplus production and control over craft production.

A number of Hittite laws pertaining to viniculture bear testimony to well established

practices and likely reflect concerns of earlier time periods. The laws clearly outline relative worth of various commodities and assign appropriate penalties for theft or damages to property. Damage to a vineyard is covered by Law 113, whereby the guilty party must take the damaged grapes and provide grapes from their own vines. Penalties for theft are discussed in Law 101 and combine monetary compensation with corporal punishment involving a spear. Over time corporal punishment was stricken from the law and the fine increased from one shekel per vine to six shekels for a free individual and three shekels for a slave. One Hittite shekel is roughly equivalent to 12.5 g of silver and could purchase 2 *parīsu* of wine, 3 *parīsu* of emmer wheat, 6 *parīsu* of barley, or 160 shekels of copper. Each *parīsu* is believed to correspond with 30 l.

While wine was undoubtedly valued as a pleasing beverage, its earliest uses were restricted to Hittite rituals, festivals, and religious ceremonies, which in general were conducted to gain favor of the gods with respect to the particular issue or problem at hand. Offerings of wine to the gods are mentioned in several Hittite prayers, including the *Prayer to Tešub of Kummani*, the *Prayer to the Sungoddess of the Underworld*, and the *Prayer of Muwatalli to the Stormgod Piḫšašši*. A number of myths, such as the *Ašertu Myth* and the *Myth of the Serpent Illuyanka*, discuss the inebriating power of wine and the potential dangers of becoming intoxicated. The cleansing nature of wine is stressed in several medical rituals, and similarly in rituals intended to purify land and prepare ground for the founding of a new palace. Soldiers also used wine as a metaphor for blood during an oath pledging ritual intended to secure their loyalty.

The association of wine with ritual and religious beliefs perpetuated for some time. During the Lydian period (687–546 BCE) in western Anatolia, Bacchus was celebrated as the god of wine. During Byzantine times in the early part of the first millennium A.D., wine was believed to be blessed by the sky-god; vineyards and stored wine afforded protection from evil spirits. Wine production decreased significantly following the

conversion of Anatolia to Islam, although wine has continually been drunk. Today wine production is increasing again and grapes are widely cultivated in many parts of Turkey, including the Mediterranean coast and Central Anatolia.

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Winemaking and Viticulture in the Ancient Near East and Egypt

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In the ancient Near East and Egypt the development of winemaking and viticulture has a discontinuous record due to the nature of both historical and archaeological evidence. Historical records include texts and pictorial evidence illustrating grapes, grape vines, wine production, and wine consumption. Tracing winemaking and viticulture to its more distant origins in prehistory is now possible through careful archaeological investigations and scientific and chemical analyses. A significant step toward understanding how scant prehistoric evidence could contribute to reconstructing the presence and manufacture of such a specific, delicate and liquid substance as wine emerged with the observation of stains on the interiors of certain pottery jars and the subsequent chemical analysis and identification of key components of these residues. Badler, McGovern, and Michel (1990) pioneered chemical residue analysis (the identification of tartaric acid as a marker for grapes and wine) coupled with archaeological evidence to establish new data points in ancient winemaking history. Guasch-Jané et al. (2004) have further differentiated red from white wine by the presence of malvindicin-glucoside and its unique by-product, syringic acid.

Prehistoric Wine and Ancient Viticulture

Because of extensive cultivation, crossbreeding, seed dispersion, and deliberate transplantation, it is difficult to determine by grape genetics alone the geographic origins of winemaking and viticulture. Probably they are located in the general area of the wild Eurasian grapevine (*Vitis vinifera sylvestris*) that presently grows from Spain to Lebanon, inland along the Danube and Rhine Rivers, around the Black Sea and southern Caspian Sea, at the headwaters of the Tigris and Euphrates Rivers, and farther east in Central Asia (McGovern, 2003, p. 7). Winemaking preceded viticulture, as grape cultivation is not necessary to make wine – it can be made from the wild grapes that were plentiful in certain areas of the Near East. The development of winemaking could have followed a similar path as that of breadmaking and the cultivation of grains. The motivation for both grape and grain cultivation would have been to provide convenient local sources and a stable supply of raw materials for the end products. Viticulture, the purposeful cultivation of grape vines, would have also provided the opportunity to exercise more control over both grape quality and quantity. If there were no wild grapes in the area, a taste for wine imported from other regions would motivate the transplantation of grape vines to secure a local supply of the beverage.

If burnt or carbonized, grape pips (seeds) can be preserved for many centuries. However, it is difficult to determine whether these ancient grape pips are from wild or cultivated grapes, due to variations in the pips themselves and the shape changes that occur when they are carbonized. Carbonized grape pips have been found in many areas of the Near East and Egypt, dating to 3000 BCE or earlier: Susa and Hajji Firuz Tepe in Iran; Hama, Mureybit, Abu Hureyra, Aswad, Jawa, Tell esh-Shuna, Ohalo, Jericho, “En Besor and Bab edh-Dhra” in the Syro-Palestinian area; and Buto, Minshat Abu Omar, Tell Ibrahim Awad and Abydos in Egypt (McGovern, 2003, p. 2, Map 2). Many of these areas (Egypt, most of the Syro-Palestinian region, and southern Iran) are now too arid to support the wild grape.

Neolithic Wine ca. 5400–5000 BCE: Hajji Firuz Tepe, Iran (http://www.museum.upenn.edu/new/exhibits/online_exhibits/wine/wineneolithic.html)

Viticulture was likely first established in the Neolithic period (from about 8000 to 4000 BCE), when for the first time in human prehistory there were numerous sedentary villages established in the Near East and Egypt supported by domesticated plants (such as grains) and animals (such as sheep and goats). Fired ceramic vessels first made their appearance ca. 6000 BCE, and it is within these vessels that we can find chemical evidence for the earliest wine.

Hajji Firuz Tepe is located southwest of Lake Urmia in northern Iran, in the Zagros Mountains at an elevation of over 1,200 m above sea level, along the eastern periphery of the wild grapevine's modern distribution. Jars with yellowish and reddish interior residues have been analyzed, and both residues are that of resinated wine. The resin was from the terebinth tree (*Pistacia atlantica*) that grows throughout the Middle East and would have been added as a preservative (McGovern et al., 1996).

Late Chalcolithic Wine ca. 3500–2900 BCE: Godin Tepe, Iran

The chemical analysis of residues in jars from Godin Tepe established that the technique could be used to determine the existence of wine in prehistoric contexts (Badler, 1995; Badler et al., 1990). Wine was found in a distinctive jar type (piriform, with rope decoration in an inverted U shape on opposite sides of the vessel) from two different contexts dating from 3500 to 3100 BCE and 3100 to 2900 BCE. The complete vessel from the later period has a bung hole a short distance from the base drilled after firing, presumably to decant the beverage.

The homeland of viticulture may be Transcaucasia (the region of modern Georgia, Armenia, and Azerbaijan located between the Black Sea and the Caspian Sea). An early sixth-millennium BCE Shulaveris-Gora jar was shown to have

contained resinated wine, making it the earliest known wine jar (McGovern, 2003, p. 75). At Godin Tepe there is an intriguing link between winemaking and the appearance of the first Transcaucasian type pottery. The earliest sherd with wine residue dates from 3500 to 3100 BCE, when there are significant numbers of Late Uruk type artifacts suggesting contact with sites in southern Iraq (such as Nippur and Warka/Uruk) and Iran (Susa). However, the earliest evidence for wine production (a funnel, heavy lid and empty wine jars, as well as a bin perhaps used for treading grapes) date from 3100 to 2900 BCE, when there is a marked increase in the number of Transcaucasian type sherds. In fact, the funnel itself is similar to the Transcaucasian sherds in its method of manufacture (handmade and fired in a reduction atmosphere), and the heavy lid is a Transcaucasian pottery type.

Late Uruk Wine ca. 3500–3100 BCE: Susa, Iran and Warka/Uruk and Tello/Girsu, Iraq

The residues of ancient resinated wine have been detected in Late Uruk type jars (a droop spouted jar, a piriform jar, and a stone vessel with vertical rope decoration) from Susa in southern Iran (McGovern et al., 1997), a droop spouted jar from Warka/Uruk (Badler, McGovern, & Glusker, 1996), and a droop spouted jar from Tello/Girsu in southern Iraq (McGovern et al., 1997). Since grapes will not grow in the hot dry climate of southern Iraq (there are no grape remains from this area), the wine was most likely an import from further north, and perhaps an important commodity in the Late Uruk trade network (Algaze, 1995).

The Early History of Wine in Syro-Palestine and Egypt

Whereas the Near East looked north to Transcaucasia for the introduction of wine and winemaking, archaeological and clay pottery jar composition evidence clearly suggests that the

origins of Egyptian wine and winemaking were to its east from the Levant: modern Israel, Palestine, and Jordan (McGovern, 2003, pp. 85–103). Hundreds of jars containing chemically attested wine and wine yeasts were found in tomb U-j of the first Scorpion king (Dynasty 0) dated by radiocarbon determination to ca. 3150 BCE. The closest stylistic parallels to these jars are from Early Bronze I sites in the Levant, later confirmed by additional scientific analyses. Although the wild grapevine does not grow there today, it flourished in the region in ancient times, beginning in the Epi-Paleolithic period nearly 20,000 years ago (McGovern, p. 212). By at least 3500 BCE, the domesticated grapevine (*Vitis vinifera vinifera*) had taken hold in the region. Very little archaeological or chemical evidence for winemaking has been found so far, although small spouted Iron Age vats could have been used to tread the grapes.

Although there was a royal winemaking industry in the Nile Delta region from as early as Dynasty 3 (ca. 2700 BCE), the wild grape never grew in ancient Egypt. It seems most likely that both the grape vines and the technology for making wine were imported from the Levant. The earliest “wine labels” in the world belong to Dynasties 1 and 2 of the Early Dynastic period (ca. 3100–2700 BCE), and show an already well developed viticulture tradition (McGovern, 2003, 85ff.).

Once local viticulture and winemaking were established in the Nile Delta, it became a source for royal wine. When there were disruptions, however, such as the Hyksos invasion (ca. 1670–1550 BCE), wine was again imported in large quantities from the Levant and, in particular, Southern Palestine. Exceptionally large quantities of wine were imported into the Hyksos capital of Tell el-Dab’a/Avaris located in the east Delta region of Egypt. The Egyptian winemaking industry rebounded (as evidenced by increasing quantities of native Egyptian wine jars) beginning in the earliest Middle Bronze IIA phases (ca. 1950 BCE) at Avaris. There is evidence that the Egyptian Delta supplied the New Kingdom towns and cities at that time. Avaris also has the only excavated winemaking installation in Egypt,

predating Hellenistic times (McGovern, 2003, p. 119). Detailed tomb paintings provide additional evidence for the Egyptian wine industry, from picking and crushing the grapes to filling the jars (the tomb of Nakht at Thebes [1550–1295 BCE]), the addition of additives and stoppering (the tomb of Khaemweset, son of Ramesses II [1279–1213 BCE], at Thebes), and a sequence of grape picking, crushing, pressing, and wine storage (tomb of Intef, Royal Herald under Thutmosis III [1479–1425 BCE], also at Thebes). Chemical analysis of the residues in the wine jars from the tomb of Tutankhamun (d.1327 BCE) established that this wine was made from red grapes (Guasch-Jané et al., 2004).

Wine in the Ancient Near East

There are chemically identified ancient resinated wine residues in a small jar from Warka/Uruk dating to the late Jemdet Nasr/early Early Dynastic period (beginning of the third millennium BCE; McGovern et al., 1997). In the early third millennium BCE, there are grape pips and even grapevine wood identified from the site of Tepe Malyan (ancient Anshan) in the Shiraz region of the southern Zagros mountains (McGovern, 2003, p. 165). Elamite seals depict drinking scenes (most likely of wine) under grape arbors (McGovern, pp. 165–166). Texts from the city of Ur mention a jar full of *geštin* (the Sumerian word for wine). At Tello/Girsu, *geštin* was stored in rooms, and *geštin* was imported from the eastern (presumably the southern Zagros) mountains. Texts mention grapevines growing within walled gardens in and around the region of the city of Tello/Girsu by the end of the third millennium BCE (McGovern, p. 150). The law code of the Babylonian king Hammurapi, dating to ca. 1790 BCE, mentions wine shops. There are detailed accounts of the wine trade (with cities further north) in the archives of the Syrian city of Mari, located along the Middle Euphrates, and dated to ca. 1750 BCE when the city was destroyed by King Hammurapi, and in the archives of the eighteenth century BCE site of Tell al-Rimah/Karana’a in upper Mesopotamia (McGovern, pp. 169–173).

In the first millennium BCE, the Assyrian rulers not only consumed large quantities of wine, but also undertook an ambitious program of planting new vineyards in their territories. The “Assyrian Domsday Book” recorded tens of thousands of vines planted in the upper Balikh River to the east of Carchemish, in the eastern part of their territory at Yaluna, probably north-east of Nineveh, and in the land of Zamua in the district of Sulaymanyah. The Assyrians produced wine described as sweet, good, aged, or strong, and in both red and white varieties. Additionally, some wines were spiked with other ingredients (McGovern, 2003, pp. 190–191). The Nimrud wine lists contain detailed accounts of the distribution of wine rations. In a wall relief of the palace at Nineveh, Assurbanipal and his wife are shown beneath a grapevine bower drinking what is probably wine, similar to the Elamite scene mentioned above. Chemical analysis of residues from a bronze drinking cup from Nineveh, a bronze goblet and pottery “beer jug” with built-in strainer spout, from Uruk (all from seventh to sixth century BCE tombs) tested positive for resinated wine (McGovern, p. 201).

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Woodcarving in Malay Architecture

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Meaning and Significance

Malay vernacular architecture is characterized by timber as the main building material, pitched roofs and woodcarving on some of the building components. As early as the fourteenth century, woodcarving was a significant craft in the vernacular architecture practiced by Malay craftsmen in Peninsular Malaysia and Southern Thailand (Ismail & Ahmad, 2001). Palaces, houses, mosques, gateways, tombs, and *wakafs* (pavilions) are adorned with more than 20 types of carved components (Ismail, 2002). The craft is

an abstract manifestation of craftsmen's ideas into architectural timber components, symbolizing artistic expression into three architectural components: structural, elemental, and decorative (Ismail). The craftsmen or woodcarvers depict five types of motifs, in order of importance: floral, geometric, calligraphy, fauna, and cosmic. These motifs are laid in six geometrical or floral shapes including oblong, square, circle, octagonal flora, semicircle and triangle. In definition, woodcarving is an art of partially removing wood from a board, a block or a plank following specific motifs, patterns, and orders. The art originated from two fronts: the kingdom of Langkasuka from the north, and the Srivijaya empire from the south of the peninsula (Nik Hassan & Nik Abdul Rahman, 1998; Nik Rashidin, 1999). In historical and geographical contexts, Malay timber architecture and carving in peninsular Malaysia stretches from the north in the province of Pattani in Southern Thailand to the south in the state of Johor.

Similar floral, geometric, fauna, and calligraphic motifs appear on nonarchitectural components such as boats, weapons, furniture, grave-markers (Fig. 1), house utensils, and musical instruments. The most elaborate carving on a boat is the *makara* carved in relief and perforated styles depicting mostly flora and sometimes figurine motifs. The hilts of kris (Fig. 2), *badek* (small dagger), and spears are some of the weapons that are intricately carved on timber such as *kemuning* (*Murraya paniculatum*), *leban* (*Vitex pubescens*), *sena* (*Pterocarpus indicus*), or *nibong* (*Oncosperma tigillarium*). The craftsmen also showed their ideas and skills on more than 15 types of furniture and house utensils.

In carving Malay craftsmen demonstrated high skills of art changing abstract ideas into physical beauty. This developed through a long apprenticeship whereby the skills and knowledge of woodcarving were passed on. By imitating a carved masterpiece, a woodcarver gradually modified the motifs and produced his own design onto the timber piece. For example, a motif of leaves and buds of *ketumbit* or *getamguri* (two shrubs) are gradually modified by the carvers to demonstrate their own stylish identity

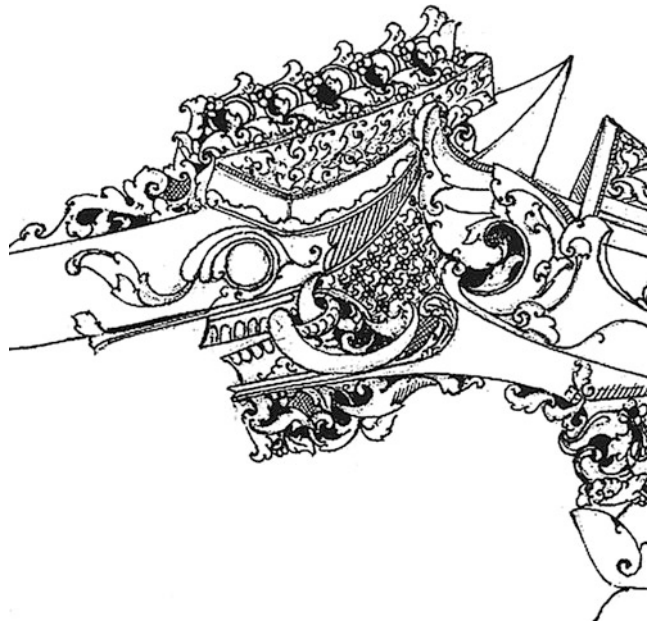


Woodcarving in Malay Architecture, Fig. 1 A grave marker (Nik Rashiddin, 2003)

called *air-tangan*, but they keep the fundamental motif form (Nik Rashiddin, 1999). This pattern becomes the trademark, both for the craver and for his architecture or craft. Differences in motifs, layouts and perforations occur from one region to another. For example, craftsmen in the northeastern states of Kelantan and Terengganu depicted different floral motifs from the central states of Negeri Sembilan and Melaka. The motifs of woodcarving signify the identity of the carvers in a region. In spite of the differences, Malay craftsmen observed three common aspects: (a) applying four principal design forms, (b) deducing motifs from home landscape elements, particularly flora and fauna, and (c) manifesting natural beauty as a devotional act to the Creator and as a gift to his fellow men (Mohd Taib, 1997).

The degree of complexity in carving varies from one component to another; intricate, or complex ones include door leaves and wall panels, and simple carvings include gable board and fascia board. From the carving characteristics including motifs and types of perforation and incision, one could differentiate the architecture of one state from another. For example, a large

Woodcarving in Malay Architecture, Fig. 2 A kris hilt (Nik Rashiddin, 2003)



gable board distinguishes a Terengganu house, whereas a large-latticed gable portrays a Perak house. As one gets closer to the carved components, the distinction is further distinguished by the composition of the motifs. The elevation of the Terengganu house is adorned with perforated wall and ventilation panels of varying sizes carved in floral motifs: leaves, tendrils, and flowers of local plants such as *ketumbit*, *getamguri*, *keraknasi*, *jari buaya*, and *bakawali* (Ismail, 2000; Ismail & Ahmad, 2001). The panels of Perak houses are carved in different floral motifs including sunflowers and *ketola*, sometimes mixed with cosmic motifs. These are regionally specific motifs found in Malay woodcarvings in Peninsular Malaysia. However, similarities occur in depicting geometrical motifs on veranda railings or tall window and fascia boards. Likewise, similar Arabic calligraphy motifs are depicted on door and window ventilation panels.

Architectural Components

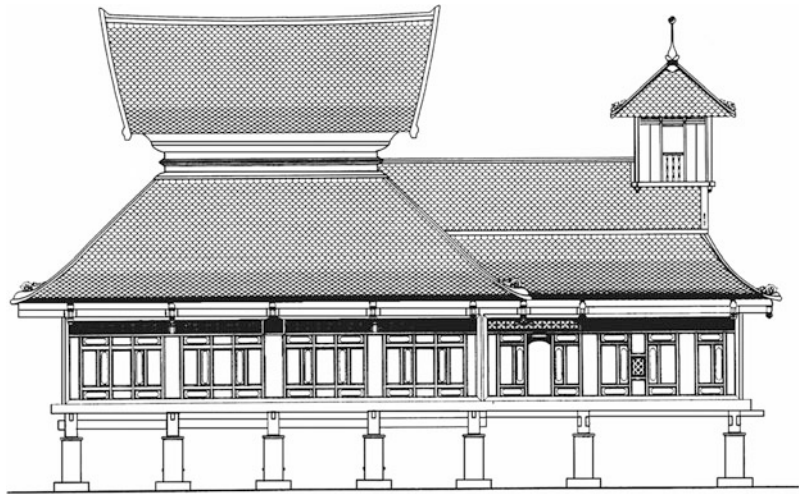
Carved building components can be categorized into three types: structural, elemental and ornamental. The structural components include *pemeleh* (bargeboard), *tunjuk langit* (king post), cross beams, stringers of stairs and braces. The *pemeleh* is the most prominent component in palaces, aristocratic houses and mosques in the state of Terengganu and in Kelantan. These differentiate the vernacular architecture of this region from other states in peninsular Malaysia. For example, a palace known as tele house, built by Sultan Zainal Abidin in 1868 in the city of Kuala Terengganu, Terengganu, has two pairs of *pemelehs*, one at the *rumah ibu* (main building) and the other at the *rumah tengah* (subsidiary building). Likewise, Langgar Mosque in the city of Kota Bharu, Kelantan, also has two pairs of elegant *pemelehs* with a simple motif of barking deer on its three-tiered roof (Marsiti, 1976). This exterior component handsomely extends the profile of the building toward the sky, making the mosque a landmark in the settlement.

The next important structural carved component in a house or a mosque is the *tunjuk langit* (kingpost). It supports the roof by holding the ridge beam and rafters. The Kampong Laut mosque in Kota Bharu has eight carved *tunjuk langits* (Zahar, 1989). This timber mosque is perhaps the oldest timber mosque, perhaps 170 years old, in Peninsular Malaysia (Ismail, 2001). The *tunjuk langit* distributes the roof load to the tie beams. The lower end usually is attached with a carved component called *buah buton*. This is an ornamental piece which covers the tenon and mortise joint of the *tunjuk langit* to the tie beam. In contrast, the Telok Manok mosque in Southern Thailand has three *tunjuk langits*, joining the three-tiered roof to the tie beam one above another (Ahmad, 1998) (see Fig. 3). They are beautifully carved with lotus blossom motifs and their ends are equipped with *buah butons* using similar motifs. The *tunjuk langits* and *buah butons* greatly enhance the beauty of the interior. Apart from the *tunjuk langit* as a structural member distributing the roof load to the tie beams, braces, or brackets are also structural components supporting the tie beam load to the post. In the Kampong Laut mosque, braces are elaborately carved in shallow relief with lotus blossoms as centerpieces framed by leaves of a different plant in an intricate arabesque.

There are at least five carved elemental components in Malay houses and mosques. These are essential components that make up the entrances and fenestrations. They are the ventilation panels of doors or windows, door or window leaves, walls, railings and gates. Ventilation panels characterize the architecture of a region. For example, the Tengku Long palace in Kuala Terengganu has 15 tall windows at its *rumah ibu*, the main house, with perforated ventilation panels (Fig. 4a, b). Each panel was designed with different floral motifs in symmetrical and asymmetrical layouts. They are part of the fenestration of the building, allowing air and light in. These perforated boards are placed on top of doors, windows, or walls allowing circulation of air and light into the building. More elaborate motifs, a combination

Woodcarving in Malay Architecture,

Fig. 3 Elevation of the Telok Manok mosque in Southern Thailand illustrating the carved components (KALAM, Universiti Teknologi Malaysia, 1998)



Woodcarving in Malay Architecture, Fig. 4 (a) A tall window at Tengku Long palace, an example of Terengganu. (b) A ventilation panel with arabesque floral motif on top of a window

of Quranic calligraphy bordered by floral motifs, are carved for interior door ventilation panels as can be seen in Fig. 5a.

Some ventilation panels are carved in simpler forms, as in the Telok Manok mosque (Fig. 6).

A floral motif of a weed called *ketumbit* is abundantly carved on the ventilation panels which are located around the building and are placed above the walls, windows and doors. The carvings transformed tender leaves of *ketumbit* into an

Woodcarving in Malay Architecture, Fig. 5

(a) A ventilation panel on top of an interior door of Tengku Long palace. (b) A panel with Quranic calligraphy and arabesque floral motifs



Woodcarving in Malay Architecture, Fig. 6 Floral motif on ventilation panels at the door and wall of Telok Manok mosque (KALAM, Universiti Teknologi Malaysia, 1997)

arabesque form both in relief and perforated styles. The perforations not only allow air to flow into the building but also permit light to illuminate the interior. This is often dark because the interior is covered by the pyramidal roof and also because of the dark hue of the timber walls and the underside of the roof. The late afternoon sun casts intricate shadows on the praying space when light passes through the carved panels. This phenomenon adds beauty to the interior setting of the mosque. At night, the scene would be reversed when light from lamps passes through the perforations casting a silhouette of the carved panels. The silhouettes of arabesque and geometric forms can be clearly seen from outside

especially in the absence of light from other surrounding buildings. Therefore the perforated panels add to the characterization of the mosque architecture.

Inside a timber mosque, the *mimbar* (pulpit) demands the most appreciation from the congregation. It is a piece of liturgical furniture from which the *iman* delivers his sermon (Zaki, 1978). The *mimbar* of Kampong Laut mosque is profusely decorated with perforated carvings of floral motifs. The most prominent panel is the front carved board attached to the canopy carved in *gunungan*, one of four principal forms. It resembles the form of the headdress worn by Malay women in the marriage ceremony. The side and



Woodcarving in Malay Architecture, Fig. 7 (a) A gate at Kota Lama Duyong for residents and neighbors. (b) A larger gate at Kota Lama Duyong for honored guests

Woodcarving in Malay Architecture,

Fig. 8 Image of soms at Masjid Telok Manok (KALAM, Universiti Teknologi Malaysia, 1997)



back walls of the *mimbar* are fully furnished with perforated carved panels as part of the structural component of the four posts.

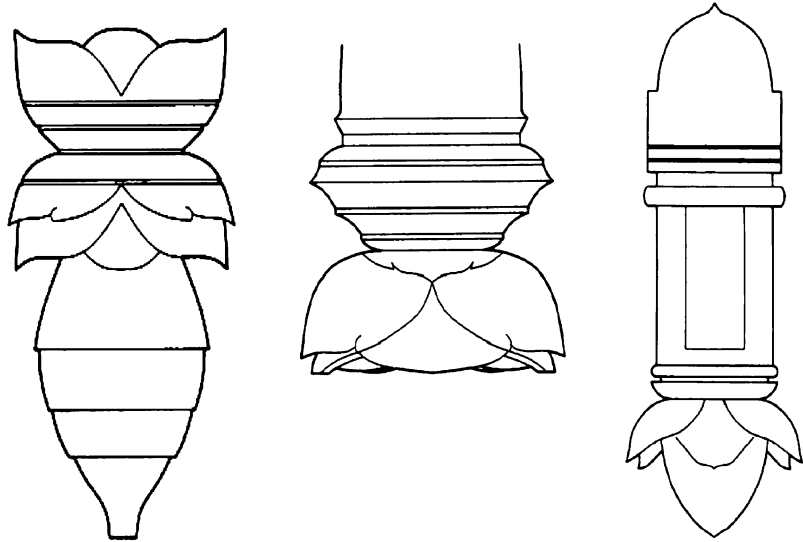
The gate is also an elemental component for vernacular Malay architecture; it demarcates the access to a palace or an aristocratic house. It is installed as part of the wall or fence in single or double-leaf doors. The leaf is generally carved in simple floral motifs with straight railings, as in the gate of Kota Lama Duyong, an aristocratic house built in 1920 in Kuala Terengganu (Mohd Hanif, 1997). This house has five types of gate incorporated with a concrete wall surrounding the building. Big and double-leaf gates are meant for honored guests located at the front yard of the building compound (Fig. 7a). Smaller single or double-leaf gates are located near to the kitchen

and deck leading to the rear of the house and are used by the residents and neighbors (Fig. 7b).

The third type of carved components found in Malay vernacular houses and mosques are ornaments. *Som* and *buah* buton are ornaments that are carved and attached to the structural members of the building. *Som* is the decorative component located at the ridge end of the pyramidal roof (Fig. 8). Each roof tier has four *soms*. Langgar mosque has the largest and most elaborate *soms* on its first and second roof tiers. A pair of *pemelehs* accentuates the third tier roof. From a considerable distance the *soms* and *pemeleh* accentuate the profile of the mosque, giving it a distinctive vernacular style. Telok Manok mosque has the most *soms*; each ridge end and minaret roof is decorated with floral motif *soms*.

Woodcarving in Malay Architecture,

Fig. 9 Lotus blossom motif on *buah buton* at Masjid Telok Manok (KALAM, Universiti Teknologi Malaysia, 1998)



Another ornament that gives character to the timber mosque is the *buah buton* – a decorative component attached to end of *tunjuk langit* jointing the tie beam or rafter to the tie beam. The attachment hides the tenon and mortise joint and is not a structural part of the building. Telok Manok Mosque has the most *buah buton* – 18 at the tie beams and three at the end of the *tunjuk langits*. All the carvings are in lotus blossom motif, but each differs in form, resembling the natural form of the flower that shrinks in the morning and gradually opens during the day (Fig. 9). The differences in form resulted from the interpretations of several craftsmen.

Types of Motif

Malay craftsmen applied five types of motif: floral, geometric, calligraphic, faunal, and cosmic onto the carved components. Flowers dominated Malay woodcarving; the carvers used the fruit, stems, tendrils, leaves, and of course the flower. Fruit of pomegranates, lotus flowers, sunflowers, *ketumbit*, *ketola* and *bakawali*, leaves of *getamguri*, and stems and tendrils of *ipomea* are depicted in a variety of abstract forms. The pomegranate is chosen as a motif because of its interesting shapes and bright orange flowers. The lotus is selected because of its auspicious

status and sacredness. Furthermore, weeds such as *ketumbit* with bright yellow flowers and *getamguri* with wavy foliage are recognized by Malay craftsmen in Terengganu and Kelantan; they translated their beauty into the tangible art (Fig. 10). Craftsmen in Perak and Negeri Sembilan favored bright yellow flowers and the intertwining character of *ketola* and large, bright sunflowers on their door leaves and ventilation panels. Malay craftsmen observed the beauty of their surroundings and transferred their intangible value into a physical product that could be appreciated by others.

Fauna are rare in Malay woodcarving because Islam prohibits depicting figurine motifs. However, a few craftsmen still carved fauna motifs such as: (a) a pair of fighting cockerels on a window ventilation panel of a Negeri Sembilan house, (b) a group of ducks waddling in a row on a stringer of a Malacca house, and (c) a lizard head on a corner of a fascia board of a Perak house (Abdul Halim, 1986). These motifs are generally carved in abstract forms, hiding the real figure of the fauna.

Calligraphy is also applied as a motif at wall and ventilation panels on Kelantan, Terengganu and Negeri Sembilan houses. It is either carved in relief, perforated or a combination of both. The Malay craftsmen put Quranic verses into wood panels written in several Arabic styles.

Woodcarving in Malay Architecture, Fig. 10

A ventilation panel of Kota Lama Duyong in Kuala Terengganu carved in floral motifs, getamguri and sulur kacang (KALAM, Universiti Teknologi Malaysia, 1997)



Woodcarving in Malay Architecture, Fig. 11

A wall panel carved in traditional calligraphy motif at a house in Kampung Pulau Panjang, Kelantan



An excellent example is a wall panel at a house in Kampung Pulau Panjang, Kelantan where a Quranic verse is carved in perforated form and laid symmetrically on an axis (Fig. 11).

This carving demonstrated the craftsman's devotion to Islam and adoration of the *Quran*. The legacy of calligraphy in Malay letter writing has contributed woodcarving, which has selected it as one of its motifs (Syed Ahmad, 1992).

In addition to arabesque motifs, Malay craftsmen also apply geometric motifs on door leaves, ventilation panels, wall panels, railings, and partitions. The configuration can be a series of diagonals repeatedly copied throughout the component. Swastikas and stars are more complex motifs that dominate the carving configurations, for example, on a ventilation panel of a wall. Repetition of similar motifs creates a sense of beauty and contrast against adjacent foliate or calligraphic motifs. The motif of the swastika, which originated from Chinese woodcarving, can be seen in ventilation panels of Kota Lama Duyong (Mohd Hanif, 1997). Geometrical motifs are easier to carve than the other four types and thus repetitive components such as railings are done by apprentices or sometimes wives of the master craftsmen (Nik Rashiddin, 1999).

The motif of the cosmos is seen the least in Malay woodcarving. The depiction of this motif in Malay carving illustrates the influence of Chinese craftsmanship and the pluralism of

cultural values in vernacular architecture. A ventilation panel at Mohd Ali Kulup Mat Yassin's house in Perak is an example where leaf and flower are combined with a cloud.

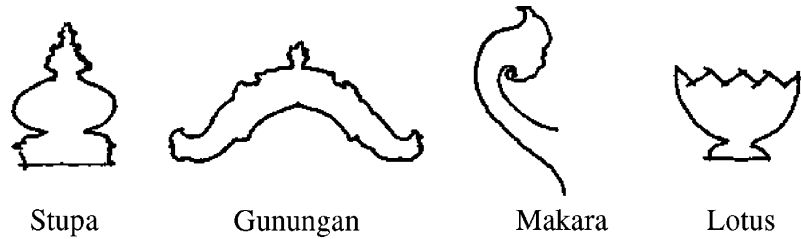
Principal Forms and Shapes of Carved Components

In terms of iconography, Malay woodcarving depicts four principal forms including *stupa*, *makara*, lotus and *gunungan* (Fig. 12).

The *stupa* form can be found in house components such as buah buton or on the newel posts of stairs or gates. These are decorative components that enliven the interior of the building. Buah buton is attached to the end of the kingpost hiding the tenon and mortise joint to a tie beam of the roof structure. It is the only volumetric component that becomes the jewel of carving, beautifying the interior of the house. The *gunungan* is a silhouette of a mountain or tree of life, a symbol of status. The gateway of a house compound is carved in *gunungan*, but other components including the ventilation panel of the door or window and door leaf also used this form. The *makara* reflects the center of the cosmological imagination for a mythological sea monster in Pattani and Kelantan. Gable-end boards on Terengganu or Kelantan houses depicted the form of *makara* that enhanced the façade of the

Woodcarving in Malay Architecture,

Fig. 12 Principal forms of Malay woodcarving



Woodcarving in Malay Architecture, Fig. 13 Shapes of carved components in the Malay houses

building. This component differentiates the form of the house in Terengganu and Kelantan over houses in Perak and Negeri Sembilan. The lotus is a symbol of purity, and its form is applied to a variety of house components, including door leaves, fascia boards, ventilation panels and buah buttons. Apart from house components, the form is carved at the foot of tombstones and bases of kris hilts (see Farish & Khoo, 2003).

The carved components are designed in six geometrical or floral shapes including oblongs, squares, circles, octagonal flora, semicircles, and triangles (Fig. 13).

Squares and oblongs are common layouts for many components, particularly door leaves and ventilation and wall panels. They are easier to carve than flowers or circles since their outlines are straight. Ventilation panels on doors, windows, and walls of Terengganu and Kelantan houses are dominated by these perforated components in floral motifs. The layout and size of the components are proportionate with the elevation of the building and volume of its interior space. The house builder and craftsmen carved sufficient amounts of fenestration to allow cross ventilation to give thermal comfort to residents without depending on mechanical means (Ismail & Ahmad, 2001).

Occasionally, a floral octagonal or circle layout is carved for special components such as the base of a ceiling lamp. Such carving can be found in aristocratic houses such as Kota Lama Duyong. The intricacy of the shape and carving

denotes the skillfulness of the Malay craftsman and wealth of the house owner.

Apart from the shapes, the carvings are generally symmetrical on at least one axis. The axis orientates the carving pattern, repeating the pattern from left to right or from the top to the bottom of a component. Figure 14 illustrates a perforated carving of a wall panel of Wan Embong house in Kuala Terengganu. Most ventilation panels, wall panels, door and window leaves, and flat railings are done in symmetrical formats with floral motifs.

Factors Influencing Timber Selection

Generally, Malay craftsmen would apply three factors in selecting appropriate timber for their carvings. The factors include availability of timber, its physical characteristics and durability, and the craftsmen's spiritual beliefs toward the timber species. The hierarchy of selection depends on the type of carved components. For example, the making of house components such as door leaves or ventilation panels is clearly determined by the availability of timber which could easily be obtained in large volume. On the other hand, the Malay craftsmen chose only kemuning or kenaung for making kris hilts and sheaths because of their fine interlocked grains and deep yellow sapwoods overlapping with dark brown heartwood. In addition, these timbers are regarded as possessing good spirit that must be



Woodcarving in Malay Architecture, Fig. 14 A perforated, arabesque wall panel carved in a symmetrical layout with a vertical axis

respected and that will accompany the weapon (Faris & Khoo, 2003; Ismail & Ahmad, 2001).

Availability of Timber

Tropical rain forests of Peninsular Malaysia produce a variety of quality, durable timber grown in the low-lying undulating land and hills of the Main Range (Appanah, 1993). Heavy hardwood species such as *chengal* (*Balanocarpus heimii*), *balau* (*Shorea spp.*), and *merbau* (*Intsia palembanica*) are the favorites. They are durable species that resist attacks from termites, powder-post beetles and fungi, which would harm their structural properties including flexibility, stiffness, and hardness. These are suitable for making large building components such as door leaves, bargeboards, kingposts, wall, and ventilation panels as well as small ones including railings and buah butons. The same timber species are used to make structural building components

such as posts, beams, and floorboards as well as the carved components. It is common to find an entire house made from *chengal*, *balau*, or *merbau* in the states of Terengganu, Kelantan, Perak, and Pahang in the peninsula. For example, a house at Kampong Bolok in Pahang built in the 1920s, was constructed wholly from *merbau*.

The timbers are air-dried under a shed or under the houses, allowing prevailing winds and the sun to dry them while protecting them from the rain. No preservative treatment is applied to the timber since the resins of most dipterocarps are able to resist the powder-post beetles, termites, and fungi attack (Farmers, 1987). The drying (seasoning) process may take months or even years for some timber species particularly *kemuning*, *kenaung*, and *sena*.

Medium hardwoods from the forests such as *medang* (*Litsea grandis*), *kundang hutan* (*Bouea macrophylla*), and *keladan* (*Dryobalanops oblongifolia*) are sometimes used for carving door leaves, furniture such as beds and cabinets, and musical instruments such as the *kenong* and *kompang*. These timbers are more prone to attacks from powder-post beetles and fungi and thus they are placed where they will not come into contact with moisture.

Craftsmen would optimize timber choice by harvesting readily available fruit trees grown in house compounds and orchards. They would cut large branches or sometimes the trunk of mature trees including *ciku* (*Achras zapota*), jackfruit (*Artocarpus heterophyllus*), *rambai* (*Baccaurea bracteata*), *belimbing* (*Averhorra belimbii*), *bacang* (*Mangifera foetida*), and *kundang* (*Bouea macrophylla*). Since these timber pieces are relatively small, the craftsmen would carve them into household tools and utensils and musical instruments in floral and geometrical relief motifs. The tools and utensils include coconut graters, ladles, food containers, biscuit moulds, and *rehal* (a cradle in which to place the *Quran* during readings). The practice of consuming timber from cultivated trees suggests that the Malay craftsmen were attentive to their environment.

Timbers for carving were also extracted from the secondary and coastal forests where mixtures of heavy, medium, and light hardwood species

grow. *Leban* (*Vitex spp.*), a heavy hardwood, and *sena* (*Pterocarpus indicus*), a light hardwood, are the common species obtained from the secondary forest for making sheaths of badek or kris and for carving some utensils. The craftsmen living in coastal villages would harvest timber from *penaga laut* (*Calophyllum inophyllum*) and *kelat jambu laut* (*Syzygium grande*) from the beach forest. They were carved for boat paddles and grave markers. Malay craftsmen optimized the timber found within or adjacent to their environments.

Physical Characteristics and Durability

In woodcarving, the physical characteristics that govern the suitability of timber are durability, color, grain and texture, and luster. Before working on the timber, the craftsmen select a timber piece that is free from all defects, namely, knots, pith flecks, resin streaks, brittlehearts, checks and splits, decay, bowing and cupping (Nik Rashiddin, 1999). Durability of hardwood is directly related to density; high density generally suggests strong resistance against fungi decay and boring insect attacks. Therefore, chengal, balau, resak, and merbau are the preferable species for most house components including structural, elemental, and decorative types (Watson, 1928). Buildings made from these species are known to last for more than 150 years. Their resistance is possibly due to the silica deposits in their storage tissue (Desch, 1981).

In some heavy hardwoods there is no color distinction between sapwood and heartwood, but usually the heartwood is more deeply colored (Desch, 1981). On exposure to the air, chengal and balau are light brown to dark red-brown and become darker as they age. On the contrary, the merbau's sapwood is pale yellow sharply defined from the dark red-brown heartwood. Generally, the final finish of the carved timber components made from these heavy hardwoods is finished with sandpaper. In carving house components, the craftsmen is less critical about the timber color but very selective when carving weapon hilts and sheaths, furniture and musical instruments. Only kemuning and kenaung, with bright yellow sapwoods and dark brown heartwoods,

are chosen for the hilts of kris, badek and *kerambit* (a small knife). These weapons are considered auspicious tools and used only for ceremonial events or special occasions.

Grain and texture are two distinct characteristics of timber. The grain refers to the direction of the fibers, and texture applies to the relative size and the amount of variation in the size of the cells (Desch, 1981; Smith, 1999). The chengal timber is easy to cut and incise because it has straight fibers and it does not give rise to ornamental figuring. It has a fine and even texture and is thus suitable for almost all carvings, from large features such as a boat's figurehead, to a building's wall panels, to small objects such as rehal. The merbau has a more interesting appearance than the chengal or balau since it has interlocked and sometimes wavy grain and a coarse texture with large vessels and coarse rays (Farmers, 1987). But it is more difficult to incise since it is denser and has a higher hardness, thus it is used for large building components such as posts and seldom used for small crafts such as house utensils.

Lustrous woods such as merbau, kemuning, tempinis (*Sloetia sideroxylon*), and kenaung have cell walls that reflect light, particularly on quarter-sawn surfaces (Desch, 1981). The luster is a natural asset that craftsmen exhibit in carved furniture and small crafts such as kris hilts, knife sheaths, walking sticks, and picture frames. The luster, however, does not last long without a finishing coat over the timber surface. Craftsmen apply several layers of shellac or varnish to a kris hilt to retain the lustrous surface of the kemuning.

Spirit of Wood

In addition to the tangible characteristics of the timber, Malay craftsmen also select timber based on its possessing either a beneficial or malignant value (Farish & Khoo, 2003). Kemuning and kenaung are regarded as the most auspicious species because the craftsmen believe that they possess strong spirits that will accompany a weapon such as a kris, badek, kerambit, or spear. A few craftsmen in Kelantan believe that this spirit is compatible with the iron blade. These timbers are reserved for creating hilts and sheaths of

weapons. As work begins, a craftsman cannot be definite on what style of kris hilt that a piece of kemuning or kenaung will finally become. Gradually, during the incision process, the timber reveals its grain, texture, and luster and only then will the craftsmen know the hilt style the timber will become. The motifs on this hilt would be similar to large architectural components such as leaves of getamguri and jaribuaya, flowers of ketumbit and keraknasi; these are shrubs or weeds commonly found in Malay house gardens (Ismail & Ahmad, 2001; Syed Ahmad, 1992).

Woodcarving is a significant craft in Malay vernacular architectural and nonarchitectural elements. It is a manifestation of craftsmen's imagination using floral, geometrical, calligraphic, faunal, and cosmic. It signifies the identity of a regional architecture as well as a pattern of the craftsmen from a region. In intangible perspective, it illustrates the belief of the Malay craftsmen toward architecture, devotion to god and their contribution to society. To understand the significance of the craft, one needs to investigate its physical forms in term of motifs, principal forms and layouts. In addition, it is important to know the characteristics of the timber species from which the carvings are made.

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Woodworking in Egypt

Geoffrey P. Killen

More is known about woodworking in Egypt than anywhere else in the ancient world. By the New

Woodworking in Egypt,

Plate 1 Bed frame, first dynasty, Metropolitan Museum of Art, MMA 12.187.52



Kingdom, Egyptian woodworking had reached its zenith with examples of woodworking such as furniture being highly prized and often sent as tribute to the rulers of neighbouring countries.

Many Pre-dynastic burials in the Nile valley have the body placed on wooden poles and covered with matting made of plant fibre, while some burials are found in primitive wooden boxes. By the unification of Upper and Lower Egypt we find bed frames, Plate 1, in common use with many examples being found in first dynasty (3100–2890 BCE) tombs. The quality of these bed frames ranged from conveniently shaped branches that were lashed together to sophisticated examples made from rounded poles that were jointed together and supported on finely carved bovine shaped legs (Petrie, 1913, Pl. VIII–IX).

At the beginning of the Old Kingdom, which opens with the third Dynasty (2686–2613 BCE), we see major advances in building and the associated trade of carpentry. The quality of royal furniture made during this period can be seen in those examples discovered by the American Egyptologist George Reisner, in the fourth Dynasty tomb of Queen Hetepheres (ca. 2600 BCE) at Giza (Reisner, 1955). When he opened the tomb, he found that the wooden elements from which the furniture had been made had rotted away to powder. However, it proved possible to reconstruct much of the Queen's furniture by studying the positions of the gold sheaths, which had encased the furniture, and the inlays that had fallen free and lay on the tomb's floor. Hetepheres' furniture consisted of two armchairs, bed frame, bed canopy, carrying chair and two boxes. What Reisner and his team achieved, from a pile of unrelated fragments of gold and faience

is remarkable for it has given us a small but superb collection of early furniture, which rivals Tutankhamun's, manufactured over a thousand years later.

We see the introduction of the wooden box at the end of the Old Kingdom. They were manufactured with flat, gable, barrel and shrine shaped lids. Some were very large and were designed with a pair of poles that enabled the box to be carried by a team of porters. In one tomb scene 14 men are carrying a box. During the Middle Kingdom we find boxes were customised to hold cosmetics. Many were designed like crates to hold small alabaster jars, which held perfumed oils. Other boxes have been found to contain mirrors, kohl containers, combs and even a pair of slippers! A box made for Sithathoriunet (ca. 1800 BCE) (Winlock, 1934) was decorated with gold fittings and bezels in which were set with polished carnelian stones. Other elaborate boxes held cosmetics or; these were usually inlaid or veneered with sheets of ivory or exotic timbers bought from lands south of Egypt (Plate 2). Scribes even had boxes in which they stored their writing implements and palettes. Their boxes were usually painted to imitate the stringing and veneered panels found on more ornate boxes.

Important directional changes in Middle Kingdom furniture can be seen by studying the large collection of stelae, which are preserved in the Egyptian Museum, Cairo. These Middle Kingdom stelae show that tables were widely used for the display of vases or holding water pots. Many are low with straight legs and have a single stretcher strung below the tabletop. We also see that Egyptian carpenters were constructing splay-legged tables, which had

Woodworking in Egypt,

Plate 2 Cosmetic box,
eighteenth dynasty,
Metropolitan Museum of
Art, MMA 26.7.1438

**Woodworking in Egypt,**

Plate 3 Table with
cavetto cornice edge,
eighteenth dynasty,
Metropolitan Museum of
Art, MMA 14.10.5



cavetto cornice mouldings below the edge of the tabletop (Plate 3). Slender vase stands were made from thin strips of timber braced with cross and angled struts. They were fitted with a shaped collar, which held the round base of a single vase. They were covered with a gesso foundation before being painted to imitate carnelian and faience inlay. Those chairs made during the Middle Kingdom had either short backs over which was draped a cover or cushion or they had backs of full height. Such chair backs were curved and made from angled slats of timber. They stood on slender gazelle-shaped legs. Often chairs were painted to simulate animal skin, which were painted with a technique, which resembles cow skin and was used on an arrow quiver case, which is preserved in the Egyptian Museum, Cairo.

By the New Kingdom, the homes of officials and nobles would have been furnished with a wide range of wooden furniture, the most common of which would have been the stools. Egyptians used a large number of different types of stool. The most commonly used were lattice stools that were made from thin struts of timber with angled braces supporting a double cove seat (Plate 4). Round-legged stools appear in some of the more important Theban tombs. The majority of legs from these stools were hand rounded although there is a small corpus of material, which have legs that appear to be turned. During the New Kingdom we see carpenters sitting on three legged stools, which allowed the stool to rest evenly on the workshop floor. The folding stool originated in the Middle Kingdom and was

Woodworking in Egypt,

Plate 4 Lattice Stool,
eighteenth Dynasty, British
Museum, BM EA 2476



made from two interlocking frames with a leather seat. New Kingdom examples are more elaborate having the floor rails and crossing spindles finished with carved goose head terminals, which are inlaid with ivory to imitate the eyes and neck feathers. We also see that lion legged stools and chairs were used in the homes of high-ranking officials.

The wooden furniture manufactured in the royal workshops was not very different in design to that used by the middle classes. However, they were exquisitely embellished with gold sheet, inlaid with coloured stones and faience or veneered with ebony and ivory. They were also adorned with the uraeus [the sacred serpent found on the headdresses of Egyptian rulers and divinities, representing sovereignty] and the symbols of kingship. Other pieces are inlaid with thousands of slivers of coloured wood in either marquetry or parquetry patterns. In the tomb of Yuya and Tuyu (ca. 1400 BCE), the parents of Queen Tiye and the wife of Amenhotep III (1390–1352 BCE), a small armchair made for Princess Sitamun was discovered. The illustrious examples of furniture discovered in the Tomb of Tutankhamun (1336–1327 BCE) show the

outstanding quality of design and construction achieved by eighteenth dynasty carpenters.

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Wool in India

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The submontane, the peninsular, and the arid zones of South Asia are home to indigenous breeds of sheep. In the past, this resource sustained two large handicrafts, manufacture of coarse blankets and knotted carpets. These industries survived into the twenty-first century. With the development of knitting technology, apparel and hosiery manufacture expanded in the region. All of these users of local wool, however, had to deal with problems of quality and supply of the material. This entry surveys the modern history of wool production and usage in the region and shows how changing land use and commercialization shaped these livelihoods. This entry focuses on the twentieth century, because systematic descriptions for earlier periods remain scarce.

Wool Production

South Asia has 5–6 % of the world's sheep population and a somewhat smaller percentage of the world production of clean wool. In the first half of the twentieth century, the region contained the fourth largest sheep stock in the world. Historically, the plains of South Asia had only one major apparel use of wool, warm blankets for winter. A comparably large use occurred also in woolen carpets, which was, and still is, an important export article. Relative to the major wool-yielding breeds of the world, the average Indian sheep yielded a small quantity of apparel-grade wool, but it was a sturdy animal and well adapted to coarse feeding, poor nutrition, extreme aridity, and long migration. Whether due to indiscriminate breeding, or environmental reasons, sheep were raised for meat and manure as much as for their wool.

Very few breeds in India produce apparel wool or fine wool suitable for garments. The

exceptions are Kashmir Merino, which is a crossbreed developed more recently, and Nilgiri. Those that do produce fine wool include products of selective breeding. By and large, the north Indian breeds produce coarser and stronger wool suitable for carpets. Carpet wool has longer staple and is coarser than apparel wool. Wool used in floor coverings needs to be long and strong to withstand rougher usage and greater abrasion than is the case with garments. On the other hand, apparels require softer, that is, fine and short-staple, wool.

Observers of the textile crafts at the turn of the century believed that within the unchangeable climatic constraint, much could still be done to improve the quality of the wool, mainly by selective breeding. Selective breeding was not known to have been widely practiced before British colonial rule began in India (c. 1765). A few farms did start under the encouragement of the state, but did not survive. Only in one instance from the 1880s, Sir Mark Cubbon's experimental firm in the hills of Mysore was a modest success reported in breeding new varieties of sheep.

Many groups of people were reportedly engaged in sheep rearing around 1900. Most of them, however, did not do this as their main occupation. Apparently, sheep farming as such was not economical. Some of these groups, for example, combined it with weaving coarse blankets for local markets and others with trade in wool. Almost all of them were mobile and travelled long distances between seasons in search of good pasture, in keeping with the tropical monsoon climate with its long dry season.

A prominent example was the Bhotias of Kumaon. In the early twentieth century, they were mainly a trading community with partial involvement in sheep rearing and weaving (Hoon, 1996). Groups of them started out on their long treks which combined grazing, spinning, and trade, in mid-Spring, with merchandise financed by a group of bankers called Kharagwals. They traversed two routes connecting the railheads of the plains with the trans-Himalayan passes. The eastern route started from Tanakpur and climbed up along Champawat, Lohaghat, Pithoragarh, and Askot.

The central route began from Ramnagar, went to Haldwani, and ascended via Ranikhet, Almora, Bageshwar, and Johar. Towards the upper reaches, the passes could be so narrow that no animal larger than sheep could negotiate them, so sheep were the natural choice as pack animals. Like the plains shepherds, they spun while the flocks travelled along with them and wove part of the wool, but unlike them, the Bhotias specialized mainly in wool trade. They travelled up to Gartok, Taklakot, and Gyanema markets in Tibet; bought wool along with salt, borax, musk furs, yak's tail, and live animals; and sold in exchange of grain, Spring crops, metal utensils, tobacco, and silver. At the onset of winter began the descent, stopping over at the major fairs of the foothills at Jouljibi, Bageshwar, and Thal where many of the transactions were completed.

From the end of the nineteenth century, formal or informal closures of the commons and wastes reduced the supply of homegrown wool and tended to sever the link between animal husbandry and the production of apparel and blankets. Long-distance trade in both wool and wool products expanded. Sheep rearing relocated towards areas that could support easier grazing conditions. The railways played a role in deciding which regions would specialize in which activity. Thus, the vast arid frontier in Rajputana specialized in wool production; Punjab, with easy access to Himalayan trading routes, carpet production; and the Rajputana grazing lands, emerging as a major market. United Provinces located in the middle Gangetic plains became the major center of the use of wool (Roy, 2003).

The declining access to common resources like pasture was connected with the "peasantization" of those communities who earlier depended on the commons. Chief among these were the sheep herders. Codification of property rights led to many customary rights on open wastes being overlooked. Large canal irrigation systems broke up grazing grounds and converted some of them into cultivable land. Population growth also led to encroachment on forests and grazing grounds. Furthermore, the British redefined their political relationship with pastoralist communities and often imposed new

taxes on them. In most parts of eastern and southern India, adverse economic conditions degenerated the existing sheep stock. Elsewhere, shepherds tended to move into the cities, into farming, permanently migrate in search of pastures, and resettle in zones where no more than tiny flocks could be maintained. They would leave their traditional mixed occupations and specialize in rearing, textile production, or trade. Sheep rearing tended to move towards two regions, western India and southern India. The regions losing sheep were the Gangetic plains. The former regions had one strong common feature: both included extremely arid regions with a plentiful supply of common and grazing lands, although a great deal of it was of poor quality.

In the process, markets and trades expanded in wool, and wool production and wool usage tended to separate. Large flocks disappeared in the Gangetic plains; there was also a fall in the number of shepherds. Yet, the Gangetic plains remained a main source of wool. It got its wool from western India (Rajputana) and from across the northern frontier. In south India, the main rearing region came to be Mysore; its clients were both a local woolen apparel industry and a carpet industry located in Arcot on the south-eastern coast.

Around 1930, the production of wool was estimated at 100 million lbs, import by sea 6 million lbs, and export 45 million lbs. Import by the land frontier was said to be, somewhat unreliably, 20 million lbs. Even with a large reexport, this should put domestic usage of wool at about 70–80 million lbs; the scale of foreign trade was growing steadily in the interwar period. Barring the First World War, the growing import trade consisted of both raw wool and woolen textiles. After the imposition of a tariff on wool manufactures in the 1930s, more raw wool was traded domestically.

The preeminent entrepôt was the Punjab. Here, trans-Himalayan, local, and Rajputana wool was imported, to be reexported towards Bombay, Karachi, and eastward via two or three important market towns. It was this overwhelming involvement in the raw material trade that

subsequently made these towns advantageous locations for power loom and hosiery industries. The most important market for wool in Punjab was Fazilka. But several other towns, notably, Amritsar, Ludhiana, and Multan, also contained important markets. Rajputana's trade was associated closely with Bikaner.

In the late nineteenth century, major Punjab markets such as Amritsar and Ludhiana grew as trading and manufacturing centers. The railways connected the wool markets of Rajputana with the carpet and apparel industries in Punjab. The railway connection along the Gangetic plains also fostered carpet industries in Agra and Mirzapur in the eastern end of the United Provinces.

Except for an end to the trans-Himalayan overland trade, which affected the enterprise of the Bhotias adversely, there was no significant change to these supply conditions in the decades after British colonial rule ended in 1947. Studies on wool production in the late twentieth century revealed further professionalization of the industry, partial success of cross-breeding programs, but also increasingly unstable production conditions mainly owing to variations in the quality of pasture. After 1990, there was a considerable increase in the domestic demand for wool from the carpet industry, which had experienced an export boom. Wool production, however, responded fitfully. In fact, the population of sheep expanded marginally in the arid areas, while declining elsewhere. The fundamental ecological constraints on the industry have progressively become more serious, because of population pressure on common grazing lands (Ray, 1999).

The Textile Industry

The five main uses of wool in India were blankets, carpets, shawls, felts, and garments. In the early twentieth century, the manufacture of woollen garments, so far confined to the cottage industry of handlooms, began in large-scale factories and knitted goods factories. The increasing production of good quality woollen garments was an effect of new middle-class choices as well as

a new raw material, imported worsteds. Felts were a disappearing industry during this period. Shawls were manufactured mainly in Kashmir and remained at a distance from other branches of the woollen textile industry.

Until 1900, a considerable quantity of cotton cloth, usually woven with handspun cotton, was used as winter wear. This use was steadily replaced by woollen garments. Better storage of wools and the growth of a middle-class urban market for garments contributed to this trend. This trend in the market touched wool weaving on handlooms marginally. In 1920, there were 100,000 handlooms engaged in wools in British India and the princely states. For a comparison, cotton and silk handlooms numbered approximately two million. By contrast with cotton or silk, handloom weaving in wool was a minor tradition. The weavers adopted a rough process that dispensed with much of finishing and dyeing. Interestingly, as in cotton or silk, artisanal weaving of wool withstood competition from factories quite well. In fact, the two traditions converged in the beginning when the factories wove wool with hand-powered looms.

The first large-scale enterprises were established in 1876 by the British India Corporation, a north Indian managing agency firm at Dhariwal in Punjab and at Kanpur. Kanpur was an emerging textile mill center, an important army base, and a center of army procurement activity. Both towns were conveniently close to trade routes in country wool. The mills in Bombay and Bangalore that followed in the next decade, likewise, had easy access to traded wool from southern Rajputana and Mysore. Initially, the main business of the mills was to supply mass produced but still handwoven blankets and garments for the army and to spin yarn for the carpet industry. In the 10 years after the First World War, dramatic changes took place. The war forced a rapid expansion in weaving capacity in the mills. Considerable excess demand still remained, met by the resources of the cottage handlooms. Many small shops manufacturing tweeds and rugs mushroomed in northern India in response. There was also diversification in product lines. The mills began to make finer

cloth using worsted yarn, for which the wool had to be imported.

The urban handlooms, especially in Muzaffarnagar and Bijnor in the middle Gangetic plains and Panipat and Ludhiana in Punjab, received great encouragement during the First World War, when the Munitions Board began to contract orders in these cities for blankets and smaller articles. Many cotton weavers in these cities shifted to wool, and the existing woolen manufactures expanded and diversified. The war orders were many times larger than the scale of the business before 1914 and were estimated to have used up practically the entire supply of blanket wool in India around 1917–1918.

At the same time, imported better-quality woolen garments altered tastes and introduced new standards. Consumers increasingly did not want the coarse rural blankets. They preferred the finer products made in new weaving establishments in the cities using traded wool. Competition from urban weaving and depletion of pastures adversely affected the practice of weaving by sheep herders themselves.

In this fashion, the more commercialized part of woolen textile industry came to concentrate in a few wool trading towns of northern India. These towns, principally Ludhiana, expanded in woolen knitwear manufacture after independence, thanks to the local manufacture of cheap machines and consolidation of the wool trade. The industry benefited greatly from trade reforms introduced in the 1990s. Easier access to technology, markets, and imported wool acted as a major boost. As small-scale production grew, the large factories stagnated. The British India Corporation had gone bankrupt in the 1970s and was taken over by the Government of India in 1981. It still possesses some of the best-known brands of wool in the Indian market, but the textile industry has developed stronger ties with the world wool market.

Conclusion

The modern history of wool production is a story of increasing concentration of commercial sheep herding from the peninsular and the plains

towards the arid western zone. The shift occurred because of two main factors, changing land use patterns in the plains and the peninsular and the growth of a railway network. The textile uses of wool concentrated too. The range of use narrowed to two main fields, carpets and winter wear, including woven and knitwear, and industrial agglomerations emerged in the wool trading towns of northern India. For four decades after 1947, the industry remained subdued if not moribund. More recently, however, trade liberalization imparted a powerful stimulating influence.

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Worked Glass Artefacts in Australia and the Pacific

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Volcanic glass, of which obsidian is the most well-known variety, was an important raw material for toolmaking among many different societies (Shackley, 2005). Volcanic glass was often traded across networks stretching over hundreds or even thousands of kilometers because of its great utility as a raw material for cutting and scraping tools. In Australia and the Pacific Islands, indigenous people developed sophisticated lithic technologies (as archaeologists call stone tools), and volcanic glass was an important component of these toolkits (Barrera & Kirch, 1973; Reepmeyer et al., 2011).

In the Old World, a different kind of glass produced by melting quartz minerals (usually sand) developed in the Mediterranean area, notably Egypt, from at least 1500 BCE (Lilyquist, 1993). When Europeans began exploring the Pacific from the end of the sixteenth century CE onward, they brought some of the earliest mass-produced glass objects with them in the form of trade beads and bottles that held alcoholic beverages, medicines, and perfumes, among other commodities. In addition to having an interest in European glass for its exotic origins and beauty, indigenous Pacific Islanders and Aboriginal Australians immediately recognized the value of glass, especially bottle glass, as a raw material for toolmaking. Adapting introduced raw materials like bottle glass to indigenous lithic technologies was not unique to the Pacific region. Worked glass tools have also been recognized throughout the Americas in various colonial contexts, primarily associated with Native Americans (Lindauer, 1997; Shackley, 2000; Silliman, 1997, pp. 160–161) but also on plantation sites in areas inhabited by African Americans (Wilkie, 1996).

Worked glass technologies are identified by archaeologists in the exploration of colonial sites (“worked glass” below will refer to European glass rather than volcanic glass). The identification of this type of artifact is somewhat difficult, because there are many natural processes (e.g., trampling by animals) that can mimic the kinds of conchoidal fracturing (the way that brittle materials break when they do not follow any natural planes of separation) associated with worked glass. Archaeologists have come up with various ways to deal with this problem, including looking for artifacts in areas where these kinds of natural processes are unlikely to occur, looking for high concentrations of flaked glass in activity areas, looking for worked stone and glass tools in the same assemblage, and looking for glass artifacts indicating fracturing or flaking on thicker parts of the bottle, especially around the base (Cooper & Bowdler, 1998; Gibbs & Harrison, 2008). This could be called a “contextual” approach, which uses related information from the context of the finds

to determine the likelihood that fracturing on glass artifacts relates to human activity in the past.

Ethnohistoric information, such as oral histories and the accounts of explorers, missionaries, and other early colonists, can also be useful for interpreting archaeological glass assemblages that appear to show evidence for toolmaking activities. These kinds of accounts might provide an independent line of evidence for the indigenous use of introduced glass as a raw material for tools. Some archaeologists suggest that for certain forms (notably side and edge scrapers), the only way to be completely certain that worked glass artifacts reflect past human activity is to use microscopy to identify use-wear on the artifacts (Conte & Romero, 2008). In practice, both kinds of approaches, microscopic and contextual, can be useful in the identification of worked glass.

For Australia and the Pacific Islands, worked glass technologies are useful artifacts for understanding indigenous technological change, innovation, and identity in an era of colonialism. The best-known worked glass artifact type from the region is probably the Kimberley point, named after a distinctive bifacially flaked lithic technology from the northwest part of Australia. Beginning in the 1800s, Kimberley points were commonly manufactured from bottle glass (Fig. 1) as well as other foreign materials such as porcelain insulators. Kimberley points were virtuoso performances, signaling the high degree of skill of the knapper (the person who shapes the stone). Shifts in material could have important social ramifications. For example, access to foreign materials meant that young men no longer had to rely on elder males who held the knowledge of the best stone sources. This resulted in shifts in some of the gendered power dynamics in Aboriginal societies. In interactions with foreigners, Kimberley points became valued commodities in the emerging tourist art trade, as artifacts of “authentic” Aboriginal masculinity that could be purchased and displayed by Westerners (Harrison, 2002, 2006).

Elsewhere in Australia, more humble scrapers and flakes played an equally important role in

Worked Glass Artefacts in Australia and the Pacific, Fig. 1

Australian Kimberley points made from bottle glass (Courtesy of the Australian Museum, inventory numbers E020554, above, and E078725, below, photograph by the author)



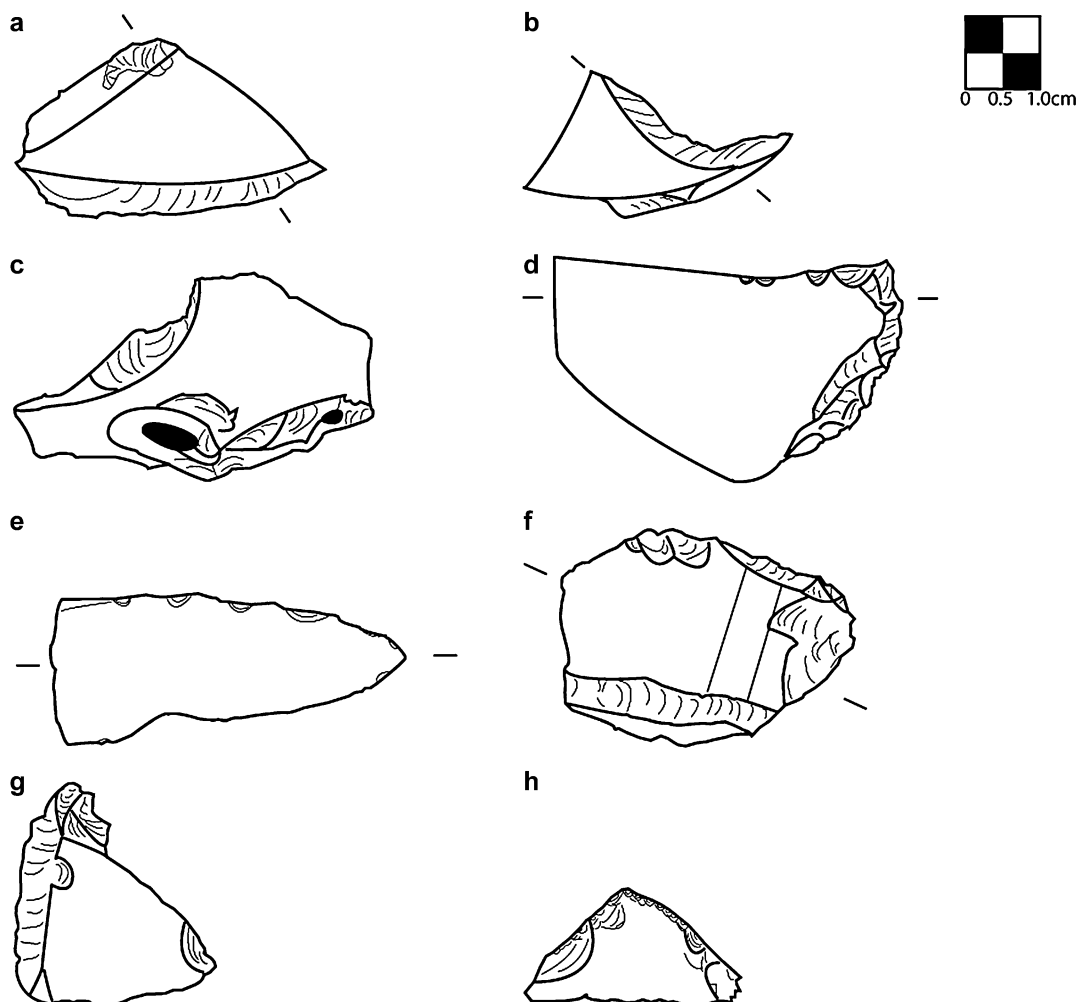
interactions between Europeans and Aboriginal people. At Port Essington, an early colonial fort in northern Australia, a significant proportion of the recovered glass artifacts (roughly 18 %) were identified as likely to have been worked by local Aboriginal people. The area around Port Essington is thought to have been poor in terms of natural stone sources, so bottle glass would have been a welcome raw material that could be scavenged from the European midden. Animal bones from the site include a number of native species, and it has been suggested that local people were hunting to provision the fort at Port Essington in exchange for trade goods, an interaction that may have been facilitated by the availability and use of glass for Aboriginal tools (Allen, 2008, pp. 79–88, 103).

Worked glass tools have been found in other Aboriginal contexts in Australia, including abandoned mining camps, pastoral sites where Aboriginal people worked as ranch hands, and Aboriginal households in Tasmania (Gibbs & Harrison, 2008; Harrison, 2004, pp. 128–137; Murray, 2010, p. 317). These assemblages show a common tendency to use the bottle base as a core from which pressure-flaked tools could be obtained. Aboriginal people sometimes scavenged the middens of long-abandoned sites for bottle glass, selectively carrying off bottle bases to particular activity areas where they could be processed into tools. Worked glass reveals the ways that Aboriginal people incorporated foreign materials into their daily lives,

appropriating mass-produced objects while maintaining their own technological skills and habits.

Elsewhere in the Pacific, studies of worked glass have been more limited. This is not because the artifacts are necessarily less common there. Rather, it reflects a lack of systematic study of this kind of material in the region. Future archaeological investigations of colonial sites in the Pacific should keep an eye out for worked glass, which is known from ethnohistoric and archaeological sources. One systematic study of worked glass tools that has been carried out in Polynesia analyzed an assemblage collected in the former leprosy settlement at Kalawao, Moloka'i, Hawaii. The worked glass tools date to between the 1860s and the 1920s. The tool form was quite variable (Fig. 2). Some artifacts were adaptations of traditional Hawaiian forms to the new raw materials, but other forms, such as those using bottle bases and necks to provide smooth handles, are interpreted to represent experimentation and innovation with this kind of technology. In part, this may relate to the situation of the people who were exiled to Kalawao because of their diagnosis of leprosy. Leprosy reduces feeling in the extremities, so when handling sharp objects, it would have been important to have a large, smooth surface to grasp (Flexner & Morgan, 2013).

Worked glass is an important artifact type for understanding colonial interactions in Australia and the South Pacific. This kind of technology



Worked Glass Artefacts in Australia and the Pacific, Fig. 2 A sample of glass artifacts from Kalawao, Moloka'i, Hawaii, interpreted as scrapers with evidence of retouch or use

could be an important form for technological persistence among indigenous people, using traditional local techniques in an introduced material medium, which was often tied up intimately with expressions of identity. At the same time, worked glass could also be a medium for innovation and cultural change. Archaeologists and anthropologists often discuss the importance of objects as facilitators of cross-cultural interactions. Worked glass is one type of object that can be informative in discussions about technology, identity, and indigeneity during a crucial period of regional history.

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Wound Healing in Ancient Egypt

Hedvig Györy

Representations of injuries are relatively infrequent in ancient Egypt. However, the accuracy in the depiction of accidents in the joiner's shop drawn on the wall of the tomb of Ipui in Deir el-Medineh, and the representations of the battle of Qades in Abu Simbel, Luxor and Ramesseum temple, reveal exceptional medical details and the consequences of specific injuries. The exact identification of injuries on the battle scenes is possible in two-thirds to three-fourths of the injured (only Hittite) soldiers. Most of them were inflicted on the chest and abdomen, or neck and head, respectively, these being the largest targets in bow-and-arrow warfare or in hand-to-hand fighting. For instance, a 'decelebrate rigidity' is shown in a Hittite soldier struck by an arrow on the top of his head, or a haematoma (accumulation of blood) is shown deep in the abdominal wall caused by an arrow entering another Hittite soldier's right lower-chest or abdomen below the rib cage. An examination of skeletons show that arrowheads severed most of the spinal cord, resulting in instant paralysis of the body below the neck (In the text, the following abbreviations are used for two medical papyri: Eb is Ebers papyrus and SM is Edwin Smith papyrus).

Types of Wounds

We can differentiate several types of wounds depending on their characteristic look, origin or severity. The same is true for ancient Egyptians. Moreover, medical papyri, especially the Edwin Smith papyrus, are very accurate and detailed in the description of various types of injuries and their treatments. They tell us that the healer was able to characterise the most important types of injuries, impressive even by today's standards.

They differentiated various types of swellings, wounds, fractures and joint injuries.

The general word for an injury, where the protective function of the skin was disturbed or hurt, i.e., a wound, is *wbn.w*. Without any explanation it means the commonest form of injury, the rupture of the soft tissue overlying the bone and leaving a constricted orifice. Beside this simple form, they spoke also about a *wbn.w n kft*, (a gaping wound) describing an open wound with a well-defined gash as, for instance, in Sm 28, where the most important clinical sign for an open oesophagus, drinking water regurgitating through the wound, is mentioned. The axillary could also be open (Sm 47). Another type of *wbn.w* could be *wbn.w sd (sg)*, (a wound smashing (sg) or contusion), or *wbn.w jsp (r3-r)*, [a wound cutting (through)]. Another description of wound, known only from the Smith papyrus, is *wbn.w jsdb (r)*, [a wound piercing (to)], which seems to be nearly synonymous with *wbn.w 'r (n)*, [a wound penetrating (to)]. According to the examples we have, the penetration reached a solid body part as bone, while the piercing came through into a void. For a simple perforation the common word was *thm*. Finally, in pEbers 877c we find the *wbn.w shm*, (a crushing wound), laceration and rupture, and in pEbers 494 *wbn.w n wbd.t* (burn wound), although for designating this last type it was enough to write *wbd.t* – (burn) alone, or to give the word for the actual phase of its development. Ancient Egyptians differentiated various types of fractures. Beside the *hsh* – simple, open fracture – there was the closed *sd* fracture, where the bone was broken in two inside the body, or the commuted compound or impacted *psn* fracture, where the bone was broken in several places. The above-mentioned *thm* and *shm* could also occur below the skin. As a diagnostic clinical sign of fracture, *nhbbh*, meaning, in all probability, ‘crepitation’ [the noise made by rubbing together the ends of a fractured bone], is mentioned.

Treatment

During the repair of any type of wound, the practitioner has to face three basic factors: pain,

bleeding and infection. The ancient Egyptians realised only two of them, since they regarded infection as part of the recovery process. The most common complaints, swelling and fever indicate that wounds were often infected.

Interestingly, they never mention anaesthesia for use in surgical interventions although pain-killing must have been an important part of the repair procedure. The possibility of anaesthesia was there because we know that they collected rush, which can be used as a narcotic, that they knew very well the effects of alcohol, that they cultivated mandrake and poppy from the New Kingdom on, and that the medical papyri reveal a knowledge of hyoscyamus [henbane, a genus of poisonous herbs] and scopolamine as well. Their use of analgesia was thus theoretically possible, either in the form of a type of food or concoction, and their use as hypnotic agents might also be hypothetically suggested. The only words, however, which might hint at anaesthesia accompanying the Old Kingdom circumcision scene where the use of local anaesthesia can be deduced from a promise to make it *ndm* – ‘sweet, agreeable’, when the region is rubbed with a piece of stone. Some consider that water was mixed with vinegar over Memphite limestone, resulting in the formation of carbon dioxide, which may have had an analgesic effect; the process would then resemble today’s cryo-analgesia.

Ancient practitioners were more deeply concerned with arresting haemorrhages, since the *mtw* (Eb. 871), tumours (Eb. 875) and wounds were susceptible to bleeding.

Medical Protocol

In preparation for medical treatment in ancient Egypt a medical protocol was first issued by describing the symptoms, making a diagnosis and giving the form of treatment. This process was usually followed by the medicine man, who was usually a physician or probably a priest of Sachmet.

Diagnosis could be divided into three categories: (1) “an ailment, which I will treat”; (2) “an

ailment which I will contend with”; (3) “an ailment not to be treated”. The main wound repairing methods were bandaging with an ointment or poultice, scorching (Eb. 876, Eb. 872) and surgery. In doubtful cases, enforced bedrest and normal diet were often recommended to the patient until he reached the decisive moment when the healer could give either a positive or negative prognosis. At the end of the treatment sometimes the verdict was also given as (a) “until he recovers”; (b) “until the period of his injury passes” by; (c) “until you know that he has reached decisive point”.

Relatively fewer examples are given for incurable ailments. Only 5 out of 48 cases in the Smith papyrus, and a few in the tumour section of the Ebers papyrus, as Eb. 874, may be leprosy, or Eb. 873, a possible cavernous haemangioma, or a twisted vascular swelling forming knot (in this case, however, the *mtw* should be straightened). The first two steps in Eb. 877 are still unidentified, although cancer, cutaneous leprosy, bubonic plague or neurofibromatosis has already been suggested. In the last step in Eb. 876, the ball-shaped extensions have tentatively been identified by Regöly-Mérei as varicosities.

The cause of wounds can be varied. They are most often trauma by accident or battle, blows or knocks, scratching or scraping, bites, burns or a symptom or stage of an illness. The preferred treatment was drug therapy accompanied by bandages, which was supplemented in severe cases by small surgical interventions. Some mechanical treatments are also known.

Surgery also took place sometimes for religious (circumcision) or aesthetical reasons (ear or nose restitution) and prosthetic surgery was also known, although not all that often.

Types of bites, such as those from crocodiles (Eb. 436, H 239-40, 243), lions (H 244) and humans (Eb 432-435, H 21), were treated like any other wound, preferably by applying fresh meat on the first day and, subsequently, honey, wax and oil or grease as in Eb. 435 or by using other herbal remedies, occasionally with the addition of some animal ingredients. Snakebites, however, were treated differently, and by different medicine men, mainly by the snake-

charmer priest of Selket, because of the venom inflicted by the bite into the body. Tumours were well differentiated. Several sorts of tumours, abscesses, cysts, swellings, and boils (*hnhn.t*, *ʒ.t*, *sft*, *nw.t*, *šfw.t*, *hsd*, *twʒ.w*, *bsj*, *hmʒ*, *sh*, *bnw.t*, *wnm-snf*) are mentioned mostly in the Ebers, Hearst and Berlin papyri, with very brief medical instructions. These were treated by the same methods as wounds caused by mechanical injuries.

In the Ebers papyrus there is a complete book on wounds originating in burns: 482–509. No. 482 lists a sequence of remedies which, it says, should be applied consecutively. In other cases, remedies applying an ointment or bandage are always the same.

Methods

Drug Therapy

Egyptian drug therapy can be regarded as having evolved from a system rooted in magic that developed from empirical observations. Sometimes a sequential approach was used (Eb 522). In the 182 cases given in the Smith, Ebers, Berlin, Hearst and Ramesseum III papyri regarding wound repair, almost 130 types of materia medica were used. All were applied externally. More than 60 % of them were herbal remedies; the remaining types were mineral or substances originating from animals (both in about the same degree), with a few undetermined components. The only human remedy was urine.

Very often (in every sixth case), fresh meat was applied to a wound on the first day as an efficient haemostatic and mechanical agent. It was bound on the wound on the first day only, and was usually followed by the application of a lint saturated with ointment composed of grease and honey, also bound on. In specific cases, many other ointments and poultices were also applied (e.g., Eb 510-42). In other cases the treatment started with these materials. Almost 80 % of the prescriptions contained oil or grease in either the form of *mrh.t* or *d*, both prepared from various plants or animals, closing off the wound from air and introducing some minerals or vitamins into

the injured tissues. In almost half of the prescriptions honey was used, which can be beneficial as a wound dressing because it inhibits the growth of micro-organisms and is hygroscopic, thus attracting an abundant secretion of leukocytes and antibodies. Taking into account that the wax, which was also frequently mentioned in these cases, must have also contained some honey, its use was as popular among Egyptian drugs in wound healing as oil or grease.

d3r.t was often used (ca. 25 %), probably because of a disinfectant effect; this has been determined from the analysis of its use in various ancient Egyptian prescriptions. Unfortunately, the identification is not fully resolved: colocynth (The colocynth is the light spongy pulp of the fruit of the bitter cucumber (*Citrullus*, or *Cucumis*, *colocynthis*), an Asiatic plant allied to the watermelon. It comes in white balls, is intensely bitter and a powerful cathartic. Also called bitter apple, bitter cucumber, bitter gourd) and carob are suggested, although the last one seems to be more probable. Besides these basic medicaments, some others are also characteristic. Typical poultice materials were beans, peas, leeks, a sort of fibre (*dbj.t*), faience powder, *bsn*- clay, *wš*-mineral, *jmrw* – eventually gypsum or plaster, and linen (both the usual colour and *jrtj.w* - a red one).

Several other materials were used for their antibiotic, antiseptic, astringent, rubefacient (for internal pain), antiphlogistic (counteracting inflammation), analgesic, fever reducing, hygroscopic or wound sealing effects, or because they could contribute to the formation or development of the epithelium. Most of them are listed, but infrequently. Only a few are common: incense, salt, acacia, sycamore, barley, millet, faeces of various animals, Christ thorn, celery, cumin and a few unidentified ones. Some of the materials used only rarely might also be very effective. This can be stated for instance for the willow (*ṯrt*) having salicyl as its analgesic, fever reducer, anti-inflammatory effects, and being also anti-rheumatoid. It is, however, only mentioned in three prescriptions. Another such component is onion, listed only once, but being a good anti-inflammatory and very effective against

staphylococci, streptococci and some sorts of dermatomycosis [fungal infections of the skin].

The question can be raised, however, how often a certain prescription was used, as we can surely attest that the medical knowledge of ancient Egyptians was slowly but continually developing, incorporating new methods and materials in their papyri, although they continued to practice medicine as they had earlier times. One of these new materials was also the willow.

Mechanical Treatment

Treatment for Joints

Dislocations (*wnh*) and sprains (*nrrw.t*) were treated. In the tomb of Ipuj in Deir el-Medineh, there is a picture of industrial accidents. Among them the use of Kochers method for dislocated shoulders (Kochers method of reduction involves bending the elbow to 90°. The arm is slowly rotated 75° laterally, then the point of the elbow is lifted forwards, and finally the arm is rotated medially) can be clearly discerned. Other methods are described in the Smith papyrus, for instance, treatment for the dislocation of a jaw (Sm 25). For neurological complications resulting from the dislocation of a cervical vertebra, the inability to move the limbs, priapism, urinary incontinence, and intestinal dilatation with gas (paralytic ileus) are mentioned (Sm 31). In another case, a positive Lasague sign is described, i.e. pain due to a sprain of the vertebral column when the legs are extended (Sm 48), which indicates a prolapsed lumbar intervertebral disc with nerve involvement.

Bandages

For drawing together a gaping wound they applied strips of adhesive plaster, putting them on both sides of the wound (Sm 10, 27). Splints could be used for administering medicament into the mouth, as it could be held open with them. The same supporting use is attested at nose and ear operations. The common application of splints was for fractures. Wounds were usually bandaged after ointment was put on them, or the bandage was saturated with it. The linen for bandaging (Sm 2, 9, 10, 27, 47) varied in texture from

the finest silk-like gauze to a canvas-like coarseness. Ancient Egyptians had special knowledge in this field, which was explained in a specific book, as a note in the Smith papyrus says. The skill was first taught for the bandaging of mummies.

Treatment for Fractures

Based on many relatively good healing settings, we can assume that ancient Egyptian bone setting was advanced. Among the skeletal remains from ancient Egypt, there are innumerable completely healed limbs with good realignment of the bone, but most other bone settings often show gross shortening and misalignment. Since fractures of the femoral bones often healed without complication, it may indicate, on the one hand, that the virulence and incidence of pyogenic [producing pus] pathogens was lower than they are today, although their existence is proved by the frequency of osteomyelitis. On the other hand, based on the skeletal remains of pyramid workers and other Egyptians, it is obvious that fractured limbs were splinted using an advanced technique. Cleverly, if only one of the bones of the lower leg or forearm was broken, the remaining intact bone served as a splint for the broken one, and healing was satisfactory. In instances where the damage was so severe, amputation was an alternative course of action.

The standard procedure for the reduction of fracture was traction (Sm 12, 35, 36). And, indeed, many humeri set in splint remained. The first procedure was, after realigning the broken limb, to set it either with a splint wrapped in bandages, or encased in a healing poultice-cast that could be made of various (often unidentified) materials, as, for instance, (to mention some known substances) cow's milk mixed with barley (H 219) or acacia leaves bound together using gum and water (H 223). For reducing a fracture of the clavicle (Sm 35), the ancient Egyptians also used a modern method, first described among Greek physicians by Hippocrates, by stretching the patient 'on his back with a folded cloth between the shoulder blades' and pulling 'on his two shoulders until the fracture falls into position'. Among the neurological

complications, as in the case of an impacted fracture of the cervical vertebrae (Sm 33), aphasia, unconsciousness and tetraplegia, are mentioned.

Surgical Processes

- Wounds were often surgically treated by suturing with *jdr* stitching (Sm. 3, 10, 14, 23, 26, 28, 47). The Smith papyrus has the first mention in history of 'stitching' a wound. Other wounds were not sutured, but kept open.
- The *thn* – piercing with the *hmm* instrument – was prescribed for opening the ascites [fluid in the abdomen] in Eb 865. Regarding the only surgical procedures for burns, Eb 504 speaks about opening a blister, this time with a sharp thorn.
- Sandwiched between two pharmaceutical prescriptions, also for a blister in Eb. 501, an incision is suggested, but, as usual, without any details.
- The *d w-^c* 'knife-treatment', meaning, probably, excision, was fairly popular, as the many prescriptions show: Eb. 866 for a vascular tumour (haemangioma?), Eb. 867 for a presumably subcutaneous lipoma, Eb. 868 for a possible sebaceous swelling with metathesis (*3t nt s3*), Eb. 869 for an abscess, Eb. 870 for a swelling. The identification of the latter has several possibilities, such as a dermoid cyst lined with skin appendages, pilonidal sinus located in the midline or sebaceous cyst of the scalp, as, for instance, atheroma, Eb. 871 for an abscess in the axillary lymph glands.
- Sometimes, the *d w-^c* 'knife-treatment' was applied with a heated (*sšmm*) knife as in Eb. 872 for a probable haemangioma.
- In some cases 'fire' is mentioned, treated 'with the *s3-hmm* (firebolt?-man)'s treatment. This scorching was used in the case of the skin-like flesh protrusion in Eb 863 or that of the (umbilical or epigastric?) hernia in Eb 864.
- The method was applied according to the state of the cause, as in the first two cases of Eb. 876, where the tumour was eliminated either by excision or by scorching fitted to its state.

In all the above cases, procedures are not described and thus nothing definite is known. The only complex and detailed surgical process is given in the Ebers papyrus (Eb. 875)-with various knife and forceps devices-and is, in all probability, the month-long treatment for dracunculiasis (which may be the origin of the medical emblem with snakes), and thus a very atypical surgical invention.

Skull Repair

According to the Edwin Smith papyrus, the ancient Egyptians recognised brain disorders and performed skull repair. They were also the first in the history of medicine to identify the inner parts of the cranium. They also provided vivid descriptions of the brain and cerebrospinal fluid. Parallel to the development of weapons, the number of head injuries increased, thus making the discussion of the many cranial injuries in the Smith surgical treatise fully understandable. The dominant factor in healing, however, seems to be the *vis mediatrix naturae*, the expectant healing power of nature. It is also manifest by the signs of treatment on heads with cranial injuries found by Elliot Smith, Wood Jones, Courville, and recently, Nerlich.

The ability to recognise the classic sign of a base fracture in the skull, i.e. bleeding from the nostrils and ears (Sm 4-5, 7-8, 17, 21-22), or the basic sign of meningeal irritation, i.e. the inability to flex the neck to the breast (Sm 3-5, 7), indicates a sound basic medical understanding. And, indeed, pathological descriptions give clues to the identification of cases, like classic meningitis in Sm 3 or cerebral prolapse and nuclear rigidity in Sm 6. In Sm 7, a complex case scenario is given dealing with a fracture at the base of the skull. First, trismus and meningeal irritation (cured by palliating treatment with an unknown hot material, allowing the patient to be able to open his mouth), then infection of the wound causing tetanus is diagnosed, again treated by palliative treatment with *md3.t* - 'wooden chisel' and tigernut drink (*w'h*), since recovery was hopeless. The Smith papyrus also discusses a *contracoup* case with a pulsating

swelling protruding through the cranial fracture (Sm 8), where, besides the symptoms of the eyes looking in the direction of the affected side, the ears and nose are bleeding and nuclear rigidity with a hemiplegia on the injured side is documented.

Snakebite

According to the Brooklyn Herpetological Papyrus, snakes and the effect of their bites were accurately identified, and their bites treated with rational medical care. The treatments comprised the application of bandages with salt and natron, both being anti-agglutinant and anti-hemolytic, thus hindering the absorption of the venom; drinking of emetic remedies with various drugs to get rid of venom by vomiting; fumigation as adjuvant; magical spells for general and specific divine help and/or the *dw*-^c-knife-treatment and the *tštš* incision in the swelling. For drug therapy many earlier, not medically attested, substances were used, which may be explained by the 30th Dynasty date of the papyrus or by our missing knowledge of empirical snakebite treatment, but eventually by both of them.

The simple cut (*dw*-^c) was applied there twice, in the case of a 'male viper' (Br. 31) and of a uraeus/cobra (Br. 32); the wound is attributed to Seth and the prognosis is positive in both cases. The action is not specified, and, for the first case, there is nothing else to do. In the second case, however, the knife treatment is preceded by a remedy ('every thing for ...') with a missing part, which is thought to be by Sauneron 'emetics'). These two procedures resulted in vomiting, thus saving the patient's life. The word *tštš* originally meant 'crush'; in these cases, however, the knife determinative finishes the hieroglyphs. Thus, here the '*tštš* with many cuts' means, in all probability, the cutting of the area of the bite into pieces by a knife, applied to the bite swelling of any type of serpent (Br. 72a) or, specifically, to that of an unidentified cobra(?) 'male snake' (Br. 81). The next step was, however, the bandaging of the wound with salt or natron, or, in the second case, a medicament with

the addition of incense, an unidentified liquid, and cobra blood. The latter one, in addition to the venom, also contains the antitoxins.

Surgical Devices

We do not know very much about medical implements. The earliest tools come from the tomb of Qar of the 6th Dynasty, including 40 scalpels and tweezers as well as other medical tools whose purposes are still unknown.

For cutting the flesh they used knives of particular shapes and sizes. Various ancient Egyptian names are also known, such as *ds*, *hpt*, *s3s*, *hmm*(?) or *swt*. There was also a peculiar fish-tailed knife, called *ps3-kf*, used for cutting the umbilical cord after delivery. In the beginning the knife was a ‘disposable’ stone, most likely made of flint or obsidian, which was still used for cutting up dead bodies for mummification in the first century AD (Diod. I. 91) or blades fashioned from reed stems. However, cuttings on the body were made from the New Kingdom on, also with a metal knife. This innovation led to a new procedure: the blade was heated until it was red hot before an incision was made so that the knife both cut and sealed at the same time.

If a bone broke, bark or cartonnage cases padded with vegetable fibre or linen for securing the injured member by splints might be used, but Eliot Smith also mentions splints made of reeds connected by a linen band.

For taking out pieces of bones or any other foreign bodies, tools such as hooks and forceps were used. There was also a pair of small leather forceps, called *hnw(h)*. For discarding pus or other amorphous formations, tweezers or spoons and spatulas or vegetable ‘knives’ (*sw* = bulrush) were used. Other plants were used in other ways; for instance, the thorn of an acacia was used for cutting up blisters (Eb. 504 = L 52 = L56).

For cauterising there was the *d3* – ‘fire drill’ and sometimes heated metal cauteries. For closing open wounds, various types of bandages (*h3yt*, *s3d*) or needles for suturing by *jdr* stitching were employed. Linen strips coated on one side

with a gummy substance were used, for instance, as strips of adhesive plaster (*3wy*). They had a sort of cotton wool made of fibres of the plant *dhj.t*, which was soaked in drugs (Sm 28) and enclosed by linen bandages (*s3d*). To prevent the dislocation or slipping of the bandage, they applied a gummy substance or varnish taken from embalmers. A wedge covered with layers of cloth is described in Smith 7 for use in prying open the jaw.

Medical devices seem to be varied and fairly specialised, each used according to its function or to the requirements of a particular stage of the operation. Their refinement was, however, primitive, although the technical skill existed to make complex instruments, as we know that some cosmetic devices are astonishingly complex and of high quality. The repertoire, naturally, continually changed and developed. The state of our current source material, however, does not allow us to deduce details. At the temple of Kom Ombo, a box of instruments for a general practitioner, carved into the outer corridor wall and originating from the Roman Period, contains 37 instruments, identified as metal shears, knives, saws, suction cups, probes, a saw, tweezers, pincers, small bags, retractors, a small scale, lances, specula, chisel, dental or cleaning tools, spatulas and spoons, together with some objects having connections with magic. The ensemble presents a good example of the last period of Egyptian medical praxis, when Pharaonic Egyptian and Graeco-Roman medicine were completely fused.

Mythological Background

The medical papyri point to the fact that pernicious beings could enter and leave the organism through the openings of the body and thus harm people. From the Egyptian medical perspective, the wound was also an opening. Thus wound management had to be twofold. The first task was to repair the harm already occurred, by closing the opening and repelling the demons who had entered. Prevention was essential too, to assure the defence of this gate by magical rites and material feared by these illness-causing

Wound Healing in Ancient Egypt,

Fig. 1 Detail from the Smith Surgical papyrus (Source: Breasted 1930)



intruders. Seth often personified their negative power. The association of Seth with wounds was close, whether the wound was received in battle or as a consequence of the mythical fight between Horus and Seth for the succession to the throne of Osiris. According to this concept, any illness could only be healed with religious rites.

Material in connection with a plant or an animal might dispose some magical power and be a device through which people could get in contact with the gods. And the same is true for minerals. Thus any medical material could also express the protective role of a deity itself. This view is the most manifested in 'magical' components of the prescriptions. But even their choice was based with all probability on long empirical observations. Many of the materials are still (may be forever) unknown for us, but most of the identified ones have proved to be reasonably explained, and are appropriate in terms of their effect. The explanation of their effectiveness could only be given at that time, however, by mythological-theological reasoning.

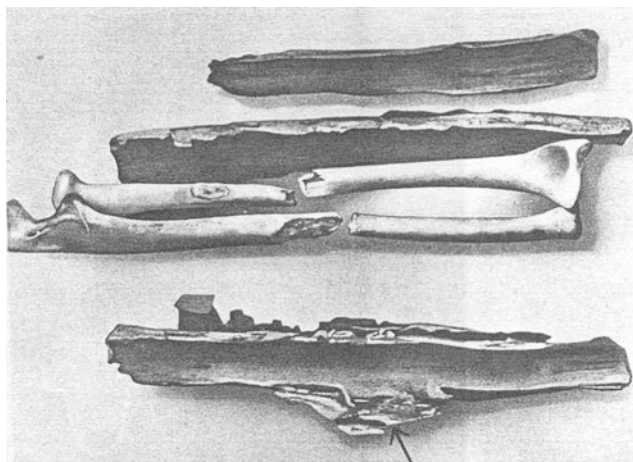
Various material combinations could be used for seemingly the same type or state of illness or

health, having the same or similar effect. There were several routes of drug administration, with a wide range of formation for use. They were usually determined by the choice of ingredients applied both for their physical-chemical properties and magical assumptions. The sycamore was, for instance, the tree of Hathor, Nut or Isis, the Christ thorn that of Thot of Pnubis, malachite was the mineral of Hathor, the donkey belonged to the god Seth, excrement was disgusting even for illness-demons, the *s3-wr* resin bore in its name ('great of magic') its magical connotation. For patients who were wounded, bandages were also used as magical devices. They were traps, so that invisible beings could be kept off or removed.

Another way of making a treatment more effective was religious-magical rite. Similar to cases in the London papyrus (15–21, 46–48, 53–61) and also among the Ebers papyrus prescriptions (482–500), magic spells had to be cast, referring to Horus having been burnt in the desert. According to the incantation of Eb. 499, which had to be recited with mother's milk, Isis used 'water in her mouth' and 'Nile springing between her thighs'. Then mother's milk, gum and ram fur

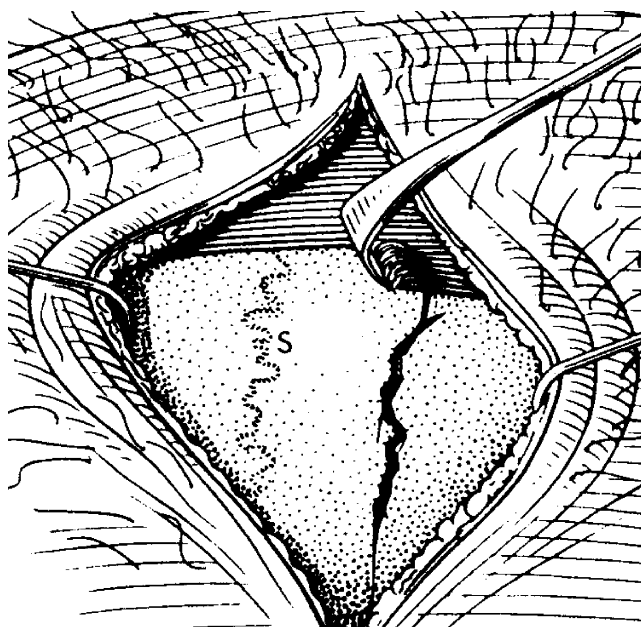
Wound Healing in Ancient Egypt,

Fig. 2 Broken bones with splints (Source: Majno 1975)



Wound Healing in Ancient Egypt,

Fig. 3 Drawing with surgical hook used during operation



(having a high cholesterol content) were put on the burnt wound.

The mythological background worked as a psychological support as well, which recent studies have shown can reduce pain perioperatively and increase patient's satisfaction (Figs. 1, 2, and 3).

See Also

► [Surgery in Ancient Egypt](#)

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Writing

Martha J. Macri

Writing ranks among the most important of human inventions. Yet it is only one of many forms of visual communication. Others include sign language, dance, and bodily adornment, notched tally marks, stones signposts, as well as the more complex painting and carving of complex narrative scenes. Some of these are, like writing, ways of recording information, that is, of creating a more or less permanent record available to persons outside the immediate time or space. All visual communication depends upon at least minimal familiarity with the cultural conventions of those producing it. Specifically, writing is a technique for recording human speech. Today speech, both the aural and the visual aspects of it, can be recorded and reproduced electronically. However, prior to the invention of the wax cylinder phonograph, human language could only be recorded, however imperfectly, in written texts.

Writing is an entirely arbitrary system in which each symbol in a script has an agreed upon value. The symbols may or may not have any association with a real world object. Thus, all scripts must be learned within the context of a specific culture, and within the context of a specific speech community. Although the Chinese script can be read by speakers of a number of different languages, the conventions of the script and the way it relates to a speaker’s own language must be painstakingly memorized.

Writing seems to have been invented at least three times in human history: in Mesopotamia, in China, and in Mesoamerica. It may be that there were other independent inventions, or it may be that all the other writing systems have been the result of stimulus diffusion – the spread of a good idea. An evolutionary theory of writing sees a development from pictures to complex symbol systems to scripts with word signs to phonetic (sound based) writing systems.

Logographic scripts (ones in which a picture or symbol represents a specific word) make use of rebuses, that is, of using a picture of an object to represent a word that sounds like the object pictured. Such a script is always language specific. For example, using the picture of a honey bee for the verb *to be* works only in English. Logographic scripts nearly always include additional elements to clarify meaning (semantic determinatives) or to indicate the sound of a word (phonetic complements). Ancient Egyptians had sets of consonant signs indicating one or two or three consonants, as well as hundreds of logographic signs and semantic determinatives. Other examples of logographic scripts are Sumerian, Chinese, Naxi (southern China), and Mi'kmaq (Canadian maritime provinces).

The next step in an evolutionary theory of writing is the addition of a significant phonetic component. In phonetic scripts most signs refer not to words, but simply to sounds. Of phonetic systems there are two types: syllabaries and alphabets. A syllable is composed of a vowel and any consonants that immediately precede or follow it. In practice, in most syllabic scripts, each sign represents a simple consonant-vowel combination. There are, for example, individual signs for *pa*, *pe*, *pi*, *po*, and *pu* instead of a single symbol for the sound *p* and symbols for each vowel. Syllabic systems often include a set of logographic signs (such as the *kanji* component of Korean and Japanese), and may have one or two symbols for a single consonant (in Japanese there is a symbol for *n*, in Cherokee a symbol for *s*). Although early students of writing considered syllabaries to be merely a step toward the culmination of the alphabet, syllabic systems have had a long history of success. Japanese, Linear B, Akkadian, West African scripts, and Cherokee are only a few examples.

In contrast to multiple inventions of syllabic scripts, the alphabet seems to have been invented only once. Certainly there are hundreds of distinctive alphabetic scripts, but the history of each one can be traced from a single origin in the Mediterranean region some 3,500 years ago. In alphabetic systems, each sign represents a single

sound – a single consonant or vowel (the earliest alphabets were largely consonantal systems). The Proto-Sinaitic, Ugaritic, and Phoenician scripts are the immediate ancestors of the Greek and Roman alphabets. Alphabets have an advantage for languages with consonant clusters such as English. The word *split*, for example, in a syllabary would have to be written with four syllabic signs: *si-pi-li-ti*, suggesting the presence of more vowels than the word has. The sequence of syllabic signs could also spell *spilt*, or any of a variety of nonsense words. Alphabetic systems generally include at least a few logographic symbols, such as the symbols for numbers.

Any script with a history – one in use longer than a single generation, or used for more than one language or one dialect – suffers from the effects of standardization and carries a baggage of archaic spellings. *Aunt* and *ant* may or may not be pronounced the same. *Beau* and *bow*, *bough* and *bow* reflect language history, and show clearly that English writing is not a purely phonetic system. Standardized spellings are much easier to read than technical transcriptions, in which linguists using a system such as the IPA, the International Phonetic Alphabet, try to capture the precise details of a specific utterance.

Although no script is ever a pure example of the above categories, each category differs in the usual number of total signs. Counting the number of individual signs can sometimes suggest the nature of an unknown script. Logographic systems contain the most signs, sometimes numbering in the thousands. Syllabic systems require only as many signs as there are consonant + vowel syllables in a language, usually in the range of 40–150 signs. Mixed logographic-phonetic scripts can range from hundreds into the thousands. Alphabets have the fewest – only enough to represent the sounds of a particular language. Only 13 letters are needed to write the Hawaiian language, compared with 24 symbols in the Germanic runic script and 44 for Cyrillic. The total number of signs in an alphabet does not necessarily match the number of distinctive sounds in a language. The alphabet used for English has only seven vowel letters (*a*, *e*, *i*, *o*, *u*, *w*, and *w*) that are used alone or in various

combinations to represent at least 12 distinct vowel sounds.

Another way that script types differ is in their longevity. Two of the best known logographic scripts, Chinese and Egyptian have had far longer life spans than the alphabet. An identifiable Chinese script was functional at least by 1200 BCE, and continues in use by millions of people today. Egyptian hieroglyphic writing ceased by the tenth century CE, but has a history of nearly 4,000 years. Akkadian in Mesopotamia was used for over 2,000 years. Syllabaries seem to have briefer lives. Linear B in Mycenaean Greece was used for about 200 years. The two syllabic components of the Japanese script, *hiragana* and *katakana*, are slightly over a 1,000 years old, developed by the eighth and ninth centuries CE, respectively. The Cherokee syllabary dates only from 1820. What of the alphabet? Probably dating no earlier than the first or second millennium BCE, its future seems promising. As a tool of the electronic age, the alphabet is a system adaptable to any language and is maximally efficient for keyboard use (this may be, however, because keyboards were invented for the alphabet).

One of the errors in an evolutionary theory of scripts is the notion that they become increasingly abstract, i.e., that over time scripts become more efficient, using fewer signs and simpler sign forms. Scripts with a heavy logographic component tend, however, to develop in the opposite direction, collecting baggage over time. Egyptian grew from 700 signs in Middle Egyptian (ca. 2000 BCE) to more than 5,000 signs by the fourth century CE. The ancient Maya script added hundreds of logographic signs over the 700 years of the Classic period (200–900 CE), while the core of syllabic signs grew at a much slower rate. Chinese characters have increased from 9,000 in the first century CE to about 60,000 by the end of the twentieth century, though today only about 2,400 are in common use.

These dramatic increases happened for several reasons. First, cultural and historical events bring additions to a script over time. This can be seen in the archaic spellings of many English words that

reflect pronunciations no longer used or used only in certain dialects. Second, although a purely alphabetic script is easier to learn and easier to write, logographic scripts, once mastered, can be read more rapidly. The debate of whether to teach English-speaking students to learn to read through phonics or through word recognition reflects the fact that even readers of alphabetic scripts make use of both its phonetic and logographic aspects. Third, universal literacy has not always been an ideal, and a difficult logographic script has sometimes been seen as a tool for limiting access to knowledge and prestige. Finally, and probably most significantly, languages rarely add a new sound to their sound inventory and rarely add new syllables. Words, however, are constantly being added. Since vocabulary is an open-ended component of language, any logographic script, one in which symbols represent words, is going to have to grow as new words come into use.

Some scripts owe their invention and development directly to contact between neighbors. One example is the Japanese writing system. Initially Chinese characters were used to approximate the Japanese language, then syllabic features were added to provide more specific phonetic information. Today the combination of *kanji* (Chinese logographs) with the *hiragana* and *katakana* syllabaries, make Japanese a script with one of the world's most arduous learning curves. Sumerian, a largely logographic system, was adopted by the Akkadians who like the Japanese added syllabic features, resulting in a mixed logographic-syllabic system that had a large syllabic component.

Some students of writing see the adoption of a logographic script by speakers of a foreign language as an explanation for the development of phonetic scripts. Foreign users reinterpret logographs that carry semantic and phonetic information as phonetic symbols representing sounds without the specific meaning, or as representing the same meaning but with the sounds it has in the new language, or they may invent phonetic signs to add phonetic information or grammatical detail. Such progressions can be seen in the development of Akkadian from

Sumerian writing, or of Japanese syllabaries, and the Korean script – both influenced by Chinese.

The vocabulary used to characterize a script varies from one to another. *Characters, hieroglyphs, glyphs, letters, symbols, icons, signs, and graphemes* all describe units of written language. The forms of the signs may be described as *pictographic, representational, linear, cuneiform, abstract, and geometric*. The organization of the units may be *columnar, clustered, horizontal (left to right or right to left), boustrophedon (back and forth, literally, as the ox plows)*. Within the texts themselves divisions between words, phrases, sentences, and larger units may be ignored or may be indicated by spaces, larger symbols (e.g., upper case letters), or a variety of punctuation conventions.

Language that is recorded in writing represents only a small subset of language that is spoken. Nearly every culture places specific limits on the kinds of information presented and on the manner of presentation. Commercial records, calendrical notations, prayers, magical spells, laws, census records, land deeds, court records, sacred and political histories, diaries, personal letters – these are among the earliest written materials. Novels, commercial advertising, and to-do lists are relatively more recent developments. The surviving examples of some ancient scripts are limited only to one or two genres.

Spoken language reflects an awareness of the speaker's audience, while written language may ultimately reach audiences never dreamed of. Written language tends to be more deliberate, generated at a much slower pace than speech. Nor does it have the meta-linguistic features that add dramatic force and subtle nuances to a speech act. Efforts to indicate variation in tempo, volume, and pitch (such as with underlining, boldface, accent marks, exclamation, or question marks) fall far short of the tools available to a speaker. Missing, too, are facial expressions, body posture, and hand gestures.

In contrast to recording language, there have developed a number of systems that approach writing, but do not fit the strictest definition of writing. Several of these hieroglyphic scripts are

or were, in fact, readable within the culture that produced them, but with no or with only minimal phonetic components they can have only uncertain meaning to the uninitiated. One example is the Mixtec writing known from eight pre-Columbian screenfold books. In these a complex iconography is tied to narrative images recording sequences of historical events and genealogies. Although the meaning is often clear, it is impossible to know exactly how the texts would have sounded when they were read – impossible to know precisely what words were associated with the images. Another example is the Naxi Dongba writing of southern China dating from the thirteenth century. This hieroglyphic script is still used and studied today. The meanings of the signs are complex, with minimal phonetic information indicated. Mixtec and Naxi represent yet another challenge to the evolutionary model. Rather than pictographic scripts always preceding true writing, some of them were created by cultures imitating neighboring scripts.

Also implied in the evolutionary theory of writing is a gradual development from picture signs to syllabic signs. Many books on the history of writing show charts of simple pictures for objects next to related but more abstract forms that exist in a particular script – the most common scripts pictured are Chinese, Akkadian, and sometimes even the Greek alphabet. However, direct evidence of this gradual development from pictures to a phonetic script is seldom available. An alternate scenario is that at some point in time one person, or a small group of persons, took an existing symbol system, and from it chose a set of signs to produce a phonetic system, usually a syllabary. We know that this happened with Sequoyah, the man who invented the Cherokee syllabary. History also tells us that this is what happened in the fifteenth century when King Sejong, or a committee created by him, developed the Korean *Han'gul* script. Because a phonetic script is a complex interdependent system it can only function when a complete set of phonetic signs are in place. For most scripts, this crucial moment of creation remains a conjecture.

Some have asserted that writing, specifically the alphabet, gave humans the ability to order and to classify information. Linguistic and cognitive anthropologists, however, have demonstrated repeatedly that complex categorization also exists in societies without writing. What then does writing contribute? Certainly it contributes a memory beyond the life span of a single person, knowledge that is independent of oral transmission. This enables an accumulation of knowledge across time and across cultures. Writing has given us detailed insight into earlier societies. Several languages, such as Sumerian, Hittite, Etruscan, and Tocharian, have no direct descendants, and are known only through their written texts.

This essay speaks about script types and script developments. For those who are interested in the variety of the world's scripts there are a number of excellent introductory texts, some generously illustrated. For example, see Coulmas (1989, 1999), DeFrancis (1989), Pope (1999), Robinson (1999, 2002), Rogers (2005), and Sampson (1990). One volume stands out for its quality and comprehensive coverage: *The World's Writing Systems*, Daniels and Bright (1996). Also excellent are the individual volumes of the *Reading the Past* series: Bonfante (1990), Chadwick (1987), Cook (1987), Davies (1987), Healey (1990), Houston (1989), Page (1987), and Walker (1987). Two dramatic stories of decipherment are Chadwick (1967) for Linear B and Coe (1999) for the Maya script. Boone (2000) and Boone and Mignolo (1994) offer enlightened discussions of nonphonetic systems. The potential of the as yet undeciphered Inca knotted *kipu* as a record of detailed information, perhaps including speech can be found in Urton (2003) and Quilter and Urton (2002).

Recent years have seen a growing number of websites, both about scripts in general, as well as sites devoted to a single script. Below are listed two general websites for writing systems, both with links to many other resources, and several sites relating to specific scripts or regions. Searching on the web for *writing systems*, or for any country, language, or script name will yield a large number of sites. Some of these are

sponsored by academic institutions, a few are commercial, and a few are sponsored by individuals. Their quality varies, though even sites with incomplete or nonstandard information often provide useful images.

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Writing in China

Uta Lauer

The origin of a comprehensive writing system in China is a matter of debate. According to an ancient Chinese legend, writing was invented by the three mythical emperors between the twenty-ninth and the twenty-sixth centuries BCE. The earliest evidence for some kind of script is marks on pottery excavated from the Banpo site near Xi'an in Shanxi-province, dating from the Neolithic Age. Proof for a highly developed writing system comes from oracle bones (*jiagu wen*). Datable to around 1300 BCE, inscriptions on bovine, pig, deer shoulder blades or on turtle shell were used for divination. The elite of the Shang dynasty (sixteenth to eleventh century BCE) employed a question and answer model, through which those in power would ask a question, incise it into the bone, and the shaman or priest would drill holes into it, insert a piece of burning coal, interpret the cracks produced by the hot coal, and then write down the answer. About 2,000 different characters have been found on Shang oracle bones, but only half of these have so far been deciphered. Another form of surviving document is short texts cast on the inside of bronze vessels. There are numerous examples of late Shang inscriptions, typically rather short, whereas in the succeeding Zhou period (eleventh century BCE to ca. 771 BCE) inscriptions on bronze ritual vessels were considerably longer. The type of script employed during the late Zhou period was called great seal script (*dazhuan*).

One of the most important steps towards the development of a comprehensive writing system was the unification of the empire under the rule of emperor Qin Shihuang (r. 221–206 BCE) in 221 BCE. Under the jurisdiction of his Prime Minister Li Si, writing was standardised into the small seal script (*xiao zhuan*). This script comprised about 12,000 characters (*zi*). Today, small seal script is still in use on seals and in

advertisements. Seals had been made since at least the late Zhou period. They were used instead of a signature and served official, commercial, personal and literary purposes.

With the advent of the Western Han dynasty (206 BCE–9 CE) a new type of script came into use, clerical script (*lishu*). It was easier to write than the angular small seal script and thus more suitable for the ever-increasing amount of official, government related texts. Based on clerical script a kind of shorthand developed for less formal occasions like writing letters or jotting down notes. Literally translated into English it is called grass script (*caoshu*), but is also frequently referred to as draft script, running script or fully cursive script. To avoid confusion of technical terms, it is best to use the unambiguous Chinese terminology. During the Han dynasty, the potential of writing as a medium for artistic expression was fully recognised. It was then, that the art of calligraphy (*shufa*) was born. Another less abbreviated form which emerged from clerical script is semi-cursive script (*xingshu*).

During the fifth century, the last type of script was codified, regular script or standard script (*kaishu*), which is still in use today. After that, the evolution of the Chinese writing system was complete. This had a culturally unifying effect this had to a high degree. Chinese characters serve as a binding element, as an identification factor and as bearers of an uninterrupted tradition.

With the end of imperial rule and the founding of the Republic of China in 1912, a debate about the simplification of characters began. Some argued to abolish Chinese characters entirely and to replace them with a romanization system in order to promote literacy. Several reforms followed until finally in 1964 a list of simplified characters (*jianti zi*) was approved. Today simplified characters are used in the People's Republic of China whereas other countries which employ Chinese characters have maintained the complex characters (*fanti zi*).

In 1979 the government of the People's Republic of China adopted the Hanyu Pinyin system, a phonemic notation and transcription to Roman script. Pinyin is very useful as a cataloguing method and for writing Chinese on computers.

Essential for the development of the art of calligraphy was the material used for writing, namely the pliable brush, absorbent paper and ink. The earliest surviving documents written with a brush and ink on strips of ► [bamboo](#) date to the third and second centuries BCE. Already by the fifth century BCE silk was also in use as a writing ground. Silk existed in China since Neolithic times. Archaeological evidence shows that paper was being made from the first or second century BCE. Paper was much cheaper than silk, relatively easy to make and less cumbersome than bamboo strips. The availability of paper made possible the steady increase in writing throughout the empire. The earliest examples of ink are found in traces of writing dating to the fourteenth century BCE. Chinese ink is made from carbon, lampblack and glue which is then dried and moulded into the form of sticks or cakes. To obtain liquid ink, the ink stick has to be ground by hand on an inkstone with the addition of water. During the tenth century CE, writing equipment (brush, paper, ink and inkstone) came to be known as the “four treasures of the scholar's studio” (*wenfang si bao*).

Since ancient times, calligraphy belonged to the six liberal arts (*liu yi*) practised by the social elite of the country. When looking at a work of calligraphy, the viewer can relive the process of its creation. The writing speed, pressure, energy, any moment of hesitation remains visible on the paper. The flexible brush allows for an endless variation of stroke shapes. Soon, the styles of individual masters of calligraphy were canonized. For transmitting calligraphic styles, various copying methods and the formation of collections were important. Before the invention of printing in the Tang dynasty (618–906 CE), several techniques for copying were employed. Exact copying (*mu*) is basically a tracing technique. To make a free copy (*lin*) the original is placed next to the sheet of paper on which the calligrapher reproduces the work at his own speed. Essential for a wider circulation of calligraphy styles were ink rubbings. For this reproduction method, a copy of the original written in ink is pasted to a stone or wood surface and then meticulously engraved into the surface through the copying paper.

Then, a moistened paper is placed over the engraved calligraphy and pushed into the incised areas with a brush. Finally, a pad soaked in ink is dabbed over the surface. The background of such a rubbing appears black and the characters white.

All types of script are employed in calligraphy but semi-cursive script and grass script are the two most suitable for artistic expression. Among the most notable calligraphers are Wang Xizhi (307–365) and his son Wang Xianzhi (344–388), Yan Zhenqing (709–782), Huaisu (725–785), Su Shi (1036–1101), Huang Tingjian (1045–1105), Mi Fu (1051–1107), Zhao Mengfu (1254–1322), Wen Zhengming (1470–1559) and Dong Qichang (1555–1636). Since the fourth century CE records and art historical treatises on calligraphy exist. Calligraphy as the embodiment and a highlight of Chinese culture forms an important part of the imperial art collection.

In 1949, when the People's Republic of China was founded and the Guomindang defeated, the Guomindang took a substantial part of the former imperial art collection to Taiwan, where it was housed at the National Palace Museum Taipei. The remainder of the collection stayed at the Palace Museum Beijing. From the beginning of the twentieth century onwards, collectors outside Asia developed a keen interest in calligraphy. Private collections and museums in the USA and in Europe now own a number of representative works of Chinese calligraphy. Research at universities on the history and the aesthetics of the art of writing is particularly prominent at some major US universities and in Germany.

In China, both the practise and theory of calligraphy are taught at art academies. Exhibitions and competitions are held regularly. Some contemporary Chinese calligraphers have gained recognition outside Asia and their works are on display in museums. Calligraphy is an art that is very much alive. Not only is the tradition passed on but there is also experimental writing. Young artists explore and challenge the basic principles of writing in their works. The brush might be replaced by a neon light, ink by water, thus highlighting the act of writing and pointing towards the perishable material.

Writing in Egypt in Its Literary Context

William S. Arnett

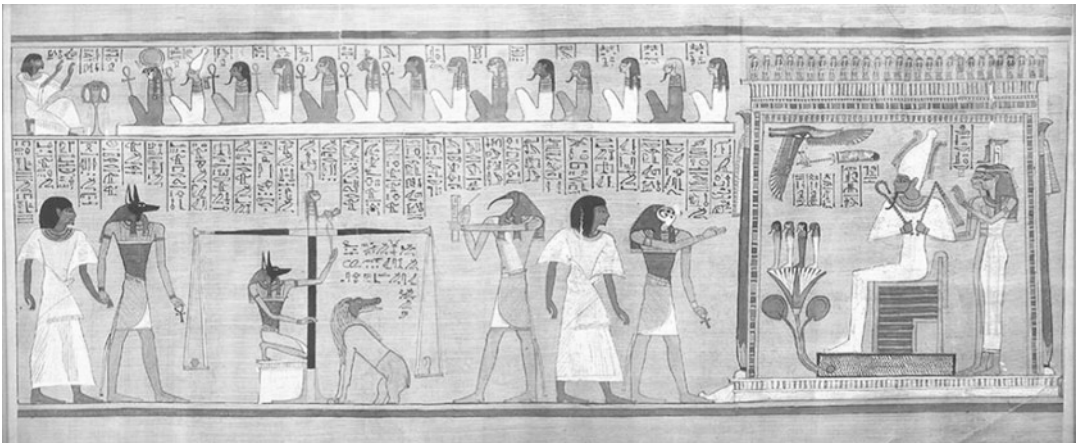
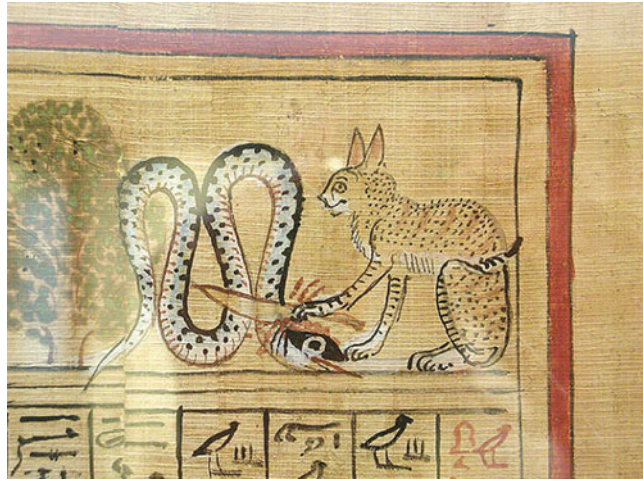
Morgantown, WV, USA

The evolution of Egyptian writing (hieroglyphs) is traditionally dated to Dynasty 1 of ancient Egypt's Proto-Dynastic Period ca. 3100–3000 BCE. Until recently, priority of first place in the history of writing seemed to belong to the Sumerians of ancient Mesopotamia (now southern Iraq). However, the recent discovery of labels in tomb U-j at Abydos, Egypt, tomb of the Scorpion King, have provided evidence of writing in Egypt as early as 3250–3200 BCE. The earliest Egyptian attempts at writing consisted of postmarks, designs painted on jars, and of motifs carved on the surfaces of cosmetic slate palettes and other artifacts found in the graves of Predynastic Egyptians at a number of sites (ca. 4500–3000 BCE) and in temple deposits at Hierakonpolis. These examples were clearly precursors to the classical Egyptian hieroglyphs (Arnett, 1982; Casson, 1965, pp. 141–148; Elkins, 1999; Gardiner, 1978).

The hieroglyphs worked best on stone, although they were also written on papyrus and other materials. Papyrus was a parchment-like paper made from the reed plant of that name which once grew in abundance along the banks of the Nile River. It was the most common material used for official record keeping, correspondence, literary works, administrative documents, etc. For these purposes the Egyptians developed a more cursive style of writing. This occurred early in the development of hieroglyphs. Scholars call the earliest type of this writing hieratic (literally “priestly” writing), although it was not used exclusively by the priests. The scribes used lamp-black and wrote with reed pens when writing on papyrus and brushes when using wood and other materials such as ostraca (An ostrakon is a piece of pottery usually broken off from a vase or other earthenware vessel. In archaeology, ostraca may contain scratched in words or other forms of

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Fig. 1 Funerary papyrus of Hunefer. The Sun god is shown in the form of a great cat killing the serpent of darkness. British Museum (EA9901.8) (Photo by Jon Bodsworth. Used with his kind permission)



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Fig. 2 Papyrus of Hunefer. The Judgment, from the papyrus of the scribe Hunefer. Nineteenth Dynasty. Jackal-headed Anubis conducts Hunefer to the balance.

The monster Ammut crouches beneath the balance so as to swallow the heart should a life of wickedness be indicated. British Museum (EA9901) (Photo by Jon Bodsworth. Used with his kind permission)

writing which may give clues as to the time when the piece was used. The word is derived from Greek *ostrakon* meaning a shell or a shard of pottery used as a voting tablet. The plural of ostrakon is ostraca). Later, in the seventh century BCE, the Egyptians developed another even more cursive system that is known as demotic, or popular. Generally, both of these more rapid writing systems were written on papyrus (Figs. 1, 2, and 3).

The quantity of such examples of Egyptian proto-writing suggests that Egyptian writing may have evolved as early as (if not earlier

than) the Sumerian cuneiform system so prominent in Mesopotamia and much of the ancient Near East from ca. 3000–1000 BCE. It certainly proves that the Egyptians developed their own, unique writing system and that, if they borrowed anything from the Mesopotamians, it was the idea of writing (Arnett, 2004; Stiebing, 2003, pp. 110–112) (Fig. 4).

The earliest extant Proto-dynastic writings consist of numerous brief texts: funerary stelae, ivory labels and plaques, and a few official monuments and royal inscriptions found in situ at locations both in Egypt proper and in the

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Fig. 3 Padiamenet papyrus. Hieratic Book of the Dead of Padiamenet, chief baker of the domain of Amun. Dynasty 22. British Museum (EA10063) (Photo by Jon Bodsworth. Used with his kind permission)

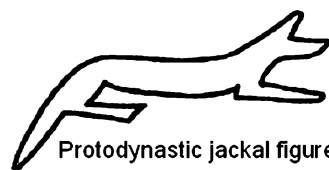


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Fig. 4 Jackal images: examples which illustrate the evolution of Egyptian writing from the earlier prototypes (proto-writing) to the historical hieroglyphs (Artwork and image by William S. Arnett. Used with his permission)



Predynastic jackal figure from Tarkhan



Protodynastic jackal figure from Abydos



Later jackal hieroglyph



Later jackal hieroglyph

Sinai Peninsula. These early texts reveal a hieroglyphic writing system that was already fully developed, which led earlier scholars to believe that the Egyptians had borrowed their writing system from the outside world, presumably Mesopotamia. The earlier use by the Sumerians of “symbolic tokens and ideographic inscriptions” as means of the accounting and recording of quantities of products and livestock was assumed to have led to the development of the earliest phonetic writing system in ancient Sumer. But the labels of Tomb U-j at Abydos can be read phonetically and may be earlier than the earliest known Sumerian writing (Stiebing, 2003, pp. 112–113). We have evidence of early trade and cultural exchange between late Predynastic Egypt and southern Mesopotamia,

and it is highly likely that ideas as well as goods and materials were being exchanged. However, the fact remains that the two earliest systems of writing (Sumerian cuneiform and Egyptian hieroglyphs) use entirely different signs and methods of inscription. While some Mesopotamian writing has survived on stone artifacts, the majority was inscribed upon clay tablets. In Egypt, stone stelae and walls of tombs or temples, stone chips (or ostraca), pieces of wood, and papyrus paper (the use of which dates back to late Predynastic times) were the primary media upon which the Egyptians did their writing. It is more likely that writing evolved in both areas at about the same time (Mark, 1997; Wilkinson, 2001, pp. 150–182) (Fig. 5).



Writing in Egypt in Its Literary Context, Fig. 5 Ugaritic alphabet using cuneiform characters. From Ugarit (Ras Shamrah), Syria. Aleppo Museum (Photo by William S. Arnett. Used with his permission)

These early texts provide only minimal details of official political and historical events as well as the accomplishments of the owners of the tombs in which they were found (Breasted, 1906; Lewis, 2003; Lichtheim, 1975: (vol. 1) p. 3; Pritchard, 1955). It is the general consensus that Egyptian writing was initially created for the sole purpose of satisfying the needs of the state to record all of its administrative, political, economic, diplomatic, and military activities and transactions (Aldred, 1998).

King Lists constitute a genre of Egyptian writing reflecting the above – stated purposes. The earliest, the Palermo Stone, provides the names of kings of the Late Predynastic period through early Dynasty 5. Primarily a list of yearly events and statistics, the main value of this monument is in the ordering of kings by the length of reign and the listing of their achievements as well as recording annual Nile flood heights, a periodic census of men and livestock, and occasional references to public works projects and foreign trade. For instance, there is a reference to forty shiploads of cedar wood imported to Egypt in 1 year during the reign of Snefru of Dynasty 4 (Gardiner, 1978; St John, 2003; Wilkinson, 2000). Other important king lists include the Turin Canon, the lists of royal ancestors of Sety I and Ramses II at Abydos, the Royal List of Karnak, and the Royal List of Sakkarah (Clayton, 1994; Shaw, 2000) (Figs. 6 and 7).

But, according to Lichtheim, the “first major application” of Egyptian writing was in the omnipresent Offering Lists found in the tombs of the well-to-do Egyptians of the Old Kingdom (Figs. 8, 9, and 10).



Writing in Egypt in Its Literary Context, Fig. 6 Royal ancestors of Sety I and Ramses II (Dynasty 19). Royal cartouches on the walls of Sety's Temple dedicated to Osiris at Abydos. This scene shows part of the list of previous Egyptian Pharaohs (Photo by Jon Bodsworth. Used with his kind permission)

These offering lists consisted of the names of the tomb owners, their family members, a record of the offices and titles held by them, and an accounting of the funerary offerings they required. By Dynasty 5, the Offering List was shortened into a Prayer for Offerings (Breasted, 1906, Vol. 1, pp. 75–175; Lichtheim, 1975, p. 3) (Figs. 11, 12, and 13).

As a result, wall space was freed for the development of a descriptive narrative containing historical and autobiographical material which the Egyptian nobles (administrators, prophets, judges, “overseers of the King’s land,” viziers, architects, soldiers, scribes, priests, etc.) had written/sculpted/painted on the walls of their tombs and/or tomb chapels. These texts and accompanying illustrations provide us with portrayals of the tomb owner, his family, and his servants (Figs. 14, 15, 16, and 17).

These texts, also called “Biographies of the Nobles,” often contain gross exaggeration and considerable boastfulness, and were meant only for their family, priests, and the gods they were meant to impress. Their discovery in modern



Writing in Egypt in Its Literary Context, Fig. 7 Sety I and Ramses II. Seti I and his son Ramesses II offering praise to a list of royal ancestors. Temple of Sety I at Abydos (Photo by Jon Bodsworth. Used with his kind permission)

times has given historians access to important primary source material for the reconstruction of ancient Egyptian history. They provide us with glimpses of the public careers and achievements of the administrative, bureaucratic, and military personnel who served the kings throughout the history of Dynastic Egypt. Tomb biographies also exist for nobles and some commoners throughout the rest of ancient Egyptian history. Lichtheim notes that, from the First Intermediate Period on, for many individuals, a shortened biography would be relegated to the tomb stela which also contained an offering prayer and an offering scene, making the stela a “self-contained memorial” (Breasted, 1906; Lichtheim, 1975: 8, pp. 15–28).

A second literary genre, Instructions Literature, is among the Old Kingdom’s greatest contributions to Egyptian writing. This category is also known as Wisdom Literature, which Miriam Lichtheim calls the “second major literary genre created in the Old Kingdom” (Lichtheim, 1975, p. 5). They are written in the guise of the advice of a King, Prince or Vizier to his son. The earliest known example is the *Instructions of Hardjedef*. The sage Hardjedef (Hordjedef) was the son of Kheops (Khufu) in Dynasty 4. He also figures as a participant in the *Three Tales of Wonder* (from the Papyrus Westcar in the Egyptian Museum of Berlin). Prince Hardjedef claims to have written the instructions for his son, Au-ib-re. Not too much of his Instruction has survived, but his name is always listed among those of

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Fig. 8 Mastaba (tomb) of Mereruka. The tomb of Mereruka is the largest extant noble’s tomb at Saqqarah. Mereruka was the vizier of Pharaoh Teti, first king of Dynasty 5 (2345–2333 BCE) (Photo by William S. Arnett. Used with his permission)





Writing in Egypt in Its Literary Context, Fig. 9 Ka statue of Mereruka in the Offering Chapel of his mastaba. The family and/or funerary priests left food offerings before Mereruka's statue in order to provide continual sustenance for him in the afterlife (Photo by William S. Arnett. Used with his permission)

the great sages of Egypt (Simpson, 1973, pp. 340–341). Lichtheim (1975, pp. 5–7 and 58–59) considers all three of the earliest Instructions (Hadjedef, Dynasty 5, and Kagemni and Ptahhotep, late Dynasty 6) to be pseudepigraphical (Pseudepigrapha (from the Greek words *pseudos* = false and *epigrapho* = write) describes texts whose claimed authorship is unfounded in actuality. The authenticity or value of the work itself, which is a separate question for experienced readers, often becomes sentimentally entangled in association. Yet few Hebrew scholars would insist that the Song of Solomon was written by the King of Israel, or ascribe the Book of Enoch to the prophet Enoch) works.

Another well-known example of this genre is the *Instructions of Ptahhotep*. The sage Ptahhotep, who, supposedly, was the vizier of the Fifth Dynasty pharaoh Izezi (2388–2356 BCE), provides maxims of good and polite conduct and of good speech.

These works constitute a form of political propaganda in a literary format. They posit that order and *ma'at* (justice and balance) are only possible when there is a strong and benevolent monarch on the throne of a united Egypt. In addition, they offer advice on proper behavior that reflects the mores of nobles of Dynasty 5 and Dynasty 6.

A third example, *The Instruction to Kagemni*, most likely written during Dynasty 6, alleges to be the advice given to Kagemni, the vizier of Huni, the last king of Dynasty 3 and of Snefru, the founder of Dynasty 4. The beginning of Kagemni's Instruction is lost, and its true date and authorship are unknown.

The Instruction of Merikare was supposedly written by King Khety II (ca. 2100 BCE), the father of Merikare of Dynasty 10. His (Merikare's) capital was at Herakleopolis. However, most scholars believe that it was actually written by scribes at the court of Merikare. Its uniqueness lies in its new dimension as a royal inscription in which a dying king bequeaths the throne to his son and successor and offers him advice on how to be a good king (Lichtheim, 1975, pp. 9–10).

The Instruction of Amenemhet I (or Amenemes I), supposedly written by Amenemhet I to his son Sesostris I (Senwosret I), of the Middle Kingdom (Dynasty 12), is a more famous example of this genre. The serenity and balance in Egyptian society as it appeared during the Old Kingdom had been replaced by the political and economic turmoil and social upheaval of the First Intermediate Period. Even though order had been restored by the Kings of the Middle Kingdom, our literary evidence suggests that the crown represented a heavier burden for the monarchs of the Middle Kingdom, and that the dangers of civil strife and revolution were lurking just below the surface. The apparent assassination of Amenemhet I (alluded to in both the *Instruction*

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Fig. 10 Mereruka Wall Scene. The diminutive figure of Meri-Teti, son of Mereruka, is seen at the feet of the Vizier Mereruka. Mastaba of Mereruka (Dynasty 5) at Saqqarah (Photo by Brian Anderson. Used with his kind permission)



of *Amenemhet I* and *The Story of Sinuhe*) suggests that things had gone awry and that men were doing evil things. In the *Instruction of Amenemhet*, the dead King (Amenemhet I) appears as a ghost to his son Sesostri I - (or Senwosret I), tells of his assassination in the palace at the hands of his own palace guard, and suggests that it was instigated by someone in the harem. He advises his son to rule with a strong hand and to trust no one in the “day of evil” (Erman, 1927, pp. 72–74; Lichtheim, 1975, pp. 135–139; Parkinson, 1997, pp. 203–211; Pritchard, 1955, pp. 418–419; Simpson, 1973, pp. 193–197).

The Teaching of Duaf’s Son Khety, elsewhere known as the “Satire of the Trades,” also dates to the Middle Kingdom and proclaims that the most exalted profession is that of the scribe. The writer belittles all other occupations by listing all the hardships experienced by those employed in them (Parkinson, 1991, pp. 72–76).

The Prophecies of Neferti (Erman, 1927, pp. 110–115; James, 1979, p. 102; Lichtheim, 1975, pp. 8–9 and pp. 139–145; Pritchard, 1955, pp. 444–446; Simpson, 1973, pp. 234–240), the *Admonitions of Ipuwer*, and the *Prophecy of Nefer-rohu* represent a new departure in Egyptian literature. Neferti was a lector priest (literally, “he who carries the ritual”) at Bubastis during

the reign of Amenemhet I. This composition purports to be the prophetic vision of someone at the court of Snefru of Dynasty 4 who predicted the coming of the troubles of the First Intermediate Period and of Egypt’s savior, Amenemhet I, the first king of Dynasty 12. In other words, this piece was probably written to justify the seizure of the throne of Egypt by Amenemhet I. Neferti and Ipuwer address the problem of evil and proclaim that a strong monarchy is the only way to protect Egypt from its dangers. The pronouncements of the sage Ipuwer are reminiscent of those of the Biblical Prophets who chastised the Kings of Israel for not doing their religious and political duties.

The Admonitions of Ipuwer was probably written in the early years of Dynasty 12 and is generally interpreted as being either a warning to a king about the disastrous consequences of misrule or else as a means of contrasting the faithfulness of a good king (presumably one of the Dynasty 12 rulers) with the inadequacies of a bad king whose failure to tend to the religious and political duties of the throne resulted in the chaos and anarchy of the First Intermediate Period.

Nefer-rohu foresees the coming of Amenemhet I and speaks of him in such familiar terms that scholars are convinced that his prophecy was actually written during the reign



Writing in Egypt in Its Literary Context, Fig. 11 Deir el-Bahri Offerings. In the private tombs of the nobles of the Old Kingdom, the List of Offerings consisted of prayers and items meant to provide sustenance to the decedent in the afterlife. In a similar manner, the royal temples of the New Kingdom, Kings portrayed themselves making offerings to the gods (see Fig. 6). Here we see a wall relief from Hatshepsut's funerary temple that depicts her offerings to the god Amun (Photo by William S. Arnett. Used with his permission)

of Amenemhet (Erman, 1927, pp. 110–115; Pritchard, 1955, pp. 444–446).

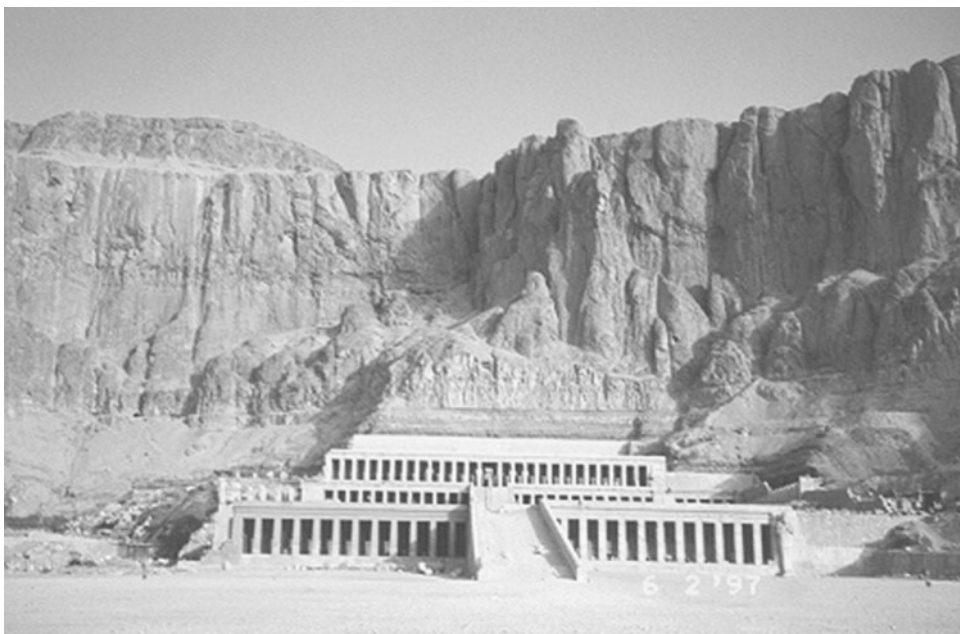
The Song of the Harper dates to the First Intermediate Period, the era of disunity and civil and social unrest following the collapse of the Old Kingdom. It reiterates the above-mentioned concern for the loss of order and expresses the sense of futility in providing and protecting the “houses of eternity” (tombs) of the kings and nobility. In addition, the song offers an unprecedented philosophy of pessimism and skepticism concerning the shortness of life and the uncertainties of life after death (Erman, 1927, pp. 14–29; James, 1979, p. 98; Lichtheim, 1975,



Writing in Egypt in Its Literary Context, Fig. 12 The female Pharaoh Hatshepsut presents offerings to the God Amun. Funerary Temple of Hatshepsut at Deir el-Bahri (Photo by William S. Arnett. Used with his permission)

pp. 193–197, 222–235; Parkinson, 1991, pp. 36–37; Pritchard, 1955, pp. 18–22; Simpson, 1973, pp. 57–74). Was this pessimism truly reflective of a new Dawn of Conscience, as Breasted suggested (1976), or was it simply an irreverent farce from some popular poem or drinking song?

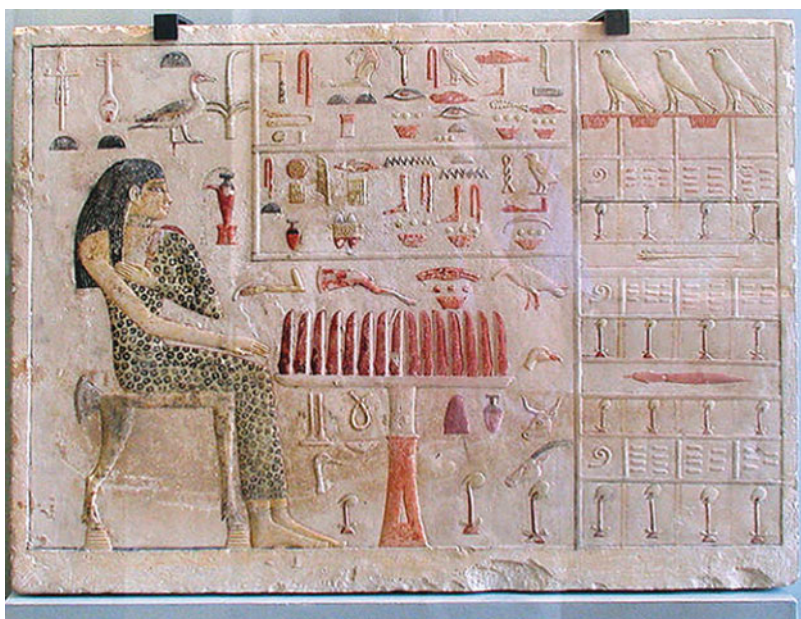
The Middle Kingdom (considered by later generations of Egyptians to have been the golden age of Egyptian culture and history for its art, calligraphy and literature) also produced a popular piece of prose, known as the *Story of Sinuhe*, a work of historical fiction. It depicts the adventures of an Egyptian nobleman who fled into exile in Palestine, perhaps because he feared he would be implicated in the murder of King



Writing in Egypt in Its Literary Context, Fig. 13 The Funerary Temple of Hatshepsut at Deir el-Bahri (Dynasty 18)
(Photo by William S. Arnett. Used with his permission)

**Writing in Egypt in Its
Literary Context,**

Fig. 14 Stele of
Nefertiabet. Princess
Nefertiabet, a daughter of
the Pharaoh Khufu
(Dynasty 4), is seen here
seated at her offering table
in her tomb at Giza. This
wall section is in the
Louvre Museum (E22745)
in Paris (Photo by Jon
Bodsworth. Used with his
kind permission)



Amenemhet I, and only returns near the end of his life to be buried in his homeland. The story also presents Senwosret I (Sesostris) as a benevolent king who restores *ma'at* (truth, the world order,

justice, etc.) and welcomes Sinuhe back to Egypt with open arms. It provides the earliest literary description of Palestine and portrays it in Bible-like fashion as a land of milk and honey:

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Fig. 15 Stele of Rahotep (Dynasty 4) from Meidum. British Museum (EA1242) (Photo by Jon Bodsworth. Used with his kind permission)



Writing in Egypt in Its Literary Context,

Fig. 16 The Necropolis of Gizeh. In the shadows of the Great Pyramids, the tombs of the princes and high-ranking nobles of Dynasty 4 were buried in tombs arranged in orderly rows so that they would be with their king in the afterlife (Photo by William S. Arnett. Used with his permission)



“Abundant was its honey, many sweets were made for me, and milk dishes of all kinds.”

Scholars are fairly certain that they know the identity of the author of this famous story. His name was Achthoes. *The Papyrus Chester Beatty IV*, in the British Museum (#10684) avers that, “It was he who made a book as the Instruction of

King Sehetepibre.” The latter is the name taken by Amenemhet I when he assumed the throne. Achthoes is also known to have written the previously mentioned Instruction book entitled the *Satire of the Trades* (Erman, 1927, pp. 14–29; James, 1979, p. 98; Lichtheim, 1975, pp. 222–235; Parkinson, 1997, pp. 21–53;

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Fig. 17 The Great Pyramids of Gizeh. Viewed from the desert to the west, the pyramids of Khufu, Khafre, and Menkaure are ancient Egypt's most famous monuments (Photo by William S. Arnett. Used with his permission)



Pritchard, 1955, pp. 18–22; Simpson, 1973, pp. 57–74).

The Tale of the Eloquent Peasant, like so many of our surviving Egyptian literary texts, is also a product of the Middle Kingdom. In fact all of the manuscripts containing this story come from that era. It may be the mere chance of discovery, but it could also mean that, unlike other tales from the twelfth Dynasty, this particular example did not enjoy continued popularity during the later New Kingdom. Social equity and the right of commoners to expect fair treatment at the hands of the nobility and the government are the central themes along with the unexpected eloquence of a peasant (Erman, 1927, pp. 116–131; Lichtheim, 1975, pp. 169–184; Parkinson, 1991, pp. 64–65; Pritchard, 1955, pp. 407–410; Simpson, 1973, pp. 31–49).

The Tale of the Two Brothers, a work composed in Dynasty 19 (ca. 1210 BCE), has elements similar to the story of Joseph and the wife of Potiphar in Genesis 39. But, as the noted Coptic scholar Plumley pointed out in 1958, the two stories have some common aspects, “but it would require much greater similarity of detail between the Egyptian and the Hebrew stories to justify the oft-made suggestion that the Egyptian story is the origin of the incident described in Genesis.”

The Capture of Joppa, found with the *Story of the Doomed Prince* on the same papyrus (Harris, #10060, Br. Museum), is an historical romance dealing with General Djehuty, who served

Thutmose III in his campaigns in Syria-Palestine (ca. 1504–1450 BCE) and depicts an event otherwise unknown in the official Egyptian annals. Djehuty outwits the city's defenders by having him and several Egyptian soldiers smuggled into Joppa in baskets (Erman, 1927, pp. 167–169; James, 1979, p. 112; Pritchard, 1955, pp. 22–23; Simpson, 1973, pp. 81–84) (Fig. 18).

Space permits only the briefest listing of several other categories of Egyptian writing that have survived in great quantities on papyri and ostraca, as well as in the form of inscriptions and paintings on the walls of tombs and temples. The reader interested in further study will find more scholarly information and examples of texts in the linked sites. These additional genres of Egyptian literature include both secular and religious songs. In addition to the above-mentioned Harper's Songs, Egyptian love songs, dating to the New Kingdom, have also survived. These have a timeless quality and can be very romantic and erotic (Foster, 1974; Simpson, 1973, pp. 296–326).

Egyptian Poetry is found in several forms, including: hymns to the gods and king; love poetry that is both beautiful and passionate, and the above-mentioned Songs of the Harper, filled with uncharacteristic pessimism and practical questioning of time-honored beliefs. Some of this poetry has been compared to the Biblical Song of Songs. It has also been noted that Egyptian love lyrics “are part of the same ancient tradition of erotic verse which we find in the cultures of the Fertile Crescent” (Erman, 1927,



Writing in Egypt in Its Literary Context, Fig. 18 Golden Bowl of Djehuty. A solid gold bowl from the tomb of the General Djehuty. He served the Pharaoh Tuthmosis III. His tomb was found at Saqqara in 1824 but the contents were distributed and the site of the tomb is now lost. Louvre Museum (Photo by Jon Bodsworth. Used with his kind permission)

pp. lviii–lxii; Erman, 1966, pp. xxxi–xxxviii; Kaster, 1968, pp. 220–233; Lichtheim, 1975, pp. 11–12; Simpson, 1972, pp. 169–326) (Figs. 19 and 20).

Egyptian hymns are not only dedicated to the gods of Egypt, but also to the kings. The most famous Egyptian hymn is the Hymn to the Aton (Aten), which, allegedly, inspired the wording in Psalm 104 in the Hebrew Bible. It is the earliest known monotheistic text in history (Pritchard, 1955, pp. 370–371; Simpson, 1972, pp. 289–295).

Egyptian letters have survived on papyrus dating as early as the Sixth Dynasty (ca. 2250 BCE). Many of the surviving letters were used as models in the education of scribes who were trained to master the style necessary for official, business, and interpersonal communication.

Egyptian Religious Texts constitute by far the greatest number of written Egyptian texts that have survived. The most common examples of this genre include the famous Pyramid Texts, the Coffin Texts, The Book of the Dead, Myths and Creation stories, Oracles and Prophecies, Hymns and Prayers, etc.



Writing in Egypt in Its Literary Context, Fig. 19 Egyptian Harp. One of several Egyptian musical instruments found in Egyptian tombs. New Kingdom period (British Museum) (Photo by Jon Bodsworth. Used with his kind permission)

The most famous of the Egyptian Mathematical Papyri and texts is the *Rhind Mathematical Papyrus* (ca.1580 BCE). It is believed to have been composed by a scribe named Ahmose during the reign of King Ahmose Auserre in the Hyksos era. It is in the British Museum.

Egyptian Medical papyri and texts are fairly plentiful. The British Museum alone has eight examples. Three of the more important ones include *The London Medical Papyrus* (#10059) which dates to the eighteenth Dynasty, *The Chester Beatty Medical Papyrus VI* (#10686) and *Chester Beatty X* (a nineteenth Dynasty text dealing with aphrodisiacs). Perhaps the most famous medical text is the *Edwin Smith Surgical Papyrus*, which is housed in the New York Academy of Medicine. Breasted published a folio-sized edition on this papyrus in 1932. It is a remarkable, scientific approach to the practice of medicine that deals with 48 different kinds of injury cases and covers surgical treatments for the head and thorax. Ancient Egyptians even knew that a mother's urine is the secret to the determination of the sex of an unborn baby. One of the remedies that it recommended for the treatment of facial wrinkles was described as a lotion that had "proved effective myriads of times." Another very important medical text, the *Ebers Medical*

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Fig. 20 Musicians from the tomb of Nebamon. A relief from the tomb of Nebamon from Thebes. Musicians and dancers accompany a feast. New Kingdom period. British Museum (EA37984) (Photo by Jon Bodsworth. Used with his kind permission)



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Fig. 21 *Amduat* scene from the Tomb of Pharaoh Ay. West Valley of the Kings (WV 23). The 12 baboons represent the 12 h of the night (Photo by Brian Anderson. Used with his kind permission)



Papyrus (in Leipzig) offers some insights into Egyptian surgical techniques. There is a section on the heart and its vessels, and one of its remedies calls for the use of castor oil as a laxative.

The Egyptian concern with the stars and planets led to serious study of astronomy. From the alignment of the pyramids with the stars to the many myths associated with the day and night-time journeys of the sun, they have left us both physical and textual evidence documenting their obsession with the universe in which they lived. The earliest evidence of Egyptian astronomical observation takes the form of a series of texts in

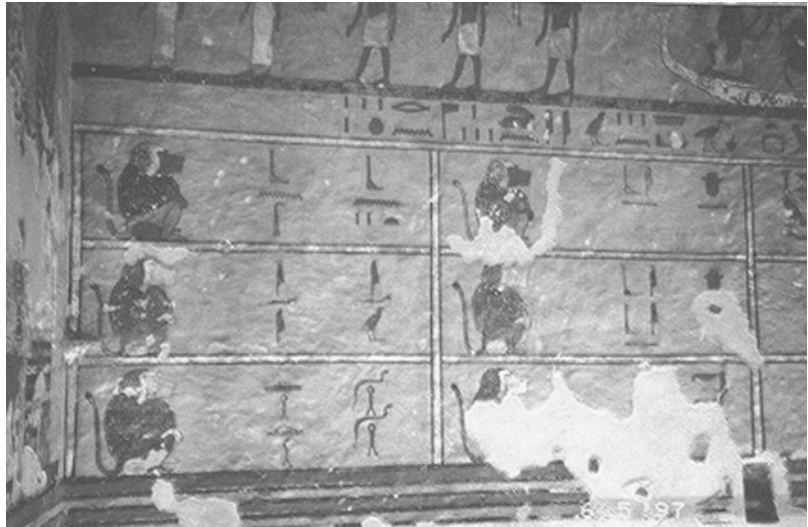
the lids of coffins dating to the Ninth Dynasty (ca. 2150 BCE) (James, 1979, pp. 124–126).

In the New Kingdom, many of the royal tombs in the Valley of the Kings were decorated with scenes from the *Amduat* (“that which is in the netherworld”) (Figs. 21 and 22).

These are found in the form of the *Book of the Day* and the *Book of the Night* in a burial chamber in the tomb of Ramses VI (1144–1136 BCE). These books deal with the day and night journeys of the sun god Ra – in the night, as he travels through the body of his mother, Nut, the goddess of the heavens, and in the day, as he travels across

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Fig. 22 *Amduat* scene from another wall of the tomb of Pharaoh Ay, West Valley of the Kings (WV23) (Photo by Brian Anderson. Used with his kind permission)



Writing in Egypt in Its Literary Context, Fig. 23 The Goddess Nut and the Book of Gates. This painted scene (from the ceiling of the tomb of Ramses VI (KV 9) in the Valley of the Kings, ca. 1141–1133 BCE) shows the upper half of the goddess Nut as she prepares to swallow her

“son,” the sun god Ra, at the end of his daily journey across the sky. The ceiling paintings portray astronomical themes as well as the various stages of the night journey of the sun god through the underworld (Photo by Brian Anderson. Used with his kind permission)

her body, after she gives birth to him once again in the endless cycle of birth, death and regeneration (Allen, 1988, pp. 38–49; Hornung, 1992, pp. 95–113; Shaw & Nicholson, 1995, pp. 29, 62, 79, 106, 273, 290, and 299; Silliotti, 1997, pp. 64–6) (Figs. 23 and 24).

Examples of Egyptian writing have survived in fairly great quantities but there are

considerable lacunae in our textual knowledge. These lacunae are the result of damage to portions of extant texts as well as to the destruction of tremendous quantities of texts recorded on perishable materials which did not survive the ravages of nature and time. We are indebted to the Egyptians for their strong desire to record their history, religious and philosophical beliefs,

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Fig. 24 The Goddess Nut and the Book of Gates (b). This scene is a continuation of the previous figure and shows the lower half of Nut's body where she gives birth to Ra at the beginning of each new day. The Book of Gates illustrates the Egyptian interest in astronomy and the universe as well as a new departure in their obsession with the afterlife and the underworld (Photo by Brian Anderson. Used with his kind permission)



as well as the fruits of their imagination and scientific, astronomical, medical, mathematical, and biological inquiries. When considering the great intellectual and cultural debt that the modern world owes to this Egyptian legacy, we can only regret that we have thus far been unable to attain the even greater quantities of writings that remain outside of our reach and understanding.

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See Also

- [Astronomy in Egypt](#)
- [Cuneiform](#)
- [Nilometer](#)
- [Pyramids in Egypt](#)

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Writing in India

This entry deals first with the evolution of writing in India in chronological order, then with the uses of writing.

Indus Civilization (c.2600–1900 BCE): A Forgotten Logosyllabic Script

The Indus or Harappan Civilization flourished in and around the Indus River in present-day Pakistan and western India c. 2600–1900 BCE. The most extensive urban culture of its time, it had its own script, which perished without descendants

when the Indus cities and their urban life-style collapsed. Thousands of short inscriptions have been preserved, mostly seal stamps and their impressions (Fig. 1). Because the Indus script has no obvious affinity with any other script (a debated issue) and because there are no multilingual texts, it is exceedingly difficult to decipher.

Indus merchants sailed to the Gulf and Mesopotamia, where about 40 seal stamps with Indus script have been found. Like the Mesopotamian seal cylinders, they were used to seal containers of goods to prevent unauthorized opening. The Mesopotamian seal inscriptions contain names and titles of the seal owners, and so do probably the Indus seal inscriptions. It is also likely that the Indus script functioned like the Mesopotamian cuneiform script.

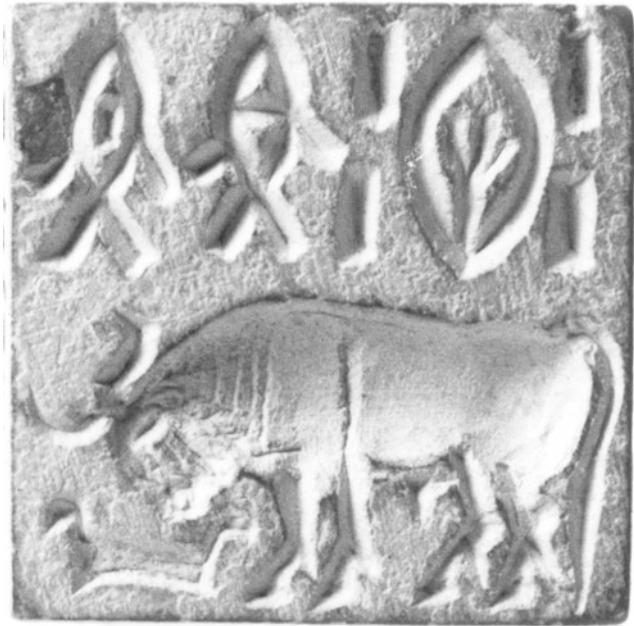
Cuneiform writing started as the world's oldest script, Archaic Sumerian (c. 3300–2900 BCE). Initially pictographic, its signs depicted human beings and animals and their body parts, plants and other things. Written on clay with wedge-shaped lines, however, the original shapes became unrecognizable, but the cuneiform script remained a logosyllabic writing system. Each sign either denoted the depicted word (logos in Greek)—an arrow-shaped sign Sumerian *ti* “arrow”—or “syllabically” its sound irrespective of its meaning —the arrow-shaped sign could also stand for Sumerian *ti* “life” or *ti* “rib.”

When the Indus script was created c. 2600 BCE, all the existing scripts were of the logosyllabic type. The Egyptian hieroglyphs and the proto-Elamite script (used widely in the Iranian plateau) were both inspired by the Archaic Sumerian script in the late fourth millennium BCE. The Indus people probably got the idea of writing from the proto-Elamites, but used their own traditional symbols and invented new ones while devising their own script.

In 2004 it was asserted that the Indus script is no real writing system reproducing speech, but only a collection of non-linguistic symbols. However, it radically differs from such symbols widely used in and around the Indus Valley for centuries right until the Indus script came into being. These earlier symbols, called

Writing in India,

Fig. 1 A seal stamp (size 20 × 20 mm) from Mohenjo-daro, engraved with the figure of a bison feeding from a trough and above it, a row of Indus script signs. The impression (in mirror image) was read from right to left (Photo Erja Lahdenperä for the University of Helsinki, courtesy Archaeological Survey of India)



“potter’s marks” because they are mainly found on ceramic vessels, usually occur one by one, whereas the signs of the Indus script occur in long and regular rows, with repeated sign sequences. The script emerged when the weights and measures were standardized and the society became more stratified and completed large and complex building projects.

The Indus script has been “deciphered” more than a hundred times. Most attempts assume the underlying language to be Indo-Aryan, which however was hardly spoken in South Asia before 2000 BCE. The horse is a very important animal in the Rigveda, the oldest surviving Indo-Aryan text composed by 1000 BCE, but the horse is not found among the many animals represented in the Indus art. On the other hand, the Rigveda contains some Dravidian loanwords. Dravidian languages such as Tamil are now mainly spoken in South India, but one (Brahui) survives in Baluchistan and the Indus Valley. Systematic and cross-checked interpretations for more than 20 signs (out of c. 400) based on the Dravidian hypothesis have been presented and won some recognition, but generally speaking the Indus script is still considered undeciphered.

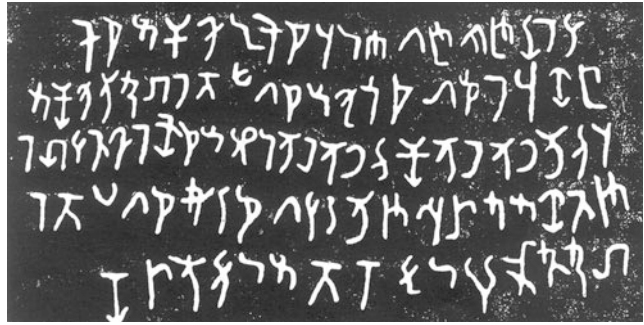
Vedic Times (c. 1300–500 BCE): Accurately Memorized Oral Literature

After the collapse of the Indus Civilization c.1900 BCE its script was forgotten. The Indo-Aryan speakers, who came to South Asia from the northwest during the second millennium BCE, were illiterate, but created sophisticated oral poetry. Over thousand hymns were assembled into a collection called Rigveda c. 1000 BCE. Elaborate repetition techniques developed to assist its accurate memorization have safeguarded the Rigveda from the hazards of oral transmission. Learning the Rigveda by heart takes 5 years of hard work in early youth, and keeping it in mind requires daily repetition. This way of memorizing Vedic texts still goes on, and their human repositories often are more reliable than manuscripts. The rules created for the preservation of oral literature have been scrupulously observed, and their further development led to astonishing achievements in the study of phonetics and grammar without the aid of writing in the first millennium BCE.

As their standard beginning (“Thus have I heard ...”) indicates, the earliest Buddhist texts of the fourth and third centuries BCE were likewise orally transmitted.

Writing in India,

Fig. 2 Kharoṣṭhī script in the Shahbazgarhi rock edict of Emperor Aśoka (c. 260 BCE). Read from right to left



Old Persian Rule (c. 500–326 BCE): Writing Re-introduced: Aramaic and Kharoṣṭhī

Around 518 BCE, Darius the Great conquered the northern and southern parts of the Indus Valley: they were attached to the Persian Empire as the provinces of Gandhāra and Hinduś for the next two centuries – until Alexander the Great took them over and soon thereafter died in 323 BCE. The Persian bureaucracy used the *Aramaic script* all over the Empire, from Egypt to India.

Aramaic is a variant of the Semitic consonantal alphabet which had been created in ancient Syria much earlier (c. 1600 BCE) on the basis of the uniconsonantal signs of the Egyptian script (where signs could express words that contained one, two or three consonants). Semitic and Hamitic (i.e., Egyptian) languages can be understood even if the vowels are left unwritten, as they usually are, but the consonantal alphabet is not so suitable for writing other languages.

The Aramaic script was adjusted for writing Indo-Aryan languages by adding markings that express vowels to the consonantal signs; if such an additional sign was missing, the respective consonant was understood to be followed by the most frequently occurring short vowel *a*; consonant groups were expressed by combining consonant signs together. Signs for consonants not represented in the Aramaic script were also created. Why this new syllabic alphabet is called *Kharoṣṭhī* is a much debated question. Kharoṣṭhī

greatly resembles the Aramaic script, also in being written from right to left. It was used in the northwest of the Indian subcontinent until c. 200 CE, and in Central Asia until c. 600 CE (Fig. 2).

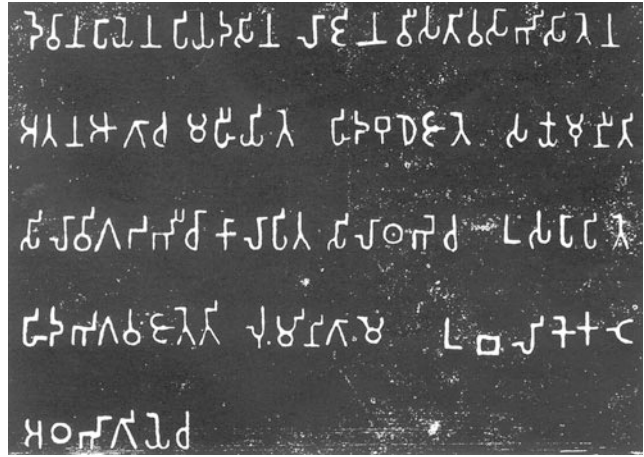
From the Mauryas to the Guptas (c. 320 BCE–550 CE): The Brāhmī Script

After Alexander's death, the Persian provinces Gandhāra and Hinduś were quickly incorporated in his emergent empire by Candragupta, the founder of the Maurya dynasty (c. 325–183 BCE). Candragupta's grandson Aśoka (in power c. 268–232 BCE) is one of the most famous rulers of India. Aśoka's rock and pillar edicts, distributed all over his large empire, are the earliest directly preserved historical records of ancient India. Written in local dialects they also provide precious information about the prevailing linguistic situation. Aśoka's inscriptions were written in the Kharoṣṭhī script, in the *Greek script* (introduced by Alexander and used by the succeeding Indo-Greeks in the Indo-Iranian borderlands) and in the *brāhmī script*, which is the basis of most writing systems used in South Asia in later times. The Indian tradition considers brāhmī as an invention of the creator god Brahṁā, who is depicted as holding a palm leaf book in the hand.

The brāhmī script is a syllabic alphabet functioning like the Kharoṣṭhī, but with its distinction of short and long vowels and different initial vowels still more perfectly adjusted to

Writing in India,

Fig. 3 Brahmi script in the Rummindei pillar edict of Emperor Aśoka (c. 240 BCE). Read from left to right



Writing in India, Fig. 4 Siddham script in the “autographed signature of me, Śrī-Harṣa, the overlord of great kings”, preserved in a Sanskrit inscription engraved on a copper tablet from Banskhera, dated 628 CE

Indo-Aryan languages, and written from left to right. It may have been commissioned by Aśoka for his rock edicts around 260 BCE; some improvements in the script appear in the pillar edicts about two decades later (Fig. 3). In that case the brāhmī script is based on the Kharoṣṭhī and Greek scripts. This recent conception about the origin of the brāhmī is however contradicted by the likewise recent discovery of potsherds inscribed with brāhmī characters in stratum J (c. 450–350 BCE) at Anurādhapura in Sri Lanka. If the dating is correct, these finds support the traditional derivation of the brāhmī script from the Phoenician consonantal alphabet long before Aśoka. Alexander’s admiral Nearchus speaks of Indians sending each other letters written on cotton cloth, but this statement limited to the northwest may refer to Persian administration in Aramaic. According to other Greek authorities quoted by Strabon, the Indians did not use writing. The Greek ambassador Megasthenes stationed in the Mauryan capital c. 300 BCE specifies that the Indians had only unwritten laws.

Post-Classical Period (550 CE Onwards): Diversified Scripts

Almost all the writing systems that are nowadays being used to write South Asian languages go back to the brāhmī script, which remained in use until the collapse of the Gupta Empire c. 550 CE. The late variety of brāhmī used in North India was c. 600 CE transformed into two principal types of script.

The *siddham* or *siddhamāṭṭṛkā* script (Fig. 4) was in general use in North India until c. 1000 CE, and the *Bengali* (Fig. 5) and *Tibetan scripts* and the *śāradā* script of Kashmir are derived from it. The siddham script spread also to Central and East Asia, being still used to write Sanskrit magical formulae in Japan.

The *nāgarī* (later called *devanāgarī*) script has been used to write especially Sanskrit (Fig. 6), Hindi, Marathi and more recently Nepalese. The *gurumukhī* script of the Punjabi language and the *Gujarati script* also go back to early variants of the nāgarī script. The southern

Writing in India,

Fig. 5 Bengali script in an autographed poem by the Nobel laureate Rabindranath Tagore (1861–1941)

প্রাণ হল প্রাণ প্রাণ (স্বা স্বাধীন)
 প্রাণ প্রাণ প্রাণ প্রাণ প্রাণ প্রাণ ।
 কি প্রাণ প্রাণ প্রাণ প্রাণ,
 কি প্রাণ প্রাণ প্রাণ প্রাণ
 প্রাণ প্রাণ প্রাণ প্রাণ প্রাণ
 প্রাণ প্রাণ প্রাণ প্রাণ প্রাণ ॥
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 প্রাণ প্রাণ প্রাণ প্রাণ প্রাণ ॥
 প্রাণ প্রাণ প্রাণ প্রাণ

अभ्यावहति कल्याणं विविधं वाक्सुभाषिता ।
 सैव दुर्भाषिता राजन्नर्थोपपद्यते ॥ ३५५३ ॥

Writing in India, Fig. 6 Devanāgarī script in a quotation from the Sanskrit epic Mahābhārata (Otto Böhtlingk, Indische Sprüche III, St. Petersburg 1895): “O King, a

kindly spoken word brings along many kinds of blessings, a harshly spoken word causes misfortune”

முகத்தா எமர்ந்தினிது நோக்கி யகத்தானும்
 இன்சொலி எஃதே யறம்.

Writing in India, Fig. 7 Tamil script in an edition of the Old Tamil classic Tirukkura (aphorism 93): “Virtue consists in speaking sweet but truthful words with a smiling face and a friendly look”

Vijayanagara empire (1336–1565) used the *nandināgarī script* imported from Maharashtra.

Tamil was written in the *brāhmī script* from the second century BCE. This South Indian variant of *brāhmī* is the basis of the relatively simple *Tamil script* used today (Fig. 7), as well as of the much more complex *grantha script* used in Tamil Nadu for writing Sanskrit, which in turn is the basis of the *Malayāam script* used in Kerala.

Kannada and *Telugu*, the two further literary members of the Dravidian language family in South India, are written in closely related script derived from the Cālukya kingdom. The Sinhala language of Sri Lanka is written in the *Sinhala script* that has evolved from the Sri Lankan variant of *brāhmī*.

The *Arabic script* imported to South Asia from Persia by the Muslims since the eighth century

CE has been used to write especially Persian – the court language of the Moghuls – and (with important modifications) Urdu – the Muslim variant of Hindi – and Kashmiri, and various minor Indo-Aryan and Iranian languages spoken in Pakistan. The *Roman alphabet* was brought to South Asia by the European colonialists who came to stay with the Portuguese in 1498, and which is used for writing not only European languages but also Konkani spoken around Goa.

Uses of Writing

Inscriptions and Coins

Because they usually can be exactly located and also dated, inscriptions engraved in stone are very important sources of political and cultural history in India. There is a continuous inscriptional tradition ever since Aśoka's edicts (from c. 258 BCE), but their number increases substantially only c. 700 CE. From c. 300 CE, royal grants of villages and the like were engraved on sealed copper tablets. Altogether c. 100,000 inscriptions in stone or metal are known today. Thousands of inscriptions in Indian languages and scripts have been discovered also outside South Asia, in Egypt, Afghanistan, Central Asia, China and most parts of South East Asia.

Numismatic material plays a crucial role also in the history of the dynasties of Iranian origin in the centuries around the beginning of the Christian era. The Indo-Greek kings are known almost exclusively from their coins. Being bilingual, these coins moreover opened up the ancient history of India. The text written in the Greek script and language on the obverse side is rendered in the Prakrit language written in the Kharoṣṭhī script on the reverse side. James Prinsep in the 1830s worked out how to read Kharoṣṭhī and applied the results to the Kharoṣṭhī inscriptions of Aśoka. These readings in turn opened up the secrets of the forgotten brāhmī script.

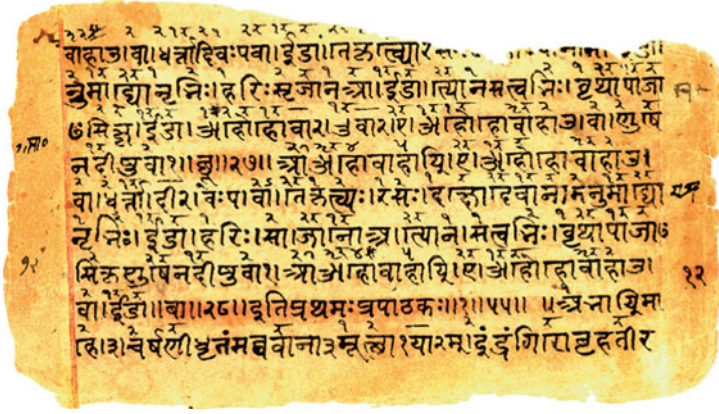
Manuscripts

The book in ancient India was usually written on long leaves of the wine palm (*Borassus*

flabelliformis), which had first been cut into regular rectangular form. Wooden covers of the same size were usually put on both sides of the bundle to protect the leaves from breaking. The ready bunch of leaves and covers was then pierced in one or two or three places in the middle, so that a rope could be inserted through the leaves to bind them together into a bundle. The long binding rope had some stopper at both ends which prevented it from coming out when the book was opened and the rope loosened: the reader places the bundle on the ground, and then turns the leaves over from one pile to another. When the book is closed, the leaves are collected together, the rope is tightened, and its long loose end is wound many times around the bundle. "Binding" the leaves thus together has given the ancient Indian book one of its Sanskrit names, *grantha*.

While writing on the empty leaves the scribe would leave some margin around the edges and the cord-holes. This was a precaution to secure that no text would be lost if the leaf was broken at its edges. The leaves would also be numbered, by putting a running number in the right or left margin of the obverse or reverse side. The margins could also be used for inserting in them corrections (for letters marked in the text with symbols of cancellation or painted over), supplementary texts (parts of text accidentally omitted in copying but noted afterwards), glosses (explanations of difficult words or expressions) or subtitles (indicating the contents of the text at that place) (Fig. 8).

The colophon at the end of the manuscript often contains not only the name of the work and its author but also the name of the scribe and possibly his genealogy and domicile and the date of completing the manuscript. Just as the author of a literary work, the scribe also starts with an auspicious word and a prayer, most frequently an obeisance to Gaṇeśa, the elephant-headed god of success, who is expected to see the task to its conclusion and to remove any obstacles. Gaṇeśa is thought to have written down the great epic Mahābhārata at the dictation of its compiler Sage Vyāsa: as the divine scribe he broke one of his tusks and used it as a stylus.



Writing in India, Fig. 8 Verso side of leaf 12 of a paper manuscript written in the devanāgarī script, dating from the seventeenth century. The manuscript contains the Āraṇyaka Gāna of Sāmaveda. Sāmavedic songs composed

c. 1000 BCE are the world's oldest known music. The small numeral signs over the lines of text are musical notation. Textual divisions are highlighted with red colour (Photo Asko Parpola)

This agrees with the South Indian practice of scratching signs on the surface of the leaf by means of a sharp iron stylus. The incised lines were afterwards made more visible by means of the juice of plants rubbed over the leaves. In North India, the scribe would use ink (made of soot) and either a brush or a pen made of reed (Fig. 8). The same methods were used if the manuscript was illustrated with miniature pictures – painted in several colours in North India, incised in South India (from Orissa to Tamil Nadu and Kerala).

In northwest India, parchment may have been used for writing during the Iranian rule, since Sanskrit *pustaka* “manuscript” or “book” is an Iranian loanword denoting “book” and “hide, parchment, bark” in the donor language. Birch bark was used as writing material in Kashmir. Paper started being used in North India around 1,000 years ago, but in South India much later. Paper used to be cut in long rectangular leaves which imitate the shape of the traditional writing material, the palm leaves (Fig. 8). The same applies to thin wooden plates that have likewise been used as writing material, especially in Sri Lanka and in communities of Indian origin in South-East Asia.

Normally manuscripts did not survive long on account of the climate and insects, even if they were treated with vegetable oils or kept in smoky

places avoided by insects. Palm leaves usually last maximally some 3 or 400 years. In exceptional circumstances palm leaves have survived much longer, however: the oldest manuscripts are from the first centuries CE and come from the dry climate of Central Asia. There they have been kept in pottery vessels – exciting discoveries of Buddhist birch bark and palm leaf manuscripts have been made in recent years in Afghanistan and northern Pakistan. Reed baskets (*piṭaka*) have provided another and more usual implement for storing manuscripts: at one time the entire Buddhist canon could be put into three baskets. In ancient India, temples, monasteries, royal palaces and even private persons had manuscript libraries, which could contain even tens of thousands of volumes. Today millions of Indian palm leaf or paper manuscripts survive in public and private libraries in and outside South Asia.

On account of their poor durability, texts to be preserved in writing had to be copied over and over again, which led to accumulating mistakes. Such copying mistakes have distorted literary texts, but if a number of manuscripts are available, their comparison may enable reconstructing a genealogy of copying and reconstituting the original text.

Palm leaves have been used in South India until the early twentieth century not only for writing literature, but also for book keeping and

for legal documents, with seal impressions attached. On the other hand, literature – especially voluminous Vedic texts – has been handed down also in a millennial oral tradition until the present day.

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Writing in Japan

Christopher Seeley

The modern Japanese writing system employs predominantly a combination of Chinese characters (1445 are taught in school education) and syllabic signs called *kana* (close to 100 in total, in two sets, viz. the angular *katakana* and the more rounded *hiragana*) (Henshall, Seeley, & de Groot, 2003). These are used together with an admixture of other signs such as Arabic numerals and Roman letters. The following sentence is an example of how the different elements function together:

Otōto wa sugoi esu-eru mania de, jūnigatsu ni mata Suisu e iku koto ni natte imasu. 'My younger brother is a huge fan of steam locomotives, and it has been arranged for him to go to Switzerland again in December.' Chinese characters are used for the noun *otōto* 'younger brother', the suffix *-gatsu* 'month (of the year)' and the first part of the stem of the verb *iku* 'to go'. *Hiragana* are employed for elements which include particles such as *wa* (topic indicator), *e* 'to, towards', for the adjective *sugoi* 'great; awful' and the second syllable of *iku* and also for the post-verbal

construction *koto ni natte imasu* ‘it has been arranged to —’. *Katakana* represent two European loanword items (*mania* ‘fan, enthusiast’ and *Suisu* ‘Switzerland’), while an acronym-type European loan (*esu-eru*) is represented by upper case Roman letters. Arabic numerals are used here to represent *jūni* ‘twelve’ in *jūnigatsu* ‘December’, which can otherwise be written all in characters, viz. 十二月 (id.).

Although still very complicated, the system in use today represents a substantial simplification of that which was employed in the early part of the twentieth century. It reflects a heritage of cultural and linguistic history in Japan that extends back to early in the first millennium A.D.

Around 400 A.D. the Japanese, who at that time had no writing of their own, actively adopted Chinese writing. At this very early period, it was the Chinese language, not Japanese, which was represented directly in written form. Due to the difficulties associated with using what for the Japanese was a foreign language, together with a very large and complicated character set, initially there was heavy reliance on Chinese and Korean scribes (Seeley, 2000, pp. 3–15).

As time went by, the Chinese script was adapted to represent the Japanese language, sometimes directly, but often in a convoluted manner. The *Kojiki* (*Record of Ancient Matters*) of 712, notable as the earliest large-scale compilation to have survived to the present, constitutes a useful example of such adaptation. The *Kojiki* preface is in Chinese, which was appropriate as the most formal style in a document addressed to the sovereign; the main part of the text is in a hybrid form which reflects Japanese influenced by Chinese (selected by the compiler with the stated aim of ease of reading [!]). The Japanese songs interspersed in the text are represented by Chinese characters employed for their sound value so as to minimise the ambiguity of reading in material of an oral nature (Seeley, 2000, pp. 40–46). At an early period, the Japanese had the means to represent their own language directly in writing, but the overwhelming prestige of Chinese culture meant that more often than not they chose a Chinese-orientated style.

Despite the high standing of written Chinese in Japan (and Japanese attempts at

Chinese composition), direct representation of Japanese also had its place, and this more straightforward form of writing enjoyed a substantial rise in popularity from around 900 A.D. This was due to a development early in the ninth century in the context of Buddhist works in Chinese. Abbreviated Chinese characters employed for their sound value as phonograms – the forerunners of modern *katakana* (used today for such purposes as representing loanwords of mainly European origin) and *hiragana* came to be used quite extensively as a convenient means of annotating the text, albeit sometimes only minimally and sporadically, to help read or ‘decode’ it as Japanese. Abbreviation was achieved through a process of (1) writing rapidly (cursively) and thereby omitting strokes (e.g., 女 > め *me*, 弟はすごい S L マニアで、12月にまたスイス波 > は *ha*) or (2) isolating one part of a character phonogram and taking it to represent the whole (e.g. 保 > 呆 *ho*, 加 > カ *ka*). After a time, *katakana*-type signs tended to be favoured for utilitarian purposes such as annotation, while *hiragana*-type signs came to be used extensively for Japanese poetry and prose. Women were seldom given the opportunity to acquire grounding in Chinese characters, and the convention arose whereby writing in phonograms of the cursivised variety tended to be associated with women. This is reflected in the early term for *hiragana*-type signs, *onna-de*, and ‘women’s hand/script’. This is best understood as meaning the script typically used by women rather than exclusively by them, for men certainly sometimes employed kana of this type (Seeley, 2000, pp. 59–89).

While some Japanese texts were written entirely in kana, much more commonly there was at least a small admixture of Chinese characters. In the early period, characters were sometimes employed as a convenient means of representing Chinese loan morphemes which involved sound segments difficult to represent in a still emergent system of kana signs. Orthography of this general type, which involved a combination of characters and kana, gradually assumed a position of increasing importance; the role played by Chinese characters as a guide

to disambiguating what would otherwise be a Japanese text consisting of a long string of kana signs spaced equidistantly should not be underestimated.

In spite of the above developments, broadly speaking, the cultural and linguistic importance of China continued to be very strong. Written Chinese, or rather an approximation of it, continued to be widely perceived as highly prestigious until modern times, is being used even at the beginning of the Meiji period (1868–1912) in some Japanese newspapers. Increasingly, though, the leaders of Japanese society were being influenced by the West. As a result of extensive debate on language and script, a movement evolved around the end of the nineteenth century with the aim of bringing written language more in line with spoken language (the *Genbun itchi* [Unification of Speech and Writing] movement) (Twine, 1991), and there was also support in some quarters for reducing the number of different Chinese characters in general use. In the year 1900 the Education Ministry (Monbushō) published a list of about 1,200 characters for use in primary school texts, together with a standardised set of kana signs and a partially simplified form of kana usage. However, there was still strong opposition from conservative elements to reform the writing system.

A radical turning point in the Japanese writing system occurred in the 1940s, following Japan's defeat in the Pacific War. In that very different environment, simplification of the written language and script was espoused as part of the movement to promote democracy. Changes effected included the adoption and promulgation in 1946 of a list of 1850 Chinese characters approved for active general use called the *Tōyō kanjihyō* (List of Interim Use Chinese Characters), followed by several supplementary lists aimed at restricting the number of readings associated with individual characters and increasing the number of officially approved simplified character shapes (e.g., 廣  へ行くことになっています。広, 藝  >芸). A more rigorous restriction took place in the area of given names which parents chose for newborn children: whereas previously it was

permitted to use any Chinese characters out of a potential corpus of tens of thousands, from late 1947 parents found themselves restricted by law in choosing from just the 1850 in the Interim Use List, or alternatively to use kana. This change was seen by many as excessive, and in 1951 this restriction was eased through a supplementary list of additional characters for use in names. 1970 onwards a significant relaxing of guidelines and regulations regarding the range of Chinese characters were used. The year 1981 saw the Interim Use List replaced by a modestly expanded new list (1945 characters) called the *Jōyō kanjihyō* (List of General Use Chinese Characters), which was given the status of a guide (*meyasu*) for usage, and the name character list has been repeatedly expanded, consisting now of close to 300 characters (Seeley, 2000, pp. 152–187).

In the Interim Use List era and before, advocates of script reform argued that kana or Romanisation should be adopted for Japanese because of the difficulties associated with mechanical production of text. A manual typewriter for Japanese was devised early in the twentieth century, but it required a specialist operator, and only about ten pages a day at most could be produced. The strength of the argument for script simplification was, however, compromised in the late 1970s with the development of a word-processor which featured Japanese language input in Romanisation or kana and output in conventional (character and kana) Japanese text. The mid 1980s then saw the appearance of portable and affordable machines which gave consumers the ability to handle Japanese text with output which encompassed the Chinese characters contained in a standard corpus of about 6,300 Chinese characters determined for universal data exchange by the Japan Industrial Standards Institute (Gottlieb, 2000; Seeley, 1994).

The popularisation of word processors and computers from the 1980s for Japanese has led to a significant rift between the number of characters taught in the school system and the corpus by more than three times the size accessible via computer-generated text. This discrepancy needs to be addressed and somehow accommodated.

Despite associated problems such as this, what seems certain is that the position of Chinese characters as a central feature of the Japanese writing system is assured for the foreseeable future.

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Writing in the Middle East

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Writing and the alphabet were two of the major inventions of the human mind. They were conceived and developed in the Middle East between about 3500 and 1000 BCE. Other writing systems appeared in China about 1200 BCE and in Central America during the first millennium BCE, probably independently, although the Chinese may have been indirectly influenced from Babylonia.

Cuneiform Writing

Writing began over 5,000 years ago in the developing urban culture of southern Mesopotamia known as the Uruk IV period. At first simple pictures were scratched on stone or clay tablets held in the hand. Some showed a complete object, such as a fish, and others part of an object, such as the head of a cow, while others cannot be identified. More than 1,200 signs were used in the

oldest known texts, which deal with the income and expenditure in kind of temples. The number of signs soon shrank to about 600, and as well as serving as word-sign (logograms), many also came to be used phonetically (phonograms) on the rebus principle. Thus in English the picture of a thin man beside a king read as ideograms could mean “The thin man is king” or “The king is a thin man,” but taking their values phonetically could yield the two syllables of “thinking,” a concept harder to express pictorially. The rebus principle enabled the script to express any words, including foreign terms and names. The syllabic signs are vowels (*a, e, i, u*), “open” (e.g., *ba, gi, du, am, ir, uz*) and “closed” (e.g., *bab, gim, dur*), and some longer ones (e.g., *alad, gibil*) (Fig. 1). Additionally, a small number of signs were placed before or after word signs to indicate their class. These determinative signs mark categories such as “man,” “woman,” “wooden object,” “fish,” “pot,” and plurality. By 3000 BCE the language of the texts is evidently Sumerian, a language unrelated to any other now known, and it is likely the script was invented by Sumerians. The Sumerian language appears to have many homophonous words, which suggests it may have been tonal, and so several signs can have the same phonetic value when transcribed into roman letters, which scholars distinguish by accents and subscript numbers (thus *sá* “to be equal,” *sa₄* “to name,” *sa₁₀* “to buy”). Simplification for speed and impressing a reed stylus on clay produced angular strokes and resulted in the signs rapidly losing their pictorial form, so becoming the wedge-shaped or cuneiform script. The range of texts expanded over the centuries from the accounts and lists of words by category of the earliest period to embrace almost every type of written composition. By ca. 2500 BCE archives of clay tablets include hymns and prayers, proverbs and wise advice, riddles, legends and myths, and brief historical records. At that time the script was adapted for writing the East Semitic Akkadian language (ancestral to Babylonian and Assyrian). Word signs could now be read in Akkadian, and a much wider use of phonetic values of signs became common as words were written syllabically (e.g., the word

Pictorial c. 3000 BCE	Cuneiform c. 2,500 BCE	c. 1,800 BCE	c. 650 BCE	Meaning	Sumerian	Akkadian	Syllabic values
				'hand'	shu	<i>qātum</i>	shu,qat
				'mouth'	ka	<i>pûm</i>	ka
				'wood'	gish	<i>its</i>	its, ets. Gish

Writing in the Middle East, Fig. 1 Cuneiform signs: their meanings and their development. *Column 1* pictorial, ca. 3000 BCE. *Column 2* cuneiform ca. 2500 BCE. *Column 3* ca. 1800 BCE. *Column 4* ca. 650 BCE. *Line 1*, meaning “hand,” Sumerian *shu*, Akkadian *qātum*, syllabic

values *shu*, *qat*. *Line 2*, meaning “mouth,” Sumerian *ka*, Akkadian *pûm*, syllabic value *ka*. *Line 3*, meaning “wood,” Sumerian *gish*, Akkadian *its*, syllabic values *gish*, *its*, *ets*

sign “bull’s head,” read in Sumerian as *gud* and in Akkadian as *alpum*, could be written *al-pu-um*). While some texts were written almost wholly with syllabic signs, especially in the early second millennium BCE (the Old Babylonian period), scribes usually wrote with a mixture of syllabic and word signs, preceded or followed by the determinative signs. This system continued until the beginning of the Christian era, spread across the Near East, especially in the second millennium BCE, and was adopted for writing unrelated languages such as Elamite in Iran and Indo-European “Hittite” languages in Anatolia. The tens of thousands of clay tablets in modern museums attest the activity of scribes in writing down almost every aspect of life, but the script never lost its complexity, and so writing remained a specialized craft, usually the monopoly of the trained scribe.

Egyptian Writing

Egyptian hieroglyphic writing began almost simultaneously with the ancestor of the cuneiform script in Babylonia and was possibly influenced by it. (There are clear signs of other influences from Mesopotamia in Egyptian culture at the end of the fourth millennium BCE, e.g., the distinctive cylindrical seal.) The hieroglyphs are pictures and from the first were closely associated with narrative art, as is evident in predynastic carvings (e.g., the Narmer Palette) and thousands of later sculptures

and objects of all kinds. They were employed both as word signs (ideograms) and, through the rebus principle, as sound signs (phonograms). In the early stages over 1,000 signs occur, a number soon diminishing to 600 or 700 which were in regular use until Hellenistic and Roman times when the number multiplied enormously. In their day-to-day activities, clerks, writing rapidly on papyrus, reduced the hieroglyphic script to a cursive form, known as hieratic, examples occurring from the earliest dynasties onward. A highly cursive and abbreviated script, demotic, developed in the first millennium BCE and continued beside the hieroglyphs well into the Christian era. Both hieratic and demotic were written from right to left; the hieroglyphs could run in any direction. The hieroglyphs are, to modern eyes, purely consonantal; the ancient readers supplied the appropriate vowels, facilitated by the structure of the language, as in the West Semitic “alphabet” (see below). There are three classes of hieroglyphs giving phonetic, apart from their ideographic, values. The 26 with a single consonant are often called the Hieroglyphic Alphabet, but it is important to recognize that the Egyptians did not separate them from the other signs. Each of these seems to denote the dominant sound of the word represented (e.g., *n* from *nt*, “water”; *dz* from *w’dzyt*, “cobra”). About eighty signs are biliteral and seventy trilateral. These phonograms often followed an ideogram, in effect “spelling out” its value, thus accompanying the sign for “pyramid,” *mr*, could be the two consonant sign *mr* and the



Writing in the Middle East, Fig. 2 Egyptian hieroglyphs: $mr + m + r + \text{pyramid} = \text{"pyramid"}$

“alphabetic” signs *m* and *r* (Fig. 2). In addition, a range of determinative signs marked categories of terms, the best known being the oval cartouche enclosing pharaohs’ names. Problems in representing foreign names in the early second millennium BCE led to a special combination of signs to produce syllabic spellings, called “group writing” or “syllabic orthography.” Egyptian scribes normally wrote on papyrus which decays rapidly when buried except in very dry situations, so most of their work is lost. Enough survives to show that, although appearing needlessly complex, the Egyptian writing system could express as wide a range of ideas as the Babylonian. Its complexity meant that it remained a specialist skill, practiced by, it is estimated, less than 1 % of the population.

Other Ancient Scripts

The second millennium BCE – the Middle and Late Bronze Ages in archaeological terms – saw a proliferation of writing systems. In Anatolia, the Indo-European-speaking Hittites invented a hieroglyphic script for writing the Luwian language, about 1600 BCE. It is known from stone monuments, seals, and a few documents engraved on lead strips, but it is likely it was written more extensively on wooden panels, now perished. It has a basic syllabary of 70 consonant + vowel signs, a few more complex syllabic signs, and 78 logograms for commonly occurring terms (e.g., king, country) and so is similar in concept to the Cretan scripts (see below). The values of the syllabic signs appear to derived acrophonically from the initial syllable of the word each picture depicted. After the Hittite empire ended ca. 1200 BCE, smaller

kingdoms in Turkey and north Syria continued to write with the hieroglyphs until the seventh century BCE.

Similar to the Hittite hieroglyphs are the scripts found in Crete, the Cretan hieroglyphs and, perhaps descended from them, Linear A and Linear B. Only the last has been convincingly deciphered, revealing a simple syllabary of 54 consonant + vowel signs and five vowel signs, with numerous logograms which sometimes have their names written syllabically beside them, all recording an early form of Greek. Linear B was scratched awkwardly on clay tablets and was probably also written on wax tablets and other perishable materials. Apparently an offshoot of Cretan writing is the Cypro-Minoan system current in Cyprus in the Late Bronze Age, with rare examples found in the Levant. Like Linear B, surviving examples are on clay, but impressed with a stylus rather than scratched. They seem to record notes of ownership or delivery and longer compositions, but the script remains unread. Later in the first millennium, the Cypriot syllabary of 50 consonant + vowel signs and five vowel signs survives on stone, pottery, and coins. It is clearly a continuation of the Cypro-Minoan signs, probably applied to a different language, and can be read, thanks to texts with parallel versions in Greek.

A clay disk found at Phaistos in Crete is a unique representative of a pictographic script impressed on the surface by 45 separate dies in various arrangements, a precursor of printing. It may have been brought to Crete from Turkey, but without other examples, there is little likelihood that it can be understood. Its authenticity is questioned.

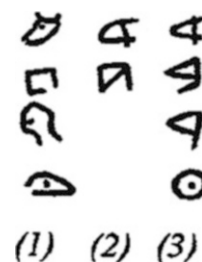
At Byblos, north of Beirut, a dozen documents were unearthed inscribed with signs evidently forming a large syllabary of 114 signs, fairly clearly based upon the Egyptian hieratic script. These “pseudo-hieroglyphs” of the mid-second millennium BCE await convincing decipherment. There are other, isolated, specimens of writing systems which cannot yet be read. Short texts scratched on clay tablets about 1200 BCE at Tell Deir ’Alla in the Jordan Valley are reminiscent of Cretan Linear B, but clearly not the same script.

The Alphabet

Out of this medley of scripts, one arose early in the second millennium BCE which would ultimately have the greatest impact since the invention of writing. A scribe working in the Levant, perhaps in Byblos, found none of the scripts available to him, Egyptian and cuneiform, suitable for registering his West Semitic language, so he created a system in which each sign stood for a major consonantal sound (phoneme). It seems that he drew a series of simple pictures and used each to stand for the initial sound of its name, thus “door” = d (the acrophonic principle), yielding between 20 and 30 signs. In the West Semitic languages (e.g., Canaanite, Aramaic, Hebrew, Phoenician), no word began with a vowel, and it proved possible to represent the languages adequately without signs for vowels, so at first they were not marked at all. That continues to be basically true for Arabic and Hebrew today. The system was not, therefore, a true alphabet, which should have a sign for each major sound in the language, whether consonants or vowels, but the term can be applied to it and its descendants for convenience. The scribe was accustomed to the Egyptian practice of writing with ink on papyrus and followed the Egyptian direction, writing from right to left, as Arabic and Hebrew are still written. The use of perishable papyrus sheets and wooden tablets coated with wax means that most examples of this Canaanite Linear Alphabet are lost. A few specimens scratched on metal, stone, and pottery have been found at Middle Bronze Age sites in Canaan, and two were discovered on a rock at Wadi el-Hol on the desert road across the bend of the Nile north of Thebes. The date of these two is debatable, but they certainly belong to a very early stage in the history of the script. More extensive examples come from the area of turquoise mines at Serabit el-Khadem in western Sinai. They were apparently written in the middle of the second millennium by workmen imported from Canaan who revered the mother-goddess, Egyptian Hathor, whom the Egyptians entitled “lady.” Although brief or badly damaged, so far as these inscriptions can be read, they refer to “lady” also (West Semitic *ba’alat*). The signs in

Writing in the Middle East, Fig. 3 Development of the early alphabet.

Column 1, Sinai mines, ca. 1500 BCE. *Column 2*, Canaan, ca. 1400 BCE. *Column 3*, Canaan, ca. 1200 BCE



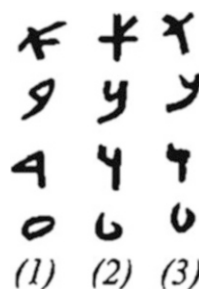
these “Proto-Sinaitic” inscriptions appear in more developed forms scratched or painted on various objects from Late Bronze Age Canaan, and by about 1000 BCE they are almost standardized across the Levant, their number reduced to twenty-two, as examples from Byblos and other sites show (Fig. 3).

Two or three centuries earlier, scribes at Ugarit (now Ras Shamra) on the coast of Syria, trained in Babylonian tradition, realized the Canaanite Linear Alphabet was better suited to their West Semitic language than Babylonian cuneiform and imitated it by creating a cuneiform “alphabet” of twenty-seven signs, then adding three to mark sounds necessary for recording the completely different Hurrian language. Scribes at Ugarit used their script to write every type of text – letters and administrative documents, rituals, legends, and myths – on clay tablets. Their survival in the ruins of the city illustrates the sort of documents which it can be surmised were written also in Canaan, but they have perished. A very few pieces of Ugaritic writing from other sites in the Levant, as far south as Beth Shemesh west of Jerusalem, demonstrate its spread, but the script disappeared with the collapse of the Late Bronze Age city-states.

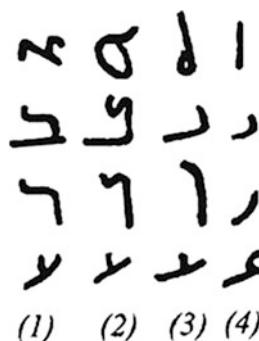
It was the Canaanite alphabet that survived the chaos at the end of the Late Bronze Age to be adopted widely. One form spread into Arabia where it became the North and South Arabic scripts, the former being known mainly from graffiti which shepherds and travelers left on rocks from the sixth century BCE to the Islamic period, the latter being attested in thousands of inscriptions on stone in the Yemen and Hadhramaut from the ninth century BCE until the seventh century AD. An offshoot of the South Arabic script

survives in the Ethiopic alphabet which has augmented the letters to mark vowels. The other form of the Canaanite alphabet was adopted by the new West Semitic-speaking kingdoms and eventually eclipsed all other writing systems in the region. The Israelites occupying Canaan found the script appropriate for Hebrew (except that it did not provide two signs to distinguish the phonemes *s* and *š*). They used this “Phoenician” or “Old Hebrew” alphabet until the Persian period, continued it for some literature, and revived it for nationalistic purposes in the Roman period. Aramaean kingdoms wrote their language with the same alphabet, despite the lack of signs to distinguish certain sounds (e.g., *t* and *ṭ*). Already in the ninth century BCE Aramaean scribes gave some characters a double value, noting both consonants and long vowels (e.g., one sign for *w* and *û*, one for *y* and *î*). Under the Persian Empire (539–331 BCE), the Aramaic language and form of script, which had been spreading widely under Assyrian and Babylonian rule, became the common vehicle of administration from the Indus to the Aegean, from the Black Sea to Egypt and the Red Sea (Fig. 4). The Jews used it for writing Hebrew, and, slightly developed, it has been the Hebrew alphabet ever since. Aramaic speakers in southern Turkey, in the area around Urfa and Haran, derived from it the forms of cursive script known as Syriac (Estrangelo and Serto) still read among Christian churches of the Middle East. Another form arose in the caravan city of Palmyra (first to third centuries AD.). Most significantly, Nabataean Arab tribes in southern Syria and Jordan began to write with the Aramaic alphabet in the last centuries BCE, and their cursive letters, known from a few papyri surviving dehydrated in caves near the Dead Sea and some other examples, are clearly the origin of the Arabic alphabet (Fig. 5). Thus the modern Arabic and modern Hebrew alphabets have the same ancestor. However, in the cursive Nabataean of the early Christian centuries, the shapes of some letters had become almost indistinguishable (e.g., *r* and *z*), and the Arabic language distinguished more consonantal sounds than the Aramaic alphabet marked, so dots were added above or below certain letters to distinguish some and to create new ones. In Syriac,

Writing in the Middle East, Fig. 4 Letters used in Hebrew handwriting ca. 600 BCE (1), Aramaic writing on stone, ca. 400 BCE (2) and on papyrus or leather, ca. 400 BCE (3)



Writing in the Middle East, Fig. 5 Letters in forms used in Hebrew handwriting, first century (1); Nabataean inscriptions, first century (2); Nabataean documents, second century (3); early Arabic (4)



Arabic, and Hebrew, besides some signs for consonants marking long vowels as well, small marks were added in the early Middle Ages above, below and occasionally within the letters to indicate all the vowels necessary for public reading of sacred texts such as the Gospels, the Torah, and the Qur'an. As Islam spread, it carried the Arabic script with it, and so it came to be applied to non-Semitic languages. For Persian, additional diacritical marks were placed on four letters to mark Iranian phonemes, and for Ottoman Turkish, modifications were needed for six. In 1928, in the Kemal Atatürk's modernization program, the Ottoman script was replaced with roman letters, augmented by diacritical marks to 29 characters (Daniels & Bright, 1996).

The Aramaic, Hebrew, and early Arabic scripts are known today from haphazard collections of inscriptions on stone and other hard surfaces and from rare groups of texts on papyrus, mostly found in Egypt. The reduced number of signs, 22–28, made the tasks of writing and reading simpler than for Babylonians, Egyptians, or Hittites, and so more people may have learned to read and write,

Writing in the Middle

East, Fig. 6 Semitic alphabetic script. *Column 1*, Phoenician, ca. 1000 BCE. *Column 2*, Moabite, ca. 830 BCE. *Column 3*, Greek, ca. 700 BCE



but widespread literacy did not result. For most people, there was no need for either skill, and if they had the need, they could find a professional scribe. Nevertheless, there is some evidence for a proportionately wider distribution of writing in ancient Israel than in neighboring lands (Millard, 1995).

On the coast of Lebanon, scribes in the Phoenician cities (Tyre, Sidon, Beirut, Byblos) continued to write with the Canaanite Linear Alphabet. Their products are almost entirely lost, only a few texts on stone, metal, and potsherds surviving. It was from them that the Greeks learned it. Greek could not be written intelligibly without marking vowels (otherwise there was no way to write the Greek word for “no,” *ou*), so signs for Phoenician, Semitic, phonemes alien to Greek were given new values as vowels, partly in line with the use of some consonants to mark long vowels in Aramaic (e.g., *w* for *û*, *y* for *î*). That yielded the first true alphabet (Fig. 6).

See Also

► [Cuneiform](#)

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Writing: Maya Writing

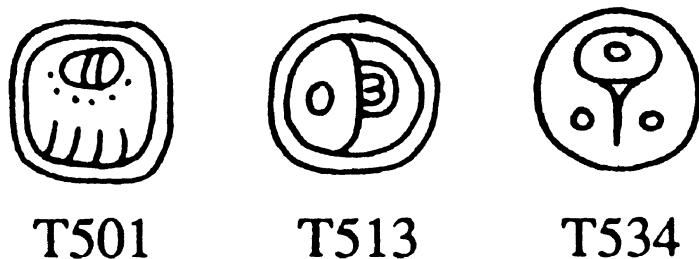
Tom Jones

Some dozen or so writing systems have been identified as having been in use at one time or another in ancient Mesoamerica, all sharing a number of general traits that include (1) pictographic signs, clearly derived from things seen, used in combination with wholly abstract signs, the derivations of which remain obscure; (2) a reading order that generally proceeds from top to bottom and from left to right; (3) a vigesimal number system (base 20) with a dot representing the unit, generally in conjunction with individualized signs for numbers of higher orders of magnitude, though in certain areas, in conjunction with bars for “5” and other signs for “0” to express higher numbers; and (4) a shared, compound, cyclical calendar of 260×365 (18,980) days’ duration, expressed with readily identifiable calendrical elements such as numbers, day names, year signs, and periods of various magnitude.

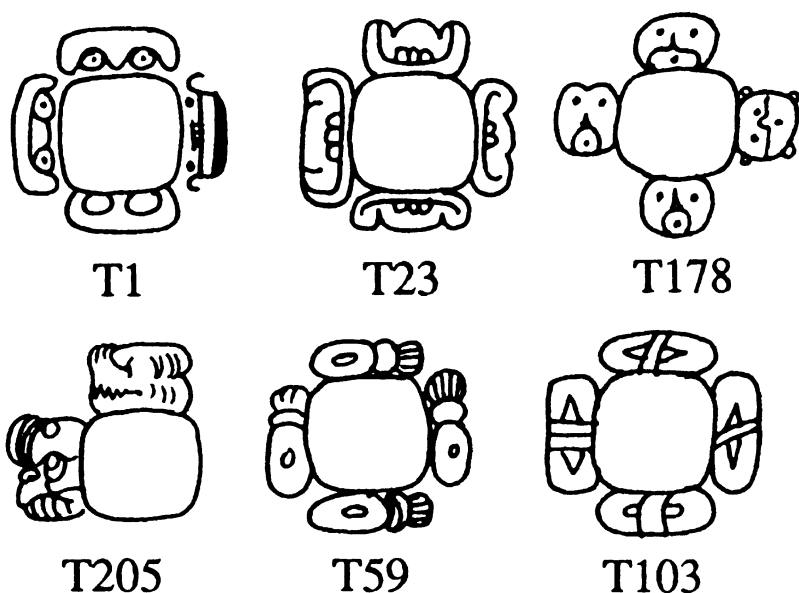
The most sophisticated writing system – and certainly the most intriguing – of Mesoamerica, and that which will serve as the basis for this discussion, is the “hieroglyphic” writing of the Maya region. Examples of Maya hieroglyphic writing are known from many sources: from carved monumental inscriptions in stone and wood, painted stucco-coated, screen-fold, paper books, or “codices”, painted and carved ceramic pots, cups, bowls, and dishes, and from other portable artifacts of stone, shell, ceramic, and bone. The visual style, syntax, and content of the writing was shaped by both the nature of the medium upon which it appeared and the message to be conveyed.

Though open to doubt for many years, there is no question today of the Maya writing system not being true writing. It follows linguistically logical rules of syntax, phonetic construction, and semantic expression, although with the same

Writing: Maya Writing,
Fig. 1 Main signs with
T-numbers



Writing: Maya Writing,
Fig. 2 Affixes with
T-numbers



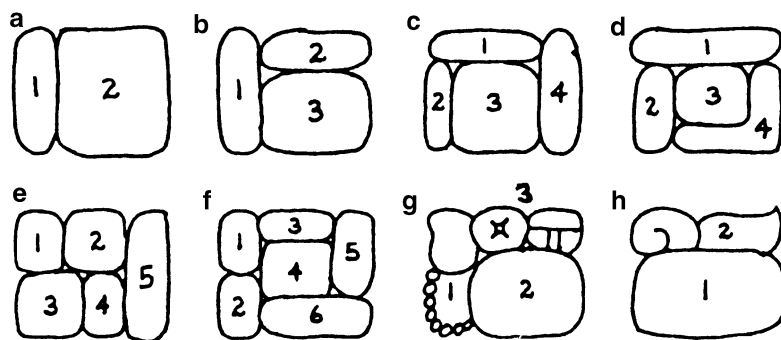
willful departure from those rules as that of creative writers of our own culture – even, at times, to the point of whimsical defiance. The Maya hieroglyphs were capable of accommodating the full range of both the sounds and the syntactical structures of spoken Mayan. Indeed, the relatively narrow range of subject matter of extant Maya writing is surely more of a reflection of its differential survival on imperishable artifacts than of any limitations in the writing system itself.

The typical Maya monument inscription is composed of a number of tightly formed glyph-blocks arranged in vertical columns and horizontal rows, with the glyph-blocks formed of glyphic elements of two general sorts: relatively large ones – known as “main signs” – generally positioned at the center of glyph-blocks and occupying most of the area (Fig. 1), and smaller

ones – known as “affixes” – often positioned before, atop, after, or beneath the main signs, and sometimes (in the absence of a main sign) forming clusters of their own (Fig. 2). In his 1962 *Catalog of Maya Hieroglyphs*, Eric Thompson attempted a classification of all the known glyphs of his time, assigning to “affixes” the numbers 1–370, and to “main signs” the numbers 501–856, with what he called “portraits” receiving the numbers 1000a–1087. The study and discussion of Maya writing have benefited enormously by the preferred use of these *T*-numbers (as they are called) over the arbitrary nicknames and labored descriptions of individual glyphs that once necessarily dominated their study.

Nevertheless, epigraphic study since the publication of Thompson’s *Catalog* has shown that this main sign/affix distinction is an artificial one.

Writing: Maya Writing,
Fig. 5 Reading order for
 the elements within a
 glyph-block



some 77 consonant-vowel (cv) syllables, leaving undetected but 23 of the 100 probable sounds employed in the ancient script. At the same time, in addition to the signs for the 20-day names, about 90 glyphic elements have been demonstrated to represent consonant-vowel-consonant (cvc), or even more complex, morphemes. Thus, words can be recorded by using a single morphemic sign (should there exist one that signifies the desired word), by assembling a phonetic construction from cv-signs that sound it out, in which case the final vowel sound is dropped, or by combining the two, perhaps using a cv-sign as a (silent) phonetic complement to reinforce the pronunciation of the intended word.

In addition to the aforementioned options available to the Maya scribe, there were four further features of the writing system:

1. Allographs are multiple signs that were used interchangeably to express the same phoneme. The sound *u*, for example, could be expressed by any one of at least a dozen different allographs (Fig. 6a).
2. Puns are single signs used to express homophonous words of multiple semantic value. As an example, the Mayan word *chan* means “snake”, “sky”, and “four”. The glyphs for these three meanings could be used interchangeably to convey the sound *chan*, with the intended semantic value, which was sometimes multiple, to be inferred from the context (Fig. 6b).
3. Polyvalent signs are single signs of multiple phonetic and/or semantic value which, again, are best understood from

their context. Thus when the sign T528 appears framed by the day-name cartouche (serving as a semantic determinant), it is understood to represent the name of the day *Kawak*; when it appears suffixed with T116, the sign for **ni** (serving as a phonetic complement), it is understood to represent the term **tun** (“stone” or “year”); and when it appears with no affixes, it *usually* represents the syllable *ku* (Fig. 6c).

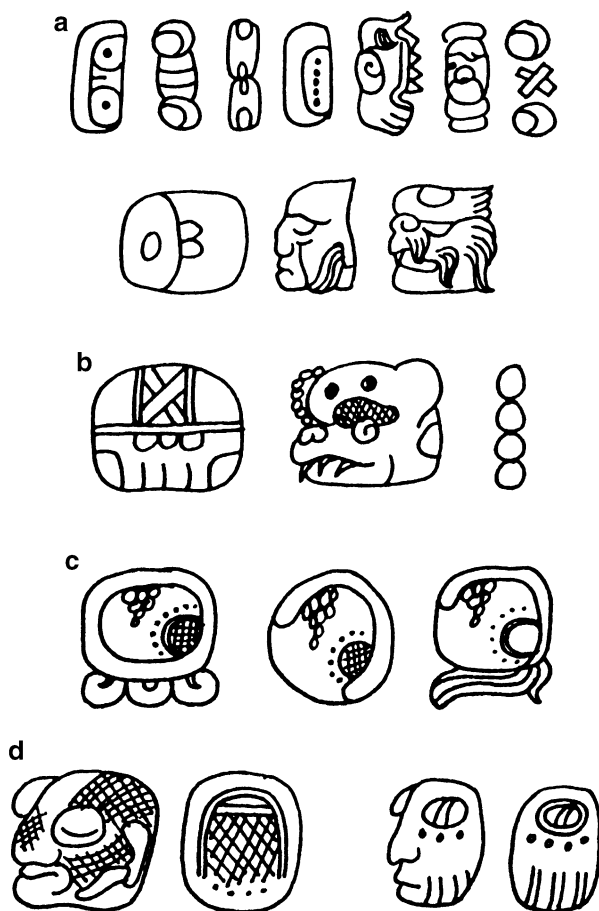
4. Head variants are main signs modified from their generally rounded forms into the profile heads of persons or monsters that retain their diagnostic markings (Fig. 6d).

The range of possible sizes of the various glyphic elements, their substitutability and variety of appearance (anthropomorphic, zoomorphic, and abstract), their use as cv syllables, cvc morphemes, and phonetic complements, all go toward accounting for the rich variety of visual expression that characterizes the Maya hieroglyphic writing system. Though many words could be written with a single glyph, those same words could also be expressed in other ways. As an example, the word for *balam* (jaguar) was variously expressed by using the sign that represents both the word and the concept (Fig. 7a), by using the signs for the syllables *ba*, *la*, and *ma* (Fig. 7b), by using the sign for **BALAM** with *ma* as a phonetic complement (Fig. 7c), or by using the **BALAM** sign with both **ba** and **ma** complements (Fig. 7d).

Similarly, *pakal* (shield) was expressed by using a sign that portrays a shield (Fig. 8a), by the signs

Writing: Maya Writing,

Fig. 6 (a) Ten allographs for the phoneme *u*. (b) Three signs for chan: “sky”, “snake”, and “four”. (c) Polyvalency of T528, as the day-name *Kawak*, the phoneme *ku*, and with phonetic complement *ni* to spell **TUN**-(ni). (d) Head variants for the phonemes **pa** and **ba**

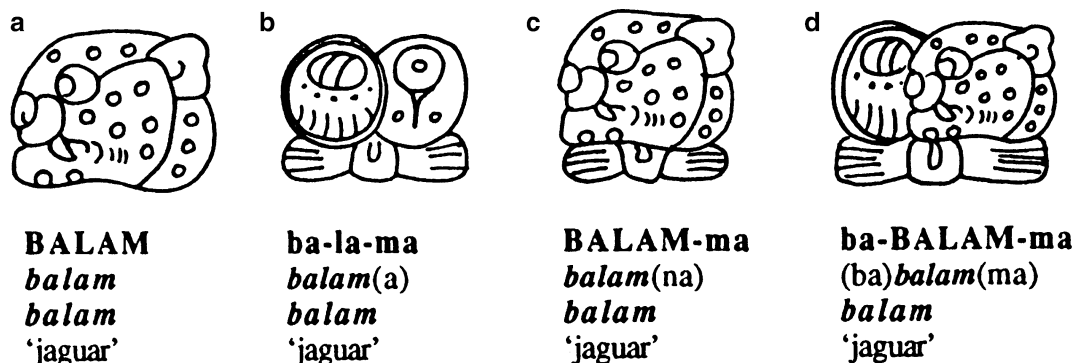


for the three syllables *pa*, *ka*, and *la* (Fig. 8b, c), or by the **PAKAL** sign with a *la* phonetic complement (Fig. 8d). It will be noted that, in spite of their difference in visual effect, both the second and third of these examples are phonetic constructions of the syllables *pa-ka-la* – the second example substituting a head variant of the more usual *pa*-glyph.

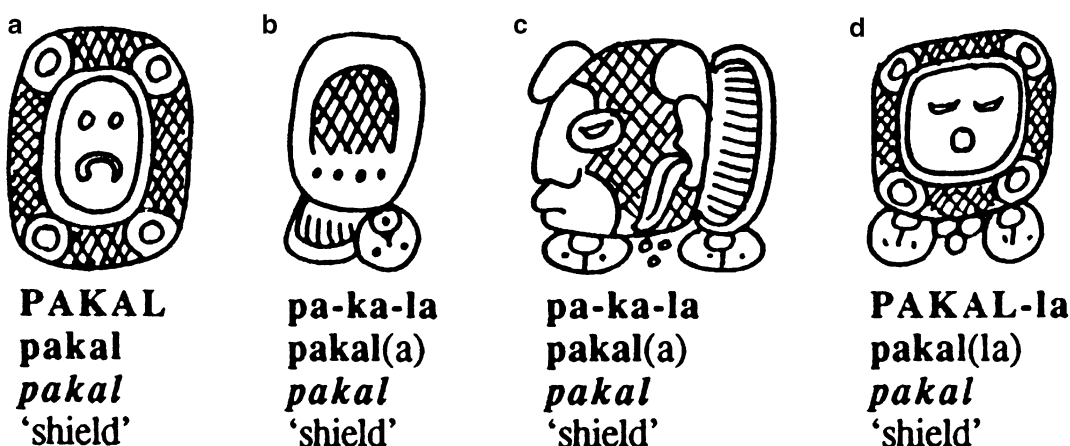
Despite these general principles, there were words for which there was no single sign and the organization of which often defied the general upper-left to lower-right reading order. The word **yichnal** (together with) is a particularly interesting example of such a construction, in part because it always includes the previously mentioned **-NAL** ending superfixed to its main sign (Fig. 9). The latter might be either the standard sign for phonetic *chi* or the “torso-and-left-arm”

sign that represents the sound **YICH**. The several ways of recording **yichnal**, with the elements read in the usual order, were **yi-NAL-chi-la** (Fig. 9a), **yi-NAL-chi** (Fig. 9b), **yi-NAL-YICH** (Fig. 9c), **NAL-yi-chi** (Fig. 9d), **NAL-YICH-la** (Fig. 9e), **NAL-YICH** (Fig. 9f), and **NAL-yi-chi-la** (Fig. 9g).

Among the tasks to which a Maya scribe might be called upon to apply his skills was the execution of commissions to inscribe in stone the dynastic history and military achievements of his city’s royal family. Commissions of this sort would typically involve the recording of a variety of genealogical relationships such as *Ah Balam yal Na Chan* (Sir Jaguar is the child of Lady Sky), where the two names are separated by a glyph-block that defines their relationship, with the subordinate person named first (Fig. 10a). A military



Writing: Maya Writing, Fig. 7 Four ways of spelling *balam* (jaguar)

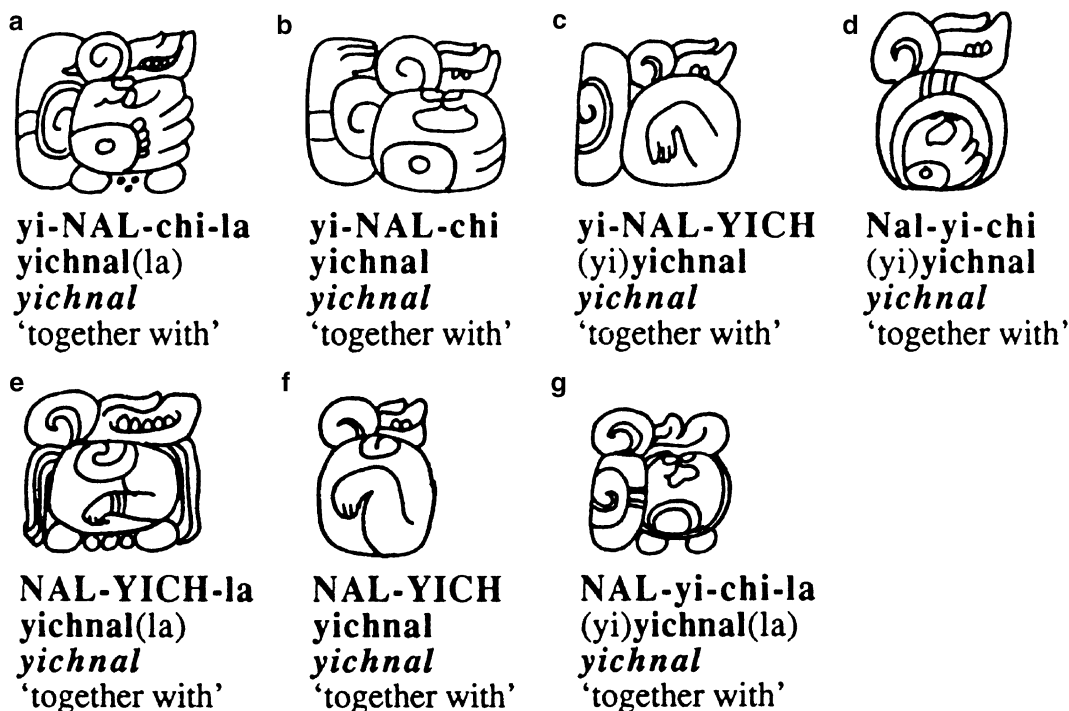


Writing: Maya Writing, Fig. 8 Four ways of spelling *pakal* (shield)

encounter might be expressed with two phrases such as *Chukah Pakal*. *Pakal u bak Ah Balam* (Pakal was captured. Pakal was the captive of Sir Balam), the first being a typical verb-initial Mayan sentence followed by the subject, the second defining another relationship with the identical syntax as the earlier example (Fig. 10b). Accession to political office might be recorded as *Chumwan ti ahawel Ah Balam* (Sir Jaguar was seated in the Lordship), in another typical verb-initial Mayan sentence where a positional verb is followed by a prepositional phrase with the subject named last (Fig. 10c). Were our scribe to turn from his work on public monuments to the designing of a personal book for and about Lady Sky, he might record such sentences as **Sinah u**

chuch Na Chan (Lady Sky strung her warpboard) or **Och-i ti te' Na Chan** (Lady Chan wove at the post), the first a verb-initial sentence with a transitive verb followed by a possessed object and the subject (Fig. 10d), and the second a verb-initial sentence with the verb followed by a prepositional phrase and the subject (Fig. 10e). It should be clear from the preceding examples of inscriptions on public monuments that Maya hieroglyphic writing is indeed a true writing system, fully capable of recording the language it represents.

However, for all of the marvelous achievements of recent Maya epigraphy, much work remains. Many glyphs are undeciphered and problems still linger amongst glyphs for which

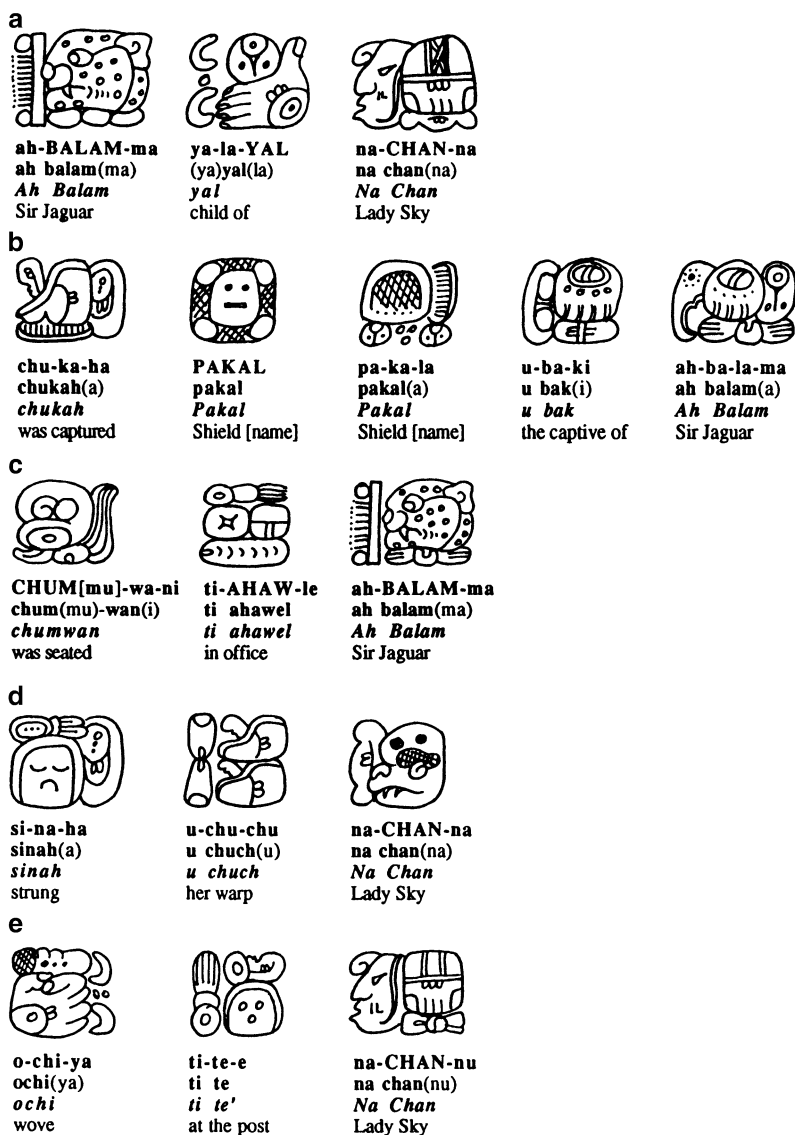


Writing: Maya Writing, Fig. 9 Seven ways of spelling *yichnal* (together with)

solutions have been offered. An understanding of the kinds of difficulties encountered by epigraphers in deciphering individual glyphs can be gained from a close look at a fairly common lordly title, the five basic forms of which preclude ready demonstration of their homophony, and suggest instead the presence of both phonetic and semantic substitutions. Known to scholars as the “penis” title, the three most widely distributed forms consist of a main sign that has the appearance of a profile representation of male genitalia infixed with the sign for *sha* and suffixed alternatively with *-ti* or *-ta* affixes (Fig. 11a–f). Desirable as it might be to have a homophonous reading for the three forms – and their interchangeability in the texts is beyond doubt – the conflicting sounds of their initiating prefixes would appear to preclude any such solution. One form is prefixed with the sign for *yo-* (Fig. 11a, b), and second with *to-* (Fig. 11c, d), and a third with both *yo-* and *to-* (Fig. 11e, f).

Because these substituting sounds are prefixed, the words that they signify must begin with the sounds *yo*, *to*, and *yoto*, respectively. The likelihood that the male genitalia-main sign is intended to convey the sound *AT* (the pan-Mayan word for penis) is confirmed by the interchangeable *-ti* and *-ta* suffixes that invariably accompany it, apparently serving as phonetic complements. If, then, the *sha* infix is read before the presumed sound of the main sign, the sound sequence should be *sha-AT* (ti/ta), or the not too promising *shat*. However, if the previously mentioned *yo-* prefix is added to this, the result is *yoshat*, or *yosh-at* (scarred penis); if *to-* is added, the result is *toshat*, or *tosh-at* (bled penis); and if *yo-to* is added, the result is *yotoshat*, or *yotosh-at* (very scarred penis). Though any such title might strike those of us with a background in Western European culture as bizarre, nevertheless given the wealth of evidence for the presence of penis-perforation ceremonies in which Maya lords

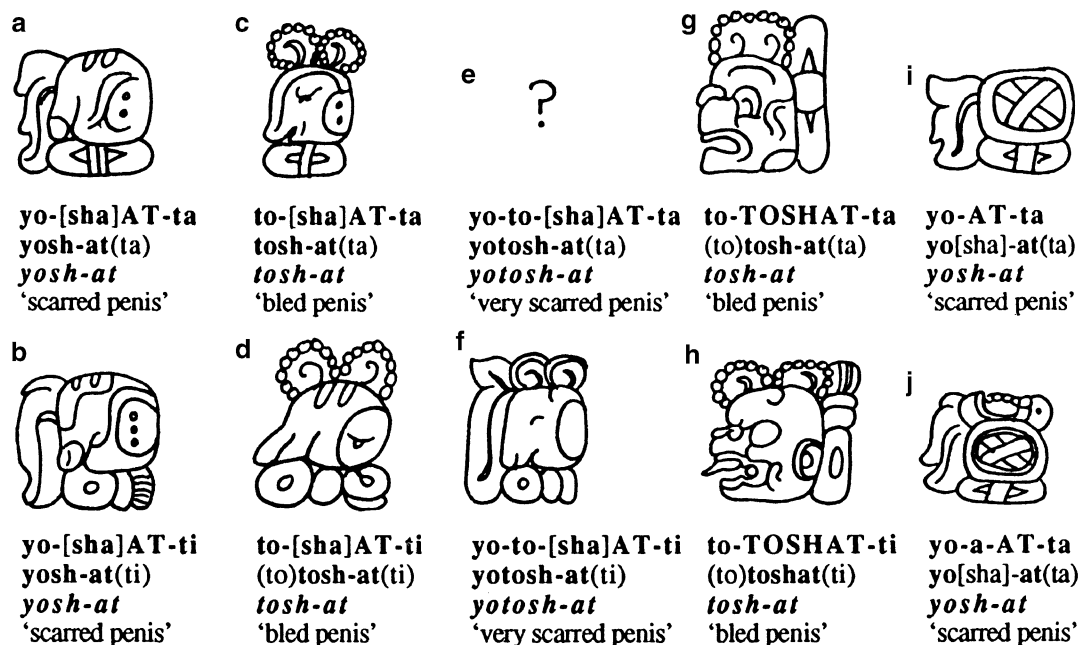
Writing: Maya Writing,
Fig. 10 The construction
 of Maya sentences



engaged and the occasional portrayal of a scarred penis on figures in Maya art, the existence of a hieroglyphic form of a title that testified to a lord's personal sacrifice perhaps ought not to surprise anyone.

Understanding of the remaining two of the five forms which this title assumes is less certain. The first of these is a head variant that is always superfixed with **to-** and postfixed with **-ti** or **-ta** (Fig. 11g, h), suggesting the possibility that the head represents the full term **TOSHAT**, or **TOSH-AT**, with both affixes serving as phonetic

complements. The second (of which there are but two examples) is a phonetic construction that is in clear contradiction to the previously discussed **yosh-at** renderings: one reads **yo-ta-ta**, the other **yo-a-ta-ta** (Fig. 11i, j). Not only is the **ta** sound doubled in each, but there is also nothing present that could be construed to represent **sha**, the necessary middle consonant of **yosh-at**. Nor is there an easy resolution of this difficulty; either the previously proposed **yosh-at**, **tosh-at**, and **yotosh-at** readings are in error and the arguments in support of them faulty, or the Maya scribe that



Writing: Maya Writing, Fig. 11 Semantic substitutions in the “penis title”

recorded the two purely phonetic constructions (they are both at Copan) failed to include all the sounds of the word he intended to record, or – and this is a solution that preserves both the earlier **yosh-at**, **tosh-at**, and **yotosh-at** readings and the literary reputation of the Copan scribe – the scribe deliberately omitted the middle (**sh**) consonant, as is thought to have been done with other two-syllable words. One can only hope that further research and further field discoveries will someday throw stronger light on this and similar difficulties. Nor has there ever been a time when Maya scholars were more optimistic about the possibilities of their ultimate decipherment of this poetically conceived, strikingly beautiful, and wonderfully complex ancient writing system.

Postscript. Since the preceding was written and submitted to the publisher, an alternative to the reading of the penis title presented above has been proposed by Linda Schele based upon a recently recognized example that appears to include a sign for the sound **ho**. Schele proposes a **yoh-at** reading for the **yo**-prefixed form and phonetic construction, a **toh-at** reading for the **to**-prefixed form (and its head-form), but is silent

regarding the **yo-to**-prefixed form. This should convey some idea of the difficulties raised in the closing paragraphs above.

See Also

► [Cuneiform](#)

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Xiahou Yang

Ang Tian Se

Much of the life story of Xiahou Yang remains unknown, and so is the date of *Xiahou Yang Suanjing* (Xiahou Yang's Mathematical Classic), a text purported to have been written by him. When Zhang Qiujiang wrote his mathematical text some time between AD 468 and 486, he criticized the inaccuracy of the solution of a "rectangular granary" problem from Xiahou Yang's work. This shows that Xiahou Yang was either Zhang's contemporary or his predecessor. The text also mentioned a change of volume standard which took place in AD 425, thus affirming that both Xiahou Yang and Zhang Qiujiang were mathematicians of the Northern Wei dynasty (AD 386–535) and that the text of Xiahou Yang was written between AD 425 and 468.

The *Xiahou Yang Suanjing* appeared to be an important text as it was selected by Yu Zhining in AD 656 for use in the National Academy during the Tang dynasty (AD 618–906). In AD 662, the text was annotated by ► [Li Chunfeng](#) along with nine others for use in the imperial examinations. However, when the text was reprinted and included as one of the *Ten Mathematical Classics* in AD 1084 during the succeeding Song dynasty, it appeared to have been rewritten, probably by

Han Yan (AD 780–804) in the Tang dynasty. This is evident in the text itself where a number of statutes governing the Tang systems of land, taxation, and official hierarchy were mentioned.

The present version of the text has three chapters consisting of 82 problems. It deals with percentages and roots, as well as the ordinary logistic operations. Xiahou Yang seemed to have understood both the positive and negative properties of powers of 10 such as $10,000 = 10^4$ and $1/10,000 = 10^{-4}$. He also seemed to have understood the developed conception of decimals. In one problem, he suggested the conversion of the last four metrological units to simply writing down the numbers in four successive places as they would be expressed in modern decimal notation. Though Xiahou Yang provided some modified forms for multiplication and division in some problems, he also repeated some inaccurate solutions found in the *Wu Cao Suanjing* (Mathematical Classics of the Five Government Departments) of the fourth century, the most glaring of which was the rule for determining the area of a figure consisting of two congruent trapezoids and a quadrilateral.

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Xu Yue

Ang Tian Se

Xu Yue, whose literary name is Gonghe, was a native of Donglai (in present Ye District, Shandong Province). Very little is known of his background except that he was a follower of ► [Liu Hong](#), an eminent mathematician and calendar expert of the second century. He studied mathematics and astronomy under Liu Hong and had frequent discussions with him and the Astronomer-Royal of the Astronomical Bureau on matters pertaining to calendrical astronomy. He was said to have written a commentary on the ► [Jiuzhang Suanshu](#) (Nine Chapters on Mathematical Art) and a mathematical text known as *Shu Shu Ji Yi* (Memoir on Some Traditions of Mathematical Art) around AD 190. The commentary had long been lost while the *Shu Shu Ji Yi* was handed down with a commentary written by Zhen Luan (fl. AD 570). There are a number of Buddhist references in Zhen Luan’s commentary.

The *Shu Shu Ji Yi* was written in a terse and obscure style, tinged with Daoism and divination. Xu Yue mentioned that the mathematics he learnt

from Liu Hong was that transmitted directly by a Daoist adept called Tian-Mu Xiansheng (Mr Eye-of-Heaven). The text mentions 14 old methods of calculation, many of them bearing the names taken from the Yijing (I Ching, Book of Changes). Of special interest is one called “ball-arithmetic,” a trough-and-ball instrument similar to an ► [abacus](#). Three other methods also involved the use of “balls”. The first involved the use of one ball per column moving up and down a board or a trough. The second used two balls of two different colors, one relating to a y-axis on the left and the other to a y-axis on the right. Both these methods seem to have utilized a map-like grid of lines, similar to that of Cartesian coordinates. The third utilized balls of three different colors for use on three horizontal positions only. Joseph Needham has commented that this system of calculation “shows an interesting appreciation of coordinate relationships.”

Another interesting aspect of *Shu Shu Ji Yi* is its reference to large numbers and to their representation in three forms of arithmetical series. Xu Yue called them the “upper, middle, and lower” classes of numbers, all beginning with *wan* (10^4). The three classes of large numbers may be summarized in Table 1.

The *Shu Shu Ji Yi* also gives a description of the “calculations of the nine balls”, which according to the commentary provided by Zhen Luan was a simple magic square of order 3.

Though brief, obscure, and couched in religious nuances, Xu Yue’s *Shu Shu Ji Yi* was selected as a prescribed mathematical text for imperial examinations during the Tang dynasty (AD 618–906). It was a difficult text, and candidates had to learn it by heart in order to pass the examinations.

Xu Yue, Table 1 The three classes of large numbers following Xu Yue

	wan	yi	zhao	jing	gai	zi	rang	gou	jian	zheng	zai
Upper	10^4	10^8	10^{16}	10^{32}	—	—	—	—	—	—	—
Middle	10^4	10^8	10^{12}	10^{16}	10^{20}	10^{24}	10^{28}	10^{32}	10^{36}	10^{40}	10^{44}
Lower	10^4	10^5	10^6	10^7	10^8	10^9	—	—	—	—	—

See Also

- [Jiuzhang Suanshu](#)
- [Liu Hong](#)
- [Magic Squares in China](#)

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Yaḥyā ibn Abī Maṣṣūr

Emilia Calvo

Yaḥyā ibn Abī Maṣṣūr was an astronomer from an important family of Persian scientists (his father was an astrologer). Yaḥyā spent his life casting horoscopes and trying to determine the positions of the stars with precision. He began working for al-Faḍl ► [ibn Sahl](#), the vizier of the Caliph ► [al-Ma'mūn](#) and, after his death, for the Caliph himself. He taught the ► [Banū Mūsā](#) and died near Aleppo, Syria in AD 832.

Yaḥyā was the director of a group of astronomers working under the Caliph al-Ma'mūn, in the observatories of Shamāsiyya in Baghdad and Dayr Murrān in Damascus. The scholars included in the group were al-Marwarrūdhī, ► [al-Khwārizmī](#), Sanad ibn 'Alī, the Banū Mūsā and ► [al-Jawharī](#). They measured 1° of meridian by using two different procedures. The results of the observations were recorded in various *zīj*es (Astronomical Handbooks with Tables), one of which is the ► [Zīj al-mumtaḥan](#) (The Tested Tables) that was written by Yaḥyā himself. The observations ended when Yaḥyā and the Caliph died almost simultaneously.

Yaḥyā's *zīj* is preserved in one manuscript (Escorial 927) which is badly bound and comprises many folios that are not from Yaḥyā's work. It contains an explanation of calendars and chronological eras. The elements to calculate planetary longitudes are the result of the combination of Hindu-Iranian and Ptolemaic methods.

Yaḥyā's tables exerted a great influence on later astronomers: Thābit ibn Qurra wrote an introduction to them, Ibn Yūnus adapted them to Egypt, and ► [Ibn al-Zarqāllu](#) derived from them certain values such as the inclination of the ecliptic.

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Yang Hui

Ho Peng Yoke

Yang Hui (fl. 1261–1275), a native of Qiantang (in modern Hangzhou), ranks with ► [Qin Jiushao](#) (ca. 1202–ca. 1261), Li Zhi (1192–1279), and Zhu Shijie (fl. 1280–1303) as one of the four great mathematicians during the golden age of mathematics in thirteenth-century China. Of the four we know the least about Yang Hui's life, yet he has left behind a much larger number of writings than the others, showing that his mathematical interest also covered a wider field than any of his contemporaries known to us.

In the year 1261 he wrote the *Xiangjie jiuzhang suanfa* (Detailed Analysis in the Mathematical Rules in the Nine Chapters and Their Reclassifications). The original work comprised 12 chapters and an Appendix, which included an arrangement of numbers which he attributed to the eleventh-century mathematician ► [Jia Xian](#) and which in 1654 came to be known as Pascal's Triangle. Although the original work is no longer extant in its entirety, sections of it are quoted in the early fifteenth-century Imperial Compendium, the *Yongle dadian*.

Yang Hui also wrote the *Xiangjie suanfa* (Mathematical Methods with Detailed Explanations) on the processes of multiplication and division. Then in 1262 he produced an elementary text for beginners called the *Riyong suanfa* (Everyday Mathematics). In 1274 he wrote the *Chengqu tongbian suanbao* (Precious Reckoner for Variations in Multiplications and Divisions). In 1275 he wrote the *Tianmou bilei chengqu jiefu* (Practical Rules of Arithmetic for Surveying). The same year he assembled some old and forgotten materials and published the *Xugu zheqi suanfa* (Continuation of Ancient Mathematical Methods for Elucidating the Strange Properties of Numbers). This is the earliest Chinese monograph that we have on magic squares.

The last three works mentioned above were published together in 1378 under a single title *Yang hui suanfa* (Yang Hui's Mathematical Methods). A full study of this book was undertaken by Lam Lay Yong in 1977.

Like his contemporaries Yang Hui used numerical equations of higher degree. His *sanchengfang* (quartic root) method is very similar to that rediscovered by Horner and Ruffini in the early nineteenth century. He employed freely the concepts of "dummies" and substitution in his algebra. At the same time his attention was on the practical side, always trying to provide the quickest working method. It seems that Chinese mathematicians were quite active during the eleventh and twelfth centuries, but none of their writings remains. At least we have come to know something about them through Yang Hui's writings.

See Also

- [Li Zhi \(Li Ye\)](#)
- [Magic Squares in China](#)
- [Qin Jiushao](#)

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Ya'qūb ibn Ṭāriq

Jan P. Hogendijk

Ya'qūb ibn Ṭāriq was one of the earliest astronomers in the Islamic tradition. Very little is known about his life. He worked in the last quarter of the

eighth century, when Arabic astronomy was not yet influenced by Ptolemy's *Almagest*. The works of Ya'qūb are lost, but some fragments have come down to us in later astronomical treatises and handbooks. The following information is based on such fragments. Ya'qūb authored three works:

1. A ► *zīj* (Astronomical Handbook with Tables), which was influenced by Indian and pre-Islamic Persian astronomy. For example, he took the zero meridian and the mean motion of the planets from India, and he seems to have adopted the planetary equations from a Persian source. In the lunar visibility theory, Ya'qūb used an Indian method to measure the width of the lunar crescent in "digits." His lunar visibility table is extant.
2. The *Tarkīb al-Aflāk* (Composition of the Heavenly Spheres) is summarized in some detail in al-Bīrūnī's *India*. In this work Ya'qūb discussed the size of the earth and the distances of the planets.
3. In the *Kitāb al-'Ilal* (Book of Reasons), Ya'qūb explained trigonometrical rules, which he probably used in his *zīj*. A few citations of this work are given by ► *al-Bīrūnī*. Ya'qūb based his trigonometrical calculations on a sine table with base 3,438.

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Yavaneśvara

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Yavaneśvara was an astronomer of western or north-western India who lived in the mid-second century CE. He is said to have rendered a Greek treatise on astrology into Sanskrit. Sphujidhvaja, who wrote the *Yavanajātaka* (the Ionian Horoscopy) in the year 269–70 CE, says that his work is a verse rendition of Yavaneśvara's prose text.

Yavaneśvara (lord of the Yavanas or Ionian Greeks) seems to have been a title in use among the ruling elites of western India in the second and third centuries, patronized by the so-called western Kṣatrapa rulers. India's contacts with Greece were established after Alexander invaded the Indus valley in 327–25 BCE and left behind several satraps to administer the region. Following the departure and demise of Alexander, some of these satraps disintegrated, while others developed into principalities in their own right. Greek officials like Megasthenes, Daimachus, and Nearchus traveled in different parts of India, and there were Greek embassies in the court of the Mauryan rulers Chandragupta Maurya and Bimbisāra (between ca. 321 and 273 BCE). Within a short period, regular contacts between India and the west were to be seen. The inscriptions of the third Mauryan king Aśoka (ca. 250 BCE) refers to western rulers like Antiochus Theos of Syria, Ptolemy Philadelphus of Egypt, Antigonos Gonatas of Macedonia, Magas of Cyrene, and Alexander of Epirus. Exchange of knowledge between the two regions might also have commenced in this period. Bimbisāra is known to have requested his Greek counterpart to depute a sophist to his court. Greek influence is perhaps best noticed in the field of sculpture, especially of the Gāndhāra and Mathura schools. Yavaneśvara's work is a result of these historical encounters.

The *Yavanajātaka*, which is the most important source providing access to the work of Yavaneśvara, is a treatise in 4,000 verses, of which only 2,300 survive. These are divided into 72 sections. Among the areas covered in the extent text are zodiac signs, planetary movements, and their influence on human beings, predictions, the making of horoscopes, omens, dreams, military astrology, and so on. Influence of the Babylonian theory of planetary motions is seen in this work.

The work of Yavaneśvara seems to have laid the foundations for a Yavana school of astrology in India. This is evident from texts like the *Yavanapārijāta*, the *Bhāvadīpika* (also called *Bhāvādhyāya*), the *Nakṣatracūḍāmaṇī* and two texts bearing the name *Candrābharaṇahorā*, one popular in northern India and the other in the south. In addition, the influence of Yavaneśvara is also seen in works like Varāhamihira's *Brhājyātaka* and Kalyāṇavarman's *Sārāvalī*.

Also see “► [Sphujidhvaja](#)” and “► [Astrology in India](#).”

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Yinyang

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Yinyang is a Chinese term composed of two words. *Yin* means the shade and *yang* the sunshine. It is the most important concept in the

traditional Chinese way of thinking, the basic concept for classification and explanation in Chinese science, medicine, and philosophy.

The word *yinyang* designates a special method for looking at things as well as for describing the phenomena of the world, including the human body. Yin and *yang* make a pair which exist together. In their coexistence, these two oppose each other in their different functions and at the same time help each other. They both contribute and are necessary to the other's existence. All phenomena can be looked at and described using the *yinyang* paradigm. This is the typical methodology of Chinese science.

The concept of *yinyang* can be compared with the Western dialectic method. However, in Chinese science this way of thinking has developed into a very complicated system of knowledge, in which *yin* and *yang* are represented in every real object. Therefore, *yinyang* is more than a way of thinking; it is also a theory that provides guidelines for human action.

The use of the concept of *yinyang* can be best illustrated by examples. The earliest example which can be found in extant Chinese ancient texts is from the Confucian classic *Yijing* (I Ching, The Book of Changes). It is not to be found in the *Yijing* proper, but in the commentaries (so-called *Yizhuan*, *I Chuan*, or the Ten Wings). It is generally accepted that *Yizhuan* was compiled during the Warring States period (the fifth to the third century BCE), so that is the earliest date we can attribute to the origin of the concept of *yinyang*. *Yizhuan* uses *yinyang* to explain the *Yijing* proper in such a way that the binary notation for every possible movement (change) in the real world is explained as representing the actual acting of the two opposing factors (or forces in the Western sense of the word) that substantiate the situation under consideration. Thus in the relation of men and women, *yang* represents man and *yin* represents woman. Likewise in the relation of heaven and earth, of sun and moon, of day and night, etc., *yang* represents the former and *yin* the latter. Furthermore, *yang* and *yin* are used to represent opposite qualities including natural attributes like hot and cold, hard and soft, bright and dark, odd

and even, as well as human dispositions like aggressiveness and submissiveness, or activeness and inactiveness.

Two points need to be emphasized here. The first is that the designation of *yang* or *yin* to an object is only effective in certain relationships. Relative to the woman, the man is *yang*. But there are other traditionally important relations that man comes into, such as that of heaven and man, of man and gods, of man and his fate, or of individual man and his family or society. In any of these, “man is *yang*” does not apply. Therefore, the traditional designation of *yang* and *yin* forms the hard core of a knowledge about the world. The second is that the use of the concept of *yinyang* is a pragmatic one. To say something or some quality is *yang* and the opposite is *yin* will be meaningful only if this designation classifies these two objects or qualities into two existing categories into which many other things or qualities are already classified. A wrong designation will make a real difference in human action when using this knowledge of classification to make a decision according to a certain theory.

According to Chinese historical records, especially the authoritative *Shi Ji* (Records of Historians) by Si Maqian (b. 145 or 135 BCE), during the Warring States period one of the six most important schools of ideas was called the *yinyang* school. It is generally accepted that, beside its political and philosophical relevance, this school brought about two important developments, which somewhat related to each other throughout the 2,000 years afterward. One is the Daoist practice of alchemy and physical immortality; the other is Chinese traditional medicine, or more accurately, Chinese body science.

From both the Chinese traditional viewpoint and from the modern Western point of view, the most important use of the *yinyang* concept can be found in the theory and practice of Chinese traditional medicine. The earliest extant medical literature was unearthed in 1973 from the Han Tomb No. 3 at Mawangtui, Changsha, Hunan Province, China. There are records which show that these texts were buried in the tomb with the dead Marquis in the year 168 BCE. In these texts the *yinyang* concept is used as the most basic

classifying concept. It is the same with the ► [Huangdi Neijing](#) (Yellow Emperor’s Classic of Internal Medicine), which contains medical essays edited in the first centuries AD. From these texts we know that the *yinyang* concept was used in Chinese medical theory much earlier than the second century BCE.

In Chinese medical theory, *yin* and *yang* are two different kinds of *qi* (literally “breath” but occasionally translated as meaning “vital force”), which function within the human body contradictorily and complementarily, and thus make the body alive. Human health is attained by keeping these two *qi* in a good, natural balance. All health problems are caused by the lost of this balance. All medical theories, diagnoses, and therapies can be understood as practical knowledge of how to classify the imbalance into a certain system of categories and how to use different means, which are classified into corresponding categories, to retrieve the natural balance. For a simplified example, two common health problems are diagnosed as *yang*-deficiency-*yin*-excess and *yin*-deficiency-*yang*-excess, which correspond to cold and heat syndromes. In diagnosis these two syndromes are related to two categories of symptoms which include every possible change in the pulse, the complexion, the tongue, the breath, the excrement and urine, etc., of the patient. In therapy, herbal medicine, or the method and location of acupuncture points are correspondingly classified.

There are two other concepts which are closely connected with the *yinyang* concept. They are the *wuxing* (five phases), which is extremely important in Chinese science, and the *taiji* (the ultimate beginning), which is more important in Chinese philosophy. The *yinyang* concept is also the basic concept used in Chinese fortune telling such as astrology (*suanming*, literally “calculating the fate”) and geomancy (► [fengshui](#), literally “wind and waters”).

See Also

- [Astrology in China](#)
- [Divination: Science, Technology, and the Mantic Arts in Traditional China](#)

- Fengshui
- Five Phases (Wuxing)
- Geomancy in China
- *Huangdi Neijing*
- Medicine in China
- *Qi*

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Yoga

A. V. Balasubramanian

Yoga is one of the six principal systems of Indian thinking known as *darśanas*. The word *darśana* is derived from the Sanskrit root *drs*, meaning “to see.” Fundamentally, *darśana* means “view” or “a particular way of viewing.” Yoga, as one of the six *darśanas*, has its source in the Vedas. In the traditional Indian view these are called *vaidika*, or Vedic *darśanas*. These are *nyāya*, *vaiśeṣika*, *sāṅkhya*, *yoga*, *mīmāṃsā*, and *vedānta* (there are other *darśanas* that do not accept the supremacy of the Vedas, such as Buddhism and Jainism). While the source of Yoga was the Vedas, Yoga was formalized by Patañjali, one of the great Indian sages. His classic text is *Yoga Sūtra* (Aphorisms on Yoga). Although there are many

other major treatises on Yoga that postdate Patañjali's, his work is the most authoritative.

All the *darśanas* proclaim that it is their aim to help human beings achieve clarity and balance of perception and action. Yoga is unique in as much as it offers practical suggestions and guidelines to achieve this end. According to the tenets of Yoga, human beings are under the influence of *avidyā*, which is what prevents correct perceptive analysis. Sage Patañjali suggests practical ways to reduce and remove *avidyā*. In his *Yoga Sūtra*, three things are suggested to help us explore the meaning of Yoga and therefore feel *avidyā*. These are *tāpas*, *svādhyāya*, and *īśvara-pranidhāna*. *Tāpas* is a means by which we keep ourselves fit and clean. Often *tāpas* is defined as penance, mortification, and dietary austerity, but what is meant is the practice of *āsana* (postures), *prāṇāyama* (control of the breath), and other disciplines. These practices aid in the removal of impurities from our systems. In so doing we gain control of our whole system. It is the same principle as heating gold to purify it.

The next part of Yoga is *svādhyāya*, the study of the self. Where are we? What are we? What is our relationship to the world? It is not enough to keep ourselves fit; we should know who we are and how we relate to others. This is not easy because we do not have an actual mirror for our minds as we do for our bodies. We must use reading, study, discussion, and reflection as a mirror to the mind.

The third means of exploration is *īśvara-pranidhāna*. It is usually defined as “love of God” but it also means “quality of action.” We must carry out our jobs, and all our actions must be done with quality. Since we can never be certain of the fruits of our labors, it is better to remain slightly detached from them and pay more attention to the actions themselves.

Together, these three cover the whole of human action: fitness, inquiry, and quality of action. Taken together, these practices are known as *Kriyā Yoga*, the Yoga of action. Yoga is not passive. We must be involved in life, and preparation is necessary for this involvement.

Patañjali's Yoga is sometimes called *Aṣṭāṅga Yoga*, which literally means Eightfold Yoga.

These eight are *yama*, *niyama*, *āsana*, *prāṇāyāma*, *pratyāhāra*, *dhāraṇa*, *dhyāna*, and *śamādhi*.

Patañjali considers five different attitudes (*yamas*) or relationships between an individual and “the outside.” The first is *ahimsā*. While the word *himsā* means injury or cruelty, *ahimsā* means more than merely the absence of *himsā*. It means kindness, consideration, or thoughtful consideration of people or things. The next *yama* is called *satya*, “to speak the truth.” The third *yama* is *asteya*. *Steya* means “to steal”; *asteya*, the opposite, means if we are in a situation where people trust us, we will not take advantage of them. The next *yama* is *brahmacarya*. The word is composed of the root *car* (to move) and *brahma* (the truth). If we move toward the understanding of truth, and sensual pleasures get in the way, we must keep our direction and not become lost. The last *yama* is *aparigraha*, “hands off.” *Parigraha* is the opposite of the word *dana*, which means “to give.” *Aparigraha* means “to receive exactly what is appropriate.”

Niyamas, like *yamas*, are attitudes and are not to be taken as actions or practices. The five *niyamas* are more intimate in the sense that they are the attitudes we have toward ourselves. The first *niyama* is *śauca*, or cleanliness. There are two parts to this, external and internal. External *śauca* has to do with simply keeping ourselves clean. Internal *śauca* has to do with cleanliness of the internal organs and mind. The practice of *āsanas* or *prāṇāyāma* could be an internal *śauca*. The second *niyama* is *santosa*, a feeling of contentment. The next is *tāpas*, a word we have already discussed. With *tāpas* the idea is to bring out *asuddhi*, “dirt” inside the body. *Svādhyāya* is the fourth *niyama*. As we defined it earlier, *sva* means self; *adhyaya* means study or inquiry. Actually, *adhyaya* means to go near. *Svādhyāya* means to go near yourself, i.e., to study yourself. Any study, reflection, or contact that helps us understand more about ourselves is *svādhyāya*. The last *niyama* has also been mentioned before. *Īśvarapranidhāna* means “to leave all our actions at the feet of the Lord.” Since our actions often come from *avidyā* it is possible that they might go wrong. That is why contentment is

so important. This attitude suggests that we have done our best, and can leave the fruits of our actions in the hands of something higher than ourselves.

The third *aṅga* is *āsana*. In the theory of *āsana* practice, there are two aspects, *sukha* and *sthira*. We must be comfortable and at ease (*sukta*) and we must be steady and alert (*sthira*). We must be involved and at the same time attentive. Yoga suggests ways to achieve these qualities in *āsana*. The fourth *aṅga* is *prāṇāyāma* which is conscious regulated breathing. *Pratyāhāra*, the fifth *aṅga*, involves the senses. The word *āhāra* means “food.” *Pratyāhāra* means “withdrawing from that on which we are feeding.” This refers to the senses: when the senses refrain from “feeding” on their objects, i.e., *pratyāhāra*.

Dhāraṇa comes from the root *dhr*, “to hold.” *Dhāraṇa* occurs when we create a condition so that the mind, normally going in a hundred different directions, is directed toward one point. *Dhāraṇa* is a step leading toward *dhyāna*. In *dhāraṇa* the mind is moving in one direction; nothing else has happened. In *dhyāna*, when we become involved with a particular thing and we begin to investigate it, there is a link between ourselves and this object; i.e., there is a perceptual and continuous communication between the object and our mind. This communication is called *dhyāna*. Further, when we become so involved with an object that our mind completely merges with it, that is called *śamādhi*. In *śamādhi* we are almost absent; we become one with that object.

There are many varieties of Yoga. Some people say that *dhyāna* is the means to *Jñāna Yoga*. In this context, this means inquiry about the truth, the real understanding that we attain in a state of *śamādhi*. Inquiry in which we hear, then reflect, and then gradually see the truth, is *Jñāna Yoga*. In the *Yoga Sūtra* it is said that in the state of mind where there is no *avidyā*, automatically there is *Jñāna*.

Bhakti Yoga comes from the root *bhak* which means “to serve that which is higher than ourselves.” This means an attitude of devotion. In *Mantra Yoga*, a teacher who knows us very well might give us a *mantra* which has a particular

connotation because of the way it has been arranged. If that *mantra* is repeated in a certain way, if we are aware of its meaning, and perhaps if we want to use a particular image, *Mantra Yoga* brings about the same effect as *Jñāna* or *Bhakti Yoga*. In *Rāja Yoga*, the word *Rāja* means “the king who is always in a state of bliss, who is always smiling.” Any process through which we achieve greater understanding of the mysterious and the obscure is *Rāja Yoga*. In the Vedas there are many references to the word *Rāja* in relation to *īśvara*.

It is best to explain *Laya Yoga* in a context of *samādhi*. When the meditator completely merges with the object of meditation, that is *Laya*. We merge with the object and nothing else exists.

In recent times, much has been written about Hinduism, and a lot of it pertains to and derives from the viewpoint of Vedānta. It is important to see that the viewpoint of Yoga differs in some crucial respects from the viewpoint of Vedānta. Brahman is considered the “*Pāramārthika Satya*” or ultimate truth, and the world we live in and experience through our senses is granted the status of truth at an operational level, i.e., “*Vyāvahārika Satya*.” In a sense, this carries the implication that the world is false and illusory. According to Yoga, everything we see, experience, and feel is not an illusion but is true and real. This concept is called *satvāda*.

Everything, including *avidyā*, dreams, and even fancy and imagination, is real. However, all these are constantly in a state of flux. This concept of change is called *pariṇāmavāda*. In Yoga, although everything we see and experience is true and real, changes do occur either in character or in content.

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Yuktibhāṣā of Jyeṣṭhadeva

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Jyeṣṭhadeva (fl. 1500–1610) was a Nambūthiri Brahmin from the Ālattūr village, an important Brahmin settlement near Cochin. He was probably a student of Dāmodara, the son of Parameśvara, who also taught Nīlakaṇṭha Somayāji. His fame rests on the authorship of one of the most important texts of the Kerala school of mathematics and astronomy, the *Yuktibhāṣā* (An Exposition of the Rationale [of mathematics and astronomy]), also called *Gaṇita-nyāya-saṅgraha* (Compendium of Mathematical Rationale). It is a unique work on the rationale of Hindu mathematics and astronomy as it was understood in medieval India. It is unique in the sense that it is neither a textbook nor a commentary but a work which is wholly devoted to a systematic exposition of mathematical rationale, written in Malayalam, the local language of Kerala.

Born about 1500, Jyeṣṭhadeva probably composed the *Yuktibhāṣā* about 1530, since it is known that a little after 1534, Śaṅkara Vāriyar, another contemporary astronomer, used it in his commentaries. Another work of Jyeṣṭhadeva, the *Ḍṛṅkaraṇam*, also in Malayalam, was composed in AD 1608.

K. V. Sarma: deceased

At the outset of the work, the author states that he is attempting “to set out in full the rationale useful for understanding the planetary motion according to the *Tantrasaṅgraha* of Nīlakaṇṭha Somayāji” (b. 1444). But he actually goes much beyond that and subjects to rationalistic analysis the entire gamut of mathematics and astronomy. In fact, he takes up the treatment from the very fundamentals, the concept of numeration and the theory of numbers. The work is made up of two divisions, each one divisible into several sequential chapters.

The first deals with the following subjects: (1) the eight fundamental operations, from simple addition to the roots of sums and differences of squares, wherein several methods, including diagrammatic solutions, are offered; (2) algebraic problems; and (3) operations on fractions. The other chapters deal with (4) the general nature of the Rule of Three (direct proportion); (5) application of the Rule of Three in the computation of mean planets; (6) elaborate rationalizations of the circumference of the circle; and (7) the rationales of the derivation of the R sines, R versed sines, their addition, properties of cyclic quadrilaterals, and the surface area and volume of a sphere. Many of the rationales are demonstrated both algebraically and geometrically.

Part Two is devoted to the exposition of rationales in astronomy, including (1) the computation of mean and true planets by means of two types of epicycles, supplemented by corrections; (2) the celestial sphere, the related great circles and secondaries, the precession of the equinoxes, and the armillary sphere; (3) declination, right ascension, and related matters; (4) problems related to spherical triangles; (5) problems connected with direction and shadow; (6) computation of the rising and setting points of the ecliptic, the ecliptic having constant variation. A direct method, enunciated in Indian astronomy for the first time, is used; (7) eclipses and the attendant parallax corrections; (8) the *Vyatipāta*, which is the moment when the sun and the moon have equal declinations but in different quadrants; and (9) reduction of computed results to observation and with the phases of the moon.

Some points are of special interest in the *Yuktibhāṣā*. One is the rationale for three or four steps for true planets, although the result can also be obtained in two steps; the derivation of inverse declination and inverse right ascension; novel solutions for some of the problems on spherical triangles and on shadows; refinements for parallax corrections; and an alternate method with a novel correction for the computation of the moment of *Vyatipāta*. A noteworthy characteristic is its elucidating rationale from the fundamentals, first setting out the axioms and postulates involved and then developing the arguments and methodologies step by step.

It might also be noted here that Śaṅkara Vāriyar provided a valuable service by incorporating rationales from the *Yuktibhāṣā* into Sanskrit, the language of scholars. This he did in two elaborate commentaries called *Kriyākramakārī* on the *Līlāvātī* by Bhāskaraṇḍyā and *Yuktidīpikā* on the *Tantrasaṅgraha*, a work on astronomy by Nīlakaṇṭha Somayāji. There is also a highly corrupt rendering of *Yuktibhāṣā* into Sanskrit.

See Also

- [Nīlakaṇṭha Somayāji](#)
- [Parameśvara](#)
- [Rationale in Indian Mathematics](#)
- [Śaṅkara Vāriyar](#)

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Yupana

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Yupana is the name given to the counting device – or abacus – of the Incas; in the indigenous Andean language of Quechua, “yupay” means “to count.” Counting was a fundamental aspect of structuring such an extensive and elaborate civilization as that of the Incas, which reached its height in the fifteenth and sixteenth centuries with an estimated population in the millions and extending across the diverse climatic regions of northern Chile and Argentina, Ecuador, Bolivia, Peru, and the southern part of Colombia. This calculating device along with its corresponding recording device – the quipu – were the main technologies that organized the Inca population and controlled the distribution of goods and labor responsibilities. While the quipu knot records were static registries of amounts calculated and served as the authoritative voice of quantities paid, quantities due, and standard measurements and statistics, the yupana would have been the device used to calculate (but not register) those amounts later tied into quipu cords. While the knot structure of the quipu was not suitable for the manipulation of numbers nor performing repeated algorithms, the yupana is a table upon which counters (of beans, corn, pebbles, grains, or other tokens) can be freely moved, thus facilitating the execution of distinct numeric operations.

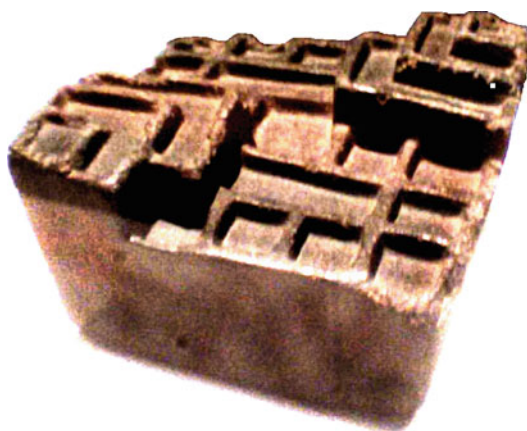
Colonial Descriptions of La Yupana

The yupana has been associated with two different artifacts: (1) the carved rock, wooden, and clay deposits of archaeological provenience and the (2) sketched figures of counting boards primarily from Guaman Poma de Ayala’s *Nueva corónica y buen gobierno*, both of which are illustrated and discussed below. The interpretation of these Inca artifacts as counting tools is supported by ample documentation of the existence of such a device in numerous colonial chronicles and texts. The Spanish missionary José de Acosta describes (without understanding) the Inca counting system:

To see them use another kind of quipu with maize kernels is a perfect joy. In order to carry out a very difficult computation for which an able accountant would require pen and ink... these Indians make use of their kernels. They place one here, three there and eight I do not know where. They move one kernel here and three there and sure enough, they are able to complete their computation quickly without making the smallest mistake. As a matter of fact, they are better at calculating what each one is to pay or give than we would know how to check with pen and ink. Whether this is not ingenious and whether these people are wild animals let those judge who will! What I consider as certain is that in what they undertake they have great advantage over us. (De Acosta, 2008, p. 211)

Archaeological Artifacts with Carved Deposits for Counting

The first archaeological finding linked to the yupana was a symmetric tablet (33 × 27 cm) found near Chordeleg (Cuenca) in 1869 exhibiting 21 carved spaces and elevated platforms on two diagonal corners (Fig. 1). Similar objects have been uncovered in the ruins of Chan Chan, between Cuenca and Sig Sig, Ancash, Caraz, Pallasca, Callejón de Huaylas, and Ica (Radicati di Primeglio, 1990, pp. 220–229). Although these objects have been classified as counting devices by certain scholars (Arriaga, 1922; Gonzales Suarez, 1878; Verneau and Rivet, 1912; Wiener, 1880), this is only one possible interpretation. At one point these carved



Yupana, Fig. 1 A carved deposit similar to the Chordeleg yupana

deposits were also believed to be architectonic models (Bastian (n.d.); Gonzales Suarez, 1878) as well as games of chance (Uhle, 1922).

La Yupana de Guamán Poma de Ayala

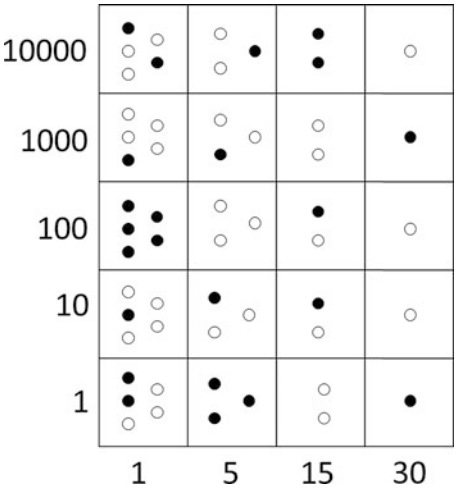
The yupana illustrated by Guamán Poma de Ayala, however, has unanimously been regarded as a counting device (whether or not scholars agree to Guamán Poma's knowledge of its functionality). Hugo Pereyra Sánchez attributes this mutual understanding to the context in which the abacus is illustrated: "In the Guamán Poma illustration the board, without a doubt, accompanies and complements the quipu that the accountant and treasurer extends. In light of such precise testimony, it would be arbitrary to place in doubt the fact that the object represented is an instrument of calculation with which operations were made and whose results were recorded on the quipu" (Radicati di Primeglio, 1990, p. 235 my translation). Henry Wassen concurs by denying that the yupana "deals with a game board. . . there is nothing in common between Guaman Poma's drawing and the game boards reproduced by Verneau and Rivet" (Wassén, 1990, p. 214 my translation). This yupana is a 5×4 table etched into the ground or similar flat surface upon which tokens are moved (Guaman Poma specifically indicates that the grain quinoa is used). The



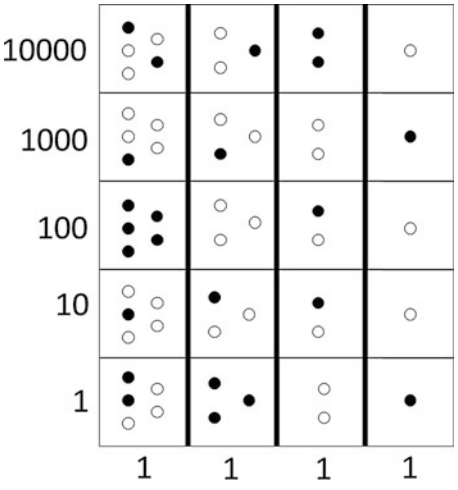
Yupana, Fig. 2 Guaman Poma de Ayala's illustration of the yupana (*bottom left corner*)

columns have distinct numbers of empty (white) and filled (black) spaces (5, 3, 2, and 1), although various scholars, including Pereyra, have proposed that the black tokens are indicative of addition/debits and the white tokens are indicative of subtraction/credits (Fig. 2).

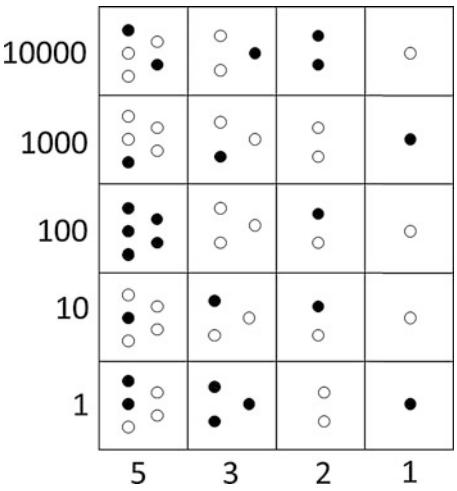
The distinct positional values given to each row and column of the yupana have led to diverse models and interpretations of this abacus. Wassen's initial interpretation (1931) (Fig. 3) has subsequently been disregarded as overly complicated and not one to one (i.e., numbers could be represented by multiple token combinations). Pereyra's model (1990) associates column position value with the etchings on the board (5, 3, 2, and 1) while preserving the decimal progression of the rows (units, tens, hundreds, thousands, ten thousands) (Fig. 4). While this is one way to make sense of the inscribed 5-3-2-1 sequence, this abacus would only require the placement of 1–2 tokens in each box which does not seem congruent with the specific number of



Yupana, Fig. 3 Wassen’s solution (1931). According to this model, Guamán Poma’s yupana would represent the value: $408,257 = 2 \times 1 + 3 \times 5 + 1 \times 30 + 1 \times 10 + 1 \times 50 + 1 \times 150 + 5 \times 100 + 1 \times 1,500 + 1 \times 1,000 + 1 \times 5,000 + 1 \times 30,000 + 2 \times 10,000 + 1 \times 50,000 + 2 \times 150,000$ (Image by author)

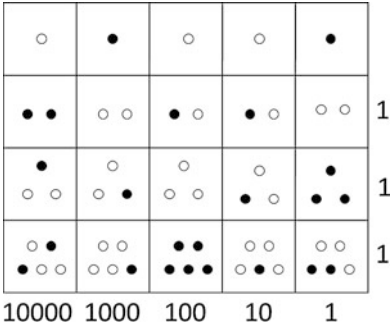


Yupana, Fig. 5 Radicati di Primeglio’s version (1979). According to this model, Guamán Poma’s yupana would represent four values: 21,512, 11,013, 20,110, and 1,001 (Image by author)



Yupana, Fig. 4 Pereyra’s proposal (1990). According to this model, Guamán Poma’s yupana would represent the value: $181,826 = 2 \times 5 + 3 \times 5 + 1 \times 1 + 1 \times 50 + 1 \times 30 + 1 \times 20 + 5 \times 500 + 1 \times 200 + 1 \times 5,000 + 1 \times 3,000 + 1 \times 1,000 + 2 \times 50,000 + 1 \times 30,000 + 2 \times 20,000$ (Image by author)

empty spaces illustrated by Guamán Poma. Radicati di Primeglio’s model (1979) gives each column the same multiplicative positional value (x1) and mirrors the way in which quipu cords represented numeric values (Fig. 5); this model



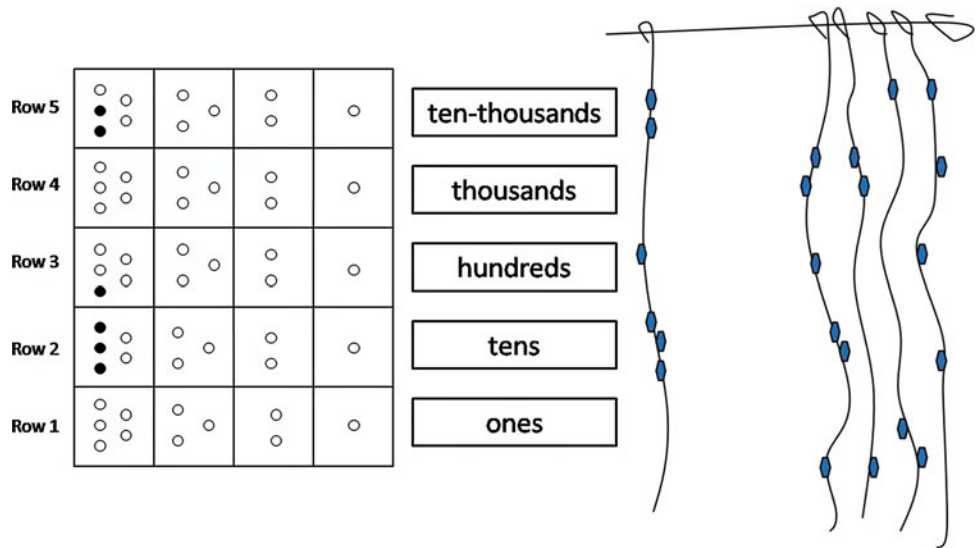
Yupana, Fig. 6 Burn’s method. According to this model, Guamán Poma’s yupana would represent the value: 53,636 or 62,645 (if the top row “memory holes” carried a token of higher place value); the placement of tokens in the top row ultimately indicates that the operation is not yet finalized (Image by author)

would allow for the simultaneous placement of four numbers (one in each column) but would also require surpassing the limit of token positions as illustrated (5, 3, 2, and 1). The Burns model (1981) preserves the same positional values but only represents one number at a time, thus effectively making use of positions 5, 3, and 2, with the 1-hole space an extra “memory” space intended for carrying over vales between the units, tens, hundreds, thousands, and ten thousands positions (Fig. 6). Burns also somewhat



Yupana, Fig. 7 First-grade students from the *Institución Educativa 3043 Ramón Castilla* using the yupana in the classroom under the direction of their instructor Miguel Angel Díaz Sotelo, the coordinator (Peru) of the

Latin-American Network of Ethnomathematics (see <http://www.etnomatematica.org/home/>) (Photos reproduced with his kind permission)



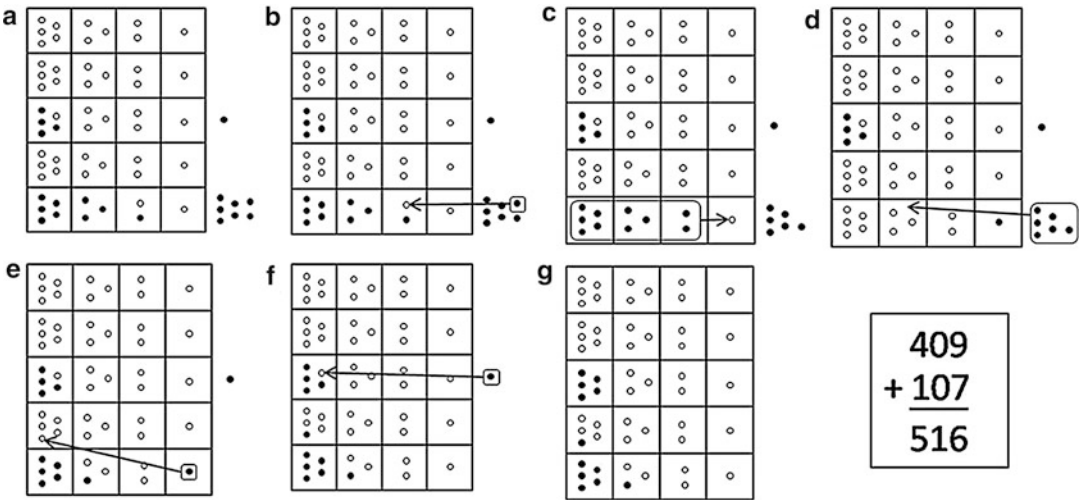
Yupana, Fig. 8 Showing how the abacus, when positioned vertically, corresponds directly with quipus cord values. This image shows how the number 20130 is

displayed on la yupana as well as the first cord of the quipus (Image by author, published in Leonard 2010, p. 92)

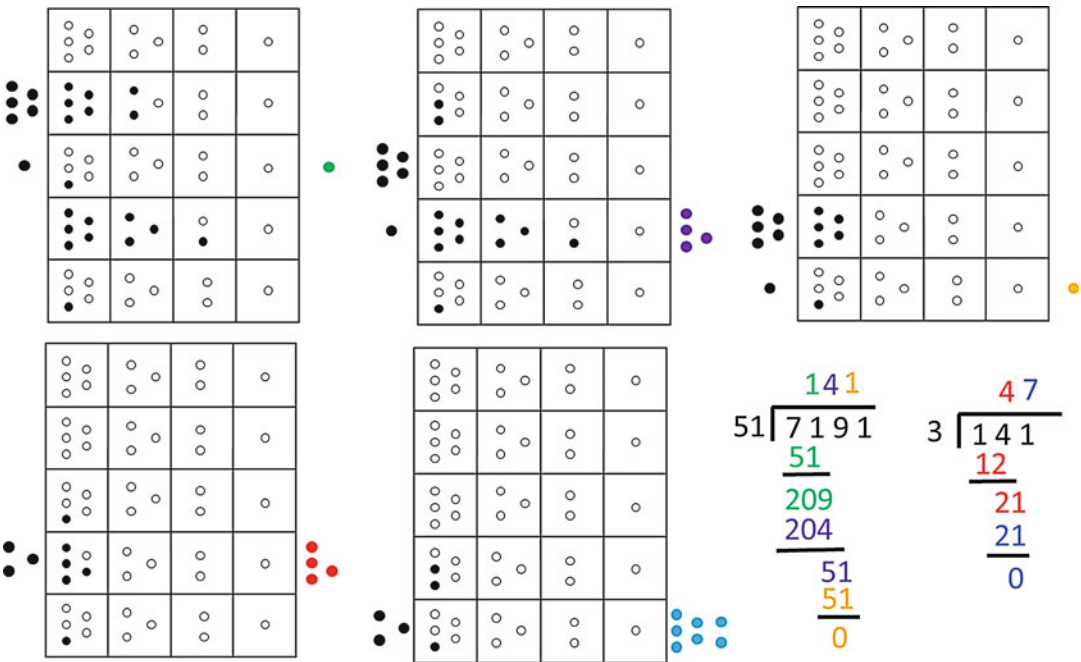
arbitrarily rotated the abacus on its side, but this position's correlation with the contemporary practice of writing numbers from left to right (along with the abacus's use of the decimal system) makes this model a popular choice for implementation in elementary schools (Fig. 7).

Performing Operations on the Yupana

The model proposed by the author (Leonard 2010) is a variation of the Burns model and essentially operates in the same way but positions the yupana as illustrated by Guamán Poma in order to preserve correspondence between the



Yupana, Fig. 9 Addition on the yupana (Image by author, published in Leonard 2010, p. 95)



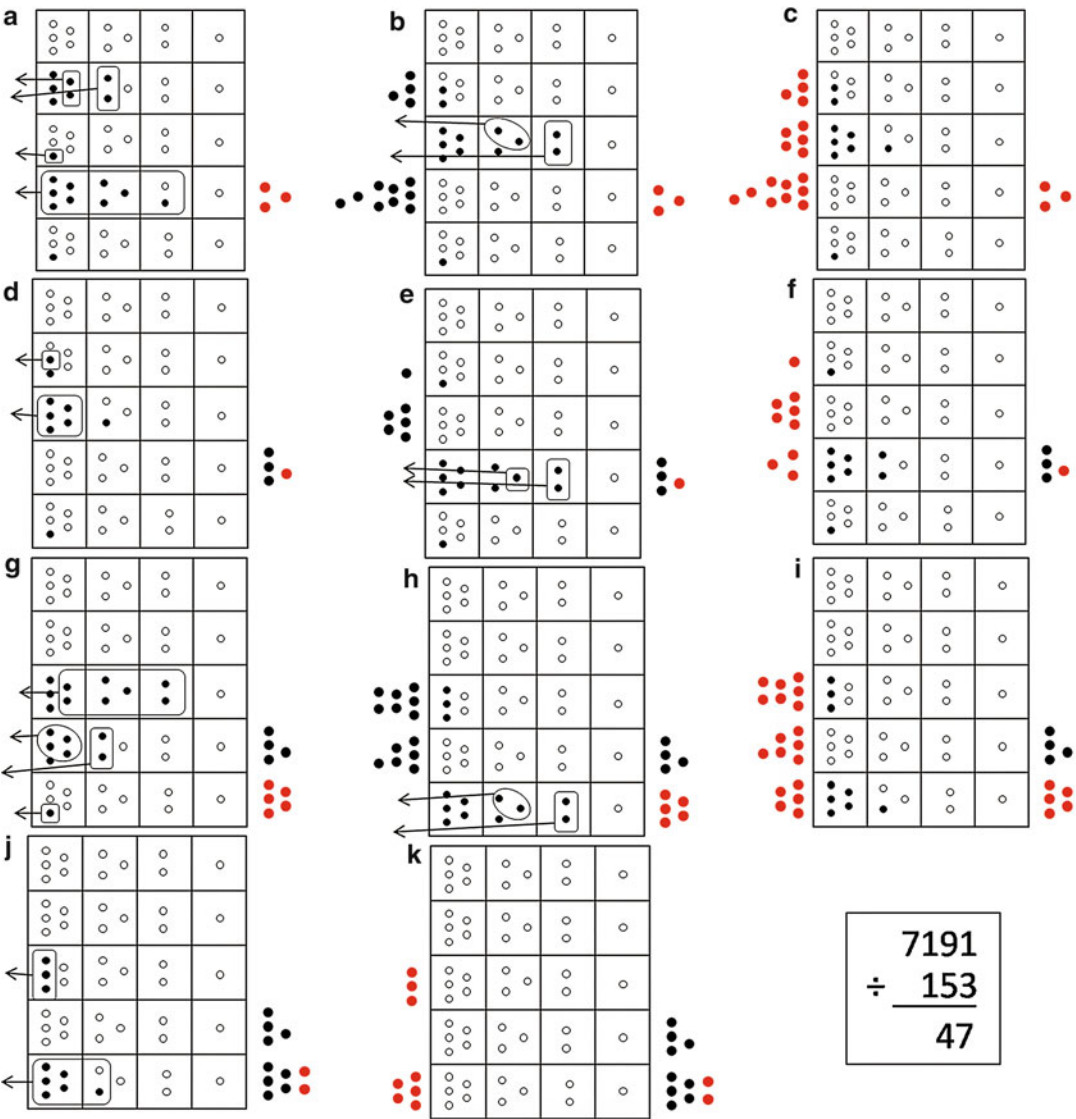
Yupana, Fig. 10 Division simplified by incorporating mental mathematics and factorization (i.e., $7,191/153 = 7,191/(51 \times 3) = (7,191/51)/3$). The long division

illustrated alongside the yupana is intended to serve as a comparison, even though pen and paper are not necessary for performing this operation (Image by author)

yupana and the quipu in which numbers are read from top to bottom (Figs. 8, 9, 10 and 11).

Addition (as executed in Fig. 7) is the most straightforward of all calculations and probably one of the most common operations. One of the

summands is placed on la yupana while the other summand is placed outside la yupana, to the right of the corresponding rows (A). The stones outside the abacus in the ones row are added to la yupana first (B), using the memory stone as needed.



Yupana, Fig. 11 Division on the yupana (Image by author, published in Leonard 2010, p. 102)

Whenever the total number of stones in any given row reaches ten (hence, the 5 square, 3 square, and 2 square are all full), then those stones can be removed and one stone placed in the single hole (the memory hole) on the right (C). The rest of the stones can then be added to the now-empty holes of that same row (D). After all the stones have been added, the stone from the memory hole can be shifted up to occupy a space in the next row up (E), and the process continues by adding the summand from that next row. All the place values

are computed in the same fashion, always moving from the bottom to top. Once all the summand stones on the right side of the abacus have been worked into the calculation, the number remaining on la yupana is the answer, in our case 516.

Subtraction is a similar computation, but the steps are done in reverse. Multiplication and division are also possible using this method but require the use of additional yupana to prepare some partial products needed in the operation.

These operations can be viewed in their entirety in this author's article "The Incan Abacus" on the website of the *Journal of Mathematics and Culture* (volume 5, number 2): <http://nasgem.rpi.edu/pl/journal-mathematics-culture-volume-5-number-2>. Here, an interesting connection between the enigmatic sequence 5-3-2-1, Fibonacci's sequence, partial products, number decomposition, and Aymara linguistics is also established.

Final Reflections and Operation Simplification

Further reflection on the functionality of the yupana, however, questions the need to establish the possibility of performing addition, subtraction, multiplication, and division. Most models have been criticized for the complexity of the multiplication and division operations, but until additional evidence of the exact nature of Inca operations and necessities of calculation is established, it is difficult to know which exact operations would have been carried out on the abacus. In addition, we must accept that those using the abacus would have been highly trained operators, greatly reducing what constitutes complexity to them. Finally, if we consider the possibility of the use of strategic mental mathematics and factorization, these abacus operations can be greatly reduced and as simple as those calculated using pen and paper, as seen by comparing a simplified version of division (Fig. 10) with a Burn's inspired model of division (Fig. 11).

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Z

Zacut, Abraham

José Chabás

Abraham bar Samuel bar Abraham Zacut was the most prominent astronomer of the late Middle Ages in the Iberian peninsula. He was born in 1452 in Salamanca (Spain), a Castilian town whose university had established a renowned chair of astrology (including astronomy) in the mid-fifteenth century.

Although he is chiefly known for his astronomical activity, Zacut wrote on other subjects such as lexicography (*Hosafot lasefer ha-'arukh*) and history (*Sefer Yuhasin*).

Zacut's most outstanding work is *Ha-ḥibbur ha-gadol* (The Great Composition), a text in Hebrew consisting of more than 50 astronomical tables and lengthy canons explaining their use. The tables have 1473 as radix, they are arranged for the Christian calendar, and their entries are computed for the meridian of Salamanca. The tables give the positions of the Sun, the Moon, and the five planets presented in the form of an almanac. Of special interest are the tables listing the daily positions of the Sun (for 4 years from 1473) and the Moon (for 31 years from 1473). All the entries are computed according to the Alfonsine Tables, well known in Salamanca since the arrival of Nicholas Polonius, the incumbent of the chair of astrology at the University of Salamanca ca. 1460. Another table lists all

true syzygies (new and full moons) for 31 years; it is based on the cycle of 767 syzygies discovered by the Catalan astronomer, Jacob ben David Bonjorn, author of astronomical tables for Perpignan (1361), and a follower of ► [Levi ben Gerson](#) (1288–1344). Among others, both these Jewish astronomers are mentioned in Zacut's *ḥibbur*. In fact, the only Christian scholar mentioned in the *ḥibbur* is king Alfonso of Castile. The work was finished around 1478, and 3 years later it was translated from Hebrew to Castilian, with the help of Zacut himself, by Juan de Salaya, who held the chair of astrology after Nicholas Polonius.

At the request of his new patron, Juan de Zúñiga, Master of the Order of Alcántara, in 1486 Zacut wrote a book on medical astrology: *Tratado de las influencias del cielo* (*Treatise on the Influence of the Heavens*), followed by a short text on eclipses: *Juicio de los eclipses* (Judgment on Eclipses). Two other works on astrology have been attributed to Zacut: *'Oṣar ḥayyim* (Treasure of Life) and *Mishpetei ha-'išṭagnin* (Judgment of the Astrologer).

Because of the expulsion of the Jews decreed by the rulers of Spain (1492), Zacut moved to Portugal and entered the service of King João II as an astronomer and chronicler.

A version of Zacut's *ḥibbur* was published in Leiria, Portugal, under the title *Tabulae tabularum coelestium motuum sive Almanach Perpetuum* (1496). The Portuguese scholar, José Vizinho, was responsible for this version, which

contains a summary of the canons of *Ha-hibbur* and most of its tables. Actually, two editions came out of the Portuguese printing house that year: one with the canons in Castilian, the translation of which was made by Vizinho, the other in Latin. The *Almanach Perpetuum* is said to have played a significant role in the navigation projects of the kingdom of Portugal, and especially the tables giving the daily positions and declinations of the Sun. For a facsimile of the tables, see <http://www.fondoantiguo.us.es/obras/200/index.html>.

After the practice of Judaism was declared illegal in Portugal in 1496, Zacut traveled to Northern Africa and settled in Tunis. He adapted his tables for the year 1501 and he compiled another set of tables, beginning with year 1513, arranged for the Jewish calendar and the meridian of Jerusalem where he then lived. Both sets of tables only survive in fragmentary texts. Zacut died in 1515, probably in Damascus.

Zacut's work had a considerable impact on the astronomical community. All, or some of, the tables in the *Almanach Perpetuum* were reprinted several times in astronomical texts published in 1498, 1502, 1525, and 1528. All four editions were printed in Venice, in three different printing houses. Further evidence for the fame of Zacut and his tables is found in many authors in the late fifteenth and sixteenth centuries, and even later, among Jewish, Muslim, and Christian scholars.

See Also

- [Alfonso X](#)
- [Levi ben Gerson](#)

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Zanzibar Stone Town

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Zanzibar, part of Tanzania, is an archipelago of two main islands, Unguja and Pemba off the coast of Africa in the Indian Ocean. The Stone Town, the old town and historical capital, has an estimated population of 30,000 people. The tropical climate, fertile soils, plentiful waters, and ready supply of building materials offered all that was required for early urban development (Siravo & Bianca, 1996). Zanzibar, strategically located merely 40km from mainland Africa coupled with regular monsoon winds, presented ideal circumstances for seaborne trading and commerce activities between merchants from Asia, primarily India and the Arab peninsula, and Africa. These circumstances also presented a perfect opportunity for a cosmopolitan and culturally diverse town to flourish.

The well-preserved stone buildings and the thriving dynamic Swahili culture have rendered Zanzibar Stone Town as one of the best manifestations of trade and maritime history on the East African Coast. Zanzibar Town is also famous for the important role it played on one hand to advance the slave trade and on the other hand to promote antislavery campaigns led by important personalities such as David Livingstone at the end of the nineteenth century.

Before the arrival of the European and Asian merchants and explorers, the island of Zanzibar only had a series of small harbors and fishing towns developed under the influence from the interior of Africa and from islands across the

Indian Ocean. Consequently, a confederation of small coastal city states known as the Zenj bar (Black Empire), which operated between the eighth and tenth centuries, grew in importance. The best preserved of these towns is Zanzibar, the name of which is derived from the Persian-Arabic word meaning “the coast of the blacks.”

With the arrival of the Portuguese in the sixteenth century, Zanzibar saw the introduction and growth of the slave trade with demand driven by the Arabs in their interest to sustain their plantation economy in the Coast of East Africa and by the French islands in the Indian Ocean. Still standing to this day is the Portuguese-constructed Old Fort on the seafront. It is a testimony to the Portuguese indirect control of Zanzibar and their interest in controlling maritime activities and particularly trading in the Indian Ocean. In 1698, Zanzibar thereafter fell under the Arab control when the Sultanate of Oman took over control from the Portuguese (Sheriff 1995a). It was only in 1840 during the reign of Sultan Seyyid Said that the Stone Town expanded to take the shape known today, set off by the Sultan’s decision to officially relocate his capital from Oman to Zanzibar.

With growing and expanding trade, particularly clove and slave trade, attaining its climax in the middle of the nineteenth century, Zanzibar Stone Town prospered under the ruling Arab Sultans and its foreign merchants from Asia and inside Africa. Under the reign of Sultan Barghash (1870–1888), the House of Wonders, a prominent landmark, was constructed along with the provision of piped water and electricity, thereafter transforming the town into a modern urban city. These developments provided an impetus of spontaneous construction of palaces and houses for the rich Arabs, simple in their architectural integrity but grand and extravagant in space and finishing, with high ceilings, huge windows from airy large rooms overlooking the Indian Ocean, and intricate and elegant large Arab doors. Amidst the predominant Arab stone architecture, Indian traders and artisanal professionals also enjoyed the prospects of extending their traditions in building multistory houses with intricate verandas, a reminiscent of the Gujarati havelis.

As the predominant Arab mortared coral and flat roof architecture became the main feature of the town, it became known as the Stone Town and was thereafter referred to along the East African Coast as the Stone Town of Zanzibar. This name symbolizes the reputation and magnificence of stone architecture along the African coast where most houses were predominately constructed with mud and thatched roofs.

In 1890 when Zanzibar became a British protectorate, the town saw the introduction of the British architectural influence. Under the influence of the architect John Sinclair, the British colonial architecture in Zanzibar was strongly influenced by Islamic architecture from Istanbul and Morocco, perfectly fitting harmoniously with Arabic fabrics. With the strong presence of the British, European missionary activities also prospered, resulting in the construction of the Anglican and Roman Catholic Cathedral.

In January 1964, shortly after the Arab Sultanate gained independence from the British, an African-led revolution overthrew the Arab Oman Sultanate, based on minority rule, ushering in a predominantly African government. The same year in April, Zanzibar made the then strategic move to unite with Tanganyika to form the United Republic of Tanzania. The new government neglected the old town, fortunately without destroying the buildings, regarded as a symbol of their oppressors.

Over two decades of abandonment, the Stone Town was left in a state of deterioration, and only in the early 1990s, when Zanzibar opened its doors to tourism, was the importance of preserving its cultural heritage recognized. With this development, Zanzibar saw the establishment of the Stone Town Conservation and Development Authority (STCDA), a government institution established primarily to assume responsibility for the reconstruction and sustainable conservation of the old town with full legal authority to empower its implementation capacity.

Today, Zanzibar Stone Town continues to boast its rich history of the Indian Ocean trade activity and its important role in the suppression of slave activities and interaction with the rich civilizations from Africa, Asia, and Europe.

It illustrates an outstanding architectural and cultural manifestation of fusion and harmonization. In 2000, Zanzibar Stone Town was officially named a UNESCO World Heritage site, under criteria II–III and VI (1):

(1) World Heritage in Africa – ICOMOS Documentation Center

Criterion ii: The Stone Town of Zanzibar is an outstanding material manifestation of cultural fusion and harmonization.

Criterion iii: For many centuries there was intense seaborne trading activity between Asia and Africa, and this is illustrated in an exceptional manner by the architecture and urban structure of the Stone Town.

Criterion vi: Zanzibar has great symbolic importance in the suppression of slavery, since it was one of the main slave-trading ports in East Africa and also the base from which its opponents such as David Livingstone conducted their campaign.

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Zero

R. N. Mukherjee

Mathematics today owes its existence in part to the discovery of zero. For the purpose of calculation it needed a short symbol, which is at present denoted by a small circle in nearly every part of

the world. In India in the early period the form of short symbol which represented zero (*śūnya*) was both a dot and a small circle.

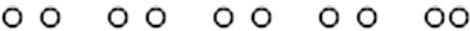
In the Vedic literature, in the *Amarakosa*, zero (*śūnyam bindau*) was represented by a dot. The form was also suggested by the word *kṣudra* (very small) in the *Atharvaveda*. The word *randhra*, used in the Hindu *Gaṇita Sastraka*, indicated a small hole. There are many examples of zero being represented as a dot in the Kashmirian *Atharvaveda*, both in the marginal notes and in the text itself.

In the marginal notes, the numbers are as follows:

Symbol	Number	Folio	Page
◇••	100	100b	192
◇•◇	101	101b	194
◇2•	170	170b	310

The symbols in the marginal notes represented the Folio numbers. In most of the pages of the book there are examples of the above type. In the text itself the following numbers are found:

Small circles in pairs have been used to denote blank spaces in the text. In Folio No. 178a, page 323 in the last line, pairs of small circles are found as follows:



The numbers in the marginal notes may be taken from a later period, but the symbols in the text itself must be from the time of the *Atharvaveda* (500 BCE).

In the Bakhshālī Manuscript, the oldest extant manuscript in Indian mathematics (AD 200), the symbol  represents the number 4,000, while the symbol  represents 500,000,000. The fourth zero in the manuscript is a small circle; the others are dots. In the Shahpur Stone image Inscription of Aditya Sena Bihar, India (AD 672), the symbol  stands for 60, and zero is represented as a dot. In the Malay Inscription at Katakapur (AD 686), symbol  represents the number 608 (*Śāka*), and zero is represented as a circle with a deep circumference.

In the above examples it is found that zero has been exhibited either as a dot or as a small circle to fit in numbers in the place value scale, or to represent absence. In the inscriptions at Sambor, Palembang, and Kotakapur, which were Indian colonies of the Far East, the numbers have been written to represent the Śāka era. Hence undoubtedly they also represent an Indian origin.

Now the question arises as to why zero has been represented as dot or a small circle and not as a square or rectangle or anything else. Two reasons can be assigned: one is spiritual or metaphysical, the other is physical or atomic.

In the spiritual sphere, *śūnya*, or zero or nothing, the symbol of absence of everything, identifies itself with *Nirguṇa* Brahma, the absence of all qualities. The no-quality (*Nirguṇa*) in Brahma represents the fact that He is not guided by any of the qualities or constituents of nature. But at the same time Brahma is the source of all qualities, energy, power, and strength. Similarly *śūnya* or zero itself signifies absence when placed independently, but it represents fullness when it is placed in the decimal system of numeration. (Placing zeros on the right side of a number increases the value to an infinite step.)

Since the conception of *śūnya* identifies with the conception of Brahma both in absence and fullness, the symbol of *śūnya* (zero) must be guided by the symbol of Brahma. The conception of Brahma lies in meditation on a particular point or small circle in the space between the two eyebrows.

Swami Sivananda has given concentration the name “one-pointedness”. Concentration can also start by fixing one’s gaze on a black dot on the wall and later on a bright light first of the size of a pinpoint and later of the size of a sun coming out from the space in between the two eyebrows. Hence the symbol of Brahma can be taken to be a dot or a small circle, and therefore the symbol of mathematical zero is either a point or a small circle.

There are also physical reasons for the symbol for zero. Planets seen from the earth look just like dots. From Vedic times Indians excelled in astronomical observations as we can see in the *Vedāṅga Jyotiṣa* (1200 BCE). So the physical reason for zeros being represented as a dot or a

small circle lies in the fact that the sun, moon, and planets were seen as dots or small circles to an observer on the earth.

Now why should a planet be chosen to represent zero? It is because of the other interpretation of mathematical zero, the absence of atoms. The idea of the atom was mentioned in ancient times in the Buddhist work *Lalita Vistara* (500 BCE). The nucleus of the atom is so small that it is a *kṣudra* (minute), a synonym for zero in the *Athravaveda*. Thus the absence in mathematical zero is guided by the absence inherent in the smallness of an atom or its nucleus. The concept of the fullness of mathematical zero is also present in the infinite motion of the planets and of the electrons around the nucleus of an atom.

The electron has no mass in the material sense, and the mass which it has developed from electrical energy is negligible. This guides the concept of mathematical zero. The movement of electrons around the nucleus with a very high velocity and in an infinite motion is identical with the concept of fullness of mathematical zero which guides the numbers to move in an infinite journey like 10, 100, 1000, 10,000 to 10^n .

Thus the double interpretations, absence and fullness, of mathematical zero are identical with the double interpretations in a planet, and the symbol of zero is guided by the symbol of a planet which is observed either as a dot or a small circle and whose path is almost circular.

Zero has a double meaning in Vedic literature. Etymologically the word *śūnya* comes from the word *śūna* (*śūna* + *yat*). The word *śūna* has two meanings. One is the killing of animals or the slaughter house, which represents absence; the other is increase, which leads to the conception of fullness.

The synonyms of zero, *randhra*, *tuccha*, *kṣudra*, and *ritka* project a concept of nothingness, while the synonyms *vyoma*, *diba*, *akasa*, *antariksa*, and *jaladhra patha* mean infinite expanse of sky. *Purna* means full, and *ananta* means infinite. *Drabinam* and *balam* mean strength, vigor, and force.

Zero, though it signifies nothing, has a full voltage battery charge when used in the decimal place value system.

To understand how the West came to the peculiar conclusion that mathematics is metaphysics, we need to go back all the way to Plato. In Plato's story of Socrates and the slave boy, Socrates first elicits the boy's innate knowledge of mathematics and then declares that he has proved the existence of the soul! (His argument is that since the slave boy did not learn mathematics in this life, his innate knowledge of mathematics proves that he learnt it in a previous life.) Indeed, "mathematics" derives from *mathesis*. Though *mathesis* just means "learning," Plato had a special understanding of "learning," and stated that "all learning is recollection" – of the knowledge the soul had acquired in its previous lives but has forgotten since its birth. This belief in the previous lives of the soul was based on the belief in quasi-cyclic time. (See article on "► [Time](#)".) With a quasi-recurrent cosmos, rebirth takes place in successive cycles of the cosmos. Not only are humans reborn, but all events repeat approximately, so it is indeed natural to suppose that memories too commence afresh. *Mathesis* then becomes a mysterious way to arouse and bring back those lost memories of previous lives in a previous cycle of the cosmos. Proclus (1970) believed that mathematics (and not geography, for instance contains eternal truths and is best suited to arouse the eternal soul.)

This notion of the soul and its previous lives ran afoul of the church, which cursed it in the sixth century, when it also banned mathematics and philosophy from Christendom (Raju, 2003). The Western understanding of mathematics changed further in the twelfth century, during the Crusades, when the church accepted back mathematics, but reinterpreted it as concerned not with arousing the soul but with rational persuasion or metaphysical proofs. Nonetheless, the belief that mathematics contains eternal truths lingered on. Indeed, Aquinas claimed that God ruled the world with eternal laws of nature, and it came to be believed that those laws were hence written in the language of mathematics (since mathematics was believed to contain eternal truths).

This belief in eternal truths led to the related belief in the "perfection" of mathematics; any imperfection was bound to be exposed during eternity! As Berkeley (1734) put it "It is said,

that the minutest Errors are not to be neglected in Mathematics." The belief in perfection led to the rejection of the empirical in Western mathematics. Indeed, Plato deprecated the empirical world as inferior, and Westerners came to believe that this perfection of mathematics could only be achieved through metaphysics, which gave a higher form of truth than empirical truth. It is still believed, on Tarski-Wittgenstein semantics, that empirical truths are contingent truths (true in some possible worlds), weaker than mathematical truths, which are necessary truths (true in all possible worlds), relative to the axioms. Consequently, the present-day philosophy of formalism still supposes that mathematics (being a higher form of truth) must be 100 % metaphysics. The number 2 is today defined solely with reference to Peano's axioms and *not* ostensibly by pointing to 2 oranges, 2 dogs, etc.

All these beliefs are in sharp contrast to zeroism. To begin with, how do we know that there are any eternal truths? Like science, zeroism admits only two means of knowledge: *pratyakṣa* or the empirically manifest and *anumāna* or inference. Totally contrary to the belief in eternal truths, it is manifest that nothing persists unchanged for even two instants. This is often wrongly called the Buddhist doctrine of flux. It is, however, not a doctrine but a simple observation, repeated thousands of times each day. Those who claim the existence of something (such as the soul) which stays constant and unchanged across time need to prove its existence. This has never been done. Thus, this *śūnyavāda* denial of the soul (*anātmavāda*) is fundamentally different from the church curse on "cyclic" time which sought to dictate the nature of the physical cosmos on doctrinaire and political grounds. All that is denied in *śūnyavāda* is the continuation of an unchanged identity from one instant to the next, and this is done solely on grounds of observation and absence of any proof for the existence of something unchanged.

Denying the continuation of identity may seem counterintuitive since our thinking involves language, and the belief in persistence of identity is part of natural language. Thus, the simple statement "When I was a boy," suggests the

persistence of some unchanging identity, the “I” which applies to both me and the boy. This clearly neglects the manifest differences, such as my gray hair or reduced physical activity, compared to the boy. On *śūnyavāda*, I and the boy are really two distinct individuals with some memories in common. For practical purposes, we may neglect the difference as somehow “small.” Zeroism accepts this practical process of neglecting or zeroing things regarded as unimportant in the context, on the grounds of the paucity of names: it would be cumbersome to speak of Ashok1, Ashok2, Ashok3, etc., with one Ashok for each instance. Treating slightly different multiple entities, as if they were one, is a necessity, because on realistic zeroism, or *śūnyavāda*, there is no valid basis for the idealistic doctrine of eternal (or persistent) entities or truths, which doctrine is rejected as erroneous. This corresponds to the exact antithesis of the formalist doctrine that only metaphysics gives “perfect” mathematics and that all practical representations (which ignore minute differences) are erroneous.

Let us illustrate this with an elementary mathematical example. Consider the iterative procedure to calculate square roots, the earliest record of which comes to us from Āryabhaṭa (Aryabhatīya, Ganita, 4, 1976). If we try to extract the square root of 2, this algorithm will not terminate. If it terminates, that will give us a finite decimal expansion or a fraction, formally called a rational number, and $\sqrt{2}$ cannot be represented by a fraction. The pattern of digits in the infinite decimal expansion for $\sqrt{2}$ will not recur either, for a recurrent decimal expansion too corresponds to a fraction by the formula for the sum of an infinite geometric series (see “► [Calculus](#)”).

This (nonterminating, nonrecurrent) decimal expansion corresponds to an infinite sum: $\sqrt{2} = 1.414\ldots = 1 + \frac{4}{10} + \frac{1}{100} + \frac{4}{1000} + \ldots$. Carrying out the infinite sum by physically adding successive terms is impossible, a supertask (or an infinite task which will take an eternity of time). Therefore, the universal practical procedure is to stop at the level of accuracy needed

for the practical application at hand and neglect or zero the remaining digits as unimportant to the practical context. For example, $\sqrt{2} = 1.414$. Or, for example, a calculator might give $\sqrt{2} = 1.4142135623730950488016887242097$ and zero the remaining digits. The exact number of decimal places after which we stop is not important. The point is we have no option but to stop, after a finite number of steps, no matter how large.

This universal procedure is good for any practical application of mathematics. Indeed, a practical task must be accomplished in a limited period of time; therefore, for practical application of mathematics, this is the only procedure available. Since each zeroed digit is at most 9, we can easily estimate the maximum possible inaccuracy by using the formula for the infinite geometric series (which formula too involves zeroing the insignificant). We can improve the accuracy to any desired level, but can never achieve perfection; contrary to Berkeley, some “minute error” would have to be neglected.

However, in search of “perfection,” formalism today insists that the only correct procedure is to sum the entire infinite series. Since that cannot be done physically, it is done metaphysically. Since the sum cannot be a fraction, it is assigned a meaning through a special metaphysics of infinity which is used to construct a number system misleadingly called the “real” number system. In fact, the usual construction of this number system requires set theory which brings in further metaphysics of infinity. Unlike practical procedures, this metaphysics is not universal, but the universal practical procedures are declared as “erroneous.” For example, most practical calculations today involve the use of computers which cannot handle the Western metaphysics of infinity implicit in formal “real numbers,” and computers use a different arithmetic (of floating point numbers) which is declared erroneous.

Indeed, on zeroism, this “discarding of insignificant quantities” is not an error; it involves a fundamentally different understanding of mathematics, not as eternal truth, not as something perfect, but as concerning practical calculations. This was the understanding with which

mathematics developed in India since the days of the *śulba sūtra*-s, through Āryabhaṭa down to the 15th c. Nīlakantha. Thus, *śulba sūtra*-s used the term *sa-viśeṣa* (with something left out) (Baudhāyana, *śulba sūtra*, 2.12, 1983) or *sānitya* (impermanent) (Apastamba *śulba sūtra* 3.2, 1930), while Āryabhaṭa used the term *āsanna* (near value) (Āryabhaṭīya, Gan. ita, 10, 1976), and Nīlakantha explained why the “real value” cannot be given. There was never any religious doctrine of mathematics as eternal truth nor its corollary that mathematics must be perfect and that this perfection can only be attained through a particular metaphysics of infinity. On zeroism, the representation $\sqrt{2}$ is acceptable only due to a paucity of names and functions exactly like the single name “Ashok” which refers to a multiplicity of slightly different entities, 1.4, 1.41, 1.414, etc.

Though we have taken $\sqrt{2}$ as an example, the practical use of numbers is inevitably tied to neglecting or zeroing of some tiny differences. Thus, when we speak of two oranges, we neglect as unimportant the fact that no two oranges are identical any more than any two persons are identical. What we mean is that the differences between the two oranges are irrelevant to the context. Hence, even the attempt to understand integers formally, through Peano’s axioms, involves the metaphysics of infinity in a subtle way. This is clear from the fact that computers can never do supposedly “perfect” Peano arithmetic. [For ints on a computer, see C. K. Raju (2001). A more detailed account of why this happens can be found in <http://ckraju.net/hps2-aiu/ints.pdf>.]

This contrast between the two different philosophies of mathematics, the religious and the practical, created enormous difficulties in understanding the infinite series of the Indian calculus when it was first imported into Europe, and Europeans conflated the two distinct streams of mathematics and tried to understand the practical in religious terms.

Thus, Descartes (1996) went so far as to declare that the ratios of curved and straight lines were beyond the capacity of the human

mind! A charitable interpretation of his statement is that he was alluding to the ratio of the circumference to the diameter of a circle. That is a number today called π and represented by the infinite series $\pi = 3.1415 \dots$, and especially the series today is wrongly called the Leibniz series. Descartes thought this involved an infinite sum or a supertask which was beyond the human mind. In fact, this comparison is very easily done using a flexible string to measure the length of the curved line and then straightening it to measure the straight line. This was how it was taught to children in India, since the days of the *śulba sūtra* (*śulba* means string), and can still be taught in preference to the ritualistic compass box which has no instrument to measure curved lines (Raju, 2009).

Of course, even on this charitable interpretation, Descartes was completely wrong in imagining that the issue specifically concerned curved lines. Thus, exactly the same problem arises with $\sqrt{2}$, which corresponds to the diagonal of a unit square: hence concerns a ratio only of two straight lines. The real issue is zeroism versus idealism. Historically speaking, however, Western mathematicians accepted Descartes’ objections, and Newton thought he had resolved them and made calculus “perfect” by making time metaphysical (Raju, 2006, 2012). Ironically, Newton’s physics failed for the very reason that he made the conceptual mistake of making time metaphysical (Raju, 1994).

This historical legacy of Western problems with the perfect way to understand infinity/eternity persists to this day in calculus as taught in schools and colleges today. Though Newton’s fluxions have been abandoned, all university calculus texts state the belief that metaphysical, formal “real” numbers are essential for the calculus. This belief is false (Raju, 2012). Indian calculus developed with a different number system (“unexpressed fractions,” formally the field of rational functions, a field larger than formal real numbers, which is hence “non-Archimedean”) in which limits are not unique, and, formally speaking, infinitesimals must be discarded (see article on Calculus). Today, differential equations are

numerically solved on a computer using a smaller number system of floating point numbers, and this too involves discarding or zeroing small numbers regarded as insignificant for the practical purpose at hand.

In the practical application of calculus to physics, there are many current problems with infinity, such as the renormalization problem of quantum field theory (Raju, 1983), the runaway solutions of Maxwellian electrodynamics (Raju and Raju, 2011), or the problem of differentiating discontinuous functions, as in shock waves in general relativity (Raju, 2007). These problems all arise just because the Indian calculus was not properly understood in Europe, just because of the belief in the perfection of mathematics which led to the metaphysics of infinity on which present-day formalism is based. More fundamentally, for example, the metaphysics of infinity in present-day mathematics is incorporated into (formal) set theory. Though many of the earlier problems (such as Russell's paradox or problems with transfinite induction) are deemed to have been resolved, we still have, for example, the Banach-Tarski paradox which provides us with a source of unlimited wealth: it says that a ball of gold can be cut into a finite number of pieces which can then be reassembled into two balls of gold each identical to the original one! The huge metaphysical structure of set theory needed even to define simple numbers such as 2 creates enormous learning difficulties in mathematics. Zeroism is of contemporary importance since it helps to resolve both pedagogical and scientific problems.

Western philosophers and mathematicians did not notice a key problem with their beliefs. On the one hand, they believed mathematics was universal, and on the other hand, they believed perfection could only be found in metaphysics. They neglected to ask: which metaphysics? Unlike the universal procedure of practical calculation, Western metaphysics is no obviously universal. For example, empirical proofs are universally accepted by all Indian systems of philosophy, without any exception. They all accept the *pratyakṣa* or the empirically manifest as a valid means of knowledge or proof as does Islam (*tajurba*) and science (experiment). Further,

empirical proofs are the only means of proof accepted by all Indian systems, since the Lokayata (or common people's philosophy) rejects *anumāna* (inference or deduction) as unreliable (and Buddhists reject as unreliable any means of proof other than *pratyakṣa* and *anumāna*). Thus, the elevation of metaphysical proofs above empirical proofs is a cultural idiosyncrasy of the West which is decidedly not universal, and its use in the philosophy of mathematics makes that Western mathematics nonuniversal. (It is another matter that the colonial education process makes Western mathematics normatively universal.)

Further, Western thought has dogmatically maintained, since the Crusades, that inference (or deduction) is the only reliable means of proof. Now, inference or reasoning is based on logic, and the West naively assumed that "reason" (meaning two-valued logic) is universal. This belief in the universality of "Aristotelian" logic was tied to the dogmas of the Christian rational theology of Aquinas and schoolmen, which developed during the Crusades, and maintained that even God was bound by logic in the sense that he could not create an illogical world. Since they, however, believed that God was free to create facts of his choice (while creating the world), therefore they thought that logical proofs are stronger than (or superior to) empirical proofs (since God is bound by logic, but not by facts). This belief is reflected in Tarski-Wittgenstein semantic of possible worlds: in contrast to facts which are contingent truths (true in some possible worlds), mathematical theorems are believed to be necessary truths (true in all possible worlds). The only difference is that instead of possible worlds which God could create, one speaks of possible logical worlds in the sense of Wittgenstein. In actual fact, there is nothing divine or unique about logic except in the Western imagination; there are an infinity of logics to choose from.

Logic is not even culturally unique (e.g., Buddhist *catuṣkoṭi* or Jain *syādvāda* are not 2-valued or even truth functional) (See article on Logic). Accordingly, if logic is decided on cultural grounds, then that obviously involves a cultural

bias. If, on the other hand, logic itself is determined empirically, from facts, logical proofs cannot be stronger than (or superior to) empirical proofs, i.e., in principle. (In practice, of course, deductive proofs are far more fallible than empirical proofs, as is clear from the most elementary first proposition of the *Elements*, which uses an empirical proof, but this was not noticed for 700 years (Raju, 2012), during which it was regarded as a model of deductive proofs.) Changing logic would naturally change the theorems that can formally be deduced from a given set of axioms. Therefore, contrary to the Western belief, mathematical theorems are not necessary truths relative to axioms but are at best truths relative to both axioms and logic.

To summarize, zeroism denies the existence of persistent truths and, consequently, treats the belief in eternal truths as an error. The West, because of its earlier belief that mathematics contains eternal truths, believed that mathematics must be perfect, and this perfection could be achieved only through metaphysics, especially the metaphysics of infinity (closely related to the theology of eternity). However, Western metaphysics is not universal as has falsely been claimed. For example, all Indian schools of philosophy accept empirical proof as applicable to mathematics and superior to metaphysical proof. Further, even logic is not universal, as has wrongly been claimed in the West, since Buddhist logic and Jain logic are fundamentally different from the two-valued logic declared universal in the West. (The Western belief in the universality of logic is based on the theological argument that logic supposedly binds the Christian God and is hence universal.) Choosing logic on cultural grounds would naturally result in a cultural bias, but choosing it on empirical grounds means the belief that metaphysical proofs are stronger than empirical proofs must be abandoned. (Also, as quantum logic shows, two-valued logic is still not the automatic choice.) In either case, there is no basis left for formalism.

Zeroism is ideally suited to the practical applications of mathematics. Indeed, zeroism enhances the practical reach of mathematics, since there are many situations where calculations are possible, but metaphysical proof is not:

for example, stochastic differential equations driven by Levy motion, where solutions can be calculated but cannot be formally proven to exist (Raju, 2001). The advantages of zeroism are particularly evident in physics where the classical calculus with limits fails as does its extension, the Schwartz theory of distributions. Limits also fail in statistics, for relative frequency converges to probability only in a probabilistic sense (Raju, 2011). Zeroism works very well in this situation.

The use of zeroism has the further advantage that it greatly simplifies mathematics in situations such as the calculus. The derivative no longer represents the slope of the tangent (the best linear approximation to a curve) but only the slope of a chord (a good linear approximation to the curve). As usual, one name serves to represent a multiplicity of slightly different entities, the differences being irrelevant for practical applications. All that is given up is the oxymoronic demand for the “best approximation.” This not only suits computational mathematics, it simplifies pedagogy. Making math easy means that students can tackle much harder problems.

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Zhang Heng

Jiang Xiaoyuan

Zhang Heng was a Chinese astronomer, writer, and machinist (AD 78–139). As a man of noble descent, he assumed many official positions, and from AD 115, twice was the head of the imperial astronomical organization for a total of 15 years. He was a versatile man who contributed greatly to Chinese astronomy.

The title of one of his works is *Ling Xian* (Mystical Laws); it is very possibly an outline of astronomy-astrology, but only part of the beginning has been handed down. He made an astronomical instrument like a planetarium to demonstrate the motion of the sun, moon, and planets with stars in the background, and to give the correct time. According to historical records he provided this instrument with an automatic mechanical installation, but the detailed information has not been preserved.

Zhang Heng made a wonderful invention for earthquake measurement. In AD 132 he invented a seismoscope called *Hou Feng Di Dong Yi* (Instrument for Earthquake), and at Luoyang (the capital of the empire) he successfully determined that an earthquake had occurred at a place in the northwest of China more than a thousand kilometers from the capital. We have the following information about this seismograph.

This instrument was cast in copper. Its main body is a standing egg-shaped shell with an erect pendulum in the center. It links eight dragons each of whom, with some dexterous mechanical installations, keeps a small copper ball in its mouth. When an earthquake happens somewhere, the dragon in that direction spits out its ball, so that people know where the earthquake has occurred.

This famous seismoscope was not preserved, so scholars have tried to reproduce it since the nineteenth century. Many reconstructive schemes on the basis of modern seismological principles have been published. Up to now, the most successful was by Wang Zhenduo (1963) of which a model has been made.

Zhang Heng is also an important writer. His *Si Chou Shi* (Four Chapters of Distressed Poems) and *Gui Tian Fu* (To Live in Seclusion) are literary masterpieces and his *Tong Shen G* (Song of Love) is one of the most important early documents for the history of Chinese sexual culture.

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Zhang Ji (Zhang Zhongjing)

Fabrizio Pregadio

The Chinese physician and medical author Zhang Ji (ca. 150–220), also known as Zhang Zhongjing, was born in the Nanyang commandery (in modern Henan). As stated in the preface to his main work, he was prompted to study medicine and collect prescriptions by the spread of epidemic diseases which caused the death of several members of his own clan. The preface adds that he was Governor (*taishou*) of Changsha (modern Hunan), but this detail is not independently confirmed by other sources.

Zhang Ji's main work, completed in the first or second decade of the second century, was originally entitled *Shanghan zabīng lun* (Treatise on Cold Damage and Miscellaneous Disorders) and included 16 chapters. The rather intricate bibliographic history of the text cast doubts on its authenticity. About one century after its compilation, Wang Shuhe (ca. 265–317) produced a revised, expanded version. The final six chapters, lost by the Song period, were replaced on the basis of an abridged version, and published as a separate work. The two main parts in which the text is extant today are entitled ► [Shanghan lun](#) (Treatise on Cold Damage) and *Jingui yaoliè* (Essentials from the Golden Casket), respectively. The latter is based on the “Miscellaneous Disorders” section of the original text.

The *Shanghan lun* is the first Chinese medical text devoted to a specific etiology. It is concerned with a class of diseases symptomatized by acute fevers, and named “Cold Damage” after one of their factors. Their diagnosis is based on the

identification of symptoms (*zheng* or “evidence”) that indicate the stage reached by the disease in its progression toward the vital centers of the body. These stages of development are defined according the Six Warps (*liujing*) system, one of the frameworks used to describe the cyclical flow of energy within the body (others are *qi* and *wuxing*, Five Agents or Phases). The text emphasizes the practical rather than the theoretical aspects of healing. Therapy is based on the administration of medicines (the whole work includes more than 300 prescriptions for specific diseases), and to a lesser extent on acupuncture, ► [moxibustion](#), and other methods such as baths and massages.

Zhang Ji's work gave rise to the second most important tradition within Chinese classical medicine after the one represented by the texts of the “Inner Canon of the Yellow Emperor” corpus (► [Huangdi neijing](#)). Although Zhang refers to this corpus in the preface, even the most basic notions of the Inner Canon – e.g., the Five Agents or Phases, the visceral systems (*zangfu*), and the circulation tracts (*jing*) of acupuncture – are absent from his work. As has been pointed out, this is not necessarily a sign of alternative or competing traditions. An extended commentatorial tradition, in fact, has tried to bring together the respective basic notions. Only recent research has shown the ways and extent to which the general framework of the two works differs.

See Also

- [Acupuncture](#)
- [Five Phases \(Wuxing\)](#)
- [Huangdi neijing](#)
- [Medicine in China](#)
- [Moxibustion](#)
- [Qi](#)
- [Shanghan lun](#)

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Zhang Qiuqian Suanjing

Lam Lay Yong

Zhang Qiuqian suanjing (The Mathematical Classic of Zhang Qiuqian) is the only known work of the fifth century mathematician, Zhang Qiuqian. It is one of ten mathematical books known collectively as *Suanjing shishu* (Ten Mathematical Classics). In A.D. 656, when mathematics was included in the official examinations, these ten outstanding works, which covered a period of over a thousand years, were specially selected as textbooks.

Jiuzhang suanshu (Nine Chapters on the Mathematical Art) and ► *Sun Zi suanjing* (The Mathematical Classic of Sun Zi) are two of these texts that precede *Zhang Qiuqian suanjing*. All three works share a large number of common topics. Though *Sun Zi suanjing* was intended as a primer, it now provides significant documentation of the rod numerals and their use in multiplication, division, and other mathematical methods. *Jiuzhang suanshu* is undoubtedly the most important and influential of the early mathematical texts. Both works occupy prominent places in the history of Chinese mathematics with one showing the initial learning stage and

the other manifesting an evolutionary culmination. *Zhang Qiuqian suanjing* demonstrates the continuation of the development of mathematics from here, and provides an important bridge of knowledge on the evolution of traditional mathematics to its apogee in the thirteenth century. It is all the more important as such surviving works are few and far between.

Zhang Qiuqian regarded fractions of primary importance; he mentioned the difficulty of the subject in his preface and provided more complicated problems than those in *Jiuzhang suanshu*. There are only very brief general descriptions of finding the square root and the cube root of a number in *Jiuzhang suanshu* and these are written with the use of technical phrases. It is a relief to scholars to find that examples are employed in *Zhang Qiuqian suanjing* to illustrate the step by step procedures of both methods and also to show how the solution of a nonintegral approximation is obtained.

Zhang Qiuqian continued with the tradition of the development of arithmetic by supplying problems involved with what is known in the west as the Rule of Three and extending to problems concerned with proportions, compound proportions, and proportional parts. Other problems are involved with relative speed, different shaped frustums and granaries, the Rule of False Position, the arithmetical progression, the computation of interests and taxes, similar right-angled triangles, and the quadratic equation. There are a number of problems concerned with the well-known *fang cheng* method, which is the Chinese way of solving a set of simultaneous linear equations. The last problem of the book is the famous problem of a hundred fowls. In this problem, somebody is to buy 100 fowls for 100 monetary units, given that a rooster costs five units, a hen 3, and chicks are sold three for one unit. Even though the answers given in the book are correct, it is not clear how the answers were obtained.

Zhang Qiuqian's lucid style has been a great help to the scholar's understanding of how the ancient mathematicians manipulated the rod numerals to arrive at the answer. The existing edition of the book has three chapters with 92 problems; the last portion of the second

chapter and the beginning of the third chapter are incomplete. The book has been translated into English by Ang Tian Se.

Zhang Qiujiang suanjing has an important place in the world history of mathematics: it is one of those rare books before A.D. 500 that manifests the upward development of mathematics fundamentally due to the notations of the numeral system and the common fraction. The numeral system has a place value notation with ten as base, and the concise notation of the common fraction is the one we still use today.

See Also

- [Computation: Chinese Counting Rods](#)
- [Jiuzhang Suanshu](#)

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Zheng He

Sally Church

Zheng He was originally from Kunyang in Yunnan province, in Southwest China. Born around 1371 to a Muslim family, he was surnamed Ma, a common Muslim surname derived from the Chinese transliteration of the name Muhammed.

During the 1380s, the Ming government sent troops to Yunnan on an expedition to pacify the region, expel any remaining Mongol influences, and incorporate it solidly into the newly founded regime. At the age of about 10, Zheng He (then Ma He) was captured by Chinese troops, taken prisoner, and selected to become a eunuch. We know that by 1382, when an inscription was written for his father who had passed away, he was taken into the service of Prince Zhu Di, fourth son of the Ming founder, Emperor Hongwu (Zhu Yuanzhang, r. 1368–1398). There Ma He served Zhu Di in his principality of Yanjing (the region of present-day Beijing). Zhu Di was later to become the third Ming emperor, Yongle (r. 1403–1424).

In his early career, Ma He accompanied Zhu Di on military campaigns against Mongol forces in the Yanjing region. He distinguished himself as a military commander in a campaign against the Mongols outside the Great Wall (1393–1397), and then in the civil war (1399–1402) launched by Zhu Di against Hongwu's successor, Jianwen. This war ended in victory for Zhu Di, who usurped the throne from Jianwen in 1402. For loyal service to him during the civil war, and as a reward for suppressing a rebellion in Yunnan, Zhu Di, then Emperor Yongle, conferred the Chinese surname Zheng on his trusted eunuch. This occurred on New Year's Day in 1404. From then on he was known as Zheng He.

Soon after ascending the throne, Yongle began planning the maritime expeditions which have made Zheng He famous. In some respects they were a continuation of the regular conduct of foreign relations – the sending and receiving of envoys to and from foreign countries, particularly in Southeast Asia – which had occurred during Hongwu's reign (1368–1398) and in previous dynasties. As early as the ninth month of 1402, only 3 months after proclaiming himself Emperor, Yongle sent ambassadors to these countries to announce his accession. We are told that envoys came to China from Calicut and Chola (the Coromandel coast) for the first time in 1403. In the eighth month of that year, Yongle reopened the three maritime supervisorates in Zhejiang, Fujian, and Guangdong that had

operated under Hongwu. Ambassadors came and went, and regular tributary and diplomatic relations proceeded as normal.

In the meantime, there were signs that the emperor had a larger-scale of activity in mind. As early as 1402 he had ordered the construction of ocean-going ships in substantial quantities – first 137 ships, and then 200 in that year alone. A further 188 vessels were to be converted (presumably from ocean-going grain transports) the following year, and 55 more new ships were ordered at the beginning of 1404. Emperor Yongle appointed Zheng He commander of the fleet and on 11 July 1405 issued the order for the first expedition to the “Western Oceans” (Xiyang).

The ultimate purpose of these expeditions is not entirely clear, though there were probably diplomatic, military, and economic motivations. The main reason given in the Ming History (*Ming shi*) – that of finding the deposed emperor Jianwen – was probably not the true purpose. It would not have been necessary to send out a fleet of over a hundred ships and 27,000–28,000 men to search for a single person in the vast oceans of Southeast Asia and beyond, nor does this explain the expeditions’ political, military and diplomatic activities in the regions they visited.

In all there were seven major expeditions, each one taking approximately 2 years from departure to return. The dates of the seven were (1) 1405–1407; (2) 1407–1409; (3) 1409–1411; (4) 1413–1415; (5) 1417–1419; (6) 1421–1422; and (7) 1431–1433. The first three departed quickly in succession, with one leaving in the same year as the previous one returned. After the third, there was a 2-year gap between each. Between the sixth and seventh expeditions a space of 9 years intervened because of the death of Emperor Yongle in 1424. He was succeeded by Emperor Hongxi (r. 1424–1425), who saw the expeditions as unnecessary extravagances and called a halt to them. The final expedition was not launched until the reign of Hongxi’s successor, Emperor Xuande (r. 1425–1435). In addition to the seven major expeditions, there were also branch or side expeditions to such countries as Bengal and Thailand.

Because of the monsoon, which Chinese sailors seem to have understood quite early on, the expeditions followed a regular seasonal pattern in their departure and return. They left the port of Taicang (near present-day Shanghai) in the autumn, and sailed down the coast to the port of Changle in Fujian province. There they waited for the monsoon until December or January, before sailing on to Champa (Xin Zhou, present-day Qui Nhon), Java, Palembang, Melaka (Malacca), and various places on the island of Sumatra, including Samudra-Pasai. After crossing the Bay of Bengal, they reached Ceylon (present-day Sri Lanka), and then proceeded to Quilon, Cochin, and finally Calicut, a major emporium of the Indian Ocean trade network at the time. The first three expeditions did not go beyond this point. The fourth went further, to Hormuz, and the fifth, sixth, and seventh expeditions traveled to the Arabian Peninsula and East Africa. The journeys beyond Calicut were probably undertaken by portions of the fleet.

The main scientific and scholarly issues involved are the dates of the various expeditions and their implications for such issues as speed of travel, the numbers and types of ships that sailed on the voyages, the logistics of carrying out such a major operation, the routes the expeditions followed, and the techniques and instruments that were used for navigation. The equipment used for military purposes is also of interest, although details are scarce. With regard to the dates, there is some disagreement in the sources, but the discovery of two stone inscriptions in the 1930s in two separate locations on the Chinese coast, each corroborating the other on the years of departure and return for the seven major voyages, has settled the matter for the most part, thanks to the careful elucidation of the issue by Duyvendak (1938). The numbers and types of ships on the voyages cannot be known exactly, but it is highly unlikely that they were the size given in the *Ming shi* of 44 *zhang* long and 18 *zhang* wide, equivalent to 447 × 183 ft. Moreover, there are serious practical reasons for thinking that the ships could not have been of that size. They would have been proportionally much too wide. Moreover the

available timber would not have allowed a longitudinal strengthening member to have been made in one continuous length, nor could masts of the height required have been made of a single tree trunk. It has also been estimated that as many as 8,000 men would have been needed for the crew, and there is no evidence for ships carrying more than 500 men on them; more likely there were 200–300 crew members. The “Mao Kun map” (see below) shows conventional ships with only three or four masts, although it has been estimated that a ship of 44 *zhang* in length would need nine masts. There are references to 48, 62, or 63, and 100 ships used on individual voyages, and the initial order for ships to be built in 1403 was for 250. Thus it is difficult to be precise as to the size of the fleet, though there were probably over 100 ships on each expedition. The ships must have been of various sizes for different purposes, including ships for military uses, the transport of supplies, and the transport of personnel. More research needs to be done on the question of logistics, to understand how so many sailors and other specialists (including doctors) were recruited, and how supplies were requisitioned and managed on the voyages. Further study of local histories and gazetteers of the coastal regions around ports such as Taicang and Changle may perhaps shed some further light on this question.

The routes and navigation techniques are perhaps the most rewarding issues for scientific investigation. For this, the most important source is the Mao Kun map, called thus by Mills because it appears in a collection of military preparedness materials (*Wu bei zhi*) compiled by Mao Yuanyi (1597–1661), a grandson of Mao Kun (1512–1601). In Chinese, the map is usually called *Zheng He hanghai tu* (Zheng He’s navigation map). It probably came from Mao Kun’s library of military materials, which he collected because of his interest in naval matters deriving from involvement in the coastal defense of Fujian. Significant work on this map has been done in the West, particularly by Mills (1970) in his book on Ma Huan, who accompanied three of Zheng He’s expeditions and wrote an account, entitled *Yingyai shenglan*, of the places they

visited. It is a strip map in 40 folios arranged from right to left, beginning in Nanjing and ending in Hormuz, also showing the east coast of Africa. It depicts not only the places roughly in their geographical locations along the contours of the coast, but also the routes from place to place, marked by dotted lines, and accompanied by sailing directions along the route markings. The sailing directions are expressed in terms of compass points and distances, with occasional references to navigation techniques, such as the need to take soundings in certain areas to avoid shallow waters. Distances are expressed in lengths of time according to the Chinese system of counting watches, or 2-h periods.

The use of astronomy in navigation is evident in some of the sailing directions, particularly those for the north-south route along the coast of Africa, where latitude is indicated by the height of constellations measured in number of fingers at arms’ length above the horizon. The Arabs also used this technique in seafaring. The work concludes with four “stellar diagrams” giving precise instructions for positioning a ship in relation to certain stars and constellations on two key segments of the route – between Sumatra and Ceylon and between Hormuz and Calicut. This was in order to ensure arrival at the correct destination over long expanses of ocean.

The expeditions provided regular contact and involvement with distant countries over the course of almost 30 years. Through the accounts not only of Ma Huan but also of Fei Xin and Gong Zhen, certain circles in China were exposed to foreign ideas, practices, and customs. Needham (1971) suggested that one of the aims of the expeditions was the “search for rarities of all kinds... gems, minerals, plants, animals, drugs and the like” for the court, and that knowledge of foreign science, particularly medicine, was transmitted to and from China during this time. This contact seems to have led to some exchange of information and technology between China and other cultures and civilizations – the Arabs and Indians for example – and could have led to more if it had not been for the suppression of information about the voyages in China due to internal politics. Fearing an increase in eunuch power,

and citing the extravagant expense of the expeditions, the official Liu Daxia, who later became president of the Ministry of War, discredited the first-hand accounts, calling them “deceitful exaggerations of bizarre things far removed from the testimony of people’s ears and eyes.” He destroyed all the documents in the official archives that concerned the voyages.

A question much discussed by scholars is why these expeditions, which showed such a high level of scientific and technological expertise, as well as energy, curiosity, and interest in other countries, stopped abruptly after 1433. Did China simply turn inward, cast aside her quest for knowledge of “the other,” reject science, technology, and progress, and willingly forfeit a prominent role in international relations, thus sealing her fate in the nineteenth and twentieth centuries? Such a view not only relies too much on hindsight but also seriously underestimates the intelligence of the Chinese people. There was also no amorphous “China” that made such a conscious decision. A handful of people with political power took certain steps for their own short-term reasons. To conclude that China at any point in her history rejected technology and progress simply ignores reality. There were engineers, mathematicians, astronomers, and scientists in many fields during all periods of Chinese history who for practical reasons as well as theoretical interest pursued scientific investigation and activities, sometimes in conjunction with, but more often independently of government policy. Instead, a more likely explanation for the cessation of the maritime expeditions is financial – the expeditions were expensive and there were other demands on the imperial coffers at the time, including not only defense against invaders in the north, but also domestic concerns such as famine relief and dyke repair.

Zheng He’s precise time and place of death is not known for certain. It is now accepted in scholarly circles that he did not die abroad, but returned to China and passed away in Nanjing in approximately 1435. A tomb in Nanjing is now conventionally accepted as his.

Despite the destruction of the documents in the official archives, many sources of information about these voyages still survive. Of prime importance are the three first-hand accounts by Ma Huan, Fei Xin, and Gong Zhen, which are remarkable for their attention to the political, economic, social, and religious conditions of the lands they visited, as well as for their frank observations and open attitudes toward the unfamiliar customs and practices they found. In addition to the Mao Kun Map and the various inscriptions on stone steles, including three in China (the Liujiatjiang, Changle, and Jinghai temple inscriptions) and others in the countries they visited, an itinerary for the seventh voyage also survives, preserved in a work by Zhu Yunming, giving the dates of arrival and departure from each place visited by the main portion of the fleet. From this itinerary it is possible to calculate the length of the various legs of the journey and the speed of travel. In addition there are numerous references in the *Ming Shilu*, or “Veritable Records” of the Ming dynasty, particularly to the exchange of ambassadors to and from China. References occur in many other Chinese historical documents as well. In the 1980s Zheng Hesheng and Zheng Yijun collected voluminous references to the voyages in Chinese historical and other documents and included them in their monumental multi-volume work entitled *Zheng He xia Xiyang ziliao huibian* (A Collection of Resource Material on Zheng He’s Voyages to the Western Oceans), a convenient resource for anyone interested in pursuing research on the expeditions.

In 2002 the British submarine commander (retired) Gavin Menzies, in a popular book entitled *1421*, claimed that the expeditions sailed beyond East Africa to “discover” America and circumnavigate the globe. This theory, though presented as historical fact, remains entirely undocumented. Serious scholars continue to pursue the truth about Zheng He’s voyages, and interest in them is currently at a height because it has now been 600 years since their initial launch.

See Also

- [Clocks: Astronomical Clocks in China](#)
- [Maps and Mapmaking in Japan](#)
- [Navigation in China](#)

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Zhenjiu Dacheng

Richard Bertschinger

The *Zhenjiu Dacheng* (Great Compendium of Acupuncture and ► [Moxibustion](#)) is a digest of acupuncture and moxibustion writings from the

Han to the Ming dynasties. As such, it forms the greatest comprehensive survey of acupuncture in China ever to be produced during classical times. Much of its greatness is due to its selection of works from the Song and Yuan. It was edited by Yang Jizhou in 1601, as the culmination of his life's work. He was then close on 80-years old and obviously still active.

An early title for the work had been “Secrets of the Dark Inner Mechanism of Acupuncture and Moxibustion for the Preservation of Health.” In this text Yang Jizhou included mainly the traditions of his own family, but later he enlarged the book to include earlier literature, and so changed the title. Generally he selected the best of the old, and reedited it, adding a certain amount of his own material where it suited.

The Grand Compendium comprises some ten volumes, covering all aspects of acupuncture and moxibustion. It also contains an appendix on massage techniques particularly suited for children, entitled *Biaoying Shenshu* (The Divine Art of Protecting Infants), taken from an earlier book which is now lost. The work includes listings of channels and points; many point-formulae for medical conditions, particular systems for choosing points; refined needling techniques such as those developed during the Song, Yuan, and Ming; detailed formulae for calculating the precise time and exact point for treatment; glossaries of point names; and selections from the classics, especially the ► [Huangdi Neijing](#) and its slighter companion the *Nan Jing*. This all constitutes a great wealth of historical material.

Particularly striking are the exquisite verse poems selected for the second volume. These include the “Ode to the Golden Needle,” which focuses on needling techniques, the *Liuzhu Zhiwei Fu* (Ode to Intricacies in the Circulating Flow), which outlines the Law of Midday-Midnight in which the choice of points is determined by the particular hour and day of treatment, and the *Biaoyou Fu* (Ode to the Streamer out of the Dark), the longest and most comprehensive of these poems, which contains an extensive commentary by Yang Jizhou.

A gradual increase in prosperity was spawned by better social conditions during the Ming. These in turn created an interest in the old ideas. Undoubtedly influential on Yang's work were the *Zhenjiu Sunan Yaozhi* (Essentials of Acupuncture and Moxibustion, 1536) and the *Zhenjiu Juying* (Gatherings of Outstanding Acupuncturists, 1546), both issued by Gao Wu during the earlier century. Gao Wu's work was particularly commendable as he made a stand against any superstitions in medicine. Where he was uncertain he would simply state it, without comment. From Gao Wu's work Yang took both an uncluttered approach and a grand overview of the acupuncture tradition. In many places Yang Jizhou pays debt to Gao Wu by copying his selection of classical extracts exactly.

Another great influence was the *Shenying Jing* (Classic of Divine Resonance, 1425) by Chen Hui. From this work Yang Jizhou borrowed his simple and practical approach, cutting great swathes through confusing systems of point selection by adhering strictly to the Divine Resonance's printed lists. This compendium is an invaluable treasure for all acupuncturists and has become well-known abroad as well as in China.

See Also

- [Acupuncture](#)
- [Medicine in China](#)
- [Moxibustion](#)

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Zhenjiu Jiayijing

Richard Bertschinger

The *Zhenjiu Jiayijing* (The A-Z Canon on Acupuncture and ► [Moxibustion](#)) was written by ► [Huangfu Mi](#) (AD 215–282), during the short-lived Jin Dynasty. Needham dates the book as being finished some time between AD 256 and AD 282.

This is the oldest surviving text devoted exclusively to acupuncture and moxibustion. It was produced after the fall of the Han nation, during a time of violent turmoil and disruption in Chinese society. Huangfu Mi summarized the knowledge of his day concerning acupuncture and moxibustion, and ordered the many texts then current. He drew from both sections of the ► [Huangdi Neijing](#) as well as the *Mingtang Kongxue Zhenjiu Zhiyao* (Therapeutic Essentials of the Acupuncture Points Revealed in the Clear-Lit Hall), of unknown authorship, a book now lost. Huangfu Mi took up medicine in middle age because of his own family's illness and his own arthritis.

This book's most impressive character lies in its systematic outline of the subject (as revealed in the title). The many points are grouped under the various channels to which they belong, with number, name, point location, and tips for finding each. Additionally there are listings of the illnesses, or syndromes, for which each can be used, detailing how deep the needle should be inserted and the number of breaths for which it should be retained in position. Tonification or reducing techniques are also described, as well as angling the needle shaft along or against the direction of energy flow down the channel. In addition, Huangfu mentions the use of moxa, the number of cones for each point being duly recorded. All this had never been so accurately or clearly laid out before.

This book, quite justifiably, has had an enormous influence throughout China and abroad. It became *de rigueur* reading for the Japanese imperial colleges from the seventh century, and found its way to Korea even earlier. Its texts have been the foundation of acupuncture teaching and practice for some 70 generations in the East. As yet, there has been no translation into English.

The book's 128 chapters comprise medical theory, the examination and diagnosis; characteristics and pathology of the channels; a complete catalogue of the points; pulse diagnosis; needling technique; outline of pathology and transmission of disease; types of fevers; pains, swelling, coughing, rheumatism, wasting diseases, and dumbness; eye, nose, and throat problems; woman's and children's illness; and appendices.

Huangfu Mi's approach, in particular, stressed the need for a proper adjustment of the patient's emotions. He knew that physical and environmental factors played a part in illness, that treatment should proceed with great care, and that signs and symptoms should be precisely differentiated. All show a clear and intelligent approach to practice.

Very little has changed in the location and identification of acupuncture points since the publication of this text some 1,800 years ago. For instance, it is mentioned in the preface to the *Essentials of Chinese Acupuncture*, the first acupuncture book produced by the Chinese for a Western audience.

See Also

► [Huangfu Mi](#)

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Zhoubi Suanjing

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The *Zhoubi suanjing* (frequently also romanized as *Zhoubei suanjing*), is an anonymous Chinese work on astronomy and mathematics. It is a composite work which probably reached its final form in the first century A.D. under the Western Han dynasty.

The contents deal mainly with calendrical astronomy, and the shape and size of heaven and earth according to the ► [gaitian](#) (umbrella [-like] heaven) cosmography. It opens with a brief dialogue between the Duke of Zhou (fl. ca. 1000 B.C.E.) and Shang Gao, an otherwise unknown figure, who explains the use of the try-square *ju* and refers briefly to a round heaven lying above a square earth. In connection with the try-square Shang Gao refers cryptically to the relationship between the sides of a 3-4-5 right triangle. The text then continues with a long and fairly coherent section which may be the original core of the book.

In this section an otherwise unknown Chen Zi discusses the use of a gnomon (a vertical pole) for observing the shadow cast by the noon sun. It is claimed that the shadow of a pole 80 *cun* (inches) long changes by 1 *cun* for every 1,000 *li* (about 400 miles) moved north or south in relation to the point on the earth where the sun is directly overhead. The use of this rule, which does not correspond to actual observation, enables the dimensions of the heavens to be calculated. Most of the rest of the book contains calculations relating to the operation of lunisolar calendrical systems of the *si fen* (quarter [remainder]) type. The text bears an important commentary by Zhao Shuang, probably written ca. A.D. 270–280, and has further annotations by ► [Li Chunfeng](#), who prepared an edition for use in the State College in A.D. 656. The book was first printed under the Song dynasty in A.D. 1084.

See Also

► [Gaitian](#)

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Zhu Shijie 朱世傑

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Virtually nothing is known of the life of this Yuan 元 mathematician, except the little we can learn from the prefaces to his two books, *Suanxue qimeng* 算學啟蒙 (*Introduction to Mathematical Studies*, 1299) and *Siyuan yujian* 四元玉鑒 (*The Jade Mirror of the Four Unknowns*, 1303). The first preface was written by Zhao Cheng and the second one by Mo Ruo 莫若 and Zu Yi 祖乙. From those we can surmise that Zhu came from Yanshan 燕山, near modern Beijing; that he traveled around China for more than 20 years in the last decades of the thirteenth century, after China had been unified under the Mongol rule; and that numerous students came to study with him.

His books attest to the fact that he inherited – from the northern milieu of the Hebei 河北 and Shanxi 山西 provinces which developed the “procedure of the celestial unknown (lit.: origin)” (*Tian yuan shu* 天元術) – how to use polynomial algebra to build an equation with which to solve a problem. This achievement seems to have been unknown in South China and benefited from the potentialities of the counting instrument on which it is based: the surface for computing, on which numbers were represented with counting rods which

could be moved or changed in their values throughout the computations. The earliest book that has come down to us and attests this procedure, though it is probably not the first to have dealt with it, dates from 1248. It is Li Ye 李冶’s (or Li Zhi 李治’s, according to the name chosen for this scholar) *Ceyuan haijing* (測軍海鏡 *Sea Mirror of the Circle Measurements*). Yet Zhu Shijie does not mention this author or any other one. On the basis of extensions to polynomials with two and three indeterminates “that the procedure of the celestial unknown had received previously to him,” according to Zu Yi’s preface, Zhu Shijie developed it to what was to remain an unsurpassed peak in Yuan and Ming China: the use of polynomial algebra with four indeterminates to establish an equation to solve a given problem. As Hoe (1977) has stressed, the language and notations with which Zhu Shijie developed this algebra can, in their conciseness and precision, stand comparison with aspects of modern algebraic symbolism. Still, he notices some ambiguous modes of expression that do not make it entirely independent from the context. This very language might help us to make the historical connections between Zhu Shijie and such previous authors as Li Ye more precise, since as far as topics such as right-angled triangles are concerned, both use the same terminology. On the other hand, as regards the expression of formulas, they present differences even though their languages share the same basic features. For the expression of formulas or algorithms, Li Ye uses a language whose syntax is restricted in such a way that the understanding of a formula is unambiguous, which makes it context-free, in contrast to Zhu Shijie’s (Chemla, 2006).

Moreover, Zhu’s writings demonstrate that he shared bits of knowledge (for instance, finite difference procedures for the summation of series, a topic to whose development he made crucial contributions) with the authors of the calendar *Shoushili* 授時曆 commissioned by the Mongol Court, the foremost being Guo Shoujing 郭守敬.

In addition to this – is it a reflection of his travels in South China? – his books reveal his

interest in algorithms for quick, daily-life computations, or for mercantile and bureaucratic mathematics. In the surviving writings from this period, such topics had mainly been treated by mathematicians from South China, such as Yang Hui 陽輝. At the same time, other topics which developed in South China, such as research connected with the Chinese remainder theorem, seem not to have found their way into his writings. Still, Du Shiran 杜石然 (1966) called attention to the fact that Zhu seems to represent a kind of synthesis of traditions that, for at least decades, had been developing in isolation from each other in North and in South China, though they shared a common basis in the same fundamental characteristics and knowledge, including algorithms to find “the root” of any algebraic equation with positive, negative, or null coefficients.

Zhu Shijie’s books do not seem to have had any impact on the development of mathematics in China; not only we do not find any mention of his name or achievements after their publication, but also the books themselves would eventually be lost, to be found again in China and reprinted only at the beginning of the nineteenth century. This merely reflects the progressive loss of mathematical knowledge from the Song-Yuan period. In contrast to other writings of the same period, his *Introduction to Mathematical Studies* was to influence the development of mathematics in Korea and Japan. It was probably printed in 1433 in Korea, where it became a textbook for studying mathematics, and was eventually recovered thanks to a Korean edition of 1660. Moreover, its introduction to Japan in the second half of the seventeenth century, where it was reprinted and commented upon many times, allowed Japanese mathematicians to reconstruct the procedure of the celestial unknown, by that time forgotten in China, and to improve it until it became a tool in some ways comparable to the algebra developed in Europe during the same period. Horiuchi (1994) studies this aspect of the mathematics developed in Japan with great care and compares it with elements of the contemporary European algebra. Indeed, Japanese mathematicians’ use of

the surface for computing for their computations was probably instrumental in that respect, whereas in China this instrument had fallen into oblivion and was completely replaced by the abacus.

See Also

- [Computation: Chinese Counting Rods](#)
- [Guo Shoujing](#)
- [Jiuzhang Suanshu](#)
- [Li Zhi \(Li Ye\)](#)
- [Mathematics in Japan](#)
- [Mathematics in Korea](#)
- [Yang Hui](#)

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Zij

Raymond Mercier

The term *zīj* is used everywhere in the study of Islamic culture to signify an astronomical handbook. These handbooks consist of a collection of astronomical tables together with such textual material as the reader would need in using the tables. The material is often divided into the following sections:

1. Calendrical conversion
2. Mean motions of the sun, moon, and planets
3. Equations of the sun, moon, and planets
4. Positions of fixed stars
5. Trigonometrical tables (sine, tangent)
6. Spherical astronomy
7. Parallax
8. Eclipses of the sun and moon
9. Geographical coordinates
10. Astrological quantities

The underlying theoretical model of planetary equations was almost invariably Ptolemy's, and to a large extent *zīj*es represent a continuation of the *Handy Tables* of Ptolemy (ca. AD 140). However the earliest Arabic *zīj* is that of ► [al-Khwārizmī](#) (ca. AD 830), which was based on procedures derived from the Indian treatise *Brāhmasphuṭasiddhānta* of ► [Brahmagupta](#) (AD 628). A large number of such works survive intact in Arabic and Persian manuscripts, and many others are known by name only. The most notable modern edition (Nallino, 1907) is that of the *Zīj al-ṣābi'* of al-Battānī' (fl. AD 880). For the long Islamic period the *zīj*es are a vital repository of data, primarily through the constant improvements in the parameters of mean motions

reflecting new observations, and also of improvements in mathematical methods.

In most *zīj*es the textual material was generally restricted to instructions in the use of the tables. Larger astronomical treatises, such as the *Qānūn al-Masūdī* of al-Bīrūnī (ca. AD 1030), included all the material which would be found in a *zīj*, but went further in its detailed treatment of the whole subject.

A number of *zīj*es were translated into Latin and Greek, and initially at least, the term *zīj* was transcribed as *ezich*, *ezeig*, etc. (=al-*zīj*), and ***, respectively. In Latin the term was soon replaced by *tabulae*, while in Greek one finds ***, reminiscent of Ptolemy's *Almagest*.

The term *zīj* is originally Middle Persian, where it means "stretched cord." The sense "astronomical handbook" goes back to the early sixth century when Sanskrit works were introduced into Iran. The name *zīj* may have arisen as a literal translation of the Sanskrit term *tantra* (from *tan* "to stretch") literally "warp, loom," but which is used in the sense of "system" or "text book." The word is singled out by ► [Varāhamihira](#) (ca. 580) as the name of the branch of astronomy which is concerned with planetary calculations. In a Middle Persian tract of the ninth century, the *Epistles of Manuščīhr*, there are references to the *zīg ī hindūg* (Indian Astronomy), and also to a *zīg ī šahrīyārān* (Royal Astronomy), a Sasanid compilation probably of the sixth century, referred to later by Arabic authors as the *Zīj al-Shātroyārān*. The former may be one of the works of Āryabhata (ca. AD 5250), which were referred to as Tantras by an early commentator.

See Also

► [Astronomy in the Islamic World](#)

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Zinc Production in China

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Zinc was one of the important metals in the ancient world, primarily as an essential component of the alloy brass. Brass was usually made by the cementation process, whereby metallic copper, zinc ores, and charcoal were heated in crucibles, and brass was formed directly through the absorption of zinc vapor by the copper, rather than by alloying two liquid metals. This technique was required because of the extreme volatility of metallic zinc (it boils at 907 °C), which means zinc immediately volatilizes when it forms from the ore (around 1,000 °C), and it reoxidizes as soon as it comes in contact with air. Thus complex reduction and

condensation installations, rather than ordinary smelting furnaces, are necessary to produce metallic zinc.

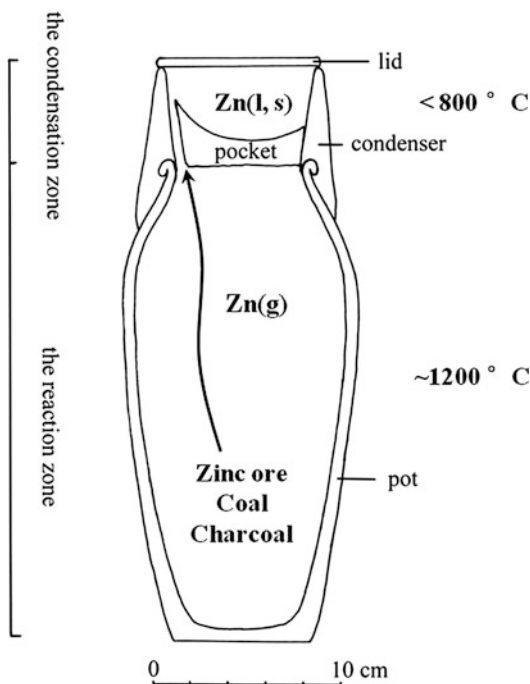
While brass cementation was widespread in ancient times, only India and China produced unalloyed zinc on an industrial scale. Indian zinc production, based on the principle of distillation by descending, first appeared about 1,000 years ago, boomed during the fourteenth to sixteenth centuries, and ceased in the nineteenth century at Zawar, northwest India (Craddock et al. 1998). In contrast, the Chinese zinc smelting process was based on the principle of distillation by ascending, which seems fundamentally different from the Indian one. Chinese zinc was mainly used for making brass coins in the Ming and Qing Dynasties (sixteenth to nineteenth centuries); some was traded via European merchants to the world. Traditional zinc smelting was still in operation in southwest China until the late twentieth century (Xu 1986; Craddock and Zhou 2003).

Since the 1920s, a number of Chinese and British scholars have studied Chinese zinc smelting technology and its history, especially its inception, based on three sources of evidence: historical records, scientific analyses of brass coins, and field surveys of traditional zinc production. Zinc had a number of terms in historical records, such as *lian*连/鑪, *baixi*白锡, *woyuan*倭铅/窩铅, and *woyuan baishuiyuan*倭源白水铅; however, it is difficult to unequivocally identify these terms due to their uncertain and changing meanings in different contexts. Based on historical records and limited analyses of coins, several views concerning the dates for the origins of zinc production in China have been put forward, including the Han Dynasty, the Five Dynasties, the Song Dynasty, and the early Ming Dynasty, but all were subsequently challenged. Since the 1980s, Zhou Weirong and his colleagues have reviewed all relevant textual evidence, offered new interpretations for some terminology and documents on which the previous discussions had been based, and carried out systematic analyses on copper-based coins. They argued that China did not begin to smelt zinc on a large scale before the Wanli period (AD 1573–1620) of the Ming Dynasty (Zhou 2007).

The earliest document clearly describing zinc distillation is *Tian Gong Kai Wu* 天工开物, which was written by Song Yingxing and published in 1637. It records that *woyuan* 倭铅 (zinc) was produced from *luganshi* 炉甘石 (oxidic zinc ores) in earthen jars, and it is described as a volatile metal. However, the text and illustration failed to show a method of distillation for the production of zinc. It is difficult to trace firm evidence of zinc production from Ming documents.

It was not until the discovery of nearly 20 zinc smelting sites dated to the Ming Dynasty (AD 1368–1644) along the Yangtze River in Fengdu, Chongqing, southwest China, since 2002 that allowed the first high resolution and contextualized technological reconstruction of zinc distillation. The analytical results of zinc ore, metal, retorts, and slag from three of these sites reveal the use of large-scale installations for zinc distillation with retorts made of pots, condensers, pockets, and lids. The retorts were charged with iron-rich oxidic zinc ores, coal, and charcoal; a high temperature of around 1,200 °C and highly reducing atmosphere were achieved to reduce the ores; the zinc vapor formed within the pots was cooled and collected in the condensers (Fig. 1). A few foundations of rectangular furnaces resembling the trough-shaped furnaces used in traditional zinc smelting were excavated. The retorts should have been placed on brick bars within the coal-fuelled furnaces (Fig. 2) (Liu et al. 2007; Zhou et al. 2012).

The picture of zinc production in Qing China is much better illustrated in historical texts. Several scholars studied the administration of zinc production and transport in southwest China based on Qing documents. During this period, zinc production was on a much larger scale in many provinces, such as Guizhou, Yunnan, Sichuan, Hunan, and Guangxi; Guizhou was the largest production area. Several zinc smelting sites of the Qing Dynasty were found 50 km southeast of Fengdu sites in Shizhu, Chongqing. The analytical results of production remains from one of these sites show that it employed a broadly similar technology to those at the Ming sites, but they used lower-grade oxidic zinc ores, a lower proportion of reducing agents, and elongated retorts



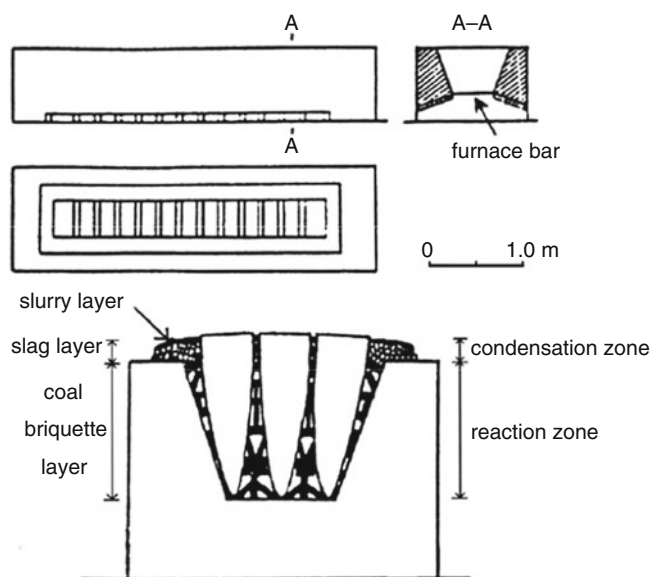
Zinc Production in China, Fig. 1 Reconstruction of a retort from zinc smelting sites in Fengdu (g gas, l liquid, s solid)

of inferior performance, leading to greater losses of zinc. The reasons for the lower technical efficiency at the later site are explained in terms of different social, political, and economic constraints (Zhou et al. 2014). In addition, zinc smelting sites were also found in Huanjiang, Guangxi (Huang et al. 2012), and Hezhang, Guizhou. The retorts at these sites are similar in shape to Dafengmen ones, suggesting that they were dated to the Qing Dynasty.

The traditional zinc smelting technology survived and evolved in southwest China throughout the twentieth century. They were in operation in Hunan province and the area where provinces of Sichuan, Guizhou, and Yunnan meet. Since the 1910s, a number of geologists, metallurgists, and historians of metallurgy have investigated these processes and left over ten ethnographic documents, which described the operational sequences from retort production, mining and ore preparation, reducing agents and fuel preparation, furnace construction, tool making, to zinc smelting. The traditional processes mainly used conical or

Zinc Production in China,

Fig. 2 Trough-shaped furnaces used in Guizhou, southwest China, in the 1980s



cylindrical retorts, while normally no extensions were added and zinc was collected in the pockets placed within the pots. Besides the rectangular trough-shaped furnaces, saddle furnaces and climbing hillside furnaces were also developed (Xu 1986; Craddock and Zhou 2003). As traditional zinc smelting processes caused serious harm to human health and pollution to the environment, they were forbidden by the Chinese government at the end of the twentieth century.

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Zodiac in Indian Astronomy

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The signs of the zodiac originated in Mesopotamia. In the first stage of development, 12 constellations along the ecliptic (i.e., the apparent course

of the sun in the sky) were roughly marked out and each was named after the animal whose shape it resembled. Later, with the need for a rigid coordinate system for planetary positions, the zodiacal sign assumed a new meaning: the length of 30° along the ecliptic, so that 12 equal signs comprised a complete circuit (360°) of the ecliptic. The change from the older irregular constellations to the signs of regular spacing took place somewhere around 500 BCE.

In the cuneiform texts the ecliptic coordinates were sidereally fixed, and the vernal equinox was several degrees off “the first point of Aries”: at the tenth degree of Aries in System A and at the eighth in System B. The Mesopotamian idea of 12 zodiacal signs of equal length was transmitted to Greece about 300 BCE, where the iconography of the signs was modified by their mythology.

With the discovery of the precession of equinoxes by Hipparchus in about 150 BCE, the significance of the zodiacal signs changed drastically. The first point of Aries was equated with the vernal equinox. Since this is in constant retrograde motion relative to the fixed stars (the shift being about 51 min of arc per year), the original relation between the constellations and signs was completely severed and the zodiacal signs became a purely mathematical reference system.

With the development of astrology, which preserved the old association of zoomorphic shape with zodiacal signs (except Libra), the zodiacal signs assumed new meanings. They were classified in various ways: by sex, the ownership of the house of planets, seasons, tastes, four humors, four elements, the governorship over parts of the body, plants, animals, geographical regions, etc.

All these ideas were transmitted to India in the second century of the Christian era. The very Sanskrit names of the zodiacal signs show that they were translated from Greek. In some texts even phonetic translations of Greek words are found. The earliest Sanskrit text which contains a list of these names is the *Yavanajātaka* (ca. AD 269), a Sanskrit version of a Greek book on horoscopic astrology (Table 1).

Zodiac in Indian Astronomy, Table 1 The signs of the zodiac

Degrees	English	Sanskrit
0	Aries	<i>meṣa</i>
30	Taurus	<i>vṛṣan</i>
60	Gemini	<i>mithuna</i>
90	Cancer	<i>karkāṭa</i>
120	Leo	<i>siṃha</i>
150	Virgo	<i>kanyā</i>
180	Libra	<i>tulā</i>
210	Scorpio	<i>vṛścika</i>
240	Sagittarius	<i>dhanus</i> or <i>dhanvin</i>
270	Capricorn	<i>makara</i> or <i>mṛga</i>
300	Aquarius	<i>kumbha</i>
330	Pisces	<i>mīna</i>

Three iconographic modifications in the process of transmission are worth mentioning. (1) While Gemini are the twin boys in Western iconography, *mithuna* in Sanskrit is a couple consisting of a male and a female, and this was interpreted as “husband and wife” in Chinese texts on Buddhist astrology. (2) The Sanskrit word *makara* stands for a kind of sea monster, and *mṛga* for a “forest animal” such as a deer. Thus Capricorn was divided into two separate animals. (3) The word *dhanvin* (one who has a bow) is a better translation of Sagittarius (archer), but the simpler *dhanus* (bow) without a human figure is more frequently used in Sanskrit texts.

In spite of the similarity of the names, the astronomical meaning of Indian zodiacal signs is different from that of the Western ones, because the precession of the equinoxes was not taken into account in India, and the first point (*meṣādi*) of the ecliptic coordinates was sidereally fixed sometime in the third or fourth century AD. The difference (*ayanāṃśa*) between the vernal equinox and the *meṣādi*, which has accumulated in the present day, is about $23^\circ 40'$; thus the sun’s entry into *meṣa* now falls on the 14th of April, and the *makarasaṃkrānti*, originally a winter solstice festival, on the 15th of January.

This seemingly conservative attitude is closely related to the Indian system of naming the lunar month. A year is divided into 12 solar

months by the sun's entry (*saṃkrānti*) into a new zodiacal sign. The lunar month is named after the *saṃkrānti* which falls during that month. For example, the lunar month Caitra is defined as the month during which the sun's entry into *meṣa* occurs. The full moon of that month has to be located near the diametrically opposite point on the ecliptic, i.e., at the lunar mansion *citrā*. Thus, in order to keep the relation of the month name and the constellation name, they had to stick to the sidereal (*nirayana*) system even at the sacrifice of the correspondence between the seasons and month names.

The Western system has ignored the original association between constellations and zodiacal signs, and the word *Aries*, for example, has two meanings, one as an actual constellation and the other as the first 30° in the ecliptic longitude. The former is used in astronomy and the latter in astrology. This is not the case in the traditional Indian system.

In South India and Nepal the solar month is still used in the civil calendar. Since a solar month is the time during which the true sun stays in one zodiacal sign, the length of a month varies from 28 to 32 days.

As mentioned above, Indian zodiacal signs were transmitted to China in the eighth century by Buddhist astrology and ultimately to Japan in the ninth century. The iconography of the Indian zodiacal signs was preserved in the star *maṇḍalas* (especially in the temples belonging to the Shingon sect) which were used in the ritual of worshipping the planetary deities.

See Also

- [Astrology in India](#)
- [Lunar Mansions in Islam](#)
- [Precession of the Equinoxes](#)

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Zodiac in Islam

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The zodiac, i.e., the band or zone around the sky through which the sun, the moon, and the planets travel in their apparent revolutions, was first established by the Babylonians. They formed the constellations along this zone and instituted its division into 12 equal portions, the “signs.” This knowledge was then handed on, in a northern branch of transmission, to the Greeks and through them further on into modern astronomy. In a southern branch of transmission, some of the zodiacal constellations reached the Arabs in the Arabian peninsula. In their folk astronomy they knew some of the zodiacal constellations – though not the complete system of 12 – which, in their astronomical lore, were sometimes located differently. For example the constellation *al-jawzāʾ* (standing for Gemini) is located in the Greek (and modern) Orion, *al-dalw* (Aquarius) in Pegasus, and *al-ḥūt* (Pisces) in Andromeda.

With the reception of Greek astronomy, through the translation of the most important Greek writings in astronomy and astrology, the system of the 12 zodiacal constellations and the 12 signs was also received and continued to be used by Arabic-Islamic astronomers and astrologers. For some constellations the translators introduced new names (derived from Greek) besides the names inherited from the old Arabs. The names for the 12 constellations of the zodiac in Arabic are:

1. Aries: *al-ḥamal*
2. Taurus: *al-thawr*
3. Gemini: *al-jawzāʾ* (old), *al-tawʾamān* (transl.)
4. Cancer: *al-saraṭān*
5. Leo: *al-asad* (both old and transl.)
6. Virgo: *al-sunbula* (old), *al-ʿadhraʾ* (transl.)
7. Libra: *al-mīzān*
8. Scorpio: *al-ʿaqrab* (both old and transl.)
9. Sagittarius: *al-qaws* (old), *al-rāmī* (transl.)

10. Capricornus: *al-jady*
11. Aquarius: *al-dalw* (old), *sākib al-mā'* (transl.)
12. Pisces: *al-ḥūt* (old), *al-samakātān* (transl.)

The zodiac was treated by the Arabic-Islamic astronomers and astrologers according to the teachings of the Greeks. When Arabic astronomical and astrological works were translated into Latin in Europe in the Middle Ages, the Arabic names of the 12 zodiacal constellations were also sometimes borrowed. But they did not gain the same popularity as the Arabic star names and the names of the lunar mansions; most Latin authors used the well-known Latin names for them.

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Zou Yan

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Our only source on Zou's life that has any chance of being reliable is the entry in Sima Qian's universal history *Shiji*, completed ca. 90 B.C.E. According to this, Zou (fl. 250 B.C.E.) was a successful member of the group of wandering scholars who moved from one feudal court to another in China's Warring States period (fifth-third centuries B.C.E.), offering expertise in statecraft and useful arts. He came from the northeastern seaboard state of Qi, where he became a member of the "academy" set up by the ruler of that state to house his more favored scholarly retainers. Although he is said to have written several voluminous books none of them has survived.

According to the *Shiji*, Zou "looked into the rise and fall of the Yin and Yang" and wrote on

their "strange transformations." His method of reasoning "started by checking some small thing, and then extrapolated to a large scale." On this basis he is said to have reasoned his way back to the state of affairs "before the origin of heaven and earth" on the basis of his knowledge of more recent times. Similarly, he claimed that China only occupied one-ninth of a large continent, which was itself only one out of nine giant land masses surrounded by a vast ocean.

One source of the seventh century A.D. (Li Shan's commentary on the Wen Xuan anthology) quotes a work said to be by Zou Yan, in which it is stated that he taught that the successive dynasties ruling in China had each come to power by virtue of the cyclical dominance in the cosmos of one of the *wude* (Five Powers) of earth, wood, metal, fire, and water. (These are more commonly called the wuxing, Five Phases.) While such a view is not inconsistent with Zou Yan's thought as known from the *Shiji*, it is by no means certain that he originated it. Whatever its origins, this theory of the cosmological determination of political dominance was adopted by the first emperor of the Qin dynasty when he came to the throne in 221 B.C.E., and remained important for several centuries thereafter.

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Zu Chongzhi

Ang Tian Se

Zu Chongzhi, whose literary name was Wenyan, was born in Jiankang (present ► [Nanjing](#) of Jiangsu Province) in AD 429 into a family of bureaucrats. His great grandfather, a native of Hebei Province, was an official during the

Eastern Jin dynasty (AD 317–420), and his grandfather and father were officials of the Northern and Southern dynasties (AD 479–581). Interestingly enough, the Zu family had, for successive generations, been involved in studies of astronomy and calendrical science. Subsequently, they moved south and settled in Jiankang, the political and economic center of the fifth and sixth centuries. From a very young age, Zu Chongzhi received instruction in a variety of subjects. He was particularly interested in mathematical astronomy. While examining many past and existing astronomical systems, he found many errors and discrepancies. This prompted him to compile a calendrical system known as the Daming calendar (Calendar of Great Brightness). However, when he presented this calendar to the throne for promulgation in AD 462, he met with vehement opposition from the emperor's minister Dai Faxin. Zu Chongzhi's innovation and improvement in the astronomical system was branded as "distorting the truth about heaven and violating the teaching of the classics." The Daming calendar was shelved for about half a century before it was finally promulgated for official use in AD 510 when Zu Chongzhi had been dead for 10 years.

The Daming calendar was the epitome of Zu Chongzhi's mathematical and astronomical skills. He was the first person to take into account the fact of precession of the equinoxes discovered by Yu Xi, an astronomer in the fourth century AD. By applying the precession of equinoxes, Zu Chongzhi differentiated the tropical year from the sidereal year (the time at which the sun's center, departing eastward from the ecliptic meridian of a given star, returns to that meridian). As a matter of fact, he determined several astronomical constants with remarkable accuracy. For example, he gave a value of 365.24281481 days for the tropical year, only about 50 s off the modern value. He also gave a value of 27.21233 days for the length of a nodal month, the modern value being 27.21222 days. For planetary motion, he found that the planet Jupiter completes 7 and 1/12 circuits of the heavens in every 7 cycles of 12 years. This gives Jupiter a sidereal period of 11.859 years, which differs from the modern value by only 1 part in 4,000.

In order to make the lunar year tally with the solar year, ancient Chinese calendar makers inserted 7 intercalary months in every 19 years. This rule of intercalation had been in use for more than a thousand years until AD 412 when Zhao Fei changed it to 221 intercalary months in every 600 years. Zu Chongzhi did not find the rule satisfactory and improved it by introducing 144 intercalations in every 391 years.

The most significant contribution by Zu Chongzhi is in the evaluation of π . He gave two approximating ratios for π : a coarse 1 of 22/7 and a fine 1 of 355/113. The true ratio, according to him, lies between 3.1415926 and 3.1415927.

Zu Chongzhi also wrote a mathematical text known by the title *Zhui Shu*. This text, prescribed as a textbook for advanced students of mathematics in the official examinations of the Tang dynasty, was unfortunately lost in the wars of the early twelfth century. Only fragments of the text still exist in the Calendrical and Astronomical Chapters of the Sui and Tang dynasties. Zu Chongzhi was said to have worked out an evaluation of the volume of a sphere. He considered a sphere as a pile of circles of varying sizes and arrived at a formula, which in modern mathematical language, could be expressed as $V = 4/3\pi r^3$.

Zu Chongzhi was a versatile person. Apart from being a celebrated astronomer and mathematician, he was well versed in engineering. He produced a "south-pointing vehicle" worked by a set of five differential cog wheels, a "thousand-mile boat" propelled by paddle wheels, a hydraulic mortar-mill, worked by a combination of separate water-driven mortars and mills, and a brass ruler for measuring the pitch of musical instruments.

Zu Chongzhi's remarkable achievements are acknowledged internationally. A crater on the reverse side of the moon, just south of the Sea of Moscow, is named after him.

See Also

- [Pi in Chinese Mathematics](#)
- [Precession of the Equinoxes](#)

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